CHAPTER 9 STRATEGY OF MASTER PLAN FORMULATION

9.1 Basic Approach to the Master Plan

9.1.1 Concept of Master Plan

The Chao Phraya River Basin is composed of three (3) areas; namely, the Highlands, the Upper Central Plain and the Lower Central Plain. The characteristics of each area and its required measures have been examined to formulate the Master Plan of Flood Disaster Management for the Chao Phraya River Basin. The study area is outlined from flood disaster management aspects as follows:

1) The Highlands are the watersheds of the major tributaries of the Chao Phraya River Basin, which are the Ping, Wang, Yom and Nan rivers. The areas are covered by forest, but the forest area has been devastated and the degraded forest areas have been identified by the Royal Forest Department. For flood disaster management, restoration of the degraded forest areas and the improvement of forest management are required.

2) The Upper Central Plain is located at the Upper Nakhon Sawan and composed of the river basins of the Ping, Wang, Yom, Nan and Chao Phraya. During the 2011 flood in the Upper Central Plain the inundation started along the Yom River in late July and at Nakhon Sawan in early September. The areas are flat and have wide low-lying areas along the rivers, which have a functional role in natural flood retarding basin and partly habitual inundation areas in rainy season, but partly used as agricultural lands in dry season. For flood disaster management purposes, optimum measures are required for local core cities and the inundation area to promote controlled inundation.

3) The Lower Central Plain is located in Lower Nakhon Sawan and also has low-lying areas which are flood retarding areas in rainy season, but mostly used as irrigation area in dry season. During the 2011 flood, dyke breaches and overflows occurred mainly in the middle of September, and huge volumes of floodwater inundated Ayutthaya and Bangkok from early October to late October. The major protection areas are Bangkok and its vicinity and the local core cities along the Chao Phraya River. For flood disaster management purposes, optimum combination of structural and non-structural measures are required for the protection area of Bangkok and its vicinity as well as the local core cities, and for the inundation area to promote controlled inundation.

Basic conditions for structural and non-structural measures are as discussed below.

9.1.2 Setting of Basic Conditions (“A” to “F”)

The Master Plan is formulated by setting the basic conditions (A to F) and action countermeasures (a to h) as shown in Figure 9.1.1.

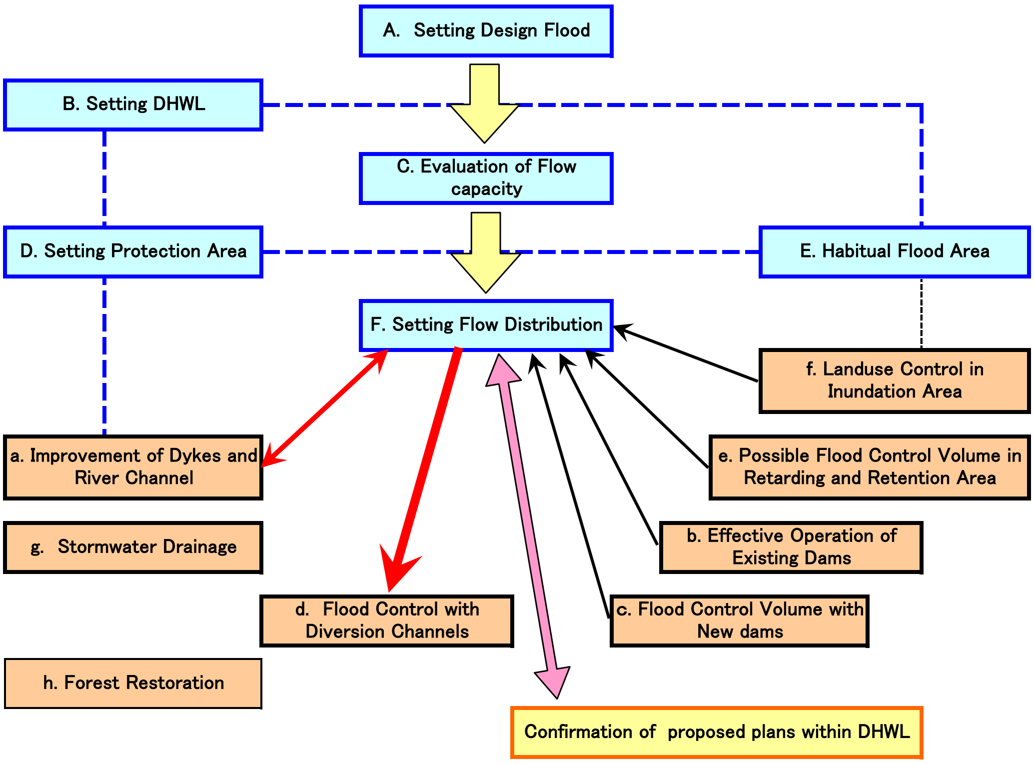

Figure 9.1.1 Basic Procedure of Master Plan Formulation

A: Design Flood

The scale of the 2011 flood was proposed as the design flood for the Master Plan. The Government of Thailand has applied a 100-year probable flood for the flood control plan of urban areas and a 25-year probable flood for agricultural/rural areas to all accros the country river basins. However, after the 2011 flood the Government decided that urgent measures of flood control like restoring the damaged flood dykes and heightening of road elevation must be undertaken to protect the urban areas against the flood crest similar to the 2011 flood.

According to the result of rainfall analysis by JST, the scale of the 2011 flood was assessed to be an approx. 100-year probable flood, which meets the above Government policy on design flood level. In additon, for considering different rainfall patterns, the study on structural measures was conducted by enlargement of the other rainfall patterns to the scale of the 100-year return period.

B: Design High Water Level (DHWL)

The setup of the DHWL is an important procedure to implement an effective river management including flood prevention, control for deliberate inundation, river improvement works and so on. The optimum DHWL of target areas was based on (i) the height of existing dykes and river banks; and (ii) the past flood water levels and design high water levels of restoration of dykes as well as the land use situation of protected areas.

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C: Evaluation of Flow Capacity

The flow capacity is imporatnt information to identify the weakness sections of the river and determine which countermeasurs to be implimented preferentially. The flow capacity of the existing rivers/canals was calculated at bankful level with one-dimensional unsteady flow analysis, considering the tide-affected and tide-unaffected compartment.

D: Protection Areas

To establish an effective comprehensive flood control plan, it is indispensable to define the area should be protected against huge flood like the 2011 flood. The economically important area (approx. 5,600 km²) which covers Bangkok and its vicinity up to the southern part of Ayutthaya and major regional core cities in the basin, were been defined as key protection areas by the Government of Thailand. Accoriding to this policy, the M/P aimed to mainly protect these areas from flooding.

E: Habitual Flood Area

Accroding to the past inundation records, some areas of the basin are consistently inundated. Consideirng the meteorological, hydrological and topograhpical featrues in the Chao Phraya River, it is much difficult to protect all areas from inundation with flood control facilities inclding construction of dams and river improvement works. Therefore, the flood-prone areas was delineated as controled inundation areas based on the past inundation areas and the land use map. And then, some management measures, mainly software measures such as land use regulation and disaster insurances were recommended.

F: Flow Distribution

The flow distribtuion of Chao Phraya River system will be changed by structural measures as followings,

1) Improvement of dyke and river channel
2) Effective operation of the existing dams
3) Effectiveness of new dams
4) Effective flow discharge capacities of diversion channels
5) Effective flood control by retarding and retention areas

Basically, a flood water after taking the countermeasures should not be larger than existing condition. Therefore, not only water level and also discharge are checked not to reduce the flood safety level due to the countermeasures.

9.1.3 Study on Countermeasures (items “a” to “h”)

(a) Improvement of Dykes and River Channels

To improve the flow capacity of the rivers/canals in the Chao Phraya River Basin, proper river improvement works were examined. In the Chao Phraya River basin, it is much difficult to prevent the flooding with river improvement works only, since the flow area of the river is absolutely not enough against inflow from river basins. In addition, if high and long dyke is constructed upstream, discharge from the upstream will increase and could cause floods inundation downstream. Therefore, the dyke elevation works should be conducted precisely considering flow capacity, land use condition along the river, the gap of flood safety level between the upstream and downstream, etc.

(b) Effective Operation of Existing Dams

Among the existing dams in the Chao Phraya River Basin, four (4) large dams, Bhumibol Dam, Sirikit Dam, Pasak Dam and Kwae Noi Dam, have high effectiveness for flood control during flood events. However, existing dam operation controlled by RID and EGAT gives priority to water use for irrigation mainly. In this study, considering existing water use condition such as irrigation, drinking and environmental flow downstream at C.2, existing dam operation rule was modified to release the water from dams adequately for both water use and flood control.

(c) New Dams

Over a hundred new dams are planned to be constructed by RID after the 2011 flood. Among the these dams, the effects of flood control of the Kaeng Sua Ten Dam in the Yom River Basin where no dam and Mae Wong Dam located in the Sakae Krung which seems to have a high effectiveness for flood control were examined. Regarding the operation of new dams, revised dam operation rule (refer to "countermeasures "b") was applied.

(d) Flood Control with Diversion Channels

The three flood diversion channels is proposed by the Government of Thailand; namely, East Diversion Channel, West Diversion Channels and Outer Ring Road Diversion Channel. Their total flow capacity is 2,000m^3/s or more. These floodways are so long and large that they seem to impact on economic and socio-environmental. In the study, not only the effectiveness of flood control but also influences on economic and socio-environmental were examined.

(e) Possible Flood Control Volume in Retarding and Retention Area

RID studied the flood control plan, conversion of thirteen (13) large agricultural low-lying areas (approx. 2,000km^2) into retention areas, of which five (5) low-lying areas are located in the northern part of Nakhon Sawan, and eight (8) areas are near Ayutthaya. They are all located in the low-lying agricultural area so that they would have functions of retarding flood water as natural retarding basins.

Originally, large agricultural low-lying areas have a high storage function to reduce flood volume flowing downstream. In this study, the improvement of this function by construction of surrounding dyke around the retention areas, water gates introducing inundated water into the retention areas and pump facilities draining inundated water and/or river water to the retention areas was examined.

(f) Land Use Control in Inundation Area

In the Chao Phraya River basin, it is much difficult to prevent flooding completely by structural measures. Therefore, non-structural measures such as land use regulation and establishment of building code etc. should be examined for mitigation of huge flooding like 2011 flood. In this study, inundation areas were divided into five (5) categories based on the inundation characteristics evaluated by flood analysis. Considering existing land use condition and inundation types, proper land use control were recommended. In addition, land-management including land use regulations and building code to avoid disorderly developments inducing the increased risk of flood damage were proposed.

(g) Storm water Drainage

Study on the drainage system for the protection area was conducted. As of the end of 2012, drainage pumps, total drainage capacity of approx. 1,600m^3/s was installed in the lower Chao Phraya River basin. In the study, the influence of drainage from inland to river was conducted examined and water level rising was estimated. In addition, whether the existing drainage capacity against inland flooding was enough or not was examined.

(h) Forest Restoration

By restoration of the degraded forest area, which consists of 20% of the forest area in the Chao Phraya River Basin, the water-retaining function in the upper including Ping River, Wang River, Yom River and Nan River seems to be improved, which also contributes to the improvement of stabilities of riverbed and reduction of sediment disasters. In this study, current forest conditions upstream of the Chao Phraya River Basin were reviewed and activities of re-foresting by Thai side were examined.

9.1.4 Evaluation of Combination of Counter Measures

Under the basic conditions (item "A" to "F"), the best combination of countermeasures (item "a" to "h") for the flood control in the Chao Phraya River Basin was examined and evaluated with the calculated water levels and DHWL. From the aspect of flood protection, it is indispensable condition that water level after taking the countermeasures is lower or equal to DHWL. Naturally, the influence of the countermeasures to social/natural environment, the feasibility and the project cost etc. were considered to determine the best combination of countermeasures.

9.2 Study on Basic Condition

9.2.1 Design Flood

The 2011 flood which is assessed as 100-year flood probability was defined as the design flood for the Master Plan Study, which is explained in Chapter 7.

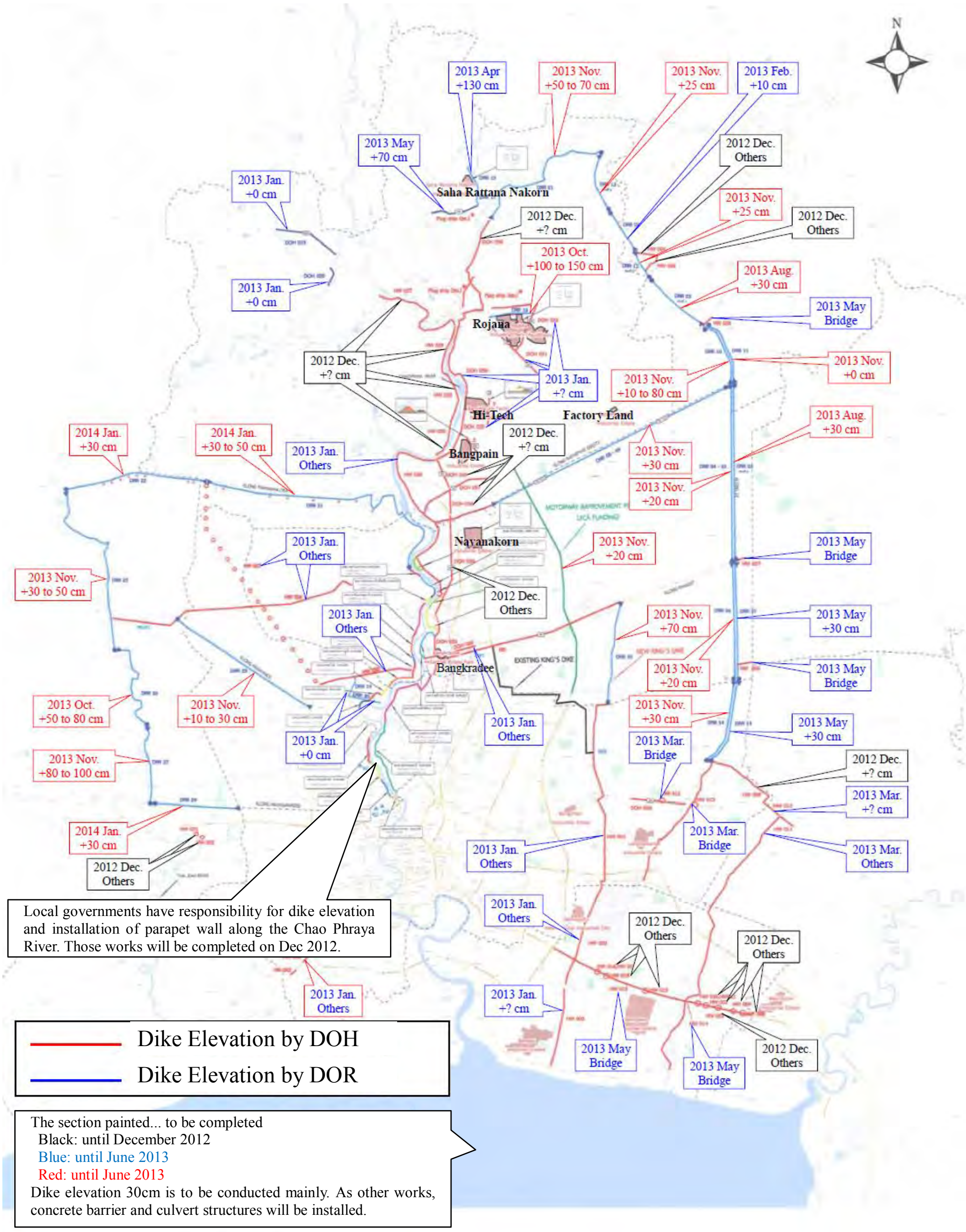
9.2.2 Design High Water Level (DHWL)

(1) Chao Phraya River

For planning a flood control plan including river improvement works, set up of Design High Water Level (DHWL) shall be necessary. For establishment of reasonable DHWL, DHWL should be examined considering the height of the existing dyke, road embankment playing role as protection dyke, land use condition along the river, recorded-high water level, tidal data etc.

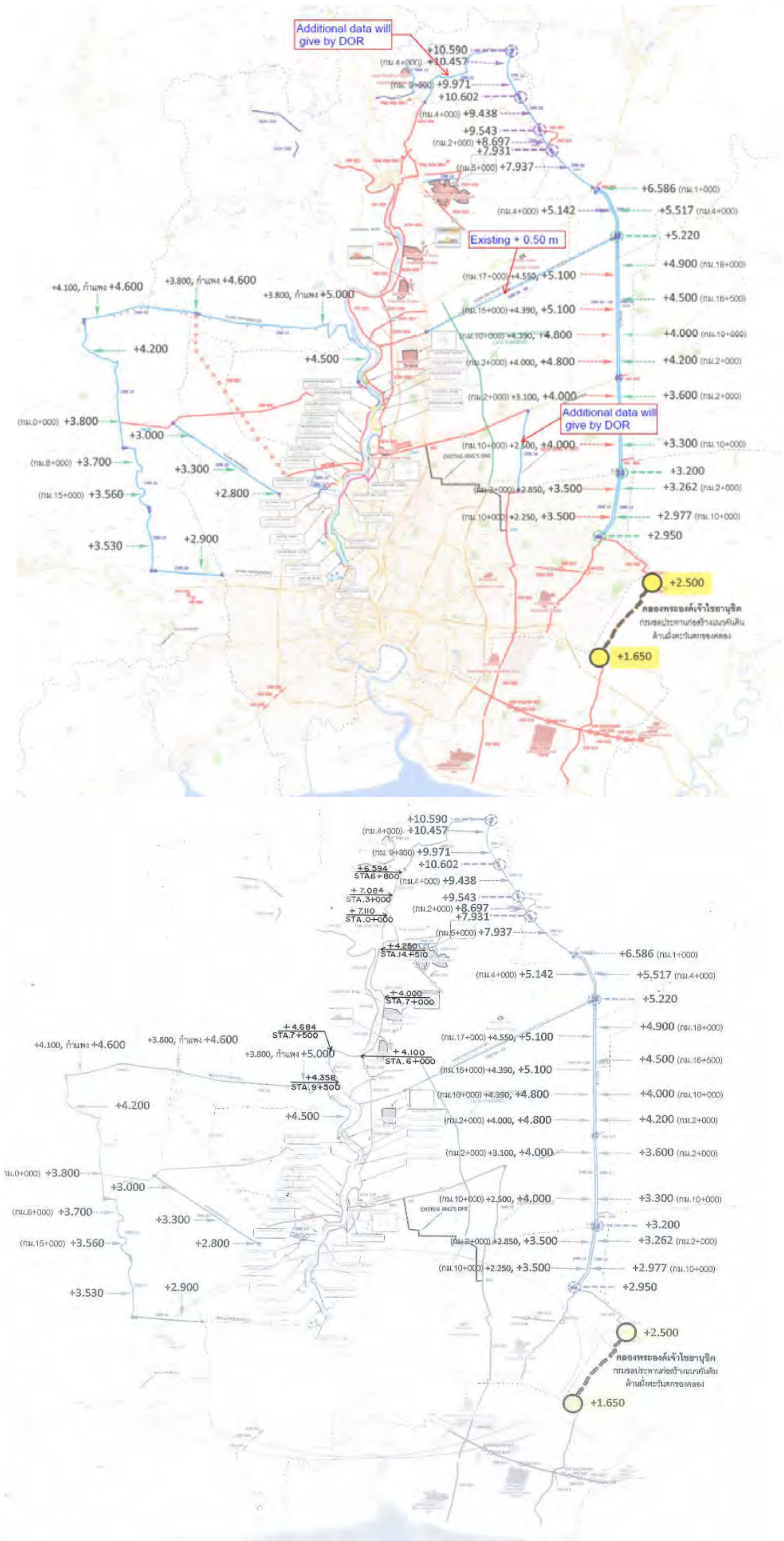
(a) Information of Present Embankment Work

The Department of Highways (DOH) and the Department of Rural Road (DOR) have already commenced the works for heightening the roads surrounding Bangkok and its vicinities that will be completed in 2013. Figure 9.2.1 and Figure 9.2.2 shows the location of project by DOH/DOR and design elevation of roads, respectively.



Data Source: DOH

Figure 9.2.1 Project of Heightening Road Surrounding Bangkok Metropolis



Data Source: DOH

Figure 9.2.2 Design Elevation of the Heightening Roads Surrounding Bangkok

(b) Condition of Dyke along the Chao Phraya River

General conditions of dykes at the downstream of the Chao Phraya River are shown in the Figure 9.2.3. There are two types of dyke. One is natural river banks (here in after "primary dyke") along the river and the other one is road-cum-embankment (here in after "secondary dyke") constructed along irrigation canals. The distance between primary dyke and secondary dyke is about 100 m to a few km, where a lot of houses are located. The following figure, which is a satellite image at the middle of November, 2011 (declining stage of the 2011 flood) shows the secondary dykes preventing overflow from the Chao Phraya River.

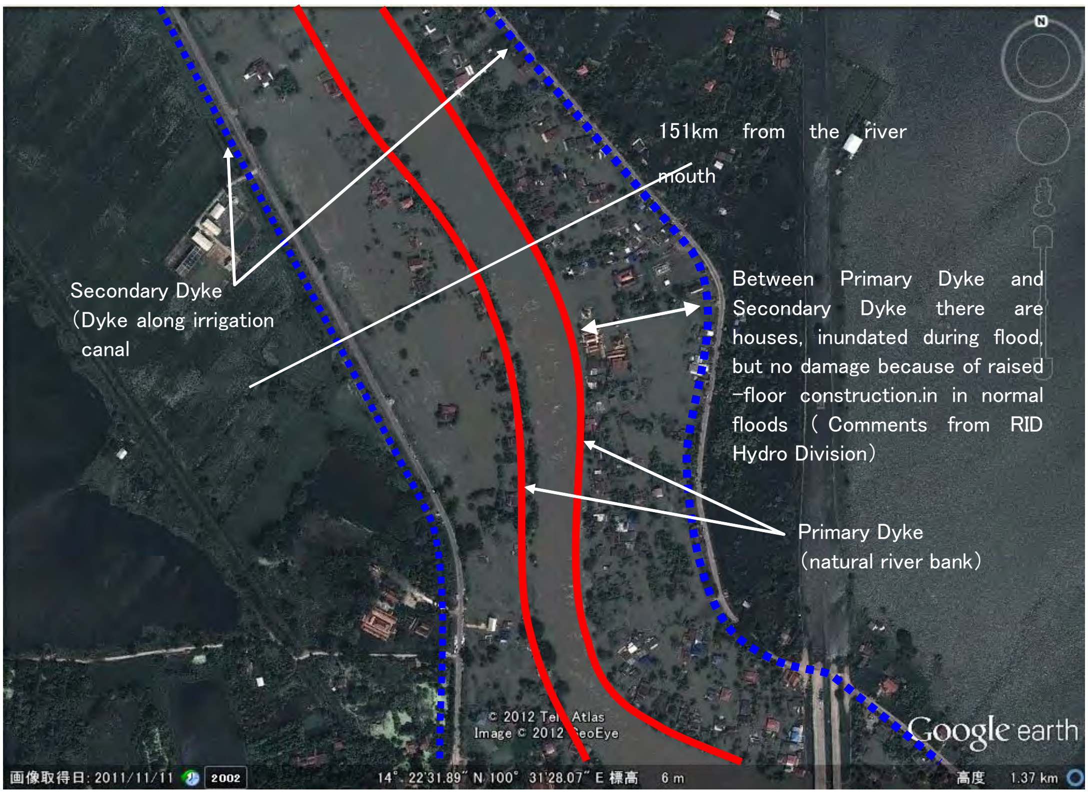


Figure 9.2.3 Secondary Dykes along the Chao Phraya River

The primary and secondary dyke is considered by the RID as follows:

- The RID is to improve the secondary dyke, but not to improve the primary dyke.
- In case of a big flood, sand bags shall be put on the secondary dyke to prevent overtopping.
- No compensation for the people living in between the primary dyke and the secondary dyke will be paid.
- Generally, the houses are raised and people lives in the second floor to avoid the inundation damage caused by floods. People can also move by boat during floods and have no difficulty for living.
- Both of primary and secondary dykes are important from flood warning aspects, because the RID gives flood warning to the residents based on the water level at the primary dyke.

Considering above mentioned RID concepts, DHWL was set up in this study for the secondary dyke because the RID utilize the secondary dykes as flood prevention.

(c) Elevation of Present Dyke

Figure 9.2.4 shows longitudinal dyke profiles of the Chao Phraya River. The elevation of primary dyke comes from the cross section data provided by RID, and that of secondary dyke comes from cross sections and the LiDAR data. Secondary dyke mainly consists of road embankment, where are partly lack of continuity, so the elevation of secondary dyke shall be extracted carefully from the LiDAR data. At downstream near Bangkok, parapet walls are installed by BMA. The record-high water level (yellow points) was marked from August to November 2011. Figure 9.2.4 also shows the dyke breach points (x indication).

In addition to the result, the interview survey from Counterpart was done and the following facts were found.

・ Downstream of the Chao Phraya River near Bangkok, water level was not beyond the elevation of existing dyke.

・ At vicinities of Ayutthaya and Nakhon Sawan, water level became higher than dyke and river water overflowed and flooded

・ Hydrology Division of RID headquarters said that at two provincial cities along the Chao Phraya River, Sing Buri (224 to 230 km from estuary) and Ang Thong (182 to 184 km), water level did not rise because river water from upstream decreased due to the dyke breaches at 240 km and 300 km. If dyke breaches at upstream did not occur, water level could increase and river water overflow at Sing Buri and/or Ang Thong.

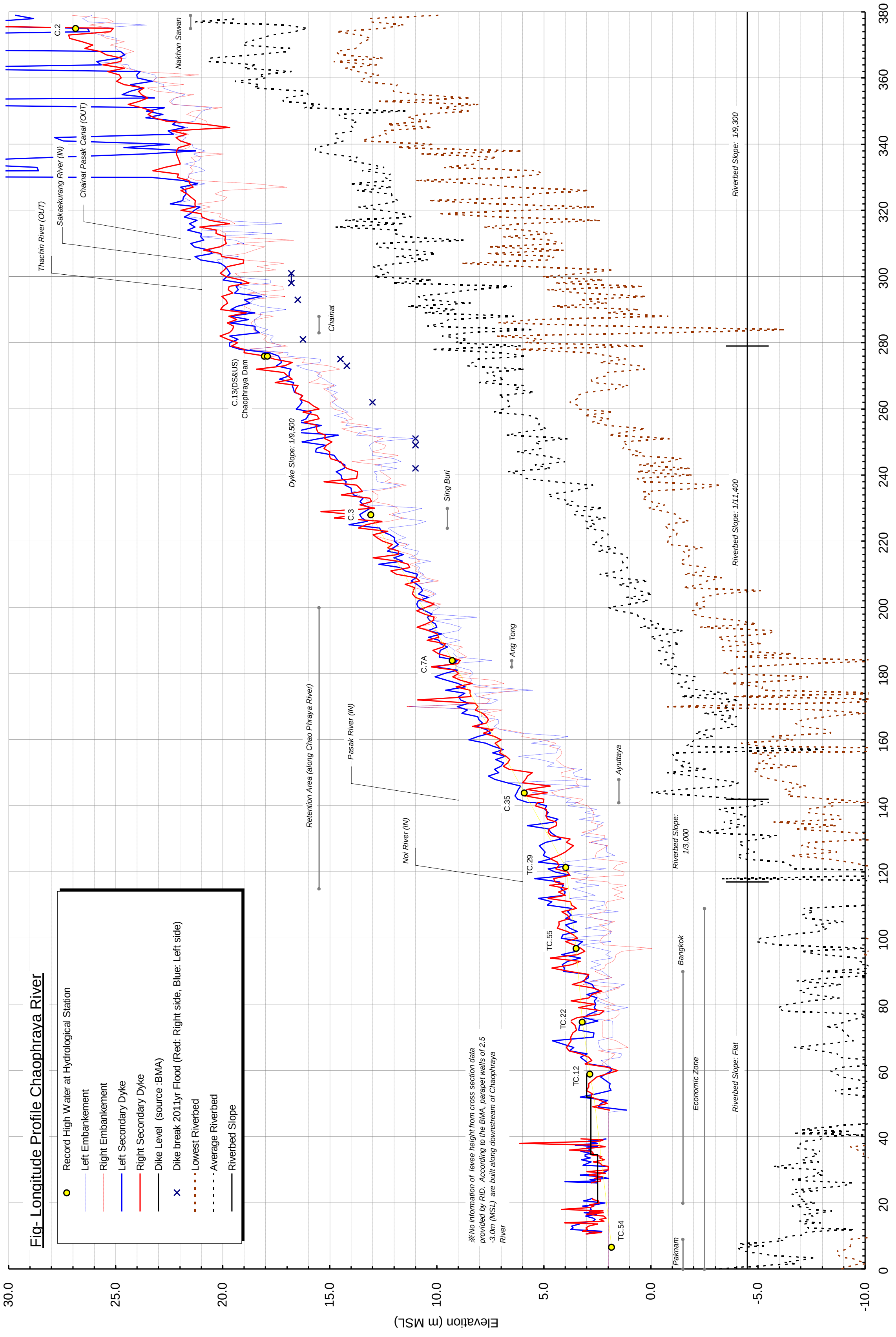


Figure 9.2.4 Longitudinal Cross Section of Chao Phraya River

(d) Identification of Control (Critical) Points/Sections

The critical points/sections where heightening is not applicable due to naturally and/or social limitations were selected, and DHWL was proposed.

Figure 9.2.5 shows the DHWL in the Chao Phraya River.

Table 9.2.1 Control Point for Set-up DHWL in Chao Phraya River

No.	Point/Section	Descriptions
1	Bangkok (20～90 km)	Along the river houses, commercial buildings, temples etc. are closely located by the river banks, and it is difficult to raise the existing dyke. Hence, DHWL is set to fit the existing dykes. For the tidal compartment the DHWL was set at a single elevation of 3.5 m (MSL) which is the flood level of 2011 Flood.
2	Ayutthaya (141～148 km)	Archaeological monuments of World Heritage are located along the river and dyke construction is not advisable. The DHWL is set at 3.5 m as around the ground elevation.
3	Ang Tong (182～184 km)	Along the river bank, there is a parapet wall against flood. The height is about 9.0 m (MSL). The DHWL is set as 8.5 m.
4	Sing Buri (224～230 km)	Sing Buri is selected as one of the local core cities for flood protection area. DHWL is set up for its secondary dyke. The height of the secondary dyke is required about 13.0 m (MSL) and the DHWL is set up as 12.5 m (MSL)
5	Chao Phraya Dam (278 km)	Chao Phraya Dam is located at 278 km from the river mouth. The design flood water level is 18.0 m (MSL); accordingly the DHWL is set up as 18.0 m. Observed flood water levels are 18.05 at the upstream nearby and 17.91 m at the downstream nearby.
6	Chai Nat (283～286 km)	At Chai Nat the secondary dyke of left bank is low in general. The DHWL is set up 18.0 m based on the elevation of the secondary left dyke.
7	Nakhon Sawan	There is no secondary dyke but primary dyke in Nakhon Sawan. The DHWL is set up as 25.5 m based on the height of bank, because of its dense residential land.

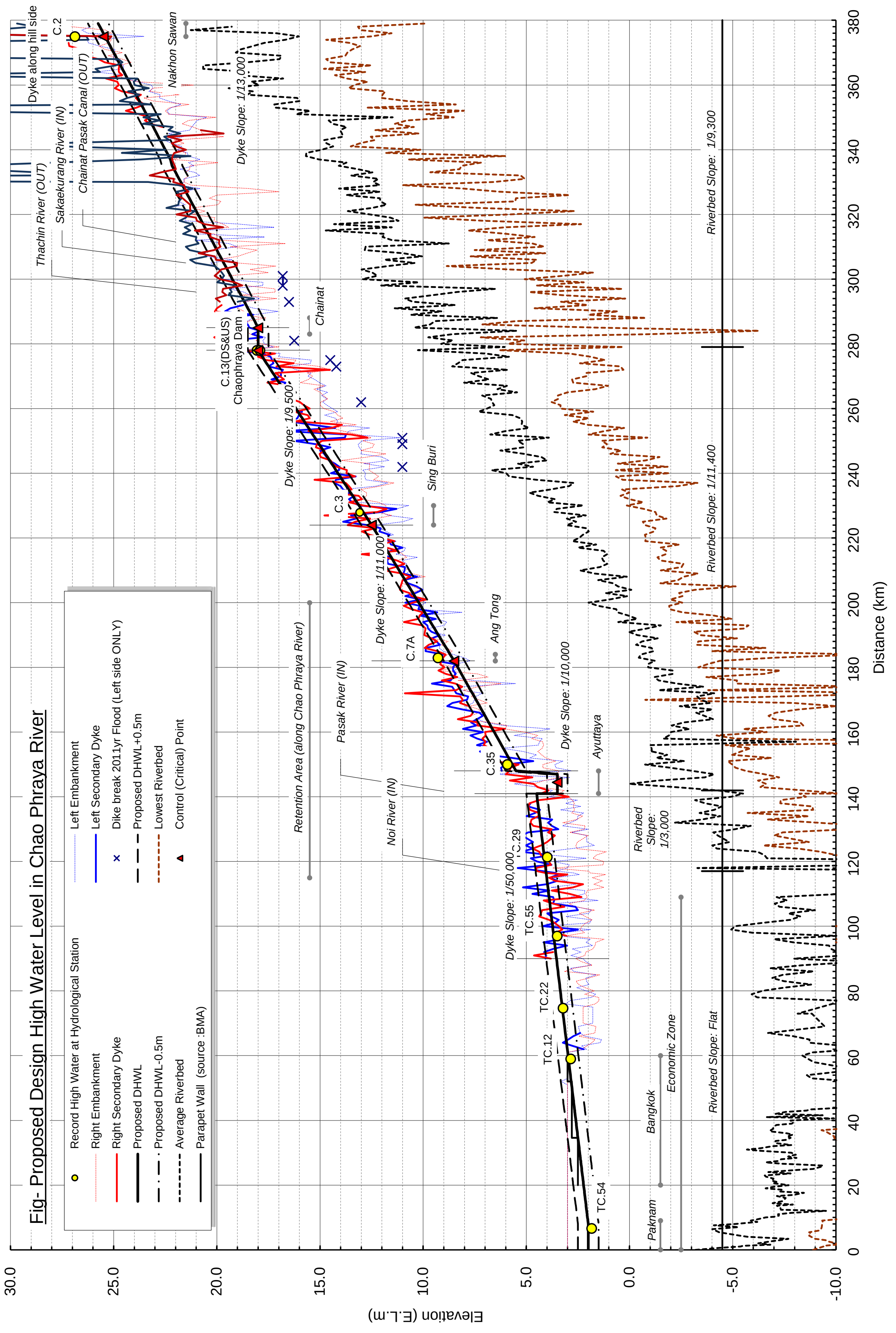


Figure 9.2.5 Design High Water Level in Chao Phraya River

(2) Tha Chin River

In the similar way of DHWL of the Chao Phraya River, DHWL of the Tha Chin River was set-up. Considering 1) construction of road dyke surrounding economic zone by DOR & DOH, 2) sea tide and 3) land use condition along the river, initial DHWL is set up as shown in Table 9.2.2.

