OFFICE OF NATIONAL ECONOMIC AND SOCIAL DEVELOPMENT BOARD (NESDB)

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

DEPARTMENT OF WATER RESOURCES (DWR)
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KINGDOM OF THAILAND

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

**Final Report**

**Volume 1: Summary Report**

**September 2013**

**JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)**

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# COMPOSITION OF FINAL REPORT

| | | |
|---|---|---|
| **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**

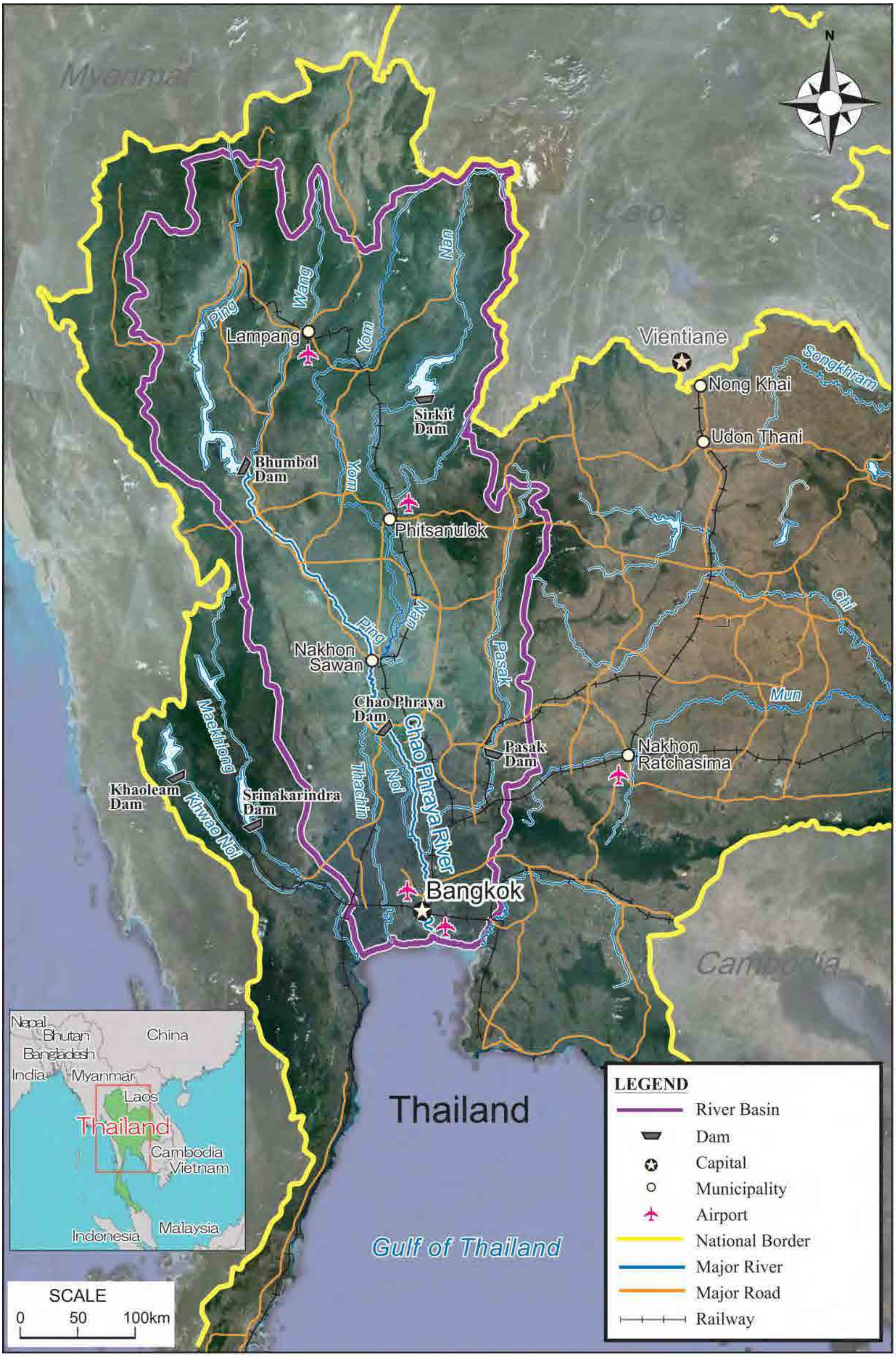
**Exchange Rate Used in the Report is**

THB1.00 = US$0.032 = JP¥2.794

JP¥100 = THB35.796 = US$1.163

US$1.00 = JP¥85.980

(as of 28 December, 2012)




**LOCATION MAP**

# EXECUTIVE SUMMARY

## 1. INTRODUCTION

### 1.1 Background

The prolonged flood in Thailand 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, in collaboration with NESDB, RID, DWR and other related agencies, has been conducting a flood management projects; namely, the "Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin". The project consists of three components:

Component 1: Upgrade of "the Flood Management Plan" with creating a new precise topographic map.

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

Component 1-2: Upgrade of "the Flood Management Plan" with creating a new and more precise topographic map.

Component 2: Urgent rehabilitation works; installing new water gates and elevating Route 9.

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

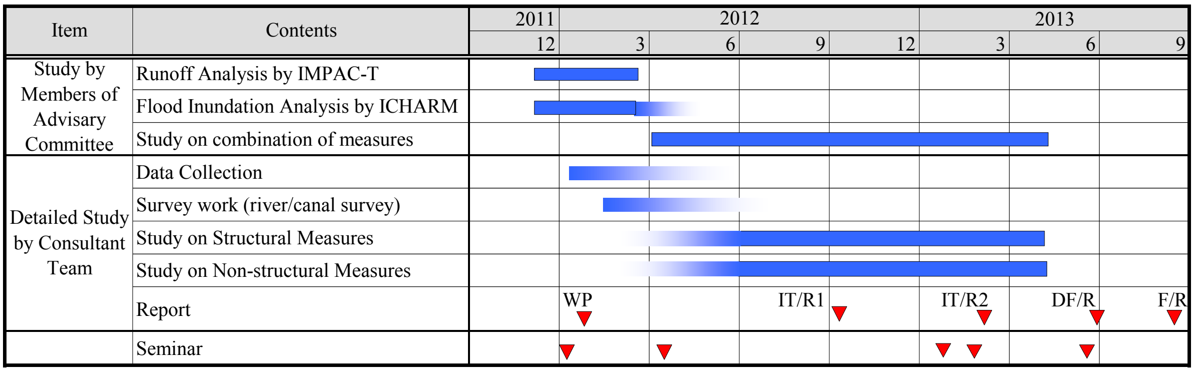
Each component has made steady progress, and this document presents the Final Report of Subcomponent 1-2 that aims to upgrade the Flood management plan for the Chao Phraya River Basin.

### 1.2 Objectives of the Project

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

### 1.3 Project Schedule

The Project Period is from December 2011 to October 2013. The schedule is presented as follows:




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

**Figure 1 Project Schedule**

# 2. BASIC ISSUES FOR THE MASTER PLAN

## 2.1 Flood Management Policy by Thai Government

In December 2011, the Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management. Flood management policy by Thai Government mentioned in this Master Plan is summarised and studied as follows:

**Flood Management Policy : Goal**
**To promote sustainable economic growth by reducing flood risk and exploiting floodwater as water resource through proper Flood Management.**

People in Thailand have long been living in flood-prone areas to easily secure water for agriculture. The wisdom of avoiding serious damage induced by floods and exploiting floodwaters for cultivation has been a great boon to the people of Thailand.

Thailand has achieved a rapid economic growth in the recent years and, consequently, the urban areas have dramatically expanded to the flood-prone areas. With the economic growth, the country seems to concentrate on expanding areas for urbanization and focus on ways to investment in urban and transportation infrastructures. Investment for flood mitigation has taken a backseat to economic development.

On top of that, the extensive flood in 2011 harshly attacked the urbanized low-lying areas and caused heavy economic damage by disrupting industrial production for several months. The damage influenced not only the Thai but also the global economy.

Since most developed countries have faced similar problems associated with haphazardly spreading the city area and increasing the vulnerability to floods, lots of experiences and lessons learned could be utilized for the protection against floods. In particular, it is certain that Flood Management is essential to promote sustainable economic growth with the reduction of flood risk and at the same time exploit floodwaters for agricultural use.

The Flood Management Policy by Thai Government aims at clearly showing the right direction of flood management to be executed. The Policy consists of six (6) principal elements, namely:

(i) To integrate all of the activities implemented by the respective organizations concerned in the whole river basin;

(ii) To maintain a harmonious balance between flood control and water utilization;

(iii) To control inundation;

(iv) At the planning stage of countermeasures, to seek the best mix of structural and nonstructural countermeasures;

(v) At the ordinary operation stage, to set the proper operation rules for flood control facilities and land use regulations with due consideration on extreme events; and

(vi) At the emergency stage, to fulfill the responsibility of each individual, community, private firm, NGO and governmental organization.

## 2.2 Design Flood

Since the 2011 Flood, the largest recorded flood, caused tremendous damage in the whole Chao Phraya River Basin, the Master Plan should consider accommodating the 2011 Flood. On the other hand, the 2011 Flood has been estimated as a 100-year return period flood in the rainfall analysis executed in this study. Since most metropolitan cities in the Asian monsoon region have similar target scales more than 100-year return period to prevent flood damages. From the above considerations, it is appropriate to set the 2011 Flood (the 100-year return period) as the design flood for the Chao Phraya River Basin.

**Table 1 Evaluation of 2011 Flood Scale**

| Evaluation Item (Annual maximum) (N is number of samples) | Probability of return period | | | | Remarks |
|---|---|---|---|---|---|
| | Nakhon Sawan (C.2) [C.A 105,000km$^2$] | | River Mouth (whole river basin) [C.A 162,000km$^2$] | | |
| | Value | Return period | Value | Return period | |
| Average rainfall watershed (mm/6months) ($N$ = 51) | 1,483 | 1/141 | 1,390 | 1/100 | 6 month-maximum rainfall is employed since it contributes to large flood. |
| Peak discharge (m$^3$/s) ($N$ = 56) | 6,857 | 1/70 | - | - | To estimate a natural runoff (uncontrolled by facilities), the impounded water in Bhumibol and Sirikit dams was added to the observed discharge at Nakhon Sawan. In addition, to evaluate the probability of actually-occurred scale of inundation at downstream of C.2, probable analysis with overflow volume (beyond 2,500m$^3$/s) was conducted. |
| Yearly water volume (MCM) ($N$ = 55) | 55,570 | 1/127 | - | - | |
| Overflow volume (MCM) ($N$ = 44) | 15,154 | 1/102 | - | - | |

* Above calculation was conducted by using "hydrological statistics utility ver1.5" released by Japan Institute of Construction Engineering, November 2003.

### 2.3 Protection Area

Bangkok and its vicinities in the east side of the Tha Chin River and the southern part of Pa Sak River in Ayutthaya have been selected as the flood protection area. The Department of Highway (DOH) and the Department of Rural Road (DOR) have started the works to heighten the elevation of the surrounding roads and road embankments. Since these works have been considered as the existing conditions for this Study, they should be one of the criteria for selecting the optimum combination of projects to reduce the risk of dyke-breach in the flood protection area.

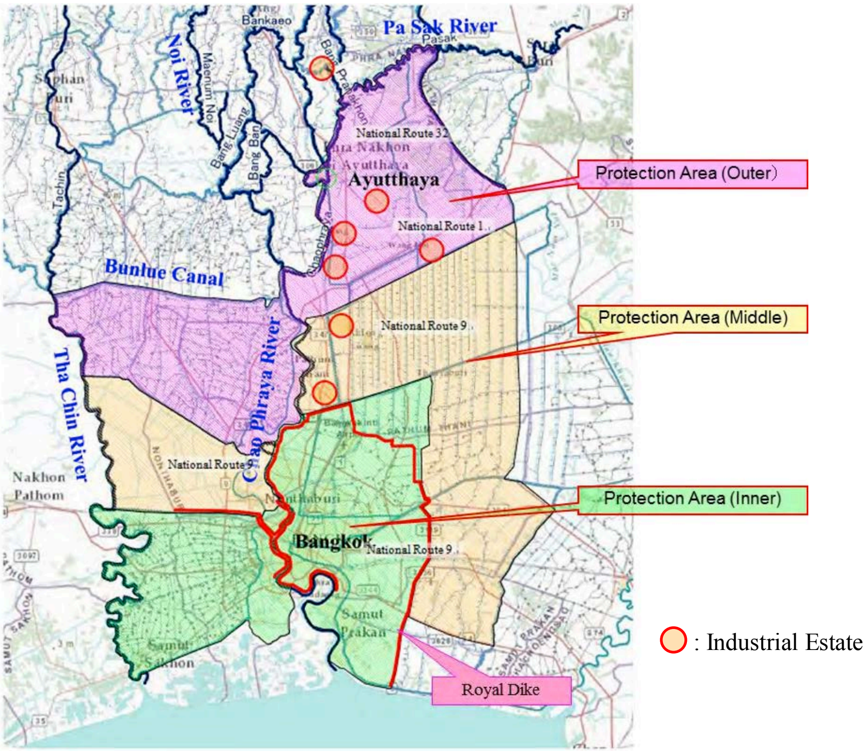



**Figure 2 Priority Protection Areas (Source from "Waterforthai" Website)**

# 3. PROPOSED COMBINATION OF COUNTERMEASURES

## 3.1 Combination of Countermeasures

More than ten (10) scenarios have been simulated after newly developing a basin-wide hydrological model incorporating the new topographical map. It has been concluded that the **Ayutthaya Bypass Channel and Outer-Ring Road Diversion Channel** in combination with other structural and nonstructural measures such as efficient operation of existing dams and river channel improvement works are the most cost-efficient and significantly effective to protect the Lower Chao Phraya River Basin.

**Proposed Combination 1**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500m$^3$/s)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400m$^3$/s)
5) Flood Forecasting

**Proposed Combination 2**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 1,000m$^3$/s)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400m$^3$/s)
5) Flood Forecasting

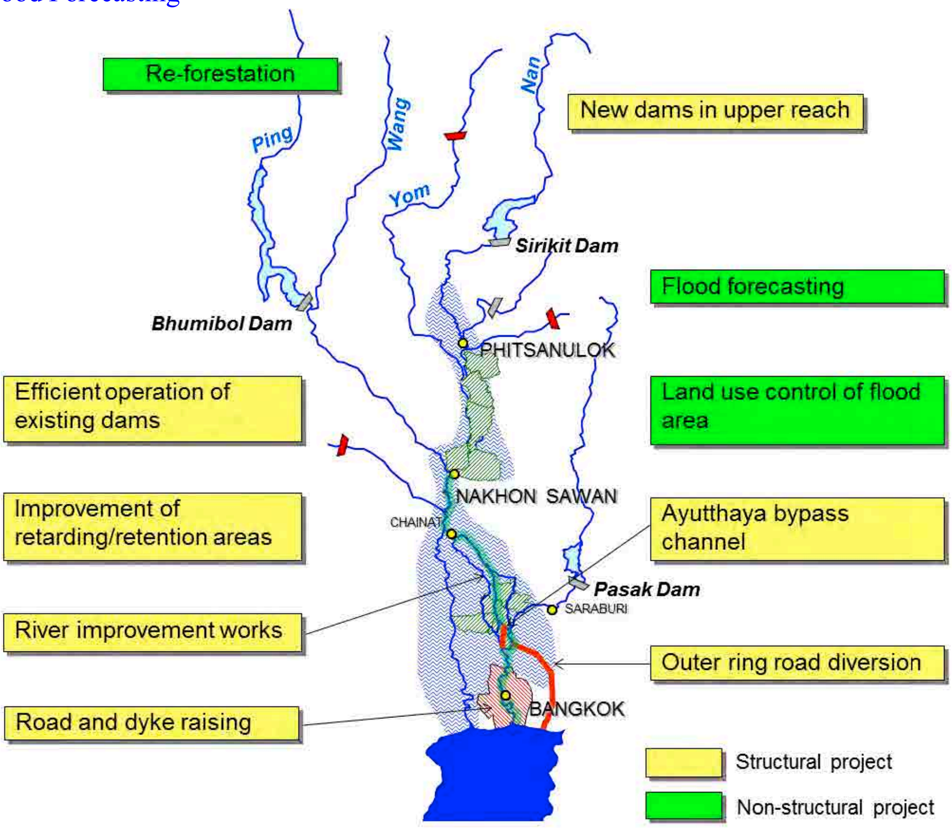



**Figure 3 Countermeasures Reviewed in the Study**

## 3.2 Effective Operation of Existing Dams

The operation of the existing dams during the 2011 flood was so effective to mitigate flood damage, because the Bhumibol and Sirikit dams stored 12 billion cubic meters of floodwater. When the dam operation rule is modified, dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose. If the proposed dam operation rule was applied during the 2011 flood, the peak discharge at Nakhon Sawan could be reduced by 400 $m^3/s$.

The concept of the recommended operation rule is as follows.

- “Target Curve” is the target storage volume for water use and the upper limit for flood control
- Following the proposed “Target Curve”, the inflow is going to be released from May 1 to August 1 to maintain the fixed reservoir water level.
- From August 1 to November 1, inflow should be stored in reservoirs with maximum outflow of 210 $m^3/s$ at Bhumibol Dam and 190 $m^3/s$ at Sirikit Dam for flood mitigation. If the storage volume is less than the Target Curve, the inflow should be stored in the reservoir for water use. The released discharge shall not be less than the minimum discharges of 8 $m^3/s$ at Bhumibol Dam and the 35 $m^3/s$ at Sirikit Dam.
- When the dry season (From November 1 to April 30 next year) starts, the stored water is released based on the schedule of the required water supply volume.
- This operation rule benefits both flood mitigation and water use.
- “Alert Curve for Drought” can provide indicators to judge whether a drought year. “10% Probability” and “20% Probability” mean the risk of drought once in every 10 years and once in every 5 years, respectively.

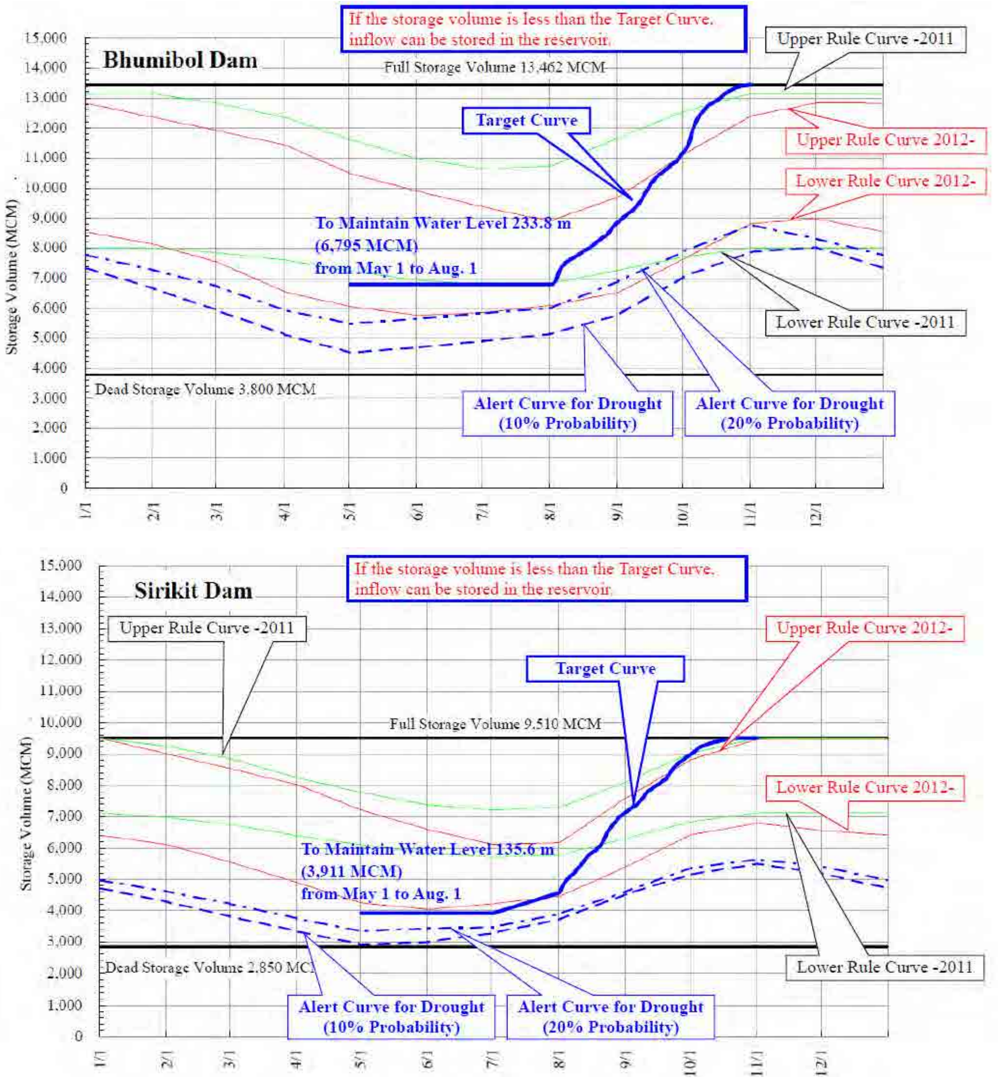



**Figure 4 Target Curve and Alert Curve for Drought**

### 3.3 Outer Ring Road Diversion Channel

The diversion channel has a certain effect in reducing water levels of: (i) the Chao Phraya River from Ayutthaya to Bangkok; and (ii) the downstream of Pa Sak River. Hence, it is very effective in reducing the risk of dyke breach along the areas to be protected.

### 3.4 River Channel Improvement

Definition of River Channel

It has been considered in the Study that the channel of rivers lie between secondary dykes, not between water edges along primary dykes, since ordinary widths of stream cannot accommodate floodwater. It is, therefore, crucial that the lower and/or weaker stretches of secondary dykes should be identified and strengthened to prevent uncontrolled inundation.

If dyke raising work is conducted based on the primary dyke alignment, a very high levee would be required, because the river area enclosed with primary dyke is much smaller than secondary dyke.

River Improvement in Chao Phraya River

At the lower reaches of the Chao Phraya River, longitudinal height of parapet wall is horizontal and step wise, which is higher than record-high water level in the 2011 flood, but actual slope of water level is slanted. In addition, some part of the parapet wall is lower than DHWL + freeboard (50cm). Therefore, dyke elevation up to DHWL + freeboard shall be executed.

River Improvement in Tha Chin River

Inundation volume and depth at right side of the Tha Chin River will increase due to the dyke heightening at the left side for protection of the economic zone. To increase discharge capacity at lower reaches of the Tha Chin River and to protect the economic zone, the following countermeasures are adopted:

i) Four (4) shortcuts are installed as follows:

ii) Primary dyke or concrete parapet wall is newly constructed at left side from river mouth (Samut Sakhon Province, Mueang Samut Sakhon) to 90 km point (Nakhon Pathom Province, Nakhon Chai Si);

iii) Secondary dyke at left side is elevated to "Design High Water Level plus Freeboard" from 90 km to 141 km point (Suphan Buri, Song Phi Nong); and

iv) South side dyke along Bunlue Canal is elevated to "Design High Water Level plus Freeboard".

### 3.5 Ayutthaya Bypass Channel

The Ayutthaya Bypass Channel is one of the alternatives of river channel improvement works, because it is extremely difficult to widen the river channel in the stretch between Bang Sai and Ayutthaya. The bypass channel is planned to be constructed from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River. The bypass channel has an effect in lowering the water levels of: (i) the Chao Phraya River between Bang Sai and Ayutthaya; and (ii) the Pa Sak River, and should be effective to reduce the risk of dyke breach along the areas to be protected.

### 3.6 Habitual Inundation Area

Protecting the priority area in the Lower Chao Phraya River Basin by the combination of countermeasures proposed above should not increase flood damage potential in other areas except for some specific areas. In addition, flood damage resilience can be improved by the following activities. Some of these activities have been already materialized.

- Flood Management Information System
- Land use regulation and planning
- Appropriate intervention in the agricultural area

Reliable and timely information can reassure residents in the basin to continue economic activities. "The Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin" has already developed a flood forecasting system, which is available to the public through the internet.

### 3.7 Controlled Inundation Area

By regulating land use appropriately, inundation with scale similar to the 2011 flood can be controlled. The prospective controlled inundation areas can be classified into five (5), depending on the flooding features. Based on this classification, the concrete land use plan could be developed and put into practice.

Type FS: Overflow water from river spreads and flows towards downstream resulting in relatively shallow inundation and shorter duration.

Type FL: Floodwater flows over through these areas and is blocked by the heightened road/embankment. Deeper inundation and longer duration than the 2011 flood would be observed near the southern border of the areas.

Type W: These areas are floodways for overflow water from Type FL areas and the west hilly areas.

Type M: These are swamp areas and floodwater stays throughout a flood season with deep inundation and long duration.

Type H: Small scale floods with shallow inundation depth and short duration come from the east hilly areas.

It will be inevitable to use many of the agricultural lands to store floodwater. However, strengthening the capacity for quick recovery can mitigate their damage and losses. "The Project for Flood Countermeasures for Thailand Agricultural Sector" is supporting and promoting this issue.

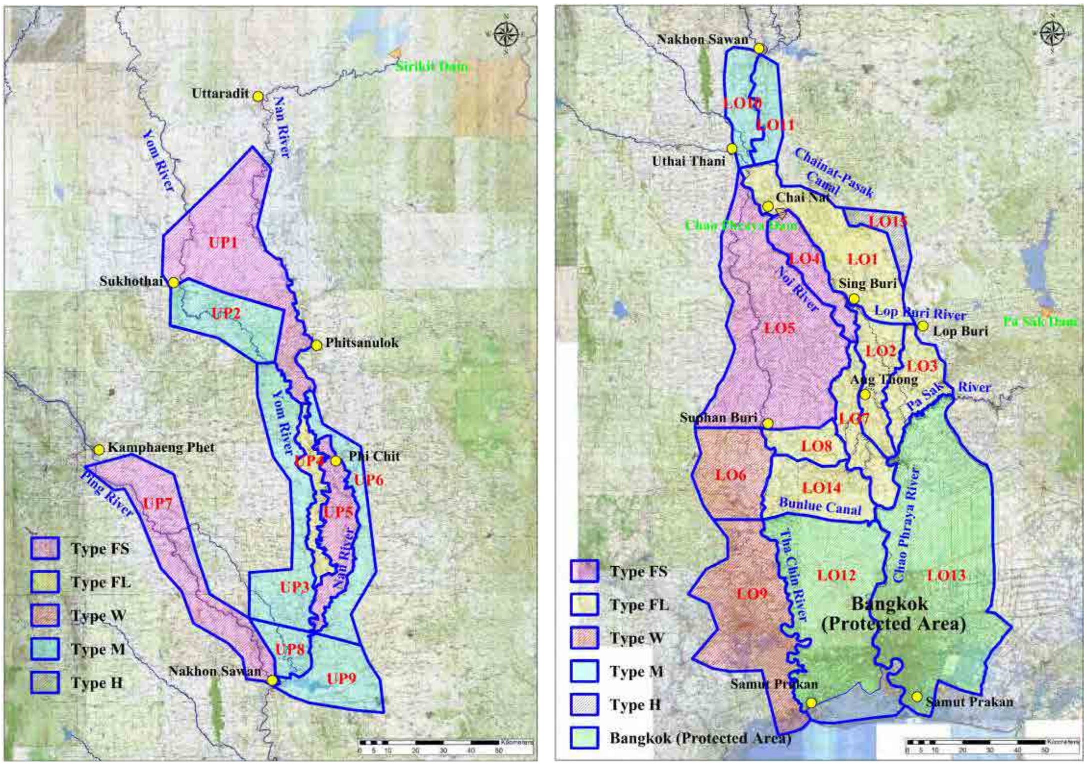



**Figure 5 Controlled Inundation Areas (Upper and Lower Chao Phraya)**

These low-lying areas have the important function of retarding floodwaters and reducing flood peaks downstream. Regardless of whether or not the proposed large facilities are constructed, structural and nonstructural measures are required for the inundation area to maintain the function, to reduce flood disaster risks and to enhance people's living condition considering coexistence with floods.

### 3.8 Solution for the Issue of Land Use Control

As mentioned in "2.1 Flood Management Policy by Thai Government", basin inundation would be inevitable even after the implementation of major countermeasures. In accordance with the prospective controlled inundation area classified into five (5) categories, it is crucial to seek solutions to minimize flood damage by controlling unplanned urbanization in inundated areas and to maximize the benefit induced by inundation especially for agricultural use.

The land use control plan should be enforceable and decided based on each inundation situation of the five (5) categories.

Concept of land use control is given as follows:

Concept 1: To implement effective land use control as the minimum corresponding to frequent flood-prone areas including retention area in order to maintain and improve people's daily life and economic activities.

Concept 2: To promote land use in order to minimize flood damage to flood-prone areas in several decades to hundred years in terms of mitigation.

Concept 3: To implement measures to improve the quality of life of people living in serious flood-prone areas.

Concept 4: To create a system for performing under full coordination of related organization for implementation of the measures discussed below.

## 4. PROJECT EFFECTIVENESS AND EVALUATION

### 4.1 Project Effectiveness

#### 4.1.1 Project Effectiveness against Design Flood

Effectiveness of combination of countermeasures against Design Flood has been checked by maximum flood discharge diagram, in which values indicate maximum flood discharge considering secondary dykes, not river flow capacity. The simulation was done to cover the period from June 1, 2011 to December 31, 2011. The following three combinations have been studied:

**Combination of SCWRM M/P**

1) Effective Operation of Existing Dams
2) Construction of New Dams
3) Improvement of Retarding/Retention Areas
4) East/West Diversion Channel (Capacity: 1,500$m^3$/s)
5) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
6) River Channel Improvement Works (not including Tha Chin River Improvement)
7) Flood Forecasting

**Proposed Combination 1**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

**Proposed Combination 2**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 1,000$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

Maximum flood discharge diagram, and inundation area and depth (Simulation Results) of each combination is given as follows:

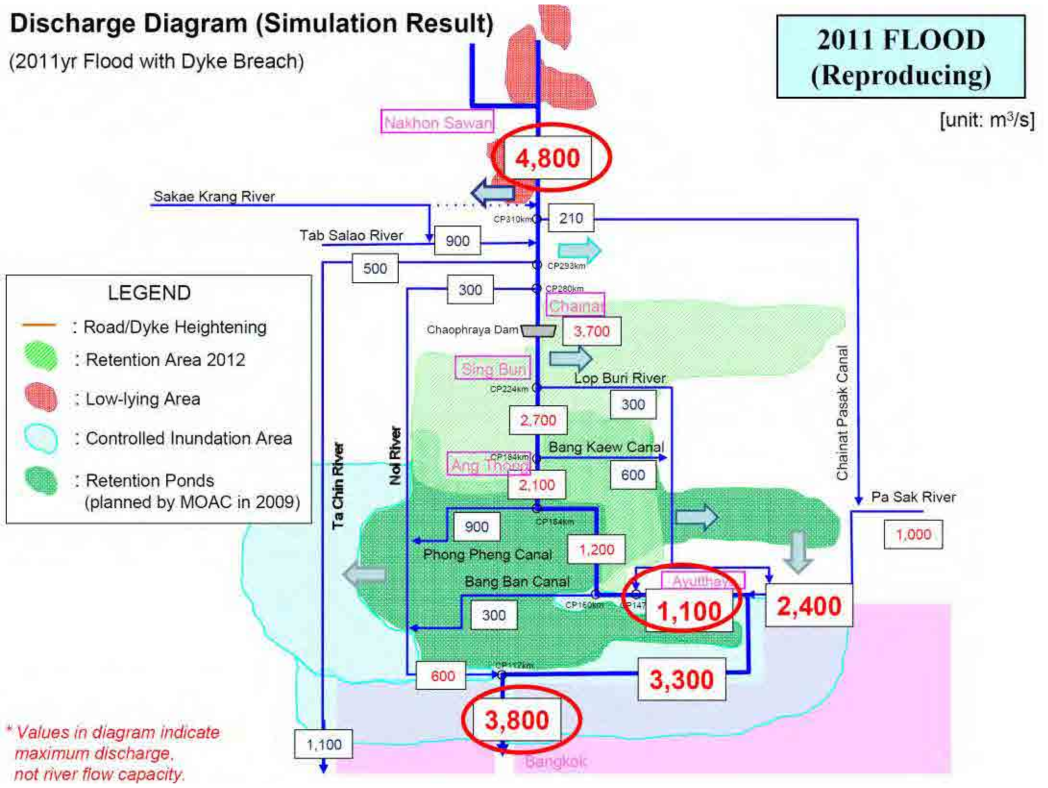



**Figure 6 Maximum Flood Discharge Diagram (2011 Flood Reproducing)**

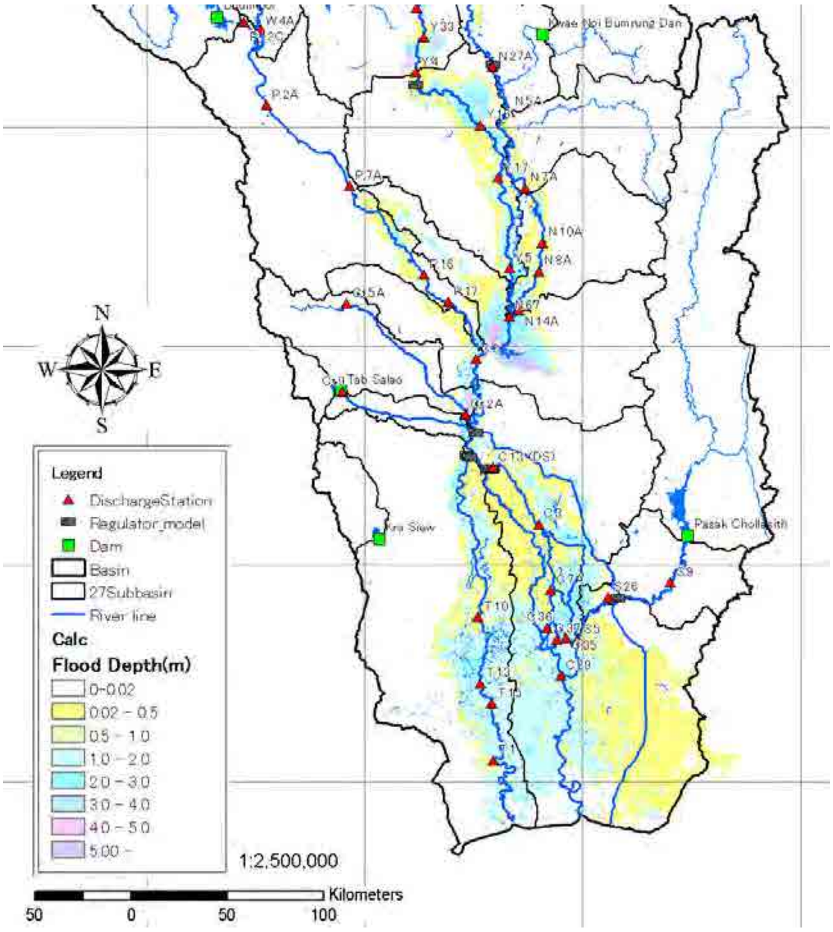



**Figure 7 Flood Inundation Area and Depth (2011 Flood Reproducing)**

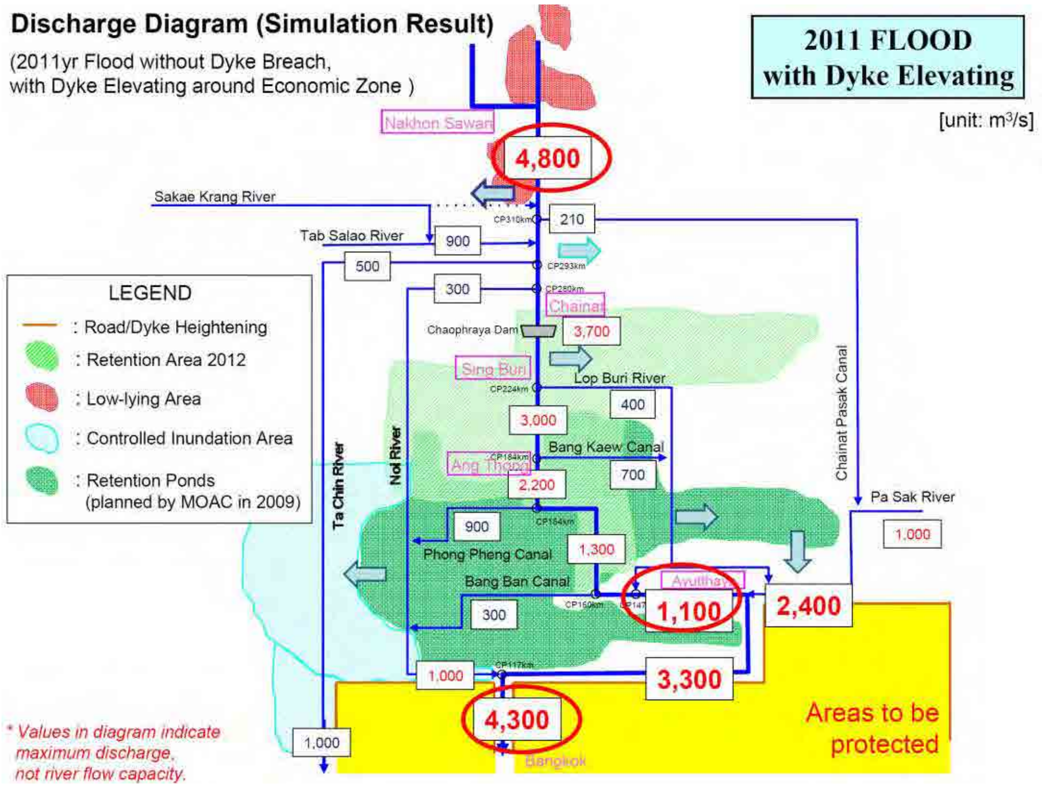



**Figure 8 Maximum Flood Discharge Diagram (2011 Flood with Dyke Elevating around Protection Area)**

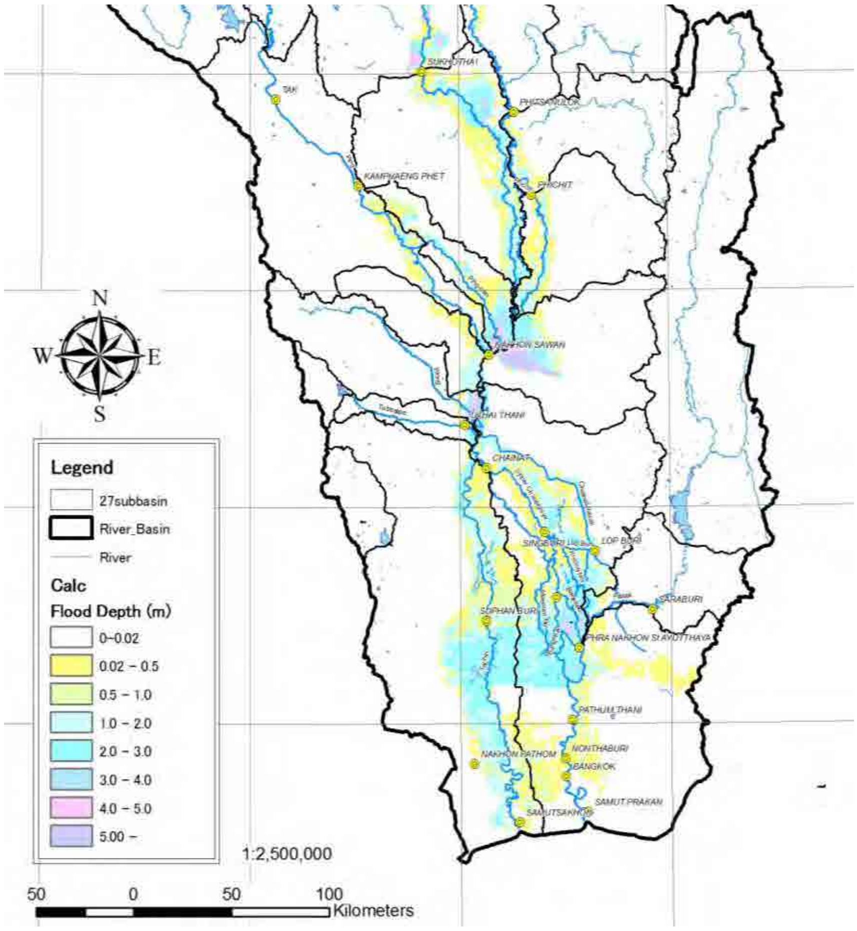



**Figure 9 Flood Inundation Area and Depth (2011 Flood with Dyke Elevating)**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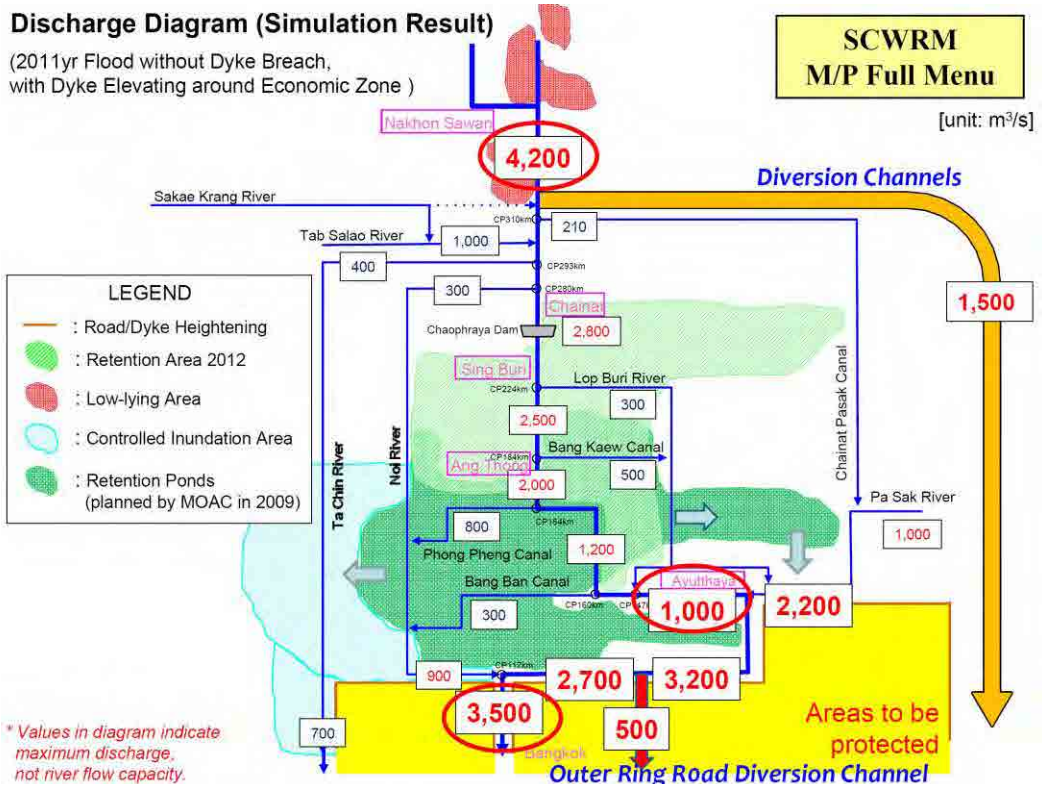



**Figure 10 Maximum Flood Discharge Diagram (SCWRM M/P)**

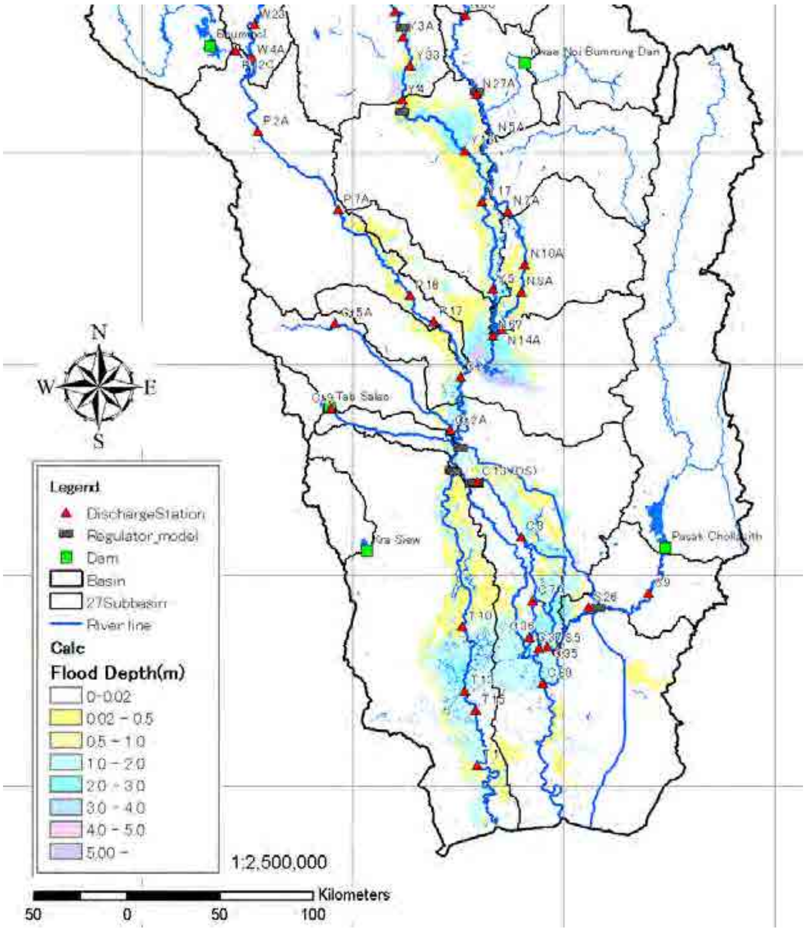
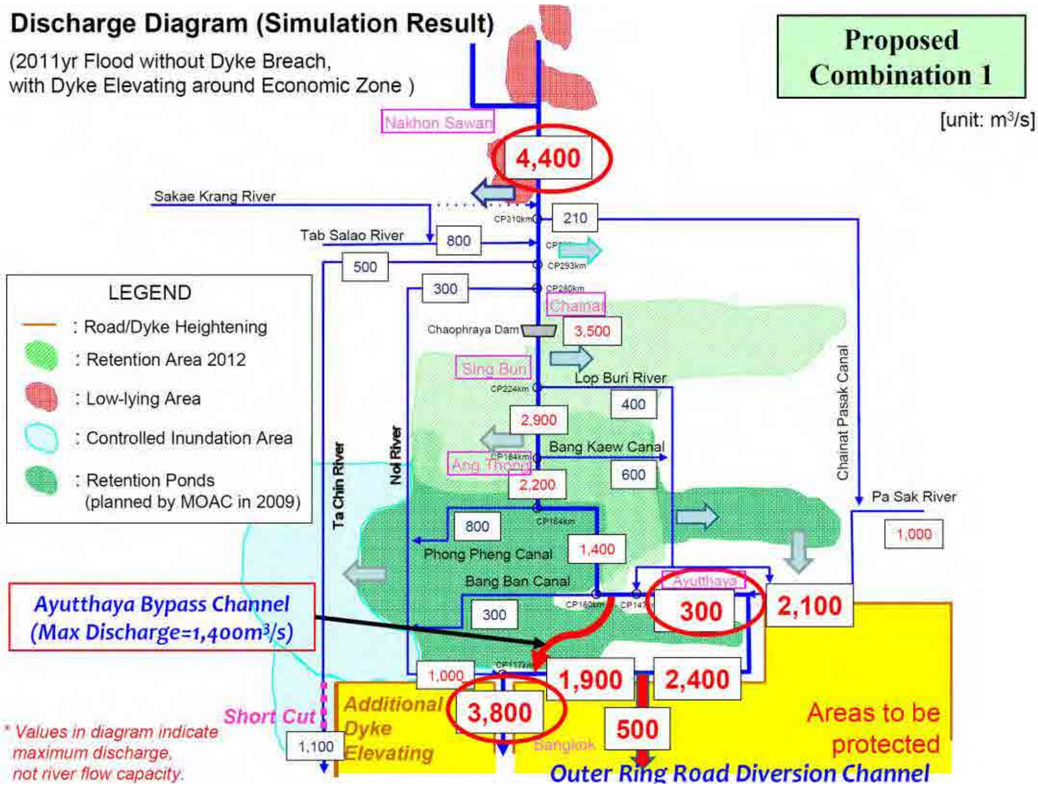



**Figure 11 Flood Inundation Area and Depth (SCWRM M/P)**




* *Discharge capacity of Chao Phraya River near Bangkok is considered to be approx. 4,000 m³/s*

**Figure 12 Maximum Flood Discharge Diagram (Proposed Combination 1)**

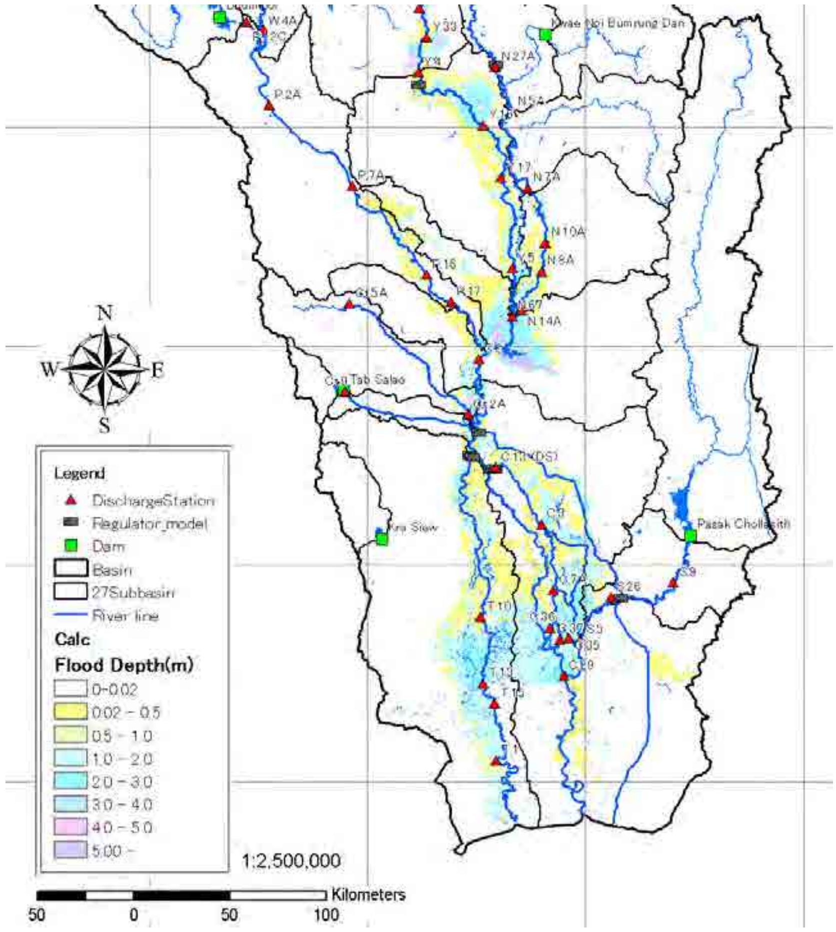



**Figure 13 Flood Inundation Area and Depth (Proposed Combination 1)**

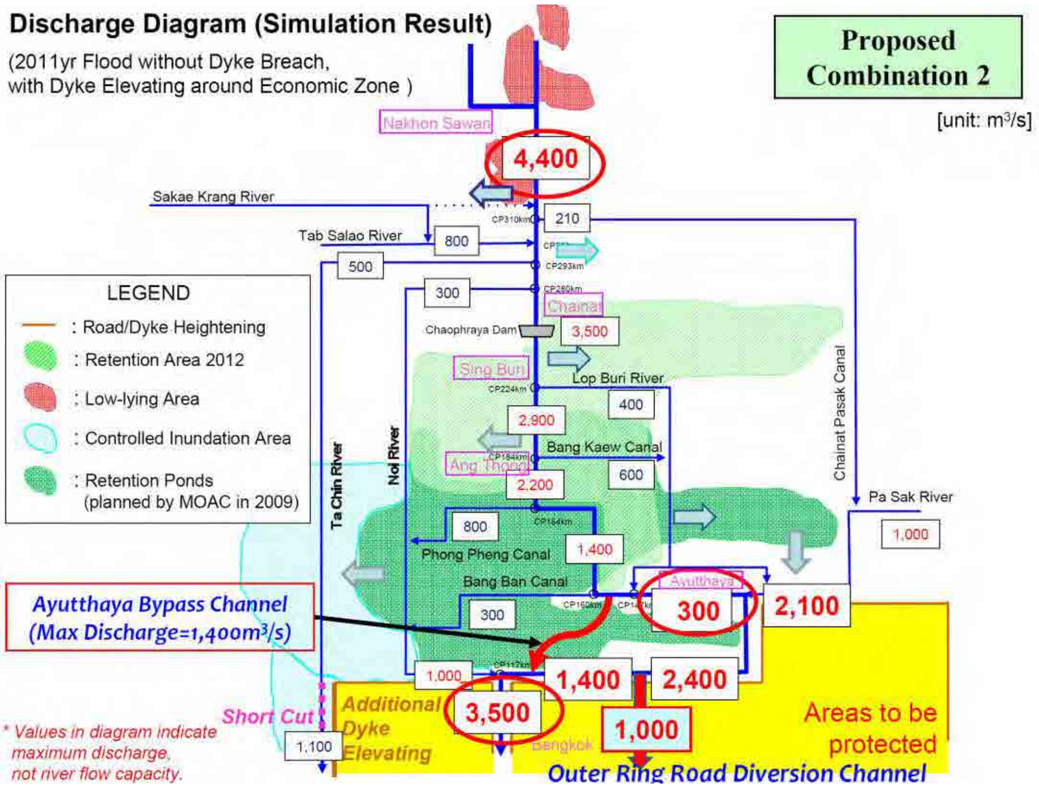



**Figure 14 Maximum Flood Discharge Diagram (Proposed Combination 2)**

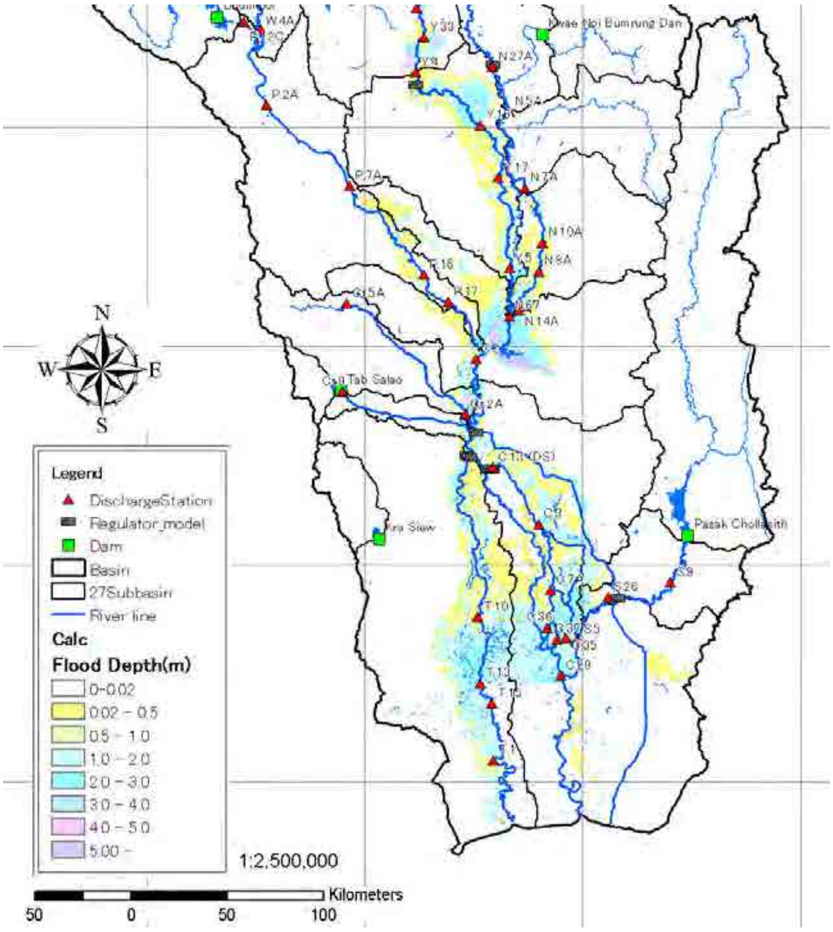



**Figure 15 Flood Inundation Area and Depth (Proposed Combination 2)**

Figure 17 shows river flow capacity considering secondary dykes (refer to Fig. 16) with river improvement works under proposed Combination 1 or Combination 2.

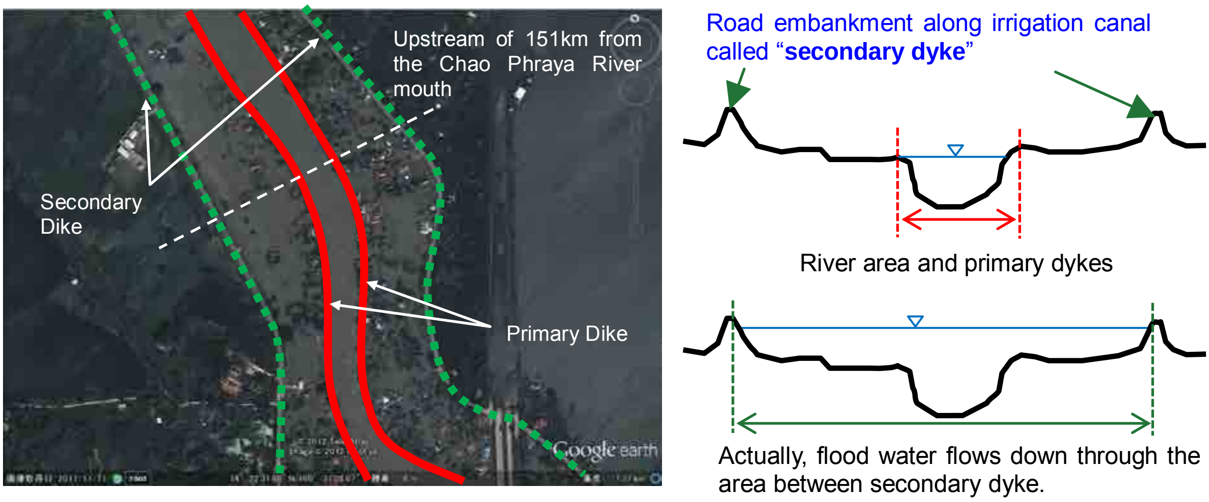



**Figure 16 River Flow Section considering Secondary Dykes**

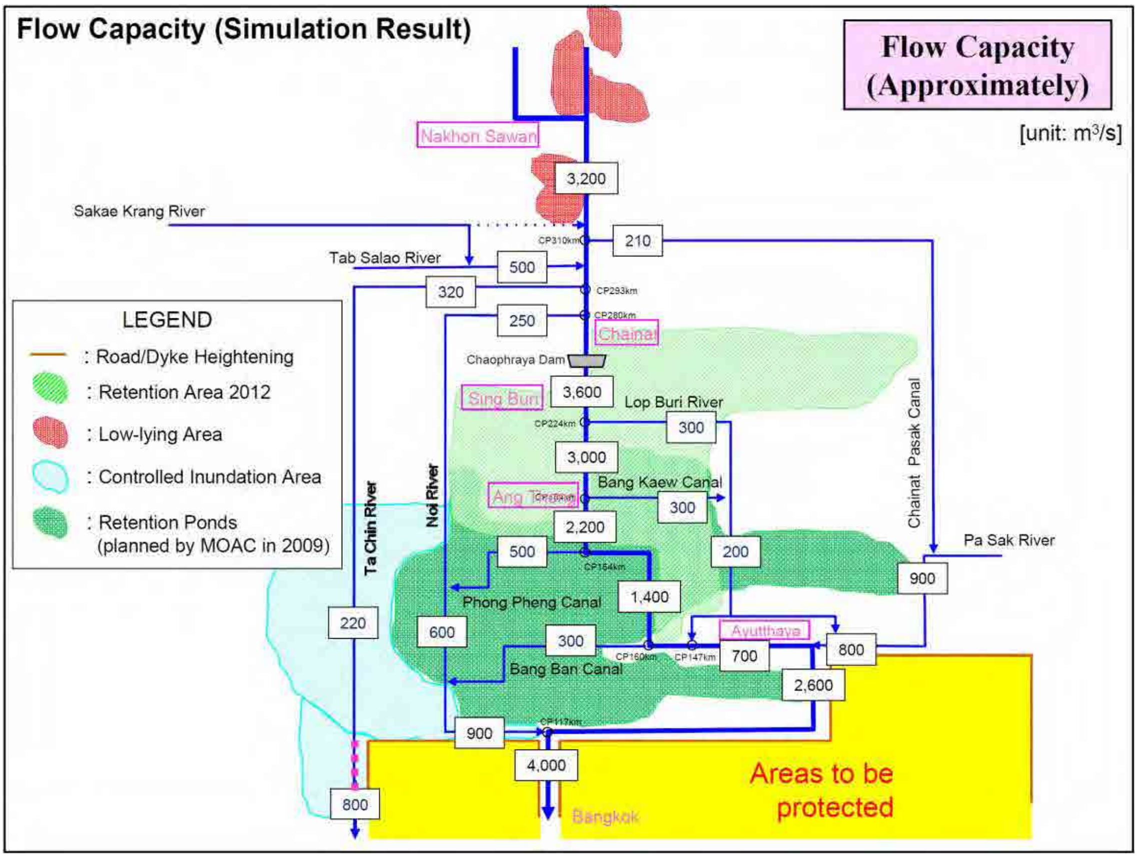



**Figure 17 River Flow Capacity Diagram**
**(Simulation Result, with River Improvement Works under Combination 1 or 2)**

### 4.1.2 Verification of Project Effectiveness against Other Rainfall Patterns

Project effectiveness should be verified against other rainfall patterns of measure flood year, namely, 1970, 1975, 1980, 1994, 1995 and 2006. Effectiveness of Combination 1 and 2 against other rainfall patterns is verified.