Figure 9.2.6 shows the DHWL in the Chao Phraya River.

Table 9.2.2 Control Point for set-up DHWL in Tha Chin River

No.	Section	Description
1	0-10km	This section is completely affected by sea tide even high flood season and the calculated water level is flat. Since record high tide level is 1.90m at Samut Sakhon station, DHWL should be 2.0m.
2	10 – 116.2km	Road dyke for protection of economic zone has been constructed along the left side of the river, whose average design height is approximately 4m. DHWL at 116km should be 4.0m.
3	116.2 – 141km	141km is confluence point of Bunlue canal and the edge of road dyke (height: approx.4.7m).
4	141- 174km	DHWL in this section is connected between the existing dyke height at 141km and 174km.
5	174 - 262km	To ensure the existing height of road dyke because major urban city, SUPHAN BURI is located in 188km. The slopes and height of DHWL from 182km to 262km should be same as existing condition.
6	262 – 317.5km	The slopes and height of DHWL from 262km to 317.5km is same as that of existing dyke.

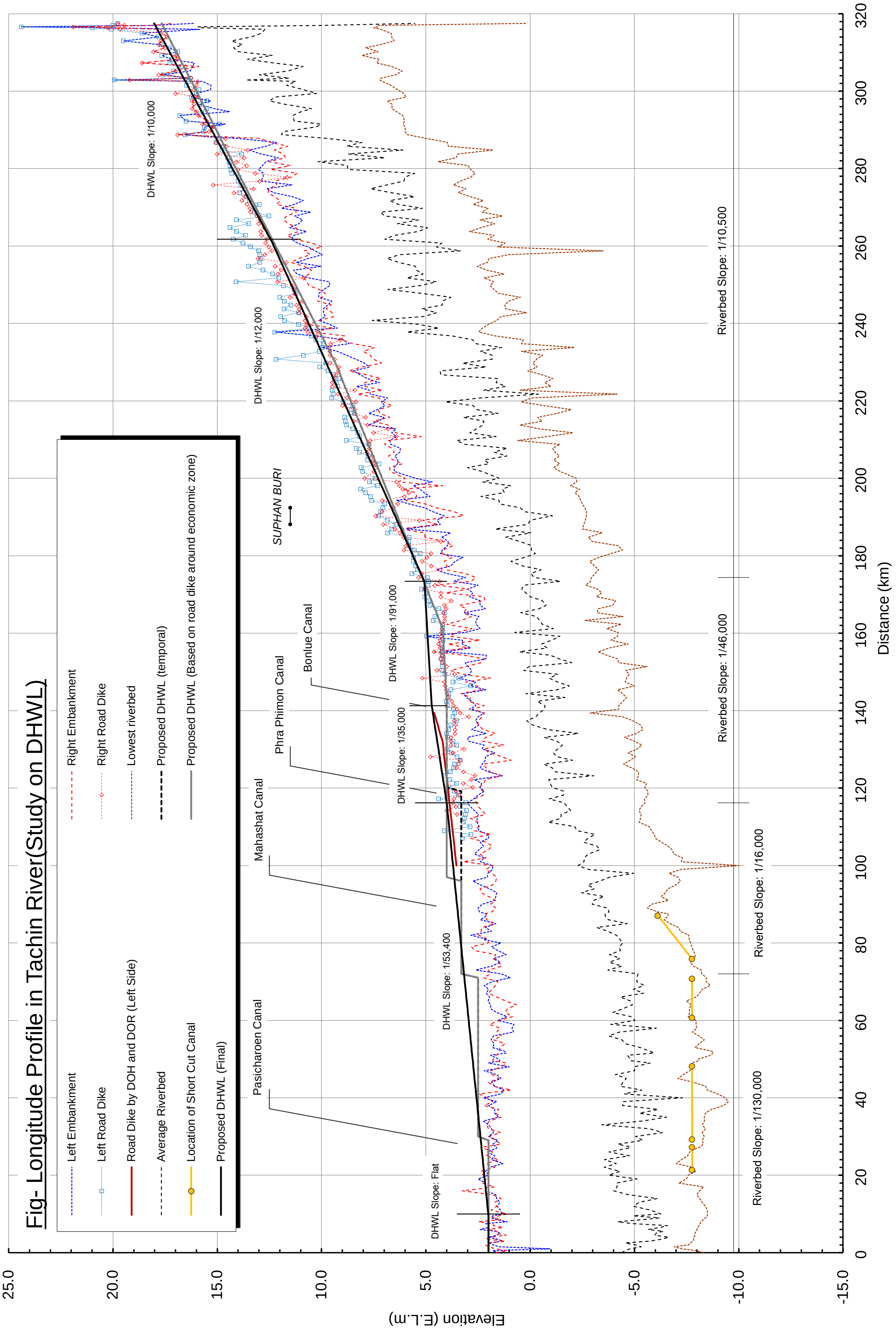
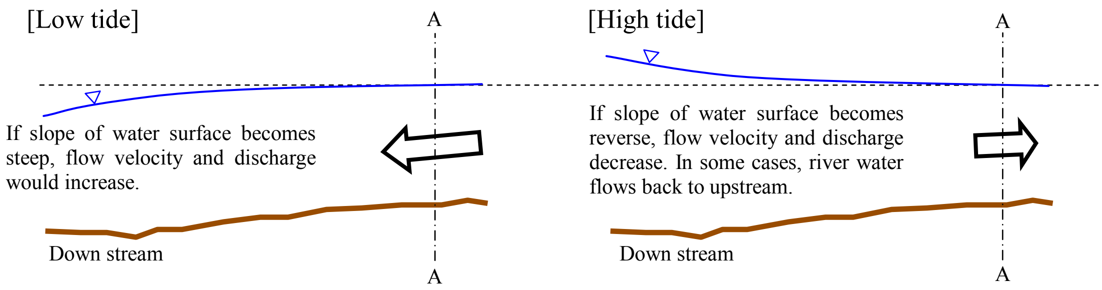


Figure 9.2.6 Design High Water Level in Tha Chin River

9.2.3 Flow Capacity

Flow capacity shall be calculated in order to understand existing rivers/canals safe level and determine necessary scales of flood control facilities and river improvement works. Usually, in no-tidal compartment, water level rises in proportion to increase of discharge and rating curve (H-Q formula) is made based on the relation between water level and discharge. And then, flow capacity at any given level, for example existing height of river bank, would be estimated.

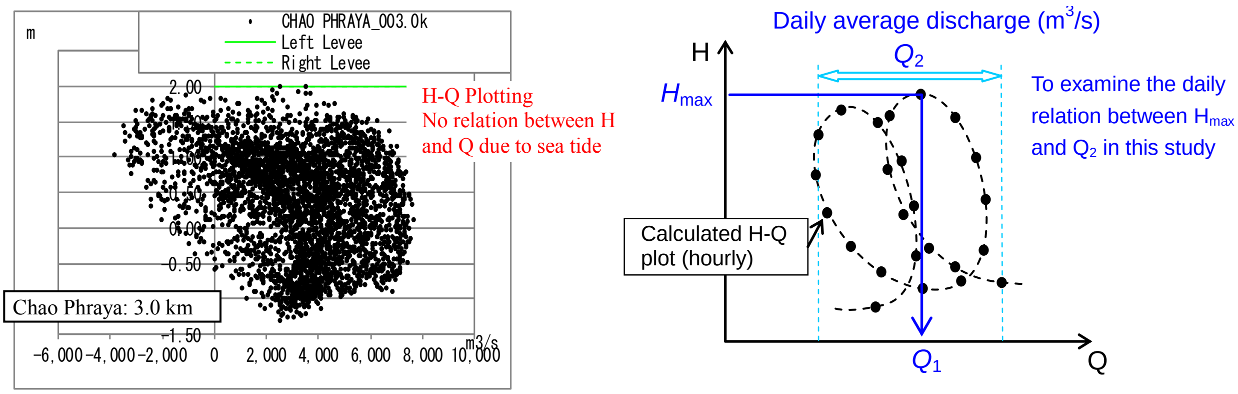
On the other hand, in tidal compartment, flow discharge is strongly influenced by tidal action and in some cases, reverse flow occurs at high tide. Therefore, even though water level is same, discharge is different within a day depending on sea tide.



Passing discharge thorough A-A section is different even if water level is same.

Figure 9.2.7 Influence of Sea Tide on River Flow

In this study, based on the relation of daily average discharge and daily maximum water level as shown in Figure 9.2.8, another rating curve is determined.



Two methods for making rating curve by reference to...

2) daily maximum water level H_{max} and instantaneous discharge Q_1

3) daily maximum water level H_{max} and daily average discharge Q_2 (apply to tidal compartment)

Figure 9.2.8 Development of Rating Curve in Tidal Compartment

Flow capacity of Chao Phraya River including other rivers/canals downstream from Nakhon Sawan is shown in Figure 9.2.9 to Figure 9.2.18 respectively. The evaluation height for flow capacity are height of both dike and embankment. Regarding to the Chao Phraya River and Tha Chin River, flow capacity at DHWL is described in the figures.

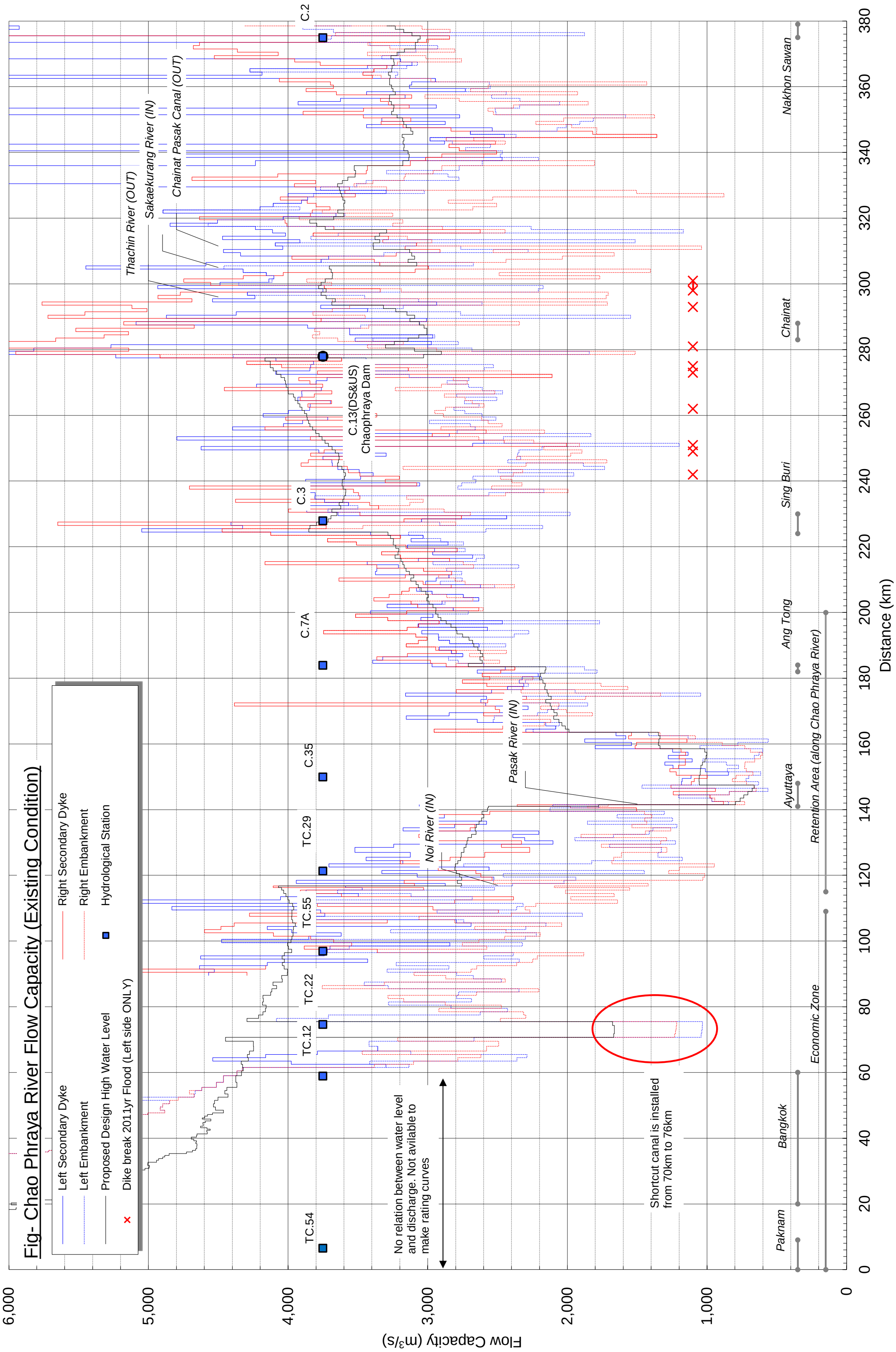


Figure 9.2.9 Flow Capacity of Chao Phraya River (River Condition: Existing)

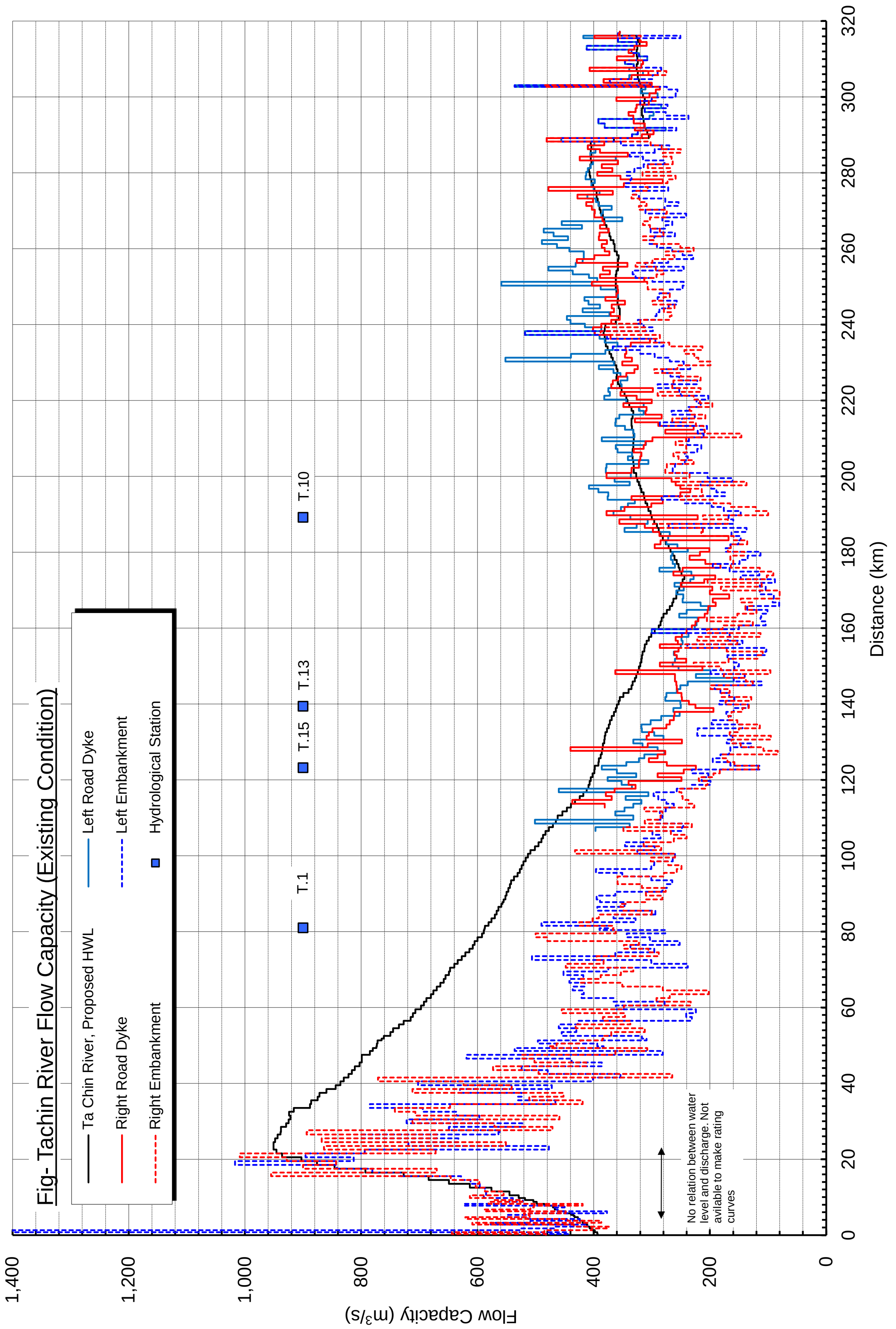


Figure 9.2.10 Flow Capacity of Tha Chin River (River Condition: Existing)

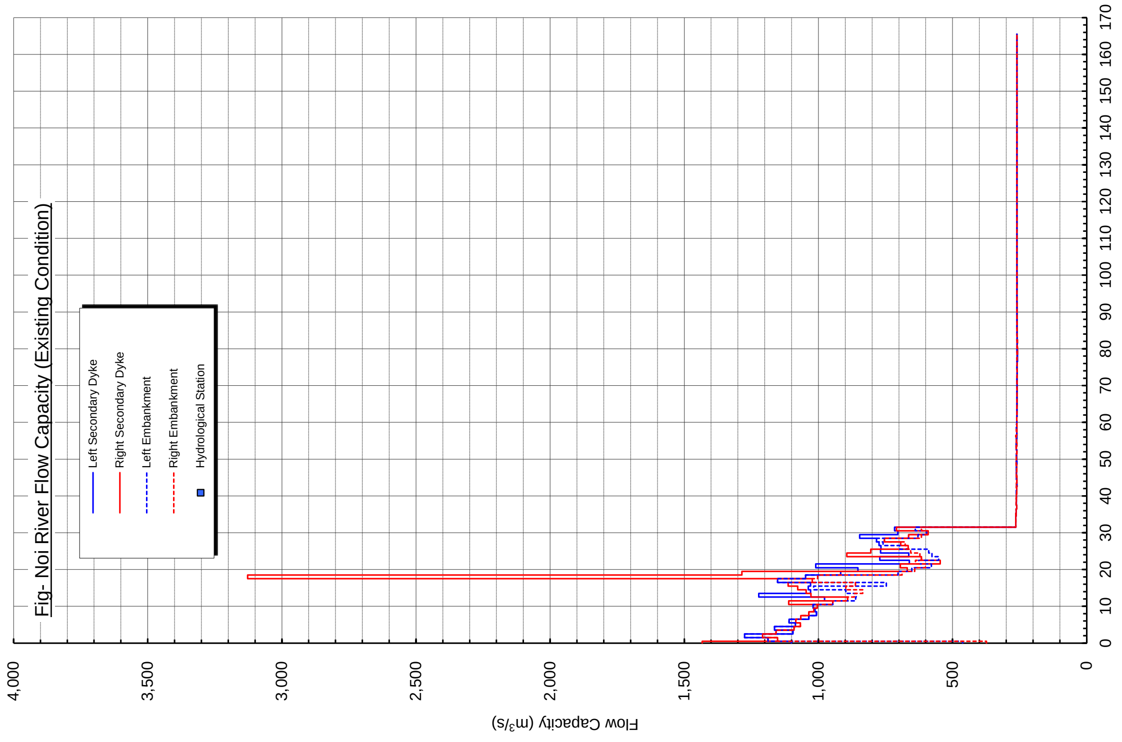


Figure 9.2.11 Flow Capacity of Noi River (River Condition: Existing)

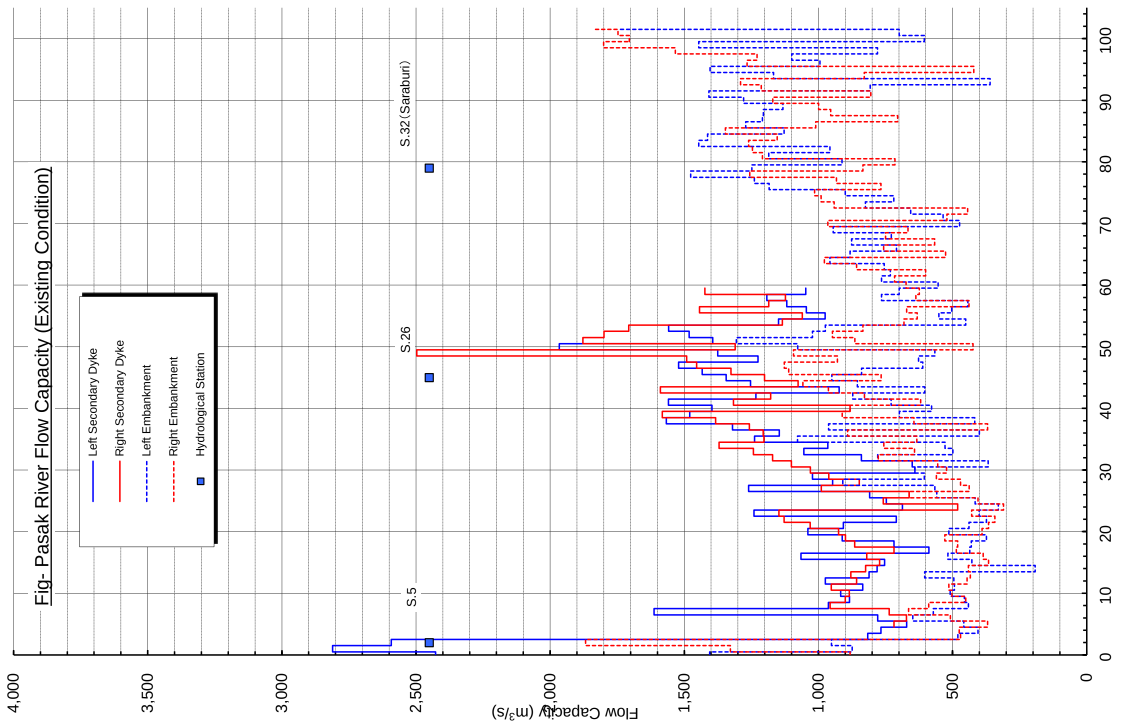


Figure 9.2.12 Flow Capacity of Pasak River (River Condition: Existing)

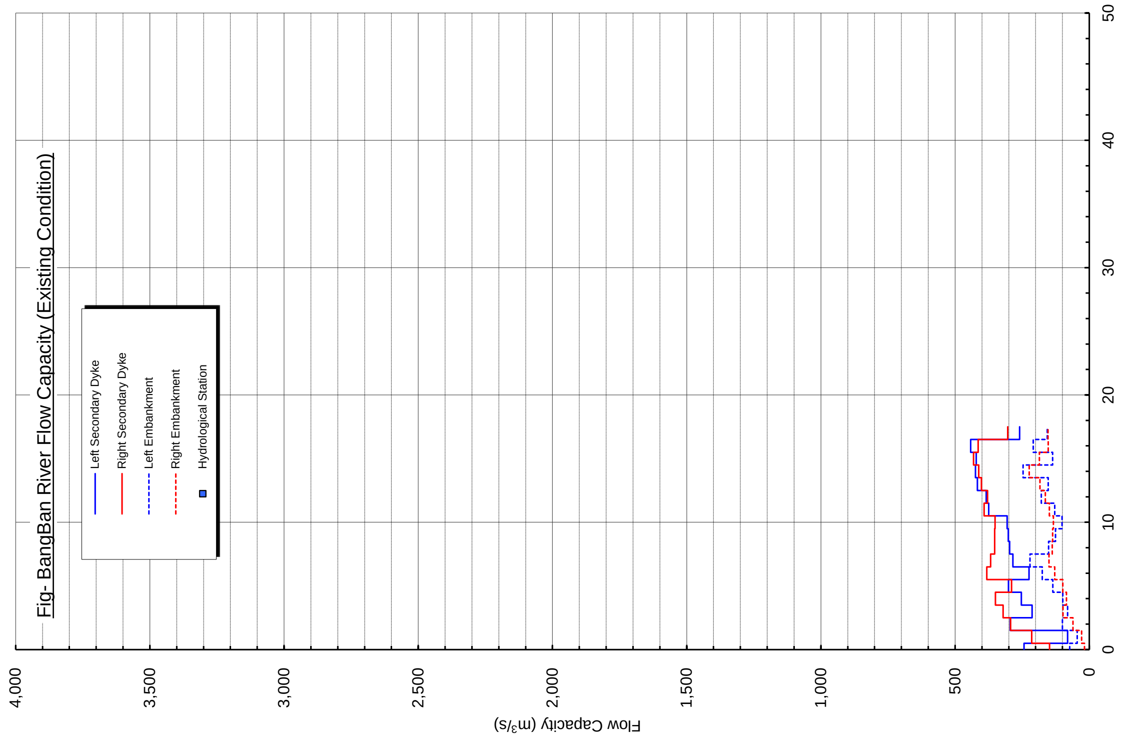


Figure 9.2.13 Flow Capacity of Bang Ban Canal (River Condition: Existing)

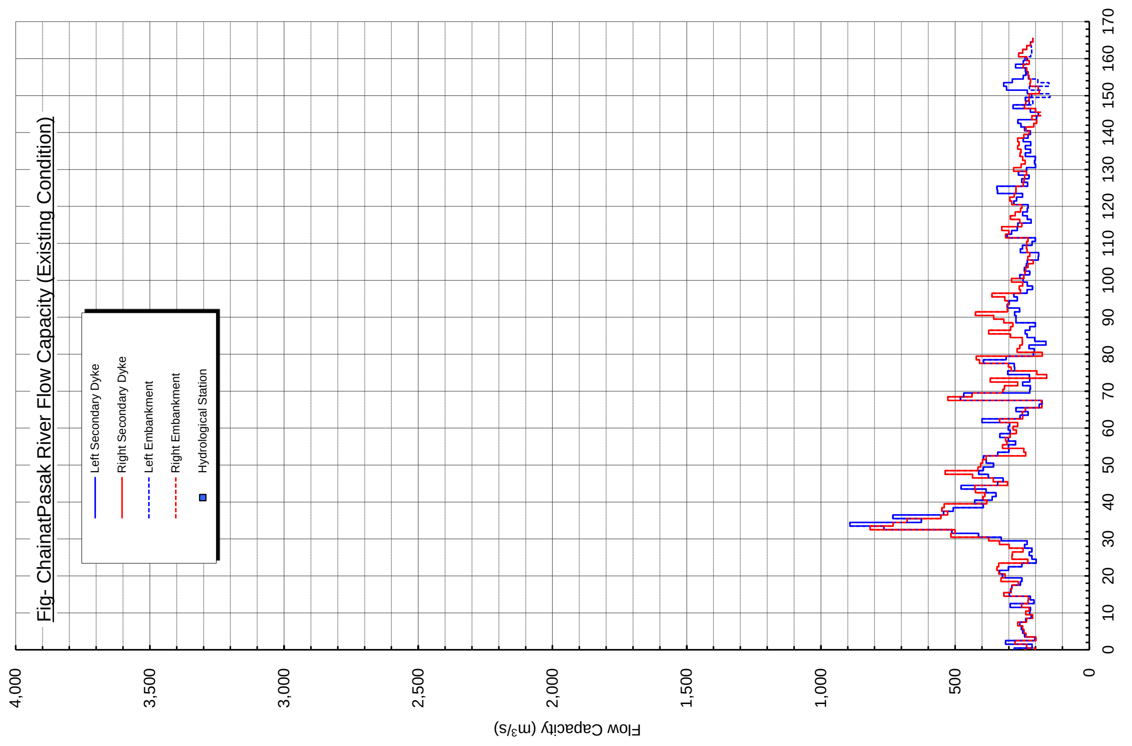


Figure 9.2.14 Flow Capacity of Chainat Pasak Canal (River Condition: Existing)

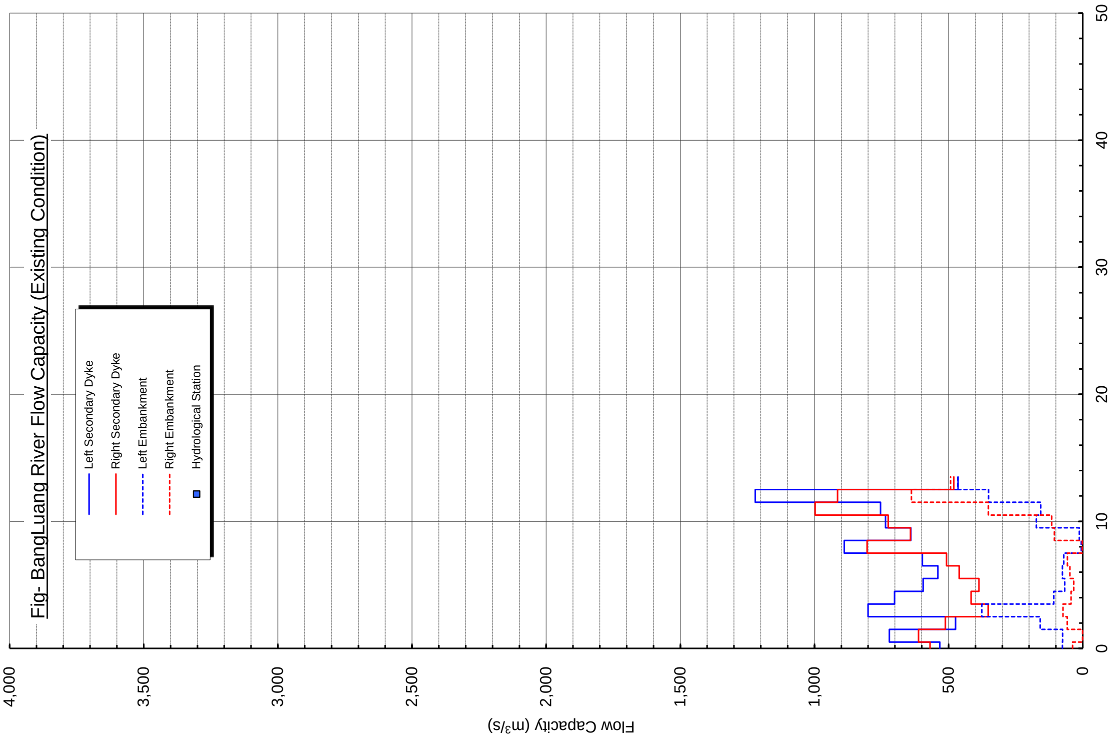


Figure 9.2.15 Flow Capacity of Bang Luang Canal (River Condition: Existing)

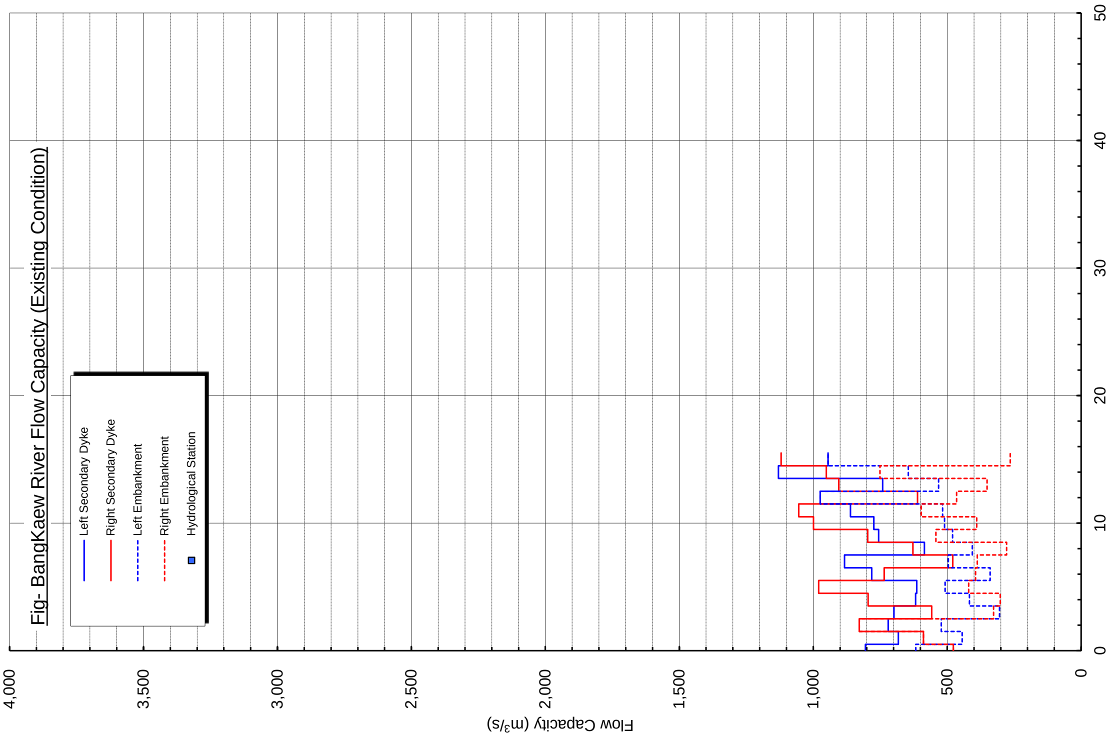


Figure 9.2.16 Flow Capacity of Bangkaew Canal (River Condition: Existing)

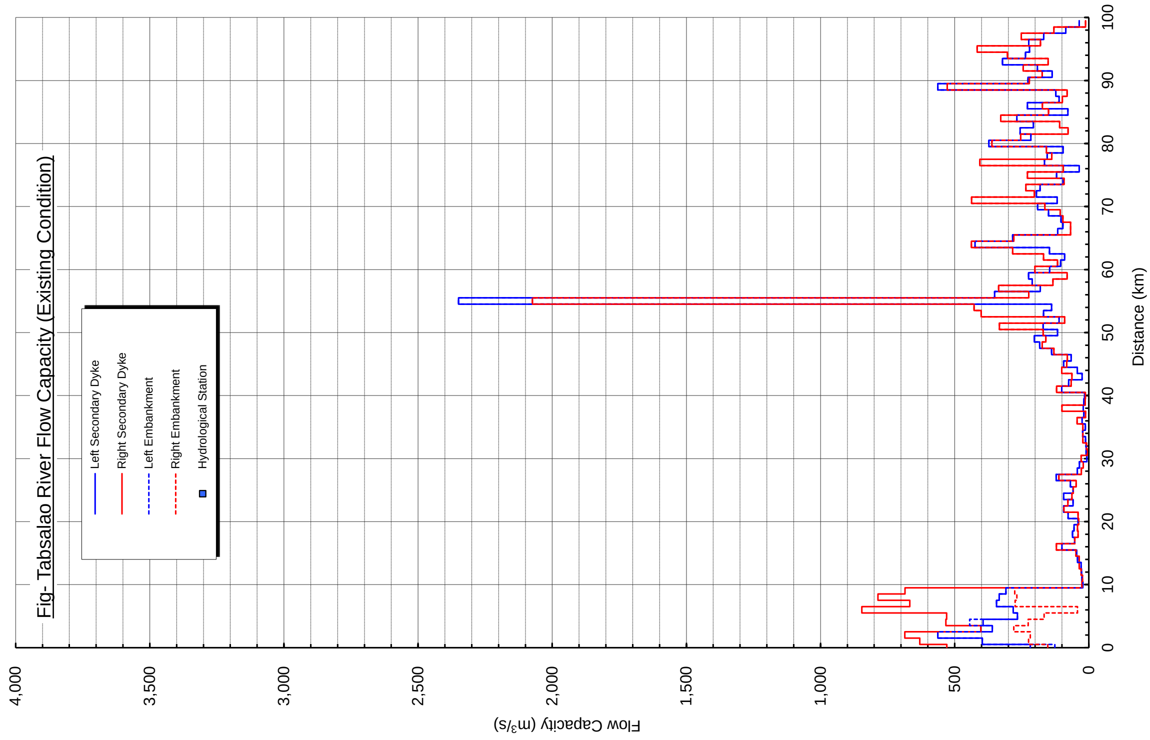


Figure 9.2.17 Flow Capacity of Tab Salao River (River Condition: Existing)

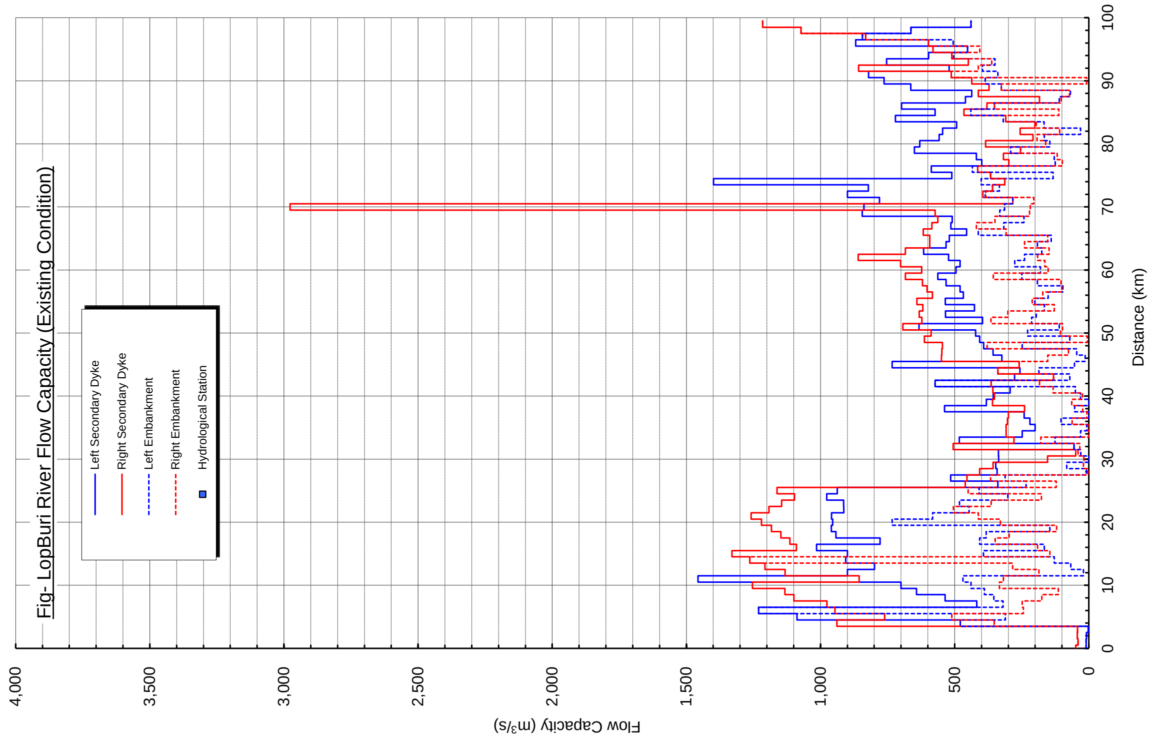


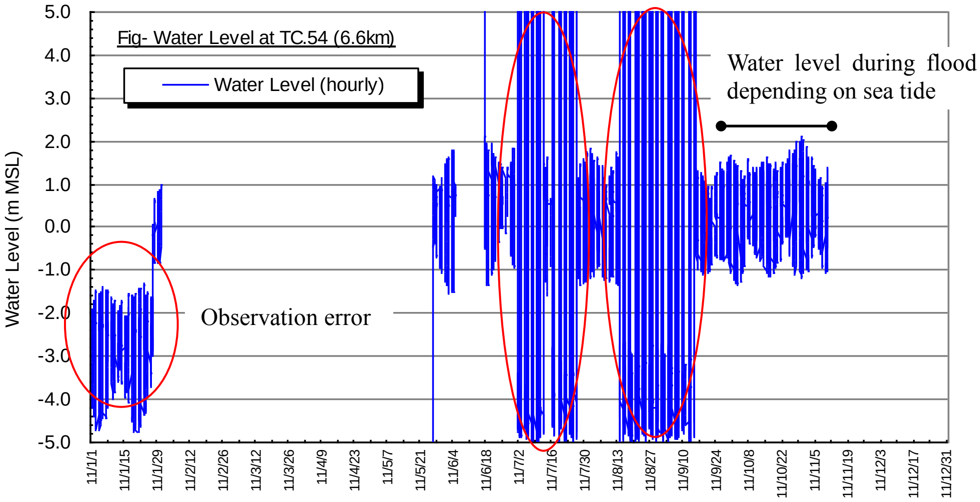
Figure 9.2.18 Flow Capacity of Lop Buri River (River Condition: Existing)

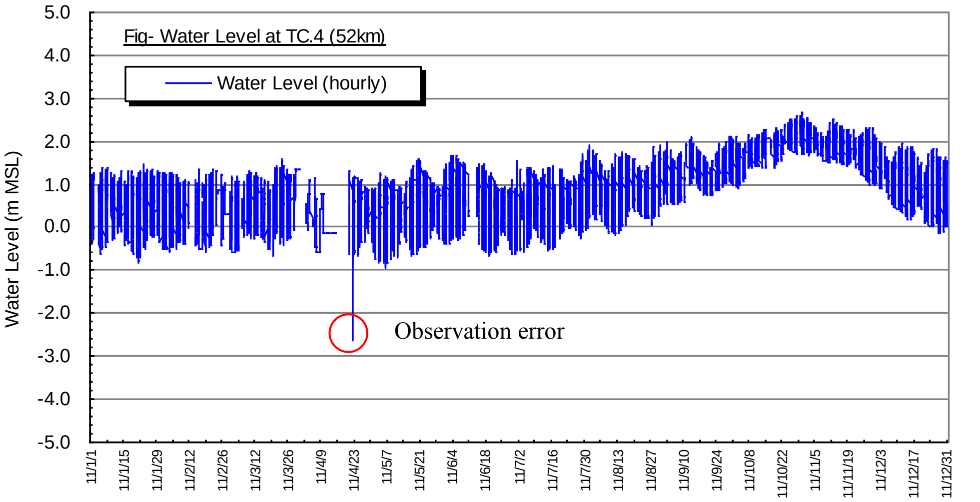
9.2.4 Setting Tidal Compartment

For setting DHWL ande evaluation of flow capacity, it is necessary to set a range of the tidal compartment. At the down stream of the Chao Phraya River, the RID's hydrological observation stations (C.35、TC.29 (C.29)、TC.55、TC.22、TC.12、TC.4 and TC.54) are located and the water levels of 2011 Flood at the each observation station are shown in the following figures.

At TC.54 observation station (6.6 km from the river mouth) located at the lowest reach, the water level was affected from the tide level even in the flood period from the early September to the middle of November. The tide effect was gradually decreased toward the upper reach and the water levels were ruled by the flood flows from the upper reach. At the observation station of TC.22 (75 km) the amplitude became low and did not show any tide effect in the flood period. Finally, at TC.29 (121 km), there is no effect of the tide during floodperiodso that the tidal compartment is assumed to be between TC.22 (75 km) and TC.29 (121 km).

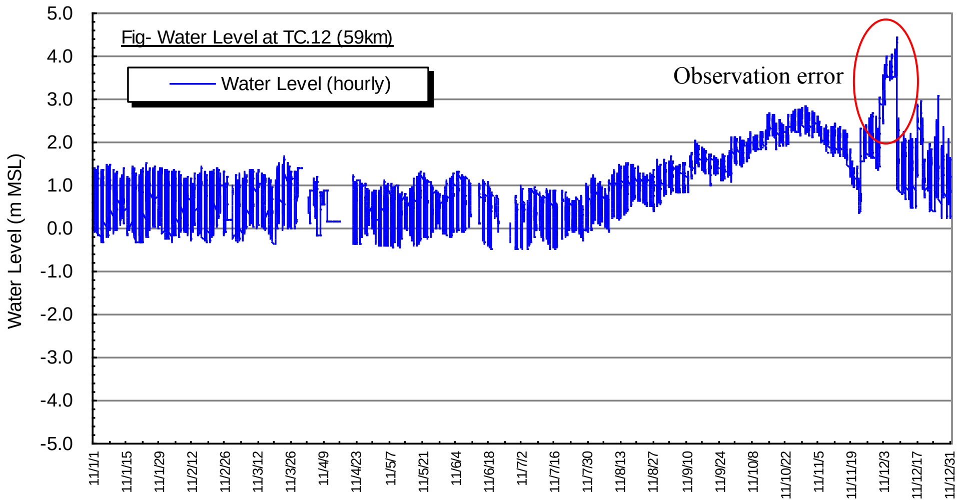
In this study the tidal compartment is up to the upper reach of Bangkok Metropolitan (90 km from the river mouth), at where the primary dykes are installed by BMA.

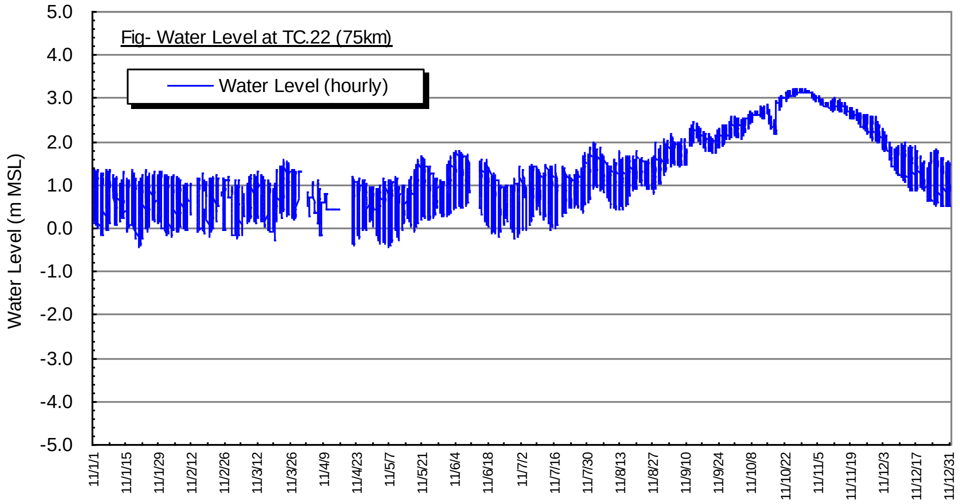


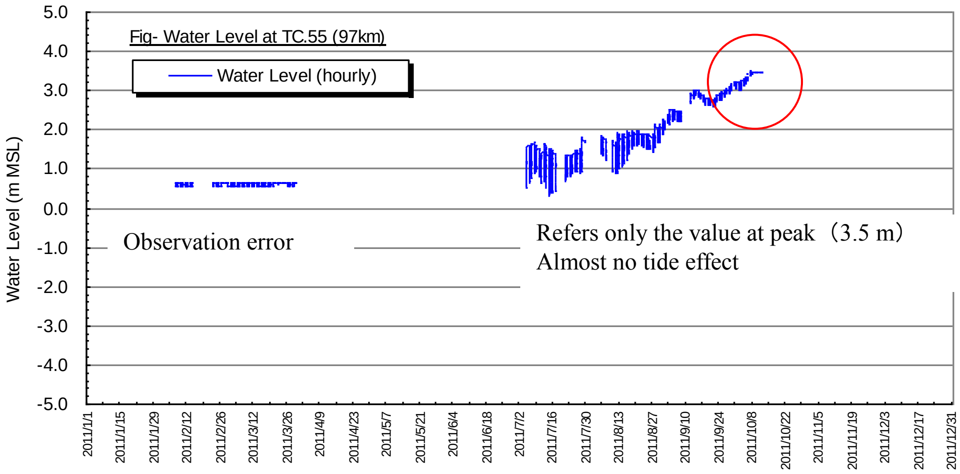


Data Source: RID

Figure 9.2.19 2011 Flood Hydrograph (1/3)

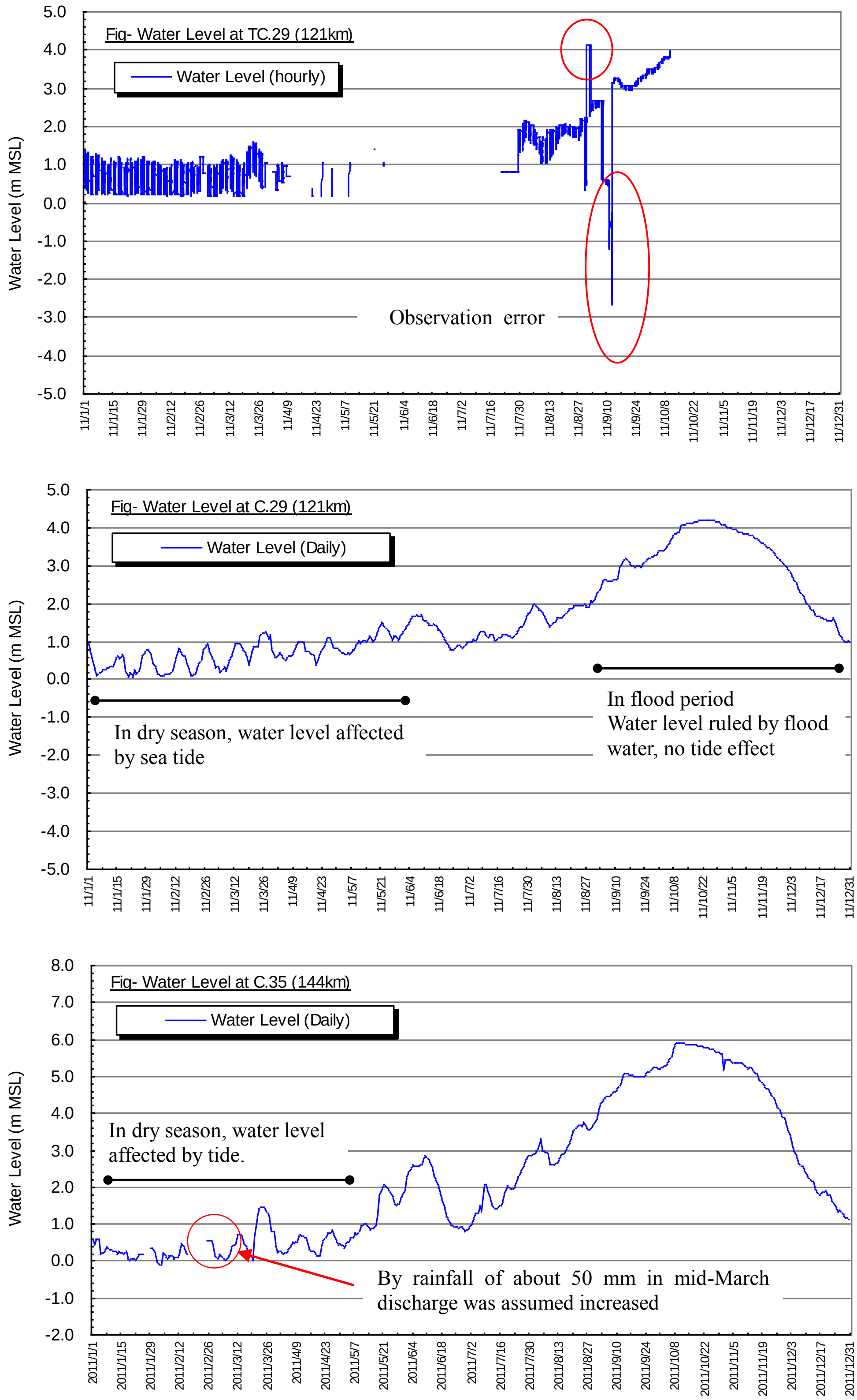






Data Source: RID

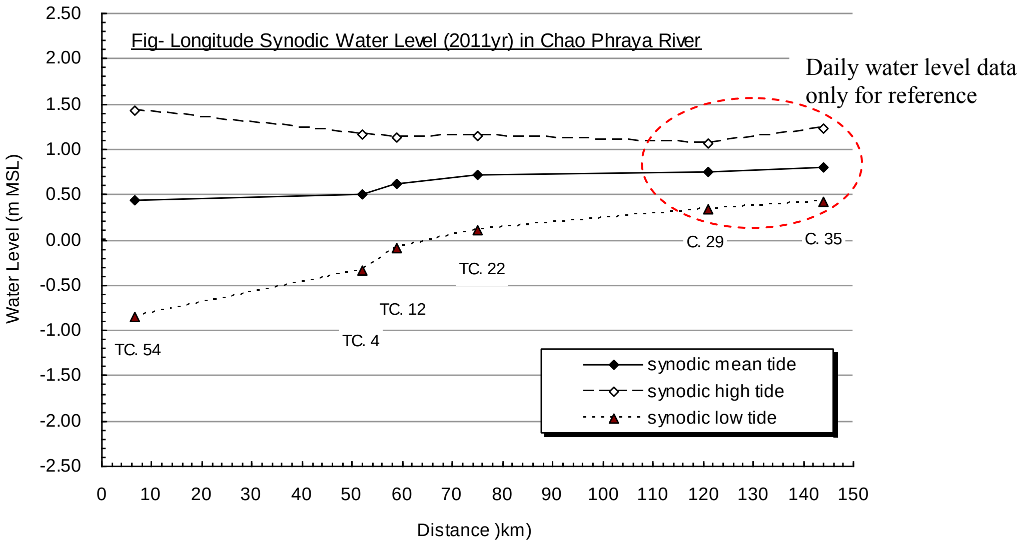
Figure 9.2.20 2011 Flood Hydrograph (2/3)



Data Source: RID

Figure 9.2.21 2011 Flood Hydrograph (3/3)

Figure 9.2.22 shows synodic tide levels (high, mean and low) in dry season (from January to June) longitudinally and the differences between high tide and low tide levels to decrease toward up stream.



Data Source: Royal Thai Navy

Figure 9.2.22 Average High and Low Tides at Syndic Month (2011)

9.2.5 Habitual Inundation Area

(1) Approach

The Chao Phraya River Basin has been affected by floods every year. Inundation areas are mostly low-lying agricultural areas, where people are living with the floods and conducting land use and water use due to the conditions. Hence, it is not practical to shut down the overflow and clean up the inundation area. On the other hand, economic development in Thailand shows striking progress and urban zone is spreading into the habitual inundation area. Because of this, the expanded urban area and industrial estates were damaged seriously in 2011 Flood. Hence, it is essential to define the protection area from floods.

(2) Study on Flood Prone Area

The area along Yom River and Nan Rivers in the upper Nakhon Sawan and the area along the Chao Phraya River in the lower Nakhon Sawan are frequently affected by floods.

Table 9.2.3 Land Use in Actual Inundation Area (Upper/Lower Nakhon Sawan)

Year	Inundated Area (km^2)	Land Use (km^2)								
		Residence	Commercial	Industrial	Agriculture	Paddy Field	Fish pond	Marsh	Pond & lake	Others
2006	19,962	1,017	68	101	953	13,324	825	2,085	752	837
2007	6,146	29	1	12	95	4,034	210	1,446	189	131
2008	6,272	104	4	15	123	4,118	190	1,381	162	175
2009	4,187	28	1	8	55	2,669	50	1,174	98	104
2010	17,801	585	20	66	698	12,882	685	1,882	342	643
2011	29,705	1,882	264	228	2,133	20,141	862	2,148	529	1,519

Note: Land use data, Land Development Department (LDD) (2009-2010 data). Inundated area, Thailand Flood Monitoring System http://flood.gistda.or.th/

Table 9.2.4 Land Use Ratio in Actual Inundation Area (Upper/lower Nakhon Sawan)

Year	Inundated Area (km^2)	Land Use (percentage of total)								
		Residence	Commercial	Industrial	Agri-culture	Paddy Field	Fish pond	Marsh	Pond & lake	Others
2006	19,962	5%	0%	1%	5%	67%	4%	10%	4%	4%
2007	6,146	0%	0%	0%	2%	66%	3%	24%	3%	2%
2008	6,272	2%	0%	0%	2%	66%	3%	22%	3%	3%
2009	4,187	1%	0%	0%	1%	64%	1%	28%	2%	2%
2010	17,801	3%	0%	0%	4%	72%	4%	11%	2%	4%
2011	29,705	6%	1%	1%	7%	68%	3%	7%	2%	5%

Note: Land use data, Land Development Department (LDD) (2009-2010 data). Inundated area, Thailand Flood Monitoring System http://flood.gistda.or.th/

9.2.6 Protection Area

(1) Introduction

The protection areas are defined with intentions of the Government of Thailand and it is the economic center (about 5,600 km²) and local core cities. The economic center was located at the southern part of Ayutthaya along the Chao Phraya River. The inundation area by the 2011 flood and in Bangkok and vicinity are shown in Figure 9.2.23.

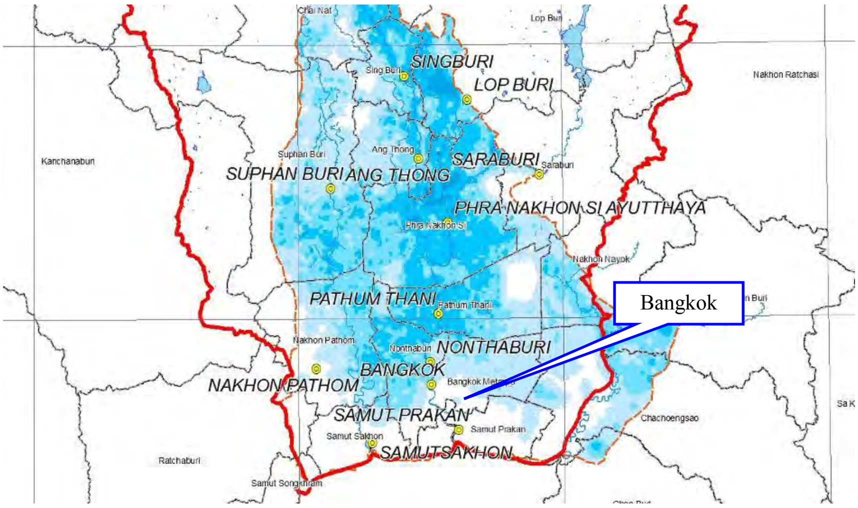


Figure 9.2.23 Inundation Area at Bangkok and its Vicinity
(From the result of Flood Mark Survey on 2012 by JST)

(2) Bangkok and its Vicinities

Figure 9.2.24 shows the flood protection area, which is located in the east side of Tha Chin River and in the southern part of Pasak River in Ayutthaya. Bangkok and its vicinities (Samut Prakan, Samut Sakhon, Pathum Thani, Nonthaburi, Nakhon Pathom, and Ayutthaya) are also shown in the figure. The area is composed of three (3) zones. The first zone is "Flood Protection Zone (Outer)." The second one is "Flood Protection Zone (Middle)." Finally, the last one is "Flood Protection Zone (Inner)". According to the website of ONWFP, the safety levels of the three zones are explained as follows:

- Outer Zone: Some parts of this zone are inundated in case of heavy rain.
- Middle Zone: Less inundated than in the outer zone, and
- Inner Zone: Inundation is allowed in very low areas only.

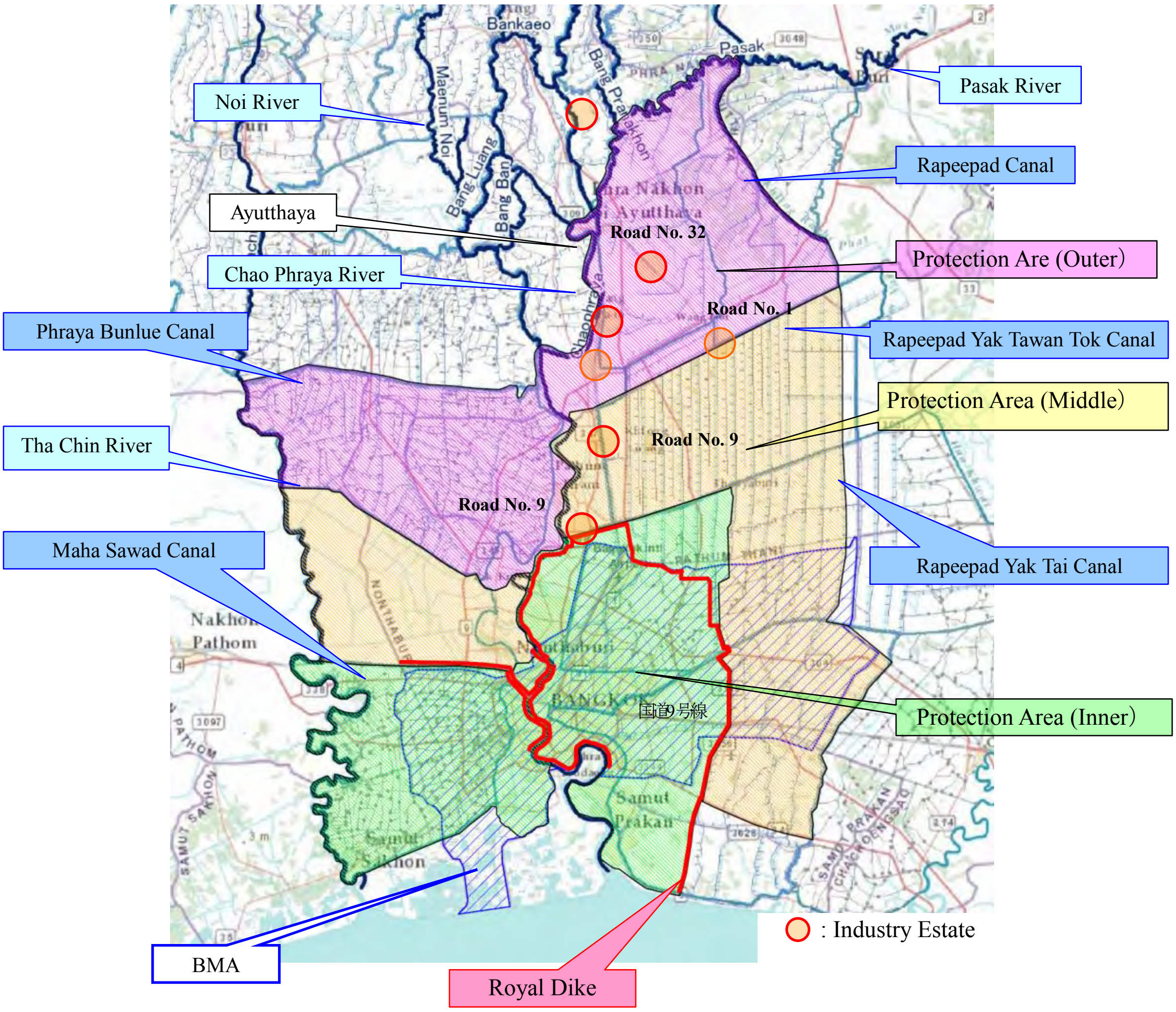


Figure 9.2.24 Flood Protection Area (Bangkok and Vicinities)

Table 9.2.5 Protection Area (Bangkok and Vicinities)

City	Area (km^2)	Population	Land Use (km^2)					
			Residential Area	Commercial Area	Industrial Area	Agricultural Area	Paddy	Others
Bangkok	1,355 (24%)	4,785,092 (60%)	311 (33%)	460 (74%)	28 (15%)	60 (11%)	145 (7%)	351 (26%)
Samut Prakan	493 (9%)	585,911 (7%)	68 (7%)	54 (9%)	45 (24%)	2 (0%)	0 (0%)	323 (24%)
Samut Sakhon	300 (5%)	164,377 (2%)	28 (3%)	32 (5%)	34 (18%)	35 (6%)	10 (0%)	161 (12%)
Pathum Thani	1,426 (25%)	896,444 (11%)	278 (29%)	18 (3%)	36 (19%)	231 (43%)	571 (29%)	291 (22%)
Nonthaburi	608 (11%)	1,020,670 (13%)	125 (13%)	40 (6%)	12 (6%)	100 (18%)	279 (14%)	51 (4%)
Nakhon Pathom	522 (9%)	203,570 (3%)	41 (4%)	13 (2%)	10 (5%)	81 (15%)	302 (15%)	76 (6%)
Ayutthaya	938 (17%)	279,832 (4%)	92 (10%)	6 (1%)	25 (13%)	34 (6%)	693 (35%)	87 (6%)
Total	5,641 (100%)	7,935,896 (100%)	944 (100%)	623 (100%)	189 (100%)	544 (100%)	2,000 (100%)	1,341 (100%)

* Values in parentheses is percentage of total
Note: Land use data Land Development Department (LDD) (2009-2010 data)
Population：Department of Provincial Administration (DOPA) (Data 31 December 2010)
{Population (Area Ratio) ＝ Population (Prefecture) X Protection Area / Total Area of Province)}

(3) Setting Other Protection Areas: Major Local Core Cities

Major local cities which have a high potential of flood risks were to be protected from floods. They are fourteen cities, Chang Mai, Lampang, Phrae, Sukhotai, Uttaradit, Phitsanulok, Phichit, Kamphaeng Phet、Nakhon Sawan, Chai Nat, Sing Buri, Ang Thong, Lop Buri and Suphan Buri. Area, population and land use of the major local cities are listed in Table 9.2.6. The area in the table is not area of protection area, but city area.