## 4.2 Cost, Benefit and EIRR

### 4.2.1 Cost

The project cost is estimated based on the domestic price level as of December, 2012 indicated in Thai Baht. The applied exchange rate (Bank of Thailand Selling Rate as of 28 December, 2012) is as follows:

- 1 USD = 30.7775 Baht (1 Baht = 0.032 USD)
- 100 JPY = 35.7960 Baht (1 Baht = 2.794 JPY)

Results of project cost estimation are given as follows:

**Table 2 Project Cost**

| Item | Project Cost (billion Baht) | | |
|---|---|---|---|
| | SCWRM M/P | Proposed Combination 1 | Proposed Combination 2 |
| Total | 508 | 143 | 190 |

Note 1: The costs in the respective columns include construction, engineering service, administration, land acquisition, resettlement, physical contingency, price escalation and valued added tax.

Note 2: Non-structural measures proposed in the study are not included in the cost estimate.

### 4.2.2 Benefit

Benefits of a flood management project are derived from the reduction of flood damage in the whole inundation area.

**Table 3 Flood Damage Estimation**

| Flood Damage | Estimation |
|---|---|
| Direct Damages on Assets of Factories | The amount of damage is estimated by summing up damaged asset values of which rates vary according to flood inundation depth. The flood simulation gives inundation depth of each 2 km x 2 km grid cell in the flood plains. |
| Direct Damages on Assets of Households | |
| Other Direct and Indirect Damages | The amount of damage is estimated with the percentages to the total amount of asset damaged derived from the research by the Ministry of Finance and the World Bank. |

### 4.2.3 EIRR, Benefit/Cost Ratio and Net Present Value

Based on the above-mentioned cost and benefit, EIRR, Benefit/Cost and Net Present Value are estimated as follows:

**Table 4 EIRR, Benefit/Cost and Net Present Value**

| Case | EIRR | Benefit/Cost | Net Present Value (Billion Baht) |
|---|---|---|---|
| SCWRM M/P Full Menu | 13 % | 1.1 | 21 |
| Proposed Combination 1 | 29 % | 2.7 | 137 |
| Proposed Combination 2 | 25 % | 2.2 | 127 |

Note 1) Price Level: 2012
Note 2) Evaluation Period: 2013 to 2050 (38 years after the commencement of the construction)
Note 3) Social Discount Rate: 12 %

## 4.3 Environment and Social Consideration

### 4.3.1 Outline of the Project

(1) Project Name

1) Ayutthaya Bypass Channel (19km length)

2) Outer Ring Road Diversion Channel (100km length)

3) Dyke Improvement of the Lower Chao Phraya River (approx. 90km length)

4) Dyke Improvement and Shortcut Channels in the Tha Chin River Basin (180km length in dyke improvement, 10.6km length in short cut channels)

(2) Objectives

After several trials to develop an effective combination of countermeasures for flood management in Thailand, establishing four structural measures: 1) Ayutthaya Bypass Channel (19km length), 2) Outer Ring Road Diversion Channel (100km length), 3) Dyke Improvement of the Lower Chao Phraya River (90km length) and 4) Dyke Improvement and Shortcut Channels in the Tha Chin River Basin (180km length in dyke improvement, 10.6km length in shortcut channels), and with other structural/non-structural measures has been proposed as the most technical and cost-effective measures for protecting the lower Chao Phraya River Basin where the industrial centers are integrated. In this section, evaluation for the four plans is to be conducted from a viewpoint of environmental and social aspects, respectively.

### 4.3.2 Categories of the Project and Environmental Assessment

According the Thai laws, 34 project types and activities require an Environmental Impact Assessment (EIA) and approval through the national approval process. However, the diversion channels and dyke improvement are sure to be outside the scope of the EIA category in accordance with the Thai environmental assessment system at present. On the other hand, impacts on the environment may arise mainly by construction activities for the project. And a case is probable to make the residents or houses resettled in the project area to other location. Taking into account the situation, it is cocluded that conducting an Initial Environmental Examination (IEE) should be essential according to the JICA Guidelines for Environmental and Social Considerations.

### 4.3.3 Project Area Outlook and Scopes of Assessment

(1) Ayutthaya Bypass Channel

The planning area is located along the west side of Route 347 where both ends intersect with the right banks of the Chao Phraya River between north area of the central Phra Nakhon Si Ayutthaya (Ayutthaya) and south Bang Sai. The area is mostly occupied with plain arable fields, and houses are found in a few sites such as the intersection of the planned bypass channel with Route 3263. Major industrial centers including an industrial estate develop along the left bank of the Chao Phraya River. Ethnic groups, national or natural parks, precious wild lives and historical memorials are not distributed over the whole planned area.

(2) Outer Ring Road Diversion Channel

The planning diversion channel starts from the left bank of Chao Phraya River in the south part of Bang Pa-in Industrial Estate in Phra Nakhon Si Ayutthaya and develops toward south in parallel with the east side of the Eastern Outer Ring Road (R9) until the Gulf of Thailand at Klong Dan, through the east side of Suvarnabhumi International Airport. The area lies low and occupies paddy fields and social activity aggregations (houses, commercial facilities, schools etc.). In general social activity aggregations lie in the upper area and paddies or swamps in the lower area, but the lower area has been developing into social activity areas thanks to recent development plans in East Bangkok. Ethnic groups, national or natural parks, precious wild lives and historical memorials are not distributed over the whole planning area.

(3) Dyke Improvement of the Lower Chao Phraya River

The target area of the dyke improvement is in lower Chao Phraya River from the estuary to approx. 90km upstream. This basin lies in the Chao Phraya Delta where business and industrial activities focus on. Bangkok and its vicinities cover the most area of the project. No specific land acquisition is required for the dyke improvement because most works are to add the height of the existing parapet walls (0-60km points, constructed by BMA) and dyke roads (constructed by DOH). All the work areas are within the Right-of-way of the RID and authorities concerned. Like the Ayutthaya project, no specific concerns like ethnic groups, national or natural parks, precious wildlife and historical memorials have been observed over the area.

(4) Dyke Improvement and Short Cut Channels in the Tha Chin River Basin

Tha Chin River is a distributary of the Chao Phraya River and located in Thailand's central plain. In this project, dyke improvement starts from the left bank of the Tha Chin River at the estuary to the connecting point with Bunlue Canal. Short Cut Channels are to be constructed within this dyke improvement area. Along the target river area, some facilities like temples, houses and shops are established. Most of lands are for agricultural use. The densely inhabited area is only around the estuary.

### 4.3.4 Comprehensive Evaluation and Mitigation Measures

It is considered feasible in general to avoid or reduce severe impacts which will be derived from construction works or caused by a direct reform from the existence of these new channels when conducting the mitigation measures. In particular careful considerations and measures will be essential to implement land acquisition and involuntary resettlement of the habitant that would have an affect by the project progress.

## 4.4 Results of Project Evaluation

The most cost-effective combination of projects is sought, since cost of all the projects is expected to exceed the budget for flood management.

The proposed combination 1 or 2 of projects needs only less than 40% of SCWRM M/P cost, while the evaluation of the project, in other words, Economic Internal Rate of return (EIRR) is more than 25%, which is very high compared with the SCWRM M/P.

According to the Thai laws, the projects have no need to conduct an EIA and no need to get approval through the national approval process because both the by-pass channel and diversion channel projects are outside the scope of the EIA category in accordance with the Thai environmental assessment system at present.

On the other hand, impacts on the environment may arise mainly by construction activities for the project. And a case is probable to make the residents or houses resettled in the project area to other location. Taking into account the situation, it is cocluded that conducting an Initial Environmental Examination (IEE) should be essential according to the JICA Guidelines for Environmental and Social Considerations.

From environmental and social consideration aspects, proposed channels seem to have no severe environmetally and socially adverse impacts. However, careful considerations and measures will be essential to implement land acquisition and involuntary resettlement of the habitant that would have an affect by the project progress.

From the above evaluations, it is recommended to prioritize implementation of the proposed combination, which includes:

1) Effective Operation of Existing Dams;
2) Outer Ring Road Diversion Channel (Capacity: 500 or 1,000 $m^3$/s);
3) River Improvement Works (including Tha Chin River Improvement);
4) Ayutthaya Bypass Channel (Capacity : 1,400 $m^3$/s); and
5) Flood Forecasting.

*Note : Peak flow discharge at Bang Sai was estimated at 3,800 $m^3$/s in Combination 1 and 3,500 $m^3$/s in Combination 2. Since daily peak flow discharge of 3,900 $m^3$/s at Bang Sai was recorded during 2011 flood without any damages cased by overflow of water in the lower reaches of the Chao Phraya River (downstream of Bang Sai), EIRR and B/C calculated as the damage caused by flooding does not come out with discharge of 3,800 $m^3$/s. In case that the damage comes out with discharge of 3,800 $m^3$/s, EIRR and B/C of Combination 2 may become values bigger than those of Combination 1.*

# 5. CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The Study Team had reviewed the Flood Management Plan of the Royal Government of Thailand for the Chao Phraya River Basin . The Flood Management Plan was formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011. Based on the concept formulated by SCWRM, this Study evaluated the combination of various countermeasures quantitatively and from the engineering point of view utilizing precise topographical information obtained by Laser Profiling and the latest knowledge.

The Water Resorces Flood Management Committee (WRFMC) revised the SCWRM plan parlty in March 2013. However, its reliability seems to be insufficient because it did not utilize precise topographical information.

The results of the review by the Study Team are as summarized below:

**Unsteady Flow Analysis**

- To evaluate the flow capacity in the lower reaches influenced by sea tide, the unsteady flow analysis method was employed for the flow routing analysis and inundation analysis. Unsteady flow is defined as the non-constant special/temporal flow. At the downstream of Chao Phraya River, river flow is influenced by sea tide as shown in the following figure, and the water level near the estuary is strongly regulated by the tidal level. To describe this natural phenomenon (ever-changing water level), it is indispensable to employ the unsteady flow analysis. From Nakhon Sawan (C2) to the coastal line of the Gulf of Thailand, both of the riverbed slope and the ground slope are almost flat, and the behavior of river flow and inundation flow is dominated by not only the riverbed/ground slope, but also by the difference of surface water head.
- Since there is no relation between water level and discharge, the estimation of flow capacity using the rating curve has been difficult. In the downstream of Chao Phraya River, water level does not rise regardless of flood scale. Therefore, the potential passing discharge, which is equivalent to the flow capacity, was used for the evaluation of high water level.

**Large Flood Water Volume Compared with River Flow Capacity**

- Through the investigation and evaluation of present conditions related to water resources and flood management and focusing on flood disaster management, it has been revealed that the Chao Phraya River Basin has a large low-lying area used as agricultural area in the dry season but have natural functions as retarding basin in the rainy season. People in the basin are coexisting with floods. As one of the main features of inundation, it is pointed out that traffic of flood water from the river to the flood plain is busy during rainy season, since the potential flood water volume from the river basin is much larger than the flow capacity of the rivers/canals. In addition, the water impounded in the flood plains, consisting of spilled water, local rainfall and side flow from sub-catchment areas, return to the rivers/canals easily because some rivers/canals have no dyke or the dyke height is low. Therefore, the flood control effectiveness of even a large diversion channel installed upstream and/or the construction of new dams will not appear enough due to the return of flood water from the flood plain.

**Design High Water Level**

- The setup of the Design High Water Level (DHWL) is very an important procedure to implement an effective river management including flood prevention, control for deliberate inundation, river improvement works and so on. Actually, river discharge and volume depends on the dyke height. If a high and long dyke is constructed upstream, discharge from the upstream will increase and could cause floods inundation downstream. Therefore, the DHWL should be designed precisely considering flow capacity, land use condition along the river, the gap of flood safety level between the upstream and downstream, etc. For instance, a large city like Bangkok must be protected from flooding so that a high river dyke should be installed. On the other hand, in rivers flowing in a natural area and agricultural area, it is highly recommended that the river dyke should be kept low and/or maintain the existing condition, because a highly elevated dyke would restrain river overflow and decrease the function of adjacent lands as the natural retention or retarding basin. Besides, a high dyke in such areas would also cause problems in water intake for irrigation. At the river mouth, sea tide must be considered since water level near estuary is dominated by tidal motion even during the flood season. Once dyke break occurs, infinite seawater will come into the land and wreak catastrophic damage on the coastal area.

- In Chao Phraya River from 0km to 90km, near the Bangkok metropolitan area, Bangkok Metropolitan Administration (BMA) is scheduled to install parapet wall for flood prevention. It seems, however, that the height of parapet wall was set based on a record-high water level in Chao Phraya River, and the height was setup in stair-steps. In actual practice, the slope of surface water level is never in the form of stair-steps and longitudinally, the dyke slope is slanted according to the gradient of water level. Therefore, JST recommends that the parapet wall installed near Bangkok be slanted based on the DHWL proposed in this study.

**Influence by Road Heightening Works around**

- As of end of June 2013, the road heightening works by DOH and DOR around the economically important zone has started. The comparative study between Simulation Case-0 (existing condition) and Simulation Case 0-1 (after completion of road dyke heightening works), clearly shows that the inundation depth and volume at Lat Bua Luang northwest from Bang Sai (see inundation block LO14 in the following figure) will dramatically increase due to the heightening works, but this is an extreme case. However, continuous structures like highway with embankment and road dyke would change the inundation condition to some extent, so that the influence of structures should be examined by flood inundation analysis and, if any, some countermeasures shall be designed so as to decrease the flood damage due to the continuous structures.

**Current Capacity of Pumps installed in Protection Area**

- A circle levee such as the road dyke heightening works being done by DOH and DOR could aggravate inland flooding since local rainfall would not spread and could accumulate resulting in deeper inundation. With regard to the lower reaches of the Chao Phraya River, it is almost flat and accumulated local rainfall would be drained to the rivers or canals not by gravitational drainage but by pumping. In this study, examined was whether or not the existing capacity of pumps of approximately 1,590$m^3$/s is enough to drain inundation water (see Chapter 10, Subsection 10.2.12, Inland Storm Water Drainage). The study results show that the current capacity of pumps is enough for inland flooding caused by floods of the 2011 flood scale; however, this is just the result of a brief survey for the whole lower basin. Therefore, a more detailed study on inland flooding in a local area is recommended to be carried out separately.

**Comprehensive Flood Management Plan**

- The Master Plan (M/P) formulated by the Thai Government had aimed to attain integrated and sustainable water resources and flood management of the Chao Phraya River Basin. All measures proposed in the M/P are more or less effective for the mitigation of flood risk. However, the priority and feasibility of the proposed measures should be examined in various terms such as technical, economic, social and environmental aspects before implementation. The measures are composed of structural and non-structural measures, and the optimum combination of measures should be examined as to their effectiveness before implementation in order to attain the objectives within a limited term, because some of the measures might take a long time for implementation.
- It has been revealed that the operation of the existing dams during the 2011 flood was effective to reduce flood disaster risks, since Bhumibol Dam and Sirikit Dam stored about 12 billion $m^3$ of floodwater. However, there is still room for modification of the operation rules of the existing dams from the flood control and water use aspects. More effective operation of the existing dams will be possible. In this study, "Target Curve" and "Alert Curve for Drought" are proposed. "Target Curve" is the target storage volume for water use and the upper limit for flood control.

"Alert Curve for Drought" can provide indicators to judge whether a drought year. "10% Probability" and "20% Probability" mean the risk of drought once in every 10 years and once in every 5 years, respectively.

The Study proposes that the reservoir levels should follow the recommended "Target Curve" until the end of July, and from August, discharges should be stored in reservoirs with maximum outflows of 210m³/s for Bhumibol Dam and 190 m³/s for Sirikit Dam. If the proposed dam operation is applied for the 2011 flood, the peak discharge at Nakhon Sawan (C2) could be reduced by 400m³/s. If the storage volume is less than the proposed Target Curve, the inflow should be stored in the reservoir. The released discharge shall not be less than the minimum discharges of 8m³/s at Bhumibol Dam and the 35m³/s at Sirikit Dam. Dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose.

- It has been revealed that there are two types of primary flood dykes along the river banks and secondary dykes of road-cum embankments of irrigation canals along the Chao Phraya River. The secondary dykes are considered as flood prevention measures. However, many local cities and communities are located along the river and numerous people are living between the two dykes. Also, even after the implementation of the proposed measures, a large part of the inundation area in the central plain will remain so that people should live with floods. Therefore, measures such as community-based flood disaster management are indispensable for the promotion of controlled inundation.

- The Study proposes the combinations of: (i) Effective Operation of Existing Dams; (ii) Construction of the Outer Ring Road Diversion Channel;(iii) Implementation of River Improvement Works including the Tha Chin River Improvement; and (iv) Construction of the Ayutthaya Bypass Channel as the optimum combination for the protection area of Bangkok and its vicinity to prevent flood disasters from the Chao Phraya River. The proposed combinations are feasible in technical, economic and environmental terms and for appropriate implementation of the proposed flood disaster management, nonstructural measures are required. It is recommended to prioritize implementation of the proposed combination as soon as possible.

  Proposed combinations of measures are as follow:

  (1) Proposed Combination 1

    a) Effective operation of existing dams
    b) Outer ring road diversion channel (Capacity: 500m³/s)
    c) River improvement works
    d) Ayutthaya Bypass Channel (Capacity: 1,400m³/s)

  (2) Proposed Combination 2

    a) Effective operation of existing dams
    b) Outer ring road diversion channel (Capacity: 1,000m³/s)
    c) River improvement works
    d) Ayutthaya Bypass Channel (Capacity 1,400m³/s)

  (3) Other Non-structural Measures

    a) Re-forestation
    b) Flood Forecasting.
    c) Land use control in inundation areas

- As a result of the Study, GIS database has been developed based on the data collected which should be utilized by the RID after the Study.

- As a basin-wide hydrological and hydraulic analysis model (using Mike 11 and Mike 21) incorporating the new topographical data, a runoff and flood analysis model has been developed. It is recommended that the simulation of flood runoff and inundation areas should be utilized for the flood risk management more precisely.

## 5.2 Recommendation

To avoid flood disasters in the protection areas and reduce the flood risks in the Chao Phraya River Basin, the Study recommends that the Thai Government should take immediate measures and arrangements for the implementation of the Comprehensive Flood Management Plan for the Chao Phraya River Basin.

Above all, the following remarks should be recommended.

- The precise topographical information obtained in the JICA Study should be distributed immediately to all organizations and agencies concerned. They should carry out the necessary investigations based on it. If this accurate topographical information is not used, any proposal in extremely lowland area like the Chao Phraya River Basin would have few engineering rationality and hardly make scientific sense.
- As indicated in the explanation of unsteady flow analysis, the amount of flood water volume stored in the entire Chao Phraya River channel is large, fluctuate itself in the river channel and inundation area, and volume is very large. So the effectiveness of even a large diversion channel from the upper reaches to the Gulf gradually decreases and may disappear at the lower reaches depending on the location of the inlet structure. Therefore, based on the idea that the effectiveness of the diversion channel is not changed regardless of the location, flood management plan by combination of channels with fixed flow capacity should not be avoided. It leads to a misdirected plan.
- This Study stated the method of evaluation of flow capacity in the area subject to tidal action. It is very important and fundamental issues of river management in the Bangkok Area until now and in the futures. It should be well understood.

**Recommendation about Comprehensive Flood Management Plan**

- To conduct effective operation of the existing dams (Bhumibol and Sirikit dams) as proposed by the Study.
- To implement the proposed combination of structural measures, i.e., river improvement works including the Tha Chin River improvement works, the Outer Ring Road Diversion Channel (500m³/s or 1000m³/s), the Ayutthaya Bypass Channel (Capacity: 1,400m³/s), and the nonstructural measures proposed by the Study.
- To promote controlled inundation, it is necessary to conduct the following: (i) To develop an accurate base map for the low-lying floodplain areas of the Chao Phraya River Basin based on the LP data prepared by JICA in 2012; (ii) To establish land use control and develop land use plan for the urban areas in the controlled inundation area; (iii) To promote community based flood disaster risk management including the implementation of structural and non-structural measures required due to the types of inundation zones; and (iv) To enhance public awareness on flood disaster risk management through improvement of dissemination of information and communication and education.
- As decision support and managing tools, the GIS data base and the river models developed in the Study should be maintained and updated in a sustainable manner for the effective flood disaster management of the Chao Phraya River Basin.

## Recommendations on the Hydrological Data Observation System

The issues identified in the hydrological data observation system are as described in the following table.

| No. | Issues | Recommendations |
|---|---|---|
| 1 | Shortage of Rainfall Station and inhomogeneous distribution<br>In this project, JST collected the rainfall data from approx. 700 stations in the Chao Phraya River Basin. Although the density of rainfall stations in the Chao Phraya River Basin is not so high at approx. $300km^2$/station, many of the rainfall stations are located disproportionately, and most of stations under RID are concentrated in the irrigation area downstream of Nakhon Sawan (C.2). In order to examine the exact water resource and establish the flood control and water use plans, etc., it is necessary to install more rainfall stations. In Japan, it is believed that the ideal density of rainfall stations is $50km^2$/station as a precautionary measure against torrential rainfall. | Rainfall stations should be installed especially in the middle basins, such as the Pa Sak River Basin, the area from Nakhon Sawan to Sukhothai and so on. It is ideal that rainfall stations should be distributed across the nation. Naturally, a higher density of stations in mountainous area is better. |
| 2 | Observation Interval (Water Level Station)<br>Basically, it is enough to use daily data when rainfall analysis in the Chao Phraya River Basin is conducted because flood arrival time is long. However, in tidal sections, hourly water level observation should be carried out. Water level in tidal sections fluctuates periodically and usually high/low tide occurs twice a day due to sea tide, which regulates river flow. As of June 2013, JST has confirmed that hourly observation on water level has been done at telemetry stations TC.54, TC.12, TC.22, TC.55 and C.29A. However, observed data at most stations included errors and hourly water level data was not available. | Firstly, the existing water level station recording hourly data should be repaired and maintained. At least up to Ayutthaya (upstream of 141km from estuary), hourly observation should be done since river bed slope from estuary to Ayutthaya is almost flat and influenced by sea tide. Hourly water level observation should then be carried out not only in Chao Phraya River but also in Tha Chin River. |
| 3 | Discharge Observation during Flood Season<br>Obtained hydrological data during flood events is very valuable; especially discharge data at tidal sections near the estuary. It is desirable that hourly discharge observation is conducted with horizontal ADCP (Acoustic Doppler Current Profiler). | It is highly recommended that hourly discharge observation at tidal sections during flood events shall be done by using ADCP. Currently, discharge data obtained with ADCP seems to be the most accurate. The RID monitoring team, which can observe discharge with ADCP, should expand their activities to other sites. |
| 4 | Installation of Hydrological Station Monitoring Water Level and/or Discharge<br>By using the flood analysis model, it was found that overflow and return flow from the flood plain is frequent from Nakhon Sawan to Ayutthaya. In order to clarify the phenomenon, water level/discharge observation should be done. | Understanding of overflow volume and return flow to the rivers/canals is necessary to control flooding and inundation so that new hydrological stations should be installed. Hydrological stations are required, especially, from Chao Phraya Dam to Nakhon Sawan because there are no water level stations in the area. In addition, water level/discharge observation should be carried out in major tributaries including Noi River, Lop Buri River, Chainat Pa Sak Canal and so on, since inflow from tributaries could impact on the flow regime at the mainstream. |

## Recommendation about Hydrological Data Management

Observed hydrological data including water level, discharge, and rainfall is valuable information for the establishment of an integrated water management plan, flood control, irrigation planning and so on. The issues on data management noticed through the Study are as listed in the following table.

| No. | Issues | Recommendations |
|---|---|---|
| 1 | Status of Hydrological Station<br>The location (latitude/longitude) of some rainfall gauging stations is not correct and the working condition (working or not-working) is unclear, which hinders the planning of flood control and other related projects. | To conduct site survey for all stations and find the current situation, not only the exact location (latitude/longitude), but also the elevation at site shall be measured. It is desired that official RID benchmarks shall be established near the hydrological station by reference to first-class benchmark defined by RTSD. Especially, stations near estuary should require considerable attention, because the elevation of water level gauge may be lowered by ground subsidence. |
| 2 | Data Collection System<br>It seems that there is room to improve the data collection system. Mainly, the RID Hydro Center maintains and collects observed data/information and posts them in their website. However, the frequency of update depends on the Hydro Center and information is not always updated. Besides, latest data is not always sent to the headquarters. | Observed data should be managed in an integrated fashion in the headquarters. The data collection system shall be reviewed and a technical guideline on data collection shall be prepared and distributed to provincial offices. In addition, periodical maintenance work on hydrological equipment should be done thoroughly. |
| 3 | Quality Control<br>Observed data could have a margin of error caused by mistake of recording data, trouble of equipment and so on. Observed data shall be examined carefully. | To ensure high accuracy and reliability of observed data, they should be examined by comparison of historical data and cross-checking with related data. Guideline on data quality control should be prepared. |
| 4 | Image Recording during Flood Event<br>The more information on flood situation, the more effective and efficient is the formulation of a flood control plan, etc. | Moving images during flood events should be recorded and stored, because they are crucially important for understanding the hydraulic behavior of rivers and for establishment of the flood control plan. It is desired that CCTV cameras shall be installed in major hydrological stations and recorded images be saved/stocked and shared with related agencies. River flow condition near the RID office should at least be recorded by digital video camera, etc. |
| 5 | Cross-Section Survey<br>The planning of water management such as flood control plan, water resources and so on should be studied considering latest natural condition. | River cross section could be changed by river improvement works, land development, etc. In Lower Chao Phraya river basin, the construction of road dyke surrounding the economically important zone has been carried out by DOH and DOR, and this would change flow regimes and inundation conditions during the rainy season. Therefore, the river cross-section should be measured periodically and the transition of river shape should also be checked, especially in Chao Phraya River after the confluence of Noi River where the deep river bed erosion occurred which could develop more after completion of the road dyke. |

## Recommendation about Hourly and Daily Flow Capacities in the Tidal Section

Hourly and daily flow capacities in the tidal section of lower reaches of the Chao Phraya River should be surveyed and clarified. During the 2011 flood, the recorded daily peak flow discharge of 3,900m$^3$/m at Bang Sai indicate that there was no damage caused by overflow of water in the lower reaches of the Chao Phraya River. Since the lower reaches of the Chao Phraya River is subject to tidal action, the recorded data in 2011 was based on the hourly automatic measurement of H-Q by H-ADCP. However, although the river width at Bang Sai is more than 500m, the maximum range of this H-ADCP is 300m only, so that it is difficult to conclude whether or not this recorded data is correct. Therefore, continuous measurement by the V-ADCP during flood is recommended in order to clarify hourly and daily flow capacities in the lower reaches of the Chao Phraya River. Clarification of the maximum hourly and daily flow capacity in the lower reaches considering tidal action is one of the most important values for evaluation of flood risk.

According to the results of simulation, during the 2011 flood, the daily peak flow discharges at Bang Sai (112km from river mouth), at TC12 (59km from river mouth), at 20km from river mouth, and at the river mouth have been simulated as about 4,300m$^3$/s, 4,320m$^3$/s, 4,440m$^3$/s and 4,490m$^3$/s, respectively. At this time, hourly peak water elevation is 4.1m MSL, 2.9m MSL, 2.2m MSL and 1.9m MSL, respectively. On the other hand, the crest elevation of existing parapet wall at TC12, at 20km point and at the river mouth is 3.0m MSL, 2.5m MSL and 2.0m MSL, respectively. It means the river water level is still lower than the crest elevation of parapet wall around Bangkok.

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

**FINAL REPORT**
**VOLUME 1: SUMMARY REPORT**

**Location Map**
**Executive Summary**
**Abbreviations**
**Measurement Units**

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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)

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

(Time)

| | | |
|---|---|---|
| s, sec | : | second(s) |
| min | : | minute(s) |
| h, hr | : | hour(s) |
| d, dy | : | day(s) |
| y, yr | : | year(s) |

(Area)

| | | |
|---|---|---|
| $mm^2$ | : | square millimeter(s) |
| $cm^2$ | : | square centimeter(s) |
| $m^2$ | : | square meter(s) |
| $km^2$ | : | square kilometer(s) |
| ha | : | hectare(s) |

(Volume)

| | | |
|---|---|---|
| $cm^3$ | : | cubic centimeter(s) |
| $m^3$ | : | cubic meter(s) |
| l, ltr | : | liter(s) |
| MCM | : | million cubic meter(s) |

(Weight)

| | | |
|---|---|---|
| g, gr | : | gram(s) |
| kg | : | kilogram(s) |
| ton | : | ton(s) |

(Speed/Velocity)

| | | |
|---|---|---|
| cm/s | : | centimeter per second |
| m/s | : | meter per second |
| km/h | : | kilometer per hour |

# CHAPTER 1 INTRODUCTION

## 1.1 Background

In 1999, after the significant floods in 1995 and 1996, the Japan International Cooperation Agency (JICA) proposed several flood mitigation measures composed of structural and nonstructural measures in 1999 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 recorded 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 conducted 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 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.

Subcomponent 1-1:

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

Subcomponent 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 Subcomponent 1-2 that aims to upgrade the Flood management plan for 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 km²and is composed of the tribitaries 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.

## 1.6 Counterpart Agencies

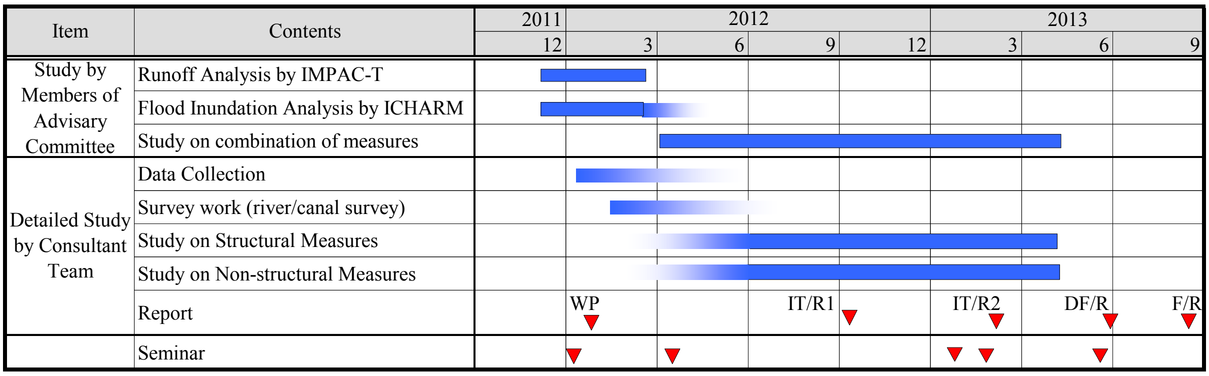
The counterpart agencies were the RID, DWR and NESDB and the executing agency was the RID which organized the “Technical Committee” and the “Technical Woring Group” for the Study in order to smoothly and effectively implement the Study on the Project.

## 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. 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 TC 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, 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 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 Subcontracts

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 STUDY AREA AND 2011 FLOOD

## 2.1 Study Area

Based on the characteristics of the study area, the required measures including the optimum combination of structural and nonstructural measures required for the reduction of flood disasters have been examined. The characteristic of the study area is given as follows:

(1) The Chao Phraya River Basin has the catchment area of 162,000km² composed of eight rivers: Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krung, Pa Sak and Tha Chin.

(2) The Chao Phraya River basin is composed of the three (3) areas: Highlands, Upper Central Plain (upper Nakhon Sawan C2) and Lower Central Plain. The upper catchment area of C2 is 104,000km², which is composed of the catchment areas of Ping, Wang and Yom Rivers. In the Lower Central Plain, the Chao Phraya River joins with a tributary from the west, the Sakae Krung River, diverts from the Tha Chin River at Chai Nat, joins the Pa Sak River at Ayutthaya from the east, flows through Bangkok and its vicinity, and then out to the Gulf of Thailand.


| 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 Chao Phraya River Basin**

(3) The Highlands are covered by forest areas. The current forest area in the highland is about 66,000km², of which 13,500km² is classified as degraded forest by the Royal Forest Department. As the result, the disasters caused by landslide, flash flood, slope failure, and surface erosion has increased. The restoration of degraded forest areas and the improvement of forest management are big issues for flood disaster management.

(4) There are vast low-lying areas in the upper and lower Central Plains, which are contributing as natural retarding basins in rainy season, but important agricultural areas in dry season.

(5) The low-lying area in the upper central plain (Upper Nakhon Sawan) is located along the Yom and Nan rivers. However, the low-lying area is an important agricultural area in dry season. The local core cities and inundation area require measures for promoting controlled inundation.

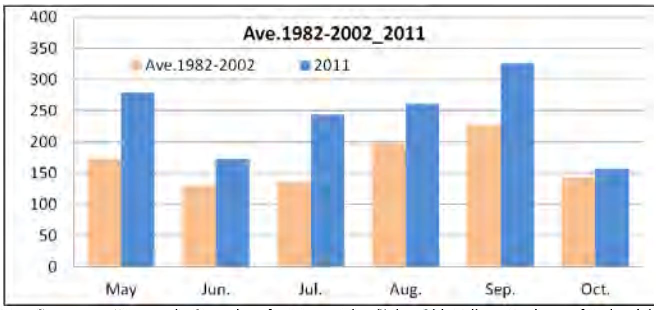
(6) The low-lying area at the lower central plain is located along the Chao Phraya River, Noi and Lop Buri rivers between Chai Nat to Ayutthaya. The area also has the function as flood retarding basin in the rainy season, but mostly used as agricultural area in the dry season. The major protection areas are: (i) Bangkok and its vicinity; (ii) local core cities, and (iii) the inundation area along the Chao Phraya, Noi and Lop Buri Rivers. Along the Chao Phraya River there are primary dykes and secondary dykes and the secondary dykes are used for flood protection. During the 2011 flood, about 15 sites at the secondary dykes were breached and the flood overtopped two sites. All of the breached and overtopped locations were located at the left bank, causing the expansion of the inundation area along the Chao Phraya River.

## 2.2 Characteristics of the 2011 Flood

(1) Rainfall

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.

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 2.2.1 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 high flood discharge 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 2.2.1 Basin Mean Monthly Rainfall of Chao Phraya River Basin**

(2) River Discharge

Figure 2.2.2 shows flood discharge hydrographs of the past major floods. The recorded biggest discharge is 5,451 $m^3$/s in 2006, followed by 4,820 $m^3$/s in 1995. The 4,686 $m^3$/s in 1995 is the third largest.

The 2011 hydrograph forms a very gentle "mountain." The discharge increases gradually. The period when the discharge exceeded the river flow capacity of 3,500 $m^3$/s is about 1.5 months. This long high floodwater weakened river dykes, and finally breached them at several locations, between Nakhon Sawan and Ayutthaya, in particular, as shown in Figure 2.2.2.

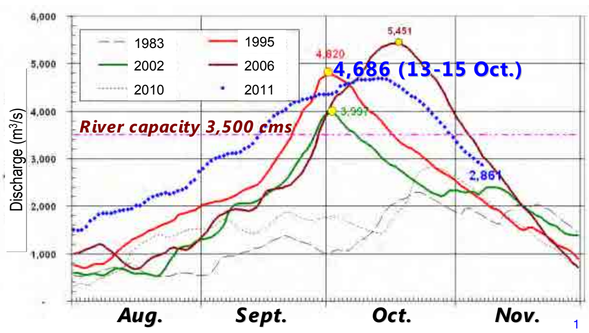
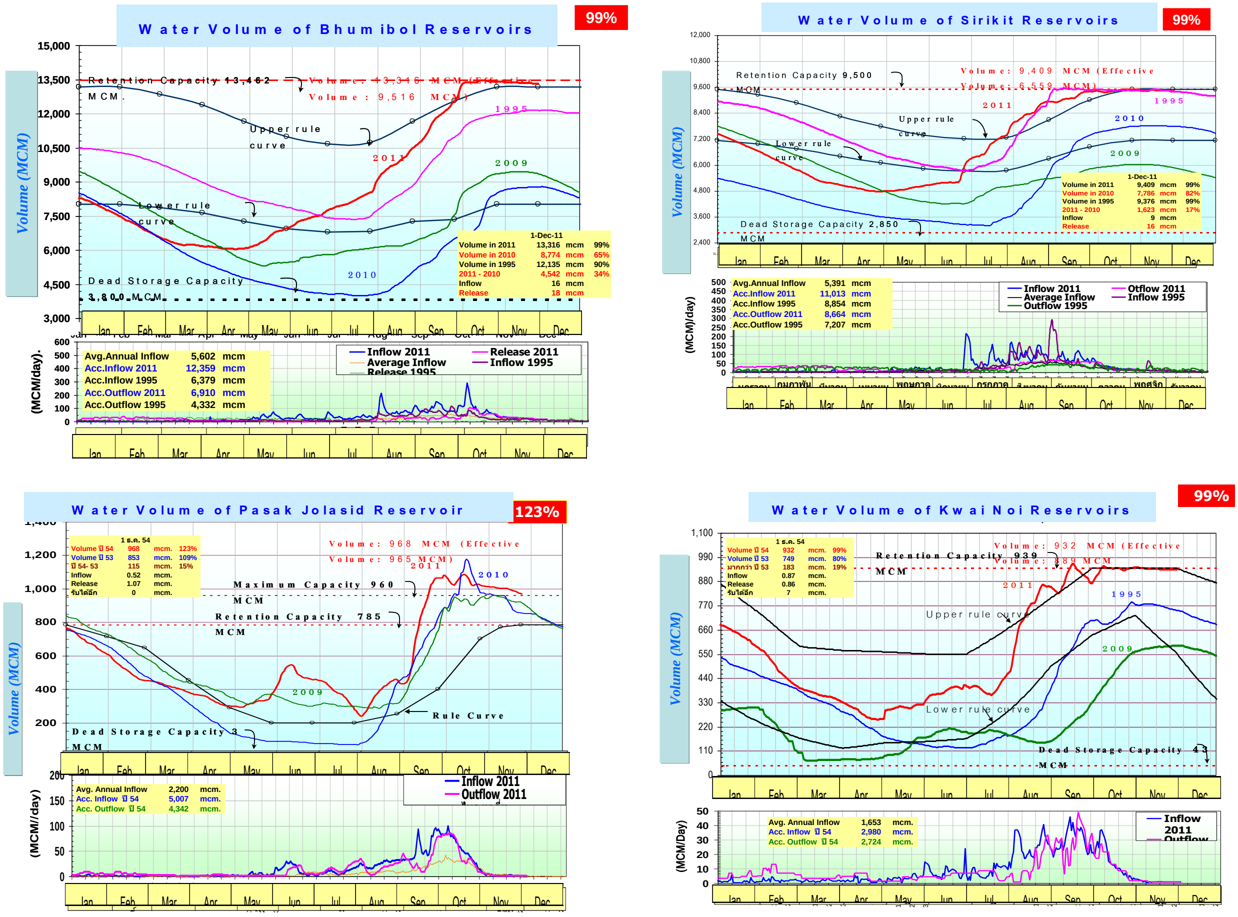



**Figure 2.2.2 Flood Discharge at Nakhon Sawan**

(3) Operation of Dam Reservoirs

There are 4 large dams, Bhumibol, Sirikit, Par Sak Chonlasit and Kwae Noi dams, located in the Chao Phraya River Basin that can regulate flood discharges significantly. During the 2011 flood, Bhumibol Dam stored 7.5 billion $m^3$, Sirikit Dam 4.7 billion $m^3$, Pa Sak Chonlasit 0.8 billion $m^3$, and Kwae Noi Dam stored 0.7 billion $m^3$ from May to October. These four dams upstream reached their full storage capacities by early October and they had to discharge floodwater into downstream.




## Figure 2.2.3 Operation Records of Four Major Dam Reservoirs in 2011

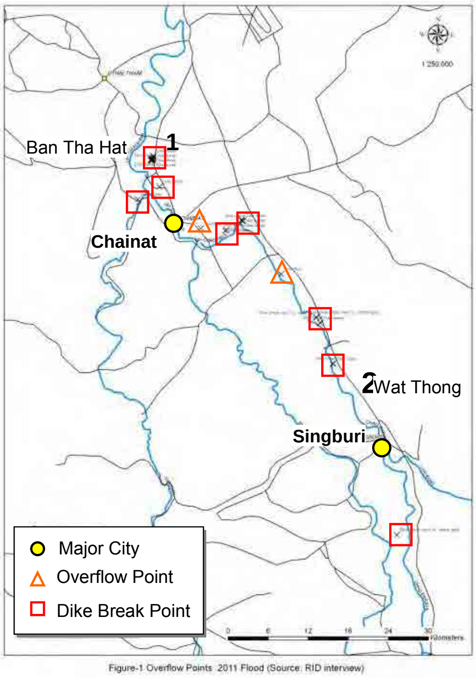
(4) Flood Inundation

With the huge volume of floodwater, dyke breaches and overflows occurred mainly in the middle of September. The spilled water flowed down in both the eastern and western sides of the Chao Phraya River. In the middle of October, floodwaters swallowed seven industrial estates in Ayutthaya and Pathum Thani provinces one after another. Finally, it entered a part of Bangkok by the beginning of November as shown in Figure 2.2.5. The estimated flood damages as of December 1, 2012 are as presented in Table 2.2.1.

### Table 2.2.1 Flood Damage as of December 1, 2011

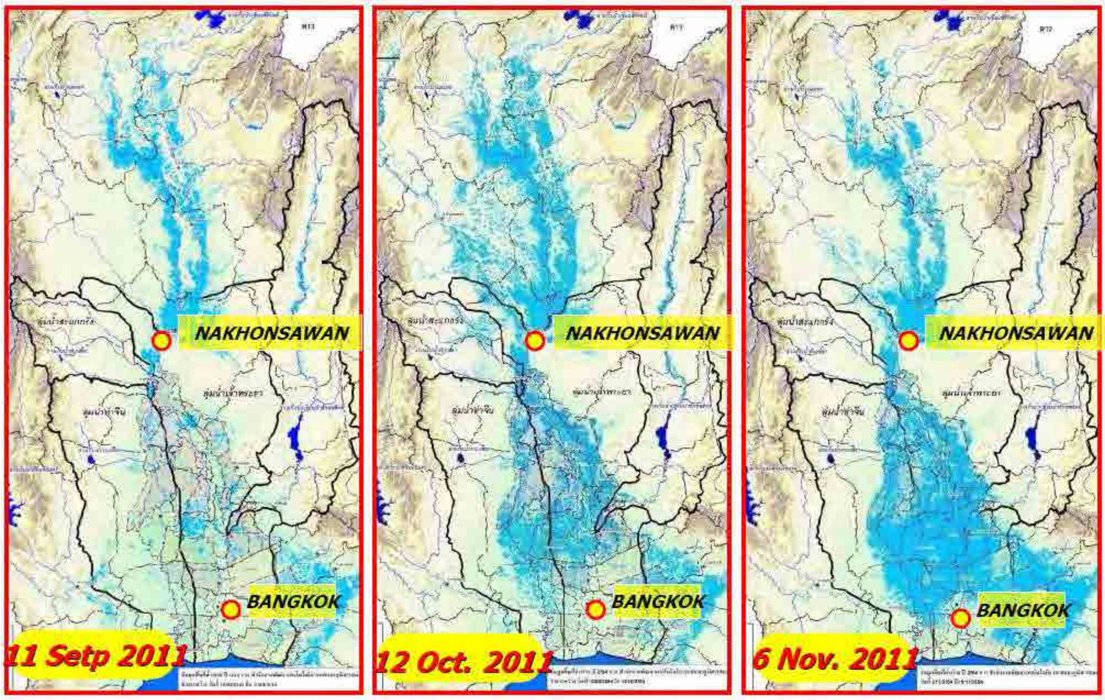
| Items | Contents |
|---|---|
| Affected Areas | 43,600 villages, 4,917 sub-districts, 684 districts of 65 provinces. |
| Affected Population | In total 13,425,869 people of 4,039,459 families are affected. |
| Damaged Houses | 2,329 houses: wholly damaged.<br>96,833 houses: partly damaged. |
| Agriculture 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) |

Date Source: DDPM




Data Source: RID

**Figure 2.2.4 Location of Dyke Breaches and Overflows during 2011 Flood**




Data Source: GISDA

**Figure 2.2.5 Flood Inundation Area by 2011 Flood**

# CHAPTER 3 BASIC ISSUES FOR THE MASTER PLAN

## 3.1 Flood Management Policy by Thai Government

In December 2011, the Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management. Flood management policy by Thai Government mentioned in this Master Plan is summarised and studied as follows:

**Flood Management Policy : Goal**
**To promote sustainable economic growth by reducing flood risk and exploiting floodwater as water resource through proper Flood Management.**

People in Thailand have long been living in flood-prone areas to easily secure water for agriculture. The wisdom of avoiding serious damage induced by floods and exploiting floodwaters for cultivation has been a great boon to the people of Thailand.

Thailand has achieved a rapid economic growth in the recent years and, consequently, the urban areas have dramatically expanded to the flood-prone areas. With the economic growth, the country seems to concentrate on expanding areas for urbanization and focus on ways to investment in urban and transportation infrastructures. Investment for flood mitigation has taken a backseat to economic development.

On top of that, the extensive flood in 2011 harshly attacked the urbanized low-lying areas and caused heavy economic damage by disrupting industrial production for several months. The damage influenced not only the Thai but also the global economy.

Since most developed countries have faced similar problems associated with haphazardly spreading the city area and increasing the vulnerability to floods, lots of experiences and lessons learned could be utilized for the protection against floods. In particular, it is certain that Flood Management is essential to promote sustainable economic growth with the reduction of flood risk and at the same time exploit floodwaters for agricultural use.

The Flood Management Policy by Thai Government aims at clearly showing the right direction of flood management to be executed. The Policy consists of six (6) principal elements, namely:

**(i) To integrate all of the activities implemented by the respective organizations concerned in the whole river basin;**

**(ii) To maintain a harmonious balance between flood control and water utilization;**

**(iii) To control inundation;**

**(iv) At the planning stage of countermeasures, to seek the best mix of structural and nonstructural countermeasures;**

**(v) At the ordinary operation stage, to set the proper operation rules for flood control facilities and land use regulations with due consideration on extreme events; and**

**(vi) At the emergency stage, to fulfill the responsibility of each individual, community, private firm, NGO and governmental organization.**

**(i) To integrate all of the activities implemented by the respective organizations concerned in the whole river basin;**

There are lots of organizations in the national government, local governments and NGOs, which are conducting various flood-control/fighting activities. To maximize the effect of these activities, it is crucial to: (a) well integrate all of the flood control/fighting activities including flood mitigation measures and proper evacuation; (b) always seek the best combination of activities in the whole river basin; and (c) well coordinate all of the organizations concerned.

**(ii) To maintain a harmonious balance between flood control and water utilization.**

Floods may induce heavy damage, but can provide water resources for agriculture. The flood management plan should focus on not only discharging floodwaters quickly into the sea, but also storing water as much as possible.

**(iii) To control inundation.**

Since basin inundation would be inevitable even after the implementation of major countermeasures, it is crucial to seek solutions to minimize flood damage in inundated areas and to maximize the benefit induced by inundation. In that case, it is imperative to limit the expected area of inundation; otherwise, heavy damage will recur.

**(iv) At the planning stage of countermeasures, to seek the best mix of structural and nonstructural countermeasures.**

Generally, the methodological principles of disaster prevention/mitigation are: (i) not to locate the residents/industries in dangerous places; (ii) to counter the inundation phenomena by implementing disaster prevention facilities; and (iii) to evacuate from hazardous areas before disaster occurs. These three countermeasures supplement each other. The best mix of structural and nonstructural measures is to be sought.

**(v) At the ordinary operation stage, to set the proper operation rule for flood control facilities and land use regulation with due consideration for extreme events.**

Floods occur every year, but not all of the floods cause heavy damage. It may not be necessary to perform emergency management in most years, but normal operation is needed every year. To manage ordinary floods, the proper operation rule for flood control facilities should be determined beforehand and followed during floods. To avoid unnecessary damage even by ordinary floods, land use regulations should be implemented.

Before extraordinary events occur, it would be difficult to predict whether or not the forthcoming event will be excessive. Therefore, both ordinary and extreme floods are to be considered in formulating the operation rule for facilities and land use regulations.

**(vi) At the emergency stage, to fulfill the responsibility of each individual, community, private firm, NGO and governmental organization.**

In actions for damage reduction, individuals, communities, private firms, NGOs and government organizations should fulfill their responsibilities in a collaborating manner. The combination of Self-help, Mutual-help, and Public--help can minimize damages and enable prompt recovery from disasters.

Self-help is to protect oneself by preparing against disasters and evacuating. Mutual-help is to help each other or to cooperate with people. Public-help is a support provided by government organizations, including construction of structural measures.

The government cannot play all the roles, but can support local societies and individuals to play their roles.

## 3.2 Design Flood

Since the 2011 Flood, the largest recorded flood, caused tremendous damage in the whole Chao Phraya River Basin, the Master Plan should consider accommodating the 2011 Flood. On the other hand, the 2011 Flood has been estimated as a 100-year return period flood in the rainfall analysis executed in this study. Since most metropolitan cities in the Asian monsoon region have similar target scales more than 100-year return period to prevent flood damages. From the above considerations, it is appropriate to set the 2011 Flood (the 100-year return period) as the design flood for the Chao Phraya River Basin.

**Table 3.2.1 Evaluation of 2011 Flood Scale**

| Evaluation Item (Annual maximum) (N is number of samples) | Probability of return period | | | | Remarks |
|---|---|---|---|---|---|
| | Nakhon Sawan (C.2) [C.A 105,000km$^2$] | | River Mouth (whole river basin) [C.A 162,000km$^2$] | | |
| | Value | Return period | Value | Return period | |
| Average rainfall watershed (mm/6month) ($N$ = 51) | 1,483 | 1/141 | 1,390 | 1/100 | 6 month-maximum rainfall is employed since it contributes to large flood. |
| Peak discharge (m$^3$/s) ($N$ = 56) | 6,857 | 1/70 | - | - | To estimate a natural runoff (uncontrolled by facilities), the impounded water in Bhumibol and Sirikit dams was added to the observed discharge at Nakhon Sawan. |
| Yearly water volume (MCM) ($N$ = 55) | 55,570 | 1/127 | - | - | |
| Overflow volume (MCM) ($N$ = 44) | 15,154 | 1/102 | - | - | In addition, to evaluate the probability of actually-occurred scale of inundation at downstream of C.2, probable analysis with overflow volume (beyond 2,500m$^3$/s) was conducted. |

* Above calculation was conducted by using "hydrological statistics utility ver1.5" released by Japan Institute of Construction Engineering, November 2003.

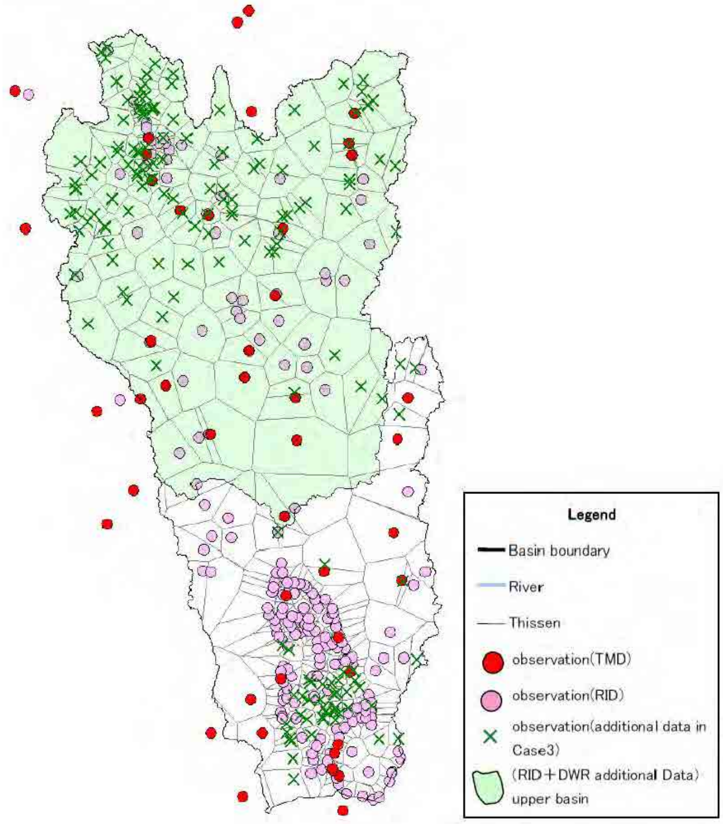



**Figure 3.2.1 Location of Rainfall Stations and Thiessen Polygons**

### 3.3 Protection Area

Bangkok and its vicinity which is to cover 5,600 km² is the national core area which is political, social and economic center of the country and identified as the most important protection area. Bangkok and its vicinity is located in the east side of the Tha Chin River and the southern part of the Pa Sak River in Ayutthaya are selected as the flood protection area, which is composed of Bangkok, Samut Prakan, Samut Sakhon, Pathum Thani, Nonthaburi, Nakon Pathom and Ayutthaya. The protection area is composed of three zones: "Flood Protection Zone (Outer)", "Flood Protection Zone (Middle)"and "Flood Protection Zone (Inner)".

The Department of Highway (DOH) and the Department of Rural Road (DOR) have already started and the works to raise surrounding roads and road-cum-embankments as urgent flood protection projects and partly completed in 2012. These works are considered as the existing conditions for the Study.

The protection area is shown in the following Figure.

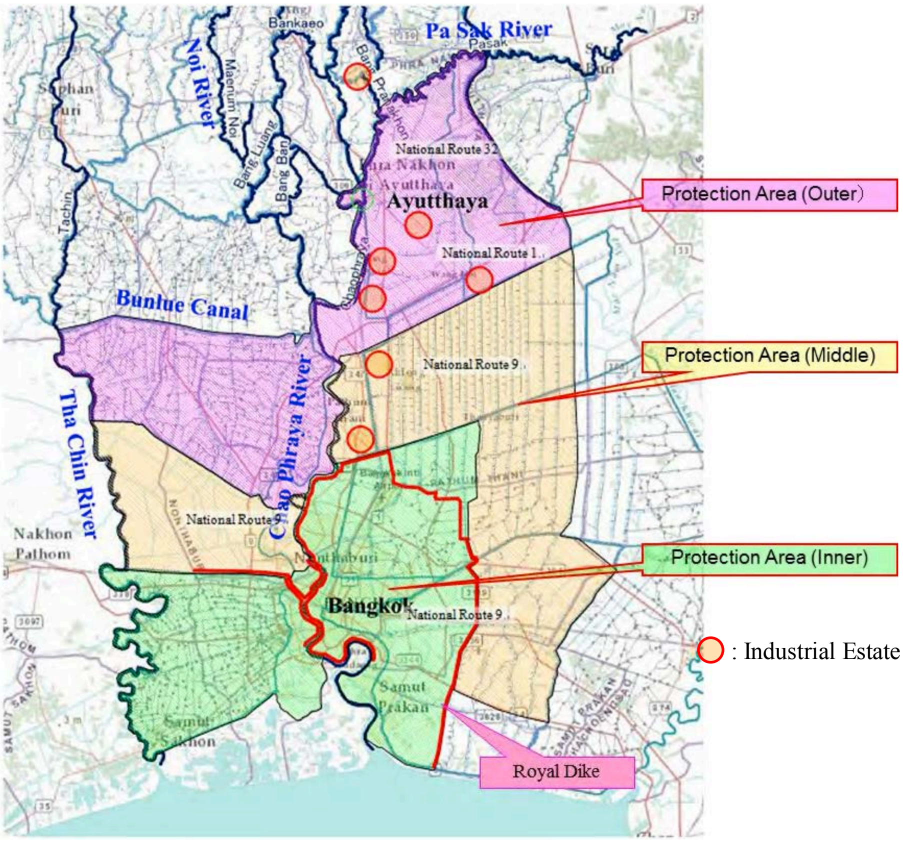



**Figure 3.3.1 Priority Protection Areas (Source from "Waterforthai" Website)**

Major local cities along the Chao Phraya River and major tributaries where have a high potential of flood risks are also to be protected as local core centers from flood risks. They are Chang Mai, Lampang, Phrae, Sukhotai, Uttaradit, Phisanulok, Phichit, Kamphaeng Phet, Nakhon Sawan, Chai Nat, Ang Thong, Lop Buri, Suphan Buri. They have already started the construction of ring dykes or flood dykes against the flood scale of 2011 flood due to the guidance of the DPT. The storm water drainage system should be reviewed.

# CHAPTER 4 REVIEW OF THE PROJECT

The following projects were reviewed to formulate the Flood Management Plan for the Chao Phraya River Basin:

1) Projects stated in the Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011;
2) Projects mentioned in Documents of Request for Proposal prepared by WFMC in July 2012; and
3) Projects newly proposed during the Study.

## 4.1 The Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011

In December 2011, the Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management composed of both urgent and long term work plans as set forth in Table 4.1.1, to ensure the continuity of country's development.

**Table 4.1.1 Summary of Work Plans Presented by SCWRM (December 2011)**

| No. | Work Plan | |
|---|---|---|
| 1 | Work Plan for Restoration and Conservation of Forest and Ecosystem | 1) to restore watershed forests in the river basin |
| | | 2) to develop additional water reservoirs according to the development potential of the areas |
| | | 3) to develop a land usage plan that fits with its socio-geographical conditions |
| 2 | Work Plan for Management of Major Water Reservoirs and Formulation of Water Management | |
| 3 | Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures | 1) Construction of flood ways or water channels roads, and dams |
| | | 2) Improvement of water dyke, reservoir, water drainage and water gateway |
| | | 3) Land use planning with appropriate zoning, including setting up an area protection system |
| 4 | Work Plan for Information Warehouse and Forecasting and Disaster Warning System | |
| 5 | Work Plan for Response to Specific Area | |
| 6 | Work Plan for Assigning Water Retention Areas and Recovery Measures (Improving/adapting irrigated agricultural areas into retention areas of around 2 million rai to enable second cropping in all the irrigated agricultural areas | |
| 7 | Work Plan for Improving Water Management Institutions | |
| 8 | Work Plan for Creating Understanding, Acceptance, and Participation in Large Scale Flood Management | |

## 4.2 Request for Proposal prepared by WFMC in July 2012

In July 2012, the Water and Flood Management Commission (WFMC) announced the Submission of a Conceptual Plan for the Design of Infrastructure for Sustainable Water Resources Management and Flood Prevention, composed of 8 projects as set forth in Table 4.2.1.