Table 9.2.6 Protection Areas (Local Core Cities)

City	Area (km^2)	Population (person)	Land Use (km^2)					
			Residential Area	Commercial Area	Industrial Area	Agricultural Area	Paddy	Others
Chang Mai	175.0	238,332	31.4	33.3	0.3	9.5	4.3	63.2
Lampang	1,192.6	233,447	93.9	28.6	4.7	178.3	178.1	620.6
Phrae	794.8	121,504	27.3	14.3	1.3	67.9	126.3	510.9
Sukhotai	553.4	105,993	32.0	2.9	1.0	14.9	274.2	47.4
Uttaradit	808.5	151,035	55.0	22.2	3.7	146.4	195.9	323.9
Phitsanulok	716.2	279,292	62.4	60.1	1.6	47.3	422.9	53.8
Phichit	547.2	112,497	37.4	7.0	1.0	55.3	258.0	1.6
Kamphaeng Phet	1,475.9	212,209	75.6	8.0	8.6	673.9	505.3	106.5
Nakhon Sawan	731.8	241,272	52.2	18.5	5.4	155.6	268.6	21.1
Chai Nat	282.7	71,830	27.2	6.9	1.4	17.6	187.4	16.5
Sing Buri	817.0	54,769	104.1	1.9	8.1	34.1	599.2	65.6
Ang Thong	113.3	56,393	22.6	1.4	1.5	10.1	64.4	0.0
Lop Buri	757.9	251,463	97.6	3.2	2.9	215.3	259.9	126.3
Suphan Buri	486.1	165,005	70.3	2.8	3.9	54.1	312.9	0.0
Total	9,452.4	2,295,041	789.0	211.0	45.4	1,680.3	3,657.5	1957.4

Note: Land use data Land Development Department (LDD) (2009-2010 data)
Population：Department of Provincial Administration (DOPA) (Data 31 December 2010)

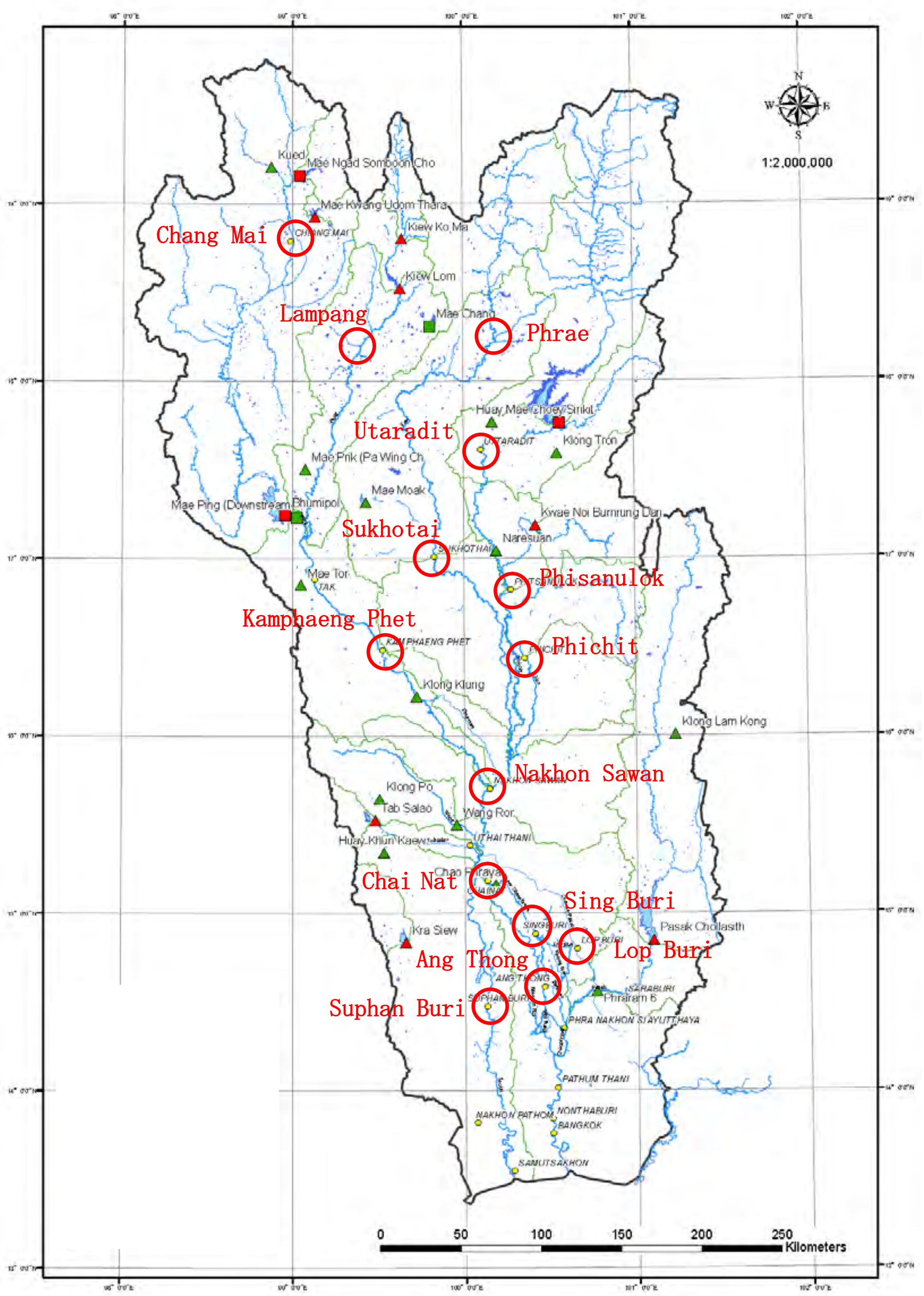


Figure 9.2.25　　Flood Protection Areas (Major Core Cities)

Flood prevention measures for local core cities and communities are under the responsibility of Municipalities. However, their abilities are technically and financially insufficient, therefore the Department of Public Works and Town and Country Planning (DPT) is totally to support them. The flood prevention measure is a polder system as same as the BMA and storm water drainage is a drainage system against 3 to 10 year probable flood scale.

Table 9.2.7 is an outline of the flood prevention plans for the local core cities. The highest water levels in 2011 flood which were estimated from the RID were considered for the design of dyke height at those cities. The free board is 20 ~ 30 cm basically.

Table 9.2.7 Flood Prevention Plans for major core cities by the DPT

City	Protection Area (km^2)	Beneficial households	Budget (Million Baht)	Project Status*	Protection (Dyke) level (m MSL)	Maximum Water Level of 2011Flood (m MSL)	Remarks
Chang Mai	5.0 (Phase-1)	13,910 (Phase-1)	2,990	Plan proposed	306	305	Phase 1 +2
Lampang	7.88	10,041	299.9	Under construction	293	288.5	
Phrae	4.3	5,000	227	Completed in 2010	167.5	166	
Sukhotai	No data	No data	No data	No data	No data	No data	No data
Uttaradit	No data	No data	170	Plan proposed	No data	No data	
Phitsanulok	28.8	3,000	75	Under construction	45.8	38.5	
Phichit	11.1	1,000	194	Completed in 2009	38	37	
Kamphaeng Phet	No data	No data	340	Plan proposed	No data	No data	
Nakhon Sawan	10.08 (phase-1)	20,000 (Phase-1)	1,346	Phase-1 completed Phase-2: Plan proposed	27.45	27.1	Phase-1+2
Chai Nat	No data	No data	No data	No data	No data	No data	
Sing Buri	No data	No data	No data	No data	No data	No data	
Ang Thong	3.0	1,850	428	Stage 1 completed	10.00	9.13	Stage 2 is under construction
Lop Buri	11.0 (Phase-1)	6,000 (Phase-1)	430 (Phase-1 +2)	Phase 1 is under construction	13	10.06	Proposal of Phase 2 is proposed.
Suphan Buri	37.7	36,810	1,170	Under construction	6.2	5.28	Stages 1 to 4

* : as of September 2012
Note: Some examples of ring dykes of flood protection measures are shown in the Supporting Report Sector L.

CHAPTER 10 MASTER PLAN

10.1 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.

10.2 Review on the Project

10.2.1 Project to be Reviewed

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.

(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 10.2.1, to ensure the continuity of country's development.

Table 10.2.1 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	

(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 10.2.2.

Table 10.2.2 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 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, 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.

(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:

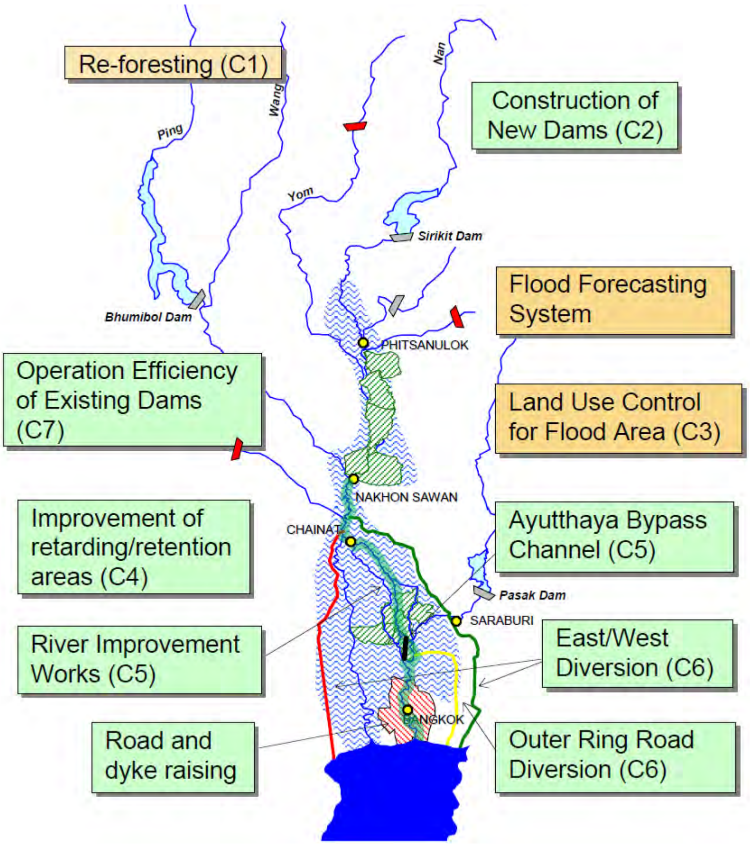


Figure 10.2.1 Countermeasures to be Reviewed

Table 10.2.3 Flood Mitigation Measures for Chao Phraya River Basin

Measures	Study Contents
1. Efficient Operation of Existing Dams	•Selection of Objective Dams •Study on Operation for Flood Mitigation •Study on Effects on Flood Mitigation and Water Use
2. Construction of New Dams	•Selection of Objective Dams •Study on Operation for Flood Mitigation •Study on Effect for Flood Mitigation
3. Retarding and Retention Areas	•Selection of Objective Areas •Study on Effect for Flood Mitigation
4. Flood Diversion Channels	•Set-up of Objective Routes: East, West and Outer Ring Road •Study on Diversion Discharge •Study on Facilities: Plan, Longitudinal Profile and Cross section, Diversion Weir and Tidal Barrages.
5. River Improvement	•Selection of Improvement Stretches •Improvement Methods: Widening, Embankment, Heightening of dykes, Deepening, Bypass channels
6. Forest Restoration	•Study on devastation conditions •Measures for Restoration of Devastated Forests •Study on Effects of Reforestation
7. Controlled Inundation	•Study on Habitual Inundation Area •Categorization of Inundation Area •Required Measures for Flood Disaster Management
8. Land Use Control in Inundation Area	•Study on Existing Land Use Regulation •Case Study •Proposition of Land Use Regulation
9. Inland Storm Water Drainage	•Extraction of Issues on Inland Storm Water Drainage in the Protection Zones •Preliminary Study on Inland Storm Water Drainage Plan

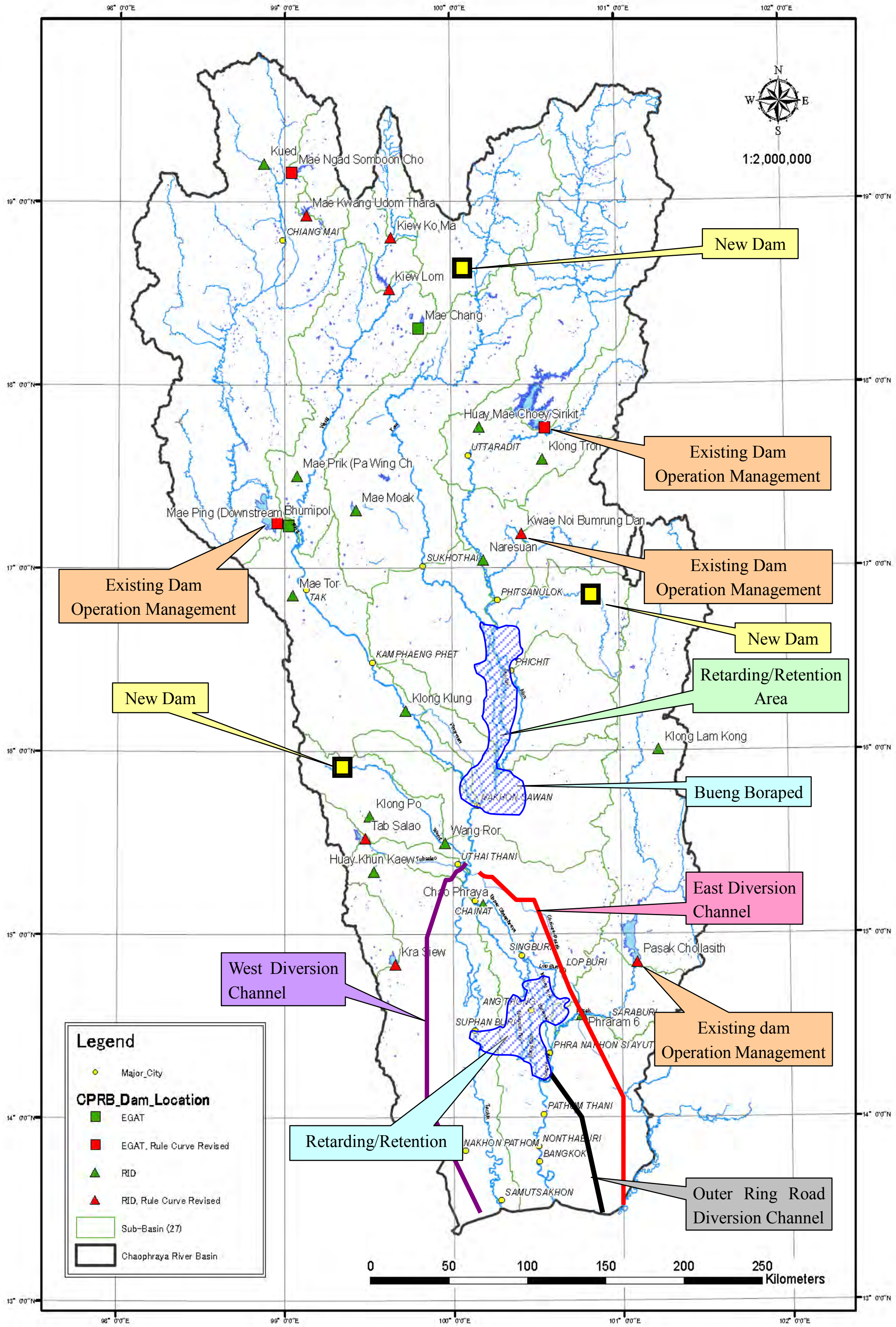


Figure 10.2.2 Location of Conceivable Flood Mitigation Facilities in Chao Phraya River Basin

10.2.2 Effective Operation of Existing Dams

(1) Introduction

In the Chao Phraya River Basin, there exist 10 dams with the storage capacity of more than 1,000 MCM. Out of these 10 dams, four (4) dams, Bhumibol Dam, Sirikit Dam, Pasak Dam and Kwae Noi Dam, have flood control functions for the whole river basin. The operation of existing dams during the 2011 flood had been effective for flood disaster management, considering that Bhumibol and Sirikit dams stored 12 billion m^3 of floodwater.

In this study, changing the current operation rule for the four (4) dams have been examined to improve their effectiveness on flood control considering the benefit as well as the loss for irrigation purposes. The results of the study are compiled in the Supporting Report (Sector G). For the Master Plan, the effective operation of the two (2) dams, Bhumibol and Sirikit dams, have been proposed to reduce the peak flood discharge at Nakhon Sawan.

(2) Specification of the Dams

The specifications of Bhumibol and Sirikit dams are as shown in the following table.

Table 10.2.4 Specifications of Bhumibol and Sirikit Dams

Specification	Bhumibol Dam	Sirikit Dam
Type	Concrete Arch - Gravity	Rockfill
Height (m)	154.0	113.6
Crest length (m)	486.0	800.0
Catchment area (km^2)	26,386	13,130
Reservoir area (km^2)	316.0	260.0
Crest level (m M.S.L)	261.0	169.0
Max. reservoir water level (m M.S.L)	260.0	162.0
Minimum water level (m M.S.L)	213.0	128.0
Storage at normal high water level (MCM)	13,462	9,510
Storage at minimum water level (MCM)	3,800	2,850
Effective storage (MCM)	9,662	6,660
Maximum design flood (m^3/sec)	Total 6,000 (Radial Gate x 4)	Total 3,250 (Radial Gate x 2)
Crest of spill way (m M.S.)0	242.9	150.5
Maximum discharge of intake pipe (m^3/sec)	Total 784.4 (8 sets)	Total 732.0 (2 sets)
Center elevation of intake pipe (m M.S.L)	207.0	110.0
Power generation (MW)	Total 779.2 (8 set)	Total 500.0 (4 set)

Figure 10.2.3 The Objective Dams, Bhumibol and Sirikit

(3) Inflow and Outflow of Bhumibol and Sirikit Dams during the 2011 Flood

The inflow and outflow of Bhumibol and Sirikit dams have been studied. The characteristics of inflow and outflow at both dams from 2000 to 2011 are summarized as follows:

(a) Characteristics of Inflow

- The average annual inflow of Bhumibol Dam was 6,640 MCM/year and that of Sirikit Dam was 6,800 MCM. Though the catchment area of Bhumibol Dam is twice larger than Sirikit Dam, the annual inflow volume of Bhumibol Dam was almost the same as Sirikit Dam.
- Maximum annual inflow volume at Bhumibol was 12,730 MCM/year in 2011, while it was 12,230 MCM/year at Sirikit Dam.
- Minimum annual inflow at Bhumibol Dam was 3,570 MCM/year in 2003, while it was 4,600 MCM/year at Sirikit Dam in 2009.
- Maximum monthly inflow at Bhumibol Dam was 2,990 MCM in August 2002, while it was 3,100 MCM at Sirikit Dam in August 2011. There is a tendency that maximum monthly inflow occurs in September at Bhumibol Dam and in August at Sirikit Dam.
- Maximum daily inflow at Bhumibol Dam was 310 MCM in October 2009, while it was 220 MCM at Sirikit Dam in August 2001.

(b) Characteristics of Outflow

- The average annual outflow from Bhumibol Dam was 6,220 MCM/year, while that of Sirikit Dam was 6,700 MCM/year. Both dams discharged almost the same volume as the annual inflows.
- Maximum annual outflow volume at Bhumibol Dam was 7,930 MCM/year in 2011, while it was 9,580 MCM/year at Sirikit Dam in 2011.
- Minimum annual outflow at Bhumibol Dam was 3,510 MCM/year in 2000, while it was 3,930 MCM/year at Sirikit Dam in 2010.
- Maximum monthly outflow from Bhumibol Dam was recorded at 1,950 MCM in October 2011), while it was 1,820 MCM from Sirikit Dam in September 2011, when the water level of both dams rose to almost maximum and the water was released through the spillways.
- Maximum daily outflow from Bhumibol Dam was 110 MCM in October 2011, while it was 70 MCM at Sirikit Dam in August 2011, when the water level of both dams rose to almost the maximum and the water was released through the spillways.

(4) Confirmation of Water Use Situation

(a) Dry Season and Rainy Season

From 2006, dry and rainy seasons are set as follows:

- Dry season: November 1 to April 30 and the planned outflows from the dams are finished (the water demand for irrigation is highest in the period from December to February).
- Rainy season: May 1 to October 31

Before 2005, the dry season and rainy season was January 1 to June 30 and July 1 to December 31, respectively.

(b) Minimum Outflow from Dam

It has been designated that the minimum outflows are 8m^3/s for Bhumibol Dam and 35m^3/s for Sirikit Dam as the maintenance flow for environmental preservation. (Source: Bhumibol Reservoir Operation Manual, Sirikit Reservoir Operation Manual)

(c) Planned Outflow from Dams in Dry Season

The purposes of the planned outflow in dry season include irrigation, environment preservation and domestic water supply. The required irrigation water discharge is estimated by each Regional Office of RID on the basis of prospected planting areas.

The required outflow is planned as follows:

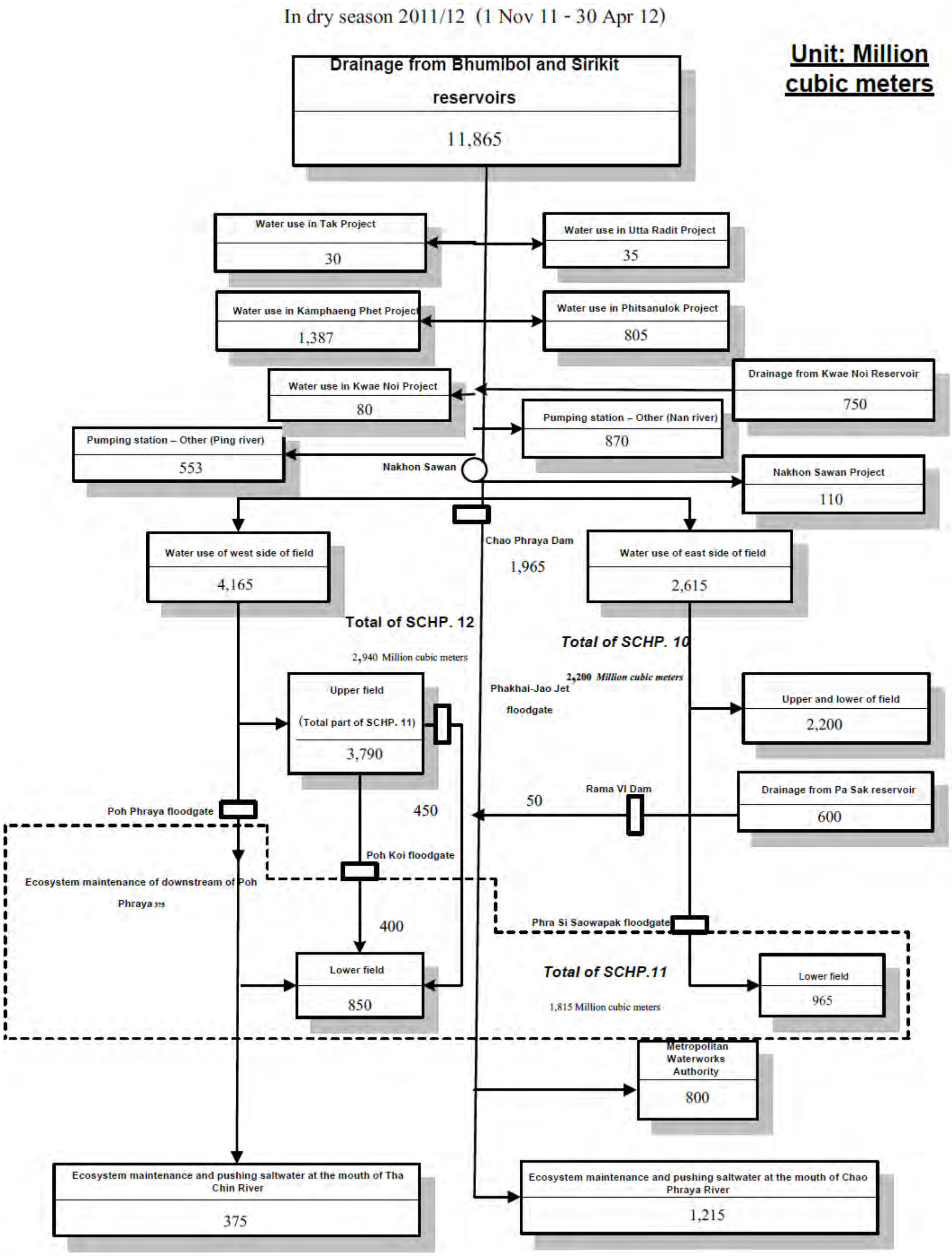
- The outflow is calculated based on the storage volume as of November 1, hence the planned outflow in each year is different depending on the storage volume.
- The planned outflow is considered in total of outflow from both Bhumibol and Sirikit dams.
- According to the record of outflow since 2004, the maximum outflow was 11,865 MCM in 2012 and the minimum was 5,500 MCM in 2005.

Table 10.2.5 Planned Outflow from Bhumibol and Sirikit Dams in Dry Season (Six Months)

Activities for Water Use		2004	2005	2006	2007	2008	2009	2010	2011	2012
Water Demand:										
Water Resource Volume for Water Use in Dry Season		9,250	9,450	12,024	16,099	12,224	10,849	8,720	9,628	16,239
1. Water Use of Upstream of Chao Phraya Dam, Chainat Province		1,300	1,500	2,340	2,905	2,550	2,800	2,350	2,345	3,870
2. Water Use in Project of Chao Phraya Yai		4,350	3,250	3,750	5,140	3,770	4,520	3,370	4,375	6,955
3. Ecosystem Maintenance and Salt Water Drive at the Mouth of River		600	500	600	405	480	480	480	480	1,590
4. Metropolitan Waterworks Authority		750	750	750	600	750	750	800	800	800
Total		7,000	6,000	7,440	9,050	7,550	8,550	7,000	8,000	13,215
Water Supply:										
Outflow from Bhumibol and Sirikit Dams	Plan	6,500	5,500	6,890	8,500	7,000	8,000	6,000	6,800	11,865
	Actual	6,469	7,228	7,662	9,648	9,530	9,152	7,678	6,867	13,274
Outflow from Kwae Noi Dam	Plan	-	-	-	-	-	-	400	600	750
	Actual	-	-	-	-	-	-	655	732	
Outflow from Pa Sak Dam	Plan	500	500	550	550	550	550	600	600	600
	Actual	673	460	544	546	779	1,023	876	543	
Total	Plan	7,000	6,000	7,440	9,050	7,550	8,550	7,000	8,000	13,215
	Actual	7,142	7,688	8,206	10,194	10,309	10,175	9,209	8,142	

Source: Operational Plan for Water Allocation in Dry Season 2011/12, RID, Water Management Division

Note: Dry season 11/1～4/30 (After 2006; 1/1～6/30 (Before 2005)



Source : Operational Plan for Water Allocation in Dry Season 2011/12, RID, Water Management Division

Figure 10.2.4 Water Distribution Plan of Chao Phraya River Basin for 2012

(d) Irrigation Area and Objective Irrigation Water Supply Area in Dry Season in 2011/2012

The large scale irrigation area, which is supplied with irrigation water from Bhumibol and Sirikit dams, is 8,796,600 rai as shown below.

Table 10.2.6 Irrigation Water Supply Areas from Bhumibol Dam and Sirikit Dam

Regional Irrigation Office	Required Water Volume (MCM)	Irrigation Area (1,000 rai)									
		Paddy	Farm Plants	Vege-tables	Sugar Cane	Fruit	Pere-nnial	Fish Pond	Shrimp Pond	Others	Total
RIO 3	1,389	922.5	10.0	0	18.1	26.4	0.8	1.8	0	4.8	984.4
RIO 4	1,252	851.6	79.1	3.9	219.8	29.4	10.4	1.5	0	14	1,209.7
RIO 10	2,170	1,848.3	37.9	1.3	26.7	54.3	7.7	8.6	0	7.6	1,992.4
RIO 11	1,730	1,537.9	4.4	29	0.3	155.8	13.2	228.3	60.1	42.8	2,071.8
RIO 12	3,200	2,326.0	2.9	1.5	103.3	71.2	5.2	19.5	7.4	1.3	2,538.3
Total	9,741	7,486.3	134.3	35.7	368.2	337.1	37.3	259.7	67.5	70.5	8,796.6

Source：Operational Plan for Water Allocation in Dry Season 2011/12, RID, Water Management Division

Based on the plan, the objective irrigation water supply area in dry season 2011/2012 is as shown in the following table.

Table 10.2.7 Objective Irrigation Water Supply Areas from Bhumibol Dam and Sirikit Dam (Dry Season 2011/2012)

Regional Irrigation Office	Planned Water Volume (MCM)	Irrigation Area (1,000 rai)									
		Paddy	Farm Plants	Vege-tables	Sugar Cane	Fruit	Pere-nnial	Fish Pond	Shrimp Pond	Others	Total
RIO 3	950	773.1	4.6	0.0	1.5	24.6	0.8	1.6	0.0	4.8	811.0
RIO 4	790	556.7	3.6	1.5	190.1	17.2	7.7	1.4	0.0	8.8	787.0
RIO 10	2,125	1,818.9	4.1	0.2	10.0	54.2	7.7	8.6	0.0	7.6	1,911.3
RIO 11	1,730	1,537.9	4.4	29.0	0.3	155.8	13.2	228.3	60.1	42.8	2,071.8
RIO 12	2,866	2,113.4	2.6	0.1	64.4	69.0	5.2	19.5	7.4	0.1	2,281.7
Total	8,460	6,800.0	19.3	30.8	266.3	320.8	34.6	259.4	67.5	64.1	7,862.8

Source： Operational Plan for Water Allocation in Dry Season 2011/12, RID, Water Management Division

As noted from the above table, the planned irrigation objective area in dry season 2011/2012 is 7,862,800 rai, corresponding to about 89% of the whole irrigation area supplied with water from Bhumibol and Sirikit dams.

The allocation of water supply from dams is shown in the following table.

Table 10.2.8 Objective Irrigation Water Supply Areas from Bhumibol Dam and Sirikit Dam (Dry season 2011/2012)

Regional Irrigation Office	Allocation of Water Supply (MCM)					
	Agriculture	Consumption	Industry	Ecosystem	Others (Pump Station, etc.)	Total
RIO 3	950	0	0	0	950	1,900
RIO 4	790	0	0	0	1,180	1,970
RIO 10	2,125	0	0	0	75	2,200
RIO 11	1,730	800	0	1,590	85	4,205
RIO 12	2,865	0	0	0	75	2,940
Total	8,460	800	0	1,590	2,365	13,215

Source：Operational Plan for Water Allocation in Dry Season 2011/12, RID, Water Management Division

(5) Evaluation of Dam Operation Rule

(a) Flood Control Aspect

- Evaluation for Bhumibol and Sirikit Dams was made for the regulation effect of the peak discharge at Nakhon Sawan (C2 water level station) for the 2011 flood.

(b) Water Supply Aspect

For the changed operation rules which considered the flood control aspect, evaluation was made from the point of view of how much water supply volume can be assured for the actual six months water supply volume.

(c) Balance between Flood Control and Water Supply Aspects

Evaluation was made for both aspects from the flood control effect and reduction of water supply volume. The strategy of RID is a very crucial factor to evaluate the balance

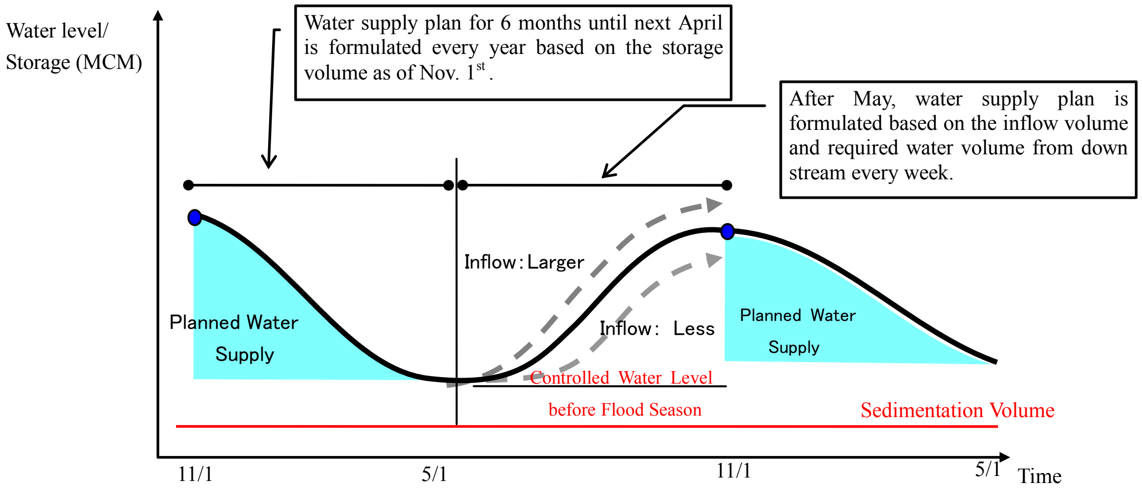


Figure 10.2.5 Outline of Dam Operation Rule

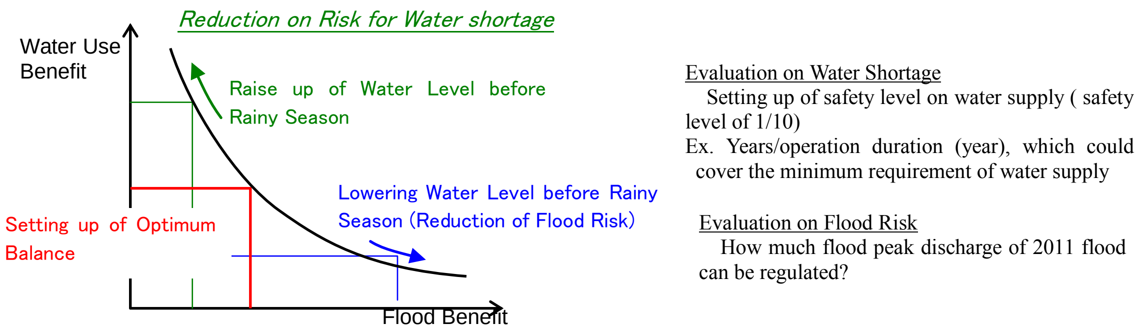


Figure 10.2.6 Study on Balance between Flood Control and Water Supply

(6) Study on Optimization of Operation Rule of Bhumibol and Sirikit Dams

(a) Study on Flood Control

(i) Flood Control Effect

In general, both Bhumibol and Sirikit dams store most of the flood run-off discharge, which contribute to the reduction of flood damage in the downstream. In the case of the flood in 2002, Bhumibol and Sirikit dams stored about 8,100 MCM of flood run-off volume in total (Bhumibol: 4,700 MCM and Sirikit: 3,400 MCM), and maintained the flood peak discharge of only 3,997 m^3/s at Nakhon Sawan (October 2, 2002).

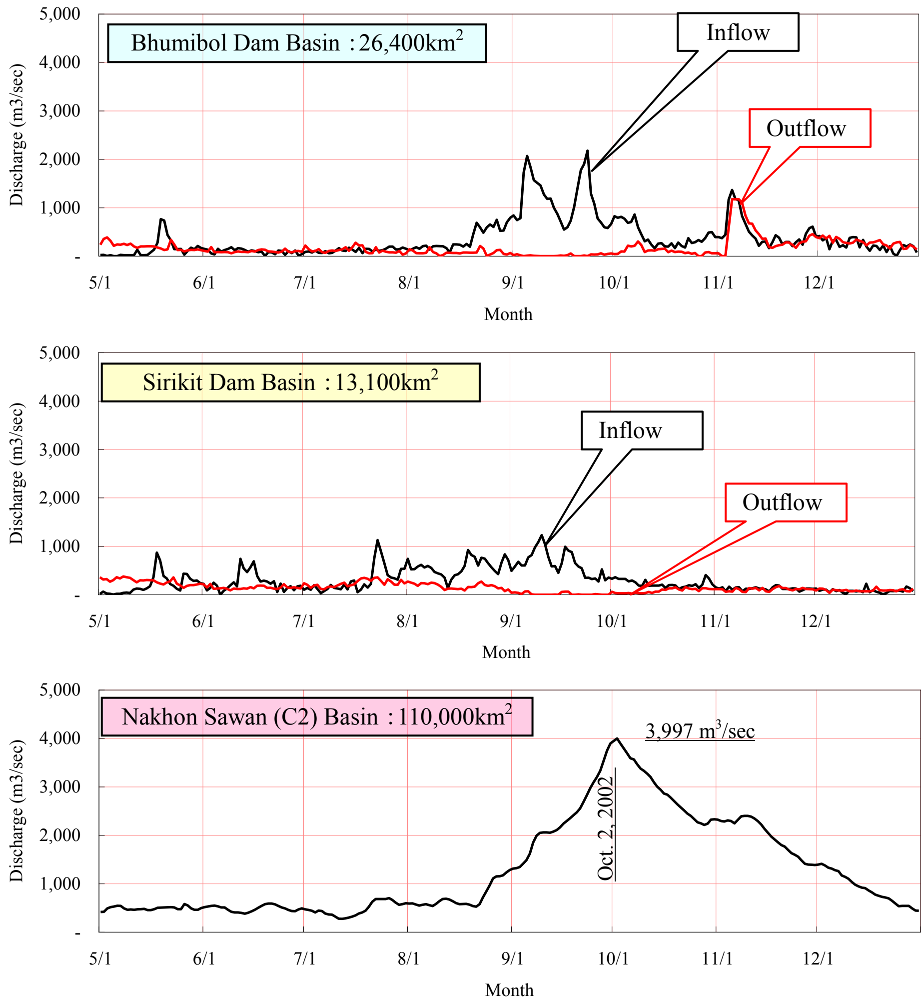


Figure 10.2.7 Flood Hydrograph at C2 Station and Dam Sites in the 2002 Flood

In the 2011 flood, both Bhumibol and Sirikit dams stored most of the flood run-off discharges since May. In the case of Bhumibol Dam, flood run-off discharge had been increasing since the beginning of August, and the dam had stored most of the flood run-off discharge, and contributed to the reduction of flood damage in the downstream, so that water level of the reservoir reached at maximum reservoir water level in October 5 (MSL+259.25m), and then, started discharge through the spillway. Likewise, Sirikit Dam had started discharge on August 25 (MSL+159.36). As the result, both dams had stored about 12 MCM in total (Bhumibol: 7,500 MCM, Sirikit: 4,700 MCM) and maintained the flood peak discharge at 4,686 m^3/s at Nakhon Sawan (C2) (October 13, 2011).

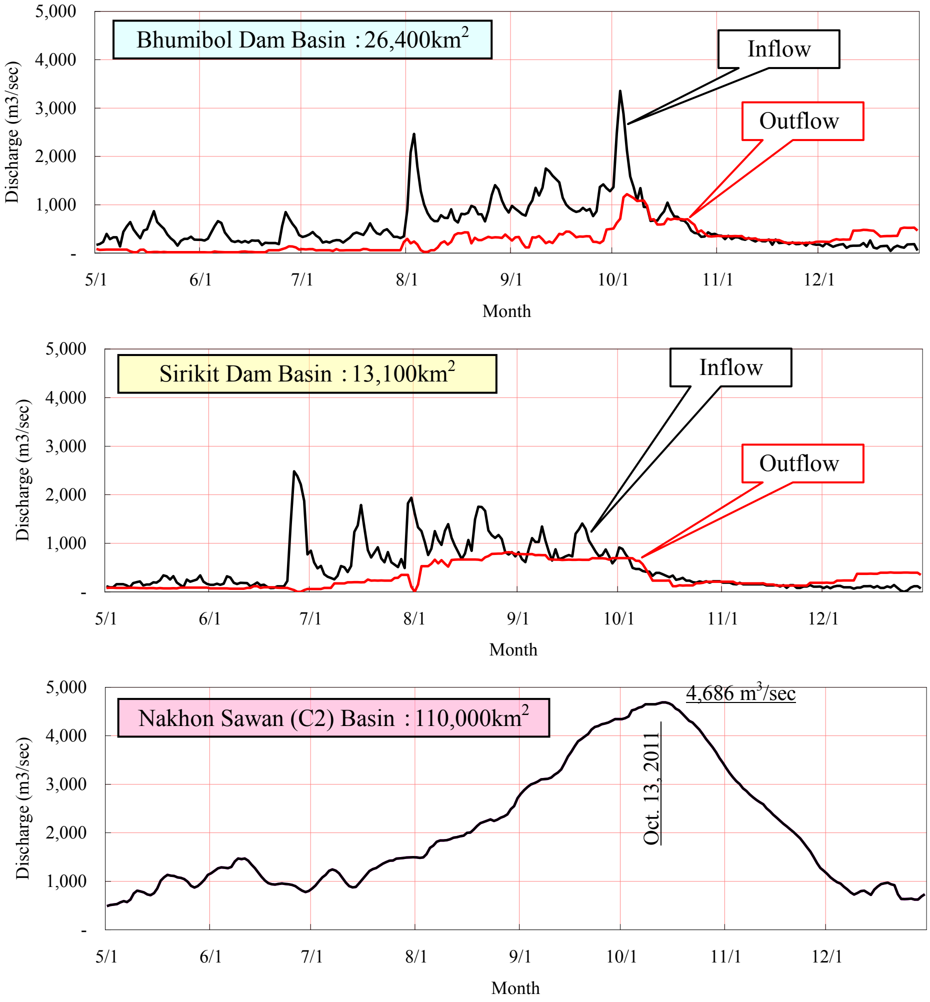


Figure 10.2.8 Flood Hydrograph at C2 Station and Dam Sites in the 2011 Flood

(ii) Setup of Study Case

According to the flood data, flood peak discharge at Nakhon Sawan usually emerges between September and October. In the 2011 flood, Bhumibol and Sirikit dams stored about 12,400 MCM of flood run-off discharge, and contributed to mitigation of flood damage in downstream. However, the water level of both dams had reached their maximum storage water level and the dams started to discharge a part of stored water. In this connection, it is considered that a new operation rule, under which flood discharge can still be stored even in the period between August and October, will lead more flood control effect in the downstream during this period.

<u>Objective Flood for Study</u>

The flood in 2011 was applied to the objective flood for study. According to the recorded inflow data of Bhumibol Dam (1964–2011) and Sirikit Dam (1974–2011), the maximum inflow volume between June and October is the 2011 flood in both dams.

Table 10.2.9 Maximum Inflow between June and August to Bhumibol and Sirikit Dams

Dam	Inflow (MCM)					
	June	July	August	September	October	Total
Bhumibol Dam	929	961	2,646	2,877	2,813	10,226
Sirikit Dam	1,238	2,792	3,300	2,614	1,031	9,631

Approach for Flood Control Purpose

The operation rule putting more emphasis on the flood control purpose is as follows:

- In principle, the inflow during the period from August to October is stored within the effective storage capacity, considering the inflow hydrograph as well as peak discharge which emerges at the beginning of October at the Nakhon Sawan water level station (C2).

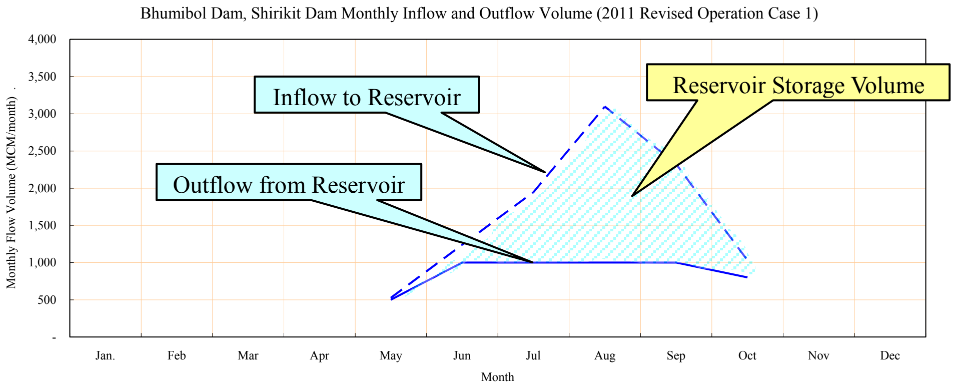


Figure 10.2.9 Typical Example of Dam Operation by Constant Outflow with Peak Cut

- Inflow to Bhumibol dam during the period from May to July is treated as "inflow=outflow."
- Since the maximum capacities of conduit pipes of Bhumibol Dam and Sirikit Dam are 784 m^3/s and 732 m^3/s , respectively, the maximum discharge through conduit pipes is treated as 700 m^3/s for both dams.
- Since the inflow of Sirikit Dam during June to July is so large that it is difficult to treat it as "inflow=outflow," operation has to be made to maintain the storage volume as much as possible applying the constant outflow discharge of 700 m^3/s at maximum.
- During the period from August to October, while the inflow is mainly stored in the reservoir, the outflow of 8 m^3/s of Bhumibol Dam and 35 m^3/s of Sirikit Dam is maintained at minimum.

Study Cases

The study cases for the above consideration were set as shown in the following table.

Table 10.2.10 Study Cases of Operation of Bhumibol and Sirikit Dams for Flood Control Purpose

Dam	Case	Outflow		Storage Volume as of May 1st (including sediment storage capacity)	Water Level as of May 1st
		May - July	Aug. – Oct.		
Bhumibol	Case 1	IN = OUT	30m^3/s	5,364 MCM	224.6 m
	Case 2		80m^3/s	5,762 MCM	227.2 m
	Case 3		210m^3/s	6,795 MCM	233.8 m
	Case 4		320m^3/s	7,670 MCM	238.4 m
Sirikit	Case 1	Basically IN=OUT	60m^3/s	2,878 MCM	128.2 m
	Case 2		190m^3/s	3,911 MCM	135.6 m
	Case 3		320m^3/s	4,835 MCM	141.0 m
	Case 4		460m^3/s	5,713 MCM	145.5 m

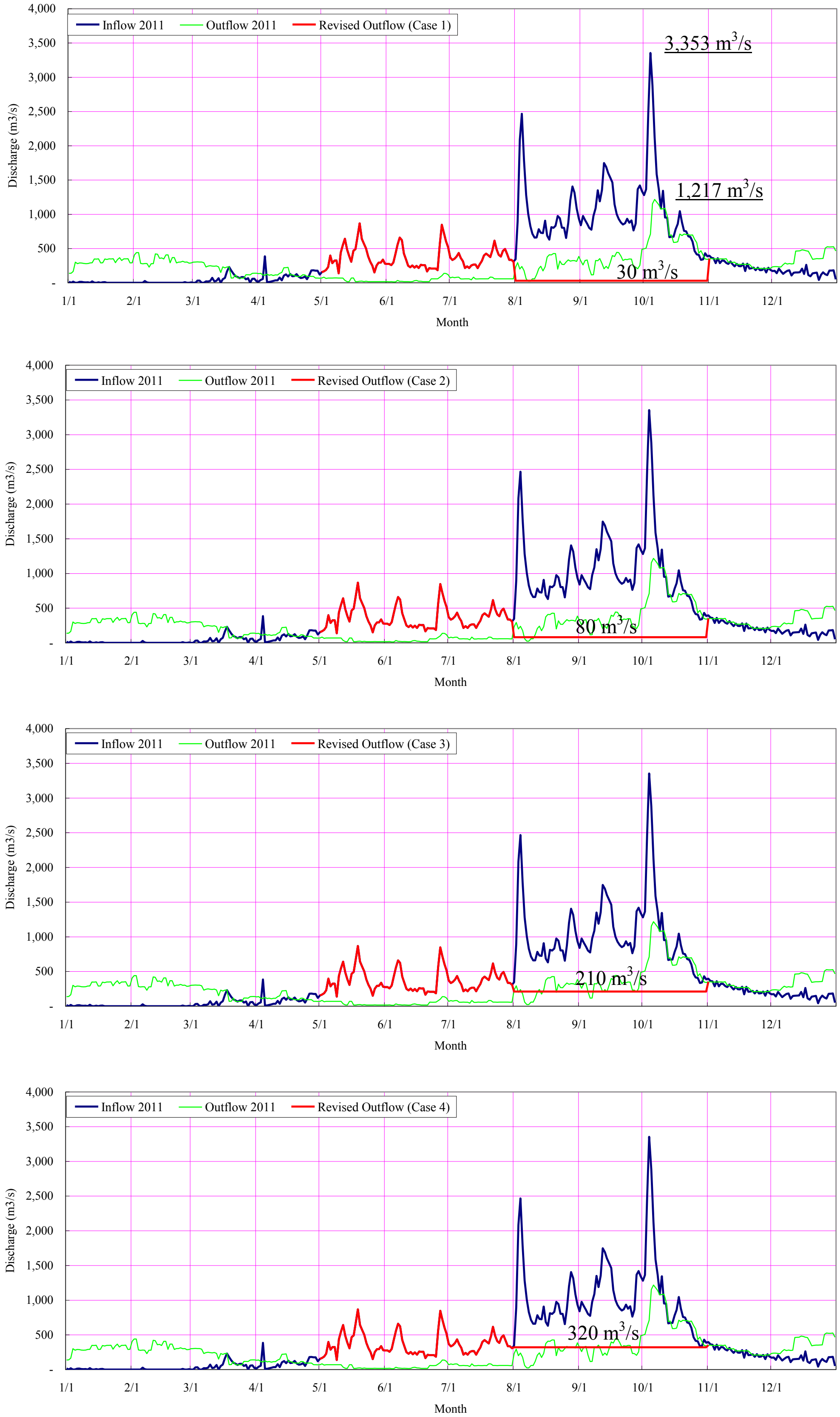


Figure 10.2.10 Cases for Operation of Bhumibol Dam for Flood Control Purpose

Figure 10.2.11 Cases for Operation of Sirikit Dam for Flood Control Purpose

(iii) Study on Operation for Bhumibol and Sirikit Dams

The study results are compiled in the following tables:

Table 10.2.11 Study Results of Operation of Bhumibol Dam for Flood Control Purpose

Case	Storage Volume as of May 1st (Include sediment capacity)	Storage Water Level as of May 1st	Maximum Outflow from Aug. to Oct. (m^3/s)	Percentage of storage volume in each case for effective storage volume	
Case 1	5,364 MCM	224.6 m	30	8,098 MCM	(84 %)
Case 2	5,762 MCM	227.2 m	80	7,700 MCM	(80 %)
Case 3	6,795 MCM	233.8 m	210	6,667 MCM	(69 %)
Case 4	7,670 MCM	238.4 m	320	5,792 MCM	(60 %)
2011 Actual	6,070 MCM	229.2 m	1,217	7,324 MCM	(76 %)

Table 10.2.12 Study Results of Operation of Sirikit Dam for Flood Control Purpose

Case	Storage Volume as of May 1st (Include sediment capacity)	Storage Water Level as of May 1st	Maximum Outflow from Aug. to Oct. (m^3/s)	Percentage of storage volume in each case for effective storage volume	
Case 1	2,878 MCM	128.2 m	60	6,632 MCM	(100 %)
Case 2	3,911 MCM	135.6 m	190	5,599 MCM	(84 %)
Case 3	4,835 MCM	141.0 m	320	4,675 MCM	(70 %)
Case 4	5,713 MCM	145.5 m	460	3,797 MCM	(57 %)
2011 Actual	4,768 MCM	140.7 m	815	4,727 MCM	(71 %)

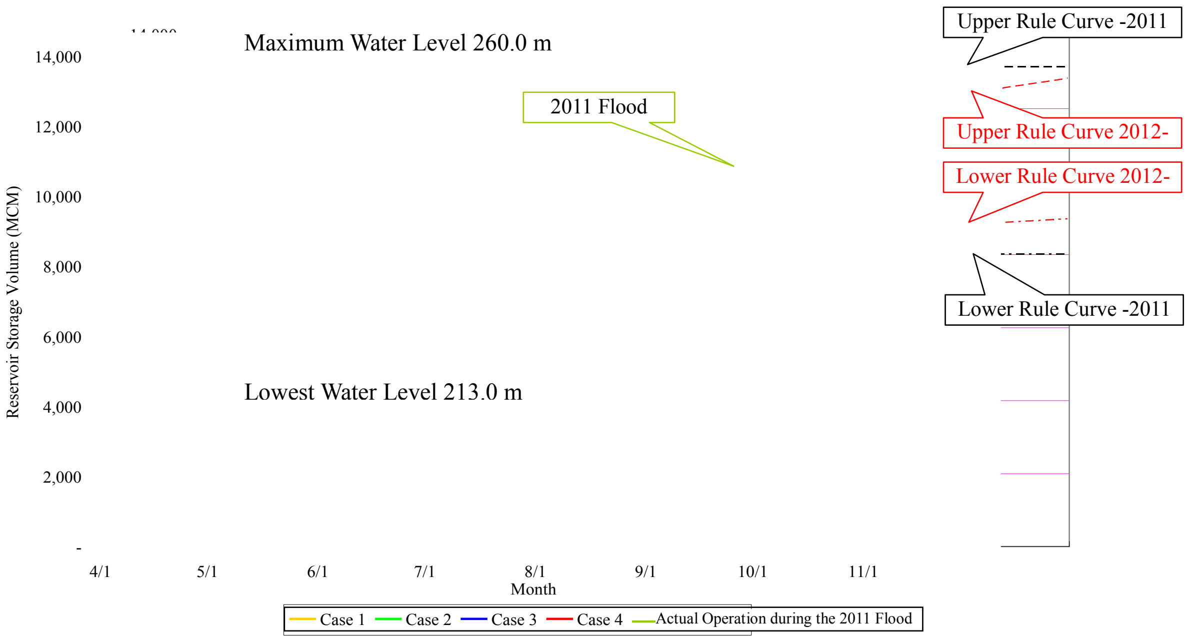


Figure 10.2.12 Study Results of Operation of Bhumibol Dam for Flood Control Purpose

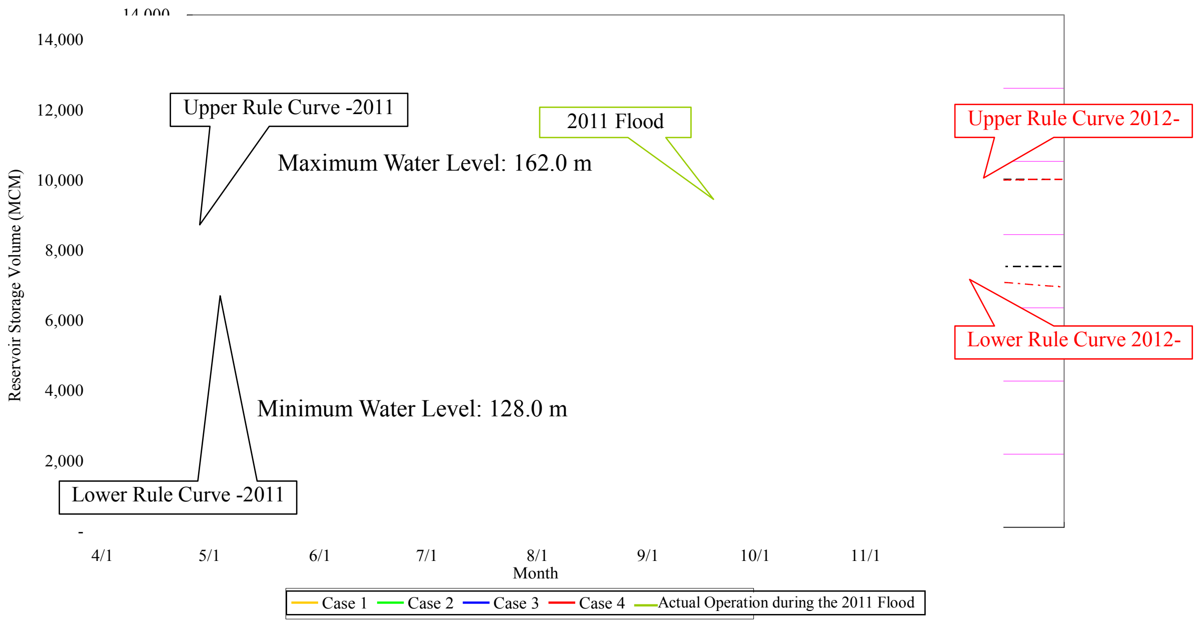


Figure 10.2.13 Study Results of Operation of Sirikit Dam for Flood Control Purpose

(b) Water Supply

As for water supply, water requirement is assumed based on the previous water supply record in the dry season. In this connection, the study on water supply was conducted to confirm how much water requirement can be assured under the changed operation rule for flood control purpose.

(i) Water Requirement based on the Previous Water Supply Record

Planned and Actual Water Supply

Planned and actual water supply for six (6) months in dry season in the previous years at Nakhon Sawan Station (C2) and Chai Nat Station (C13) is as shown in the following table. Since the discharge of local rainfall is not included in the record of "Planned released water discharge from dam and distribution amount in dry season by RID", the actual discharge amounts at C2 and C13 stations are quite different from the planned ones in some years.

Table 10.2.13 Summary of Planned and Actual Discharge at Each Observation Point

Item	Discharge（Dry Season from Nov. to next April） Upper Colum ： Planned Discharge（MCM） Lower Colum: Actual（MCM）						
	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12
A. Released Discharge from Dam（Bhumibol + Sirikit）	6,890	8,500	7,000	8,000	6,000	6,800	11,865
	7,850	9,647	9,510	9,141	7,697	6,874	13,274
B. Nakhon Sawan（Actual: C2 observed discharge）	4,550	5,595	4,450	5,200	4,050	5,055	8,745
	6,948	12,351	8,177	10,869	6,523	9,877	17,722
C. Chai Nat（Actual: C13 observed discharge）	1,150	880	1,030	1,030	1,080	1,080	1,965
	2,015	5,294	2,205	5,136	1,408	4,991	10,988
D. Water Supply Amount for East and West Irrigation area in Nakhon Sawan downstream (Actual: Calculated by 『B.–C.』 and discharge from Sakae Krang River is not considered)	3,400	4,715	3,420	4,170	2,970	3,975	6,780
	4,933	7,057	5,972	5,733	5,115	4,886	6,734

Estimation of Water Requirement at Nakhon Sawan

Recorded observed discharge at Chai Nat (C13) is summarized as follows:

Table 10.2.14 C13 Recorded Observed Discharge

Year	C13 Recorded Observed Discharge (MCM)						
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
2005/06	1,330	156	155	120	161	93	2,015
2006/07	4,377	303	189	109	146	170	5,294
2007/08	1,511	140	137	134	133	150	2,205
2008/09	4,291	296	134	120	166	128	5,136
2009/10	839	108	116	103	106	136	1,408
2010/11	3,779	262	184	161	430	175	4,991
2011/12	5,863	846	1,165	1,764	1,074	275	10,988

Note: Yellow colour means discharge remarkably affected by rainfall.

From this table, the average discharge excluding those remarkably affected by rainfall is 140 MCM/month. On the other hand, estimated water supply amount to the East and West irrigation areas in the Nakhon Sawan downstream is summarized in the following table (actual value is calculated by "B-C" without consideration of inflow from Sakae Krang river basin.

Table 10.2.15 Estimation of Water Supply Amount to East and West Irrigation Area in Nakhon Sawan Downstream

Year	Estimation of Water Supply Amount to East and West Irrigation Areas in Nakhon Sawan Downstream (MCM)						
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
2005/06	817	849	896	848	842	681	4,933
2006/07	1,271	1,207	1,167	1,179	1,174	1,059	7,057
2007/08	794	1,023	1,041	1,019	983	1,112	5,972
2008/09	523	975	990	1,025	1,092	1,129	5,733
2009/10	1,030	972	988	859	862	404	5,115
2010/11	461	874	938	996	951	667	4,886
2011/12	144	1,345	1,312	1,257	1,397	1,280	6,734

Judging from the table above, the maximum amount of water supply to the East and West Irrigation areas in Nakhon Sawan downstream is about 1,200 MCM/month. Consequently, water requirement in the Nakhon Sawan downstream is estimated as "140 MCM/month + 1,200 MCM/month = 1,340 MCM/month."

Estimation of Water Requirement in Nakhon Sawan Downstream based on Actual Discharge in the Dry Season

The discharge assuming no dam operation by Bhumibol and Sirikit dams is calculated based on the actual discharge as shown in the following table:

Table 10.2.16 Calculation of Discharge at Nakhon Sawan (C2) without Dam Operation

Year	(MCM)	Year	(MCM)	Year	(MCM)
1957	3,807	1977	8,505	1997	7,740
1958	3,142	1978	3,735	1998	1,778
1959	1,872	1979	5,086	1999	1,470
1960	3,428	1980	1,343	2000	8,851
1961	4,415	1981	5,710	2001	5,034
1962	8,075	1982	5,930	2002	5,378
1963	4,953	1983	4,155	2003	8,777
1964	7,915	1984	9,700	2004	637
1965	7,923	1985	4,272	2005	710
1966	4,898	1986	10,071	2006	3,233
1967	4,325	1987	2,417	2007	6,097
1968	3,753	1988	4,402	2008	2,658
1969	1,600	1989	5,144	2009	6,596
1970	4,400	1990	3,218	2010	1,968
1971	6,256	1991	2,854	2011	6,123
1972	4,944	1992	2,665		
1973	4,850	1993	3,138		
1974	4,426	1994	1,217	Average	4,741
1975	8,100	1995	2,810	Max.	10,071
1976	7,496	1996	6,743	Min.	637

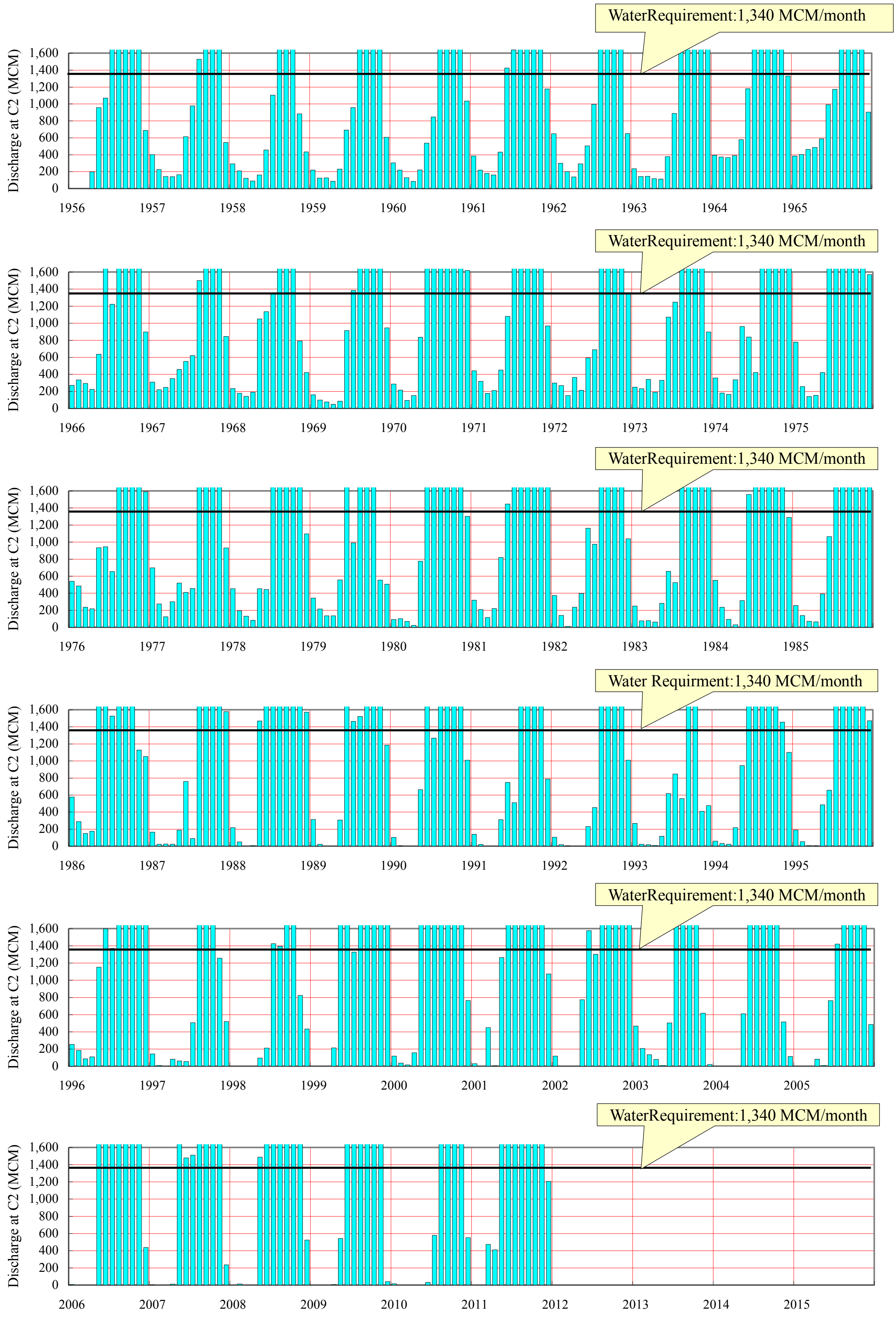


Figure 10.2.14 Discharge without Dam Operation at Nakhon Sawan (C2)

In case that the discharge without dam operation in dry season (from November to next April) is less than the water requirement (estimated amount: 1,340 MCM/month), it is necessary to fill in the shortage through dam operation. Such yearly shortage amount to be offset by dam operation has been estimated, as shown below.

Table 10.2.17 Estimation of Annual Shortage Amounts of Water Requirement at Nakhon Sawan (C2)

Year	Estimated Shortage Amounts (MCM)	Year	Estimated Shortage Amounts (MCM)	Year	Estimated Shortage Amounts (MCM)
1957	5,099	1977	3,964	1997	5,126
1958	5,441	1978	4,909	1998	6,262
1959	6,168	1979	4,776	1999	6,570
1960	5,358	1980	6,697	2000	5,032
1961	4,719	1981	4,537	2001	5,454
1962	4,236	1982	4,599	2002	5,509
1963	5,407	1983	5,195	2003	4,473
1964	3,837	1984	4,448	2004	7,403
1965	3,630	1985	4,882	2005	7,330
1966	4,677	1986	4,169	2006	6,208
1967	4,679	1987	5,623	2007	6,250
1968	5,112	1988	5,085	2008	6,451
1969	6,440	1989	5,024	2009	6,167
1970	5,007	1990	5,408	2010	6,643
1971	4,215	1991	5,529	2011	5,266
1972	4,653	1992	5,790		
1973	4,346	1993	5,372		
1974	4,763	1994	6,823	Average	5,250
1975	4,033	1995	5,346	Max.	7,403
1976	3,880	1996	4,724	Min.	3,630

The released discharge necessary from Bhumibol and Sirikit to offset the shortage of water requirement has been estimated by adding inflow to the dams to the value in Table 10.2.18.

Table 10.2.18 Estimation of Necessary Discharges Released from Bhumibol and Sirikit Dams in Dry Season

Year	Estimated Necessary Discharge Released in Dry Season (MCM)	Year	Estimated Necessary Discharge Released in Dry Season (MCM)	Year	Estimated Necessary Discharge Released in Dry Season (MCM)
1957	-	1977	5,299	1997	5,980
1958	-	1978	6,479	1998	7,638
1959	-	1979	5,687	1999	7,258
1960	-	1980	7,436	2000	5,961
1961	-	1981	5,651	2001	6,617
1962	-	1982	5,422	2002	6,504
1963	-	1983	6,041	2003	5,868
1964	-	1984	5,176	2004	8,351
1965	-	1985	5,806	2005	8,717
1966	-	1986	5,177	2006	7,663
1967	-	1987	6,889	2007	7,534
1968	-	1988	5,647	2008	7,498
1969	-	1989	5,723	2009	7,299
1970	-	1990	6,141	2010	7,312
1971	-	1991	6,438	2011	6,454
1972	-	1992	6,690		
1973	-	1993	6,436		
1974	-	1994	7,773	Average	6,505
1975	5,315	1995	7,149	Max.	8,717
1976	5,389	1996	6,257	Min.	5,176

(ii) Study Case

Objective Year for Study

As the objective year for the study, the period from 1975 when the release of discharge in dry season from the Bhumibol and Sirikit dams was started to 2012, was applied.