**Table 4.2.1 Summary of Projects Presented by WFMC (July 2012)**

| No. | Project |
|---|---|
| 1 | Aiming at the formation of a balanced ecosystem, conservation and restoration of forest and soil condition: Project Area is approx. 10 million rai (1 rai = 1,600 $m^2$). |
| 2 | Construction of appropriate and sustainable reservoirs in the Ping, Yom, Nan, Sakae Krang and Pa Sak River Basins. |
| 3 | Development of land use/land utilization plans, establishment of national and provincial residential areas and major economic areas in the possible inundation areas. |
| 4 | Development of the Phitsanulok Irrigation project (North of Nakhon Sawan) to store excess waters temporally during floods, and the Main Chao Phraya Irrigation Project (North of Ayutthaya) to convert existing irrigated lands to retention/retarding areas (storage volume: approximately 6 to 10 billion $m^3$, area: approximately 2 million rai), and improvement of agriculture and fishery industries to increase the productivity yield. |
| 5 | Improvement of canals and river channel dykes of major rivers (the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krang, Pa Sak, and Tha Chin Rivers). |
| 6 | Construction of floodway(s) and national roads to divert discharge that exceeds the flow capacity of main channel from the Chao Phraya River･Pa Sak River with east/west routes of the Chao Phraya River to the Gulf of Thailand. The structures include flood way with more than 1,500 $m^3/s$ flow capacity and/or flood diversion channel. |
| 7 | Improvement of the existing systems including database system, weather forecasting system, disaster forecast/warning system and other water management (flooding and draught) system. |
| 8 | Improvement of water management institutions including development of appropriate law and policies on flood control, formulation of a single command authority, and management, monitoring and relief activities. |

## 4.3 Projects to be Reviewed

For flood risk management purposes structural and non structural measures are studied. Structural measures are planned for mid- and long-terms, and non-structure measures are necessary from the beginning for reducing the flood disaster risks. The non-structural measures such as land use control, flood warning and other non structural measures are required.

Projects to be reviewed are described as follows:

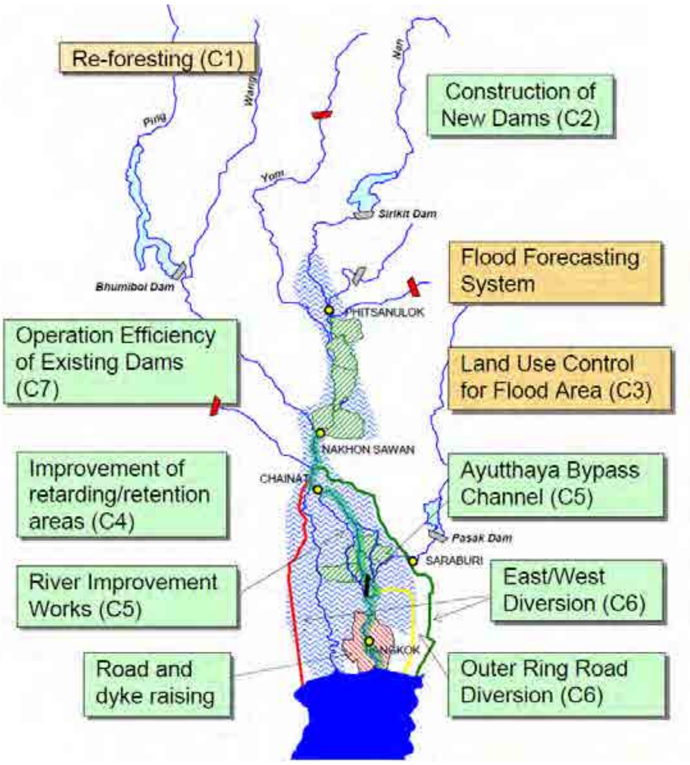



**Figure 4.3.1 Countermeasures to be Reviewed**

1) Operation Efficiency of Existing Dam (C7)

To implement new operation rule at the existing dams in order to improve the effectiveness on the flood mitigation function by considering both flood mitigation and irrigation benefits.

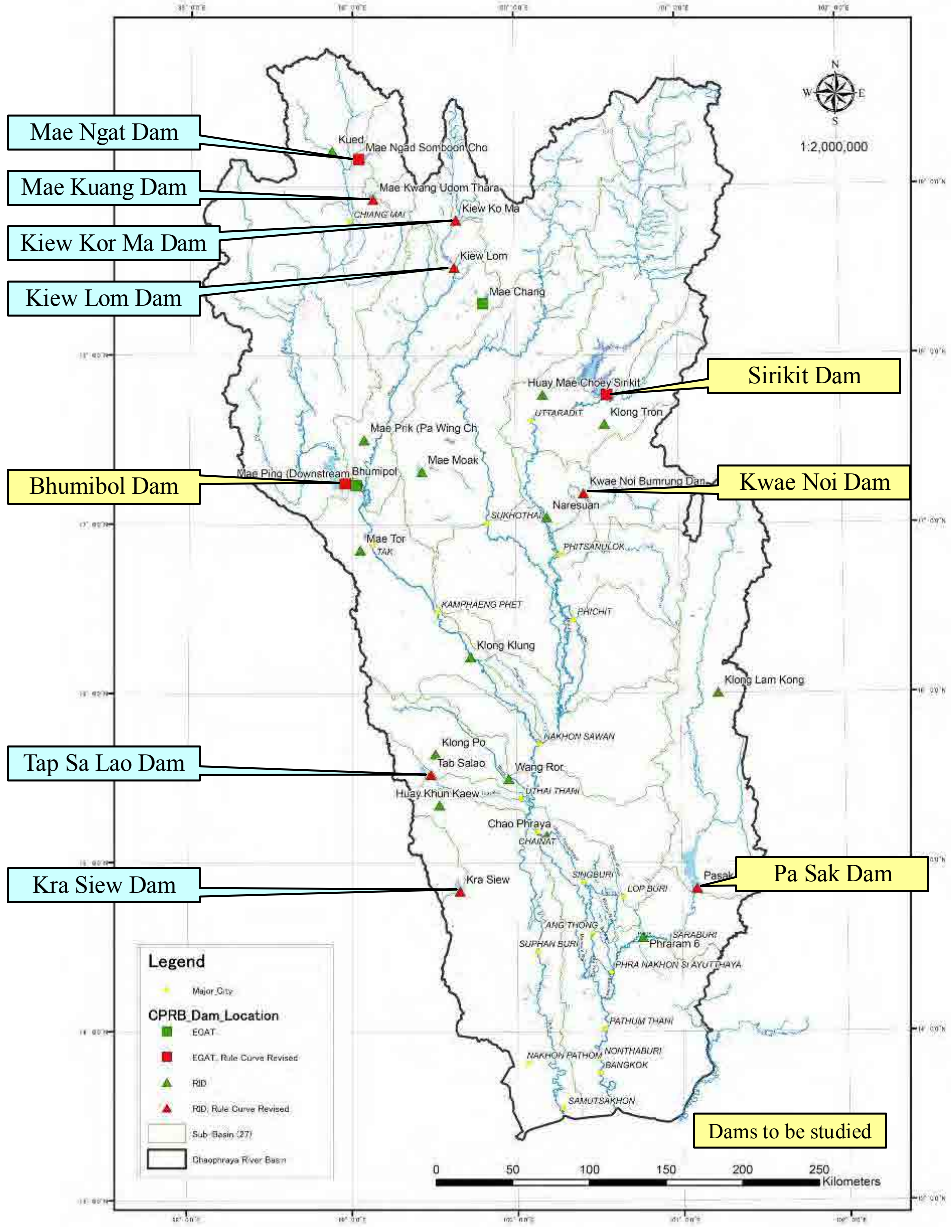



**Figure 4.3.2 Location of Large Scale Dams in the Chao Phraya River Basin**


**Figure 4.3.3 Scenery of Bhumibol and Sirikit Dams**

2) Construction of New Dams (C2)

   To construct appropriate and sustainable reservoirs (new dams) in major river basins.

3) Improvement of Retarding/Retention Areas (C4)

   To improve retarding/retention areas in the Chao Phraya River Basin to mitigate flood damage by temporarily storing floodwater and to improve the agricultural and fisheries productions by utilizing the stored water.

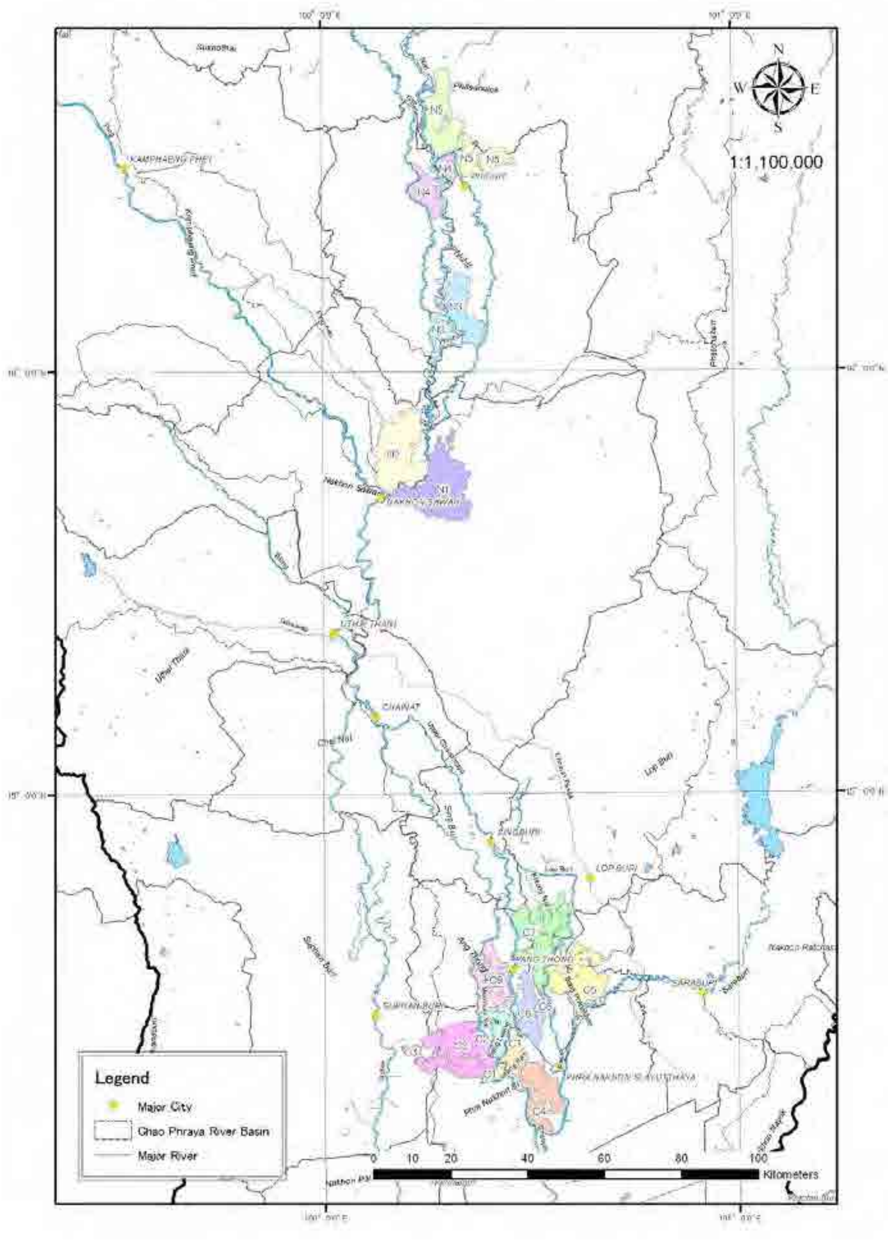



**Figure 4.3.4 Location of Retention Areas planned by RID**

4) East/West Diversion Channels (C6)

   To construct diversion channels to divert water eastward/westward from the upstream of the Chao Phraya Dam to the Gulf of Thailand.

5) Outer Ring Road Diversion Channel (C6)

   To construct a diversion channel along outer ring road to divert water from the downstream of Ayutthaya to the Gulf of Thailand.

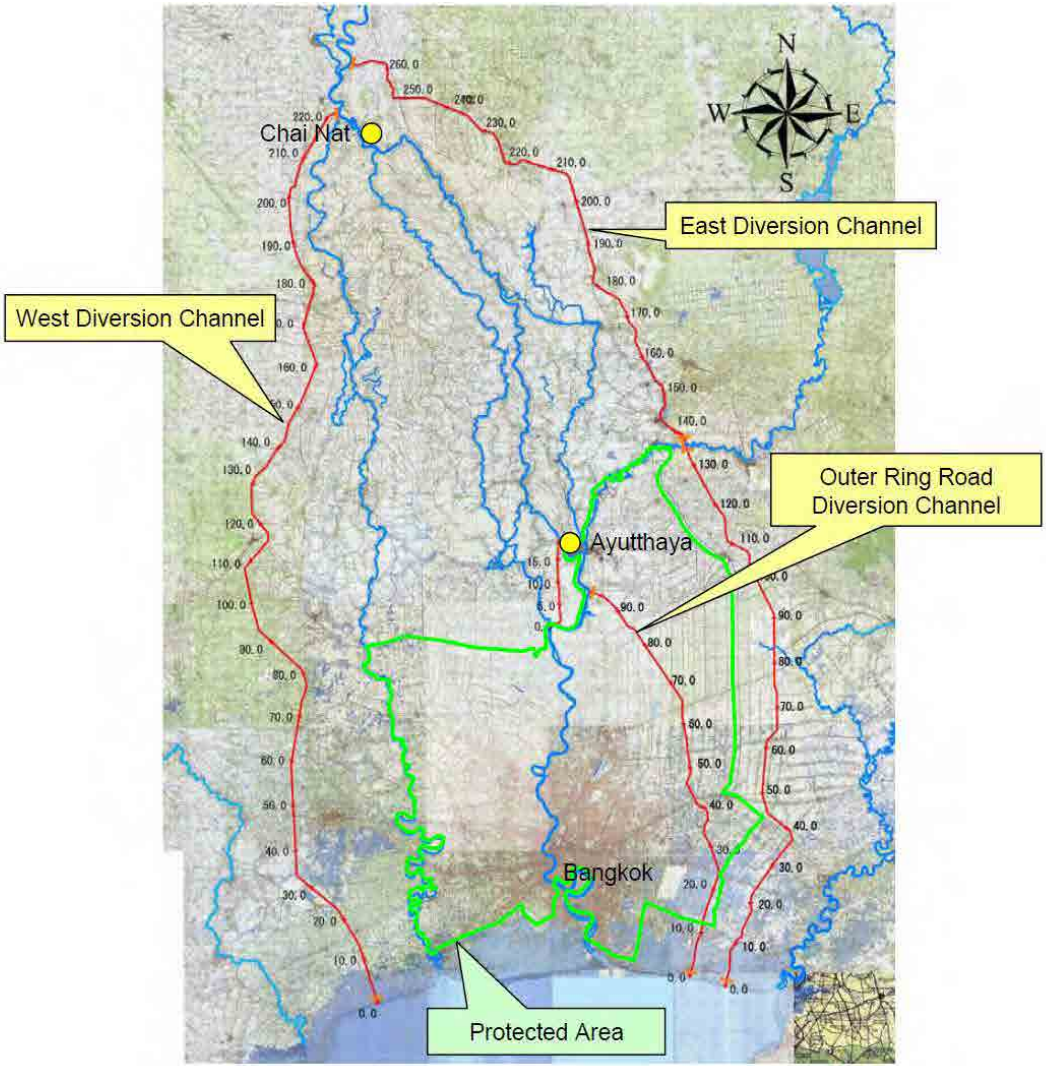



**Figure 4.3.5 Location of Diversion Channels**

6) River Channel Improvement Works (C5)

To rehabilitate and improve the existing river channels and dykes to increase flow capacity of the rivers.
Inundation volume and depth at right side of the Tha Chin River will increase due to the dyke heightening at the left side for protection of the economic zone. As channel improvement in the Tha Chin River, the following countermeasures are to be reviewed:

i) Four (4) shortcuts are installed;

ii) Primary dyke or concrete parapet wall is newly constructed at left side and Secondary dyke at left side is elevated to "Design High Water Level plus Freeboard".

7) Ayutthaya Bypass Channel (C5)

According to the results of analysis, discharge capacity of the Chao Phraya River is shown in Figure 4.3.6. Discharge capacity at Ayutthaya is very low.
To construct a bypass channel from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River in order to transfer the confluence of the Chao Phraya River and the Pa Sak River.
According to the results of analysis, discharge capacity of the Chao Phraya River is given as following figure. Discharge capacity at Ayutthaya is very low.

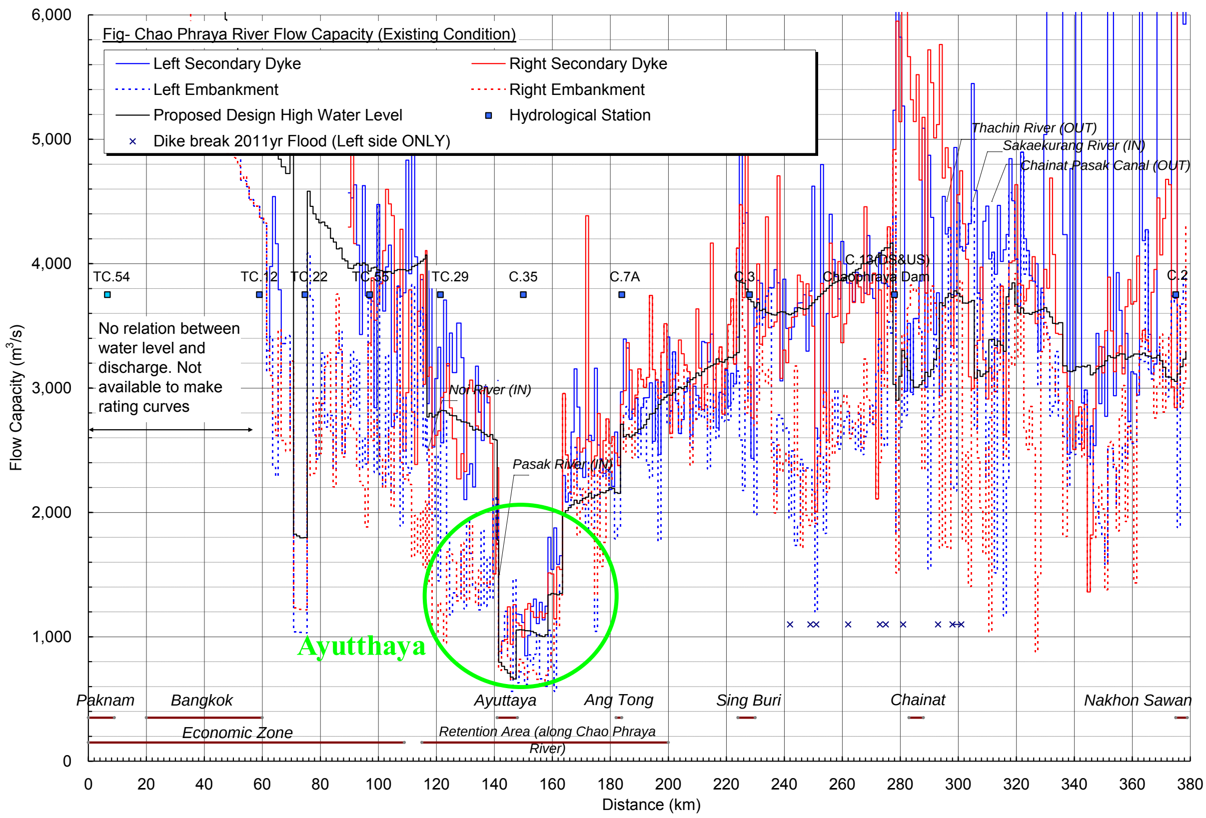



**Figure 4.3.6 Present Discharge Capacity of Chao Phraya River**

**Figure 4.3.7 Scenery of Ayutthaya along Chao Phraya River**

8) Reforesting at Upstream of River Basin (C1)

To apply restoration measures in the degraded forest areas located in the upper basin (mainly in the Ping, Wang, Yom, Nan, Sakae Krang, Pa Sak and Tha Chin basins) to conserve forest resources and ecosystem.

9) Flood Management Information System

To develop flood management information system including database system, flood forecasting system and other water management system to enable timely monitoring and analysis of the water situation in the whole river basin.

## 4.4 Findings of the Review

1) Operation Efficiency of Existing Dam (C7)

The operation of the existing dams during the 2011 flood was so effective to mitigate flood damage, because the Bhumibol and Sirikit dams stored 12 billion cubic meters of floodwater. When the dam operation rule is modified, dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose.

2) Construction of New Dams (C2)

Construction of new dams is highly encouraged, since it is effective for both flood mitigation and water utilization for irrigation, especially in the tributary river basins. It is also promoted for response to climate change. However, dam sites currently identified cannot provide such large storage capacities as the Bhumibol and Sirikit dams that the effectiveness of flood mitigation to the mainstream of Chao Phraya River is relatively limited.

3) Improvement of Retarding/Retention Areas (C4)

The areas with around 18,000 $km^2$, adjacent to river channels, currently have an important function to retard and retain floodwater. Therefore, it is crucial to preserve the areas not to lose the existing function by appropriately controlling land use.
It is therefore recommended that land use regulations should be stipulated, considering scenarios such as excess flooding and climate change. To enhance the capacity of retarding floodwater, some measures such as installation of gates and pumps can be taken. Those measures are useful to not only store floodwater but also to utilize the floodwater for irrigation; however, the enhanced retarding effect is limited.

4) East/West Diversion Channels (C6)

The diversion channels produce an enormous effect in reducing: (i) water levels of the Chao Phraya River between Nakhon Sawan and Chai Nat; and (ii) inundation volumes flowing into adjacent retention/retarding areas. However, the effect of lowering water level produced by these diversion channels is fading away in the downstream stretch of Chao Phraya River close to the areas to be protected.

5) Outer Ring Road Diversion Channel (C6)

The diversion channel along the outer ring road has a certain effect in reducing water levels of: (i) the Chao Phraya River from Ayutthaya to Bangkok; and (ii) the downstream of Pa Sak River. Hence, it is so effective to reduce the risk of dyke breaches along the areas to be protected.
This diversion channel runs through the east side of protection area. During its design stage, it is possible to provide a function as a defense line to protect the most important center area. For example, measures to increase the height of the west side embankment than the east side one should be considered.

6) River Channel Improvement Works (C5)

Definition of River Channel

In the Study, it is considered that the channel of the rivers lies between secondary dykes, not between water edges along primary dykes, since ordinary width of stream cannot accommodate floodwater. It is crucial that lower and/or weaker stretches of secondary dykes should be identified and strengthened to prevent uncontrolled inundation. If dyke raising work is conducted based on the primary dyke alignment, very high height of levee would be required, because river area enclosed with primary dyke is much smaller than secondary dyke.

River Improvement in Chao Phraya River

Some part of the parapet wall near the Bangkok is lower than DHWL + freeboard (50cm). Therefore, parapet wall or dyke elevation up to DHWL + freeboard shall be executed.

River Improvement in Tha Chin River

The adopted countermeasures consisting of dyke improvement at left side of lower reaches and four (4) shortcuts can increase discharge capacity of the Tha Chin River and eliminate the negative impact of the left side dyke heightening for protection of the economic zone. In addition, river water level during flood can be lower than the design high water level.
Since existing regulators for irrigation on the Tha Chin River are located at upper reaches as shown in Figure 4.4.1, flood management facilities adopted at lower reaches do not affect water use for irrigation. Also, since lower reaches of the Tha Chin River is subject to tidal action, flood management facilities adopted at lower reaches do not affect river navigation.

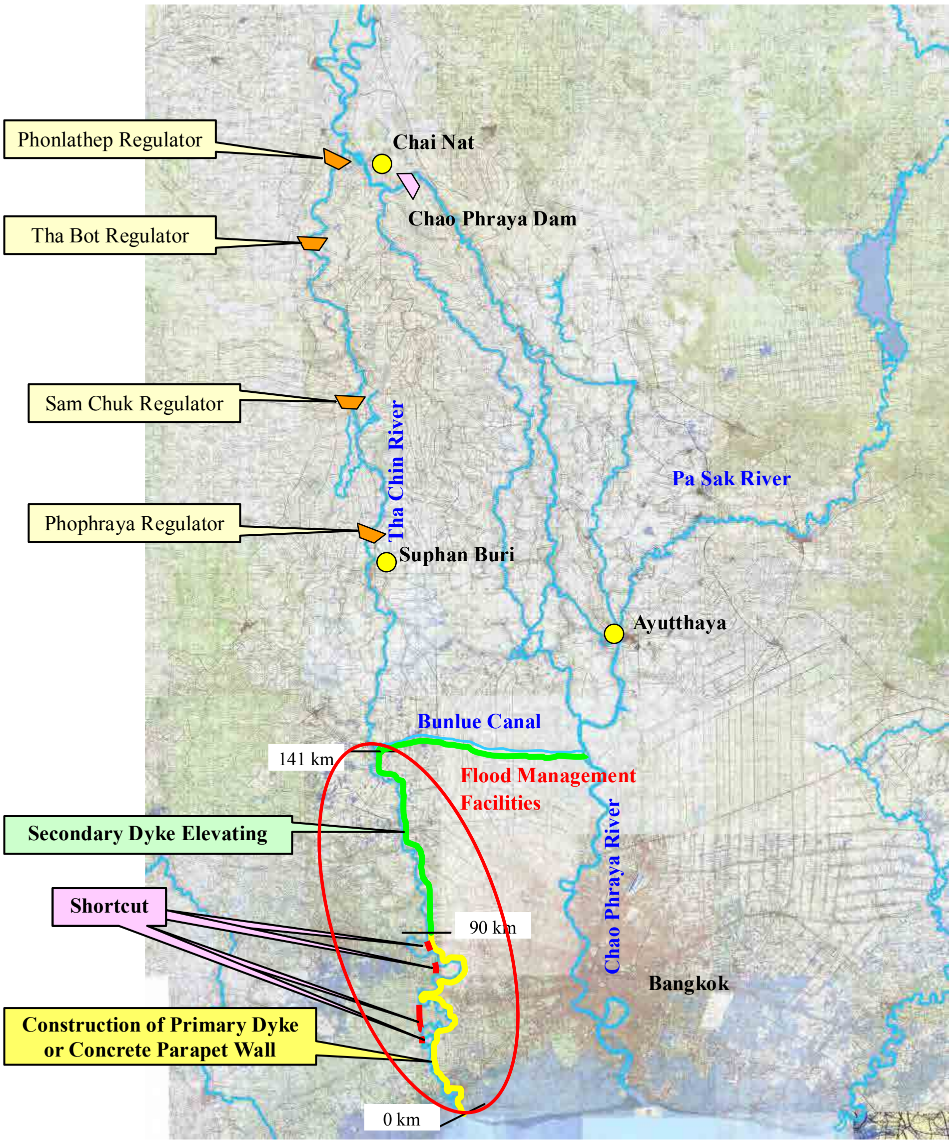



**Figure 4.4.1 Location of Regulators for Irrigation on Tha Chin River**

7) Ayutthaya Bypass Channel (C5)

The Ayutthaya Bypass Channel is one of the alternatives of river channel improvement works, since it is extremely difficult to widen the river channel in the stretch between Bang Sai and Ayutthaya. The Bypass Channel has an effect in lowering the water levels of (i) the Chao Phraya River between Bang Sai and Ayutthaya, and (ii) the Pa Sak River. Hence, it is very effective in reducing the risk of dyke breach along the areas to be protected.

8) Reforesting at Upstream of River Basin (C1)

Deforestation amplifies flood. Forest restoration requires continuous treatment over a prolonged period. In our study, quantitative effects of flood mitigation produced by reforestation are not considered.

9) Flood Management Information System

The Flood Management Information System would play a critical role on proper flood management. It is particularly emphasized that most of the damages in the factories can be minimized if proper information on flooding and inundation is provided in a timely manner. The system will be covered by another component of the Project.

# CHAPTER 5 PROPOSED COMBINATION OF COUNTERMEASURES

## 5.1 Combination of Countermeasures

More than ten (10) scenarios have been simulated after newly developing a basin-wide hydrological model incorporating the new topographical map. It has been concluded that the **Ayutthaya Bypass Channel and Outer-Ring Road Diversion Channel** in combination with other structural and nonstructural measures such as efficient operation of existing dams and river channel improvement works are the most cost-efficient and significantly effective to protect the Lower Chao Phraya River Basin.

**Proposed Combination 1**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

**Proposed Combination 2**

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 1,000$m^3$/s)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

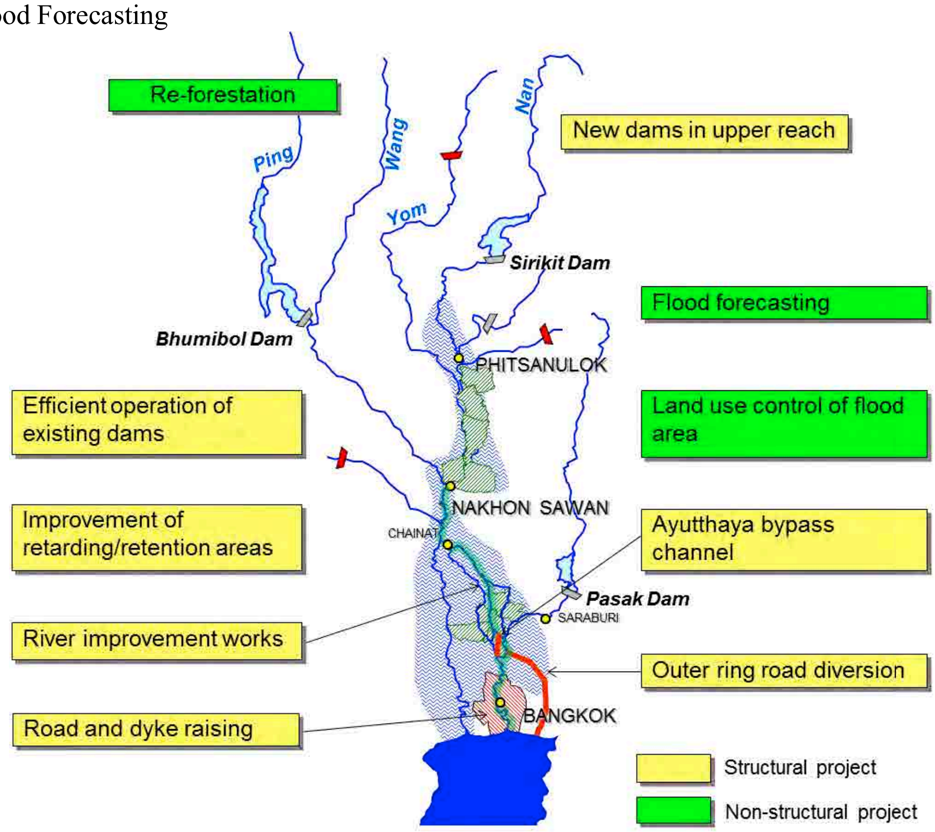



**Figure 5.1.1 Countermeasures Reviewed in the Study**

## 5.2 Effective Operation of Existing Dams

The operation of the existing dams during the 2011 flood was so effective to mitigate flood damage, because the Bhumibol and Sirikit dams stored 12 billion cubic meters of floodwater. When the dam operation rule is modified, dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose. If the proposed dam operation rule was applied during the 2011 flood, the peak discharge at Nakhon Sawan could be reduced by 400 $m^3/s$.

The concept of the recommended operation rule is as follows.

- "Target Curve" is the target storage volume for water use and the upper limit for flood control.
- Following the proposed "Target Curve", the inflow is going to be released from May 1 to August 1 to maintain the fixed reservoir water level.
- From August 1 to November 1, inflow should be stored in reservoirs with maximum outflow of 210 $m^3/s$ at Bhumibol Dam and 190 $m^3/s$ at Sirikit Dam for flood mitigation. If the storage volume is less than the Target Curve, the inflow should be stored in the reservoir for water use. The released discharge shall not be less than the minimum discharges of 8 $m^3/s$ at Bhumibol Dam and the 35 $m^3/s$ at Sirikit Dam.
- When the dry season (From November 1 to April 30 next year) starts, the stored water is released based on the schedule of the required water supply volume.
- This operation rule benefits both flood mitigation and water use.
- "Alert Curve for Drought" can provide indicators to judge whether a drought year. "10% Probability" and "20% Probability" mean the risk of drought once in every 10 years and once in every 5 years, respectively.

**Table 5.2.1 Proposed Operation Rules at Bhumibol Dam and Sirikit Dam**

| Dam | Maximum Outflow | | Storage Volume in May 1 (includes Sedimentation Volume) | Water Level in May 1 |
|---|---|---|---|---|
| | May to July | August to October | | |
| Bhumibol | In = Out | 210$m^3/s$ | 6,795MCM | 233.8m |
| Sirikit | Basically In = Out | 190$m^3/s$ | 3,911MCM | 135.6m |

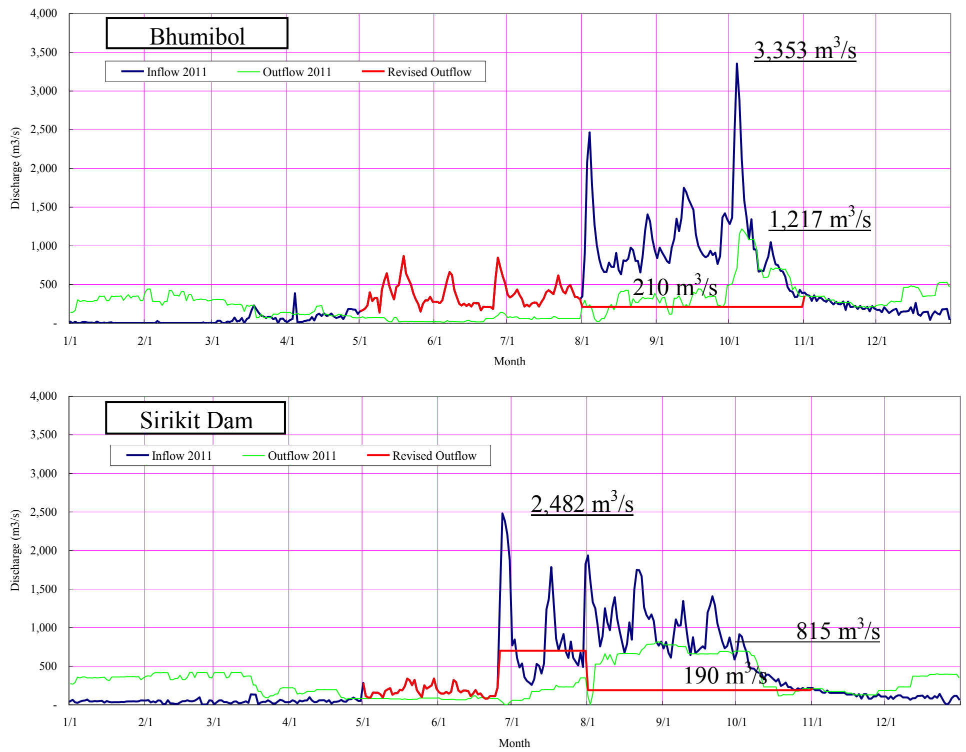
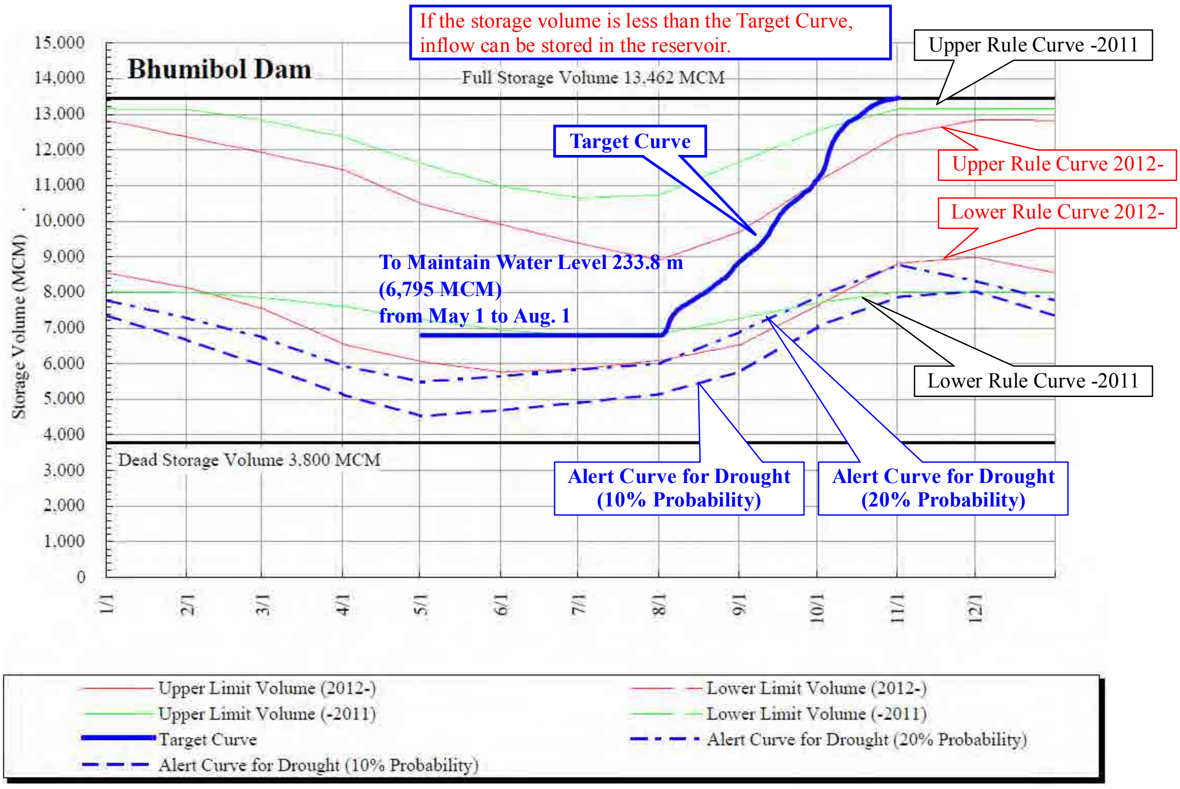



**Figure 5.2.1 Proposed Operation Curves of Bhumibol and Sirikit Dams during 2011 Flood**



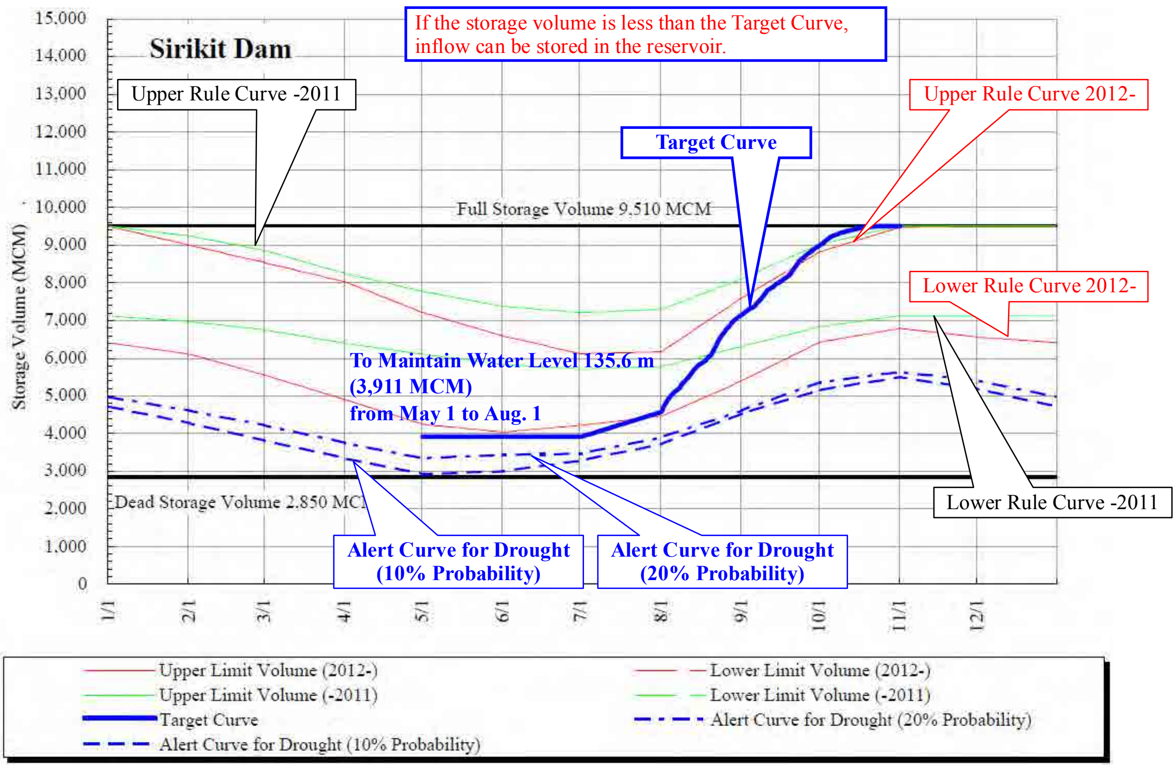




**Figure 5.2.2 Target Curve and Alert Curve for Drought for Bhumibol and Sirikit Dams**

## 5.3 Outer Ring Road Diversion Channel

The diversion channel has a certain effect in reducing water levels of: (i) the Chao Phraya River from Ayutthaya to Bangkok; and (ii) the downstream of Pa Sak River. Hence, it is very effective in reducing the risk of dyke breach along the areas to be protected.

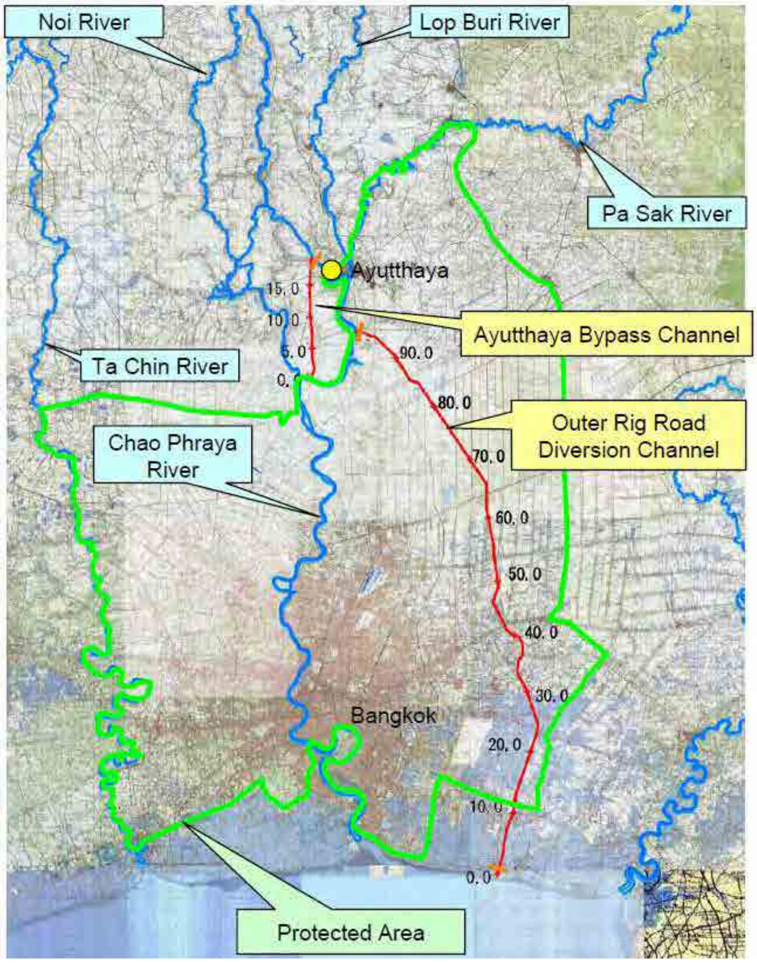



**Figure 5.3.1 Proposed Outer Ring Road Diversion Channel**

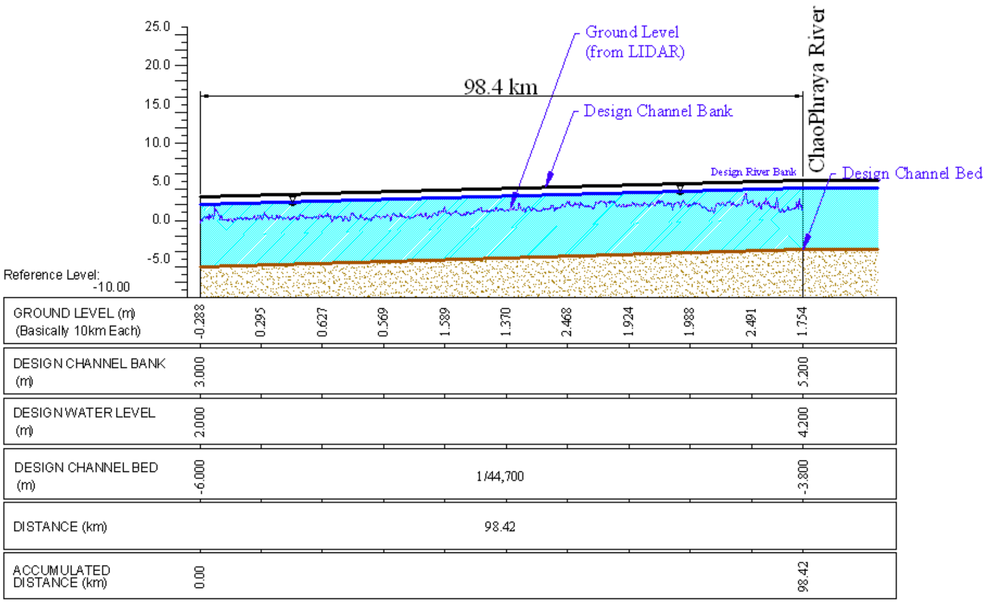
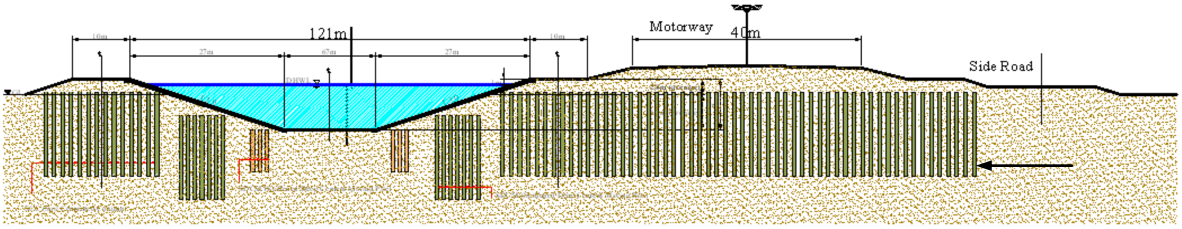
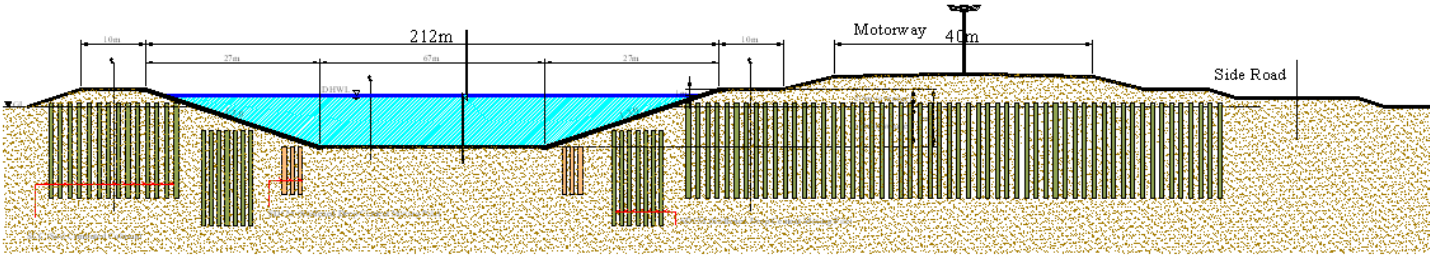



**Figure 5.3.2 Longitudinal Section of Outer Ring Road Diversion Channel**




(Capacity: 500 $m^3/s$)




(Capacity: 1,000 $m^3/s$)

**Figure 5.3.3 Cross Section of Outer Ring Road Diversion Channel[1]**

## 5.4 River Channel Improvement

### 5.4.1 Definition of River Channel

It has been considered in the Study that the channel of rivers lie between secondary dykes, not between water edges along primary dykes, since ordinary widths of stream cannot accommodate floodwater. It is, therefore, crucial that the lower and/or weaker stretches of secondary dykes should be identified and strengthened to prevent uncontrolled inundation.

If dyke raising work is conducted based on the primary dyke alignment, a very high levee would be required (red line), because the river area enclosed with primary dyke is much smaller than secondary dyke.

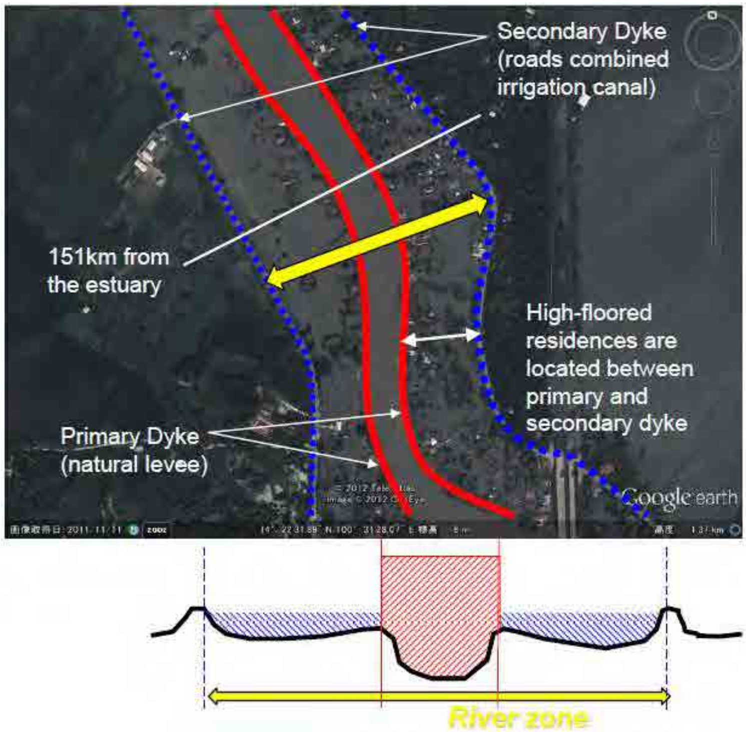



**Figure 5.4.1 Primary and Secondary Dykes**

[1] Cost for Construction of Motorway and Side Road is not included in this study.

### 5.4.2 River Improvement in Chao Phraya River

At the lower reaches of the Chao Phraya River, longitudinal height of parapet wall is horizontal and step wise, which is higher than record-high water level in the 2011 flood, but actual slope of water level is slanted. In addition, some part of the parapet wall is lower than DHWL + freeboard (50cm). Therefore, dyke elevation up to DHWL + freeboard shall be executed.

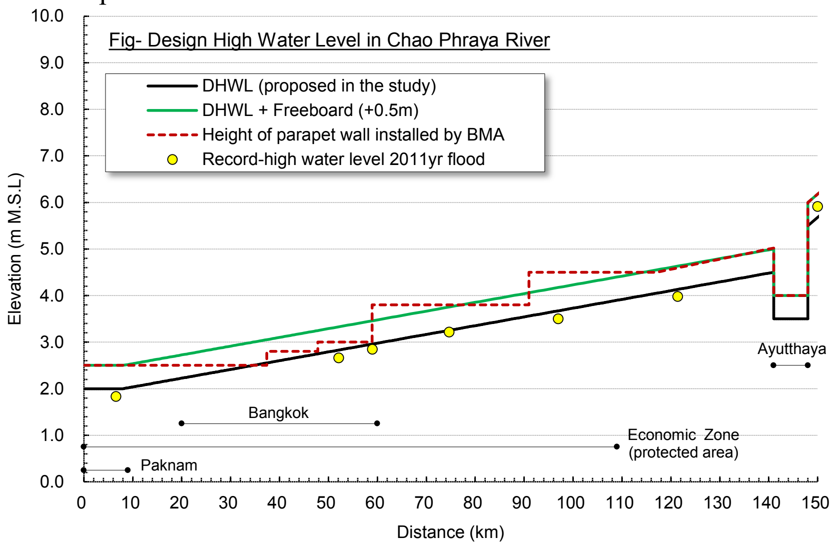



**Figure 5.4.2 Installation of Parapet Wall along the Lower Chao Phraya River**

### 5.4.3 River Improvement in Tha Chin River

Inundation volume and depth at right side of the Tha Chin River will increase due to the dyke heightening at the left side for protection of the economic zone. To increase discharge capacity at lower reaches of the Tha Chin River and to protect the economic zone, the following countermeasures are adopted:

i) Four (4) shortcuts are installed as follows:

1) Shortcut 1 at Ngue Rai-Taiyawat (original: 11.2 km, shortcut: 2.0 km);
2) Shortcut 2 at Hom Gret-Tha Tarad (original: 10.7 km, shortcut: 1.9 km);
3) Shortcut 3 at Sam Phan-Krathum Ban (original: 21.5 km, shortcut: 4.9 km); and
4) Shortcut 4 at Ban Paew (original: 5.1 km, shortcut: 1.2 km);

ii) Primary dyke or concrete parapet wall is newly constructed at left side from river mouth (Samut Sakhon Province, Mueang Samut Sakhon) to 90 km point (Nakhon Pathom Province, Nakhon Chai Si);

iii) Secondary dyke at left side is elevated to “Design High Water Level plus Freeboard” from 90 km to 141 km point (Suphan Buri, Song Phi Nong); and

iv) South side dyke along Bunlue Canal is elevated to “Design High Water Level plus Freeboard”.

**Figure 5.4.3 Scenery of Tha Chin River**

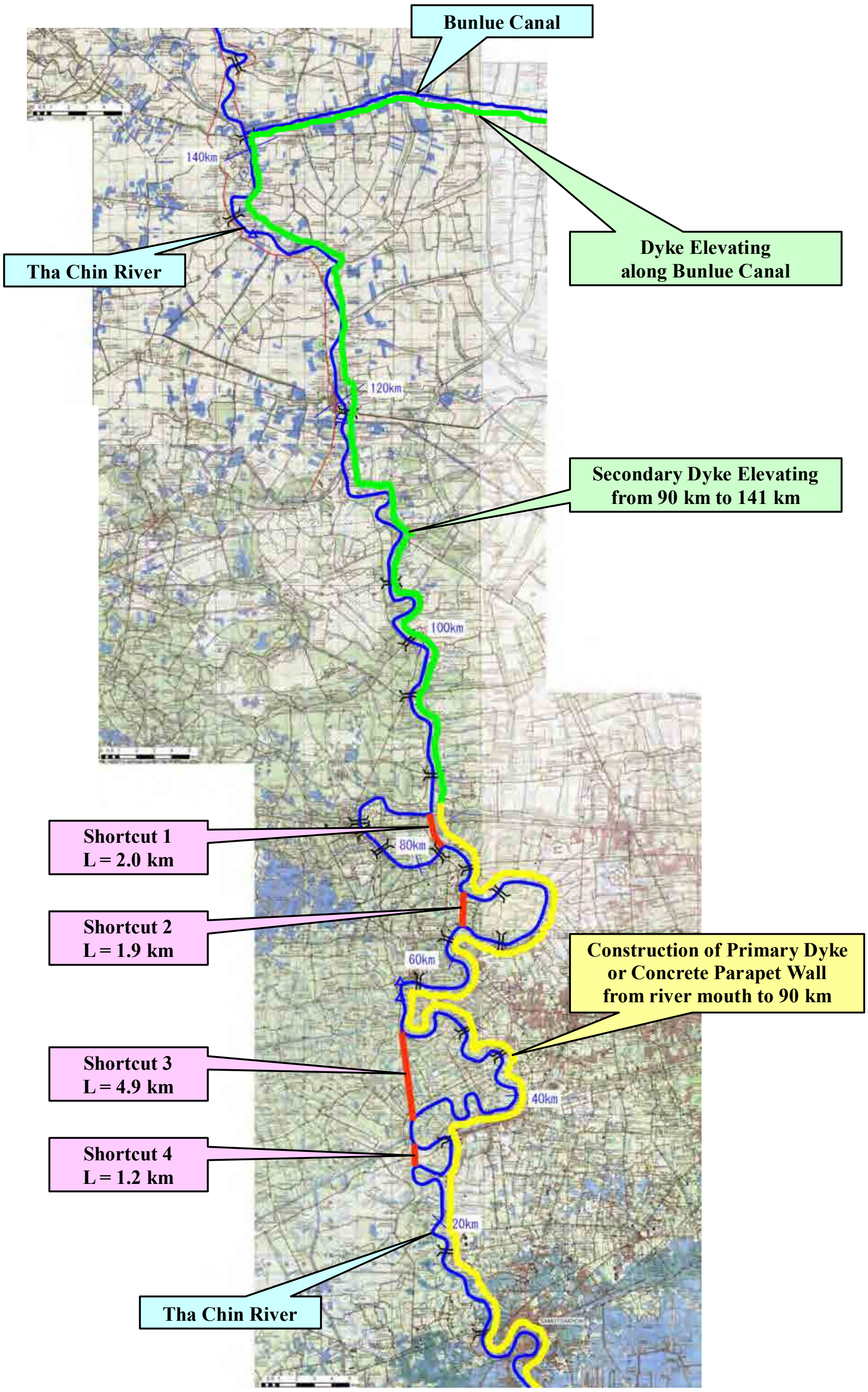



**Figure 5.4.4 River Improvement in Tha Chin River**

## 5.5 Ayutthaya Bypass Channel

The Ayutthaya Bypass Channel is one of the alternatives of river channel improvement works, because it is extremely difficult to widen the river channel in the stretch between Bang Sai and Ayutthaya. The bypass channel is planned to be constructed from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River. The bypass channel has an effect in lowering the water levels of: (i) the Chao Phraya River between Bang Sai and Ayutthaya; and (ii) the Pa Sak River, and should be effective to reduce the risk of dyke breach along the areas to be protected.

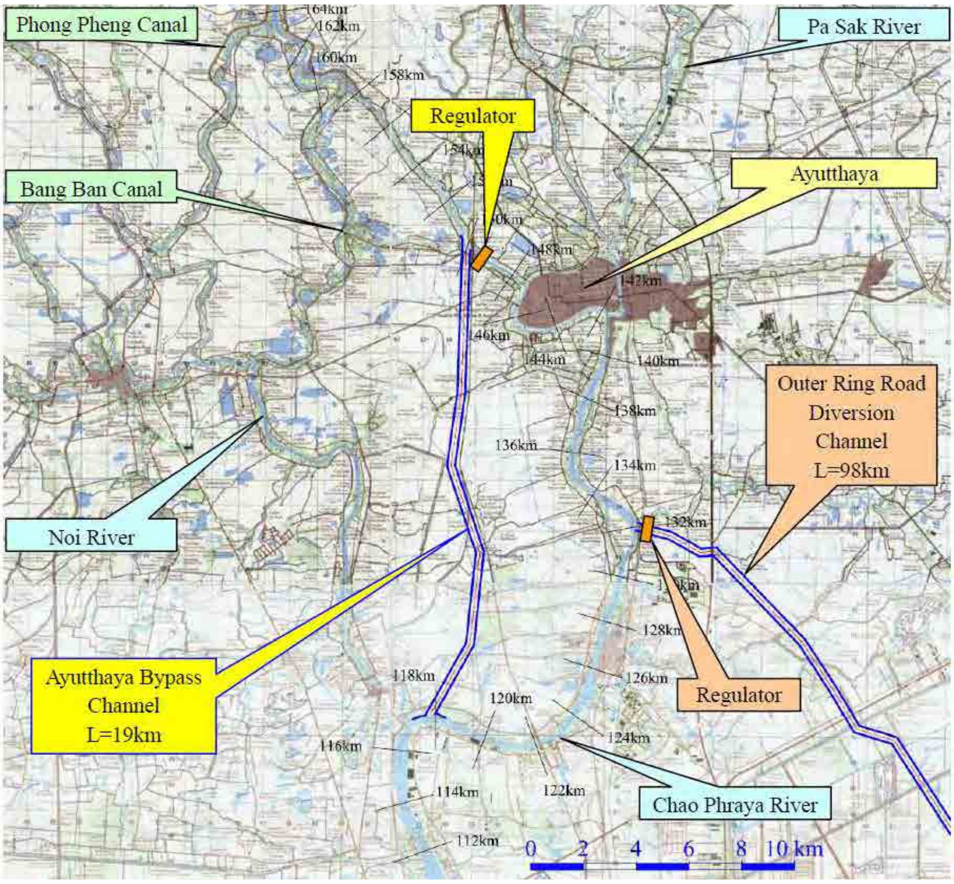



**Figure 5.5.1 Proposed Ayutthaya Bypass Channel**

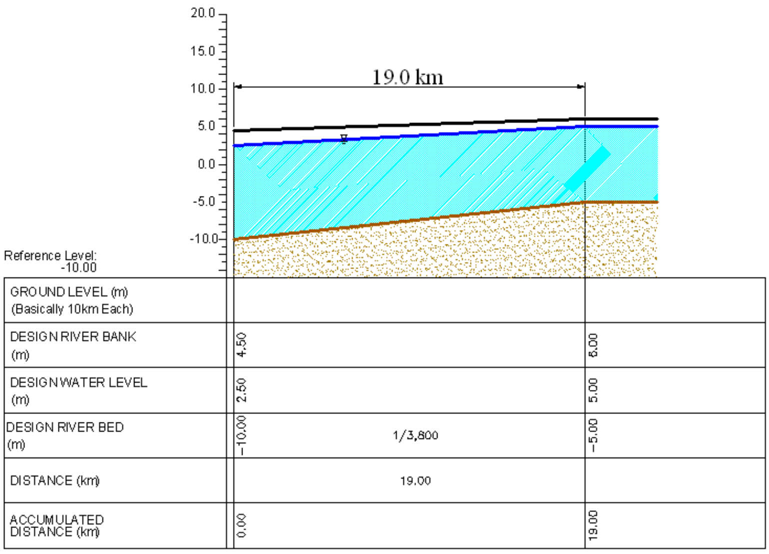



**Figure 5.5.2 Longitudinal Section of Ayutthaya Bypass Channel**

The slope of the bypass channel bank was designed at 1:3.0 with concrete frame protection, because excavated slope composed of silt and clay was very week. In addition, the bank slopes were strengthened by two types of the foundation pillars. One of the piles is a soil cemented column (SCC) and the other is a stiffened deep cement mixing pile (SDCM).

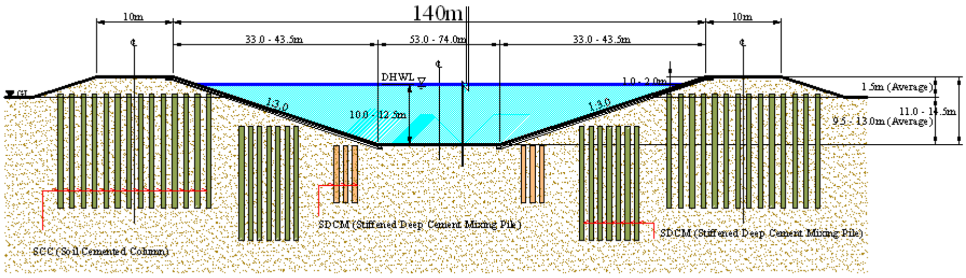



**Figure 5.5.3 Channel Cross Section of Ayutthaya Bypass Channel (Capacity: 1,400 $m^3/s$)**

## 5.6 Habitual Inundation Area

Protecting the priority area in the Lower Chao Phraya River Basin by the combination of countermeasures proposed above should not increase flood damage potential in other areas except for some specific areas. In addition, flood damage resilience can be improved by the following activities. Some of these activities have been already materialized.

- Flood Management Information System
- Land use regulation and planning
- Appropriate intervention in the agricultural area

Reliable and timely information can reassure residents in the basin to continue economic activities. "The Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin" has already developed a flood forecasting system, which is available to the public through the internet.

### 5.6.1 Controlled Inundation Area

By regulating land use appropriately, inundation with scale similar to the 2011 flood can be controlled. The prospective controlled inundation areas can be classified into five (5), depending on the flooding features. Based on this classification, the concrete land use plan could be developed and put into practice.

Type FS: Overflow water from river spreads and flows towards downstream resulting in relatively shallow inundation and shorter duration.

Type FL: Floodwater flows over through these areas and is blocked by the heightened road/embankment. Deeper inundation and longer duration than the 2011 flood would be observed near the southern border of the areas.

Type W: These areas are floodways for overflow water from Type FL areas and the west hilly areas.

Type M: These are swamp areas and floodwater stays throughout a flood season with deep inundation and long duration.

Type H: Small scale floods with shallow inundation depth and short duration come from the east hilly areas.

It will be inevitable to use many of the agricultural lands to store floodwater. However, strengthening the capacity for quick recovery can mitigate their damage and losses. "The Project for Flood Countermeasures for Thailand Agricultural Sector" is supporting and promoting this issue.

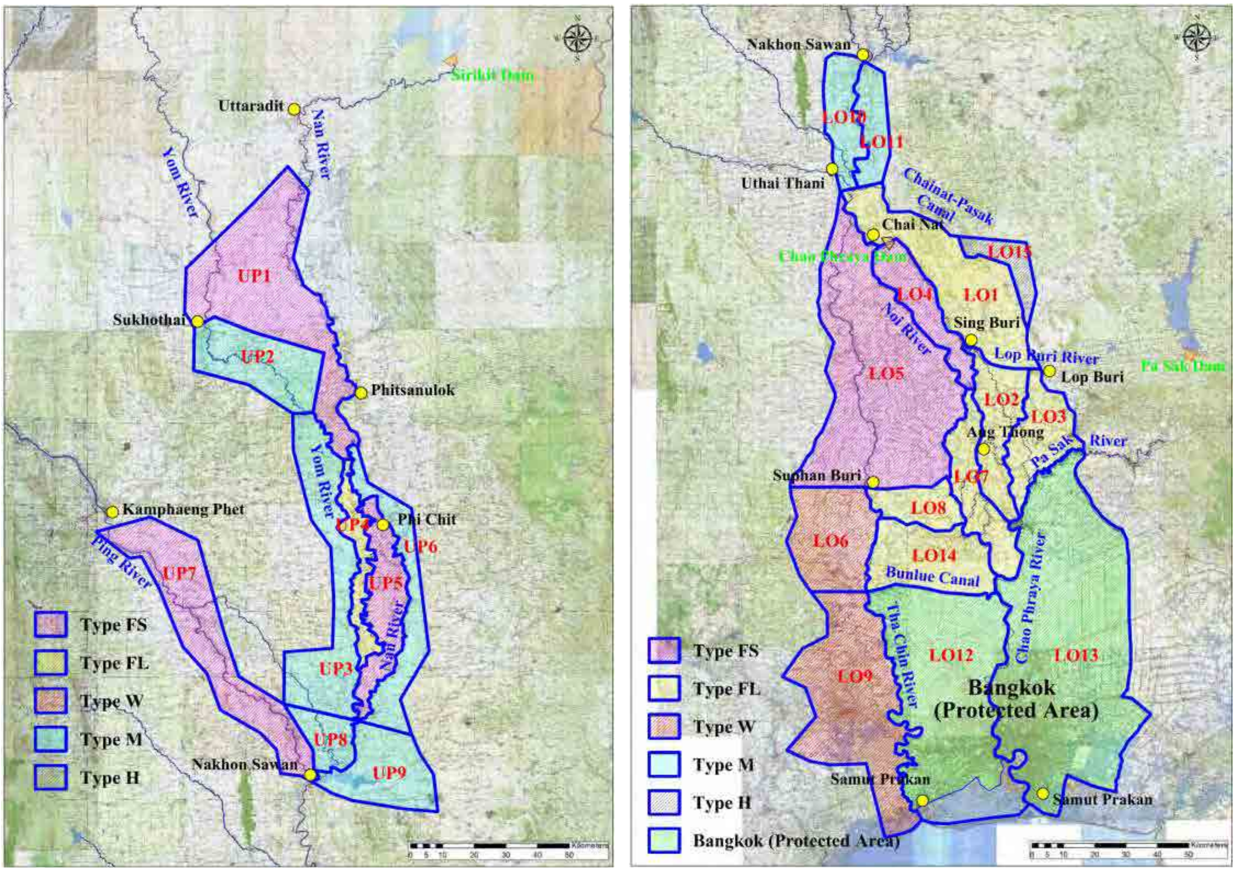



**Figure 5.6.1 Controlled Inundation Areas (Lower and Upper Chao Phraya)**

These low-lying areas have the important function of retarding floodwaters and reducing flood peaks downstream. Regardless of whether or not the proposed facilities are constructed, structural and nonstructural measures are required for the inundation area to maintain the function, to reduce flood disaster risks and to enhance people's living condition considering coexistence with floods. The following measures will be required:

(1) Type FS

Structural Measures

- Strengthening measures for retention areas by the government.
- Dredging of drainage channels and lakes/marshes.
- Improvement of small-scale irrigation facilities (gates, weirs, etc.).
- Construction of community-based small-scale retention pond (controlled intake and discharge facilities, irrigation water supply in dry season).
- Strengthening of existing levees.

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Preparation of community based hazard map.
- Agricultural guidance like changing forms of farming schedule.
- Measures to secure feed for livestock.
- Improvement of flood information.

(2) Type FL

Structural Measures

- Strengthening measures for retention areas by the government.
- Construction of community-based small scale retention ponds (Controlled intake and discharge

facilities, irrigation water supply in dry season).
- Dredging of drainage channels and lakes/marshes.
- Improvement of small-scale irrigation facilities (gates, weirs, etc.).
- Strengthening of existing levees.
- Installation of drainage pumps (reduction of inundation depth and duration).

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Agricultural guidance like changing forms of farming schedule.
- Measure to secure income during inundation period (combined agriculture and fishery or aquaculture, etc.).
- Measures to secure domestic water supply for inundation period.
- Preparation of community based hazard map and land use control.
- Improvement of flood information.

(3) Type W

Structural Measures

- Construction of community-based small scale retention ponds (Controlled intake and discharge facilities, irrigation water supply in dry season).
- Dredging of drainage channels and lakes/marshes.
- Improvement of small-scale irrigation facilities (gates, weirs, etc.).
- Strengthening and raising the existing levees.
- Improvement of main canal (increase of discharge capacity to Gulf of Thailand).
- Maintenance of canals (increase of drainage capacity to main canal).
- Installation of drainage pumps (reduction of inundation depth and duration).

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Agricultural guidance like changing forms of farming schedule, introduction of floating vegetable, etc.
- Measure to secure income during inundation period (combined agriculture and fishery or aquaculture, etc.).
- Measures to secure domestic water supply for inundation period.
- Measures to secure feed for livestock.
- Preparation of community based hazard map and land use control.
- Improvement of flood information.

(4) Type M

Structural Measures

- Strengthening of existing levee surrounding low-lying mash area.

Nonstructural Measures

- Measures to maintain the current retarding function like land use control, etc.
- Improvement of flood information.

(5) Type H division

Structural Measures

- Construction of community-based small scale retention ponds (Controlled intake and discharge facilities, irrigation water supply in dry season).
- Strengthening of existing levees.

Nonstructural Measures

- Improvement of flood information.

### 5.6.2 Flood Management Information Plan

Further description of the Flood Management Information System is stated in "The Basic Plan on the Flood Management Information System" prepared by another JICA Study.

A summary of the project is given as follows:

**Basic Plan of Flood Management Information System of Thailand**

Information is the most important factor in combining different fields of water resources management, including structural measures, emergency measures, raising awareness, etc.

A basic plan has been formulated for the flood management information system of Thailand, with most importance attached not to the sender of information, but to the receiver of information.

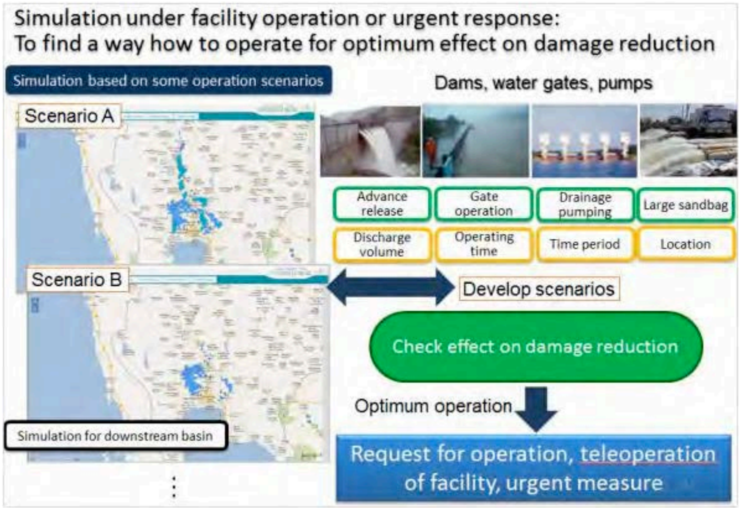
The plan consists of the following four chapters:

I. Current Status and Issues;

II. Function of Information in Flood Management;

III. Basic Strategies of Flood Management Information System Construction; and

VI. Specific Measures Development Plan of Flood Management Information System




**One of Specific Measures: Facility Operation**

Operation situations of major facilities (dams, major barrages and water gates) in the basin should be monitored together with flow rate information of rivers and water ways.

Facility operations should be effective by utilizing present water level and flow rate information.

Simulate downstream situation with dam water gate and pump operation, so that optimum selection of damage alleviation alternatives is made.

**JICA/FRICS Flood Forecasting System**

A prototype flood forecasting system was developed in September 2012, and information was provided to the registered monitors during the 2012 flood season. Through discussion with the related personnel of the Thai Government for practical application, necessary improvements were added, and, by January 2013, became widely open to the general public. A version with further functions added for experts of the government would be completed.

Water-level/flow-rate and inundation areas are forecast, with RRI model or H08 model simulation based on the observed data (rainfall, water-level, and flow-rate) and meteorological forecast data of RID, DWR and TMD. Highly accurate inundation area is forecast by using detailed geographic data obtained by LiDAR data, and by calibrating with GISTDA's satellite images of inundation situations.

### 5.6.3 Solution for the Issue of Land Use Control

As mentioned in "3.1 Flood Management Policy by Thai Government", basin inundation would be inevitable even after the implementation of major countermeasures. In accordance with the prospective controlled inundation area classified into five (5) categories, it is crucial to seek solutions to minimize flood damage by controlling unplanned urbanization in inundated areas and to maximize the benefit induced by inundation especially for agricultural use.

The land use control plan should be enforceable and decided based on each inundation situation of the five (5) categories.

(1) Concept of Land Use Control

Concept of land use control is given as follows:

Concept 1: To implement effective land use control as the minimum corresponding to frequent flood-prone areas including retention area in order to maintain and improve people's daily life and economic activities.

Concept 2: To promote land use in order to minimize flood damage to flood-prone areas in several decades to hundred years in terms of mitigation.

Concept 3: To implement measures to improve the quality of life of people living in serious flood-prone areas.

Concept 4: To create a system for performing under full coordination of related organization for implementation of the measures discussed below.

(2) Specific Measures of Land Use Control

(a) Revision of Existing System

In areas at risk of inundation, control of land use should be applied to minimize flood damage depending on the characteristics of flooding. It is proposed that the control is collateral by revision or abolition of the provisions of each regulation of town planning promulgated as Ministerial Regulation.

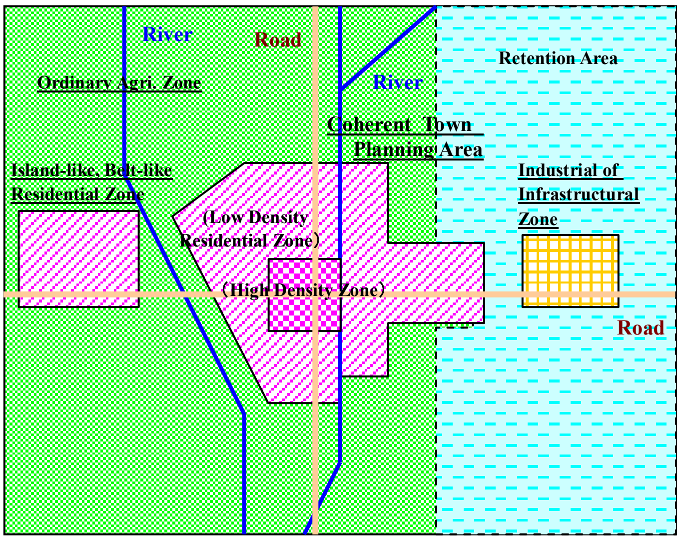



**Figure 5.6.2 Image of Land Use**

**Table 5.6.1 Contents of Specific Measures of Land Use Control**

| Category of Inundation Area | | Town Planning Area | Island-like, Belt-like Residential Zone | Island-like, Belt-like Industrial, Infrastructure Zone | Ordinary Agricultural Zone | New Designation |
|---|---|---|---|---|---|---|
| FS | Relatively shallow inundation and shorter duration | Basically Protection; Continuation of Current System | Continuation of Current System | Continuation of Current System | Continuation of Current System | Continuation of Current System |
| FL | Deeper inundation and longer duration | | Allowed to flood; Uninhabitable to ground floor | Basically Protection; Not allowed to residential and commercial | Basically Protection; Abolition of Exception Provision | Not allowed |
| W | Floodways for overflow water located west of protection area | | Allowed to flood; Uninhabitable to ground floor | Basically Protection Residential and accommodation not allowed | Allowed to flood Uninhabitable to ground floor | Allowed to flood Uninhabitable to ground floor |
| M | Swamp, deep inundation and long duration | | Allowed to flood; Uninhabitable to ground floor | Basically Protection Residential and accommodation not allowed | Allowed to flood Abolition of Exception Provision | Not allowed |
| H | Small scale floods from the east hilly area | | Continuation of Current System | Continuation of Current System | Continuation of Current System | Continuation of Current System |

(b) New Measure for Land Use: Creation of Land Use Guideline

To further reduce flood damage, orientation on land use is to be undertaken in flood prone areas. It is proposed that this orientation on land use should be implemented with the formulation of a “Guideline of Land Use for Flood Mitigation” based on the features of flood area considering the backlash against the free use and disposal of land.

**Table 5.6.2 Scheme of Building Control in accordance with Features of Flooding**

| Category of Flood Area | | Scheme of Building Control | | | | | |
|---|---|---|---|---|---|---|---|
| | | Residential; Commercial | Industrial Infrastructure | Religious; Cultural; Educational | Agricultural | Public Service | Tourism; Recreational |
| FS | Relatively shallow inundation and shorter duration | Δ1 | Δ1 | ○ | ○ | ○ | ○ |
| FL | Deeper inundation and longer duration | × | Δ1 | Δ1 | Δ1 | Δ1 | Δ1 |
| W | Floodways for overflow water located west of protection area | Δ2 | Δ1 | Δ1 | Δ1 | Δ1 | Δ1 |
| M | Swamp, deep inundation and long duration | × | × | Δ1 | Δ1 | Δ1 | Δ1 |
| H | Small scale floods from the east hilly area | Δ1 | Δ1 | ○ | ○ | ○ | ○ |

Policy of Land Use Restriction: ○ Buildable as usual
Δ Buildable conditionally,
Condition 1: With levee or raising of ground level
Condition 2: Uninhabitable to ground floor
× Not newly built, renovation

(c) Relocation of Land Use by using Existing Systems

The flood area covers most of the Chao Phraya River Basin with high density of residences extending linearly along the river. The measures to protect these areas from flood are:

- Protection of the area by structures such as levee or flood wall, etc.
- Relocation of entire community to the raised land to reduce the influence of flood

In this case, the application of existing systems of land readjustment can be carried out in accordance with the arrangement of parcels of land and the development of roads and other infrastructure.

(d) Enhancement of Coordination of Land Use

To secure cooperation in a particular flooding from the perspective of disaster risk reduction as a consultative body, the establishment of a "Coordination Committee of Land use in Flood-Prone Area" (tentative name) is assumed to work as an organization to consider policies related to land use of large scale, such as special economic zone, and to discuss land use under flood control measures in consideration of potential of floods.

Membership is assumed to consist of the Royal Irrigation Department (RID), the Department of Public Works and Town and Country Planning (DPT), the Department of Rural Roads (DOR), the Department of Highway (DOH), the Economic and Social Development Board (NESDB), the Ministry of Industry, etc. Matters of coordination are assumed as the following:

- Positioning of area based on flood potential
- Vulnerability assessment in predicted inundation
- Effect of mitigation on Land Use
- Advice to the measure of flood based on the guideline, etc.

### 5.6.4 Appropriate Intervention in the Agricultural Area

Further description of the Appropriate Intervention in the Agricultural Area is stated in “Project for Flood Countermeasures for Thailand Agricultural Sector.”

The objective of The Project is to prepare a guideline for disaster-resilient agriculture and agricultural community, which will be applied for the whole Chao Phraya Basin in the future. Cultivating “resilience” of communities is the primary concern, by which a community can enhance its capacity in learning from the past disasters and to facilitate risk reduction measures. It tries to cope with disaster and to recover from the damage of a particular hazard, when it happens. “Sufficiency Economy” is the central concept to prepare the guideline.

Community-level approach is believed to increase the relevance, effectiveness and sustainability of disaster risk reduction. Thus, in the process of disaster-resilience planning, people in various social groups of the community, including vulnerable groups, are invited to contribute. About 20 countermeasures varying from structural measures to the introduction of crop production techniques to other income generation activities were tried as pilot activities in 7 model areas, and the lessons learned from implementation are to be discussed and summarized as technical papers and community case studies.

Guidelines on: i) Community-based Disaster Management, ii) Community Water Resources Management, iii) Flood Damage Reduction Measures in Agriculture, iv) Income Generation, and v) Community Strengthening, will be compiled and expected to be utilized to prepare the disaster-resilient plan at *Tambon* level with the assistance of the provincial government in flood risk areas in Chao Phraya Basin according to their physical, social, and cultural situations.


## 5.7 Consideration on Climate Change and Storm Surge

### 5.7.1 Sea Level Rise caused by Climate Change

There are several studies on the impact of climate change available for Thailand. The 2009 World Bank Study[2] predicted 2 to 3% of increase of precipitation and 19 to 29 cm sea level rise in 2050. The Southeast Asia START Regional Center study in 2010[3] also predicted 10% of increase in annual precipitation in the Chao Phraya River Basin for the period from 2045 to 2065, and sea level rise of 9.4 cm on average and the maximum of 17.0cm during 2010-2029, while it is 20.0 cm on average, and maximum of 28.9 cm during 2030-2049 in the Gulf of Thailand.

According to the previous studies on Climate Change, the sea level rise in the Gulf of Thailand is not much different from the average of global sea level rise. The following figures show flow capacity in case of sea level rise of 30 cm at downstream of the Chao Phraya River. Since flow capacity is affected by sea level rise, further consideration is encouraged in the next stage.

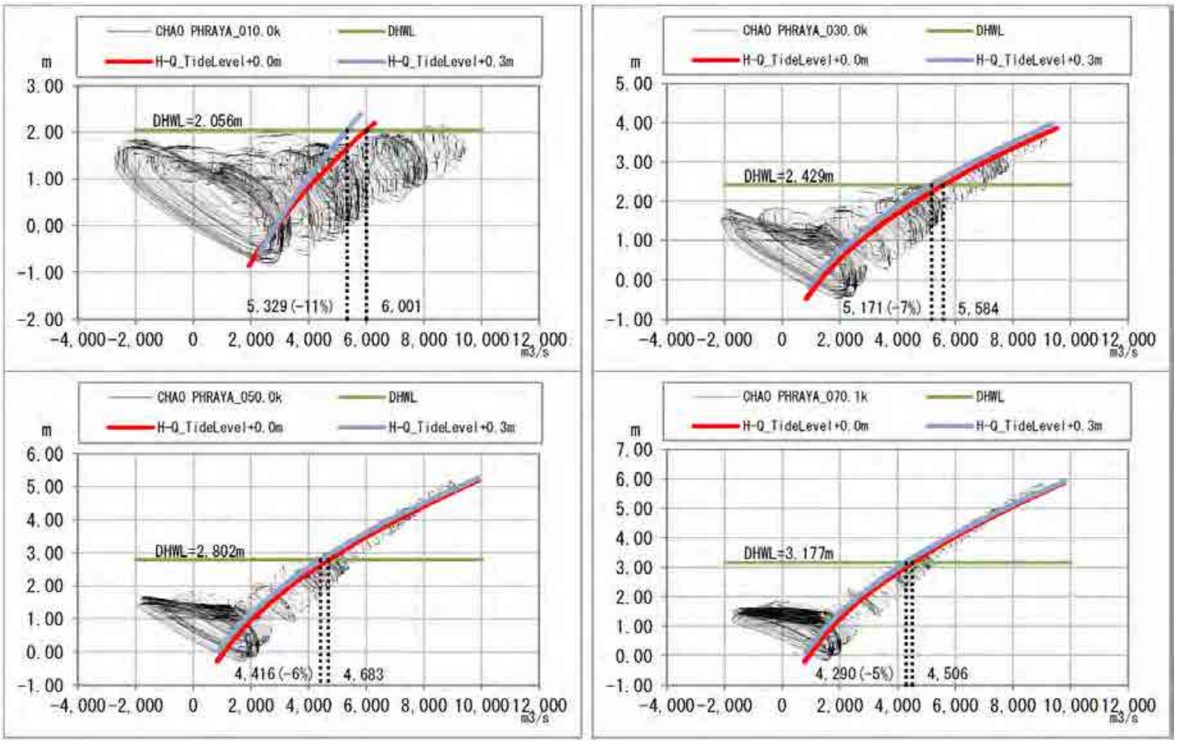



**Figure 5.7.1 Discharge Capacity in Case of Sea Level Rise of 30 cm**

### 5.7.2 Storm Surge

A storm surge is an offshore rise of water associated with a low pressure weather system, typically typhoons. Coastal areas along the Gulf of Thailand have been historically affected by storm surges. An analysis is being made to assess risk of storm surge in the coastal area of the Chao Phraya River Basin including Bangkok.

Firstly, a storm surge simulation model was established through model validation using observation data of Typhoon Gay (1989) and Typhoon Linda (1997). Then a storm surge simulation was conducted under a scenario that a typhoon similar to Typhoon Linda hits the river mouth of the Chao Phraya River (refer to Figure 5.7.3).

2 Climate Change Impact and Adaptation Study for Bangkok Metropolitan Region, Panya Consultants Co., Ltd. March 2009

3 Preparation of Climate Change Scenarios for Climate Change Impact Assessment in Thailand, Southeast Asia START Regional Center, January 2010

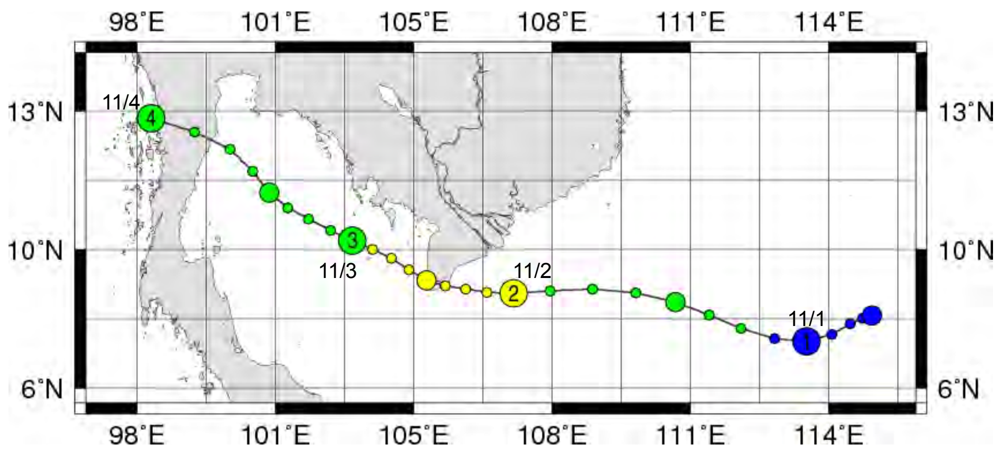
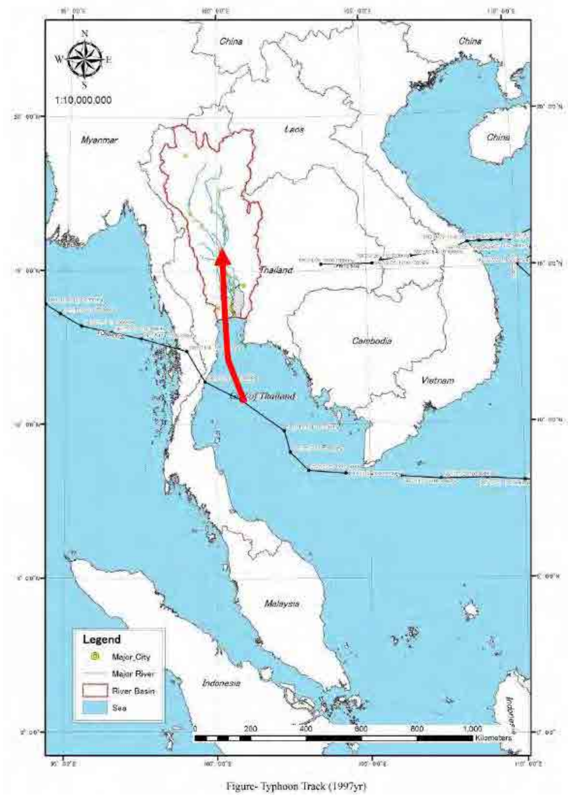



**Figure 5.7.2 Track of Typhoon Linda in 1997**



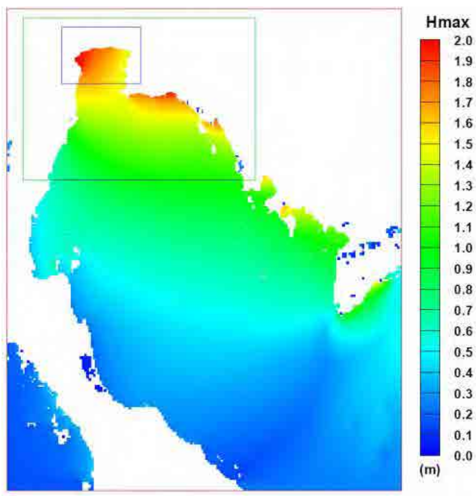




**Figure 5.7.3 Modified Typhoon Route** **Figure 5.7.4 Simulated Maximum Surge 2m**

Moreover a flood inundation simulation for the 2011 flood was also conducted with river mouth water levels raised by the simulated storm surge as the downstream end condition.. The following conditions were set.

- The storm surge with the highest sea water rise occurred in October 30, 2011 at the time of the highest river water level;
- The seawater rise was max. 2.0m (refer to Figure 5.7.4) and lasted for 24 hours (refer to Figure 5.7.5); and
- The simulation on the reproduction of the 2011 Flood is executed with i) the dyke elevation around the protection area along the Chao Phraya River and Pa Sak River, ii) Effective Operation of Existing Dams, iii) Ayutthaya Bypass and iv) Outer Ring Road Diversion Channel.

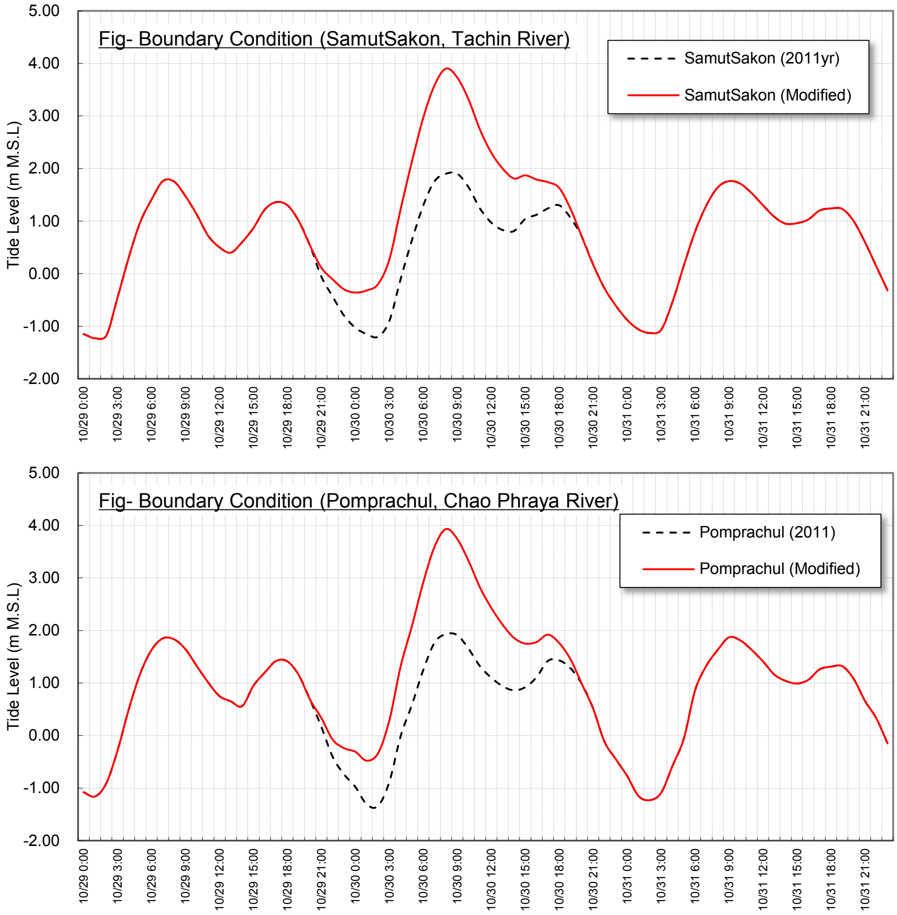
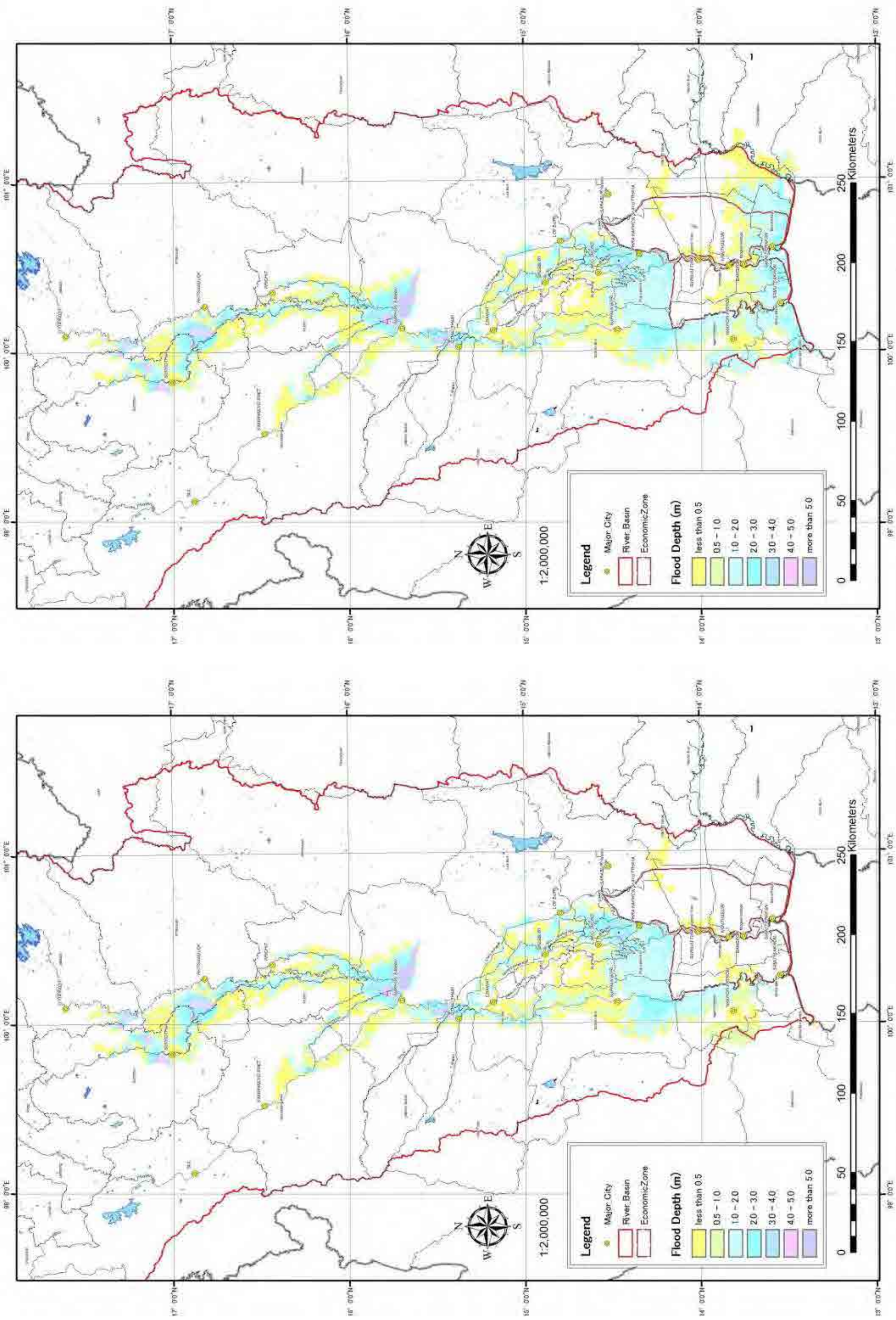



**Figure 5.7.5 Application of Sea Level at Estuary of Chao Phraya River and Tha Chin River**

Estimated inundation area is shown in Figure 5.7.6 and Figure 5.7.7. This figure shows that the effect of storm surge to floods in Chao Phraya River Basin is not negligible. Inundated volume to the flood plain was estimated as 3,600 MCM due to storm surge. In case of a huge storm surge, countermeasures including road elevation along the coastline, river improvement works, construction of tide wall etc., would be necessary.

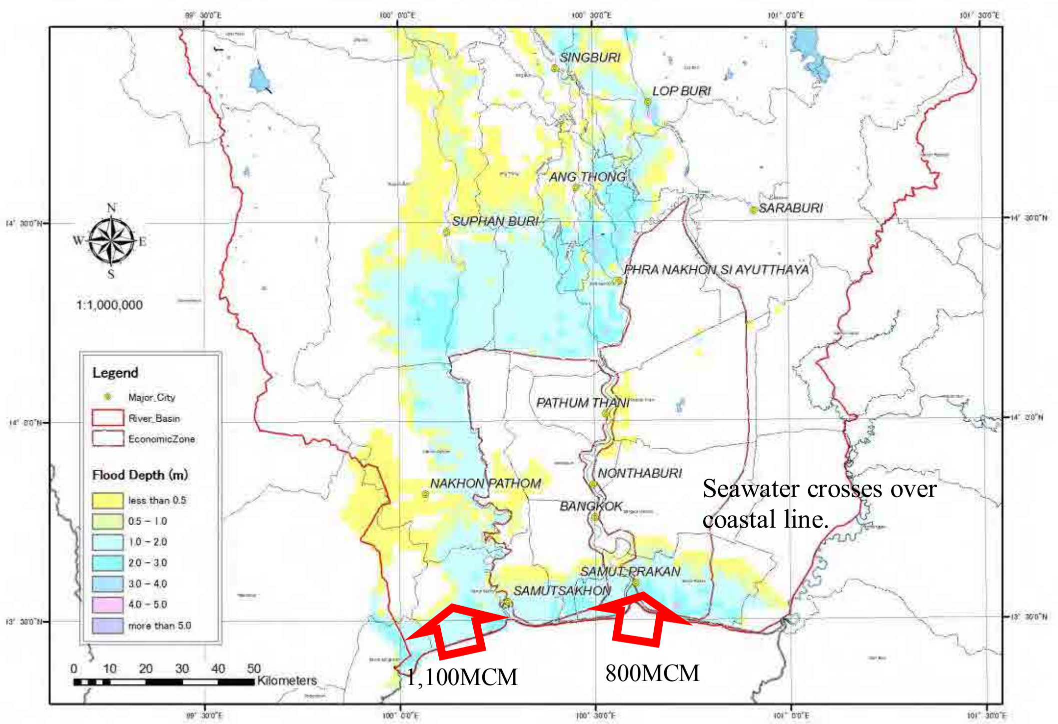



Without Storm Surge

With Storm Surge (Elevation of Sea Level by 2m)

**Figure 5.7.6 Estimated Inundation Area in Chao Phraya River Basin**

(October 30)




(October 31)

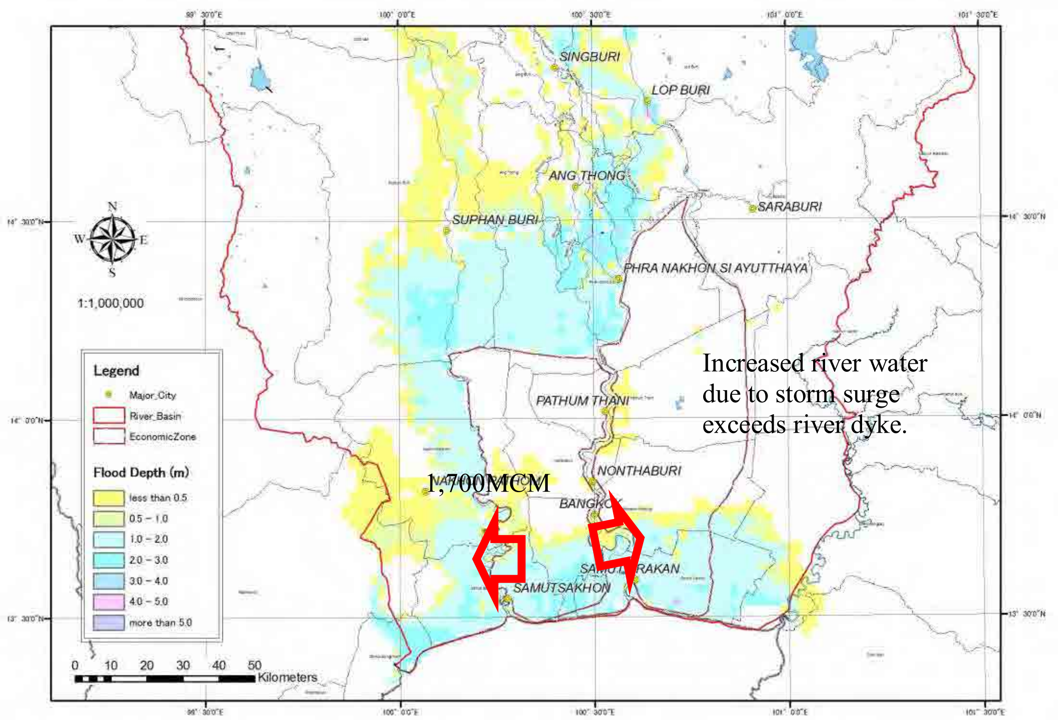



**Figure 5.7.7 Simulation on 2m of Storm Surge with 2011 Flood**

# CHAPTER 6 PROJECT EFFECTIVENESS AND EVALUATION

## 6.1 Project Effectiveness

### 6.1.1 Project Effectiveness against Design Flood

Effectiveness of combination of countermeasures against Design Flood has been checked by maximum flood discharge diagram, in which values indicate maximum flood discharge considering secondary dykes, not river flow capacity. The simulation was done to cover the period from June 1, 2011 to December 31, 2011. The following three combinations have been studied:

Combination of SCWRM M/P

1) Effective Operation of Existing Dams
2) Construction of New Dams
3) Improvement of Retarding/Retention Areas
4) East/West Diversion Channel (Capacity: 1,500$m^3$/s)
5) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
6) River Channel Improvement Works (not including Tha Chin River Improvement)
7) Flood Forecasting

Proposed Combination 1

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

Proposed Combination 2

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 1,000$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

Maximum flood discharge diagram, and inundation area and depth (Simulation Results) of each combination is given as follows:

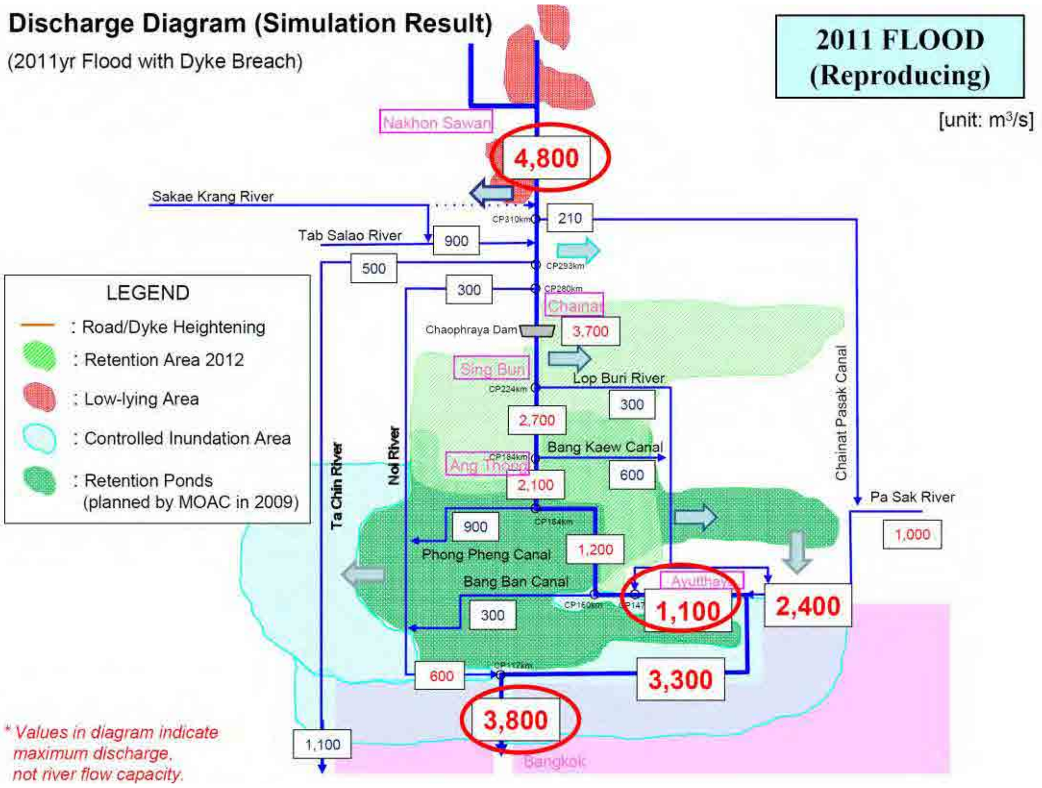



**Figure 6.1.1 Maximum Flood Discharge Diagram (2011 Flood Reproducing)**

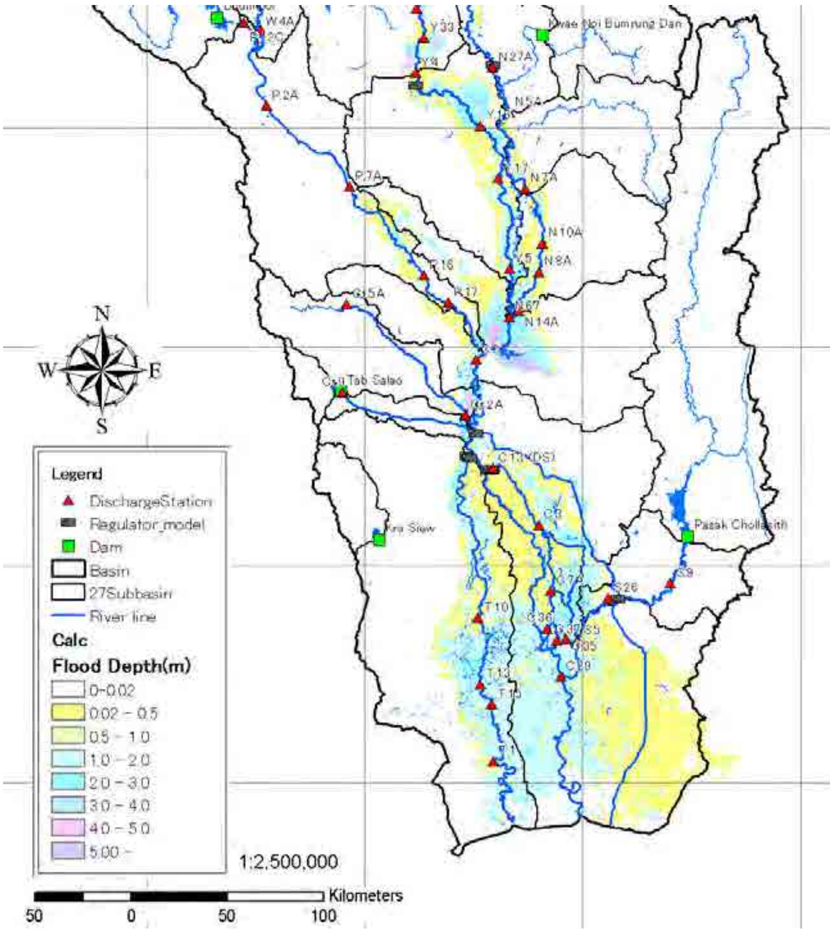



**Figure 6.1.2 Flood Inundation Area and Depth (2011 Flood Reproducing)**

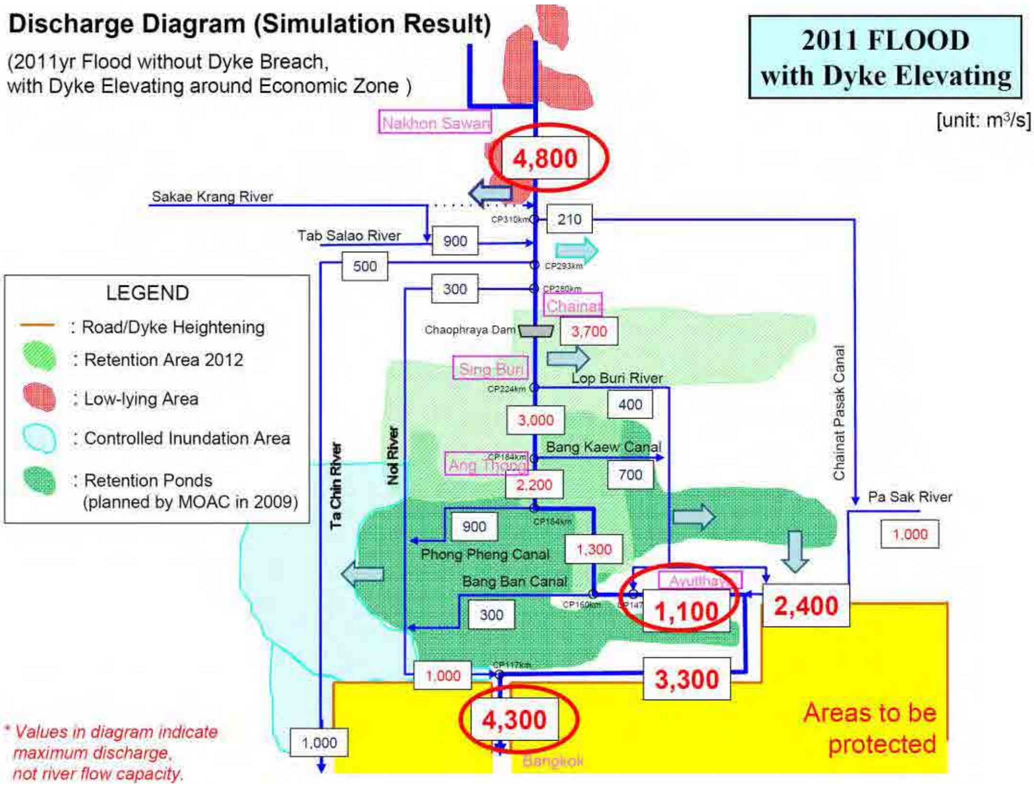



**Figure 6.1.3 Maximum Flood Discharge Diagram**
**(2011 Flood with Dyke Elevating around Protection Area)**

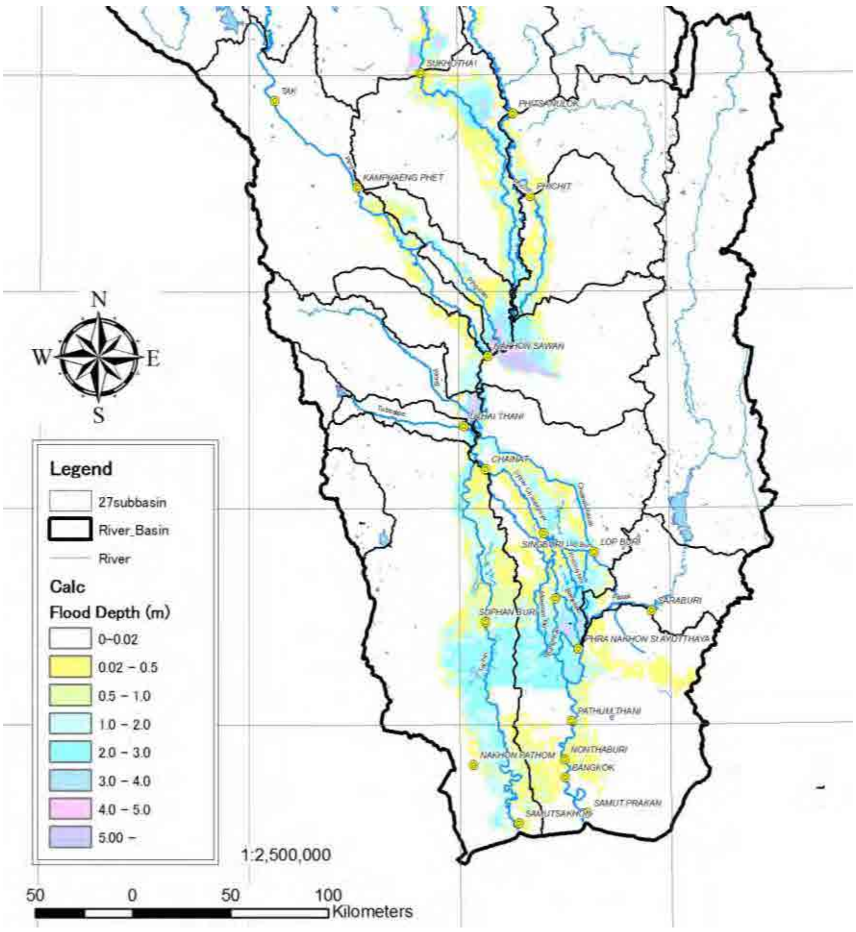



**Figure 6.1.4 Flood Inundation Area and Depth (2011 Flood with Dyke Elevating)**

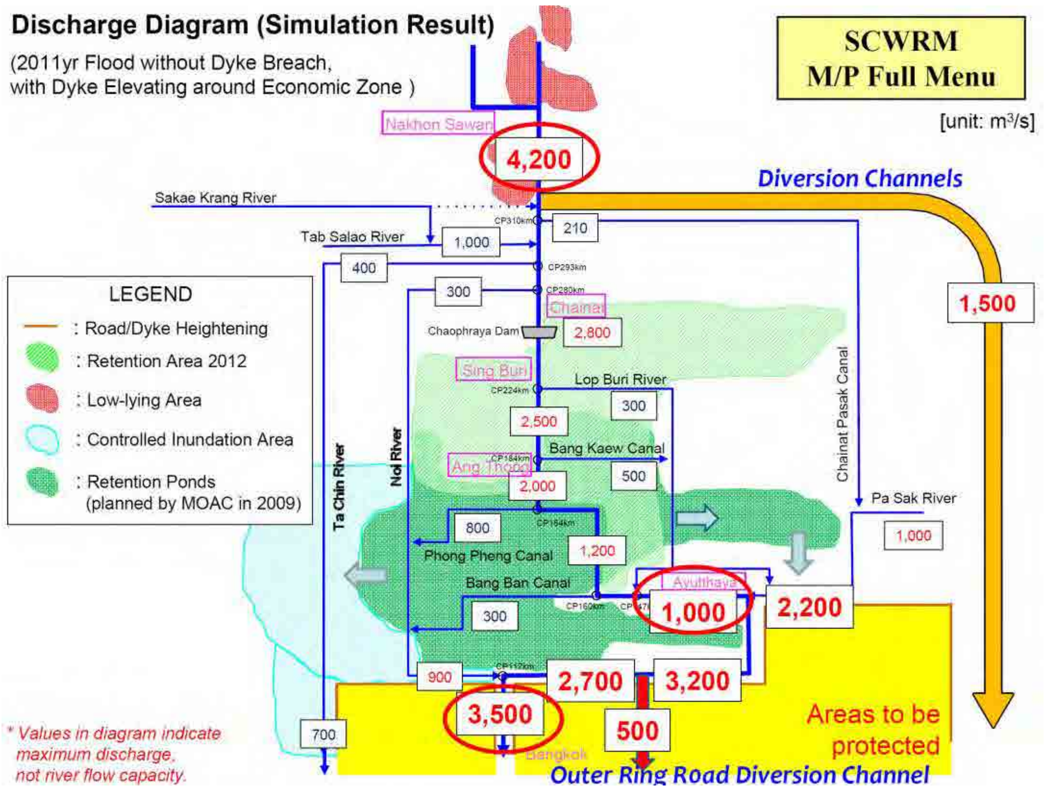



**Figure 6.1.5 Maximum Flood Discharge Diagram (SCWRM M/P)**

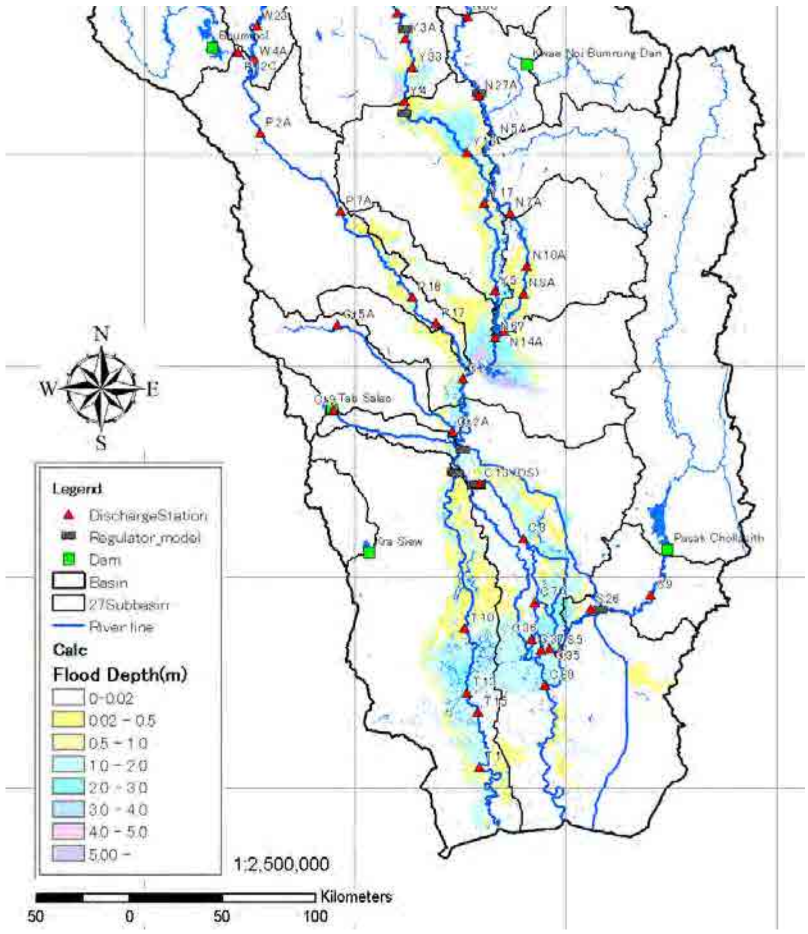
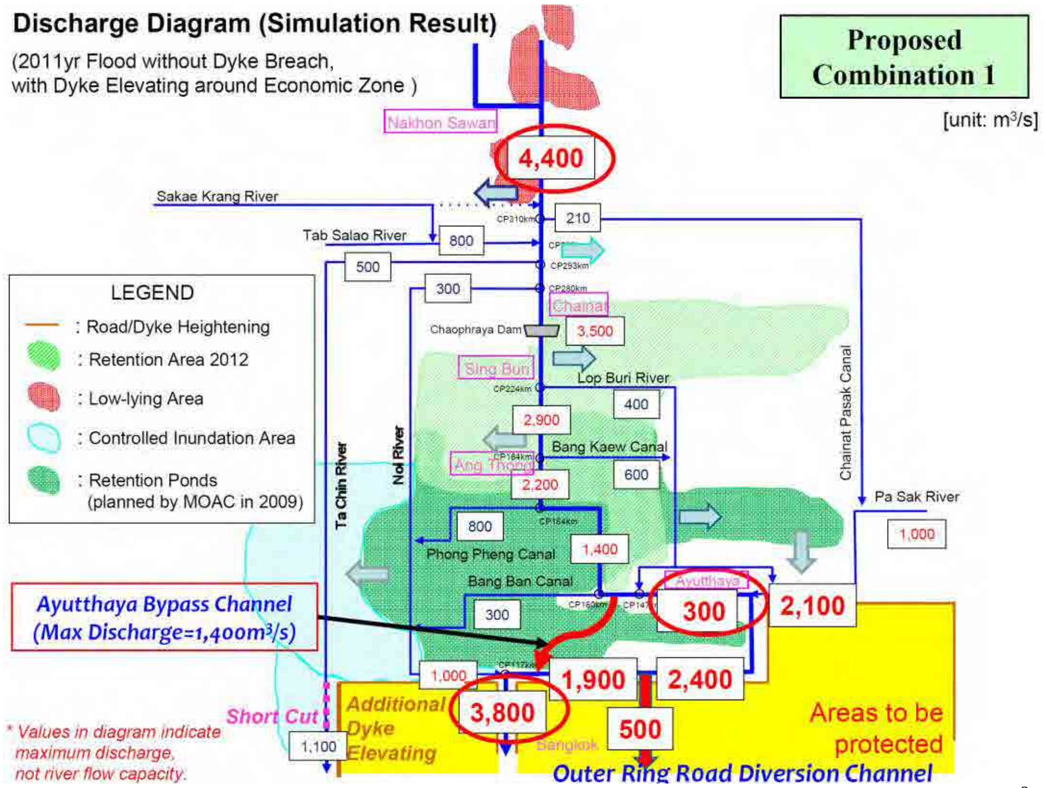