Manner of Dam Operation

The principle of dam operation is as follows:

- Monthly inflow volume is used for calculation.
- The starting water level as of May 1st, which was examined in the study on "Dam Operation for Flood Control," is fixed and inflow discharge since then is stored based on the rule for "Dam Operation for Flood Control," and outflow discharge is released in accordance with the recorded actual discharge.
- For calculation, evaporation volume is considered based on the observed data for both dams in the following manner:

  Bhumibol Dam: 21 MCM/month in rainy season, and 40 MCM/month in dry season

  Sirikit Dam: 23 MCM/month in rainy season, and 28 MCM/month in dry season

- The water level as of April 30th is based on the case studied in "Dam Operation for Flood Control.". However, when the released discharge cannot reach the planned released discharge in dry season, extra discharge using the storage water up to the sediment storage capacity is arranged, as long as the water level is within the effective storage capacity.
- During the period from May to July, all inflow discharge in principle is released without storage. However, when the storage volume in the reservoir is less than the case setting at "the storage volume as of May 1st," part of inflow discharge is stored under the condition that water requirement in the downstream is assured, i.e., 8 m^3/s for Bhumibol dam and 35 m^3/s for Sirikit dam based on the actual data from May to July in 2011.
- During the period from August to October for storage of flood discharge, Bhumibol and Sirikit dams released the minimum requirement of 8 m^3/s and 35 m^3/s, respectively. The storage space set by "Dam Operation for Flood Control" is preserved, i.e., operating the released outflow discharge depending on the inflow discharge.

Study Case

The study cases are as the same as those in "Dam Operation for Flood Control."

Table 10.2.19 Study Case of Operation of Bhumibol and Sirikit Dams for Flood Control Purpose

Dam	Case	Released Discharges		Storage Volume as May 1st (Including sediment storage capacity)	Water Level as of May 1st
		May - July	Aug. to Oct.		
Bhumibol	Case 1	IN = OUT	30m^3/s	5,364 MCM	224.6 m
	Case 2		80m^3/s	5,762 MCM	227.2 m
	Case 3		210m^3/s	6,795 MCM	233.8 m
	Case 4		320m^3/s	7,670 MCM	238.4 m
Sirikit	Case 1	May – Mid. of June: IN=OUT End of June - July: 700m^3/s	60m^3/s	2,878 MCM	128.2 m
	Case 2		190m^3/s	3,911 MCM	135.6 m
	Case 3		320m^3/s	4,835 MCM	141.0 m
	Case 4		460m^3/s	5,713 MCM	145.5 m

(iii) Study Results

Simulation has been made for the combination of Bhumibol Dam (4 cases) and Sirikit Dam (4 cases). The results are as shown in the following Figure.

Table 10.2.20 Results of Dam Operation for the Purpose of Water Supply from Bhumibol and Sirikit Dams (from November to April)

Unit: Billion m^3

Year	Required Outflow	Bhumibol : Case 1				Bhumibol : Case 2				Bhumibol : Case 3				Bhumibol : Case 4			
		Sirikit				Sirikit				Sirikit				Sirikit			
		Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
1975	5.3	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
1976	5.4	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.7
1977	5.3	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
1978	6.5	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
1979	5.7	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
1980	7.4	5.4	6.4	7.3	7.4	5.8	6.8	7.4	7.4	6.8	7.4	7.4	7.4	7.4	7.4	7.4	7.4
1981	5.7	8.2	8.2	7.5	7.4	7.8	7.8	7.4	7.4	6.8	7.1	7.4	7.4	6.2	6.8	7.2	7.4
1982	5.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
1983	6.0	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
1984	5.2	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
1985	5.8	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
1986	5.2	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
1987	6.9	5.9	6.9	6.9	6.9	6.3	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
1988	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
1989	5.7	6.5	6.4	6.1	6.3	6.2	6.2	6.2	6.5	5.6	6.4	6.6	6.4	5.7	5.7	6.3	6.1
1990	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
1991	6.4	5.6	6.4	6.4	6.4	5.9	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
1992	6.7	5.5	6.7	6.7	6.7	5.5	6.7	6.7	6.7	6.0	6.7	6.7	6.7	6.7	6.7	6.7	6.7
1993	6.4	5.3	5.5	6.4	6.4	5.3	5.9	6.4	6.4	5.3	6.4	6.4	6.4	5.5	6.4	6.4	6.4
1994	7.8	3.1	3.8	3.9	4.8	3.1	3.8	4.3	5.2	3.1	4.4	5.3	6.2	3.1	4.7	6.2	7.1
1995	7.1	11.3	11.3	10.5	9.7	10.9	10.9	10.1	9.3	9.9	9.9	9.1	8.2	9.0	8.7	8.2	7.4
1996	6.3	12.8	12.3	11.4	10.5	12.8	12.3	11.4	10.5	12.8	12.3	11.4	10.5	12.8	12.3	11.4	10.5
1997	6.0	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
1998	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
1999	7.3	2.9	4.4	5.3	6.2	3.3	4.4	5.7	6.6	4.4	5.8	6.8	7.3	5.3	6.7	7.3	7.3
2000	6.0	8.6	8.4	7.4	6.6	8.2	8.4	7.0	6.2	7.2	6.9	6.0	6.0	6.3	6.0	6.0	6.0
2001	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
2002	6.5	8.5	8.5	8.5	7.8	8.5	8.5	8.5	7.8	8.5	8.5	8.5	7.8	8.5	8.5	8.5	7.8
2003	5.9	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
2004	8.4	6.5	7.5	8.4	8.4	6.5	7.9	8.4	8.4	7.9	8.4	8.4	8.4	8.4	8.4	8.4	8.4
2005	8.7	8.6	8.7	8.7	8.7	8.6	8.7	8.7	8.7	8.6	8.7	8.7	8.7	8.6	8.7	8.7	8.7
2006	7.7	9.7	10.1	10.4	10.4	9.7	9.7	10.1	10.3	8.3	9.0	9.4	9.6	7.9	8.2	8.8	9.6
2007	7.5	11.2	11.2	11.2	10.7	11.2	11.2	11.2	10.7	11.2	11.2	11.2	10.7	11.2	11.2	11.2	10.7
2008	7.5	7.4	7.5	7.5	7.5	7.4	7.5	7.5	7.5	7.4	7.5	7.5	7.5	7.4	7.5	7.5	7.5
2009	7.3	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
2010	7.3	7.4	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
2011	6.5	8.7	9.2	9.2	9.2	8.7	9.2	9.2	9.2	8.7	9.2	9.2	9.2	8.7	9.2	9.0	9.2
Ave.	6.5	7.8	8.0	8.0	7.9	7.8	8.0	8.0	7.9	7.8	8.0	8.0	7.9	7.8	7.9	8.0	7.9
Max.	8.7	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.8	13.0	13.0	12.6	11.7
Min.	5.2	2.9	3.8	3.9	4.8	3.1	3.8	4.3	5.2	3.1	4.4	5.3	5.6	3.1	4.7	5.6	5.6
Number of years with shortage		10	6	3	2	10	5	2	2	8	2	2	1	5	2	1	1
Rate of Shortage		27%	16%	8%	5%	27%	14%	5%	5%	22%	5%	5%	3%	14%	5%	3%	3%

Note: Yellow color means calculated outflow is less than the planned outflow.

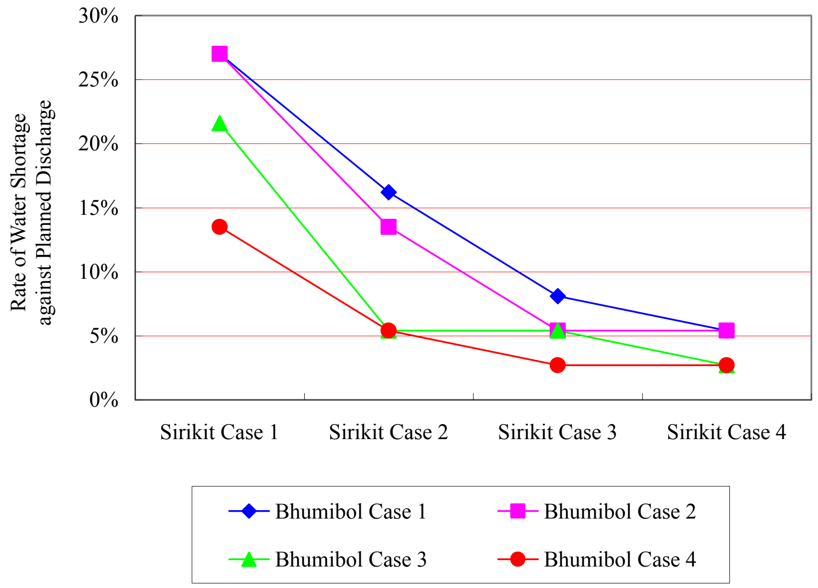


Figure 10.2.15 Study Results of Operation of Bhumibol and Sirikit Dams for Water Supply Purpose

From the study results, the following points have been clarified:

- As regards the planned discharge, Case-1 is the most advantageous in both dams from the flood control aspect, while Case-4 is the most advantageous from the water supply purpose.
- Case-1 requires a heavy burden on both dams from the water supply aspect (Bhumibol Dam Case-1 and Sirikit Dam Case-1). The combinations of "Bhumibol Dam Case 2 and Sirikit Dam Case 1" show that shortage in the planned water supply emerges at the rate of 27%, corresponding to once in every 4 years of occurrence.
- On the other hand, the combinations of "Bhumibol Dam Case-3 and Case-4, and Sirikit Dam Case-2, Case-3 and Case-4) shows that shortage in the planned water supply emerges at the rate of only 3% to 5%, corresponding to once in every 20 to 30 years.
- In the combinations of Bhumibol Dam Case-3 and Case-4, there is not much difference in the water supply aspect.
- In the combinations of Sirikit Dam Case-2, Case-3 and Case-4, there is not much difference in the water supply aspect.
- Finally, the combinations which have high advantage in both flood control and water supply are "Bhumibol Dam Case-3 and Sirikit Dam Case-2" and the shortage of water supply in the planned one emerges with the rate of about 5% corresponding to once in every 20 years of occurrence.

(c) New Operation Rules for Bhumibol and Sirikit Dams

The concept of the proposed operation rules for Bhumibol and Sirikit dams 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 m³/s at Bhumibol Dam and the 35 m³/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.

The proposed operation rules and rule curves are shown in the following table and figures.

Table 10.2.21 Proposed Operation Rule for Flood Control by Bhumibol and Sirikit Dams

Dam	Case	Discharge		Storage as of May 1st (Including Sediment Capacity)	Water Level as of May 1st
		May - July	Aug. - Oct		
Bhumibol	Case 3	IN = OUT	210m³/s	6,795 MCM	233.8 m
Sirikit	Case 2	May – Mid. Of June : IN=OUT End of June - July : 700m³/s	190m³/s	3,911 MCM	135.6 m

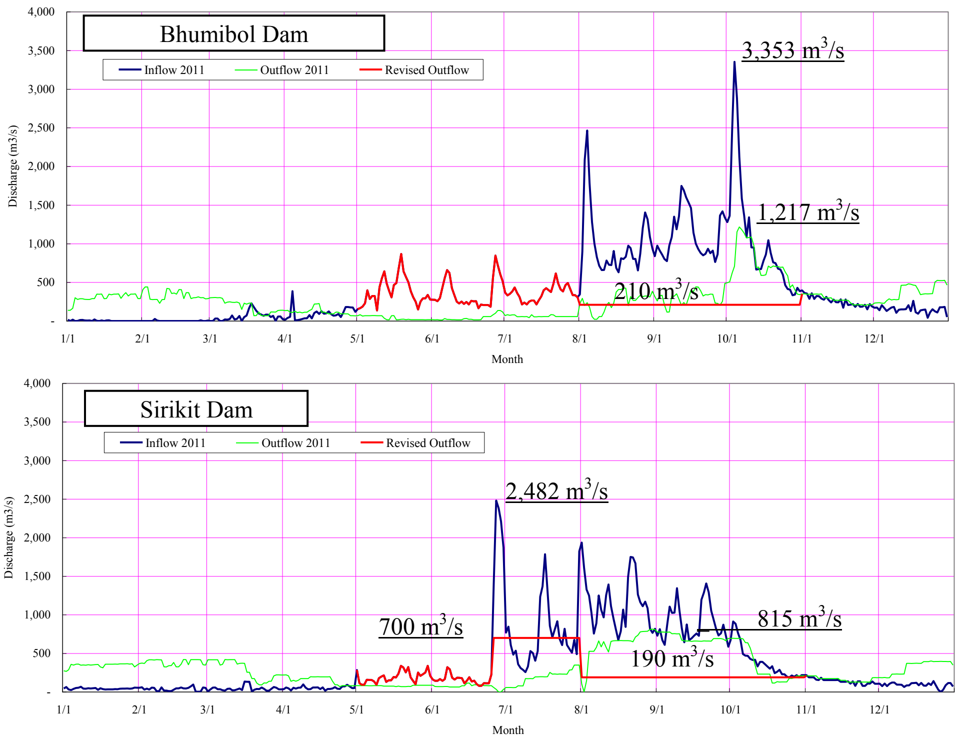
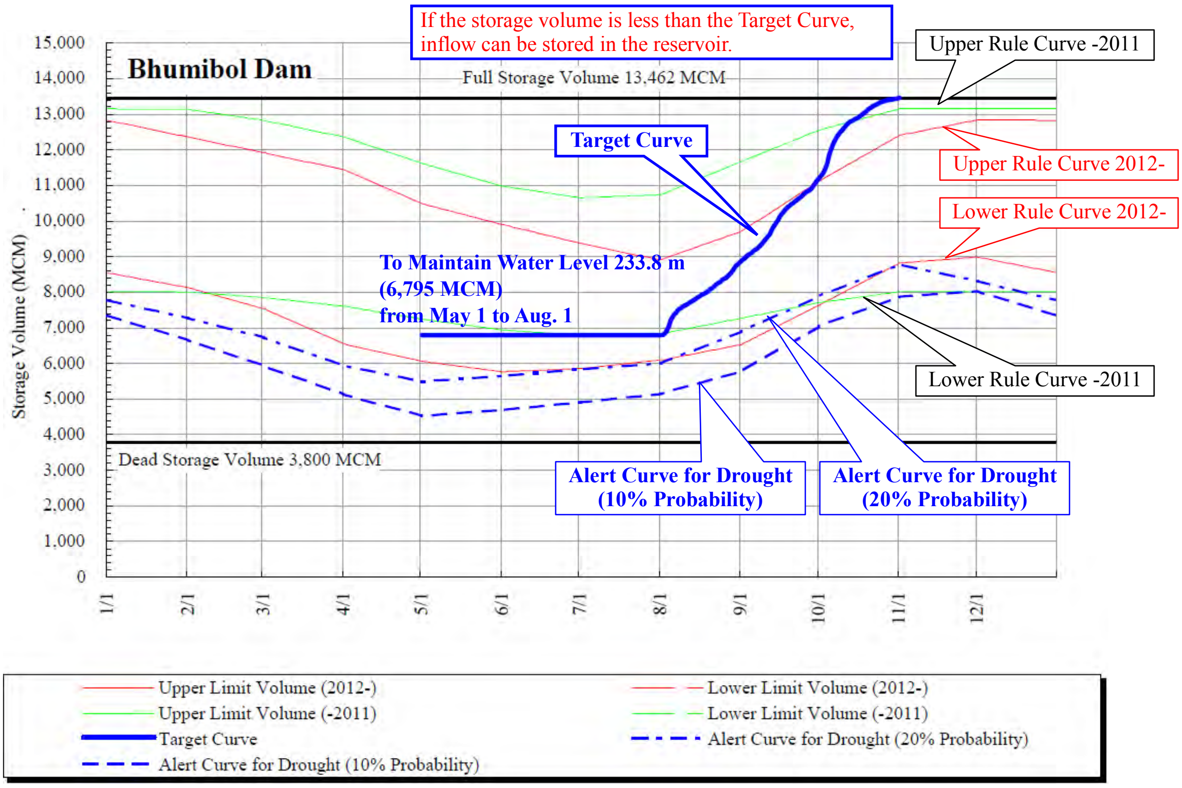


Figure 10.2.16 Proposed Operation for Flood Control by Bhumibol and Sirikit Dams (2011 Flood)



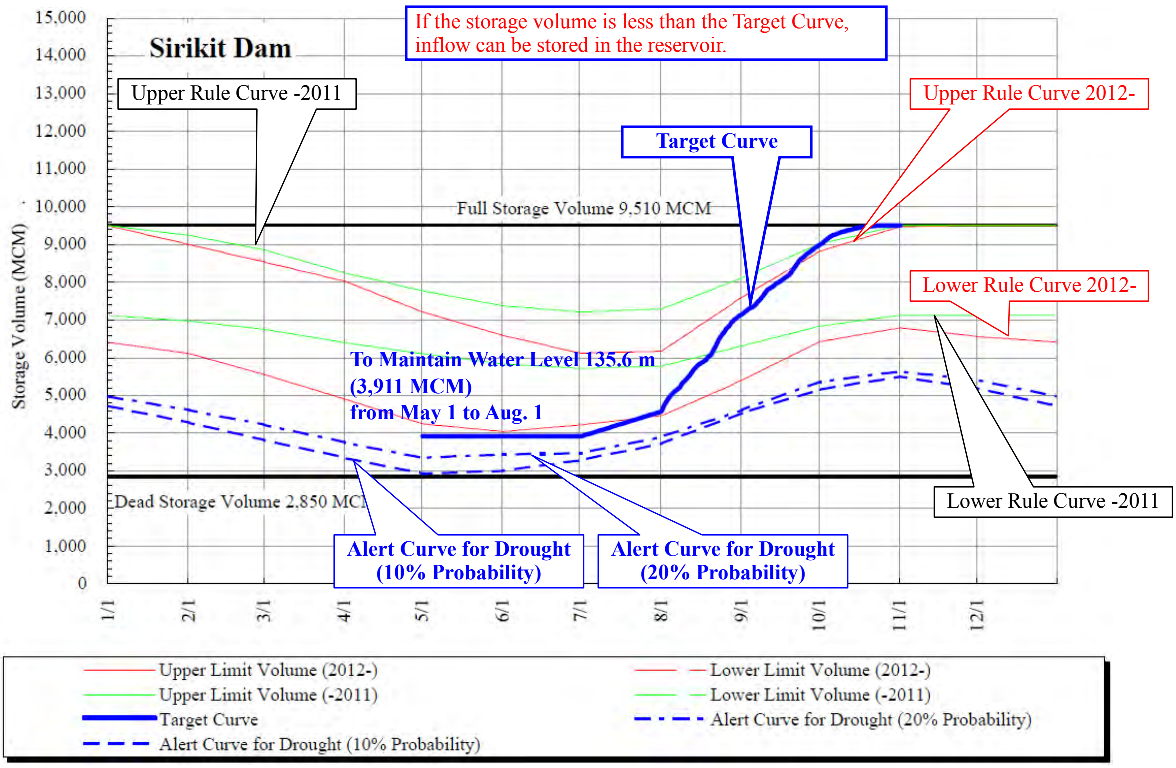


Figure 10.2.17 Target Curve and Alert Curve for Drought for Bhumibol and Sirikit Dams

(d) Water Supply Simulation using Observed Daily Inflow Data

Condition

The water supply simulation was performed applying the observed daily inflow at Bhumibol Dam and Sirikit Dam.

Target Term

Target term was set from 1975 to 2012, in which the water supply was done from Bhumibol Dam and Sirikit Dam.

Dam Operation for Water Supply

Following the proposed operation rules, the inflow is going to be stored from May 1 at Bhumibol Dam and Sirikit Dam, as the start of the storage and the water level rise.

When the dry season (From November to April next year) starts, the stored water is supplied based on the estimation of the necessary released Discharge.

Table 10.2.22 Proposed Optimum Operation Rules at Bhumibol Dam and Sirikit Dam

Dam	Maximum Outflow		Storage Volume (includes Sedimentation Volume)	Water Level as of May 1
	May to July	August to October		
Bhumibol	In = Out	210m^3/s	6,795MCM	233.8m
Sirikit	May to Mid of June: In = Out Late June to July: 700m^3/s	190m^3/s	3,911MCM	135.6m

An evapotranspiration at the Dam Reservoir is considered. The amount of evapotranspiration was considered as Table 10.2.23

Table 10.2.23 Amount of Evapotranspiration at Bhumibol Dam and Sirikit Dam

Month	Bhumibol Dam (MCM/day)	Sirikit Dam (MCM/day)
January	1.00	0.80
February	1.70	1.00
March	2.30	1.00
April	2.20	1.10
May	1.20	1.00
June	0.80	0.80
July	0.50	0.60
August	0.50	0.60
September	0.50	0.70
October	0.60	0.70
November	0.70	0.80
December	0.70	0.70

- If the storage on May 1 is not enough for the water supply in the dry season, the water is going to be released down to Low Water Level (Sedimentation Level).
- Basically, the inflow at the dams will not be stored in the dry season. However, if the storage on May first is less than the estimated amount of required water supply, the inflow can be stored as long as the minimum discharges of 8m^3/s at Bhumibol Dam and one of 35m^3/s at Sirikit Dam for the environmental preservation are guaranteed.
- During flood season, which is from August until October, 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 one in 2011, the discharges from those Dams are decreased and stored. The amount of discharge cannot be less than the minimum discharges of 8 m^3/s at Bhumibol Dam and one of 35 m^3/s at Sirikit Dam.

Result of Water Supply Simulation

The result of water supply simulation with observed daily inflow was shown in Table 10.2.24. According to those results, it was only two seasons when the water supply was not enough to the required amount in the dry season, which were 1993 to 1994, and 1998 to 1999 among 38 years. The simulation results are given in Supporting Report Sector G.

Table 10.2.24 Comparison of Water Requirement and Water Release from Dams in Dry Season

Year	Water Requirement from Dams in Dry Season (MCM)	Water Release from Dams in Dry Season (Simulation Result) (MCM)	Evaluation
1974-1975	5,315	8,346	OK
1975-1976	5,389	13,167	OK
1976-1977	5,299	8,779	OK
1977-1978	6,479	7,488	OK
1978-1979	5,687	9,433	OK
1979-1980	7,436	7,436	OK
1980-1981	5,651	7,869	OK
1981-1982	5,422	8,425	OK
1982-1983	6,041	7,246	OK
1983-1984	5,176	8,427	OK
1984-1985	5,806	7,021	OK
1985-1986	5,177	8,606	OK
1986-1987	6,889	6,889	OK
1987-1988	5,647	5,647	OK
1988-1989	5,723	6,677	OK
1989-1990	6,141	6,141	OK
1990-1991	6,438	6,438	OK
1991-1992	6,690	6,690	OK
1992-1993	6,436	6,436	OK
1993-1994	7,773	5,794	NO
1994-1995	7,149	10,342	OK
1995-1996	6,257	11,836	OK
1996-1997	5,980	9,166	OK
1997-1998	7,638	7,638	OK
1998-1999	7,258	6,438	NO
1999-2000	5,961	7,233	OK
2000-2001	6,617	6,689	OK
2001-2002	6,504	8,700	OK
2002-2003	5,868	11,607	OK
2003-2004	8,351	8,351	OK
2004-2005	8,717	8,717	OK
2005-2006	7,663	10,550	OK
2006-2007	7,534	11,405	OK
2007-2008	7,498	7,576	OK
2008-2009	7,299	8,900	OK
2009-2010	7,312	7,312	OK
2010-2011	6,454	9,740	OK
2011-2012	6,727	14,439	OK

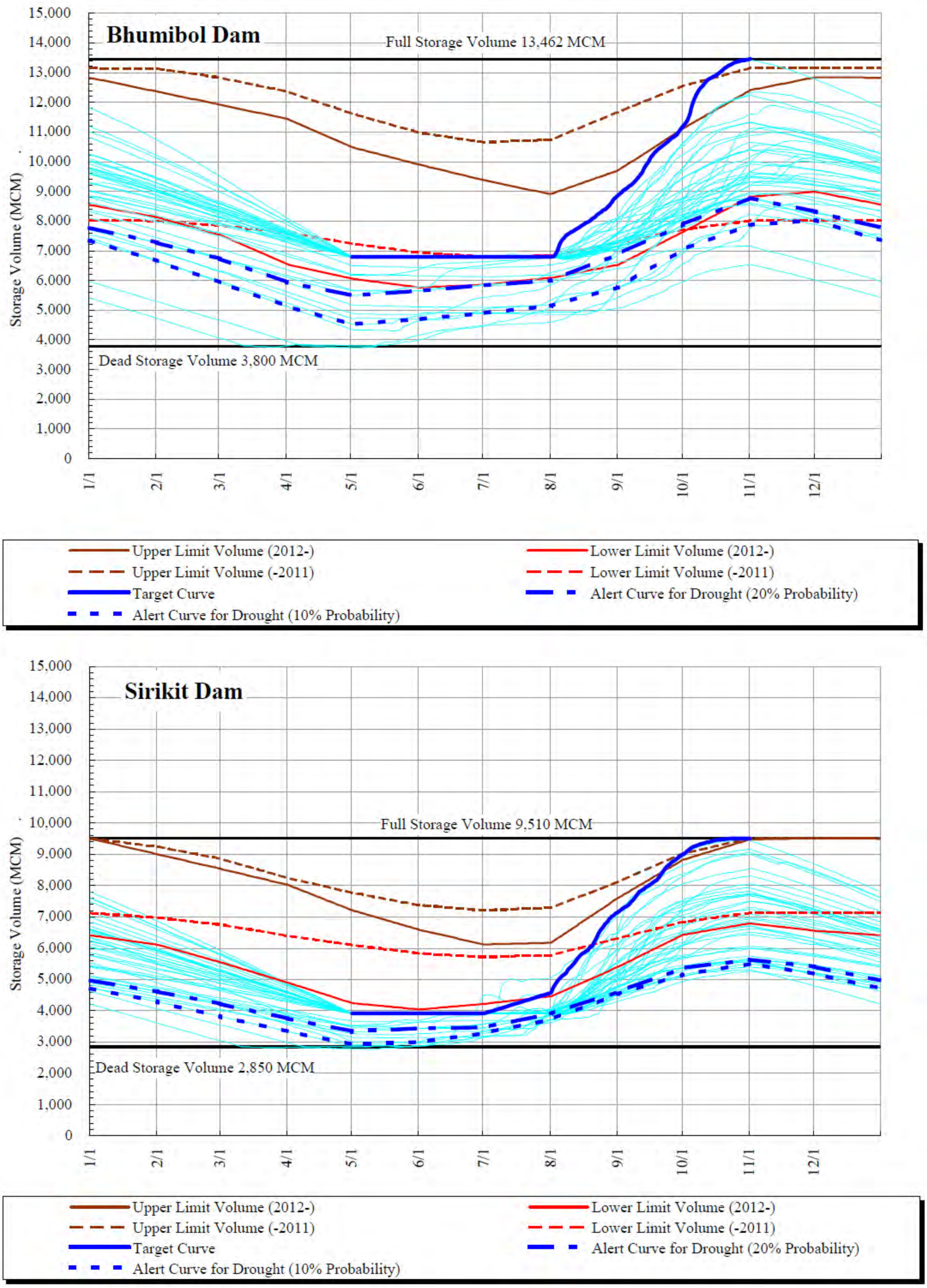


Figure 10.2.18 Results of Water Supply Simulation using Daily Inflow (1975 – 2012)

(e) Influence of Modified Operation Rules

The proposed operation rules and rule curves recommends that Bhumibol and Sirikit dams do not impound in May to July to maximize the room of storage volume for flood control in rainy season. Therefore, from May to July, runoff from upstream of both dams flows into downstream directly (inflow to the dams are equal to outflow). In some cases, there is fear that if runoff from upstream of dams in May to July is larger than usual, flood inundation may occur at downstream of dams. Here, the impact of advanced water release for ensuring flood control volume in 2011yr flood was examined. In 2011, tropical storms, Haima (in June) and Nock-Ten (in July) hit Chao Phraya River Basin.

Following figures shows that the calculated hydrograph at major hydrological station in Ping River and Nan River. Actually, the flow discharge from June to July is larger by modified dam operation but it is less than the flow discharge during flood season, from September to October. Therefore, it could be said that inundation risk at downstream caused the by advanced release water should be low.

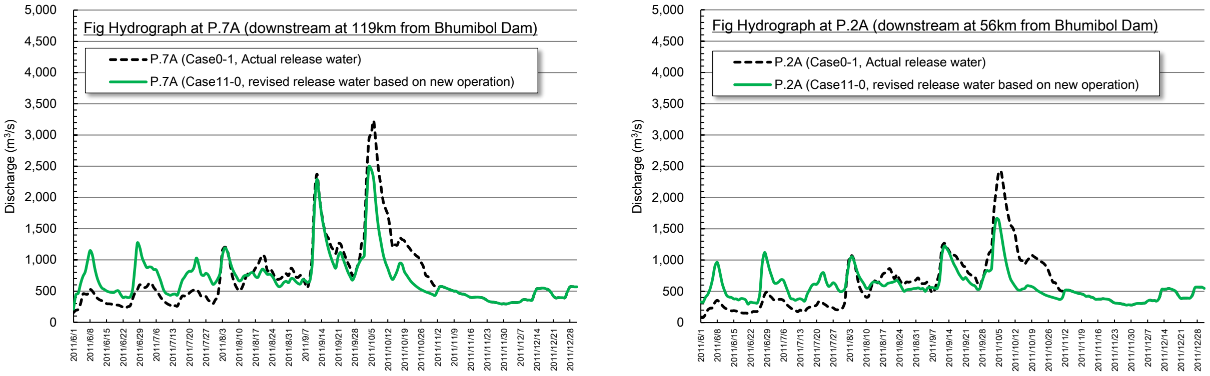


Figure 10.2.19 Impact of Advanced Release Water from Bhumibol Dam

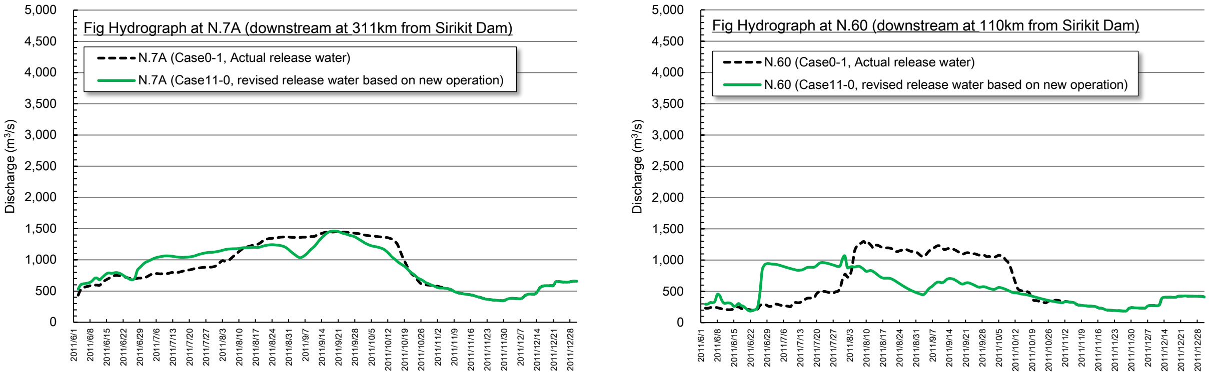


Figure 10.2.20 Impact of Advanced Release Water from Sirikit Dam

10.2.3 Construction of New Dams

The Government of Thailand has planned to construct several new dams. Among them, Kaeng Sue Tein Dam in the Yom River Basin, Nam Kheg Dam in the Nan River Basin and Mae Wong Dam in the Sakae Krang are assessed on their flood regulation effects.

(1) Plan of New Dams

In the Chao Phraya River Basin there are 10 large dams with reservoir storage capacities of more than 100MCM as shown below.

Table 10.2.25 Existing Large Dam Reservoirs in Chao Phraya River Basin

River	Name	Type	Height (m)	Catchment Area (km^2)	Effective Reservoir Capacity (MCM)	Elevation of Dam Crest (m MSL)
Ping	Bhumibol	Arch	154.0	26,386	9,662.0	261.0
	Mae Ngat	Fill	59.0	1,280	243.4	404.0
	Mae Kuang	Fill	68.0	569	249.0	390.0
Wang	Kiew Lom	Gravity Concrete	26.5	1,425	102.0	277.4
	Kiew Kor Ma	Fill	43.5	1,275	163.8	355.5
Nan	Sirikit	Fill	113.6	13,130	6,660.0	169.0
	Kwae Noi	Fill	80.0	4,254	896.0	135.0
Pa Sak	Pa Sak	Fill	36.5	14,520	782.0	46.5
Sakae Krang	Tap Sa Lao	Fill	26.0	534	143.0	159.5
Tha Chin	Kra Siew	Fill	32.5	1,220	200.0	92.5

RID is presently promoting 107 dams for investigation, study or implementation. Their location map is presented in Figure 10.2.21. While only six (6) dam reservoirs are larger than 100MCM, the others are very small with an average of 17MCM. Major salient features of the six (6) dams are presented in Table 10.2.26 and Table 10.2.27.

Table 10.2.26 Salient Features of Large Dam Reservoirs Planned by RID (1/2)

No.	No. 1	No. 22	No. 23
Main Features	Mae Chaem Dam	Upper Yom Dam	Mae Yom Dam
River	Ping River	Yom River	Yom River
Location	Chiang Mai Province Mae Chaem District Mae Na Jon Sub-district	Phrae Province Song District Sa Aieb Sub-District	Phrae Province Song District Tao Poon Sub-district
Dam Type	-	Rockfill (Concrete-faced)	Rockfill (Concrete faced)
Dam height (m)	70.00	40.00	53.00
Length of Dam (m)	520.00	254.00	1,800.00
Catchment Area (km^2)	685.00	3,305.10	5,433.50
Reservoir Area (km^2)	-	17.37	37.40
Normal High Water Level (MCM)	135.00	166.06	588.00
Storage Capacity at Lowest Water Level (MCM)	-	38.60	41.52
Effective Storage Volume (MCM)	-	127.46	546.48
Irrigation Area (rai)	71,837	674,000	
Present Status	Desk Plan	F/S Completed	

Table 10.2.27 Salient Features of Large Dam Reservoirs Planned by RID (2/2)

No.	No. 21	No. 40	No. 100
Main Features	Kaeng Sua Ten Dam	Nam Kheg Dam	Mae Wong Dam
River	Yom River	Nan River	Sakae Krang River
Location	Phrae Province Song District Sa Aieb Sub-District	Phitsanulok Province Nakhon Thai District Baan Yang Sub-district	Nakhon Sawan Province Mae Wong District Mae Lei Sub-district
Dam Type	Rockfill (Concrete-faced)	Rockfill	Rockfill
Dam height (m)	69.00	128.0	56.00
Length of Dam (m)	540.00	757	903.02
Catchment Area (km^2)	3,538.00	936.75	612.00
Reservoir Area (km^2)	66.78	11.16	17.60
Normal High Water Level (MCM)	1,175.00	550.25	258.00
Storage Capacity at Lowest Water Level (MCM)	50.00	7.45	20.00
Effective Storage Volume (MCM)	1,125.00	542.80	238.00
Irrigation Area (rai)	774,000	50,000	251,900
Present Status	D/D completed	Desk plan	D/D completed

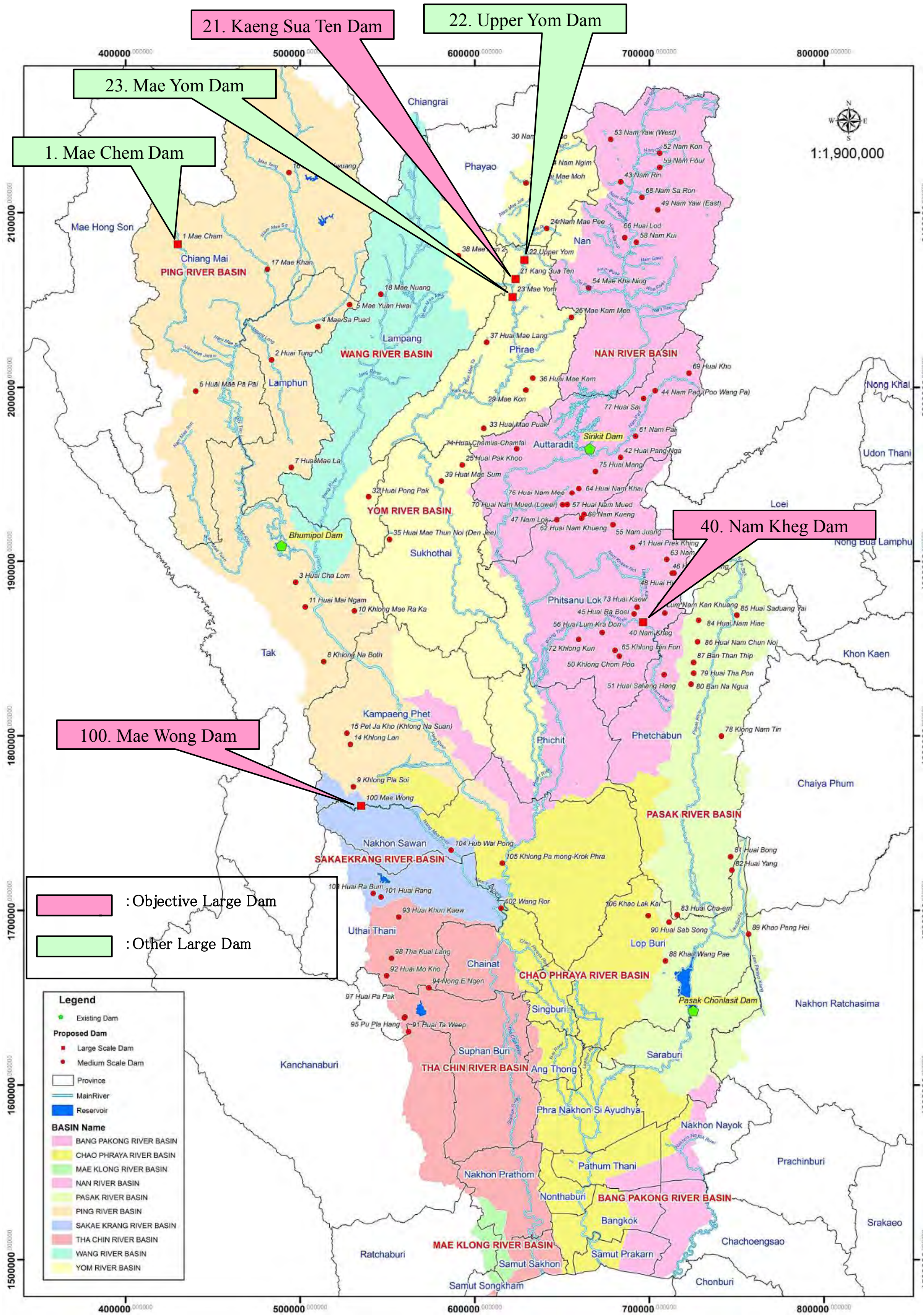


Figure 10.2.21 Location Map of Planned Dams

(2) Selection of Objective Dams

From the following reason, three (3) out of the six (6) large dams, Mae Cham, Upper and Lower Yom dams have been discarded and the remaining dams, Kaeng Sua Ten, Nam Kheg and Mae Wong Dams were selected as the objective dams. Salient features of the three (3) selected dams are summarized in Table 10.2.28.

- Since Mae Cham Dam is located upstream of Bhumibol Dam and its reservoir capacity is much smaller than that of Bhumibol Dam, significant flood mitigation effects are hardly expected.
- Upper Yom and Lower Yom dams are alternatives to Kaeng Sua Ten Dam.

Table 10.2.28 Salient Features of Planned Kaeng Sua Ten, Nam Kheg and Mae Wong Dams

No.	No.21	No.40	No.100
Main Features	Kaeng Sua Ten Dam	Nam Kheg Dam	Mae Wong Dam
River	Yom River	Nan River	Sakae Krang River
Dam Type	Rockfill (Concrete-faced)	Rockfill	Rockfill
Dam height (m)	69.00	128.0	56.00
Length of Dam (m)	540.00	757	903.02
Catchment Area (km^2)	3,538.00	936.75	612.00
Reservoir Area (km^2)	66.78	11.16	17.60
Elevation of Dam Crest (m M.S.L)	261.00	538.00	210.00
Normal High Water (m M.S.L)	258.00	529.50	204.50
Lowest Water Level (m M.S.L)	218.00	421.4	180.00
Storage Capacity at Normal High Water (MCM)	1,175.00	550.25	258.00
Storage Capacity at Lowest Water Level (MCM)	50.00	7.45	20.00
Effective Storage Capacity (MCM)	1,125.00	542.80	238.00
Maximum Discharge of Spillway (m^3/sec)	5,355 (Radial Gate × 4)	-	1,449 (Radial Gate × 3)
Elevation of Crest of Spillway (m M.S.L)	245.00	-	197.60
Maximum Discharge of Intake Conduit (m^3/sec)	-	-	-
Elevation of Center of Intake Conduit (m M.S.L)	-	-	-
Power Output (MW)	-	-	-
Irrigation Area (rai)	774,000		251,900
Present Status	D/D completed	Desk Plan	D/D completed

(3) Study on Flood Mitigation Effect of Kaeng Sua Ten Dam

In the same way as the study on the reservoir operation of the existing dams, the dam reservoir operation of Kaeng Sua Ten Dam for flood mitigation has been examined.

(a) Reservoir Operation for Flood Mitigation

The reservoir operation method where flood inflow from August to October is cut by a constant outflow has been examined.

(b) Simulation Conditions

Model Flood

The 2011 flood was used as the model flood. Inflow to the reservoir was estimated by modifying the observed discharge data of the nearby station Y2.

Table 10.2.29 Inflow to Kaeng Sua Ten Dam in 2011

Dam	Inflow（MCM）					
	June	July	August	September	October	Total
Kaeng Sua Ten	416	409	916	577	372	2,690

Reservoir Operation for Flood Mitigation

Concepts of the reservoir operation for flood mitigation are as follows:

- From August to October, flood inflow discharge is stored in the reservoir with a constant outflow.
- From May to July, outflow is in principle the same as the inflow (“IN = OUT”)
- The discharge capacity of the outlet conduit is so small that it is impossible to release as much water as the inflow during a flood. When the water level reaches the crest level of the spillway, 245 m MSL (Storage Capacity: 560 MCM), flood inflow is released through the spillway (4 radial gates).

Study Cases

Since the required outflow of Kaeng Sua Ten Dam in the dry season has not been determined yet, it is assumed that 80% of the effective storage capacity is assured as flood mitigation volume.

Table 10.2.30 Proposed Reservoir Operation of Kaeng Sua Ten Dam for Flood Mitigation

Dam	Case	Outflow		Storage Capacity as of May 1（Sedimentation Capacity included）	Water Level as of May 1
		May to July	Aug. to Oct.		
Kaeng Sua Ten	Case 1	May to July: IN=OUT Excessive inflow over 100 m^3/s, capacity of outlet conduit is stored.	220m^3/s (from Spillway)	275 MCM	234.5 m MSL

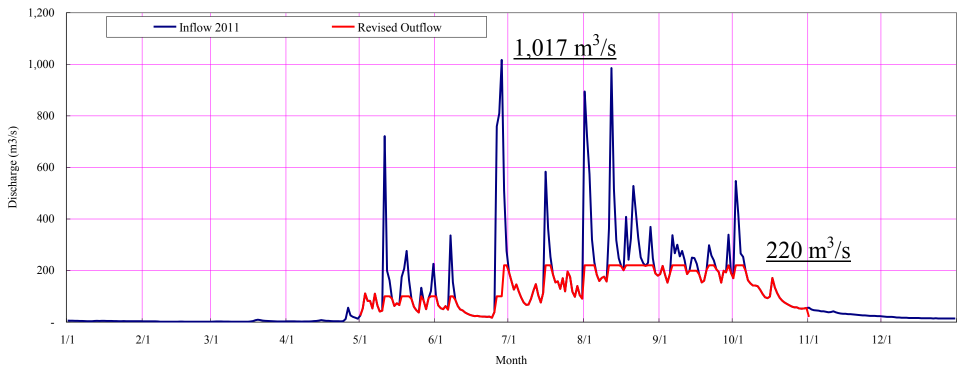


Figure 10.2.22 Proposed Flood Regulation Plan for Kaeng Sua Ten Dam (2011 Flood)

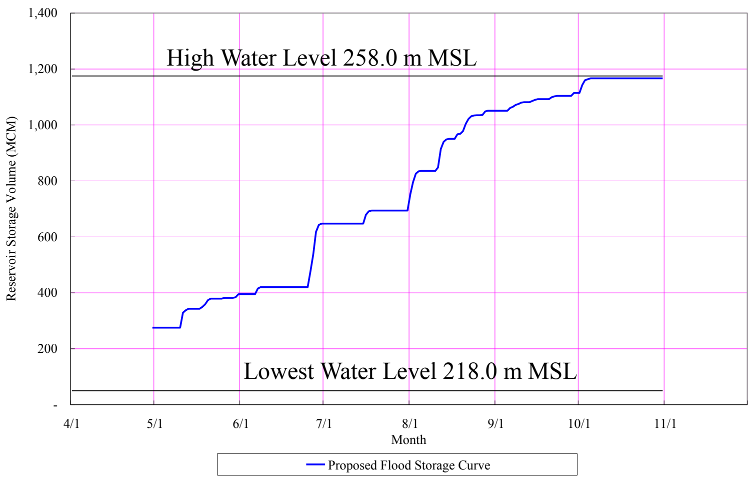


Figure 10.2.23 Proposed Reservoir Operation Plan for Flood Mitigation of Kaeng Sua Ten Dam (2011 Flood)

(4) Study on Flood Mitigation Effect of Nam Kheg Dam

In the same way as the study on the reservoir operation of the existing dams, the dam reservoir operation of Nam Kheg Dam for flood mitigation has been examined.

(a) Reservoir Operation for Flood Mitigation

The reservoir operation method where flood inflow from August to October is cut by a constant outflow has been examined.

(b) Simulation Conditions

Model Flood

The 2011 flood was used as the model flood. Inflow to the reservoir was estimated by modifying the observed discharge data of the nearby station N24A.

Table 10.2.31 Inflow to Nam Kheg Dam in 2011

Dam	Inflow (MCM)					
	June	July	August	September	October	Total
Nam Kheg	69	81	154	290	99	693

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Reservoir Operation for Flood Mitigation

Concepts of the reservoir operation for flood mitigation are as follows:

- While Nan Kheg Dam has a reservoir capacity of 542.8 MCM, flood inflow between August to October is 543 MCM. Therefore, it is possible to store almost all inflow from August to October.
- As environmental flow, the minimum outflow 15 m^3/s (1.5 $m^3/s/km^2$) is ensured.

Study Cases

Since the required outflow of Nam Kheg Dam in the dry season has not been determined yet, it is assumed that 80% of the effective storage capacity is assured as flood mitigation volume.

Table 10.2.32 Proposed Reservoir Operation of Nam Kheg Dam for Flood Mitigation

Dam	Case	Outflow		Storage Capacity as of May 1 (Sedimentation Capacity included)	Water Level as of May 1
		May to July	Aug.to Oct.		
Nam Kheg	Case 1	May to June: IN=OUT	15m^3/s	116 MCM	-

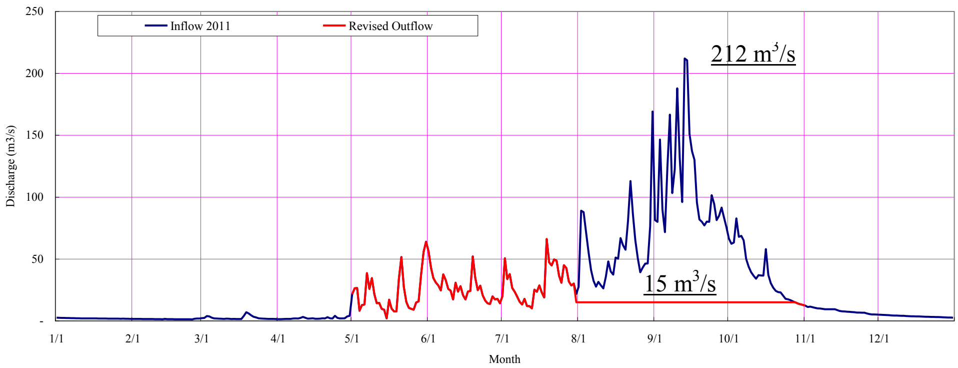


Figure 10.2.24 Proposed Flood Regulation Plan for Nam Kheg Dam (2011 Flood)

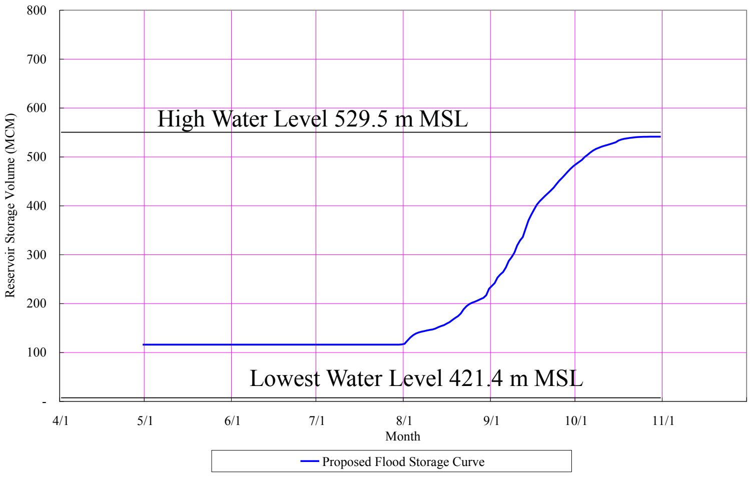


Figure 10.2.25 Proposed Reservoir Operation Plan for Flood Mitigation of Nam Kheg Dam (2011 Flood)

(5) Study on Flood Mitigation Effect of Mae Wong Dam

In the same way as the study on the reservoir operation of the existing dams, the dam reservoir operation for flood mitigation of Mae Wong Dam has been examined.

(a) Reservoir Operation for Flood Mitigation

A reservoir operation method where flood inflow from August to October is cut by a constant outflow has been examined.

(b) Simulation Conditions

Model Flood

The 2011 flood was used as a model flood. Inflow to the reservoir was estimated by runoff analysis.

Table 10.2.33 Inflow to Mae Wong Dam in 2011

Dam	Inflow (MCM)					
	June	July	August	September	October	Total
Mae Wong	39	58	61	131	89	378

Reservoir Operation for Flood Mitigation

Concepts of the reservoir operation for flood mitigation are as follows:

- From August to October, flood inflow discharge is stored in the reservoir with a constant outflow.
- From May to July, outflow is in principle the same as the inflow ("IN=OUT")

Study Cases

Since the required outflow of Mae Wong Dam in the dry season has not been determined yet, it is assumed that 80% of the effective storage capacity is assured as flood mitigation volume.

Table 10.2.34 Proposed Reservoir Operation for Flood Mitigation of Mae Wong Dam

Dam	Case	Outflow		Storage Capacity as of May 1 (Sedimentation Capacity included)	Water Level as of May 1
		May to July	Aug. to Oct.		
Mae Wong	Case 1	May to July: IN=OUT	12m^3/s	67.6 MCM	188.7 m

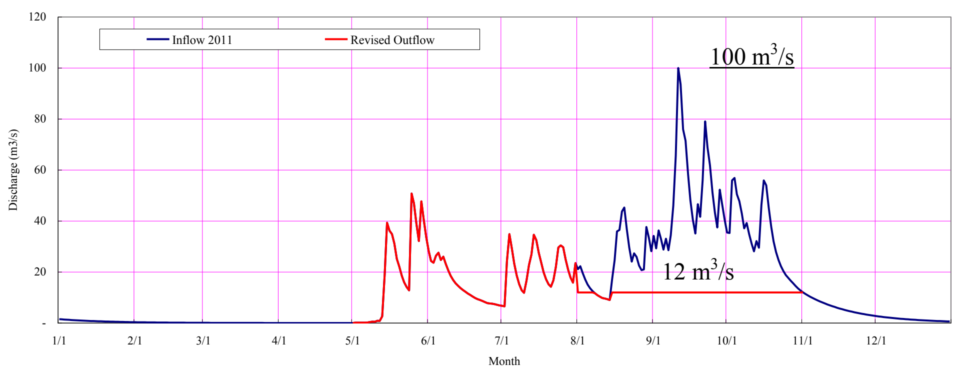


Figure 10.2.26 Proposed Flood Regulation Plan for Mae Wong Dam (2011 Flood)

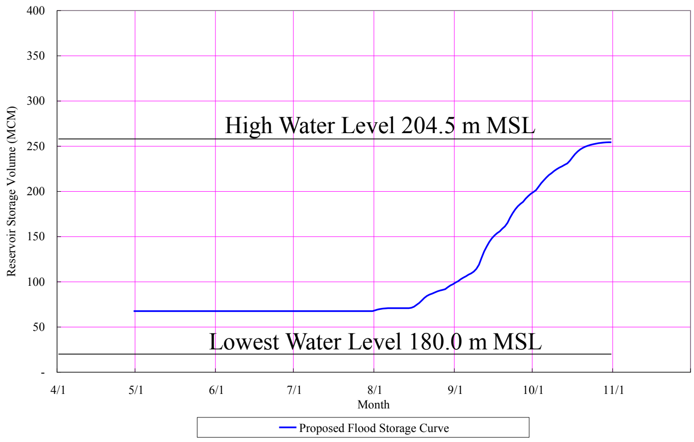


Figure 10.2.27 Proposed Reservoir Operation Plan for Flood Mitigation of Mae Wong Dam (2011 Flood)

10.2.4 Retarding and Retention Areas

(1) Selection of Objective Retention Areas for the Study

The master plan of the Government of Thailand for the upper reach of Nakhon Sawan and the vicinity of Ayutthaya retention areas (about 2,000 km²) have been planned and examined. These retarding areas are located in low-lying areas having functions as natural retarding areas.

Among the retarding areas, those areas with artificial flood control functions are called as "Monkey Cheek." Natural retarding areas have been assessed and optimum operation methods for Monkey Cheeks (methods of flood flow reduction, embankment, gates and pumps) have been studied.

(2) Study on Retarding and Retention Areas

According to the "Feasibility Study on the Development of Flood Low Lands in Chao Phraya Basin (2009)," RID has proposed to establish a total of 13 retarding basins (Monkey Cheek) including 5 locations in the northern part of Nakhon Sawan and 8 locations in Ayutthaya and the vicinities. Table 10.2.35 summarizes the proposed retarding basins and Figure 10.2.28 shows the location of each retarding basin (Monkey Cheek).

Table 10.2.35 Design Storage Volume of Monkey Cheek

No	Retarding Basin (Monkey Cheek)		Design Storage Volume (Million m^3)		Submerged Level (m MSL)
N1	Northern Part of Nakhon Sawan	Tha Bau District (East Side)	233		25.0
N2		Tha Bau District (West Side)	238		25.5
N3		Dong Set Thi District (South Side)	240	57	30.5
				183	31.0
N4		Dong Set Thi District (North Side)	147	25	37.5
				50	37.0
				72	36.0
N5		Phai Chum Phon District	303	99	39.0
				85	38.0
				74	36.0
				45	36.0
		Sub_Total	1,161		
C1	Northern Part of Ayutthaya	Bang Ban District (North-West Side)	126	54	5.0
				35	5.2
				37	5.8
C2		Phak Hai District (East Side)	125	51	5.0
				74	5.0
C3		Phak Hai District (West Side)	257		4.0
C4		Bang Ban District (South Side)	279		4.0
C5		Reong Rang District	257	172	5.0
				85	8.0
C6		Maharat District	249	124	6.0
				23	7.0
				102	7.0
C7		Khok Krathiam District	259	10	6.0
				249	7.0
C8		Yang Mani District	186		7.0
		Sub_Total	1,738		
		Total	2,899		

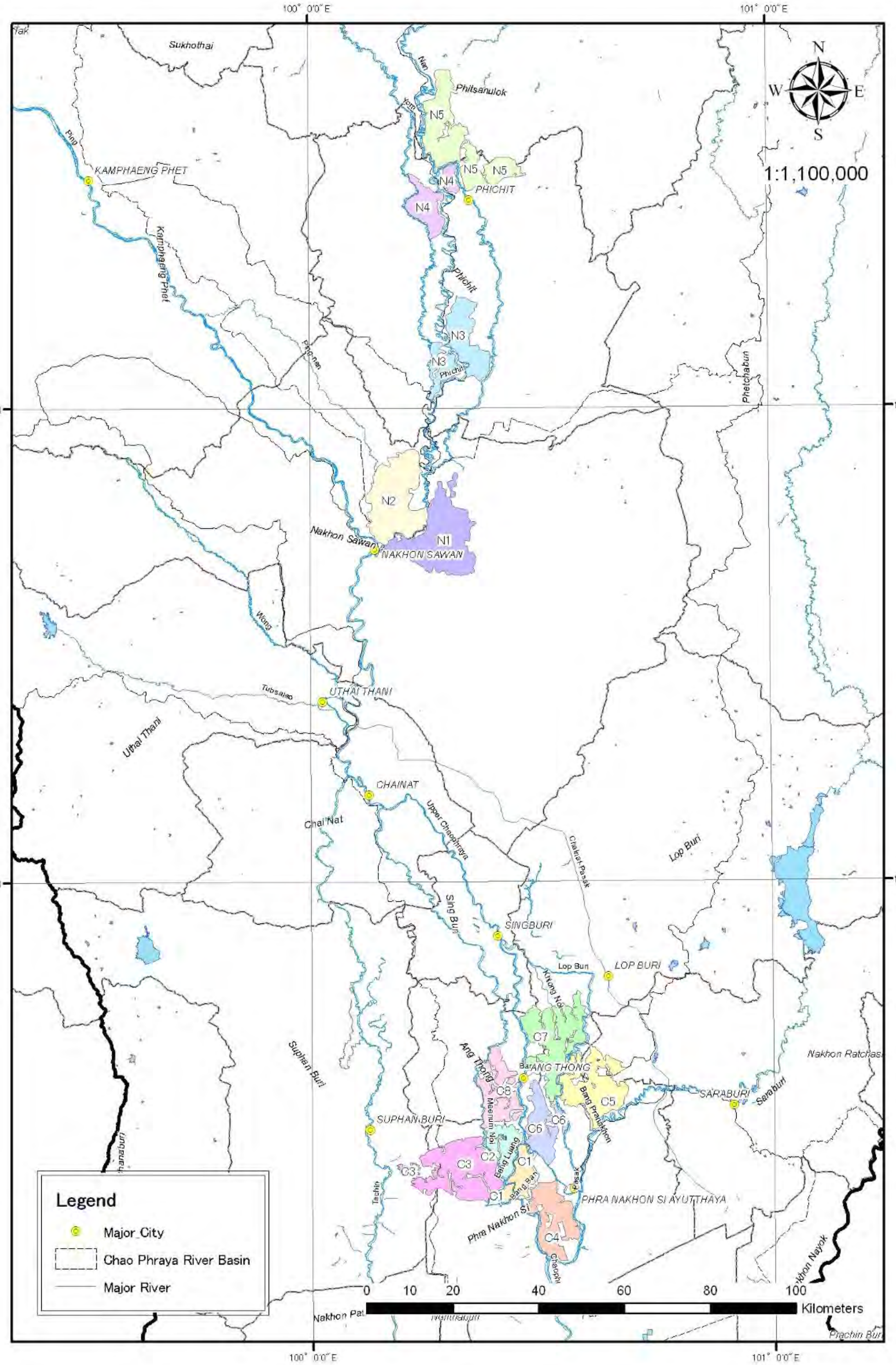


Figure 10.2.28 Location of Retention Areas Planned by RID

(a) Operation Rule

The Chao Phraya River tends to have a prolonged flooding period and it is challenging to estimate flood hydrographs. For such flood pattern, establishing only one operational rule on "how to operate and control the retention areas/retarding basins" is neither effective nor practical. It is also true that the operational rule set to be effective for the 2011 flood event does not always have effect or impact on the other significant flooding events such as the floods in 1995 and 2006. In addition, since the stored water in retention areas/retarding basins is often utilized for irrigation and dry-field cropping, it is not practical if the operational rule focuses only on flood control. Therefore, it is necessary to establish the operational rule which considers both flood control and irrigation usage.

The proposed retention areas/retarding basins are classified into two categories: (i) irrigated area; and (ii) rainfed paddy field area, as summarized in Table 10.2.36. The period for water storage varies based on the paddy field types; therefore, the flood control effects have been examined by applying various storage curves corresponding to each paddy field type in retention areas/retarding basins.

Table 10.2.36 Variation in Water Storage Period based on Cropping Type

Paddy Field Type	Monkey Cheeks	Water Storage Periods
Irrigated Area	N3、N4、C1～C8 (Total 10 Monkey Cheeks)	・**May to August**: cultivate rice season → Flood Control is difficult ・**September to October**: store water for dry season → capable to include flood control volume, the government recommends farmers to refrain from cropping between September to November. ・**October to November**: prepare for cropping by releasing the stored water from reservoir between the end of November to December. The retention areas/retarding basins shall be completely drained and completely dried during the dry season.
Rainfed Paddy Field Area	N1、N2、N5 (Total 3 Monkey Cheeks)	・**May to August**: wet-field rice cultivation and dry-field crop season → Flood control is difficult. ・**Dry Season**: wet-field rice and cultivation and dry-field crop. In June, ploughing and irrigating the field will start. ・Water storing period is 10 months, longer than the Monkey Cheeks within the irrigated areas, starting from September to June in the next year.

(b) Method to Drain Flood Water into Retention Area

The methods to drain flood waters from river channels to retarding basins are: (i) by pump; and (ii) by water gates as shown in Figure 10.2.29. With the gate operation method, the model tends to be unstable having the complicated modeling procedure. To stabilize and simplify the flood analysis model, gate operation has not been considered in this study. Also, since the storage volume of the retention area fluctuates quickly due to inflow of inundated water from outside of the area, it is difficult to establish the proper pump operation rule. Therefore, virtual retarding ponds with design storage volume were built in the flood analysis model, and effectiveness of retention area was examined.