**Figure 6.1.6 Flood Inundation Area and Depth (SCWRM M/P)**




* *Discharge capacity of Chao Phraya River near Bangkok is considered to be approx. 4,000 $m^3$/s*

**Figure 6.1.7 Maximum Flood Discharge Diagram (Proposed Combination 1)**

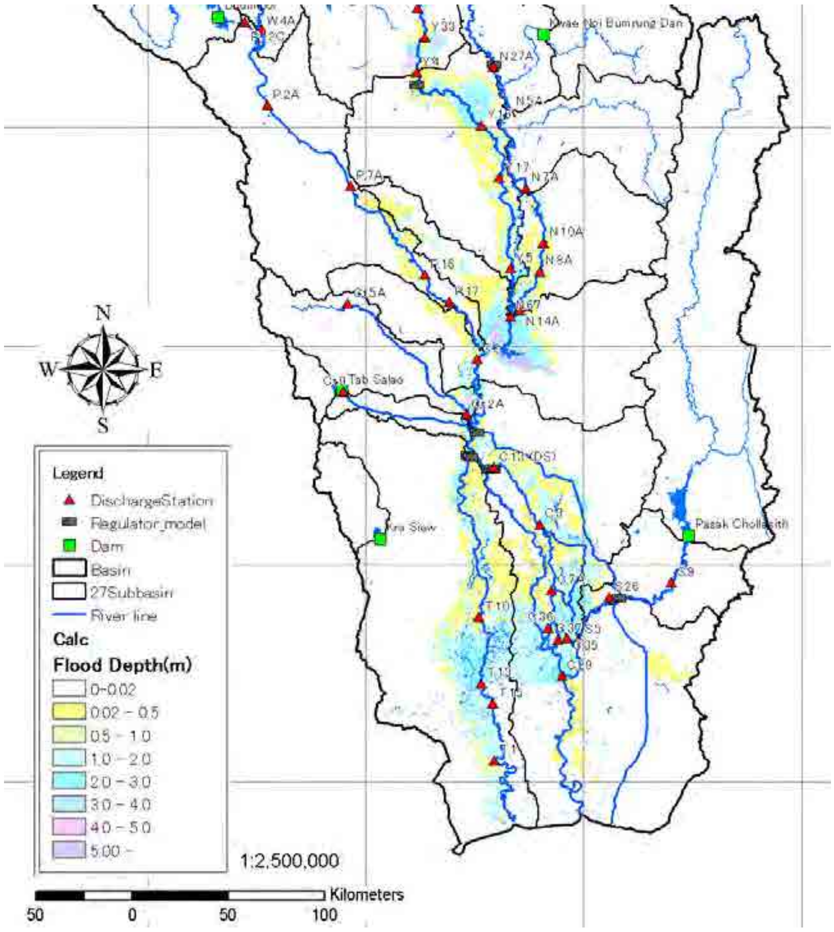



**Figure 6.1.8 Flood Inundation Area and Depth (Proposed Combination 1)**

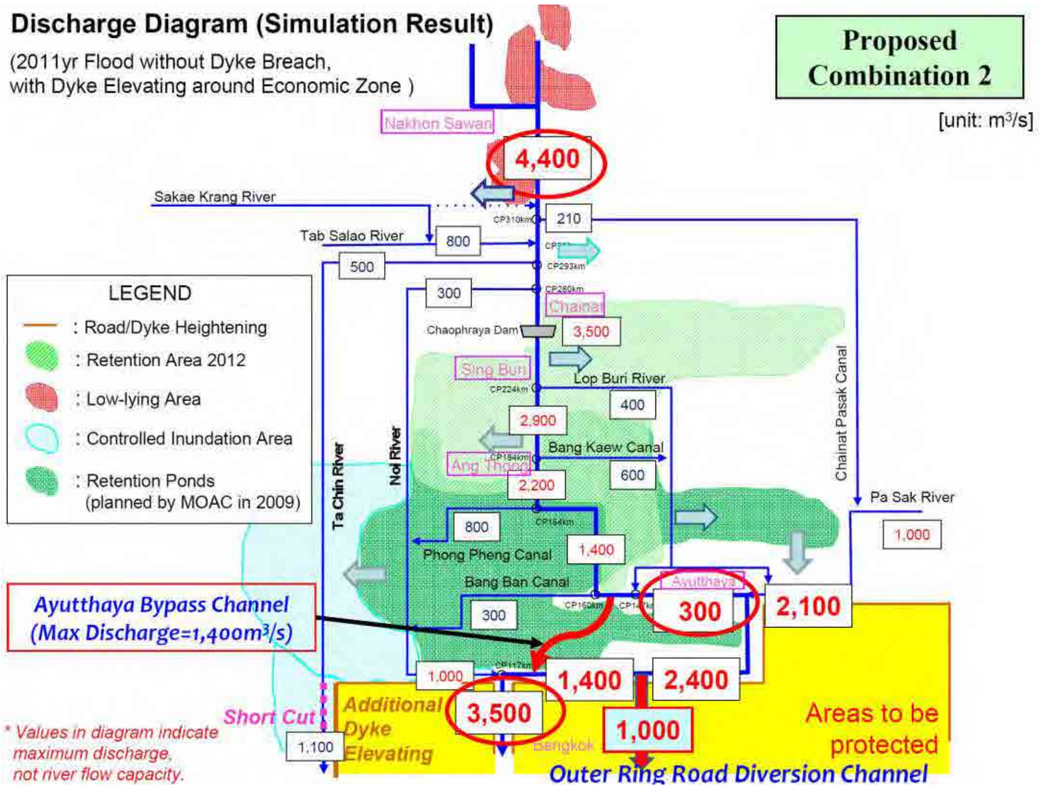



**Figure 6.1.9 Maximum Flood Discharge Diagram (Proposed Combination 2)**

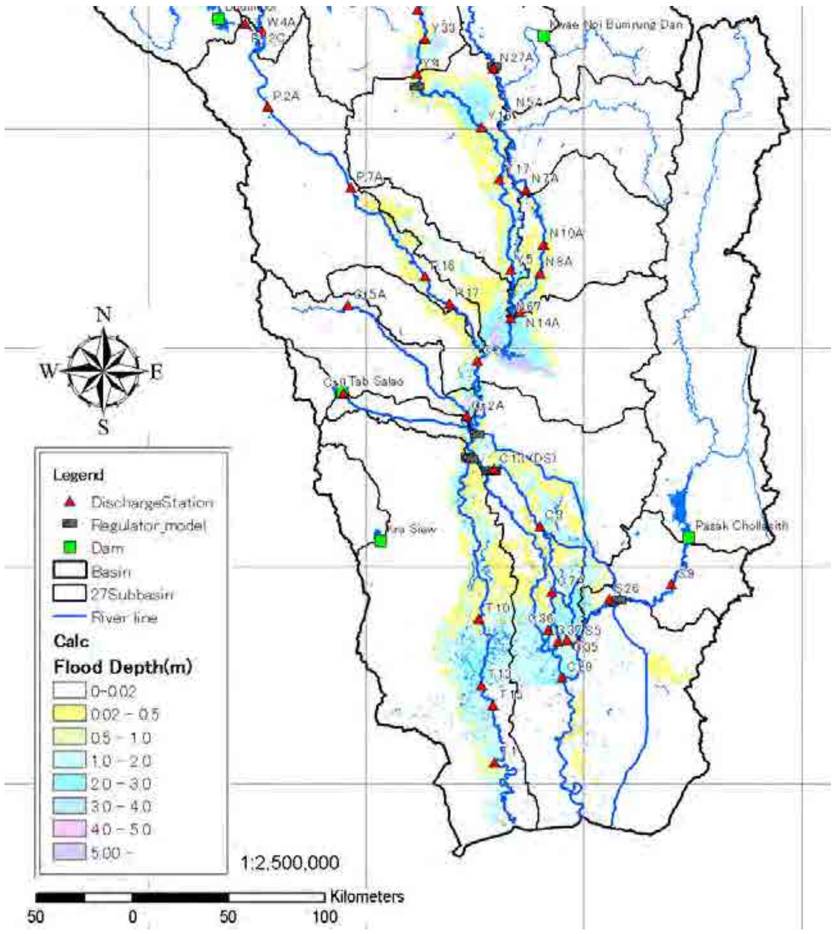



**Figure 6.1.10 Flood Inundation Area and Depth (Proposed Combination 2)**

Figure 6.1.12 shows river flow capacity considering secondary dykes (refer to Figure 6.1.11) with river improvement works under proposed Combination 1 or Combination 2.

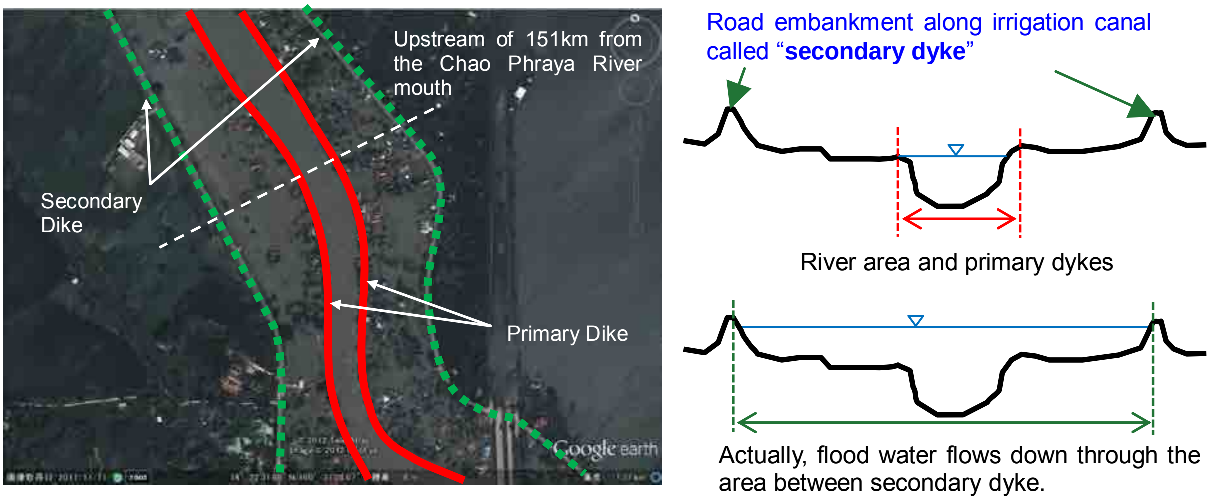



**Figure 6.1.11 River Flow Section considering Secondary Dykes**

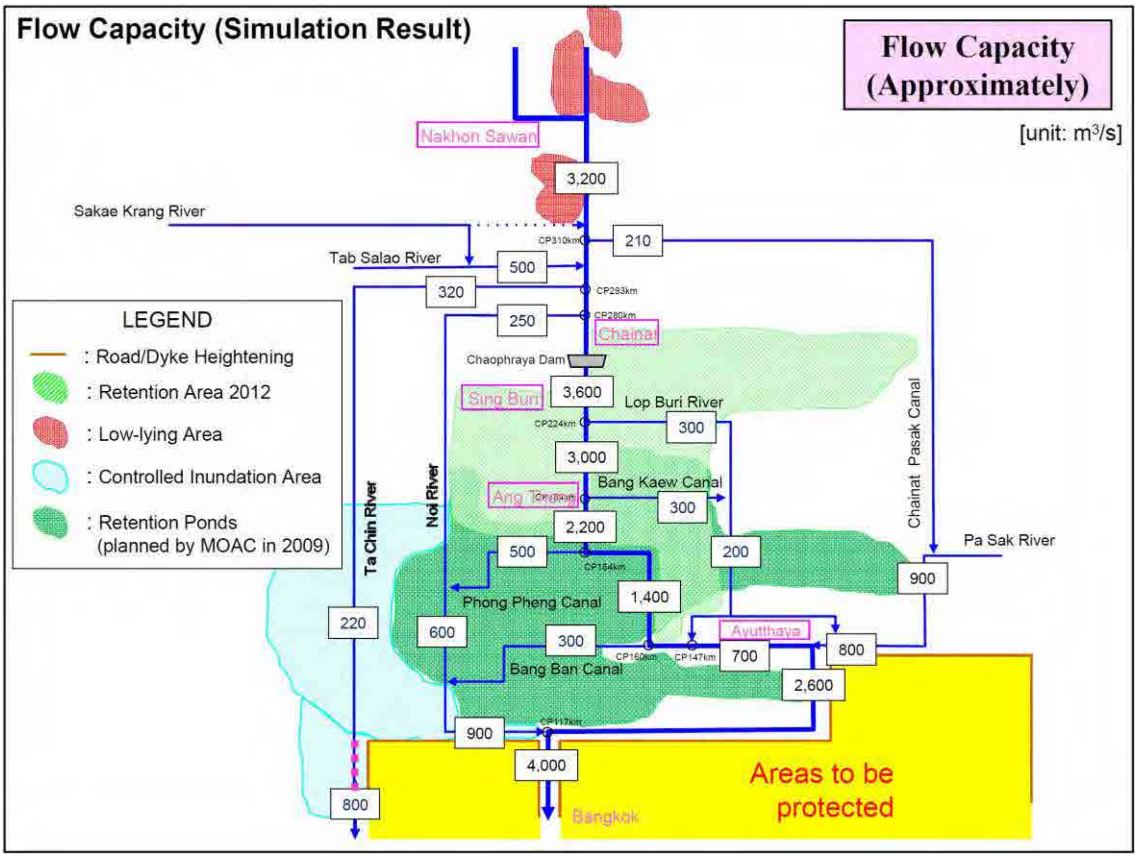



**Figure 6.1.12 River Flow Capacity Diagram**
**(Simulation Result, with River Improvement Works under Combination 1 or 2)**

### 6.1.2 Project Effectiveness against Design Flood (New TOR)

The Terms of Reference (TOR) of "the International Competition for the integrated flood control measures" which has been on going by the Royal Thai Government was issued on March 19, 2013. The effects of the proposed measures in the New TOR are reviewed by using the flood analysis model:

Combination of New TOR

1) Effective Operation of Existing Dams
2) Construction of New Dams (7 dams)
3) Improvement of Retarding/Retention Areas (Upper Nakhon Sawan)
4) East/West Diversion Channel
   (East Channel Capacity: 300-400m$^3$/s, West Channel Capacity: 1,200m$^3$/s)
5) Ayutthaya Bypass Channel (Capacity: 1,200m$^3$/s)
6) River Channel Improvement Works (including 3 locations of Tha Chin River Shortcut Canals)
7) Flood Forecasting

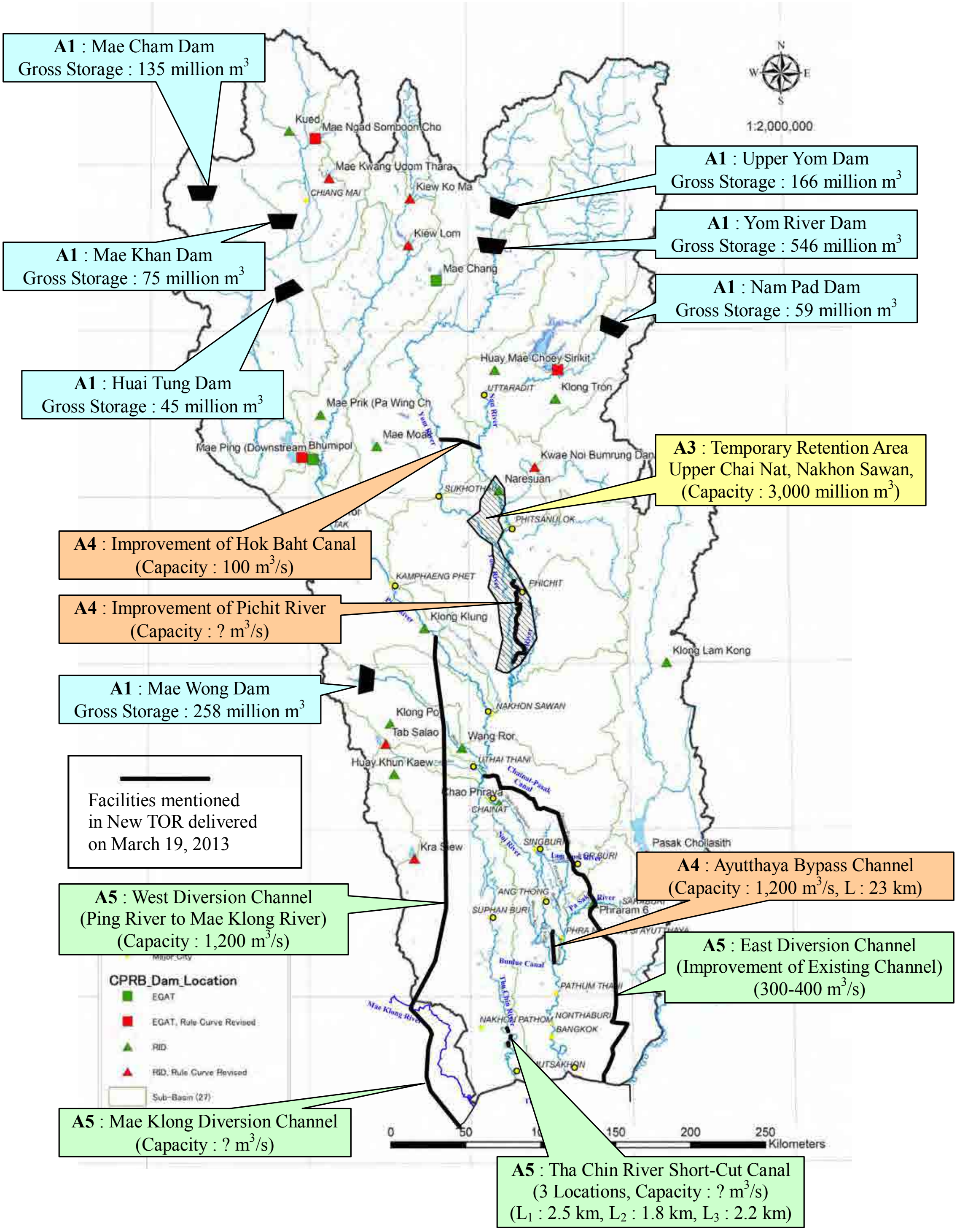



**Figure 6.1.13 Combination of Structural Measures (New TOR)**

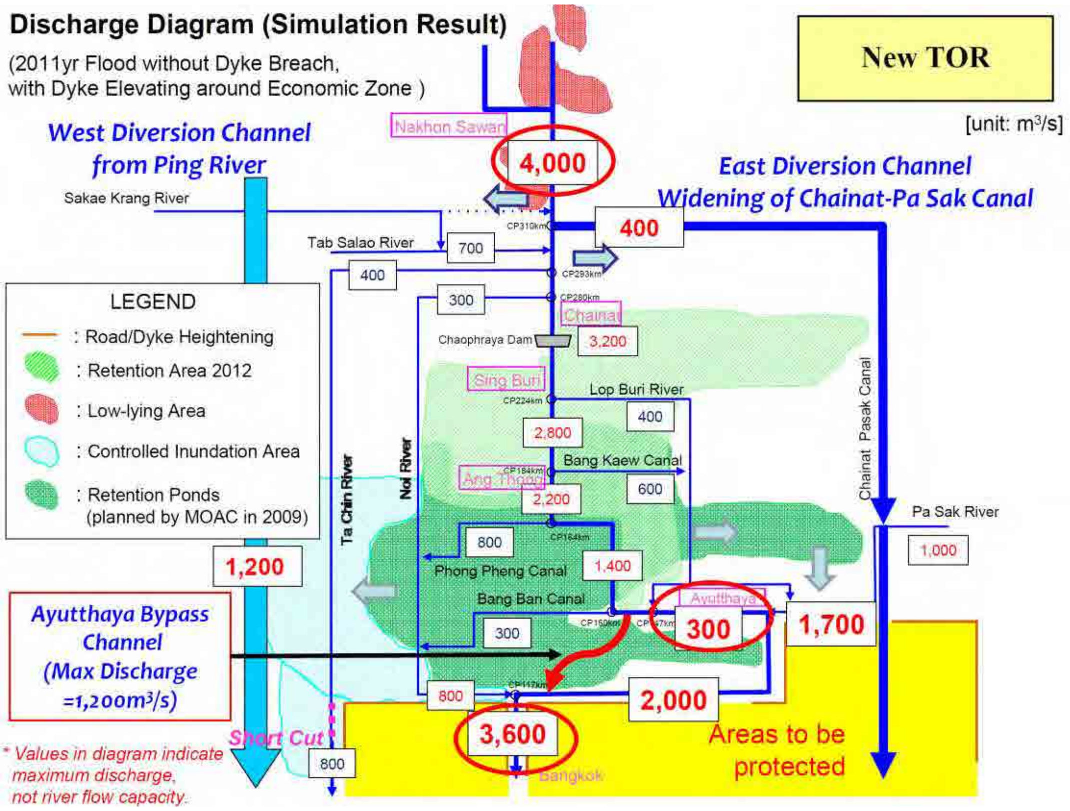



**Figure 6.1.14 Maximum Flood Discharge Diagram (New TOR)**

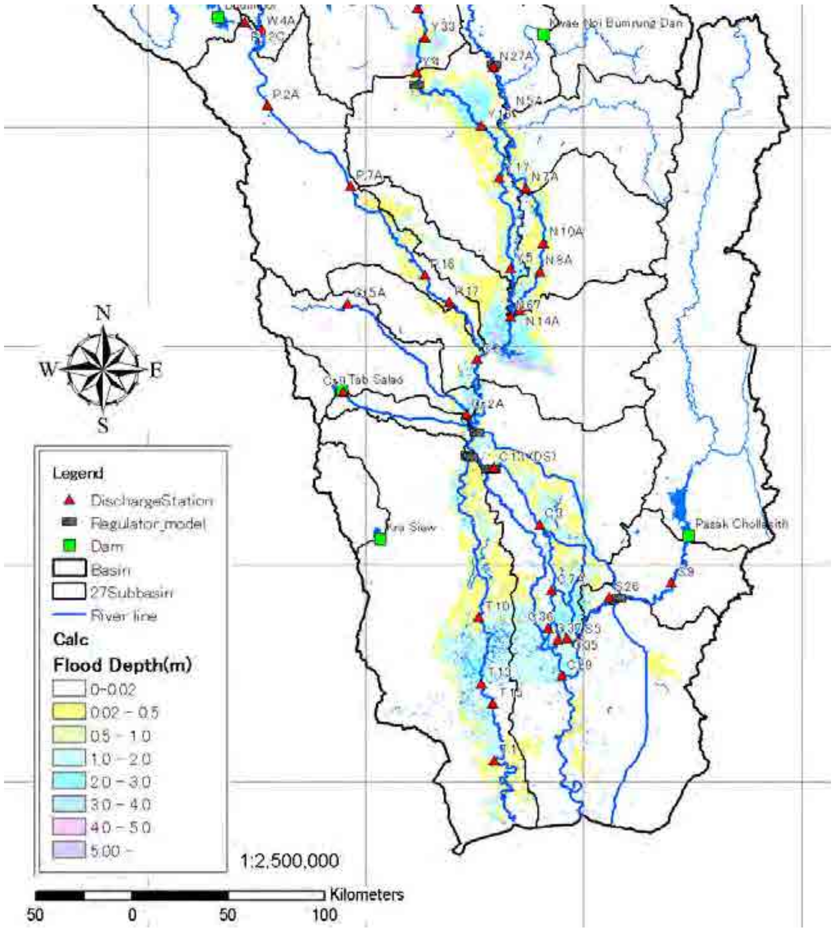



**Figure 6.1.15 Flood Inundation Area and Depth (New TOR)**


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

### 6.1.3 Verification of Project Effectiveness against Other Rainfall Patterns

Project effectiveness should be verified against other rainfall patterns of measure flood year.

**Table 6.1.1 Other Rainfall Patterns to be evaluated**

| Flood Year | 6-month Rainfall (mm) | | Peak Discharge at Nakhon Sawan ($m^3$/s) | | Remarks |
|---|---|---|---|---|---|
| | Upper Nakhon Sawan [C.A. = 105,000$km^2$] | Whole River Basin [C.A. = 162,000$km^2$] | Observed Value | Calculated Value (without Dams) | |
| **2011** | **1,483** | **1,390** | **4,686** | **6,857** | **Design Flood** |
| 1970 | 1,266 | 1,232 | 4,420 | 5,830 | Other Rainfall Pattern |
| 1975 | 1,254 | 1,166 | 4,336 | 5,535 | |
| 1980 | 1,255 | 1,207 | 4,320 | 5,839 | |
| 1994 | 1,313 | 1,168 | 2,533 | 4,268 | |
| 1995 | 1,262 | 1,230 | 4,820 | 5,612 | |
| 2006 | 1,375 | 1,266 | 5,450 * | 6,385 | |

* 5,450 $m^3$/s is the recorded peak discharge in 2006. However, the observed peak water level in 2006 is much lower than the value in 2011. Based on the H – Q curve of the year 2011, it is estimated that the peak discharge in 2006 is approximately 3,800 $m^3$/s.

Effectiveness of Combination 1 and 2 against other rainfall patterns has been verified as shown in the followings. Table 6.1.2 shows calculation results against actual rainfalls of other years. On the other hand, Table 6.1.3 shows calculation results against rainfalls which are enlarged to the same quantity as the design external force (2011's 6-month rainfall).

**Table 6.1.2 Verification Results of Project Effectiveness against Other Actual Rainfalls**

| Flood Year | Peak Discharge ($m^3$/s) | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dyke Elevating around Protection Area Without Countermeasures | | | Dyke Elevating around Protection Area With Combination 1 | | | Dyke Elevating around Protection Area With Combination 2 | | | |
| | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | |
| **2011** | **4,800** | **1,100** | **4,000** | **4,400** | **300** | **3,800** | **4,400** | **300** | **3,500** | **Design Flood** |
| 1970 | 3,600 | 1,000 | 3,500 | 3,200 | 300 | 2,900 | 3,200 | 300 | 2,400 | Other Rainfall Pattern |
| 1975 | 3,700 | 1,000 | 3,000 | 3,200 | 300 | 2,600 | 3,200 | 300 | 2,100 | |
| 1980 | 4,200 | 1,000 | 3,700 | 3,800 | 300 | 3,100 | 3,800 | 300 | 2,700 | |
| 1994 | 3,500 | 1,000 | 2,900 | 3,000 | 300 | 2,600 | 3,000 | 300 | 2,200 | |
| 1995 | 4,100 | 1,000 | 3,800 | 3,500 | 300 | 3,100 | 3,500 | 300 | 2,700 | |
| 2006 | 4,400 | 1,000 | 3,700 | 3,600 | 300 | 2,900 | 3,600 | 300 | 2,500 | |

**Table 6.1.3 Verification Results of Project Effectiveness against Rainfalls enlarged to Same Quantity as 2011's 6-month Rainfall**

| Flood Year | Peak Discharge ($m^3/s$) | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dyke Elevating around Protection Area **Without Countermeasures** | | | Dyke Heightening around Protection Area **With Combination 1** | | | Dyke Heightening around Protection Area **With Combination 2** | | | |
| | Nakhon Sawan | Ayuttha-ya | Bang Sai | Nakhon Sawan | Ayuttha-ya | Bang Sai | Nakhon Sawan | Ayuttha-ya | Bang Sai | |
| **2011** | **4,800** | **1,100** | **4,000** | **4,400** | **300** | **3,800** | **4,400** | **300** | **3,500** | **Design Flood** |
| 1970 | 4,300 | 1,000 | 3,900 | 4,000 | 300 | 3,500 | 4,000 | 300 | 3,100 | Other Rainfall Pattern |
| 1975 | 4,800 | 1,100 | 4,400 | 4,400 | 300 | 3,800 | 4,400 | 300 | 3,400 | |
| 1980 | 4,800 | 1,100 | 4,400 | 4,600 | 300 | 3,900 | 4,600 | 300 | 3,600 | |
| 1994 | 5,000 | 1,000 | 4,200 | 4,500 | 300 | 3,600 | 4,500 | 300 | 3,200 | |
| 1995 | 4,600 | 1,100 | 4,400 | 4,300 | 300 | 3,900 | 4,300 | 300 | 3,600 | |
| 2006 | 4,800 | 1,100 | 4,200 | 4,400 | 300 | 3,600 | 4,400 | 300 | 3,200 | |

## 6.2 Cost, Benefit and EIRR

### 6.2.1 Cost

The project cost is estimated based on the domestic price level as of December, 2012 indicated in Thai Baht. The applied exchange rate (Bank of Thailand Selling Rate as of 28 December, 2012) is as follows:

- 1 USD = 30.7775 Baht (1 Baht = 0.032 USD)
- 100 JPY = 35.7960 Baht (1 Baht = 2.794 JPY)

Results of project cost estimation are given as follows:

**Table 6.2.1 Project Cost**

| SCWRM M/P Module | | Description | Capacity ($m^3/s$) | Project Cost (billion Baht) | | |
|---|---|---|---|---|---|---|
| | | | | SCWRM M/P | Proposed Combination 1 | Proposed Combination 2 |
| C1 | Re-foresting | - | - | *NE* * | *NI* ** | *NI* |
| C2 | Construction of New Dams | 3 dams | - | 71 | *NI* | *NI* |
| C3 | Land Use Control for Flood Area | - | - | NE | *NI* | *NI* |
| C4 | Improvement of Retarding / Retention Areas | 13 retention ponds | - | 46 | *NI* | *NI* |
| C5 | River Improvement | River channel improvement | - | 11 | 14 **** | 14 **** |
| | | Ayutthaya bypass channel (L=19km) | 1,400 | *NI* | 18 | 18 |
| C6 | Flood Diversion Channel | West diversion channel (L=223km) | 1,500 | 211 | *NI* | *NI* |
| | | Outer ring road diversion channel (L=98km) | 500 | 91 | 91 | - |
| | | | 1,000 | - | - | 132 |
| C7 | Operation Efficiency of Existing Dams | Bhumibol, Sirikit, Kwae Noi, Pa Sak dams | - | *NB* *** | *NB* | *NB* |
| C8 | Flood Forecasting System | - | - | 4 | 4 | 4 |
| Price Escalation (2013 to 2020 or 2023) | | - | - | 74 | 16 | 22 |
| **Total** | | - | - | **508** | **143** | **190** |

* *NE*: Not estimated (included in SCWRM M/P)
** *NI* : Not included in the proposed combinations
*** *NB*: Budget allocation is not necessary
**** including river improvement of the Tha Chin River

Note 1: The costs in the respective columns include construction, engineering service, administration, land acquisition, resettlement, physical contingency, price escalation and valued added tax.

Note 2: Non-structural measures proposed in the study are not included in the cost estimate.

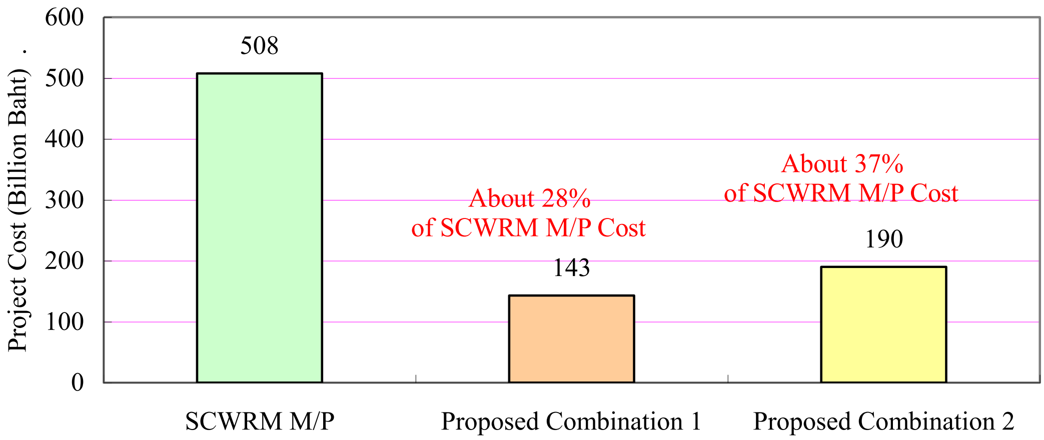



**Figure 6.2.1 Project Cost of Each Combination**

### 6.2.2 Benefit

Benefits of a flood management project are derived from the reduction of flood damage in the whole inundation area.

**Table 6.2.2 Flood Damage Estimation**

| Flood Damage | Estimation |
|---|---|
| Direct Damages on Assets of Factories | The amount of damage is estimated by summing up damaged asset values of which rates vary according to flood inundation depth. The flood simulation gives inundation depth of each 2 km x 2 km grid cell in the flood plains. |
| Direct Damages on Assets of Households | |
| Other Direct and Indirect Damages | The amount of damage is estimated with the percentages to the total amount of asset damaged derived from the research by the Ministry of Finance and the World Bank. |

The method to estimate flood damage is described in Table 6.2.2. Since the flood causing inundation is a probability event, the amount of damage to be calculated is the yearly expected value based on the probability of flood occurrence.

**Table 6.2.3 Estimated Amount of Total Assets in Whole Affected Area**

| Item | Factories | | | Households | | |
|---|---|---|---|---|---|---|
| | Fixed Assets | Stocks | Total | Houses | Assets | Total |
| Estimated Amount of Total Assets (billion Baht) | 2,167 | 844 | 3,011 | 1,638 | 1,064 | 2,702 |

Note 1:Estimated amount of total assets is common to all project combinations; namely, SCWRM M/P, Combination 1 and Combination 2.

### 6.2.3 EIRR, Benefit/Cost Ratio and Net Present Value

Based on the above-mentioned cost and benefit, EIRR, Benefit/Cost and Net Present Value are estimated as follows:

**Table 6.2.4 EIRR, Benefit/Cost and Net Present Value**

| Case | EIRR | Benefit/Cost | Net Present Value (Billion Baht) |
|---|---|---|---|
| SCWRM M/P Full Menu | 13 % | 1.1 | 21 |
| Proposed Combination 1 | 29 % | 2.7 | 137 |
| Proposed Combination 2 | 25 % | 2.2 | 127 |

Note 1) Price Level: 2012
Note 2) Evaluation Period: 2013 to 2050 (38 years after the commencement of the construction)
Note 3) Social Discount Rate: 12 %

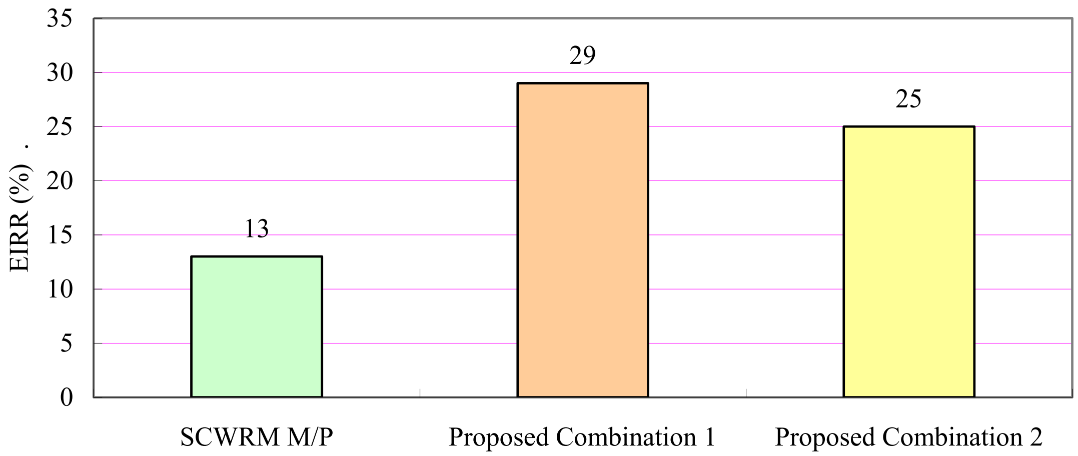



**Figure 6.2.2 EIRR of Each Combination**

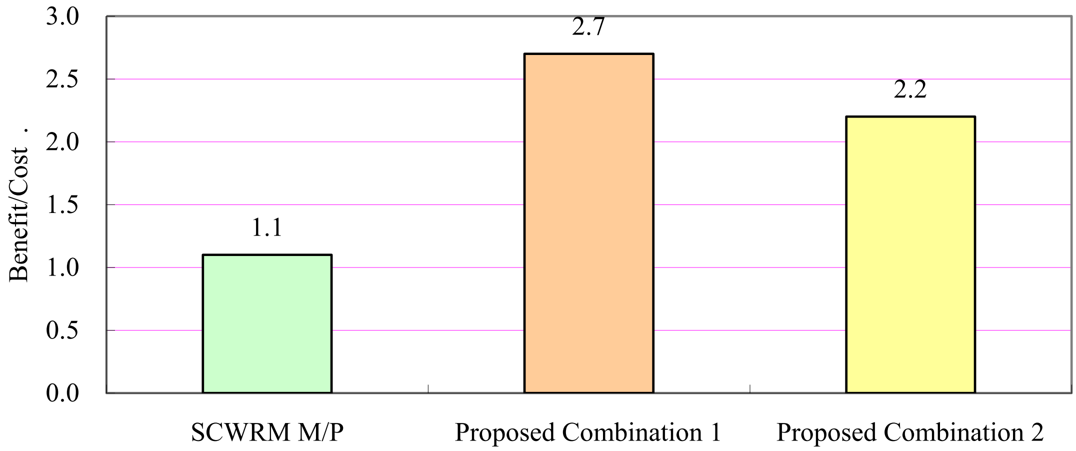



**Figure 6.2.3 Benefit/Cost Ratio of Each Combination**

## 6.3 Environment and Social Consideration

### 6.3.1 Outline of the Project

(1) Project Name

1) Ayutthaya Bypass Channel (19km length)
2) Outer Ring Road Diversion Channel (100km length)
3) Dyke Improvement of the Lower Chao Phraya River (90km length)
4) Dyke Improvement and Shortcut Channels in the Tha Chin River Basin (180km length in dyke improvement, 10.6km length in shortcut channels)

(2) Objectives

After several trials to develop an effective combination of countermeasures for flood management in Thailand, establishing four structural measures: 1) Ayutthaya Bypass Channel (19km length), 2) Outer Ring Road Diversion Channel (100km length), 3) Dyke Improvement of the Lower Chao Phraya River (90km length) and 4) Dyke Improvement and Shortcut Channels in the Tha Chin River Basin (180km length in dyke improvement, 10.6km length in shortcut channels) and with other structural/non-structural measures has been proposed as the most technical and cost-effective measures for protecting the lower Chao Phraya River Basin where the industrial centers are integrated. In this section, evaluation for the four plans is to be conducted from a viewpoint of environmental and social aspects, respectively.

### 6.3.2 Categories of the Project and Environmental Assessment

According the Thai laws[4], 34 project types and activities require an Environmental Impact Assessment (EIA) and approval through the national approval process. However, the diversion channels and dyke improvement are sure to be outside the scope of the EIA category in accordance with the Thai environmental assessment system at present. On the other hand, impacts on the environment may arise mainly by construction activities for the project. And a case is probable to make the residents or houses resettled in the project area to other location. Taking into account the situation, it is cocluded that conducting an Initial Environmental Examination (IEE) should be essential according to the JICA Guidelines for Environmental and Social Considerations.

### 6.3.3 Project Area Outlook and Scopes of Assessment

(1) Ayutthaya Bypass Channel

The planning area is located along the west side of Route 347 where both ends intersect with the right banks of the Chao Phraya River between north area of the central Phra Nakhon Si Ayutthaya

[4] *The Enhancement and Conservation of National Environmental Quality Act (NEQA) of B.E. 2535 (1992)*

(Ayutthaya) and south Bang Sai. The area is mostly occupied with plain arable fields, and houses are found in a few sites such as the intersection of the planned bypass channel with Route 3263. Major industrial centers including an industrial estate develop along the left bank of the Chao Phraya River. Ethnic groups, national or natural parks, precious wild lives and historical memorials are not distributed over the whole planned area. The planning bypass channel also intersects with 14 existing canals and two vehicle roads running through the paddy field.

(2) Outer Ring Road Diversion Channel

The planning diversion channel starts from the left bank of Chao Phraya River in the south part of Bang Pa-in Industrial Estate in Phra Nakhon Si Ayutthaya and develops toward south in parallel with the east side of the Eastern Outer Ring Road (R9) until the Gulf of Thailand at Klong Dan, through the east side of Suvarnabhumi International Airport. The area lies low and occupies paddy fields and social activity aggregations (houses, commercial facilities, schools etc.). In general social activity aggregations lie in the upper area and paddies or swamps in the lower area, but the lower area has been developing into social activity areas thanks to recent development plans in East Bangkok. Ethnic groups, national or natural parks, precious wild lives and historical memorials are not distributed over the whole planning area. Swamps in the whole planning area that develop some ponds and canals spreading out around the area mainly contribute to the area's eco system with small-scale shrubs. The planning diversion channel intersects with 14 major roads, two railways and some 85 canals.

(3) Dyke Improvement of the Lower Chao Phraya River

The target area of the dyke improvement is in lower Chao Phraya River from the estuary to approx. 90km upstream. This basin lies in the Chao Phraya Delta where business and industrial activities focus on. Bangkok and its vicinities cover the most area of the project. No specific land acquisition is required for the dyke improvement because most works are to add the height of the existing parapet walls (0-60km points, constructed by BMA) and dyke roads (constructed by DOH). All the work areas are within the Right-of-way of the RID and authorities concerned. Like the Ayutthaya project, no specific concerns like ethnic groups, national or natural parks, precious wildlife and historical memorials have been observed over the area.

(4) Dyke Improvement and Shortcut Channels in the Tha Chin River Basin

Tha Chin River is a distributary of the Chao Phraya River and located in Thailand's central plain. In this project, dyke improvement starts from the left bank of the Tha Chin River at the estuary to the connecting point with Bunlue Canal. Shortcut Channels are to be constructed within this dyke improvement area. Along the target river area, some facilities like temples, houses and shops are established. Most of lands are for agricultural use. The densely inhabited area is only around the estuary. Six major roads and one railway cross over the River within the project area. The River functions with multipurpose uses such as transportation, irrigation, water supply and recreation as well as waste water discharge.

### 6.3.4 Environmental Consideration

(1) Natural Environmental Consideration

During the construction, generation of noise and vibration from construction traffic or machinery and increase in traffic volume are possible issues. Treating by-products such as excavated soil can be also a task. In-use period of the channels, considerations should be required as to surface water (turbidity with sand/soil) and groundwater (water level), ground (topography/geographical features, ground subsidence) and landscape. Impacts on rare species of animals and plants are expected minor because most of the planning area is covered with secondary woodland and arable fields. However, the impact on soil organisms by soil excavation is to be considered. For the Outer Ring Road Diversion Channel, salinization of surface water or soil is a possible problem in case the seawater would run up from the mouth at the Gulf of Thailand. For the Dike Improvement in the Tha Chin River Basin, shortcut channel construction may cause salt water intrusion toward more upstream from the Gulf of Thailand because of shrinking the river length.

(2) Social Environmental Consideration

Land acquisition or expropriation is needed for the channels and roads for trucks used during the construction work. In addition, income compensation due to loss of opportunities of crop production would be necessary because both planning areas stretch out in paddy/arable fields. At the intersections with existing main roads, coordination with competent authorities is essential. For resettlement and compensation for the houses scattered in the planning area, an intensive household survey and compensatory negotiation complying with the Thai legislation will be required for smoother progress. For the Ayutthaya Bypass Channel, more than eighty houses are expected to be eligible even though most project area in arable fields. For the Outer Ring Road Diversion Channel, the expected number of eligible houses or the Project Affected Persons (PAPs) vary depending on the discharge capacity set up: about 600 houses at $500m^3/s$ capacity and about 900 houses at $1,000m^3/s$, respectively.

### 6.3.5 Comprehensive Evaluation and Mitigation Measures

It is considered feasible in general to avoid or reduce severe impacts which will be derived from construction works or caused by a direct reform from the existence of these new channels when conducting the mitigation measures. In particular careful considerations and measures will be essential to implement land acquisition and involuntary resettlement of the habitant that would have an affect by the project progress.

**Table 6.3.1 Summary of the Mitigation Measures**

| Influence Factor | Mitigation Measures |
|---|---|
| ***Natural Environmental Consideration*** | |
| Air Quality | Equalize construction works. |
| | Decentralize transport routes of construction trucks. |
| | Thoroughly implement maintenance for construction machines. |
| | Monitor the air quality to comply with legislations. |
| Salt Intrusion/ Salinization | Install a barrage at the estuary (floodgate) |
| | Discharge fresh water downstream in order to exclude the salted water |
| Water Quality | Introduce sewage treatment units and do monitoring. |
| | Monitor the water quality to comply with legislations. |
| Topographic/ Geographic Features | Investigate vulnerable topography / geographical features by a field survey or literature search. |
| Ground Subsidence | Avoid construction working on weak ground. |
| | Monitor the ground water level. |
| Ecology (Fauna & Flora) | Confirm precious species before construction. |
| | (In case of existing precious species) Move and conserve the species. |
| Landscape | Allocate a construction yard and roads for trucks properly. |
| | Building consensus with stake holders at the planning stage by showing the finishing drawing. |
| Wastes | Prevent excavated materials from contamination and process properly (Recycling if possible). |
| ***Social Environmental Consideration*** | |
| Land Acquisition / Compensation | Promote understandings with affected persons through measures like a public consultation etc. |
| | Establish and implement a Resettlement Action Plan (RAP) for affected persons and follow up them after relocation as well. |
| Involuntary Relocation | Establish and implement a Resettlement Action Plan (RAP) reflecting the regional conditions. |
| | Take care of the resettled people not to receive inconvenience for their livelihood by the construction work (ex. Follow-up by interviewing). |
| Affection on Existing Infrastructure | Develop a closer relationship with relevant ministries and agencies. |

## 6.4 Results of Project Evaluation

The most cost-effective combination of projects is sought, since cost of all the projects is expected to exceed the budget for flood management.

The proposed combination 1 or 2 of projects needs only less than 40% of SCWRM M/P cost, while the evaluation of the project, in other words, Economic Internal Rate of return (EIRR) is more than 25%, which is very high compared with the SCWRM M/P.

According to the Thai laws, the projects have no need to conduct an EIA and no need to get approval through the national approval process because both the by-pass channel and diversion channel projects are outside the scope of the EIA category in accordance with the Thai environmental assessment system at present.

On the other hand, impacts on the environment may arise mainly by construction activities for the project. And a case is probable to make the residents or houses resettled in the project area to other location. Taking into account the situation, it is cocluded that conducting an Initial Environmental Examination (IEE) should be essential according to the JICA Guidelines for Environmental and Social Considerations.

From environmental and social consideration aspects, proposed channels seem to have no severe environmetally and socially adverse impacts. However, careful considerations and measures will be essential to implement land acquisition and involuntary resettlement of the habitant that would have an affect by the project progress.

From the above evaluations, it is recommended to prioritize implementation of the proposed combination, which includes:

1) Effective Operation of Existing Dams;
2) Outer Ring Road Diversion Channel (Capacity: 500 or 1,000 $m^3$/s);
3) River Improvement Works (including Tha Chin River Improvement);
4) Ayutthaya Bypass Channel (Capacity : 1,400 $m^3$/s); and
5) Flood Forecasting.

*Note : Peak flow discharge at Bang Sai was estimated at 3,800 $m^3$/s in Combination 1 and 3,500 $m^3$/s in Combination 2. Since daily peak flow discharge of 3,900 $m^3$/s at Bang Sai was recorded during 2011 flood without any damages cased by overflow of water in the lower reaches of the Chao Phraya River (downstream of Bang sai), EIRR and B/C calculated as the damage caused by flooding does not come out with discharge of 3,800 $m^3$/s. In case that the damage comes out with discharge of 3,800 $m^3$/s, EIRR and B/C of Combination 2 may become values bigger than those of Combination 1.*

# CHAPTER 7 CONCLUSION AND RECOMMENDATION

## 7.1 Conclusion

The Study Team had reviewed the Flood Management Plan of the Royal Government of Thailand for the Chao Phraya River Basin . The Flood Management Plan was formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011. Based on the concept formulated by SCWRM, this Study evaluated the combination of various countermeasures quantitatively and from the engineering point of view utilizing precise topographical information obtained by Laser Profiling and the latest knowledge. The Water Resources Flood Management Committee (WRFMC) revised the SCWRM plan parlty in March 2013. However, its reliability seems to be insufficient because it did not utilize precise topographical information.

The results of the review by the Study Team are as summarized below:

**Unsteady Flow Analysis**

- To evaluate the flow capacity in the lower reaches influenced by sea tide, the unsteady flow analysis method was employed for the flow routing analysis and inundation analysis. Unsteady flow is defined as the non-constant special/temporal flow. At the downstream of Chao Phraya River, river flow is influenced by sea tide as shown in the following figure, and the water level near the estuary is strongly regulated by the tidal level. To describe this natural phenomenon (ever-changing water level), it is indispensable to employ the unsteady flow analysis. From Nakhon Sawan (C2) to the coastal line of the Gulf of Thailand, both of the riverbed slope and the ground slope are almost flat, and the behavior of river flow and inundation flow is dominated by not only the riverbed/ground slope, but also by the difference of surface water head.

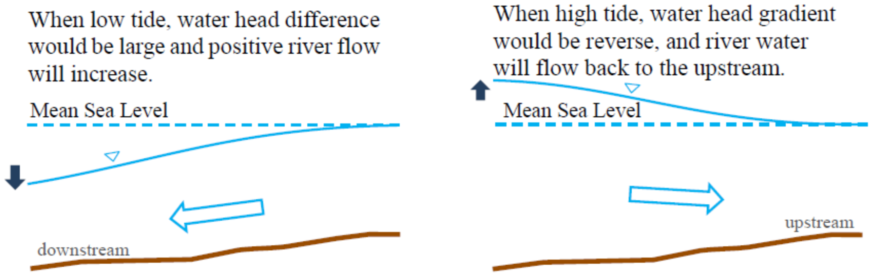
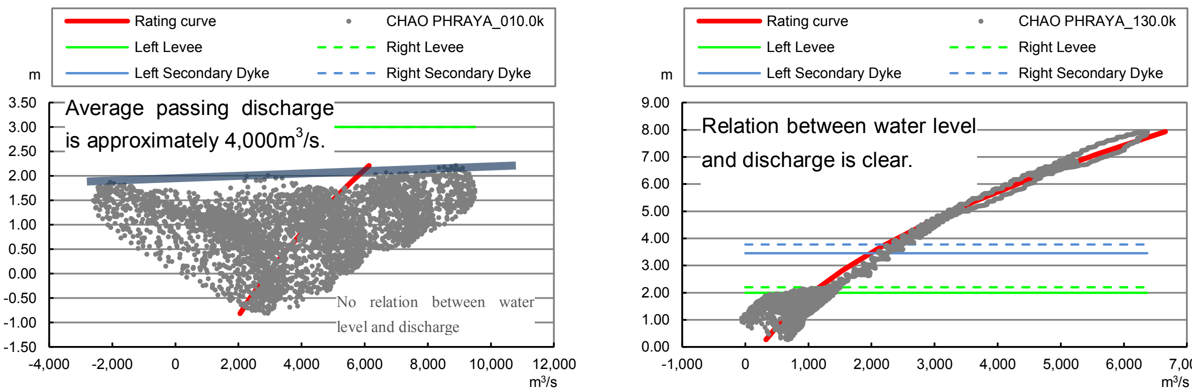



**Figure 7.1.1 Influence of Sea Tide**

- Since there is no relation between water level and discharge, the estimation of flow capacity using the rating curve has been difficult. In the downstream of Chao Phraya River, water level does not rise regardless of flood scale. Therefore, the potential passing discharge, which is equivalent to the flow capacity, was used for the evaluation of high water level.




Chao Phraya River: 10.0km    Chao Phraya River: 130.0km

**Figure 7.1.2 H-Q Plotting Chao Phraya River (without Overflow)**

## Large Flood Water Volume Compared with River Flow Capacity

- Through the investigation and evaluation of present conditions related to water resources and flood management and focusing on flood disaster management, it has been revealed that the Chao Phraya River Basin has a large low-lying area used as agricultural area in the dry season but have natural functions as retarding basin in the rainy season. People in the basin are coexisting with floods. As one of the main features of inundation, it is pointed out that traffic of flood water from the river to the flood plain is busy during rainy season, since the potential flood water volume from the river basin is much larger than the flow capacity of the rivers/canals. In addition, the water impounded in the flood plains, consisting of spilled water, local rainfall and side flow from sub-catchment areas, return to the rivers/canals easily because some rivers/canals have no dyke or the dyke height is low.

  Due to the overflow and the return of floodwater from the flood plain, the flood control effectiveness of even a large diversion channel with capacity of 1,500m$^3$/s from Nakhon Sawan to the Gulf and the construction of new dams with small capacity will not appear enough at the lower reaches.

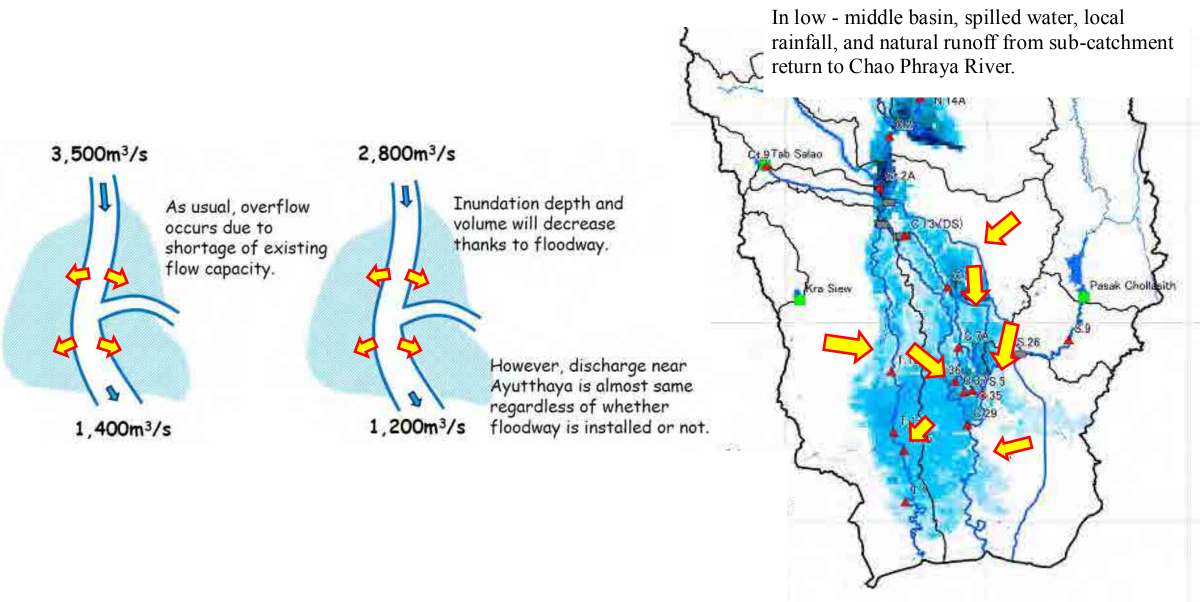



**Figure 7.1.3 Overflow from Rivers/Canals and Return Flow to Rivers/Canals**

## Design High Water Level

- The setup of the Design High Water Level (DHWL) is very an important procedure to implement an effective river management including flood prevention, control for deliberate inundation, river improvement works and so on. Actually, river discharge and volume depends on the dyke height. If a high and long dyke is constructed upstream, discharge from the upstream will increase and could cause floods inundation downstream. Therefore, the DHWL should be designed precisely considering flow capacity, land use condition along the river, the gap of flood safety level between the upstream and downstream, etc. For instance, a large city like Bangkok must be protected from flooding so that a high river dyke should be installed. On the other hand, in rivers flowing in a natural area and agricultural area, it is highly recommended that the river dyke should be kept low and/or maintain the existing condition, because a highly elevated dyke would restrain river overflow and decrease the function of adjacent lands as the natural retention or retarding basin. Besides, a high dyke in such areas would also cause problems in water intake for irrigation. At the river mouth, sea tide must be considered since water level near estuary is dominated by tidal motion even during the flood season. Once dyke break occurs, infinite seawater will come into the land and wreak catastrophic damage on the coastal area.

- In Chao Phraya River from 0km to 90km, near the Bangkok metropolitan area, Bangkok Metropolitan Administration (BMA) is scheduled to install parapet wall for flood prevention. It seems, however, that the height of parapet wall was set based on a record-high water level in Chao Phraya River, and the height was setup in stair-steps as illustrated in the following figure (broken line). In actual practice, however, the slope of surface water level is never in the form of stair-steps and longitudinally, the dyke slope is slanted according to the gradient of water level. Therefore, JST recommends that the parapet wall installed near Bangkok be slanted based on the DHWL proposed in this study.

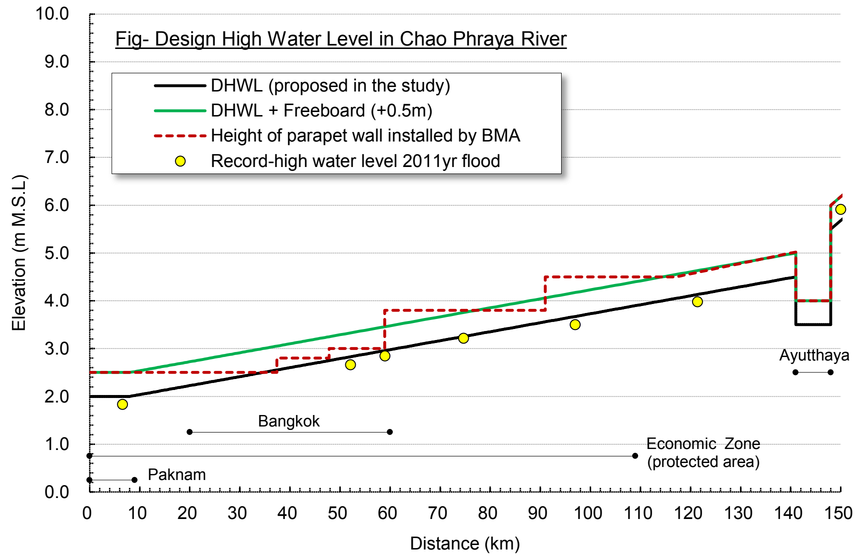



**Figure 7.1.4 Proposed Design High Water Level for Lower Reaches of Chao Phraya River**

**<u>Influence by Road Heightening Works</u>**

- As of end of June 2013, the road heightening works by DOH and DOR around the economically important zone has started. The comparative study between Simulation Case-0 (existing condition) and Simulation Case 0-1 (after completion of road dyke heightening works), clearly shows that the inundation depth and volume at Lat Bua Luang northwest from Bang Sai (see inundation block LO14 in the following figure) will dramatically increase due to the heightening works, but this is an extreme case. However, continuous structures like highway with embankment and road dyke would change the inundation condition to some extent, so that the influence of structures should be examined by flood inundation analysis and, if any, some countermeasures shall be designed so as to decrease the flood damage due to the continuous structures.

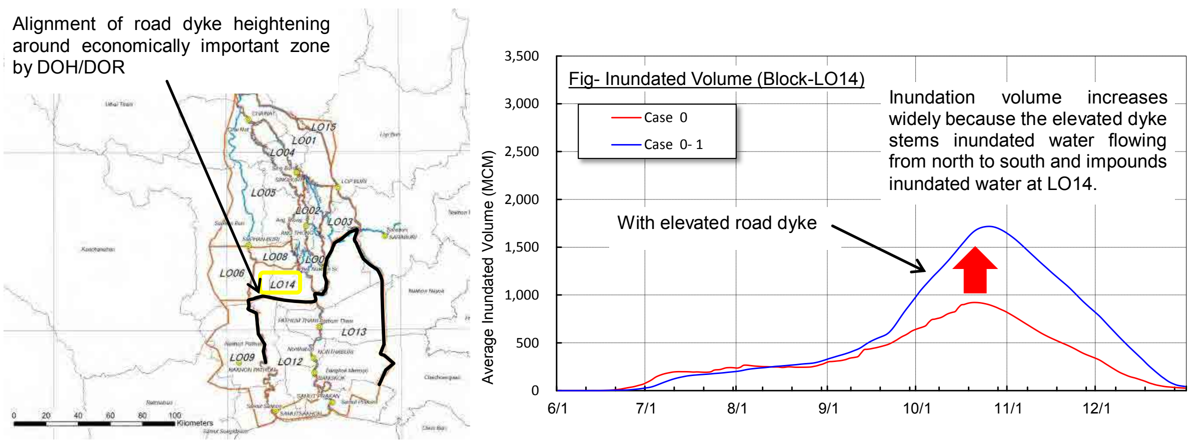



**Figure 7.1.5 Inundation Volume (Influence of Road Dyke Elevation)**

**Current Capacity of Pumps installed in the Protection Area**

- A circle levee such as the road dyke heightening works being done by DOH and DOR could aggravate inland flooding since local rainfall would not spread and could accumulate resulting in deeper inundation. With regard to the lower reaches of the Chao Phraya River, it is almost flat and accumulated local rainfall would be drained to the rivers or canals not by gravitational drainage but by pumping. In this study, examined was whether or not the existing capacity of pumps of approximately 1,590$m^3$/s is enough to drain inundation water (see Main Report Chapter 10, Subsection 10.2.12, Inland Storm Water Drainage). The study results show that the current capacity of pumps is enough for inland flooding caused by floods of the 2011 flood scale; however, this is just the result of a brief survey for the whole lower basin. Therefore, a more detailed study on inland flooding in a local area is recommended to be carried out separately.

**Comprehensive Flood Management Plan**

- The Master Plan (M/P) formulated by the Thai Government had aimed to attain integrated and sustainable water resources and flood management of the Chao Phraya River Basin. All measures proposed in the M/P are more or less effective for the mitigation of flood risk. However, the priority and feasibility of the proposed measures should be examined in various terms such as technical, economic, social and environmental aspects before implementation. The measures are composed of structural and non-structural measures, and the optimum combination of measures should be examined as to their effectiveness before implementation in order to attain the objectives within a limited term, because some of the measures might take a long time for implementation.

- It has been revealed that the operation of the existing dams during the 2011 flood was effective to reduce flood disaster risks, since Bhumibol Dam and Sirikit Dam stored about 12 billion $m^3$ of floodwater. However, there is still room for modification of the operation rules of the existing dams from the flood control and water use aspects. More effective operation of the existing dams will be possible. In this study, “Target Curve” and “Alert Curve for Drought” are proposed. “Target Curve” is the target storage volume for water use and the upper limit for flood control. “Alert Curve for Drought” can provide indicators to judge whether a drought year. “10% Probability” and “20% Probability” mean the risk of drought once in every 10 years and once in every 5 years, respectively.

  The Study proposes that the reservoir levels should follow the recommended “Target Curve” until the end of July, and from August, discharges should be stored in reservoirs with maximum outflows of 210$m^3$/s for Bhumibol Dam and 190 $m^3$/s for Sirikit Dam. If the proposed dam operation is applied for the 2011 flood, the peak discharge at Nakhon Sawan (C2) could be reduced by 400$m^3$/s. If the storage volume is less than the proposed Target Curve, the inflow should be stored in the reservoir. The released discharge shall not be less than the minimum discharges of 8$m^3$/s at Bhumibol Dam and the 35$m^3$/s at Sirikit Dam. Dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose.

- It has been revealed that there are two types of primary flood dykes along the river banks and secondary dykes of road-cum embankments of irrigation canals along the Chao Phraya River. The secondary dykes are considered as flood prevention measures. However, many local cities and communities are located along the river and numerous people are living between the two dykes. Also, even after the implementation of the proposed measures, a large part of the inundation area in the central plain will remain so that people should live with floods. Therefore, measures such as community-based flood disaster management are indispensable for the promotion of controlled inundation.

- The Study proposes the combinations of: (i) Effective Operation of Existing Dams; (ii) Construction of the Outer Ring Road Diversion Channel;(iii) Implementation of River Improvement Works including the Tha Chin River Improvement; and (iv) Construction of the Ayutthaya Bypass Channel as the optimum combination for the protection area of Bangkok and its vicinity to prevent flood disasters from the Chao Phraya River. The proposed combinations are feasible in technical, economic and environmental terms and for appropriate implementation of the proposed flood disaster management, nonstructural measures are required. It is recommended to prioritize implementation of the proposed combination as soon as possible.

Proposed combinations of measures are as follows:

(1) Proposed Combination 1

a) Effective operation of existing dams
b) Outer ring road diversion channel (Capacity: 500$m^3$/s)
c) River improvement works
d) Ayutthaya Bypass channel (Capacity: 1,400$m^3$/s)

(2) Proposed Combination 2

a) Effective operation of existing dams
b) Outer ring road diversion channel (Capacity: 1,000$m^3$/s)
c) River improvement works
d) Ayutthaya bypass channel (Capacity 1,400$m^3$/s)

(3) Other Nonstructural Measures

a) Re-forestation
b) Flood Forecasting
c) Land use control in inundation areas

- As a result of the Study, GIS database has been developed based on the data collected which should be utilized by the RID after the Study.
- As a basin-wide hydrological and hydraulic analysis model (using Mike 11 and Mike 21) incorporating the new topographical data, a runoff and flood analysis model has been developed. It is recommended that the simulation of flood runoff and inundation areas should be utilized for the flood risk management more precisely.

## 7.2 Recommendation

To avoid flood disasters in the protection areas and reduce the flood risks in the Chao Phraya River Basin, the Study recommends that the Thai Government should take immediate measures and arrangements for the implementation of the Comprehensive Flood Management Plan for the Chao Phraya River Basin.

Above all, the following remarks should be recommended.

- The precise topographical information obtained in the JICA Study should be distributed immediately to all organizations and agencies concerned. They should carry out the necessary investigations based on it. If this accurate topographical information is not used, any proposal in extremely lowland area like the Chao Phraya River Basin would have few engineering rationality and hardly make scientific sense.
- As indicated in the explanation of unsteady flow analysis, the amount of flood water volume stored in the entire Chao Phraya River channel is large, fluctuate itself in the river channel and inundation area. and volume is very large. So the effectiveness of even a large diversion channel from the upper reaches to the Gulf gradually decreases and may disappear at the lower reaches depending on the location of the inlet structure. Therefore, based on the idea that the effectiveness of the diversion channel is not changed regardless of the location, flood management plan by combination of channels with fixed flow capacity should not be avoided. It leads to a misdirected plan.

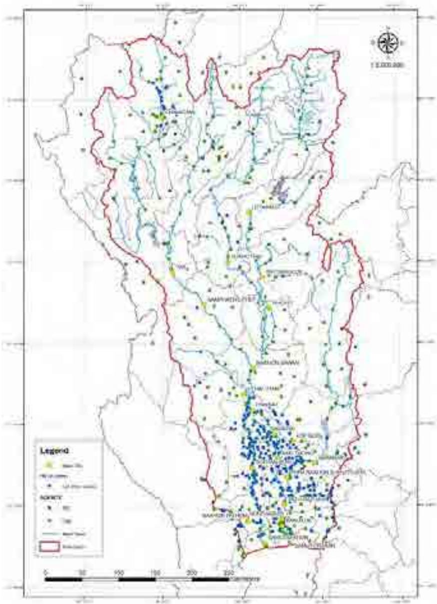
- This Study stated the method of evaluation of flow capacity in the area subject to tidal action. It is very important and fundamental issues of river management in the Bangkok Area until now and in the futures. It should be well understood.

**Recommendation about Comprehensive Flood Management Plan**

- To conduct effective operation of the existing dams (Bhumibol and Sirikit dams) as proposed by the Study.
- To conduct a feasibility study (F/S) on the proposed combination of structural measures, i.e., river improvement works including the Tha Chin river improvement works, the Outer Ring Road Diversion Channel (500$m^3$/s or 1000$m^3$/s), the Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s), and the nonstructural measures proposed by the Study.
- About prioritization of implementation, it is indispensable to consider the flood safety level of upstream/downstream. If Ayutthaya bypass channel is constructed before installation of Outer Ring Road Diversion Channel, river water flowing into the downstream around protection area is supposed to enlarge by approximately 300$m^3$/s, according to the flood analysis, which could increase the flood risk at downstream. Therefore, it is highly recommended that Outer Ring Road Diversion Channel should be constructed before Ayutthaya bypass channel.
- To promote controlled inundation, it is necessary to conduct the following: (i) To develop an accurate base map for the low-lying floodplain areas of the Chao Phraya River Basin based on the LP data prepared by JICA in 2012; (ii) To establish land use control and develop land use plan for the urban areas in the controlled inundation area; (iii) To promote community based flood disaster risk management including the implementation of structural and non-structural measures required due to the types of inundation zones; and (iv) To enhance public awareness on flood disaster risk management through improvement of dissemination of information and communication and education.
- As decision support and managing tools, the GIS data base and the river models developed in the Study should be maintained and updated in a sustainable manner for the effective flood disaster management of the Chao Phraya River Basin.

## Recommendations on the Hydrological Data Observation System

The issues identified in the hydrological data observation system are as described in the following table.

| No. | Issues | Recommendations |
|---|---|---|
| 1 | Shortage of Rainfall Station and inhomogeneous distribution<br>In this project, JST collected the rainfall data from approx. 700 stations in the Chao Phraya River Basin. Although the density of rainfall stations in the Chao Phraya River Basin is not so high at approx. 300km$^2$/station, many of the rainfall stations are located disproportionately, and most of stations under RID are concentrated in the irrigation area downstream of Nakhon Sawan (C.2). In order to examine the exact water resource and establish the flood control and water use plans, etc., it is necessary to install more rainfall stations. In Japan, it is believed that the ideal density of rainfall stations is 50km$^2$/station as a precautionary measure against torrential rainfall. | Rainfall stations should be installed especially in the middle basins, such as the Pa Sak River Basin, the area from Nakhon Sawan to Sukhothai and so on. It is ideal that rainfall stations should be distributed across the nation. Naturally, a higher density of stations in mountainous area is better.<br><br>Locations of Rainfall Station (as of 2011) |
| 2 | Observation Interval (Water Level Station)<br>Basically, it is enough to use daily data when rainfall analysis in the Chao Phraya River Basin is conducted because flood arrival time is long. However, in tidal sections, hourly water level observation should be carried out. Water level in tidal sections fluctuates periodically and usually high/low tide occurs twice a day due to sea tide, which regulates river flow. As of June 2013, JST has confirmed that hourly observation on water level has been done at telemetry stations TC.54, TC.12, TC.22, TC.55 and C.29A. However, observed data at most stations included errors and hourly water level data was not available. | Firstly, the existing water level station recording hourly data should be repaired and maintained. At least up to Ayutthaya (upstream of 141km from estuary), hourly observation should be done since river bed slope from estuary to Ayutthaya is almost flat and influenced by sea tide. Hourly water level observation should then be carried out not only in Chao Phraya River but also in Tha Chin River. |
| 3 | Discharge Observation during Flood Season<br>Obtained hydrological data during flood events is very valuable; especially discharge data at tidal sections near the estuary. It is desirable that hourly discharge observation is conducted with ADCP (Acoustic Doppler Current Profiler). | It is highly recommended that hourly discharge observation at tidal sections during flood events shall be done by using ADCP. Currently, discharge data obtained with ADCP seems to be the most accurate. The RID monitoring team, which can observe discharge with ADCP, should expand their activities to other sites. |
| 4 | Installation of Hydrological Station Monitoring Water Level and/or Discharge<br>By using the flood analysis model, it was found that overflow and return flow from the flood plain is frequent from Nakhon Sawan to Ayutthaya. In order to clarify the phenomenon, water level/discharge observation should be done. | Understanding of overflow volume and return flow to the rivers/canals is necessary to control flooding and inundation so that new hydrological stations should be installed. Hydrological stations are required, especially, from Chao Phraya Dam to Nakhon Sawan because there are no water level stations in the area. In addition, water level/discharge observation should be carried out in major tributaries including Noi River, Lop Buri River, Chainat Pa Sak Canal and so on, since inflow from tributaries could impact on the flow regime at the mainstream. |

**Recommendation about Hydrological Data Management**

Observed hydrological data including water level, discharge, and rainfall is valuable information for the establishment of an integrated water management plan, flood control, irrigation planning and so on. The issues on data management noticed through the Study are as listed in the following table.

| No. | Issues | Recommendations |
|---|---|---|
| 1 | Status of Hydrological Station<br>The location of some rainfall gauging stations is not correct and the working condition (working or not-working) is unclear, which hinders the planning of flood control and other related projects. | To conduct site survey for all stations and find the current situation, not only the exact location (latitude/longitude), but also the elevation at site shall be measured. It is desired that official RID benchmarks shall be established near the hydrological station by reference to first-class benchmark defined by RTSD. Especially, stations near estuary should require considerable attention, because the elevation of water level gauge may be lowered by ground subsidence. |
| 2 | Data Collection System<br>It seems that there is room to improve the data collection system. Mainly, the RID Hydro Center maintains and collects observed data/information and posts them in their website. However, the frequency of update depends on the Hydro Center and information is not always updated. Besides, latest data is not always sent to the headquarters. | Observed data should be managed in an integrated fashion in the headquarters. The data collection system shall be reviewed and a technical guideline on data collection shall be prepared and distributed to provincial offices. In addition, periodical maintenance work on hydrological equipment should be done thoroughly. |
| 3 | Quality Control<br>Observed data could have a margin of error caused by mistake of recording data, trouble of equipment and so on. Observed data shall be examined carefully. | To keep/ensure high accuracy and reliability of observed data, they should be examined by comparison of historical data and cross-checking with related data.<br>Together with data collection, a technical guideline on data quality control should be prepared. |
| 4 | Image Recording during Flood Event<br>The more information on flood situation, the more effective and efficient is the formulation of a flood control plan, etc. | Moving images during flood events should be recorded and stored, because they are crucially important for understanding the hydraulic behavior of rivers and for establishment of the flood control plan.<br>It is desired that CCTV cameras shall be installed in major hydrological stations and recorded images be saved/stocked and shared with related agencies. River flow condition near the RID office should at least be recorded by digital video camera, etc. |
| 5 | Cross-Section Survey<br>The planning of water management such as flood control plan, water resources and so on should be studied considering latest natural condition. | River cross section could be changed by river improvement works, land development, etc. In Lower Chao Phraya river basin, the construction of road dyke surrounding the economically important zone has been carried out by DOH and DOR, and this would change flow regimes and inundation conditions during the rainy season. Therefore, the river cross-section should be measured periodically and the transition of river shape should also be checked, especially in Chao Phraya River after the confluence of Noi River where a deep river bed erosion occurred which could develop more after completion of the road dyke. |

**Recommendation about Hourly and Daily Flow Capacities in the Lower Reaches**

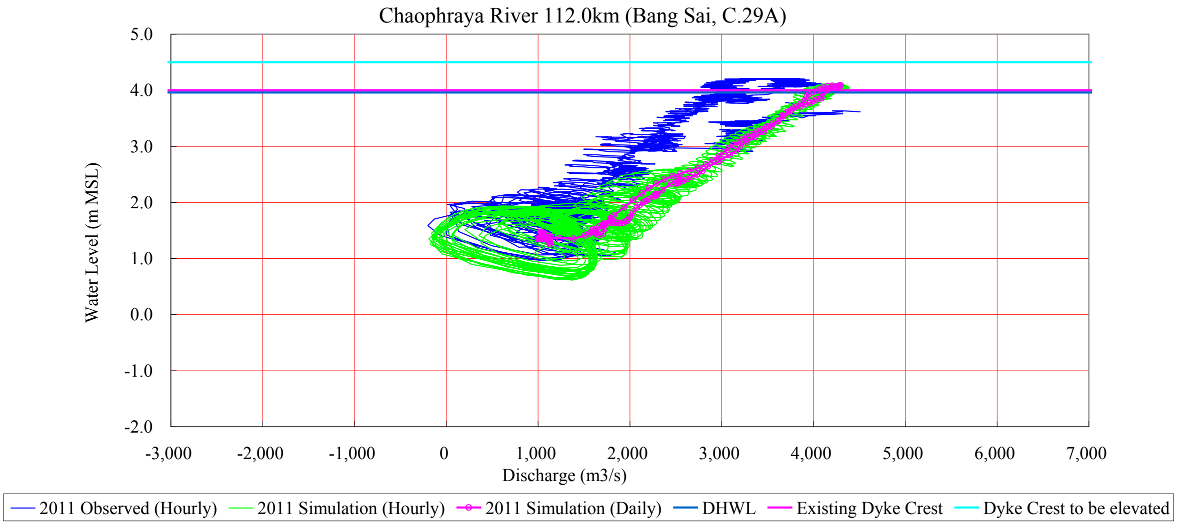
In addition, hourly and daily flow capacities in the lower reaches of the Chao Phraya River should be surveyed and clarified. During the 2011 flood, the recorded daily peak flow discharge of 3,900$m^3$/m at Bang Sai indicate that there was no damage caused by overflow of water in the lower reaches of the Chao Phraya River. Since the lower reaches of the Chao Phraya River is subject to tidal action, the recorded data in 2011 was based on the hourly automatic measurement of H-Q by H-ADCP (Horizontal Acoustic Doppler Current Profiler). However, although the river width at Bang Sai is more than 500m, the maximum range of this H-ADCP is 300m only, so that it is difficult to conclude whether or not this recorded data is correct. Therefore, continuous measurement by the V-ADCP (Vertical Acoustic Doppler Current Profiler) during flood is recommended in order to clarify hourly and daily flow capacities in the lower reaches of the Chao

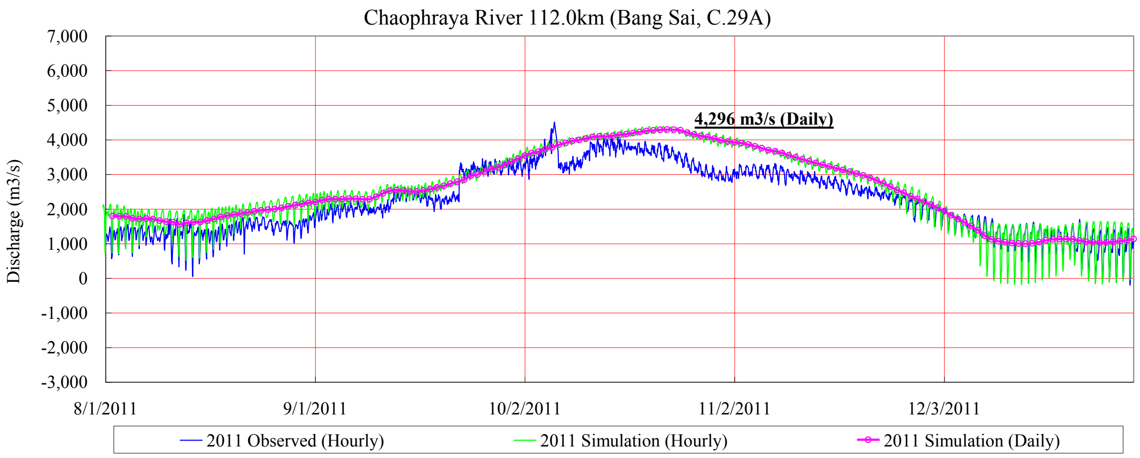
Phraya River. Clarification of the maximum hourly and daily flow capacity in the lower reaches considering tidal action is one of the most important values for evaluation of flood risk.


**Figure 7.2.1 River Surveyor M9 (V-ADCP) prepared by RID**

The following figures show the results of simulation. During the 2011 flood with dyke elevating by DOH and DOR, the daily peak flow discharges at Bang Sai (112km from river mouth), at TC12 (59km from river mouth), at 20km from river mouth and at the river mouth have been simulated as about 4,300$m^3$/s, 4,320$m^3$/s, 4,440$m^3$/s and 4,490$m^3$/s, respectively. At this time, hourly peak water elevation is 4.1m MSL, 2.9m MSL, 2.2m MSL and 1.9m MSL, respectively.

On the other hand, the crest elevation of existing parapet wall at TC12, at 20km point and at the river mouth is 3.0m MSL, 2.5m MSL and 2.0m MSL, respectively. It means the river water level is still lower than the crest elevation of parapet wall around Bangkok.



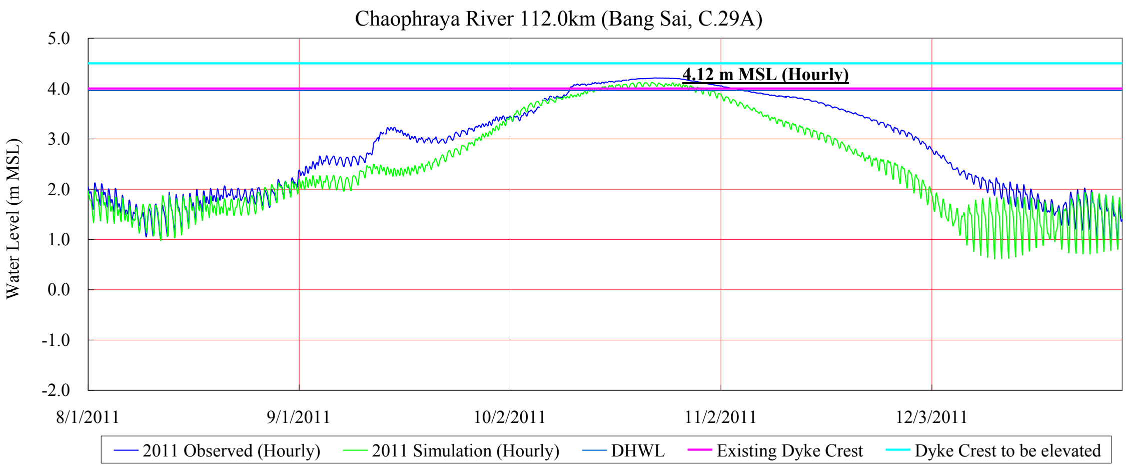




**Figure 7.2.2 Water Level and Discharge at 112km Point from River Mouth (Bang Sai, C29A)**

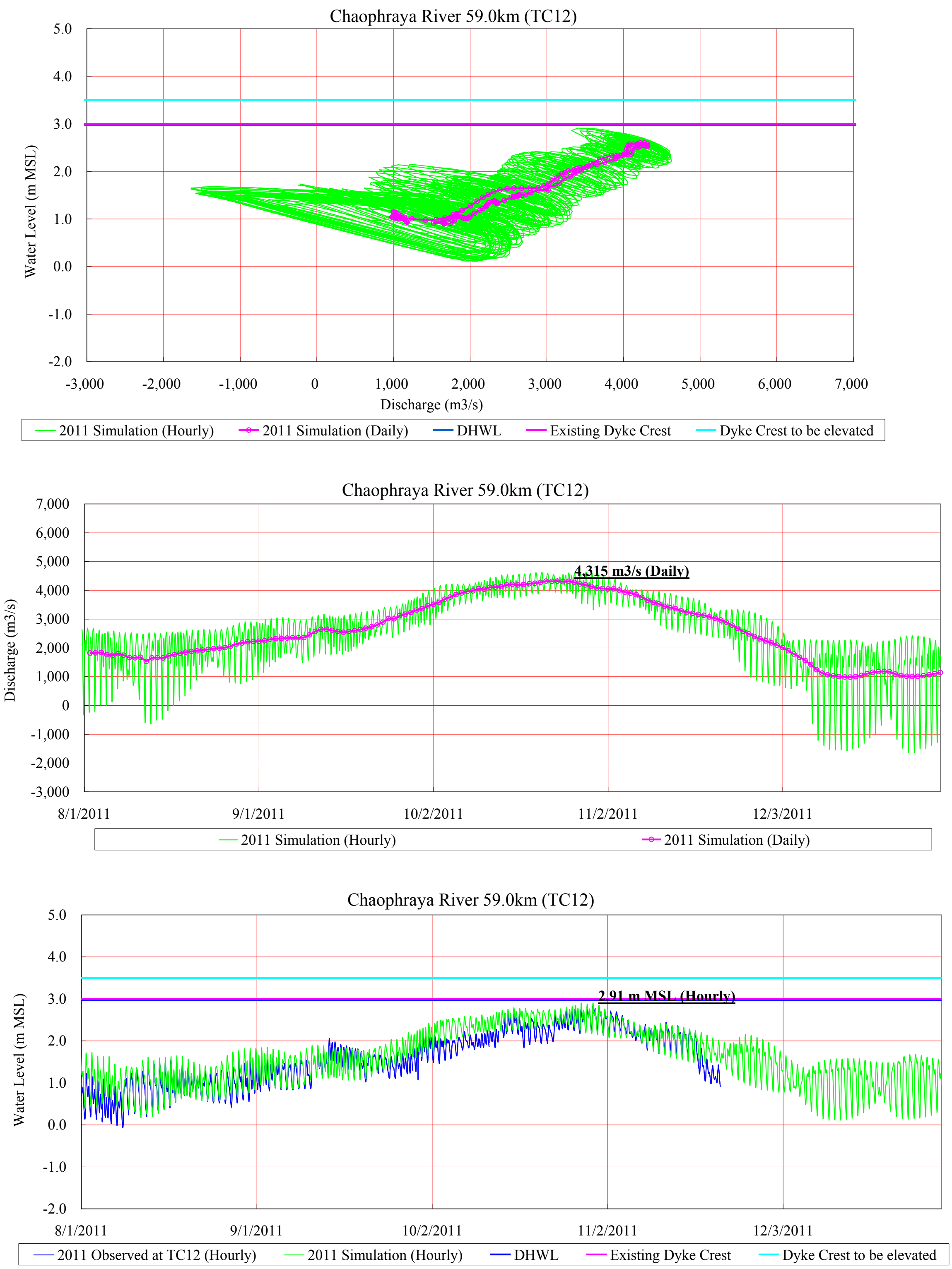
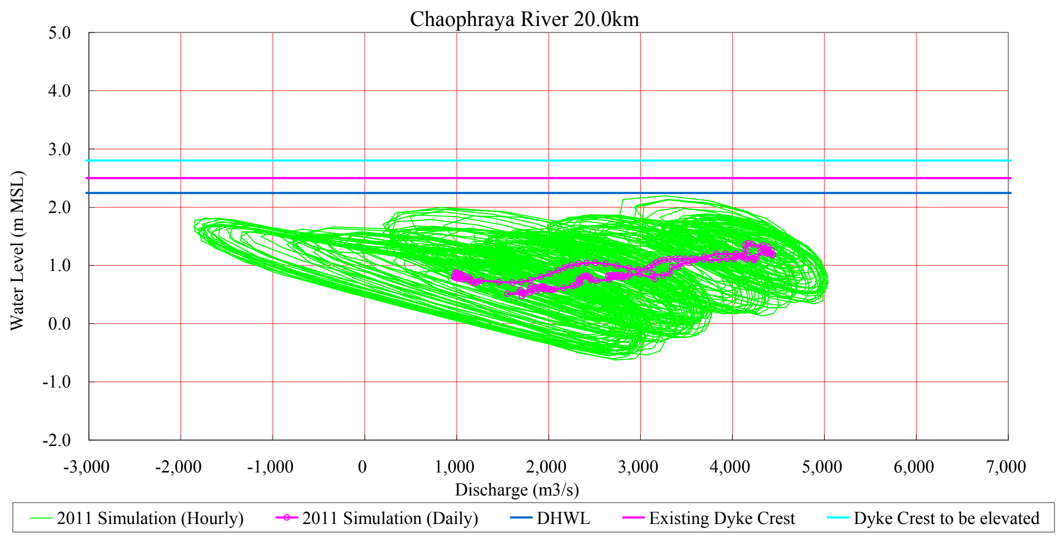
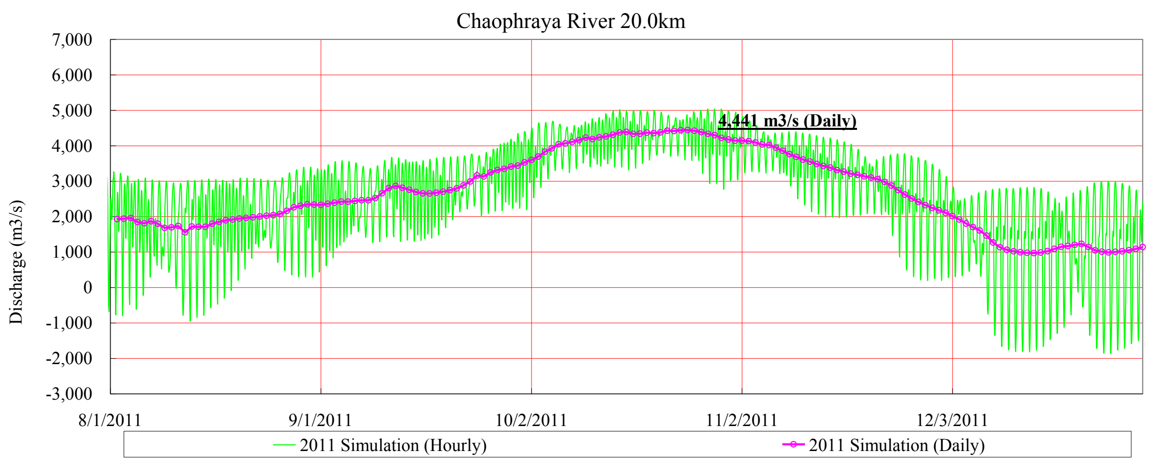



**Figure 7.2.3 Water Level and Discharge at 59 km Point from River Mouth (TC12)**



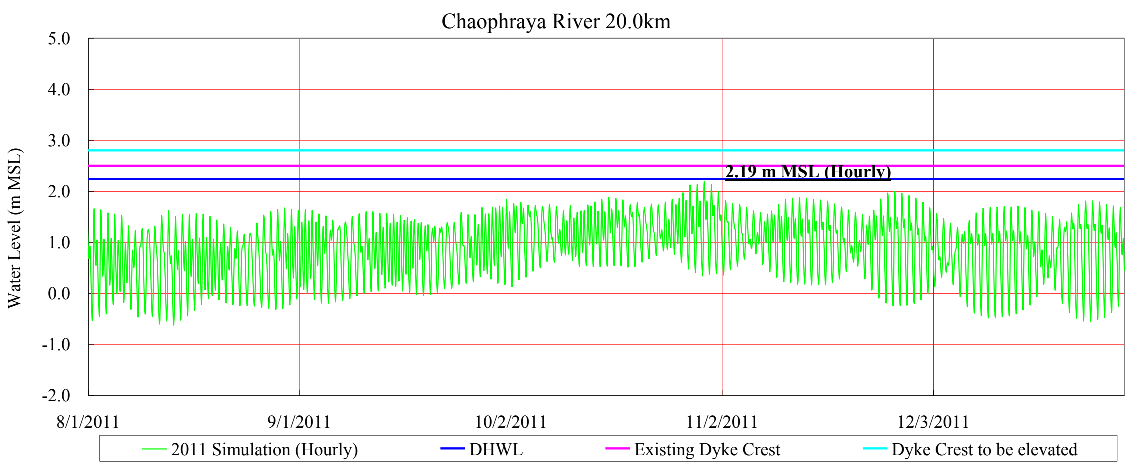
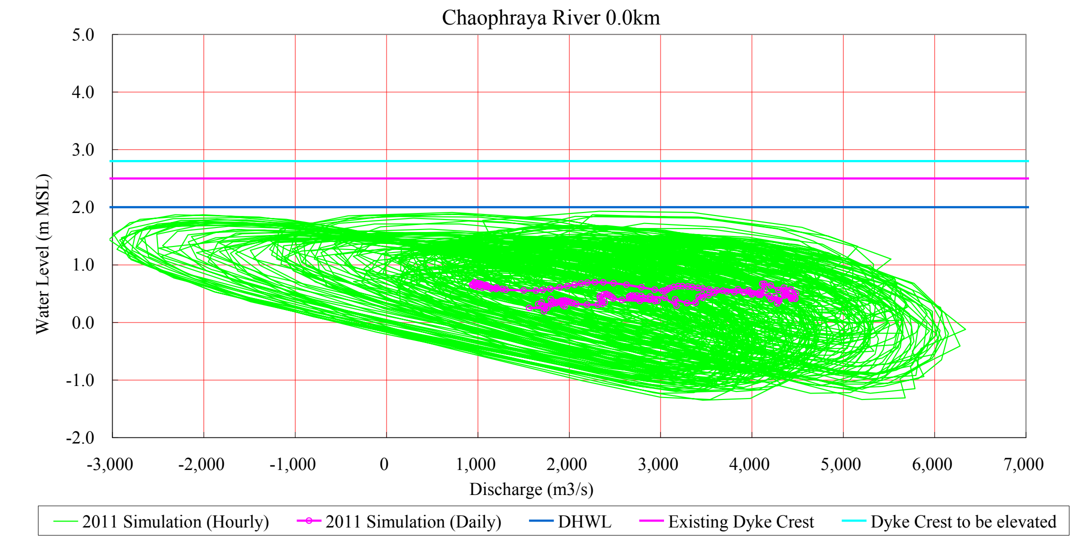
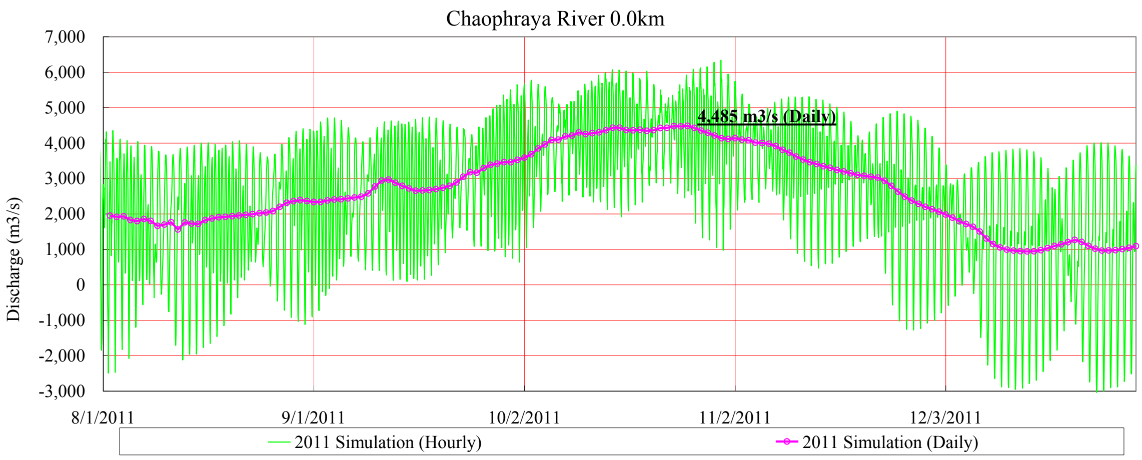




**Figure 7.2.4 Water Level and Discharge at 20km Point from River Mouth**



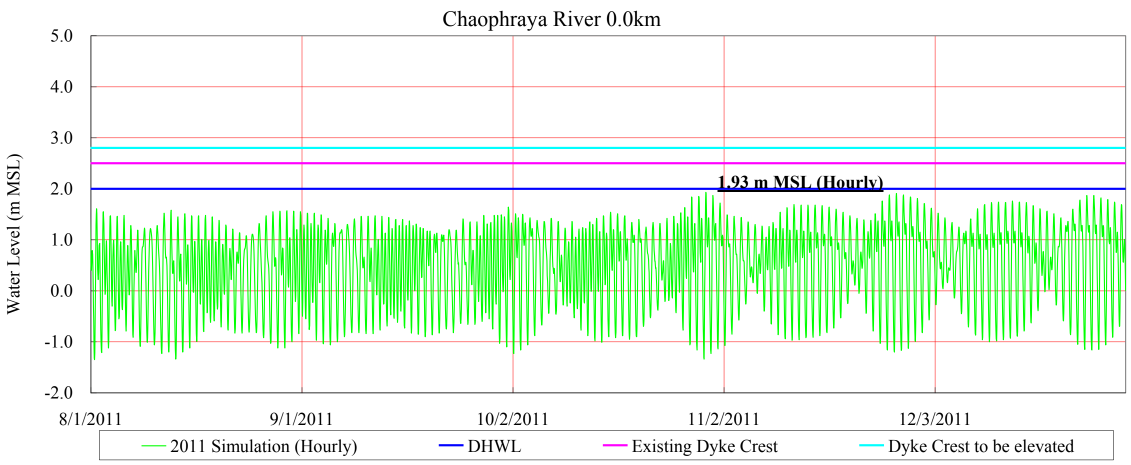




**Figure 7.2.5 Water Level and Discharge at River Mouth**

*Annex 1*

*Executive Summary*
*distributed in the Final Seminar*
*held on June 20, 2013*

# EXECUTIVE SUMMARY
# OF
# COMPREHENSIVE FLOOD MANAGEMENT PLAN FOR THE CHAO PHRAYA RIVER BASIN IN THE KINGDOM OF THAILAND


**OFFICE OF NATIONAL ECONOMIC AND SOCIAL DEVELOPMENT BOARD (NESDB)**

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

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

**JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)**



**June 2013**

# Preface

The prolonged flood in Thailand 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, in collaboration with NESDB, RID, DWR and other related agencies, has been conducting two flood management projects; namely, the "Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin" and the "Project for Flood Countermeasures for Thailand Agricultural Sector". These projects respectively consist of three components:

(1) Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin

| | |
|---|---|
| Component 1: | Upgrade of "the Flood Management Plan" with creating a new precise topographic map. |
| Component 2: | Urgent rehabilitation works; installing new water gates and elevating Route 9. |
| Component 3: | Improving flood information system and development of Flood Forecasting System. |

(2) Project for Flood Countermeasures for Thailand Agricultural Sector

| | |
|---|---|
| Component 1: | Reproduction of pastures |
| Component 2: | Rehabilitation and reinforcement of irrigation facilities |
| Component 3: | Guideline for disaster resilient agriculture and agricultural community |

Each component has made steady progress, and this document presents a summary of the Flood Management Plan that has been formulated under Component 1 of the Project for the Comprehensive Flood Management Plan.

**The Flood Management Plan**
**for the Chao Phraya River Basin in the Kingdom of Thailand**

**Executive Summary**

Table of Contents

## 1. Flood Management Policy in Thailand

**Goal**

**To promote sustainable economic growth by reducing flood risk and exploiting floodwater as water resource through proper Flood Management.**

People in Thailand have long been living in flood-prone areas to easily secure water for agriculture. The wisdom of avoiding serious damage induced by floods and exploiting floodwaters for cultivation has been a great boon to the people of Thailand.

Thailand has achieved a rapid economic growth in the recent years and, consequently, the urban areas have dramatically expanded to the flood-prone areas. With the economic growth, the country seems to concentrate on expanding areas for urbanization and pay less attention to the wisdom of living with floods.

On top of that, the extensive flood in 2011 harshly attacked the urbanized low-lying areas and caused heavy economic damage by disrupting industrial production for several months. The damage influenced not only the Thai but also the global economy.

Since most developed countries have faced similar problems associated with haphazardly spreading the city area and increasing the vulnerability to floods, lots of experiences and lessons learned could be utilized for the protection against floods. In particular, it is certain that Flood Management is essential to promote sustainable economic growth with the reduction of flood risk and at the same time exploit floodwaters for agricultural use.

The Flood Management Policy in Thailand aims at clearly showing the right direction of flood management to be executed. The Policy consists of six (6) principal elements, namely:

(i) **To integrate all of the activities implemented by the respective organizations concerned in the whole river basin**;

(ii) **To maintain a harmonious balance between flood control and water utilization**;

(iii) **To control inundation**;

(iv) At the planning stage of countermeasures, **to seek the best mix of structural and nonstructural countermeasures**;

(v) At the ordinary operation stage, **to set the proper operation rules for flood control facilities and land use regulations with due consideration on extreme events**; and

(vi) At the emergency stage, **to fulfill the responsibility of each individual, community, private firm, NGO and governmental organization.**

(i) **To integrate all of the activities implemented by the respective organizations concerned in the whole river basin.**

There are lots of organizations in the national government, local governments and NGOs, which are conducting various flood-control/fighting activities. To maximize the effect of these activities, it is crucial to: (a) well integrate all of the flood control/fighting activities including flood mitigation measures and proper evacuation; (b) always seek the best combination of activities in the whole river basin; and (c) well coordinate all of the organizations concerned.

(ii) **To maintain a harmonious balance between flood control and water utilization.**

Floods may induce heavy damage, but can provide water resources for agriculture. The flood management plan should focus on not only discharging floodwaters quickly into the sea, but also storing water as much as possible.

(iii) **To control inundation.**

Since basin inundation would be inevitable even after the implementation of major countermeasures, it is crucial to seek solutions to minimize flood damage in inundated areas and to maximize the benefit induced by inundation. In that case, it is imperative to limit the expected area of inundation; otherwise, heavy damage will recur.

(iv) At the planning stage of countermeasures, **to seek the best mix of structural and nonstructural countermeasures.**

Generally, the methodological principles of disaster prevention/mitigation are: (i) not to locate the residents/industries in dangerous places; (ii) to counter the inundation phenomena by implementing disaster prevention facilities; and (iii) to evacuate from hazardous areas before disaster occurs. These three countermeasures supplement each other. The best mix of structural and nonstructural measures is to be sought.

(v) At the ordinary operation stage, **to set the proper operation rule for flood control facilities and land use regulation with due consideration for extreme events.**

Floods occur every year, but not all of the floods cause heavy damage. It may not be necessary to perform emergency management in most years, but normal operation is needed every year. To manage ordinary floods, the proper operation rule for flood control facilities should be determined beforehand and followed during floods. To avoid unnecessary damage even by ordinary floods, land use regulations should be implemented.

Before extraordinary events occur, it would be difficult to predict whether or not the forthcoming event will be excessive. Therefore, both ordinary and extreme floods are to be considered in formulating the operation rule for facilities and land use regulations.

(vi) At the emergency stage, **to fulfill the responsibility of each individual, community, private firm, NGO and governmental organization.**

In actions for damage reduction, individuals, communities, private firms, NGOs and government organizations should fulfill their responsibilities in a collaborating manner. The combination of Self-help, Mutual-help, and Public--help can minimize damages and enable prompt recovery from disasters.

Self-help is to protect oneself by preparing against disasters and evacuating. Mutual-help is to help each other or to cooperate with people. Public-help is a support provided by government organizations, including construction of structural measures.

The government cannot play all the roles, but can support local societies and individuals to play their roles.

## 2. Target

The target scale of flood to formulate the Flood Management Plan for the Chao Phraya River Basin is 100-year return period. The area to be protected against flood is also determined.

### 2.1 Design Flood

Since most metropolitan cities in the Asian monsoon region have similar target scales ranging from 100 to 200-year return period to prevent flood damage, it is appropriate to set the 100-year return period of design flood as the current target to be achieved.

Since the 2011 Flood caused tremendous damage in the whole Chao Phraya Basin, the Plan should also consider accommodating the 2011 Flood, that is, the Plan should approximately be the same scale as a 100-year return period flood as shown in the rainfall analysis.

**Table 1 Evaluation of 2011 Flood Scale**

| Evaluation Item (Annual maximum) (N is number of samples) | Probability of return period: Nakhon Sawan (C.2) [C.A 105,000km$^2$] | | Probability of return period: River Mouth (whole river basin) [C.A 162,000km$^2$] | | Remarks |
|---|---|---|---|---|---|
| | Value | Return period | Value | Return period | |
| Average rainfall watershed (mm/6month) ($N$ = 51) | 1,483 | 1/141 | 1,390 | 1/100 | 6 month-maximum rainfall is employed since it contributes to large flood. |
| Peak discharge (m$^3$/s) ($N$ = 56) | 6,587 | 1/70 | - | - | To estimate a natural runoff (uncontrolled by facilities), the impounded water in Bhumibol and Sirikit dams was added to the observed discharge at Nakhon Sawan. |
| Yearly water volume (MCM) ($N$ = 55) | 55,570 | 1/127 | - | - | |
| Overflow volume (MCM) ($N$ = 44) | 15,154 | 1/102 | - | - | In addition, to evaluate the probability of actually-occurred scale of inundation at downstream of C.2, probable analysis with overflow volume (beyond 2,500m$^3$/s) was conducted. |

* Above calculation was conducted by using “hydrological statistics utility ver. 1.5” released by Japan Institute of Construction Engineering, November 2003.

## 2.2 Areas to be Protected

Bangkok and its vicinities in the east side of the Tha Chin River and the southern part of Pa Sak River in Ayutthaya have been selected as the flood protection area. The Department of Highway (DOH) and the Department of Rural Road (DOR) have started the works to heighten the elevation of the surrounding roads and road embankments. Since these works have been considered as the existing conditions for this Study, they should be one of the criteria for selecting the optimum combination of projects to reduce the risk of dyke-breach in the flood protection area.

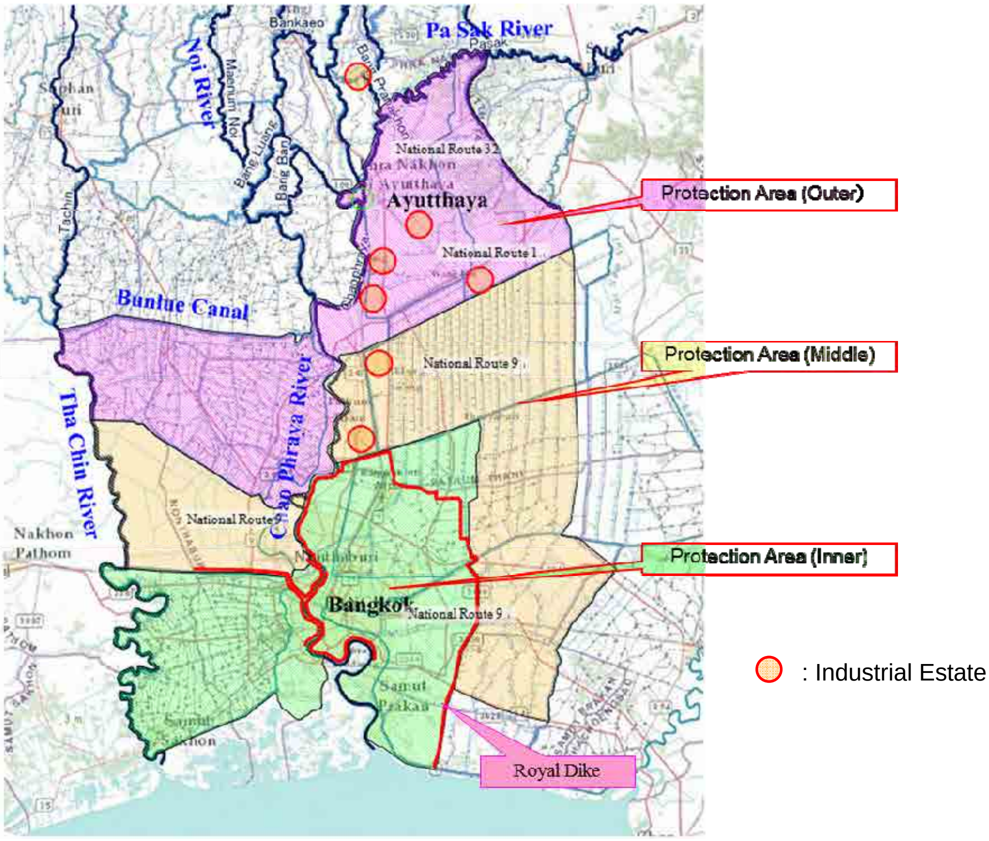



**Figure 1 Priority Protection Areas (Source: "Waterforthai" Website)**

**Picture 1 Areas Inundated during 2011 Flood**

## 3. Proposed Combination of Countermeasures

More than ten (10) scenarios have been simulated after newly developing a basin-wide hydrological model incorporating the new topographical map. It has been concluded that the **Ayutthaya Bypass Channel and Outer-Ring Road Diversion Channel** in combination with other structural and nonstructural measures such as efficient operation of existing dams and river channel improvement works are the most cost-efficient and significantly effective to protect the Lower Chao Phraya River Basin.

### Proposed Combination 1

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500 $m^3/s$)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400 $m^3/s$)
5) Flood Forecasting

### Proposed Combination 2

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity : 1,000 $m^3/s$)
3) River Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity : 1,400 $m^3/s$)
5) Flood Forecasting

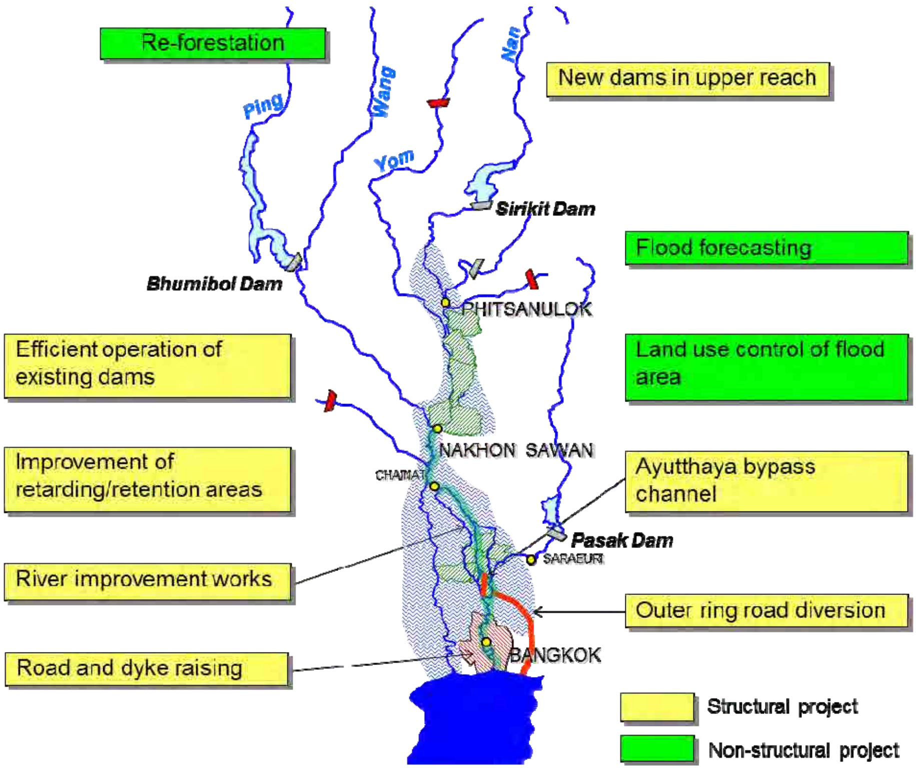



**Figure 2 Countermeasures Reviewed in the Study**

According to the simulation results, the east or west diversion channel with capacity of 1,500$m^3$/s from Nakhon Sawan to the Gulf of Thailand will work less effectively than the above combination, while the project cost of this 250 km long diversion channel will be more than double with a wider range of social and environmental impacts.

### 3.1 Effective Operation of Existing Dams

The operation of the existing dams during the 2011 flood was so effective to mitigate flood damage, because the Bhumibol and Sirikit dams stored 12 billion cubic meters of floodwater. Since the dam operation rule was modified in February 2012, dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purpose. It is proposed that reservoir level should follow the new upper rule curve until the end of July, and from August, flood discharge should be stored in reservoir with maximum outflow of 210 $m^3$/s for Bhumibol Dam and 190 $m^3$/s for Sirikit Dam. If the proposed dam operation rule was applied during the 2011 flood, the peak discharge at Nakhon Sawan could be reduced by 400 $m^3$/s.

The concept of new operation rule is as follows.

- Following the proposed new operation rules (Upper Rule Curve), the inflow is going to be released from May 1 to August 1 to maintain the fixed reservoir water level.
- During flood season, which is from August 1 to November 1, the proposed design maximum discharges, which are 210 $m^3$/s at Bhumibol Dam and 190 $m^3$/s at Sirikit Dam, are released. If the storage volume is less than the recommended New Upper Rule Curve, the inflow should be stored in the reservoir. The released discharge shall not be less than the minimum discharges of 8 $m^3$/s at Bhumibol Dam and the 35 $m^3$/s at Sirikit Dam.
- When the dry season (From November 1 to April 30 next year) starts, the stored water is released based on the schedule of the required water supply volume.

**Table 2 Proposed Operation Rules at Bhumibol Dam and Sirikit Dam**

| Dam | Maximum Outflow | | Storage Volume in May 1 (includes Sedimentation Volume) | Water Level in May 1 |
|---|---|---|---|---|
| | May to July | August to October | | |
| Bhumibol | In = Out | 210$m^3$/s | 6,795MCM | 233.8m |
| Sirikit | Basically In = Out | 190$m^3$/s | 3,911MCM | 135.6m |

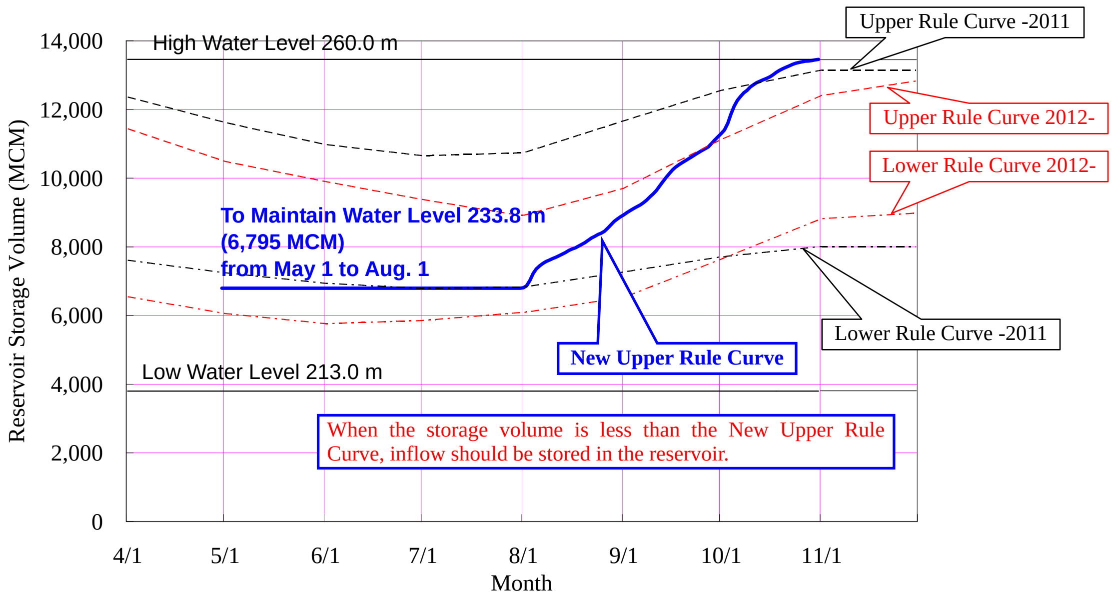



**Figure 3 New Upper Rule Curve of Bhumibol Dam**

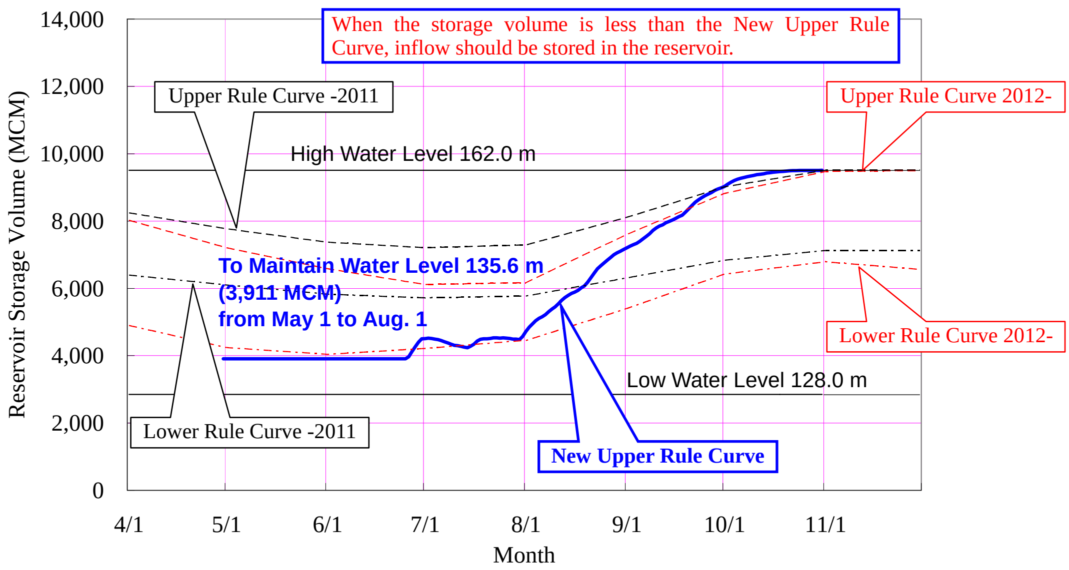



**Figure 4 New Upper Rule Curve of Sirikit Dam**

### 3.2 Outer Ring Road Diversion Channel

The diversion channel has a certain effect in reducing water levels of: (i) the Chao Phraya River from Ayutthaya to Bangkok; and (ii) the downstream of Pa Sak River. Hence, it is very effective in reducing the risk of dyke breach along the areas to be protected.

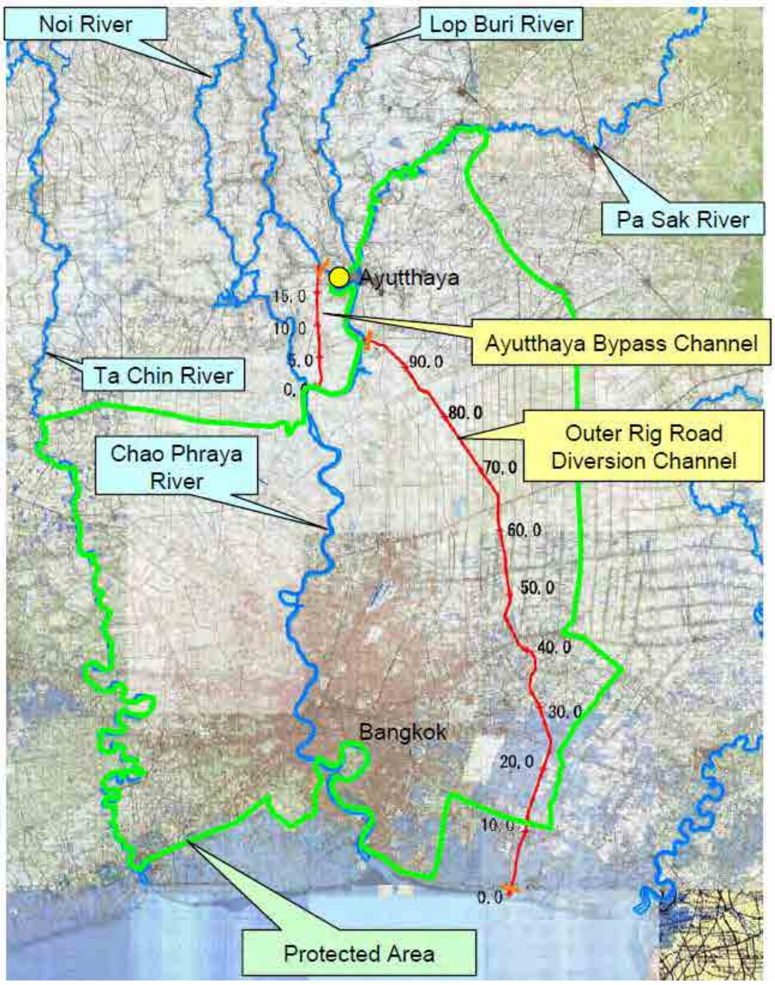



**Figure 5 Proposed Outer Ring Road Diversion Channel**

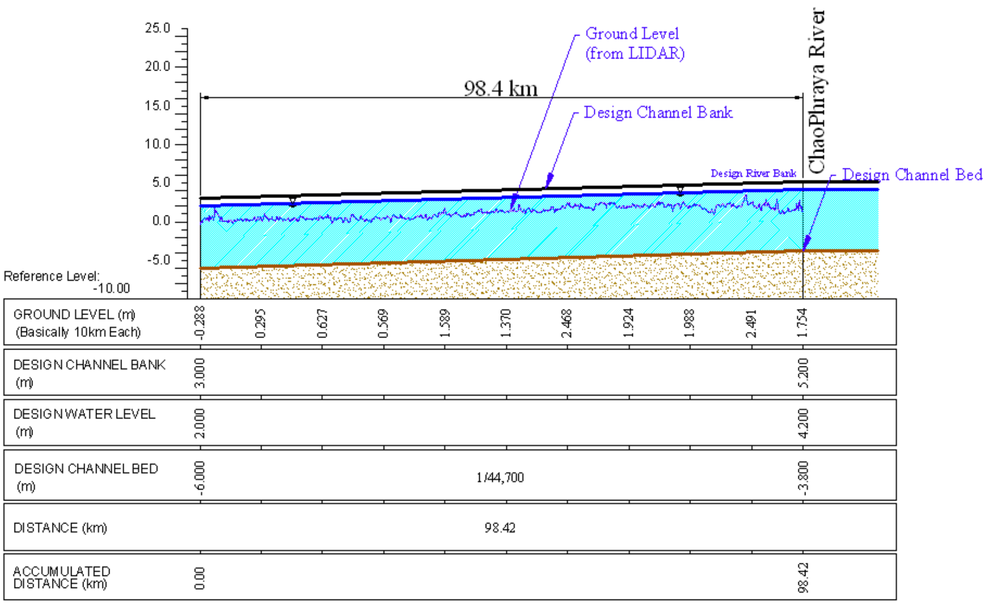
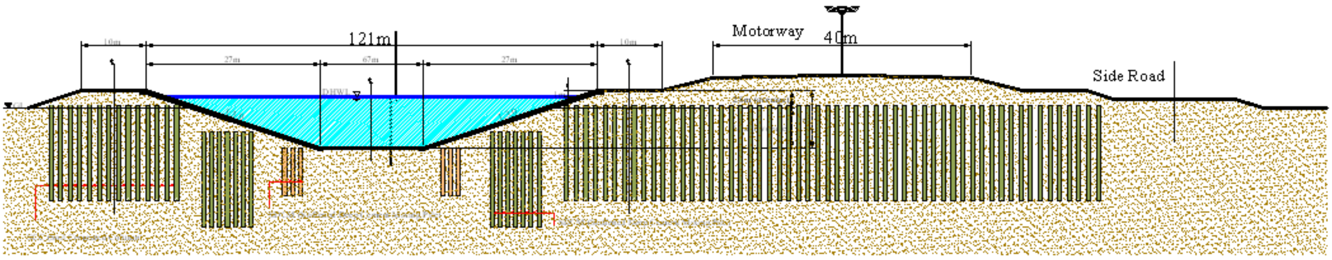
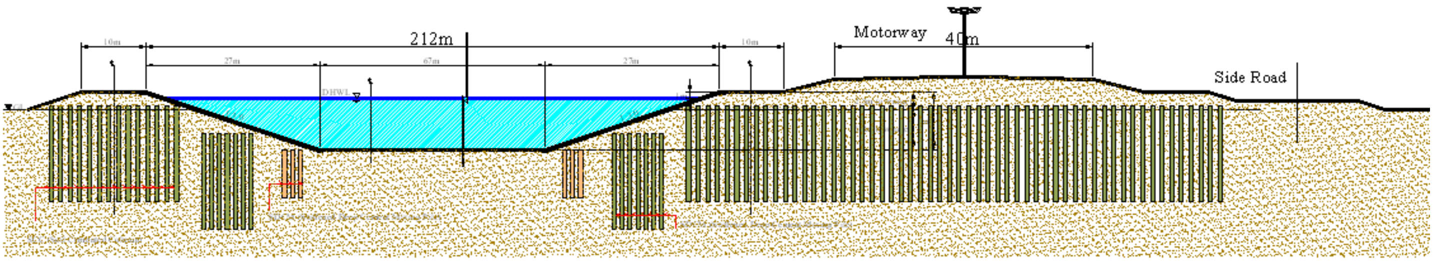



**Figure 6 Longitudinal Section of Outer Ring Road Diversion Channel**




**(Capacity: 500 m³/s)**




**(Capacity: 1,000 m³/s)**

**Figure 7 Cross Section of Outer Ring Road Diversion Channel** [1]

## 3.3 River Channel Improvement

### (1) Definition of River Channel

It has been considered in the Study that the channel of rivers lie between secondary dykes, not between water edges along primary dykes, since ordinary widths of stream cannot accommodate floodwater. It is, therefore, crucial that the lower and/or weaker stretches of secondary dykes should be identified and strengthened to prevent uncontrolled inundation.

If dyke raising work is conducted based on the primary dyke alignment, a very high levee would be required (red line), because the river area enclosed with primary dyke is much smaller than secondary dyke.

[1] Cost for Construction of Motorway and Side Road is not included in this study.

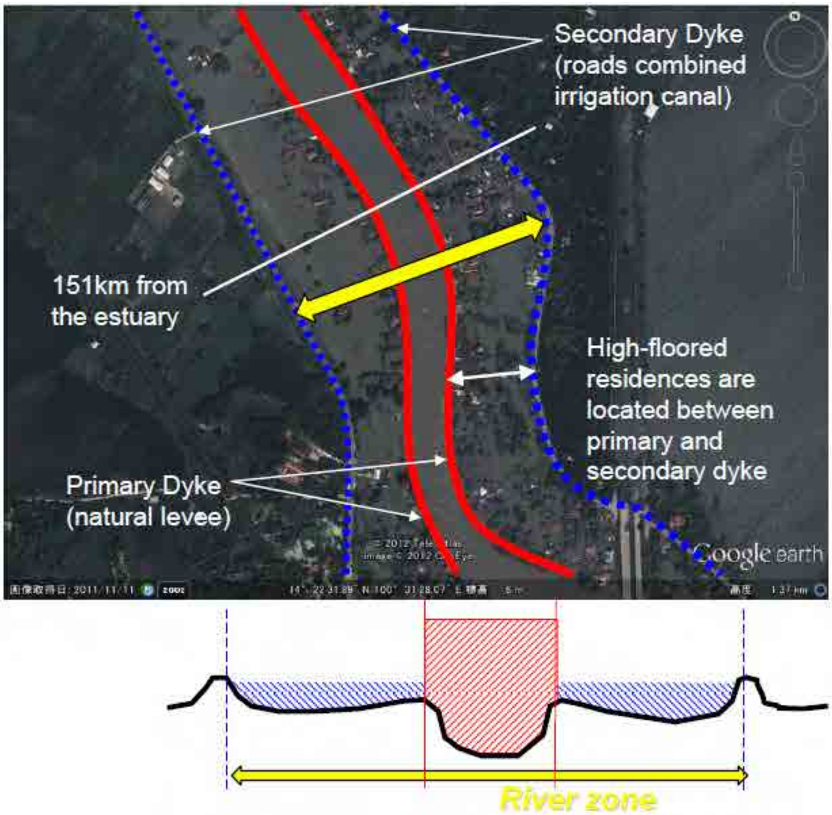



**Figure 8　Primary and Secondary Dykes**

### (2) River Improvement in Tha Chin River

Inundation volume and depth at right side of the Tha Chin River will increase due to the dyke heightening for protection of the economic zone. To increase discharge capacity at lower reaches of the Tha Chin River and to protect the economic zone, the following countermeasures are adopted:

i) Four (4) shortcuts are installed as follows:

   1) Shortcut 1 at Ngue Rai-Taiyawat (original: 11.2 km, shortcut: 2.0 km);

   2) Shortcut 2 at Hom Gret-Tha Tarad (original: 10.7 km, shortcut: 1.9 km);

   3) Shortcut 3 at Sam Phan-Krathum Ban (original: 21.5 km, shortcut: 4.9 km); and

   4) Shortcut 4 at Ban Paew (original: 5.1 km, shortcut: 1.2 km);

ii) Primary dyke or concrete parapet wall is newly constructed at left side from river mouth to 90 km point; and

iii) Secondary dyke at left side is elevated to “Design High Water Level plus Allowance” from 90 km to 141 km point.

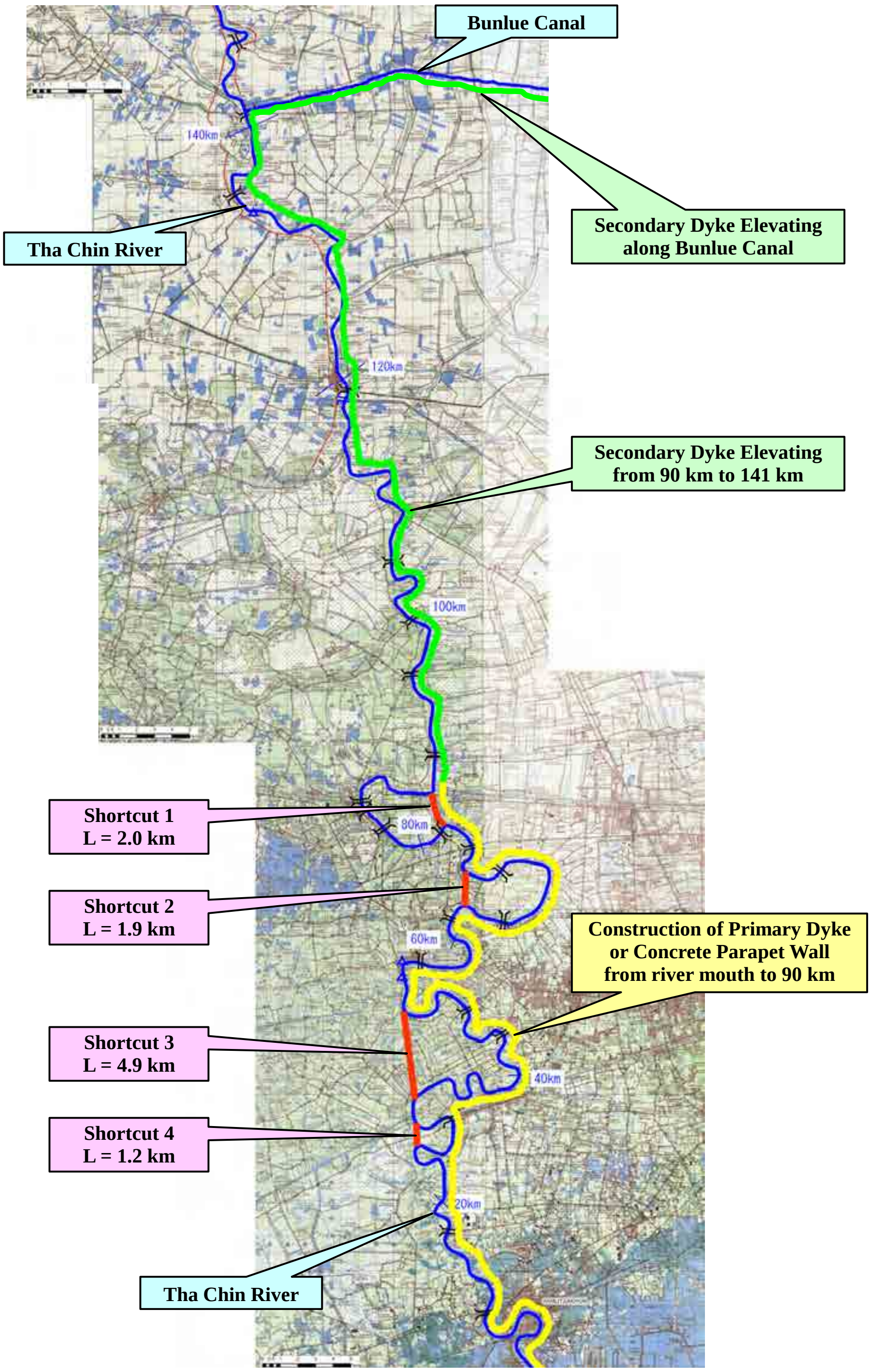



**Figure 9 River Improvement in Tha Chin River**

### 3.4 Ayutthaya Bypass Channel

The Ayutthaya Bypass Channel is one of the alternatives of river channel improvement works, because it is extremely difficult to widen the river channel in the stretch between Bang Sai and Ayutthaya. The bypass channel is planned to be constructed from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River. The bypass channel has an effect in lowering the water levels of: (i) the Chao Phraya River between Bang Sai and Ayutthaya; and (ii) the Pa Sak River, and should be effective to reduce the risk of dyke breach along the areas to be protected.

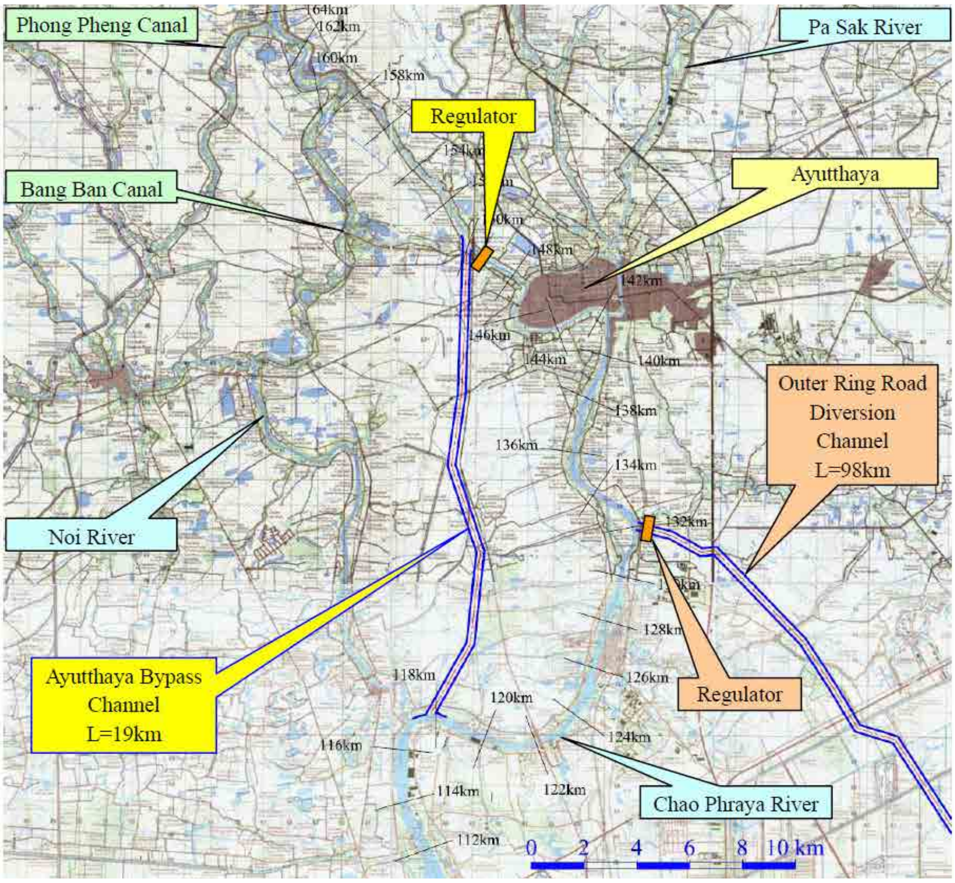



**Figure 10 Proposed Ayutthaya Bypass Channel**

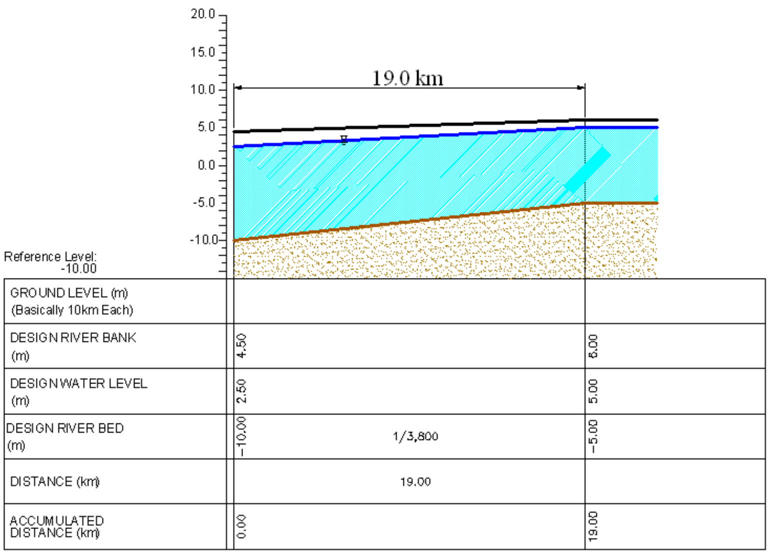



**Figure 11 Longitudinal Section of Ayutthaya Bypass Channel**

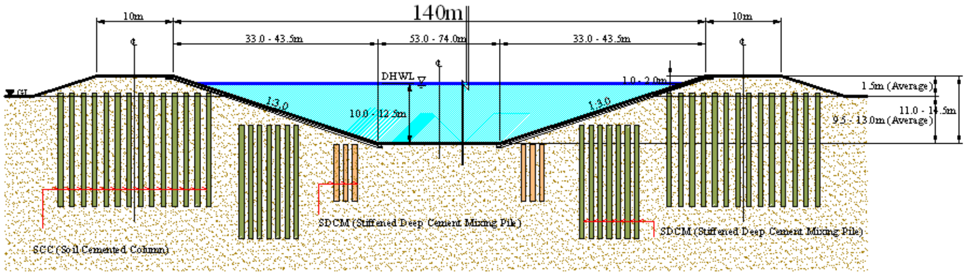


**Figure 12 Cross Section of Ayutthaya Bypass Channel (Capacity: 1,400 $m^3/s$)**

### 3.5 Habitual Inundation Area

Protecting the priority area in the Lower Chao Phraya River Basin by the combination of countermeasures proposed above should not increase flood damage potential in other areas except for some specific areas. In addition, flood damage resilience can be improved by the following activities. Some of these activities have been already materialized.

- Flood Management Information System
- Land use regulation and planning
- Appropriate intervention in the agricultural area

Reliable and timely information can reassure residents in the basin to continue economic activities. "The Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin" has already developed a flood forecasting system, which is available to the public through the internet.

#### 3.5.1 Controlled Inundation Area

By regulating land use appropriately, inundation with scale similar to the 2011 flood can be controlled. The prospective controlled inundation areas can be classified into five (5), depending on the flooding features. Based on this classification, the concrete land use plan could be developed and put into practice.

Type FS: Overflow water from river spreads and flows towards downstream resulting in relatively shallow inundation and shorter duration.

Type FL: Floodwater flows over through these areas and is blocked by the heightened road/embankment. Deeper inundation and longer duration than the 2011 flood would be observed near the southern border of the areas.

Type W: These areas are floodways for overflow water from Type FL areas and the west hilly areas.

Type M: These are swamp areas and floodwater stays throughout a flood season with deep inundation and long duration.

Type H: Small scale floods with shallow inundation depth and short duration come from the east hilly areas.

It will be inevitable to use many of the agricultural lands to store floodwater. However, strengthening the capacity for quick recovery can mitigate their damage and losses. "The Project for Flood Countermeasures for Thailand Agricultural Sector" is supporting and promoting this issue.

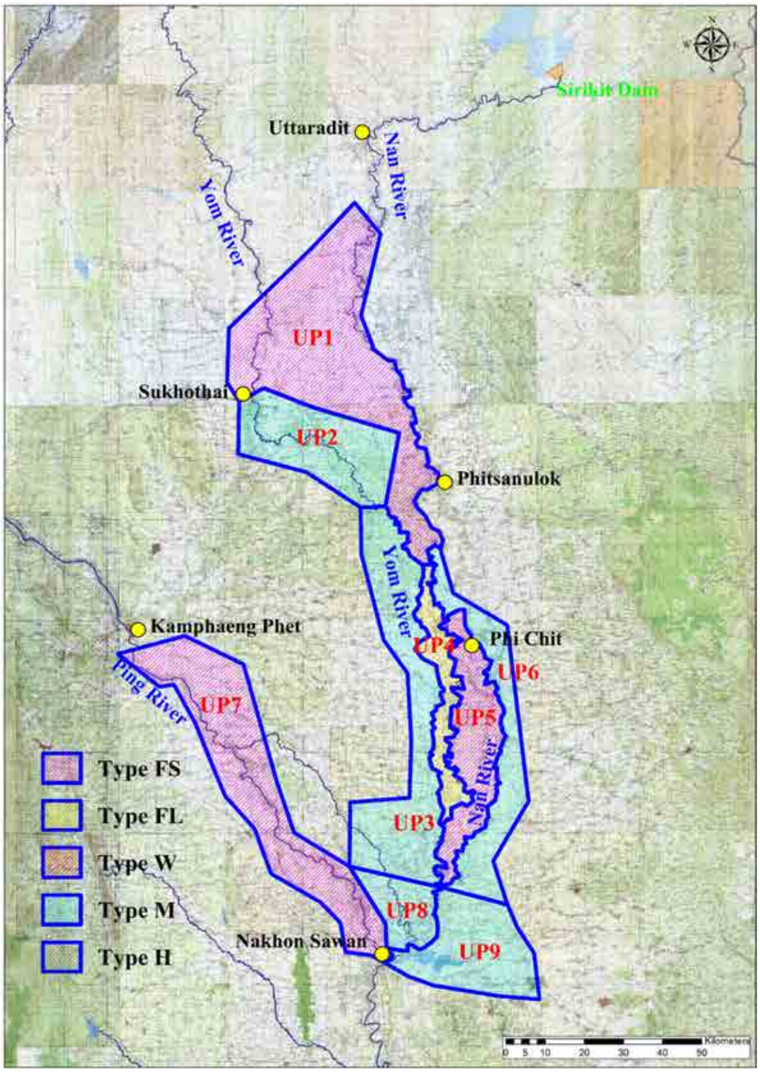



**Figure 13 Controlled Inundation Areas (Upper Chao Phraya)**

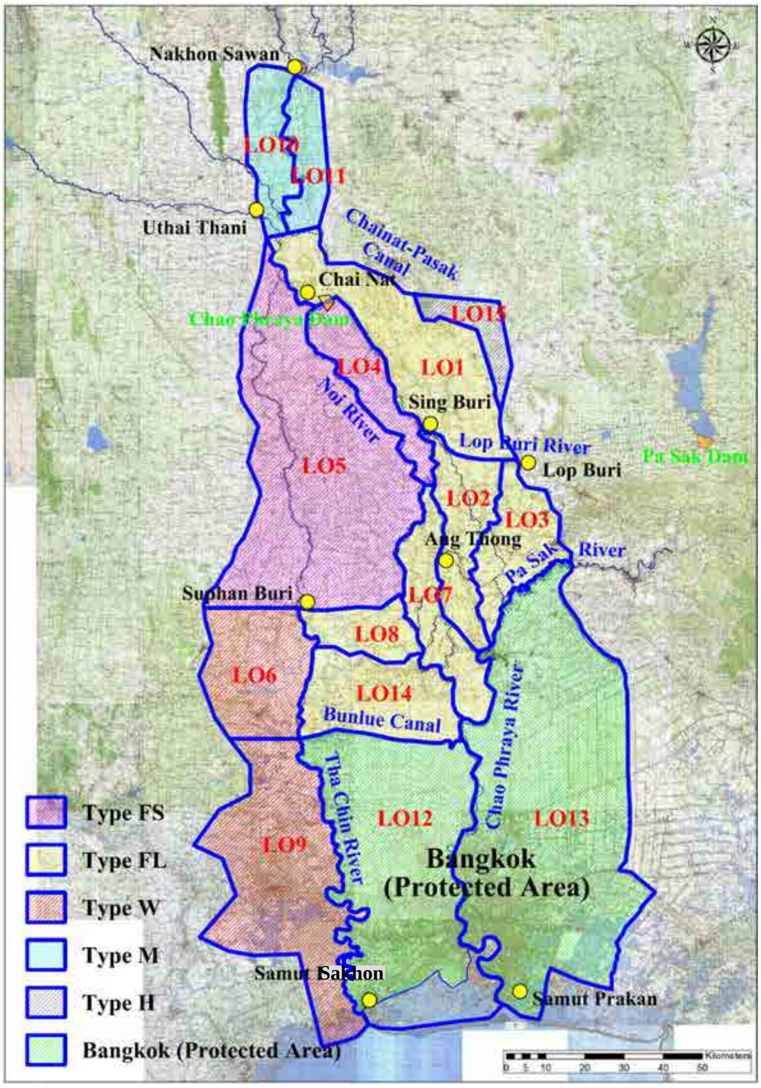



**Figure 14 Controlled Inundation Areas (Lower Chao Phraya)**

These low-lying areas have the important function of retarding floodwaters and reducing flood peaks downstream. Regardless of whether or not the proposed facilities are constructed, structural and nonstructural measures are required for the inundation area to maintain the function, to reduce flood disaster risks and to enhance people's living condition considering coexistence with floods. The following measures will be required:

1) Type FS

Structural Measures

- Strengthening measures for retention areas by the government.
- Dredging of drainage channels and lakes/marshes.
- Improvement of small-scale irrigation facilities (gates, weirs, etc.).

- Construction of community-based small-scale retention pond (controlled intake and discharge facilities, irrigation water supply in dry season).
- Strengthening of existing levees.

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Preparation of community based hazard map.
- Agricultural guidance like changing forms of farming schedule.
- Measures to secure feed for livestock.
- Improvement of flood information.

2) Type FL

Structural Measures

- Strengthening measures for retention areas by the Government.
- Construction of community-based small scale retention ponds (Controlled intake and discharge facilities, irrigation water supply in dry season).
- Dredging of drainage channels and lakes/marshes.
- Improvement of small scale irrigation facilities (gates, weirs, etc.).
- Strengthening of existing levees.
- Installation of drainage pumps (reduction of inundation depth and duration).

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Agricultural guidance like changing forms of farming schedule.
- Measure to secure income during inundation period (combined agriculture and fishery or aquaculture, etc.).
- Measures to secure domestic water supply for inundation period.
- Preparation of community based hazard map and land use control.
- Improvement of flood information.

3) Type W

Structural Measures

- Construction of community-based small scale retention ponds (controlled intake and discharge facilities, irrigation water supply in dry season).
- Dredging of drainage channels and lakes/marshes.
- Improvement of small scale irrigation facilities (gates, weirs, etc.).
- Strengthening and raising the existing levees.

- Improvement of main canal (increase of discharge capacity to Gulf of Thailand).
- Maintenance of canals (increase of drainage capacity to main canal).
- Installation of drainage pumps (reduction of inundation depth and duration).

Nonstructural Measures

- Compensation for farmland damaged by inundation.
- Agricultural guidance like changing forms of farming schedule, introduction of floating vegetable, etc.
- Measure to secure income during inundation period (combined agriculture and fishery or aquaculture, etc.).
- Measures to secure domestic water supply for inundation period.
- Measures to secure feed for livestock.
- Preparation of community based hazard map and land use control.
- Improvement of flood information.

4) Type M

Structural Measures

- Strengthening of existing levee surrounding low-lying mash area.

Nonstructural Measures

- Measures to maintain the current retarding function like land use control, etc.
- Improvement of flood information.

5) Type H division

Structural Measures

- Construction of community-based small scale retention ponds (controlled intake and discharge facilities, irrigation water supply in dry season).
- Strengthening of existing levees.

Nonstructural Measures

- Improvement of flood information.

### 3.5.2 Flood Management Information Plan

Further description of the Flood Management Information System is stated in “The Basic Plan on the Flood Management Information System” prepared by another JICA Study.

A summary of the project is given as follows:

## Basic Plan of Flood Management Information System of Thailand

Information is the most important factor in combining different fields of water resources management, including structural measures, emergency measures, raising awareness, etc.

A basic plan has been formulated for the flood management information system of Thailand, with most importance attached not to the sender of information, but to the receiver of information.

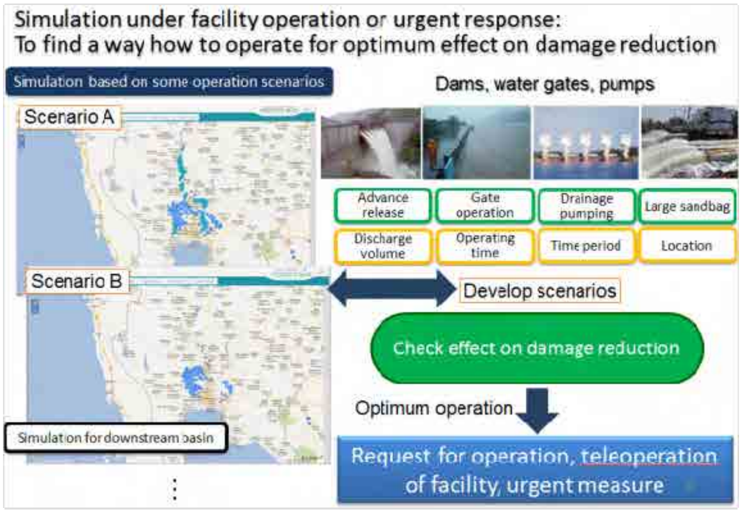
The plan consists of the following four chapters:

I. Current Status and Issues;

II. Function of Information in Flood Management;

III. Basic Strategies of Flood Management Information System Construction; and

VI. Specific Measures Development Plan of Flood Management Information System




**One of Specific Measures: Facility Operation**

Operation situations of major facilities (dams, major barrages and water gates) in the basin should be monitored together with flow rate information of rivers and water ways.

Facility operations should be effective by utilizing present water level and flow rate information.

Simulate downstream situation with dam water gate and pump operation, so that optimum selection of damage alleviation alternatives is made.

While various proposals have been made as part of the comprehensive flood countermeasures as of February 2013, the plan summarizes universally required items of the flood management information system of Thailand in the future which all proposing parties should consider: The plan does not prejudice in favor of any of such proposals.

## JICA/FRICS Flood Forecasting System

A prototype flood forecasting system was developed in September 2012, and information was provided to the registered monitors during the 2012 flood season. Through discussion with the related personnel of the Thai Government for practical application, necessary improvements were added, and, by January 2012, became widely open to the general public. A version with further functions added for experts of the government would be completed by May 2013.

Water-level/flow-rate and inundation areas are forecast, with RRI model or H08 model simulation based on the observed data (rainfall, water-level, and flow-rate) and meteorological forecast data of RID, DWR and TMD. Highly accurate inundation area is forecast by using detailed geographic data obtained by LiDAR data, and by calibrating with GISTDA's satellite images of inundation situations.

### 3.5.3 Solution for the Issue of Land Use Control

As mentioned in "1. Flood Management Policy in Thailand", basin inundation would be inevitable even after the implementation of major countermeasures. In accordance with the prospective controlled inundation area classified into five (5) categories, it is crucial to seek solutions to minimize flood damage by controlling unplanned urbanization in inundated areas and to maximize the benefit induced by inundation especially for agricultural use.

The land use control plan should be enforceable and decided based on each inundation situation of the five (5) categories.

#### (1) Concept of Land Use Control

Concept of land use control is given as follows:

Concept 1: To implement effective land use control as the minimum corresponding to frequent flood-prone areas including retention area in order to maintain and improve people's daily life and economic activities.

Concept 2: To promote land use in order to minimize flood damage to flood-prone areas in several decades to hundred years in terms of mitigation.

Concept 3: To implement measures to improve the quality of life of people living in serious flood-prone areas.

Concept 4: To create a system for performing under full coordination of related organization for implementation of the measures discussed below.

## (2) Specific Measures of Land Use Control

(a) Revision of Existing System

In areas at risk of inundation, control of land use should be applied to minimize flood damage depending on the characteristics of flooding. It is proposed that the control is collateral by revision or abolition of the provisions of each regulation of town planning promulgated as Ministerial Regulation.

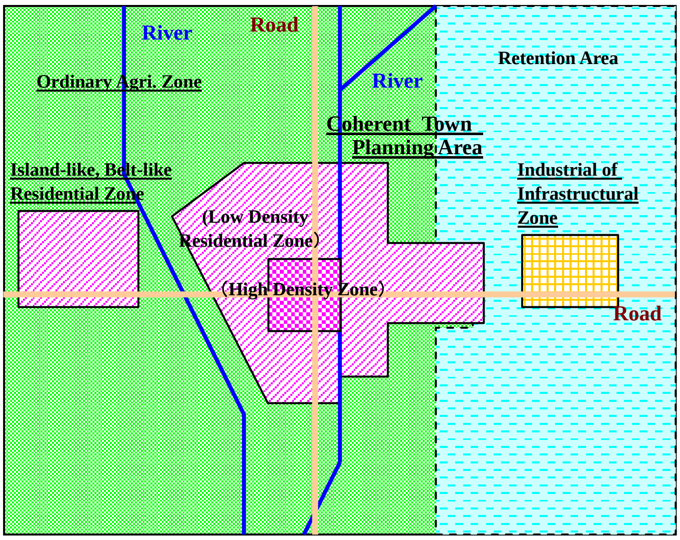



**Figure 15 Image of Land Use**

**Table 3 Contents of Specific Measures of Land Use Control**

| Category of Inundation Area | | Town Planning Area | Island-like, Belt-like Residential Zone | Island-like, Belt-like Industrial, Infrastructure Zone | Ordinary Agricultural Zone | New Designation |
|---|---|---|---|---|---|---|
| FS | Relatively shallow inundation and shorter duration | | Continuation of Current System | Continuation of Current System | Continuation of Current System | Continuation of Current System |
| FL | Deeper inundation and longer duration | | Allowed to flood; Uninhabit-able to ground floor | Basic Protection; Not allowed to residential and commercial | Basic Protection; Abolition of Exception Provision | Not allowed |
| W | Floodways for overflow water located west of protection area | Basic Protection; Continuation of Current System | Allowed to flood; Uninhabit-able to ground floor | Basic Protection Residential and accommod-ation not allowed | Allowed to flood Uninhabit-able to ground floor | Allowed to flood Uninhabit-able to ground floor |
| M | Swamp, deep inundation and long duration | | Allowed to flood; Uninhabit-able to ground floor | Basically Protection Residential and accommod-ation not allowed | Allowed to flood Abolition of Exception Provision | Not allowed |
| H | Small scale floods from the east hilly area | | Continuation of Current System | Continuation of Current System | Continuation of Current System | Continuation of Current System |

(b) New Measure for Land Use: Creation of Land Use Guideline

To further reduce flood damage, orientation on land use is to be undertaken in flood prone areas. It is proposed that this orientation on land use should be implemented with the formulation of a “Guideline of Land Use for Flood Mitigation” based on the features of flood area considering the backlash against the free use and disposal of land.

**Table 4 Scheme of Building Control in accordance with Features of Flooding**

| Category of Flood Area | | Scheme of Building Control | | | | | |
|---|---|---|---|---|---|---|---|
| | | Residential; Commercial | Industrial Infrastructure | Religious; Cultural; Educational | Agricultural | Public Service | Tourism; Recreational |
| FS | Relatively shallow inundation and shorter duration | △1 | △1 | ○ | ○ | ○ | ○ |
| FL | Deeper inundation and longer duration | × | △1 | △1 | △1 | △1 | △1 |
| W | Floodways for overflow water located west of protection area | △2 | △1 | △1 | △1 | △1 | △1 |
| M | Swamp, deep inundation and long duration | × | × | △1 | △1 | △1 | △1 |
| H | Small scale floods from the east hilly area | △1 | △1 | ○ | ○ | ○ | ○ |

Policy of Land Use Restriction:
○ Buildable as usual
△ Buildable conditionally,
Condition 1: With levee or raising of ground level
Condition 2: Uninhabitable to ground floor
× Not newly built, renovation

(c) Relocation of Land Use by using Existing Systems

The flood area covers most of the Chao Phraya River Basin with high density of residences extending linearly along the river. The measures to protect these areas from flood are:

- Protection of the area by structures such as levee or flood wall, etc.
- Relocation of entire community to the raised land to reduce the influence of flood

In this case, the application of existing systems of land readjustment can be carried out in accordance with the arrangement of parcels of land and the development of roads and other infrastructure.

(d) Enhancement of Coordination of Land Use

To secure cooperation in a particular flooding from the perspective of disaster risk reduction as a consultative body, the establishment of a "Coordination Committee of Land use in Flood-Prone Area" (tentative name) is assumed to work as an organization to consider policies related to land use of large scale, such as special economic zone, and to discuss land use under flood control measures in consideration of potential of floods.

Membership is assumed to consist of the Royal Irrigation Department (RID), the Department of Public Works and Town and Country Planning (DPT), the Department of Rural Roads (DOR), the Department of Highway (DOH), the Economic and Social Development Board (NESDB), the Ministry of Industry, etc. Matters of coordination are assumed as the following:

- Positioning of area based on flood potential
- Vulnerability assessment in predicted inundation
- Effect of mitigation on Land Use
- Advice to the measure of flood based on the guideline, etc.

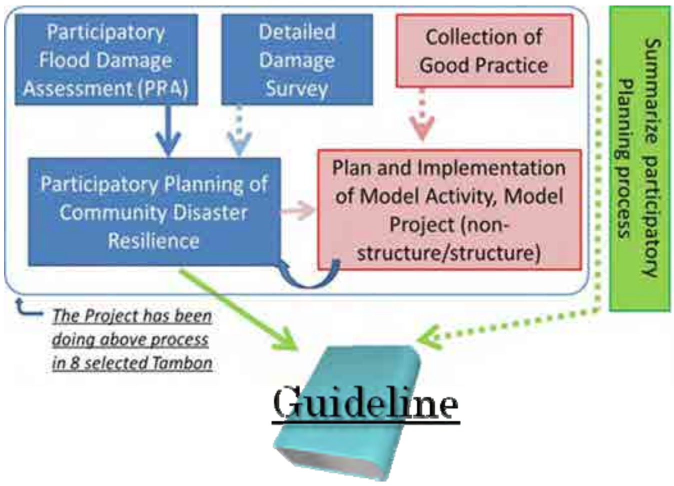
### 3.5.4 Appropriate Intervention in the Agricultural Area

Further description of the Appropriate Intervention in the Agricultural Area is stated in “Project for Flood Countermeasures for Thailand Agricultural Sector.”

The objective of The Project is to prepare a guideline for disaster-resilient agriculture and agricultural community, which will be applied for the whole Chao Phraya Basin in the future. Cultivating “resilience” of communities is the primary concern, by which a community can enhance its capacity in learning from the past disasters and to facilitate risk reduction measures. It tries to cope with disaster and to recover from the damage of a particular hazard, when it happens. “Sufficiency Economy” is the central concept to prepare the guideline.

Community-level approach is believed to increase the relevance, effectiveness and sustainability of disaster risk reduction. Thus, in the process of disaster-resilience planning, people in various social groups of the community, including vulnerable groups, are invited to contribute. About 20 countermeasures varying from structural measures to the introduction of crop production techniques to other income generation activities were tried as pilot activities in 7 model areas, and the lessons learned from implementation are to be discussed and summarized as technical papers and community case studies.

Guidelines on: i) Community-based Disaster Management, ii) Community Water Resources Management, iii) Flood Damage Reduction Measures in Agriculture, iv) Income Generation, and v) Community Strengthening, will be compiled and expected to be utilized to prepare the disaster-resilient plan at *Tambon* level with the assistance of the provincial government in flood risk areas in Chao Phraya Basin according to their physical, social, and cultural situations.




### 3.6 Consideration on Climate Change and Storm Surge

#### 3.6.1 Sea Level Rise caused by Climate Change

There are several studies on the impact of climate change available for Thailand. The 2009 World Bank Study predicted 2 to 3% of increase of precipitation and 19 to 29 cm sea level rise in 2050. The 2010 START study also predicted 10% of increase in annual precipitation in the Chao Phraya River Basin for the period from 2045 to 2065, and sea level rise of 9.4 cm on average and the maximum of 17.0cm during 2010-2029, while it is 20.0 cm on average, and maximum of 28.9 cm during 2030-2049 in the Gulf of Thailand.

According to the previous studies on Climate Change, the sea level rise in the Gulf of Thailand is not much different from the average of global sea level rise. The following figures show flow capacity in case of sea level rise of 30 cm at downstream of the Chao Phraya River. Since flow capacity is affected by sea level rise of 30 cm, further consideration is encouraged in the next stage.

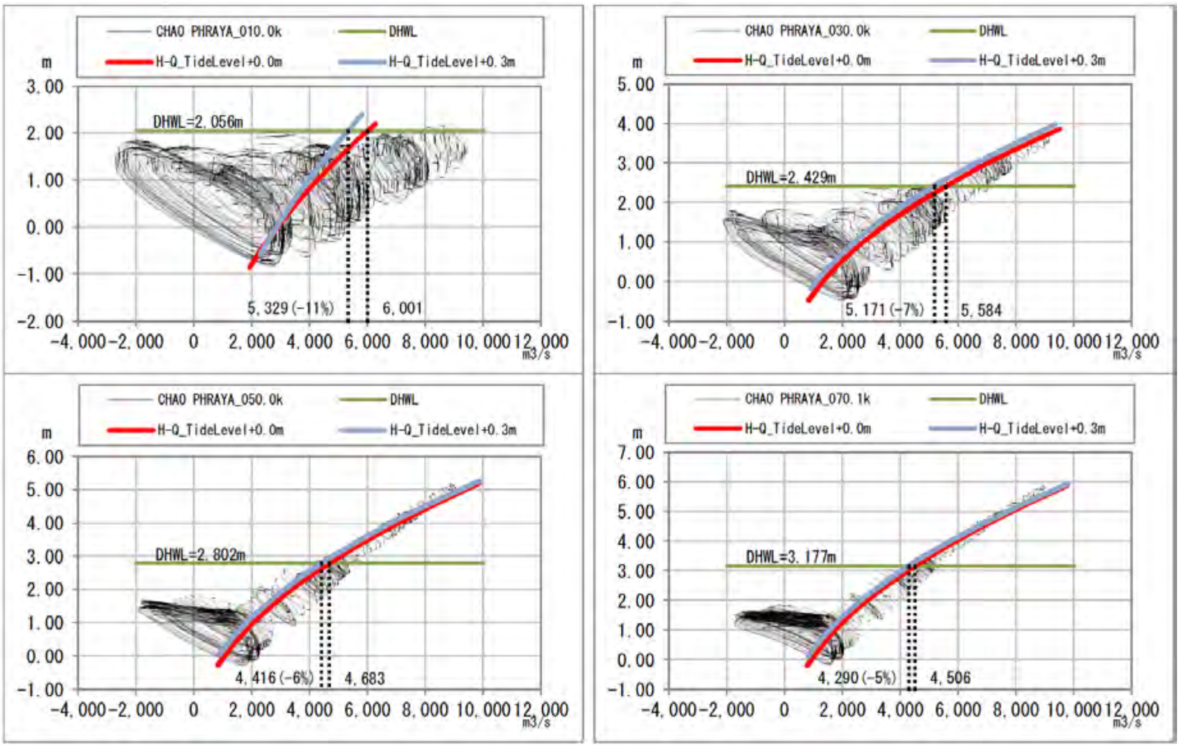
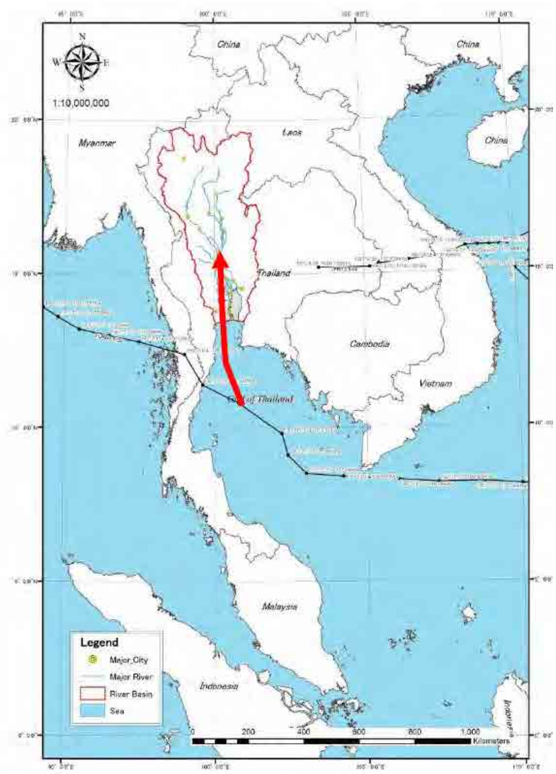



**Figure 16 Discharge Capacity in Case of Sea Level Rise of 30 cm**

### 3.6.2 Storm Surge

A storm surge is an offshore rise of water associated with a low pressure weather system, typically typhoons. Coastal areas along the Gulf of Thailand have been historically affected by storm surges. An analysis is being made to assess risk of storm surge in the coastal area of the Chao Phraya River Basin including Bangkok.

Firstly, a storm surge simulation model was established through model validation using observation data of Typhoon Gay (1989) and Typhoon Linda (1997). Then a storm surge simulation was conducted under a scenario that a typhoon similar to Typhoon Linda hits the river mouth of the Chao Phraya River. Moreover a flood inundation simulation for the 2011 flood was also conducted with river mouth water levels raised by the simulated storm surge as the downstream end condition.



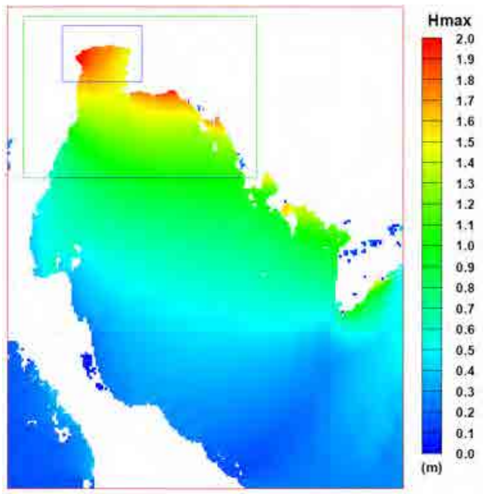




**Figure 17 Modified Typhoon Route** **Figure 18 Simulated Maximum Surge**

Following the simulation result, the effect of the storm surge to the flood in the Chao Phraya River Basin was analyzed. In this study, the following conditions were set.

- The storm surge with the highest sea water rise occurred in October 30, 2011 at the time of the highest river water level;
- The seawater rise was 2.0m and lasted for 24 hours; and
- The simulation on the reproduction of the 2011 Flood is executed with the dike elevation around the economic zone along the Chao Phraya River and Pa Sak River, Ayutthaya Bypass and Outer Ring Road Diversion Channel.

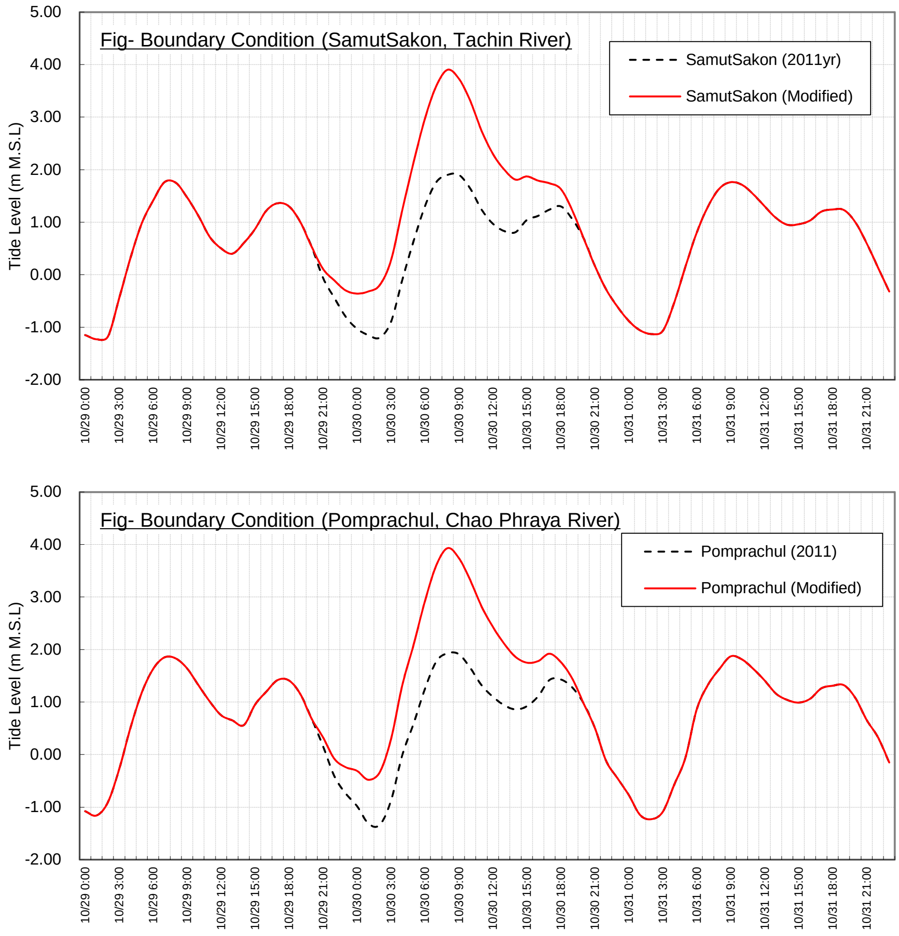
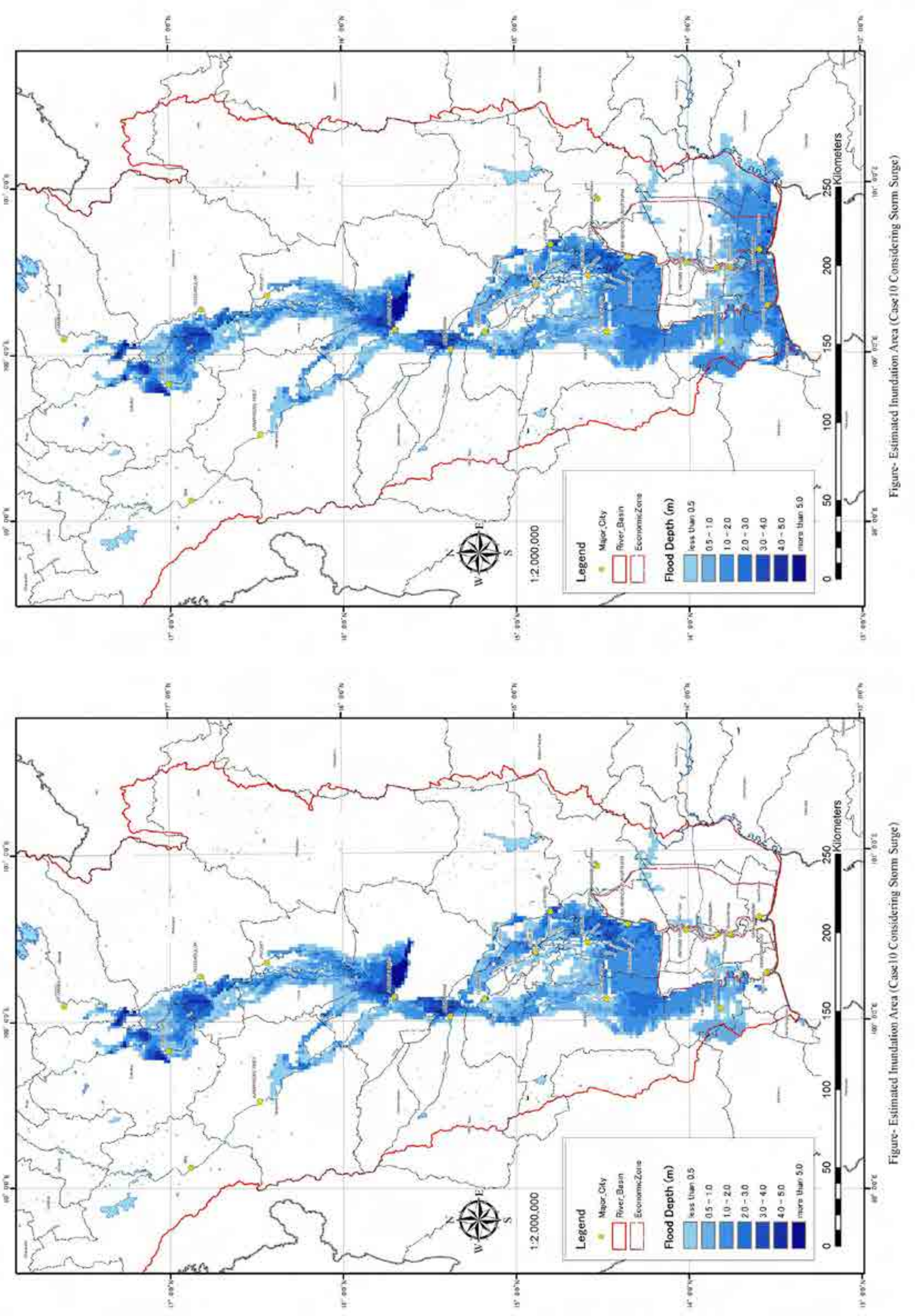



**Figure 19 Application of Sea Level at Estuary of Chao Phraya River and Tha Chin River**

Estimated inundation area is shown in Figure 20. This figure shows that the effect of storm surge to floods in Chao Phraya River Basin is not negligible.

Inundated volume to the flood plain was estimated as 3,600 MCM due to storm surge. In case of a huge storm surge, countermeasures including road elevation along the coastline, river improvement works, construction of tide wall etc., would be necessary.

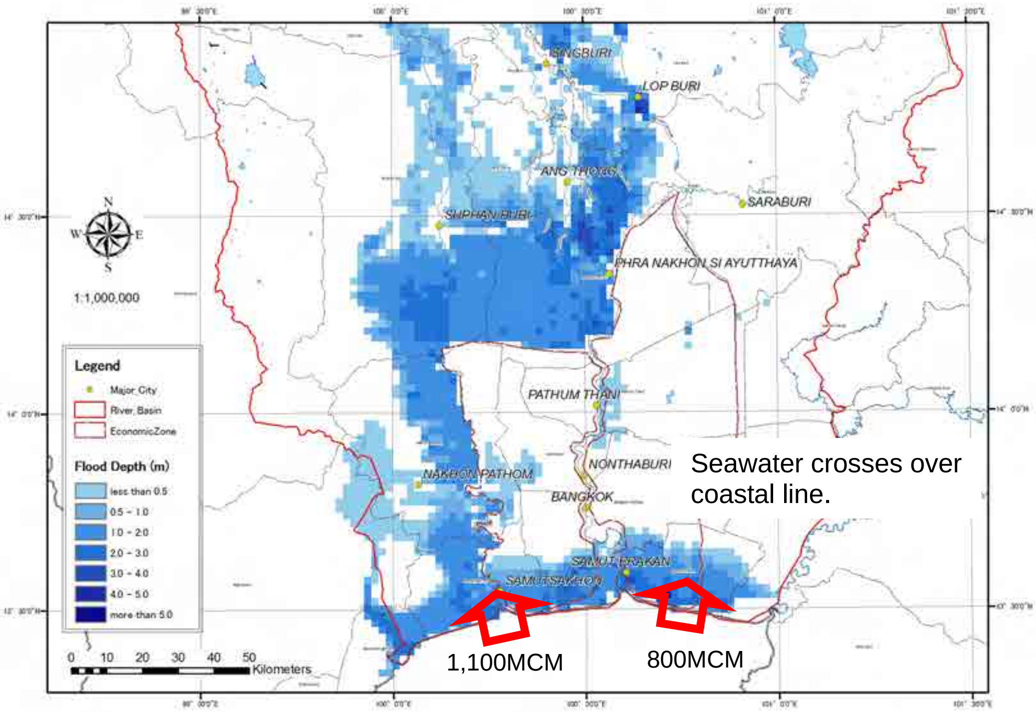


With Storm Surge (Elevation of Sea Level by 2m)

Without Storm Surge

**Figure 20 Estimated Inundation Area in Chao Phraya River Basin**

(October 30)




(October 31)

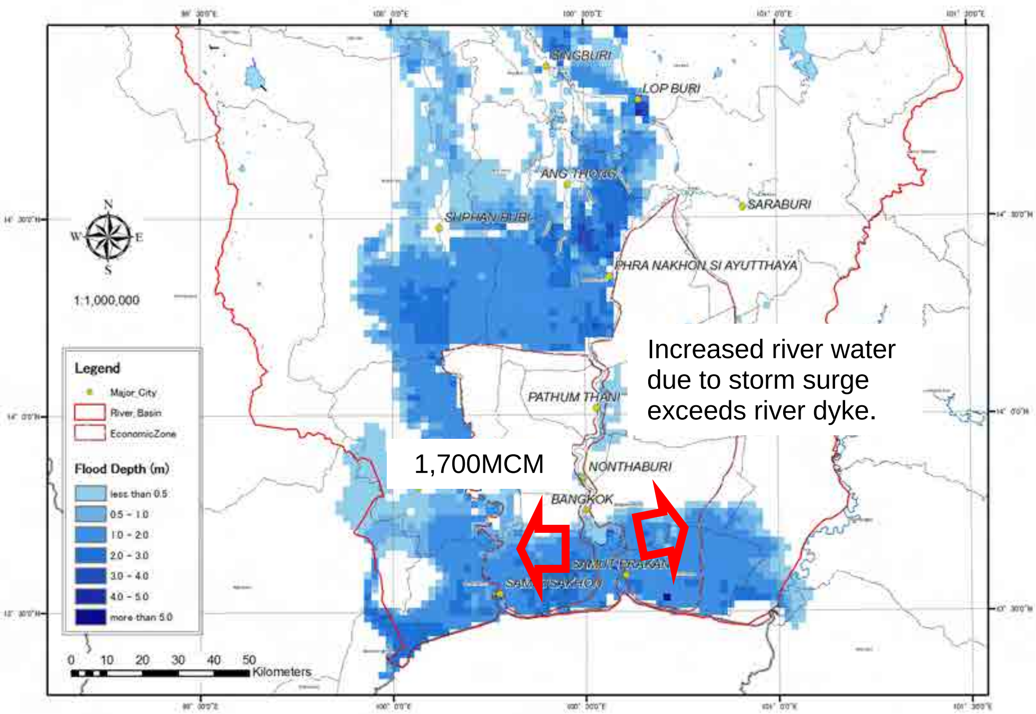



**Figure 21 Simulation on 2m of Storm Surge at Estuary of Chao Phraya River**

## 4. Project Effectiveness and Evaluation

### 4.1 Project Effectiveness

#### 4.1.1 Project Effectiveness against Design Flood

Effectiveness of combination of countermeasures against Design Flood has been checked by flood discharge distribution. The following three combinations have been studied:

Combination of SCWRM M/P

1) Effective Operation of Existing Dams
2) Construction of New Dams
3) Improvement of Retarding/Retention Areas
4) East/West Diversion Channel (Capacity: 1,500$m^3$/s)
5) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
6) River Channel Improvement Works (not including Tha Chin River Improvement)
7) Flood Forecasting

Proposed Combination 1

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity: 500$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400$m^3$/s)
5) Flood Forecasting

Proposed Combination 2

1) Effective Operation of Existing Dams
2) Outer Ring Road Diversion Channel (Capacity : 1,000$m^3$/s)
3) River Channel Improvement Works (including Tha Chin River Improvement)
4) Ayutthaya Bypass Channel (Capacity : 1,400$m^3$/s)
5) Flood Forecasting

Flood discharge distribution of each combination is given as follows:

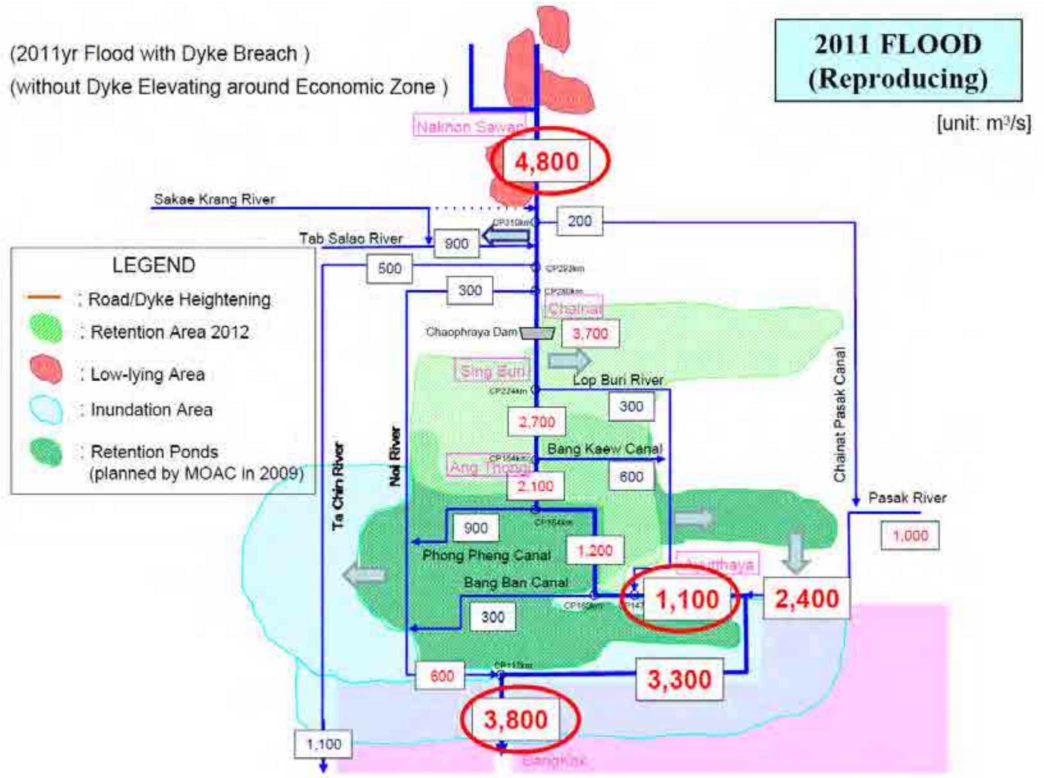



**Figure 22 Flood Discharge Distribution (2011 Flood Reproducing)**

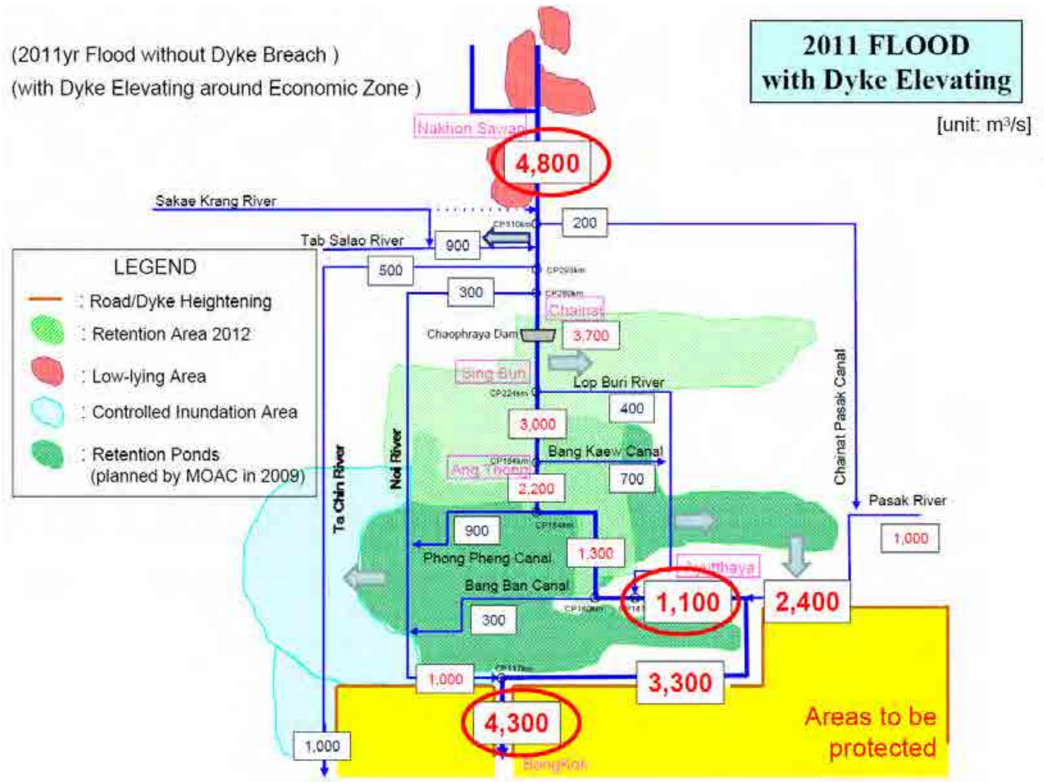



**Figure 23 Flood Discharge Distribution**
**(2011 Flood with Dyke Heightening around Economic Zone)**

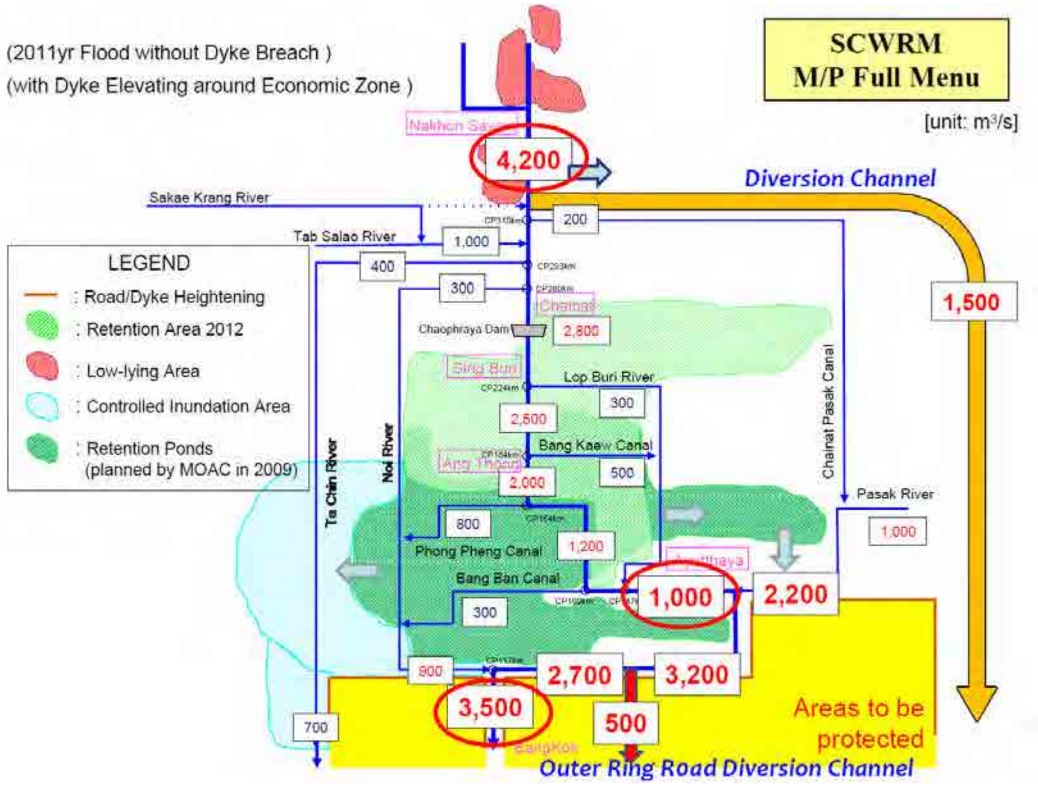
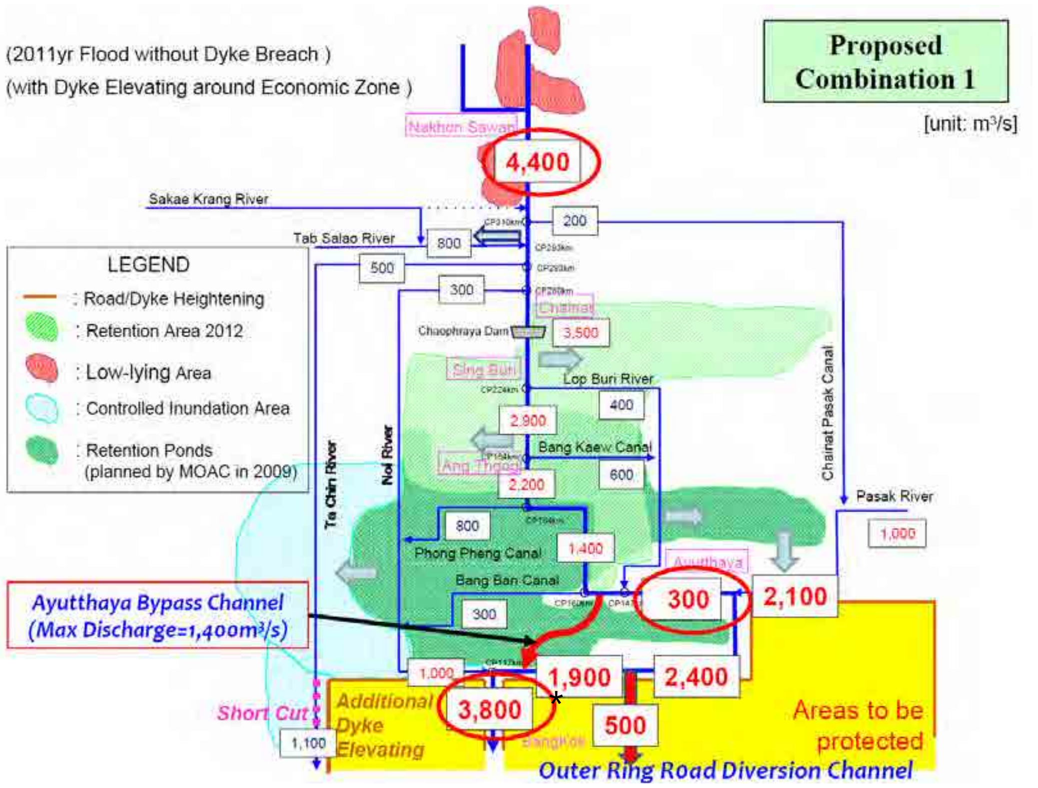



**Figure 24 Flood Discharge Distribution (SCWRM M/P)**




* *Discharge capacity of Chao Phraya River near Bangkok is considered to be approx. 4,000 m$^3$/s.*

**Figure 25 Flood Discharge Distribution (Proposed Combination 1)**

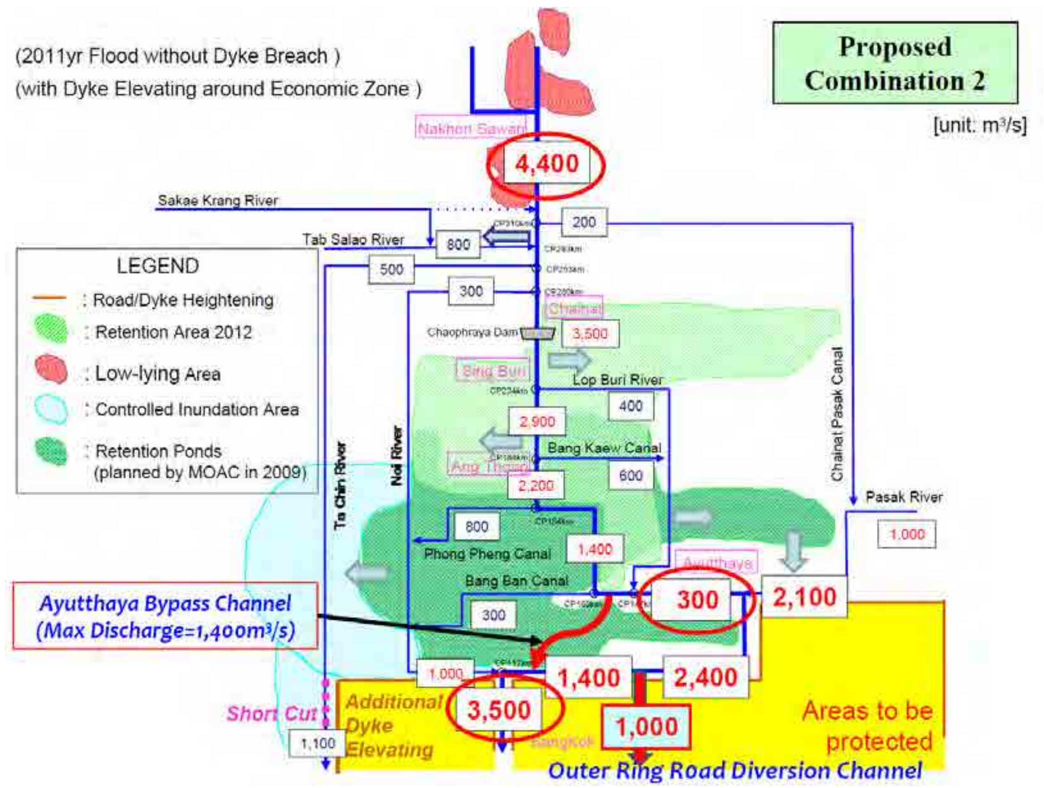



**Figure 26 Flood Discharge Distribution (Proposed Combination 2)**

### 4.1.2 Verification of Project Effectiveness against Other Rainfall Patterns

Project effectiveness should be verified against other rainfall patterns of measure flood year.

**Table 5 Other Rainfall Patterns to be evaluated**

| Flood Year | 6-month Rainfall (mm) | | Peak Discharge at Nakhon Sawan ($m^3$/s) | | Remarks |
|---|---|---|---|---|---|
| | Upper Nakhon Sawan [C.A. = 105,000km$^2$] | Whole River Basin [C.A. = 162,000km$^2$] | Observed Value | Calculated Value (without Dams) | |
| **2011** | **1,483** | **1,390** | **4,686** | **6,587** | **Design Flood** |
| 1970 | 1,266 | 1,232 | 4,420 | 5,830 | Other Rainfall Pattern |
| 1975 | 1,254 | 1,166 | 4,336 | 5,535 | |
| 1980 | 1,255 | 1,207 | 4,320 | 5,839 | |
| 1994 | 1,313 | 1,168 | 2,533 | 4,268 | |
| 1995 | 1,262 | 1,230 | 4,820 | 5,612 | |
| 2006 | 1,375 | 1,266 | 5,450 * | 6,385 | |

* 5,450 $m^3$/s is the recorded peak discharge in 2006. However, the observed peak water level in 2006 is much lower than the value in 2011. Based on the H – Q curve of the year 2011, it is estimated that the peak discharge in 2006 is approximately, 3,800 $m^3$/s.

Effectiveness of Combination 1 and 2 against other rainfall patterns is verified as shown in the following verification results. Table 6 shows calculation results against actual rainfalls of other years. On the other hand, Table 7 shows calculation results against rainfalls which are enlarged to the same quantity as the design external force (2011's 6-month rainfall).

**Table 6 Verification Results of Project Effectiveness against Other Actual Rainfalls**

| Flood Year | Peak Discharge ($m^3/s$) | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dyke Elevating around Economic Zone Without Countermeasures | | | Dyke Elevating around Economic Zone With Combination 1 | | | Dyke Elevating around Economic Zone With Combination 2 | | | |
| | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | |
| **2011** | **4,800** | **1,100** | **4,000** | **4,400** | **300** | **3,800** | **4,400** | **300** | **3,500** | **Design Flood** |
| 1970 | 3,600 | 1,000 | 3,500 | 3,200 | 300 | 2,900 | 3,200 | 300 | 2,400 | Other Rainfall Pattern |
| 1975 | 3,700 | 1,000 | 3,000 | 3,200 | 300 | 2,600 | 3,200 | 300 | 2,100 | |
| 1980 | 4,200 | 1,000 | 3,700 | 3,800 | 300 | 3,100 | 3,800 | 300 | 2,700 | |
| 1994 | 3,500 | 1,000 | 2,900 | 3,000 | 300 | 2,600 | 3,000 | 300 | 2,200 | |
| 1995 | 4,100 | 1,000 | 3,800 | 3,500 | 300 | 3,100 | 3,500 | 300 | 2,700 | |
| 2006 | 4,400 | 1,000 | 3,700 | 3,600 | 300 | 2,900 | 3,600 | 300 | 2,500 | |

**Table 7 Verification Results of Project Effectiveness against Rainfalls enlarged to Same Quantity as 2011's 6-month Rainfall**

| Flood Year | Peak Discharge ($m^3/s$) | | | | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dyke Elevating around Economic Zone **Without Countermeasures** | | | Dyke Heightening around Economic Zone **With Combination 1** | | | Dyke Heightening around Economic Zone **With Combination 2** | | | |
| | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | Nakhon Sawan | Ayuttha -ya | Bang Sai | |
| **2011** | **4,800** | **1,100** | **4,000** | **4,400** | **300** | **3,800** | **4,400** | **300** | **3,500** | **Design Flood** |
| 1970 | 4,300 | 1,000 | 3,900 | 4,000 | 300 | 3,500 | 4,000 | 300 | 3,100 | Other Rainfall Pattern |
| 1975 | 4,800 | 1,100 | 4,400 | 4,400 | 300 | 3,800 | 4,400 | 300 | 3,400 | |
| 1980 | 4,800 | 1,100 | 4,400 | 4,600 | 300 | 3,900 | 4,600 | 300 | 3,600 | |
| 1994 | 5,000 | 1,000 | 4,200 | 4,500 | 300 | 3,600 | 4,500 | 300 | 3,200 | |
| 1995 | 4,600 | 1,100 | 4,400 | 4,300 | 300 | 3,900 | 4,300 | 300 | 3,600 | |
| 2006 | 4,800 | 1,100 | 4,200 | 4,400 | 300 | 3,600 | 4,400 | 300 | 3,200 | |

## 4.2 Project Evaluation

### (1) Cost

The project cost is estimated based on the domestic price level as of December, 2012 indicated in Thai Baht. The applied exchange rate (Bank of Thailand Selling Rate as of 28 December, 2012) is as follows:

- 1 USD = 30.7775 Baht (1 Baht = 0.032 USD)
- 100 JPY = 35.7960 Baht (1 Baht = 2.794 JPY)

Results of project cost estimation are given as follows:

**Table 8 Project Cost**

| SCWRM M/P Module | | Description | Capacity ($m^3/s$) | Project Cost (billion Baht) | | |
|---|---|---|---|---|---|---|
| | | | | SCWRM M/P | Proposed Combination 1 | Proposed Combination 2 |
| C1 | Re-foresting | - | - | *NE* * | *NI* ** | *NI* |
| C2 | Construction of New Dams | 3 dams | - | 71 | *NI* | *NI* |
| C3 | Land Use Control for Flood Area | - | - | NE | *NI* | *NI* |
| C4 | Improvement of Retarding / Retention Areas | 13 retention ponds | - | 46 | *NI* | *NI* |
| C5 | River Improvement | River channel improvement | - | 11 | 14 **** | 14 **** |
| | | Ayutthaya bypass channel (L=19km) | 1,400 | *NI* | 18 | 18 |
| C6 | Flood Diversion Channel | West diversion channel (L=223km) | 1,500 | 211 | *NI* | *NI* |
| | | Outer ring road diversion channel (L=98km) | 500 | 91 | 91 | - |
| | | | 1,000 | - | - | 134 |
| C7 | Operation Efficiency of Existing Dams | Bhumibol, Sirikit, Kwae Noi, Pa Sak dams | - | *NB* *** | *NB* | *NB* |
| C8 | Flood Forecasting System | - | - | 4 | 4 | 4 |
| Price Escalation (2013 to 2020) | | - | - | 74 | 16 | 22 |
| **Total** | | **-** | **-** | **508** | **143** | **192** |

* *NE*: Not estimated (included in the SCWRM M/P)

** *NI*: Not included in the proposed combinations

*** *NB*: Budget allocation is not necessary

**** including river improvement of the Tha Chin River

Note 1: The costs in the respective columns include construction, engineering service, administration, land acquisition, resettlement, physical contingency, price escalation and valued added tax.

Note 2: Non-structural measures proposed in the study are not included in the cost estimate.

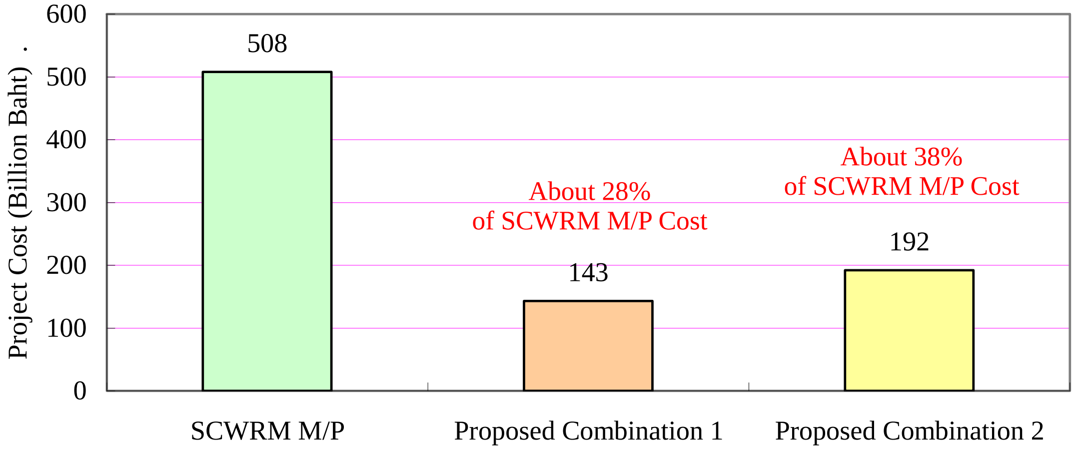



**Figure 27 Project Cost of Each Combination**

### (2) Benefit

Benefits of a flood management project are derived from the reduction of flood damage in the whole inundation area.

**Table 9 Flood Damage Estimation**

| Flood Damage | Estimation |
|---|---|
| Direct Damages on Assets of Factories | The amount of damage is estimated by summing up damaged asset values of which rates vary according to flood inundation depth. The flood simulation gives inundation depth of each 2 km x 2 km grid cell in the flood plains. |
| Direct Damages on Assets of Households | |
| Other Direct and Indirect Damages | The amount of damage is estimated with the percentages to the total amount of asset damaged derived from the research by the Ministry of Finance and the World Bank. |

The method to estimate flood damage is described in Table 9. Since the flood causing inundation is a probability event, the amount of damage to be calculated is the yearly expected value based on the probability of flood occurrence.

**Table 10 Estimated Amount of Total Assets in Whole Affected Area**

| Item | Factories | | | Households | | |
|---|---|---|---|---|---|---|
| | Fixed Assets | Stocks | Total | Houses | Assets | Total |
| Estimated Amount of Total Assets (billion Baht) | 2,167 | 844 | 3,011 | 1,638 | 1,064 | 2,702 |

Note 1: Estimated amount of total assets is common to all project combinations; namely, SCWRM M/P, Combination 1 and Combination 2.

### (3) EIRR, Benefit/Cost Ratio and Net Present Value

Based on the above-mentioned cost and benefit, EIRR, Benefit/Cost and Net Present Value are estimated as follows:

**Table 11 EIRR, Benefit/Cost and Net Present Value**

| Case | EIRR | Benefit/Cost | Net Present Value (Billion Baht) |
|---|---|---|---|
| SCWRM M/P Full Menu | 13 % | 1.1 | 21 |
| Proposed Combination 1 | 29 % | 2.7 | 137 |
| Proposed Combination 2 | 25 % | 2.2 | 127 |

Note 1) Price Level: 2012

Note 2) Evaluation Period: 2013 to 2050 (38 years after the commencement of the construction)

Note 3) Social Discount Rate: 12 %

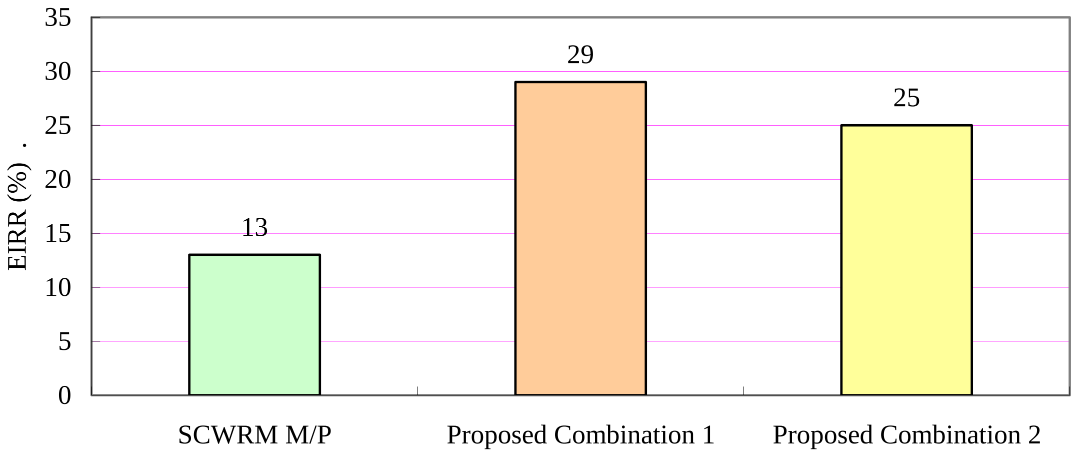



**Figure 28 EIRR of Each Combination**

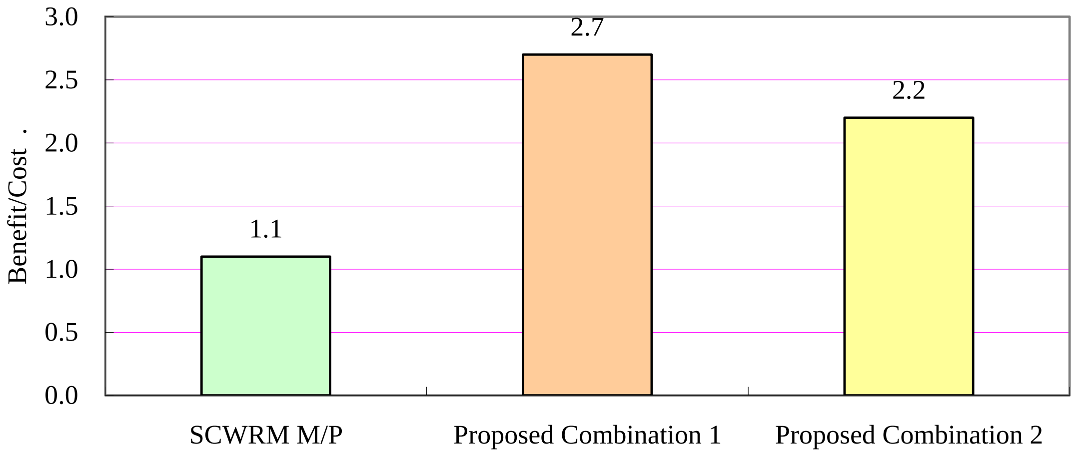



**Figure 29 Benefit/Cost Ratio of Each Combination**

### (4) Results of Project Evaluation

The most cost-effective combination of projects is sought, since cost of all the projects is expected to exceed the budget for flood management.

The proposed combination 1 or 2 of projects needs only less than 38% of SCWRM M/P cost, while the evaluation of the project, in other words, Economic Internal Rate of return (EIRR) is more than 25%, which is very high compared with the SCWRM M/P.

Therefore, it is recommended to prioritize implementation of the proposed combination, which includes:

1) Effective Operation of Existing Dams;
2) Outer Ring Road Diversion Channel (Capacity: 500 or 1,000 $m^3$/s);
3) River Improvement Works (including Tha Chin River Improvement);
4) Ayutthaya Bypass Channel (Capacity : 1,400 $m^3$/s); and
5) Flood Forecasting.

*Note : Peak flow discharge at Bang Sai was estimated at 3,800 $m^3$/s in Combination 1 and 3,500 $m^3$/s in Combination 2. Since daily peak flow discharge of 3,900 $m^3$/s at Bang Sai was recorded during 2011 flood without any damages caused by overflow of water in the lower reaches of the Chao Phraya River (downstream of Bang sai), EIRR and B/C calculated as the damage caused by flooding does not come out with discharge of 3,800 $m^3$/s. In case that the damage comes out with discharge of 3,800 $m^3$/s, EIRR and B/C of Combination 2 may become values bigger than those of Combination 1.*

# Appendixes

1. Review of the Projects

2. Flood Forecasting System

3. Appropriate Interventions in the Agricultural Area,
   JICA Technical Assistance Project

# Appendix 1: Review of the Projects

## 1. Review of the projects

The following projects were reviewed to formulate the Flood Management Plan for the Chao Phraya River Basin:

1) Projects stated in the Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011;
2) Projects mentioned in Documents of Request for Proposal prepared by WFMC in July 2012; and
3) Projects newly proposed during the Study.

## 2. The Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011

In December 2011, the Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management composed of both urgent and long term work plans as set forth in Table 1.1, to ensure the continuity of country's development.

**Table 1.1 Summary of Work Plans Presented by SCWRM (December 2011)**

<table>
<tr><th>No.</th><th colspan="2">Work Plan</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Work Plan for Restoration and Conservation of Forest and Ecosystem</td><td>1) to restore watershed forests in the river basin</td></tr>
<tr><td>2) to develop additional water reservoirs according to the development potential of the areas</td></tr>
<tr><td>3) to develop a land usage plan that fits with its socio-geographical conditions</td></tr>
<tr><td>2</td><td colspan="2">Work Plan for Management of Major Water Reservoirs and Formulation of Water Management</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures</td><td>1) Construction of flood ways or water channels roads, and dams</td></tr>
<tr><td>2) Improvement of water dike, reservoir, water drainage and water gateway</td></tr>
<tr><td>3) Land use planning with appropriate zoning, including setting up an area protection system</td></tr>
<tr><td>4</td><td colspan="2">Work Plan for Information Warehouse and Forecasting and Disaster Warning System</td></tr>
<tr><td>5</td><td colspan="2">Work Plan for Response to Specific Area</td></tr>
<tr><td>6</td><td colspan="2">Work Plan for Assigning Water Retention Areas and Recovery Measures (Improving/adapting irrigated agricultural areas into retention areas of around 2 million rai to enable second cropping in all the irrigated agricultural areas</td></tr>
<tr><td>7</td><td colspan="2">Work Plan for Improving Water Management Institutions</td></tr>
<tr><td>8</td><td colspan="2">Work Plan for Creating Understanding, Acceptance, and Participation in Large Scale Flood Management</td></tr>
</table>

### 3. Request for Proposal prepared by WFMC in July 2012

In July 2012, the Water and Flood Management Commission (WFMC) announced the Submission of a Conceptual Plan for the Design of Infrastructure for Sustainable Water Resources Management and Flood Prevention, composed of 8 projects as set forth in Table 1.2.

**Table 1.2 Summary of Projects Presented by WFMC (July 2012)**

| No. | Project |
|---|---|
| 1 | Aiming at the formation of a balanced ecosystem, conservation and restoration of forest and soil condition: Project Area is approx. 10 million rai (1 rai = 1,600 m2). |
| 2 | Construction of appropriate and sustainable reservoirs in the Ping, Yom, Nan, Sakae Krang and Pa Sak River Basins. |
| 3 | Development of land use/land utilization plans, establishment of national and provincial residential areas and major economic areas in the possible inundation areas. |
| 4 | Development of the Phitsanulok Irrigation project (North of Nakhon Sawan) to store excess waters temporally during floods, and the Main Chao Phraya Irrigation Project (North of Ayutthaya) to convert existing irrigated lands to retention/retarding areas (storage volume: approximately 6 to 10 billion m3, area: approximately 2 million rai), and improvement of agriculture and fishery industries to increase the productivity yield. |
| 5 | Improvement of canals and river channel dykes of major rivers (the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krang, Pasak, and Tha Chin Rivers). |
| 6 | Construction of floodway(s) and national roads to divert discharge that exceeds the flow capacity of main channel from the Chao Phraya River・Pasak River with east/west routes of the Chao Phraya River to the Gulf of Thailand. The structures include flood way with more than 1,500 $m^3/s$ flow capacity and/or flood diversion channel. |
| 7 | Improvement of the existing systems including database system, weather forecasting system, disaster forecast/warning system and other water management (flooding and draught) system. |
| 8 | Improvement of water management institutions including development of appropriate law and policies on flood control, formulation of a single command authority, and management, monitoring and relief activities. |

## 4. Projects to be Reviewed

Projects to be reviewed are described as follows:

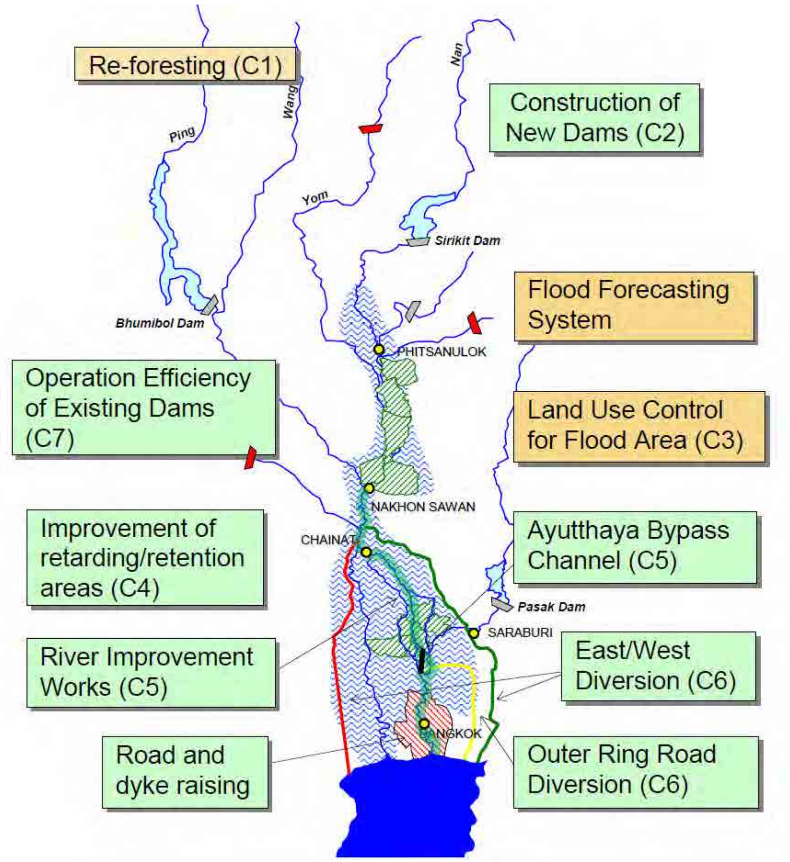



**Figure 1.1 Countermeasures to be Reviewed**

1) Operation Efficiency of Existing Dam (C7)

   To implement new operation rule at the existing dams in order to improve the effectiveness on the flood mitigation function by considering both flood mitigation and irrigation benefits.

2) Construction of New Dams (C2)

   To construct appropriate and sustainable reservoirs (new dams) in major river basins.

3) Improvement of Retarding/Retention Areas (C4)

   To improve retarding/retention areas in the Chao Phraya River Basin to mitigate flood damage by temporarily storing floodwater and to improve the agricultural and fisheries productions by utilizing the stored water.

4) East/West Diversion Channels (C6)

To construct diversion channels to divert water eastward/westward from the upstream of the Chao Phraya Dam to the Gulf of Thailand.


**Figure 1.2 Location of Diversion Channels**

5) Outer Ring Road Diversion Channel (C6)

To construct a diversion channel along outer ring road to divert water from the downstream of Ayutthaya to the Gulf of Thailand.

6) River Channel Improvement Works (C5)

To rehabilitate and improve the existing river channels and dykes to increase flow capacity of the rivers.

Inundation volume and depth at right side of the Tha Chin River will increase due to the dyke heightening for protection of the economic zone. As channel improvement in the Tha Chin River, the following countermeasures are to be reviewed:

i) Four (4) shortcuts are installed;

ii) Primary dyke or concrete parapet wall is newly constructed at left side from river mouth to 90 km point; and

iii) Secondary dyke at left side is elevated to “Design High Water Level plus Allowance” from 90 km to 141 km point.

7) Ayutthaya Bypass Channel (C5)

To construct a bypass channel from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River in order to transfer the confluence of the Chao Phraya River and the Pa Sak River.

8) Reforesting at Upstream of River Basin (C1)

To apply restoration measures in the degraded forest areas located in the upper basin (mainly in the Ping, Wang, Yom, Nan, Sakae Krang, Pasak and Tha Chin basins) to conserve forest resources and ecosystem.

9) Flood Management Information System

To develop flood management information system including database system, flood forecasting system and other water management system to enable timely monitoring and analysis of the water situation in the whole river basin.

## 5. Findings of the Review

1) Operation Efficiency of Existing Dam (C7)

The operation of existing dams during the 2011 flood was so effective to mitigate flood damage, because the Bhumibol and Sirikit dams stored 12.1 billion cubic meters of floodwater. Since the rule of dam operation was modified in February 2012, dam operation will have more flexibility to manage water resources with the minimization of flood damage as well as provision of water for irrigation purposes. It is proposed that reservoir level should follow the new upper rule curve until the end of July, and from August, flood discharge should be stored in reservoir with maximum outflow of 210 $m^3/s$ for Bhumibol Dam and 190 $m^3/s$ for Sirikit Dam. If the proposed rule of dam operation was applied during the 2011 flood, the peak discharge at Nakhon Sawan could have been reduced by 400 $m^3/s$.

2) Construction of New Dams (C2)

Construction of new dams is highly encouraged, since it is effective for both flood mitigation and water utilization for irrigation, especially in the tributary river basins. It is also promoted for response to climate change. However, dam sites currently identified cannot provide such large storage capacities as the Bhumibol and Sirikit dams that the effectiveness of flood mitigation to the mainstream of Chao Phraya River is relatively limited.

3) Improvement of Retarding/Retention Areas (C4)

The areas with around 18,000 $km^2$, adjacent to river channels, currently have an important function to retard and retain floodwater. Therefore, it is crucial to preserve the areas not to lose the existing function by appropriately controlling land use. It is therefore recommended that land use regulations should be stipulated, considering scenarios such as excess flooding and climate change.

To enhance the capacity of retarding floodwater, some measures such as installation of gates and pumps can be taken. Those measures are useful to not only store floodwater but also to utilize the floodwater for irrigation; however, the enhanced retarding effect is limited.

4) East/West Diversion Channels (C6)

The diversion channels produce an enormous effect in reducing: (i) water levels of the Chao Phraya River between Nakhon Sawan and Chai Nat; and (ii) inundation volumes flowing into adjacent retention/retarding areas. However, the effect of lowering water level produced by these diversion channels is fading away in the downstream stretch of Chao Phraya River close to the areas to be protected.

5) Outer Ring Road Diversion Channel (C6)

The diversion channel along the outer ring road has a certain effect in reducing water levels of: (i) the Chao Phraya River from Ayutthaya to

Bangkok; and (ii) the downstream of Pa Sak River. Hence, it is so effective to reduce the risk of dyke breaches along the areas to be protected.

This diversion channel runs through the east side of protection area. During its design stage, it is possible to provide a function as a defense line to protect the most important center area. For example, measures to increase the height of the west side embankment than the east side one should be considered.

6) River Channel Improvement Works (C5)

Definition of River Channel

In the Study, it is considered that the channel of the rivers lies between secondary dykes, not between water edges along primary dykes, since ordinary width of stream cannot accommodate floodwater. It is crucial that lower and/or weaker stretches of secondary dykes should be identified and strengthened to prevent uncontrolled inundation.

If dyke raising work is conducted based on the primary dyke alignment, very high height of levee would be required (red line), because river area enclosed with primary dyke is much smaller than secondary dyke.

River Improvement in Tha Chin River

The adopted countermeasures consisting of dyke improvement at left side of lower reaches and four (4) shortcuts can increase discharge capacity of the Tha Chin River and eliminate the negative impact of the dyke heightening for protection of the economic zone. In addition, river water level during flood can be lower than the design high water level.

Since existing regulators for irrigation on the Tha Chin River are located at upper reaches as shown in Figure 1.3, flood management facilities adopted at lower reaches do not affect water use for irrigation.

Also, since lower reaches of the Tha Chin River is subject to tidal action, flood management facilities adopted at lower reaches do not affect river navigation.

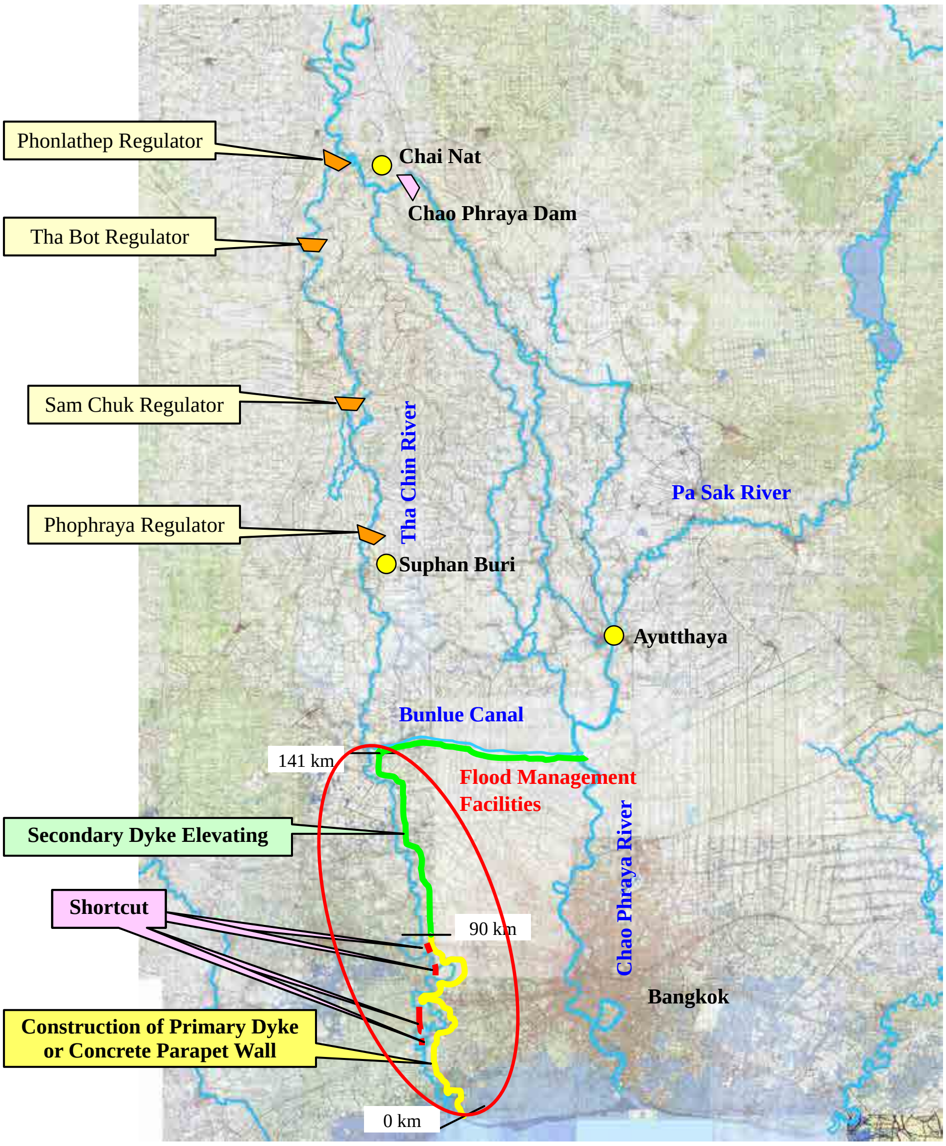



**Figure 1.3 Location of Regulators for Irrigation on Tha Chin River**

7) Ayutthaya Bypass Channel (C5)

The Ayutthaya Bypass Channel is one of the alternatives of river channel improvement works, since it is extremely difficult to widen the river channel in the stretch between Bang Sai and Ayutthaya. The Bypass Channel has an effect in lowering the water levels of (i) the Chao Phraya River between Bang Sai and Ayutthaya, and (ii) the Pa Sak River. Hence, it is very effective in reducing the risk of dyke breach along the areas to be protected.

8) Reforesting at Upstream of River Basin (C1)

Deforestation amplifies flood. Forest restoration requires continuous treatment over a prolonged period. In our study, quantitative effects of flood mitigation produced by reforestation are not considered.

9) Flood Management Information System

The Flood Management Information System would play a critical role on proper flood management. It is particularly emphasized that most of the damages in the factories can be minimized if proper information on flooding and inundation is provided in a timely manner. The system will be covered by another component of the Project.

## Appendix 2: Flood Forecasting System

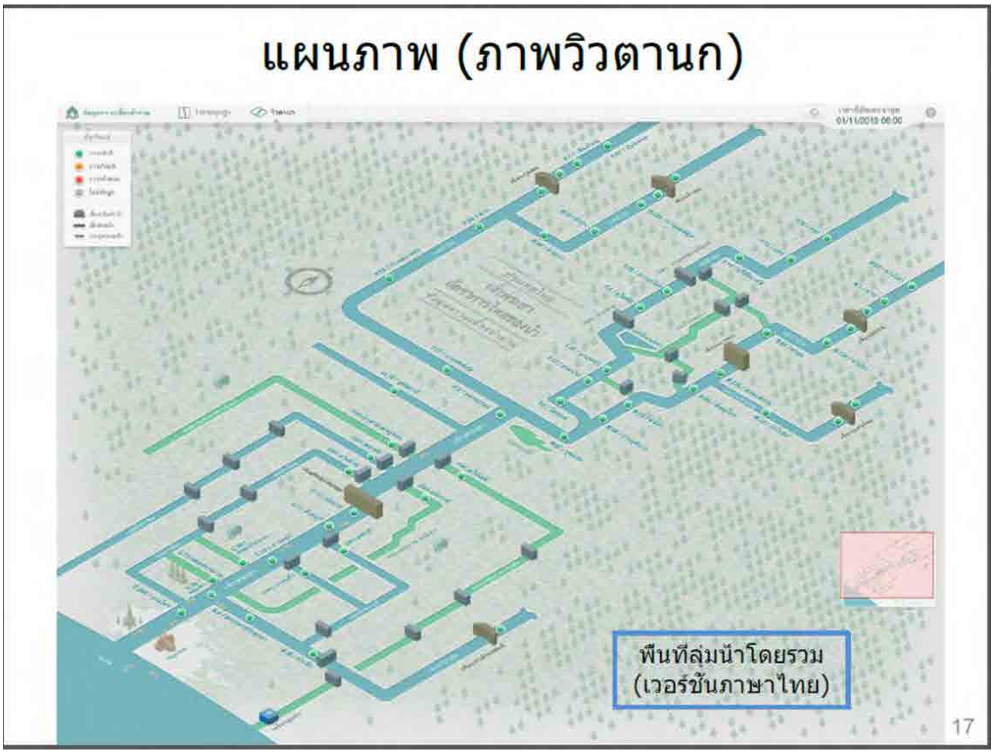
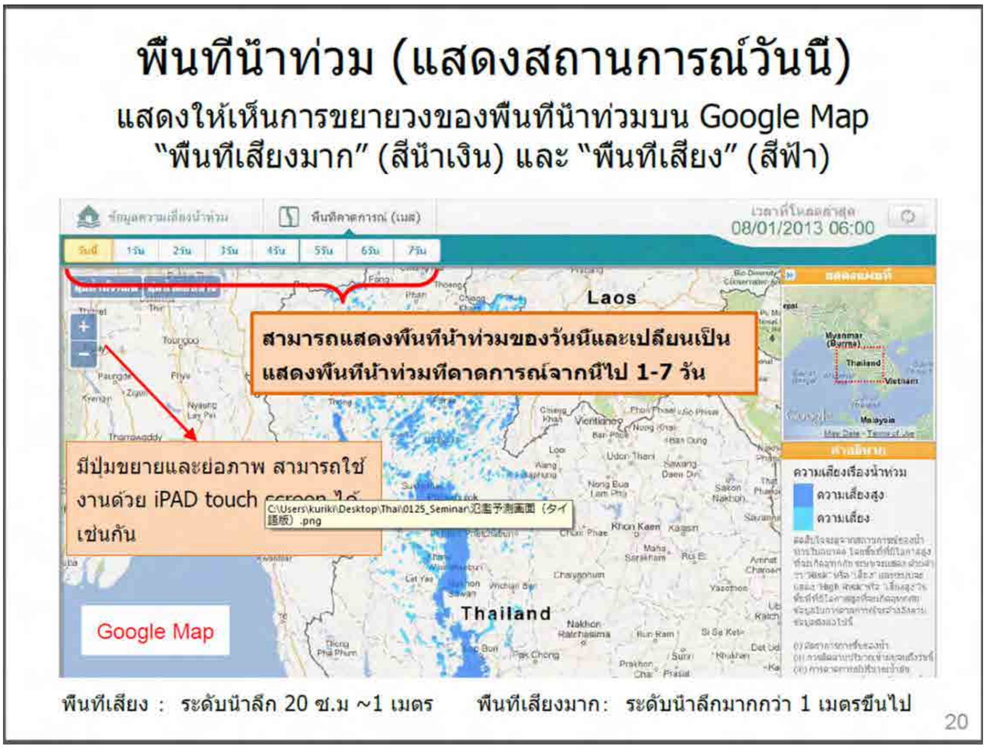




**Figure 2.1 Operation Screen Shots of Flood Forecasting System (1/2)**



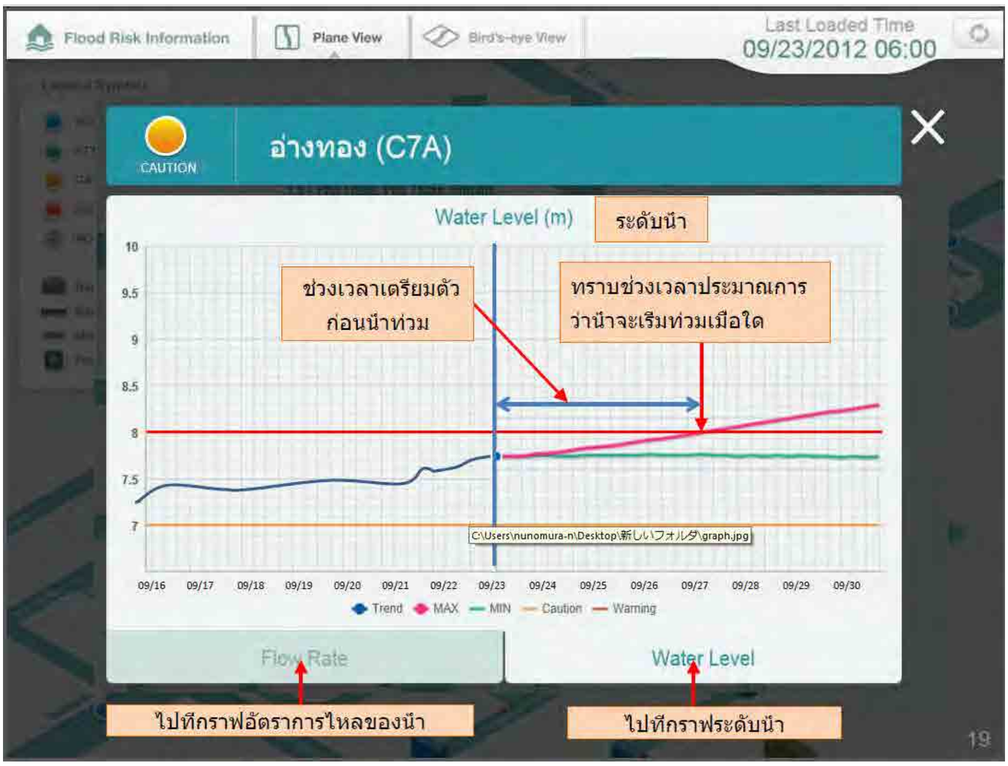




**Figure 2.2 Operation Screen Shots of Flood Forecasting System (2/2)**

## Appendix 3: Appropriate Interventions in the Agricultural Area, JICA Technical Assistance Project

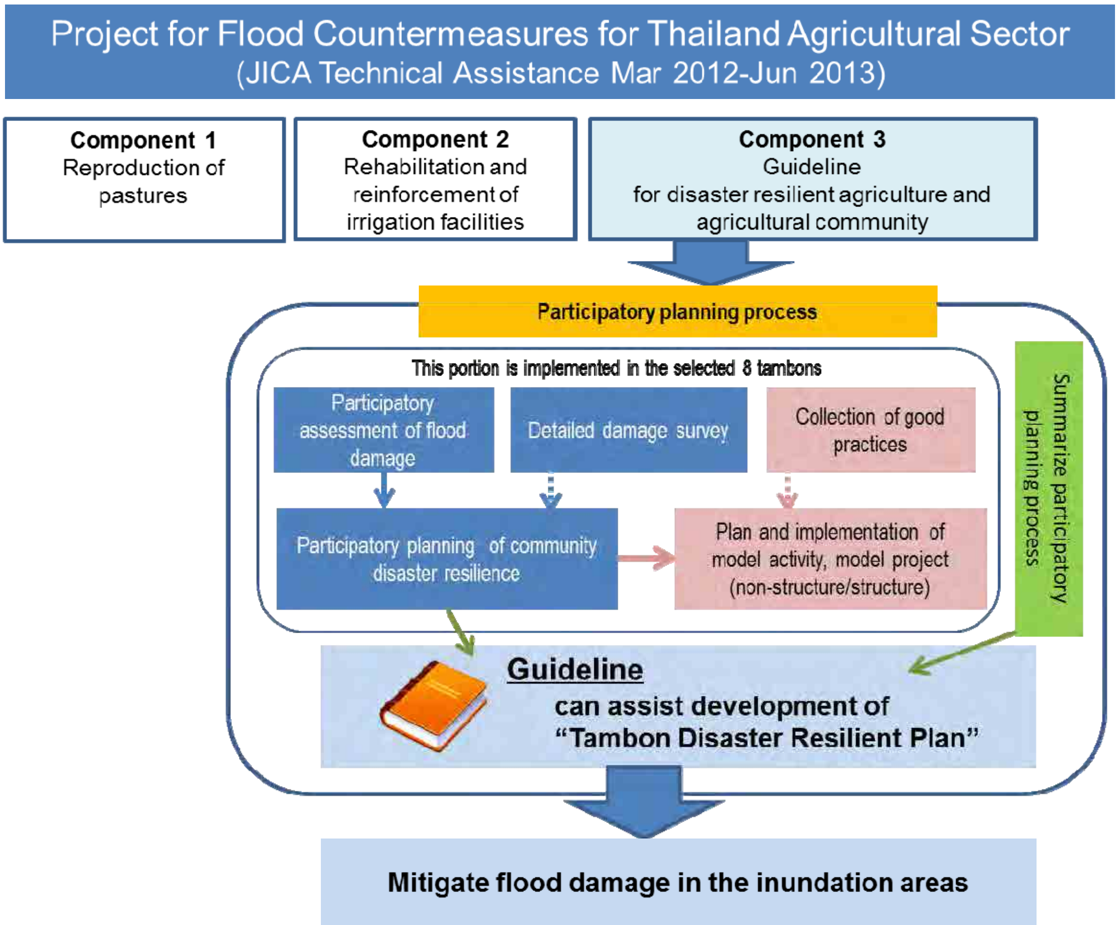



**Figure 3.1 Project Scheme and Participatory Planning**

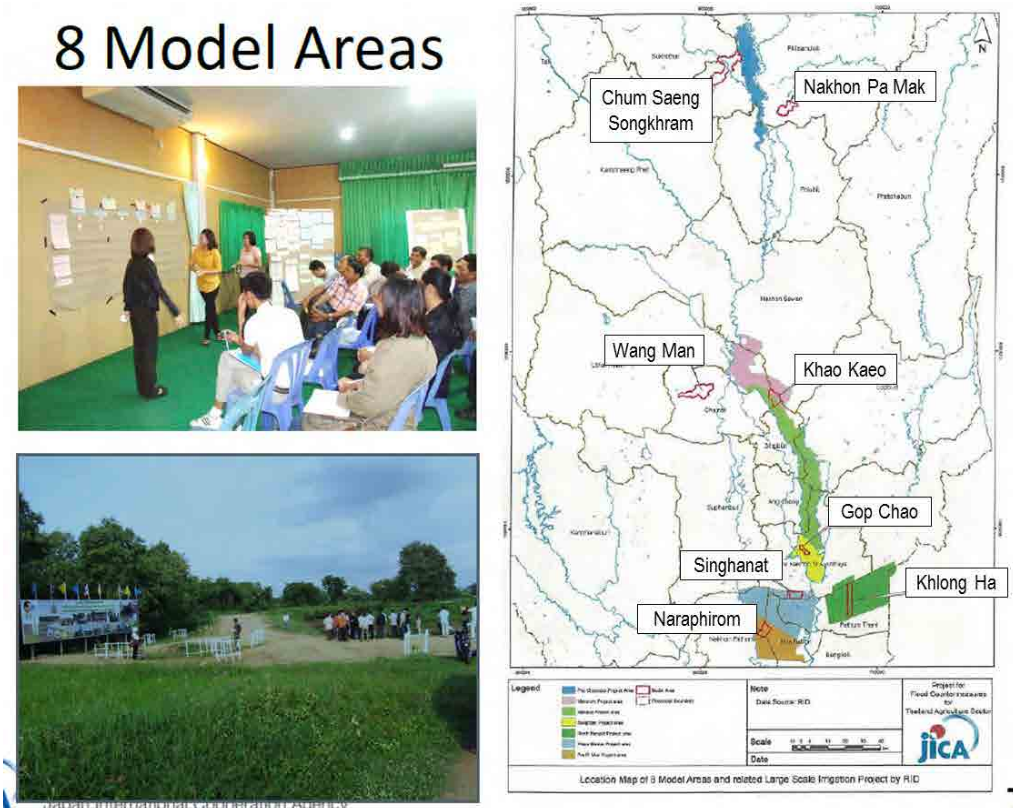



**Figure 3.2 Model Areas for Participatory Planning**

Technical papers for disaster prevention, mitigation and recovery

| | Technical papers (Tentative) | Effectual Timing | | | Effectual condition | | |
|---|---|---|---|---|---|---|---|
| | | Disaster Prevention | Emegency measures | Quick Recovery | Normal | Normal Flood | Big Flood (ex. 2011) |
| 1 | Securing Drinking Water in Emergency Case | | ○ | | | ○ | ○ |
| 2 | Participatory Water Measurement | ○ | | | | ○ | |
| 3 | Participatory Flood Hazard Map Making | ○ | | | | ○ | ○ |
| 4 | Community Water Resource Study and Plan | ○ | ○ | ○ | ○ | ○ | |
| 5 | Water Management of Community Monkey Cheek | ○ | ○ | ○ | ○ | ○ | |
| 6 | Paddy Plantation by Different Transplanting Method | ○ | | | ○ | ○ | ○ |
| 7 | Cost Reduction of Paddy to Reduce Flood Risk | ○ | | | ○ | ○ | ○ |
| 8 | Safe Vegetable Production for Diversification | | ○ | ○ | ○ | ○ | ○ |
| 9 | Floating Vegetable Growing for Flooding Period | | ○ | ○ | | ○ | ○ |
| 10 | Aquaponics/ Hydro ponics | | ○ | ○ | | ○ | ○ |
| 11 | Alternative Media of Orchid Production | | | ○ | ○ | ○ | ○ |
| 12 | Bio-fertilizer/ Bio Control | | ○ | ○ | ○ | ○ | ○ |
| 13 | Feed Storage for Livestock during Flood | | ○ | ○ | | ○ | ○ |
| 14 | Goat Raising | ○ | ○ | ○ | ○ | ○ | ○ |
| 15 | Bio-gas using Animal Waste for Alternative Energy | | ○ | ○ | ○ | ○ | ○ |
| 16 | Fish Capturing during Flood Period for Subsistance | | ○ | | | ○ | ○ |
| 17 | Fish Processing for Value Adding for Increase Income | | ○ | ○ | ○ | ○ | ○ |
| 18 | Community Market for Self-Sufficiency | | ○ | ○ | ○ | ○ | ○ |
| 19 | Agro-Processing as income diversification | | ○ | ○ | ○ | ○ | ○ |
| 20 | Income Generation Activities during Flood and Post-Flood | | ○ | ○ | | ○ | ○ |
| 21 | Bamboo Variety and Local Knowledge for Flood Protection | ○ | | | | ○ | |
| 22 | Utilization of Bamboos for Agricultural Inputs | | ○ | ○ | ○ | ○ | ○ |
| 23 | Land Use/ land Ownership Survey using RS/GIS | ○ | ○ | ○ | ○ | ○ | ○ |
| 24 | JMC and Inter-Tambon Organization for Monkey Cheek Area | ○ | ○ | ○ | | ○ | ○ |

**Figure 3.3 Technical Papers Corresponding to Variety of Disaster Phase and Scale**