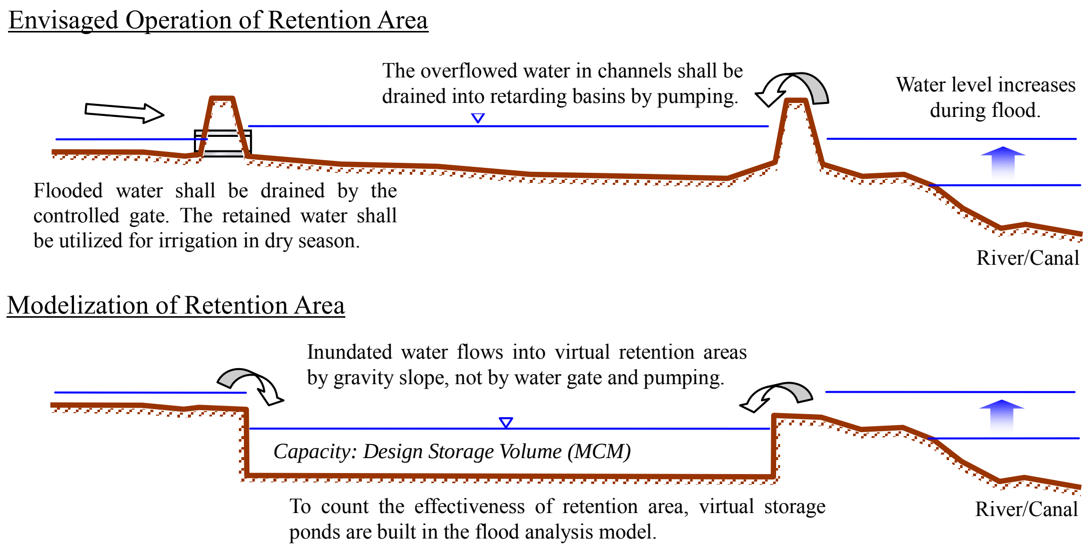
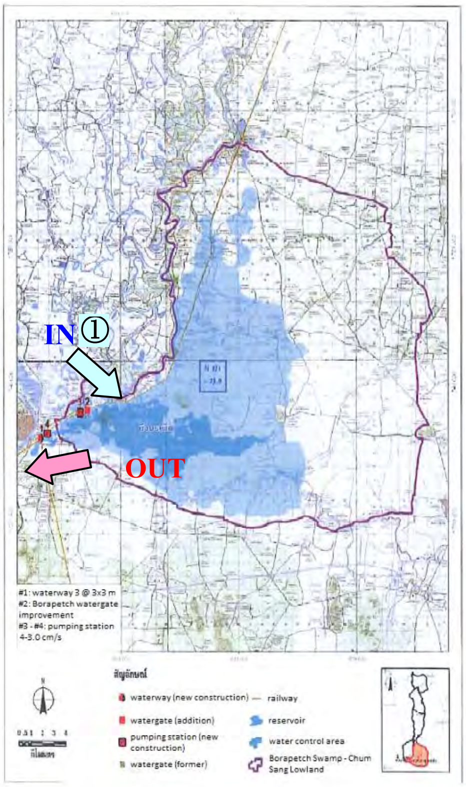
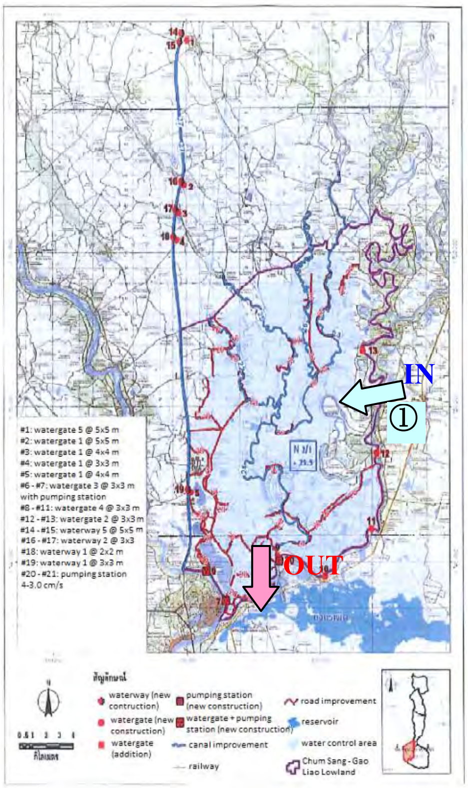


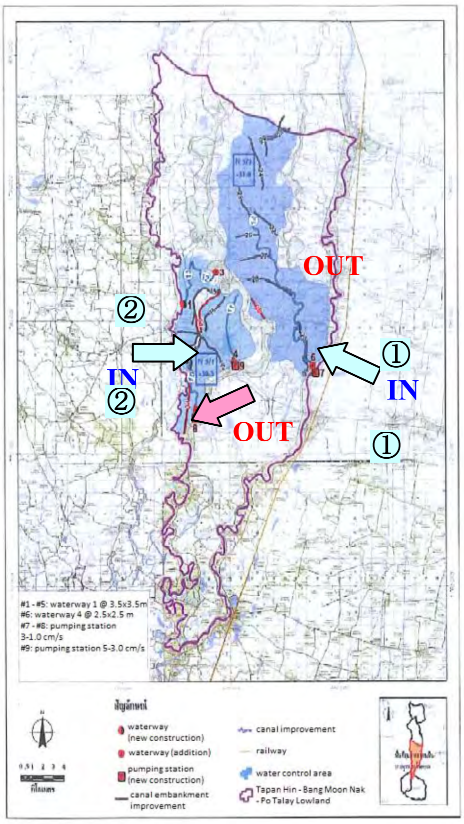
Figure 10.2.29 Method to Drain Flood Water into Retarding Basins



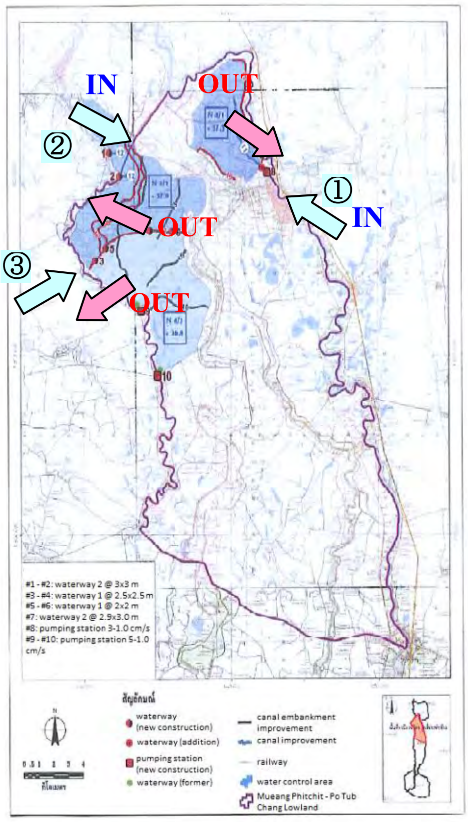
(N1)



(N2)

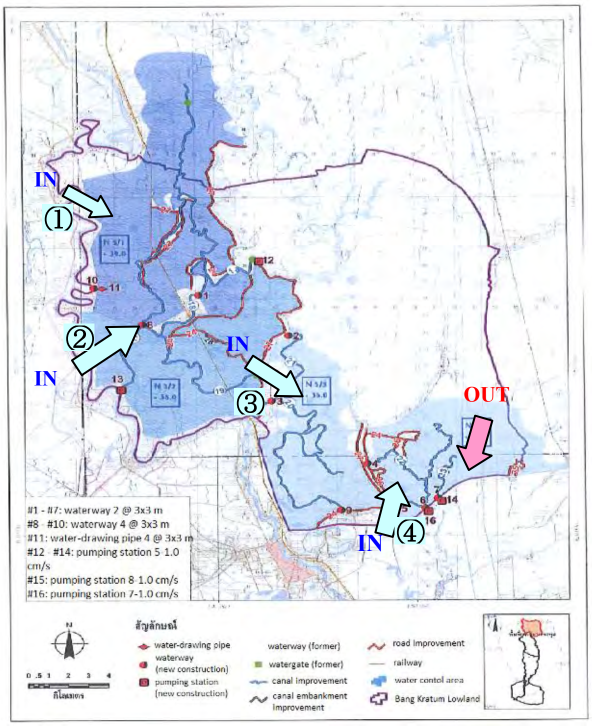


(N3)

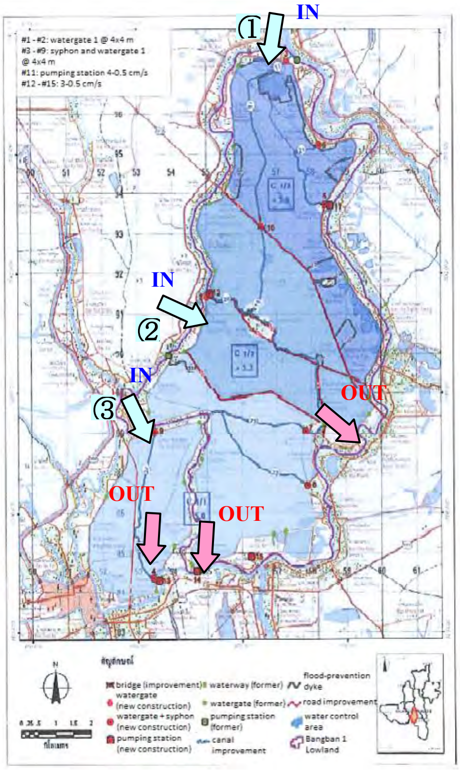


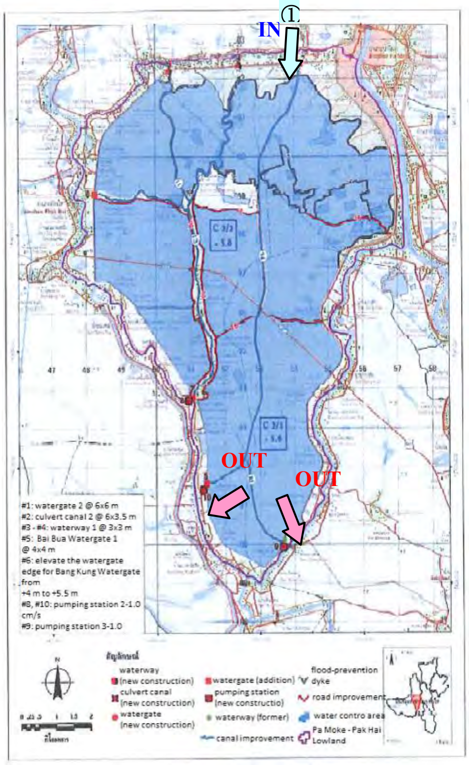
(N4)

Figure 10.2.30 Retention Area Located North of Nakhon Sawan N1, N2, N3 and N4 (Proposed)



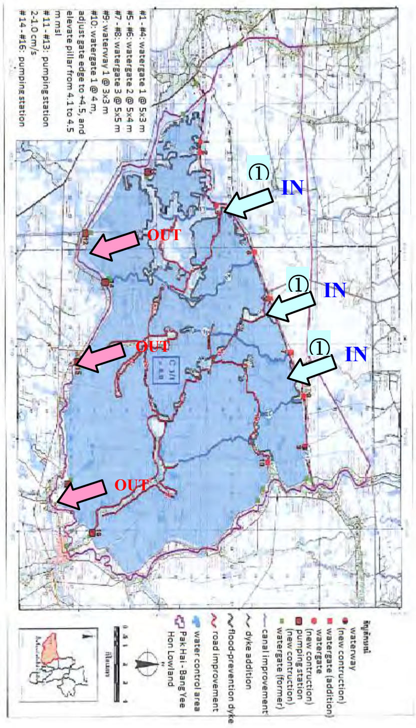
(N5)



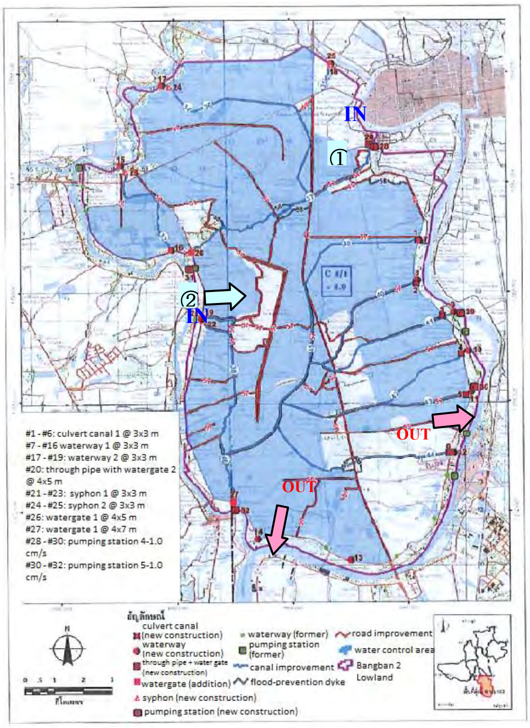


(C1) (C2)

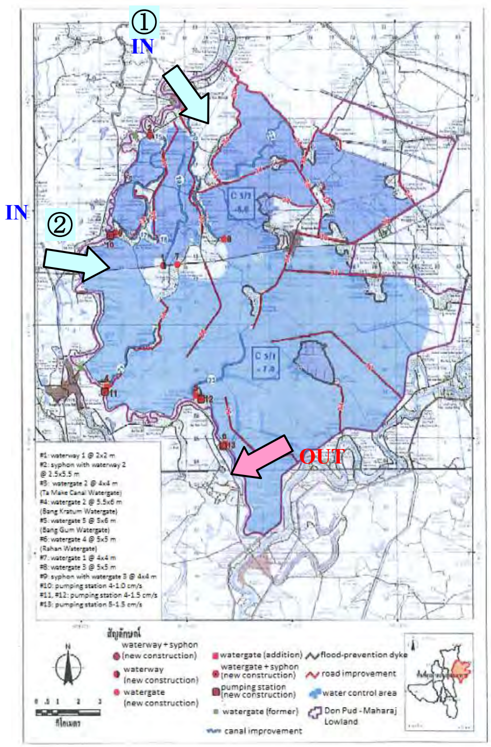
Figure 10.2.31 Retention Area Located North of Nakhon Sawan N5, C1 and C2 (Proposed)



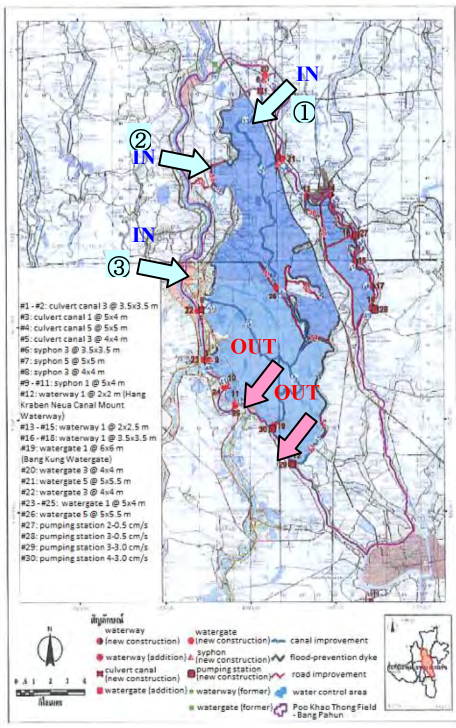
(C3)



(C4)



(C5)



(C6)

Figure 10.2.32 Retention Area Located at Vicinity of Ayutthaya C3, C4, C5 and C6 (Proposed)

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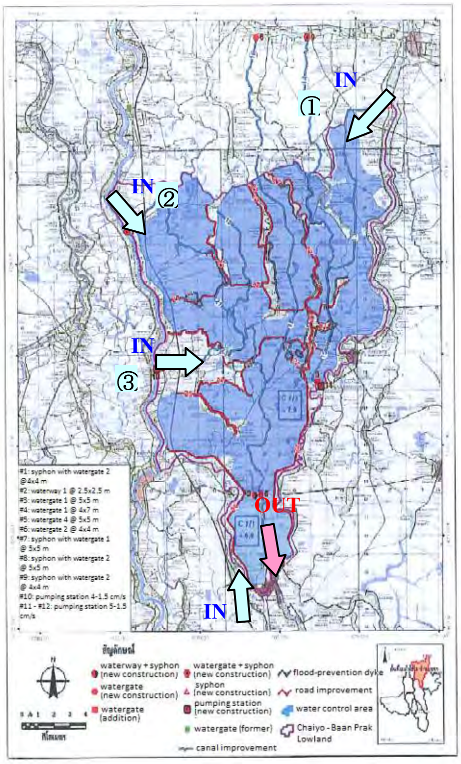
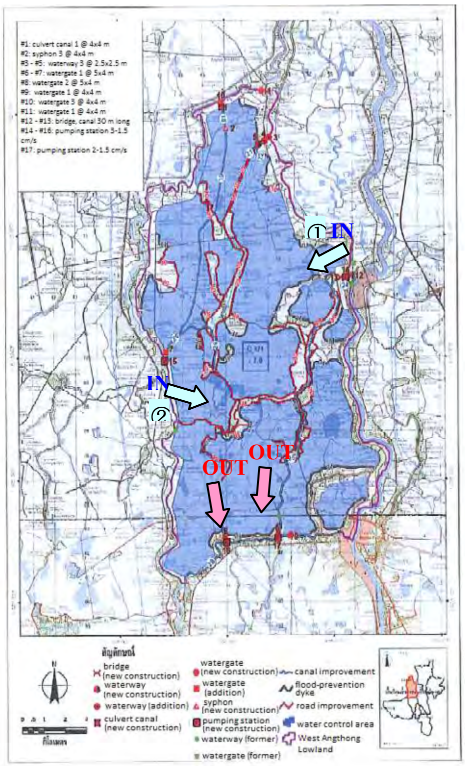


(C7)



(C8)

Figure 10.2.33 Retention Area Located at Vicinity of Ayutthaya C7 and C8 (Proposed)

(c) Ensuring Storage Volume before Flood Season

To ensuire the storage volume in reteintion area before rainy season is considered as one alternative. Actually, the more room of storage volume, the better to contorl flood water. However, accumuated water in retention area before rainay season is used for irrigation and upland cropping, so it is difficult to cordon off the storage volume completely in retention areas. As well as dam operations, retention areas should be utlized not only for flood control also for agirtuclure.

10.2.5 Flood Diversion Channel

The Thai Government has studied on three diversion channels in the Chao Phraya River basin. In this study, those plans of three diversion channles were reviewed and the effects of optimum diversion channel or the optimum combination of the diversion channels were proposed.

(1) Review on Flood Diversion Channels Proposed by Thai Government

One of the three flood diversion channel proposed by the Thai Government runs from Chainat to the Gulf of Thailand, along with the Chainat-Pasak irrigation channel and crossing Pasak River on the east side of Chao Phraya River. The feasibility study of this channel has been already compiled in "Feasibility Studies of Drainage Canals within the East Side of Chao Phraya River." The report proposed the construction of the new diversion channel whose length is approximately 270 km and improvement of the whole stretch of the existing Chainat-Pasak irrigation channel, which is at approximately 135 km.

The second one also originates from similar area or upstream and runs into the Gulf of Thailand although it is located on the west side of Tha Chin River. This route of this channel has been studied in the master plan level by the Thai Government and the report of it will be compiled soon. The lengths of the proposed routes are at approximately 260 km or longer.

The last diversion channel is called the Outer Ring Road Diversion Channel. The route has been studied and tentative one along outside of the proposed the Outer Ring Road was presented in a report. However, it is presently under revision by the Thai Government so that there is no fixed route yet. The diversion channel is started at the lower part of Ayutthaya and goes into the Gulf of Thailand.

Referring to the above mentioned information, the new and rectilinear routes were proposed for those three flood diversion channels in order to apply the most effective hydraulic gradient. Geological features and land use were also considered with satellite photos, topographic maps in 1:50,000 scale, elevation data with 1:50:000 maps and LiDAR data to fix the route of the diversion channel.

The result of the revision of the route is shown in Figure 10.2.34.

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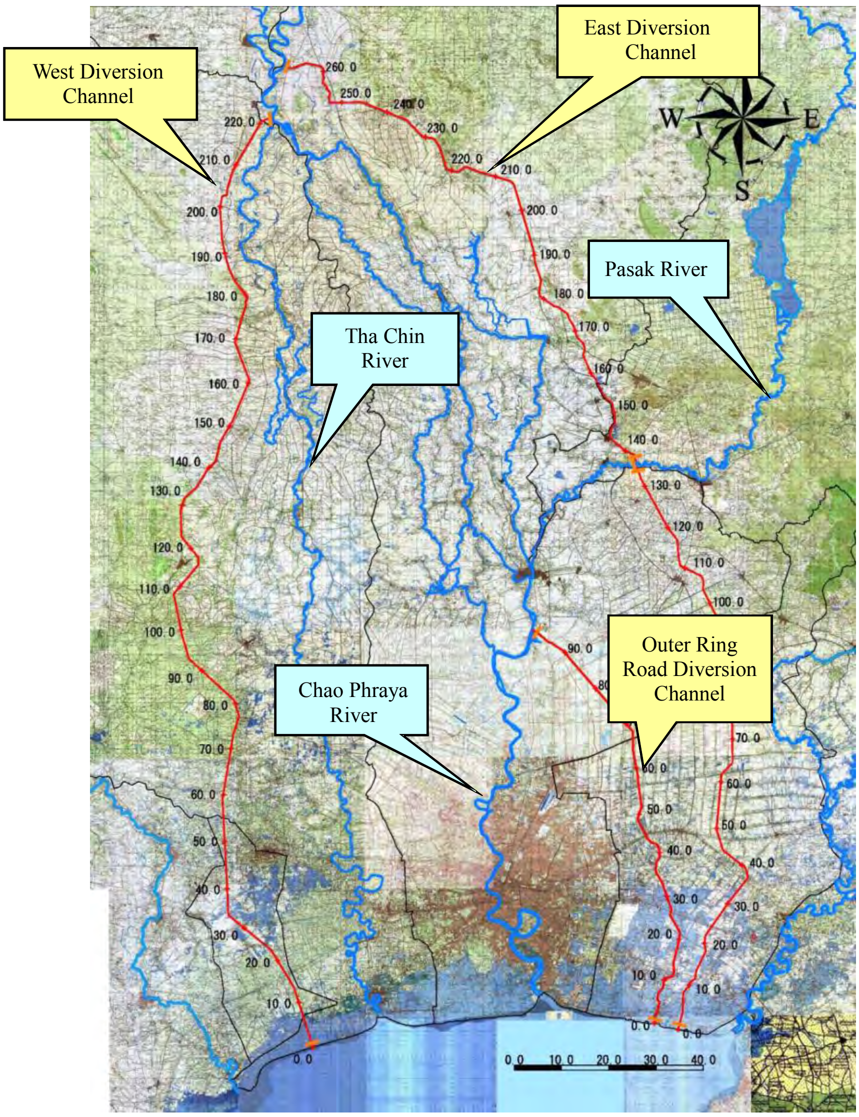

Figure 10.2.34 Location Map of Three New Diversion Channels

(2) Selection of Flood Diversion Channel(s)

With above mentioned routs, the hydraulic analysis explained in Supporting Report Sector J was performed.

As a result, the Outer Ring Road Diversion Channel was chosen for the optimal flood diversion channel.

(3) Discharge

As defined in the hydraulic analyses, the design discharge was set at 500 m^3/s (or 1,000 m^3/s).

(4) Route

As mentioned before, the diversion channel was designed connecting the lower part of Ayutthaya and the Gulf of Thailand. Since the layout of Outer Ring Road is not fixed at present, the diversion channel cannot be along it. Hence, the new and rectilinear route was proposed in order to apply the most effective hydraulic gradient. Geological features and land use were also considered with satellite photos, topographic maps in 1:50,000 scale, elevation data with 1:50:000 maps and LiDAR data to fix the route of the diversion channel.

(5) Longitudinal River Bed Gradient

Considering the existing ground slope and the standard cross section described below, the longitudinal river bed gradient was set at 1:44,700.

(6) Standard Cross Section

In order to lower the design water level, the cross section was mainly designed with excavation and the small heightening of river banks was designed with an embankment. Lowering the water level aims at lowering the risk of unexpected collapse of embankment because the rainy season in Thailand lasts for a couple of months with rise of water level. The effect of the inland storm water drainage is also large if the water level in the diversion channel is low.

(7) Bank Slope and River Bed

In the feasibility study of the east floodway done by the Thai government, the slope of river bank was set at 1:2.0 in the upstream side and 1:3.0 in the downstream side, as distinguished by Pasak River. In the Outer Ring Road Diversion Channel, the slope of the river bank was designed at 1:3.0 because the speed of water flow during floods would be small and soil of the ground is very week. Initially, two kinds of bank and river bed protection were proposed. One is the protection for only bank slope and the other is for both bank slope and river bed. Considering the difficulty of maintenance of the rigid and smooth surface of the river bed protection, the protection for only the bank slopes was selected.

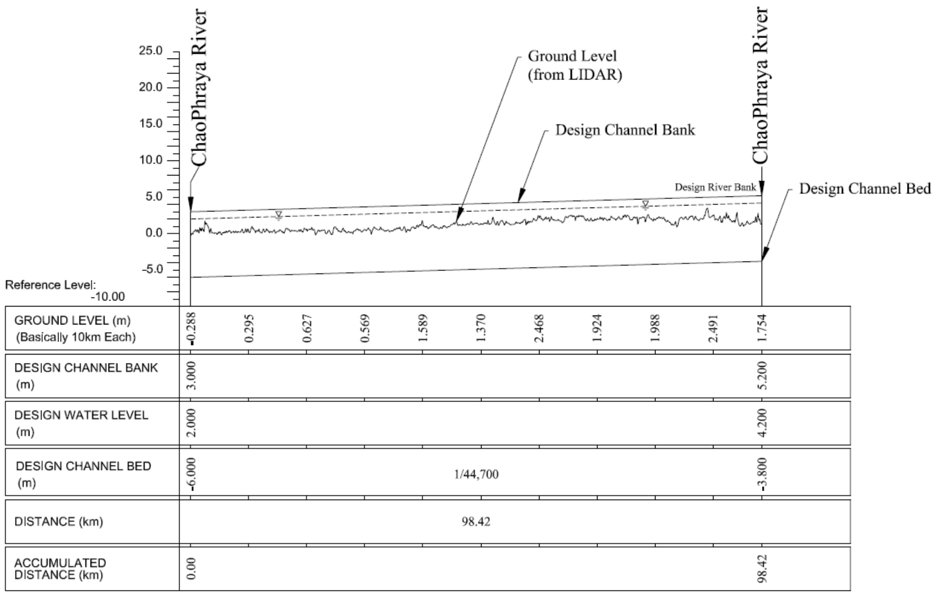

Figure 10.2.35 Longitudinal Profile of Outer Ring Road Diversion Channel

(8) Foundation Treatment

The lower part of the Chao Phraya River basin consists of an expansive low land with soft ground. Hence, foundation piles are considered to be necessary to protect the stability of the bank slopes and the roads of the diversion channel. Considering the geomorphic characteristics and soil distributions, the foundation treatment was proposed for the diversion channel.

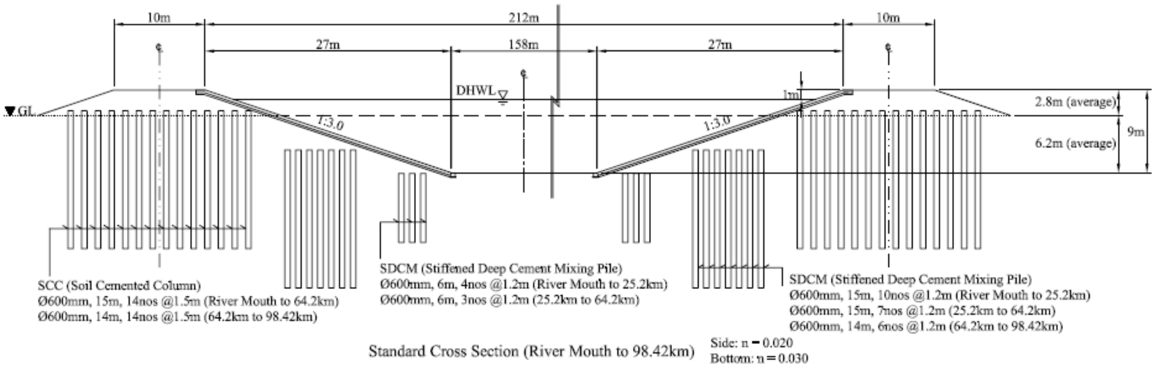

Figure 10.2.36 Standard Cross Section of Outer Ring Road Diversion Channel with Slope Protection

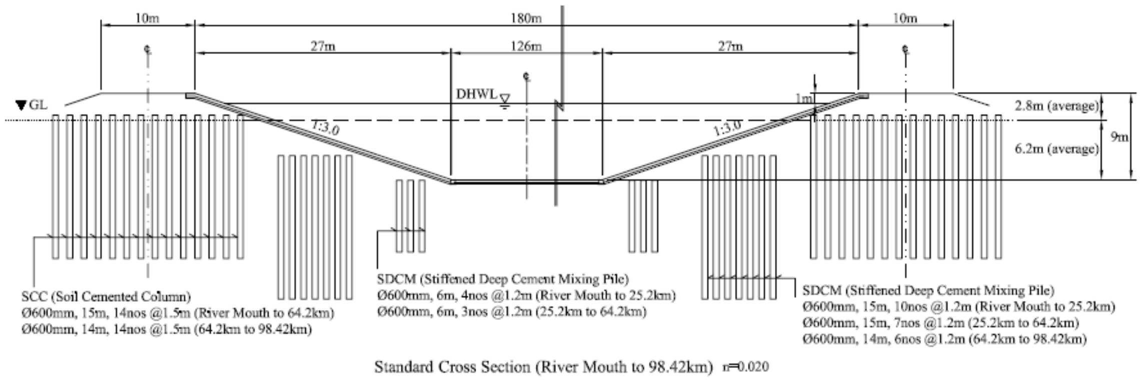

Figure 10.2.37 Alternative Cross Section of Outer Ring Road Diversion Channel with Slope and River Bed Protection

(9) Crossing Road

The diversion channel crosses a lot of roads so that bridges are required. Referring to the pitch of the bridges on Chainat-Pasak Irrigation Canal, which is at approximately 3 km, 33 bridges along 98.3km of the diversion channel were proposed. These consist of 14 for national roads and 19 for supporting ones. The widths of bridges for the national roads were set to coincide with the crossing roads measured on the satellite photo and the ones for the supporting bridges were set at 7m.

(10) Crossing Canal and River

The diversion channel also crosses a lot of canals and rivers. All of them with the width of or more than 2 m were connected with siphons. The widths of siphon were designed as those of canals and rivers. The height of the siphons was basically set at one-half of their widths and less than 10m.

(11) Gate

The diversion channel is to drain river water to the sea smoothly during the flood so that the two gates, one at the diversion point and the other at the diversion channel mouth, are basically closed during ordinary time and open during the flood.

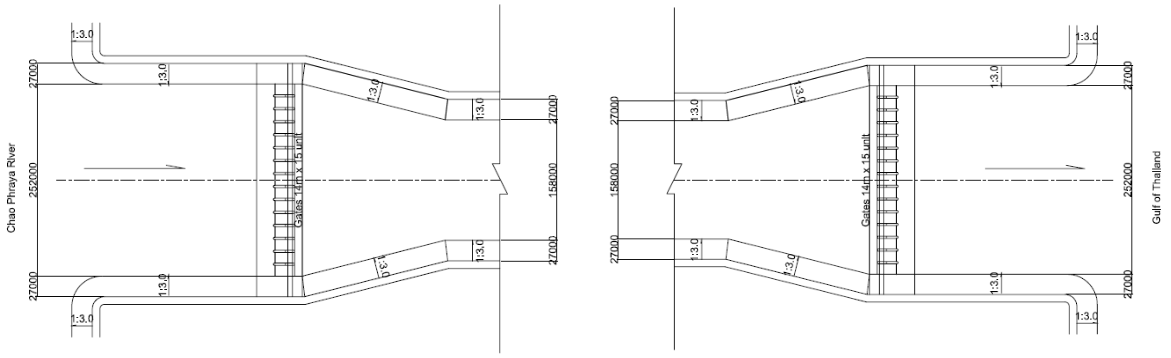

Figure 10.2.38 Gate at Diversion Point and Tidal Gate

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10.2.6 River Improvement Works of Chao Phraya River

(1) Outline

Chao Phraya River flows through the center of proposed protection area including Bangkok metropolitan. To protect the Bangkok and its vicinity from flood damage, river improvements work should be carried out. According to the hydraulic study on Chao Phraya River, river reach from 0 km to approx.90 km is estimated to be tidal affected reach. Since water level near estuary is dominated by se tide, necessary work should be not dredging but elevating of the dyke. At the present (as of July 2013), BMA plans to install the parapet wall along the Chao Phraya River from 0 km to 117 km for protection from flooding as following.

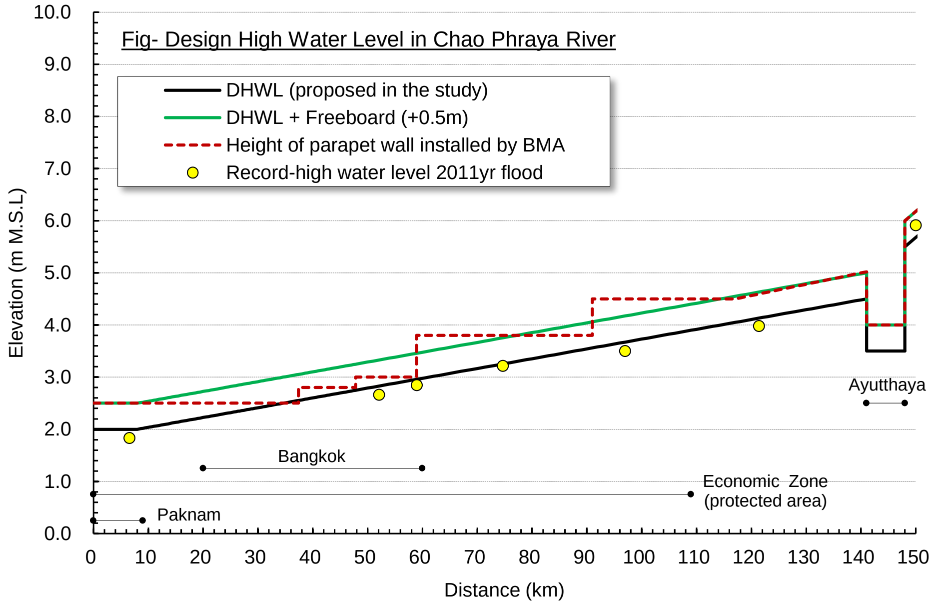
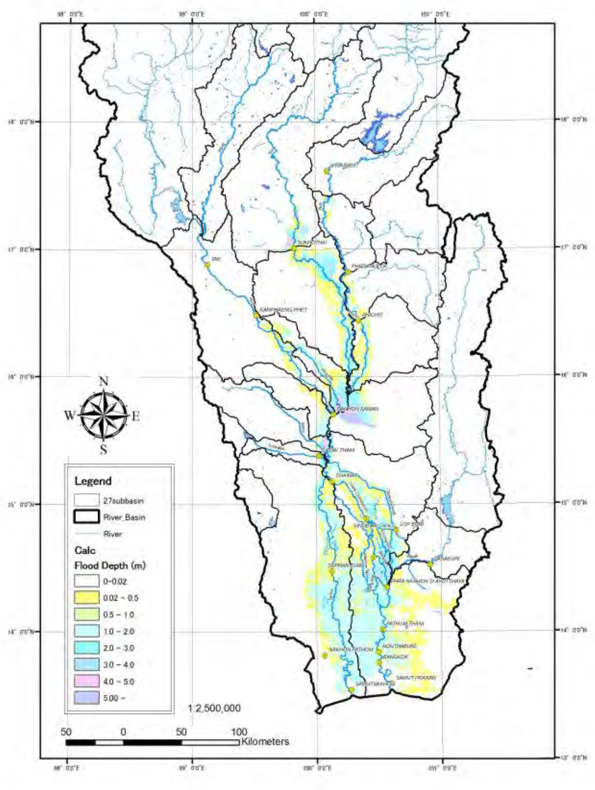


Figure 10.2.39 Installation of Parapet Wall along the Lower Chao Phraya River

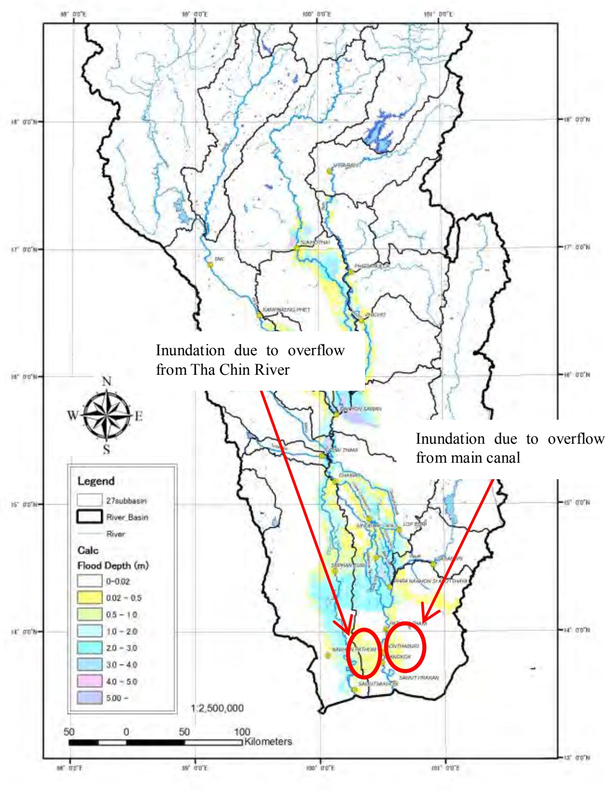
Longitudinal height of parapet wall is horizontal and step wise, which is higher than record-high water level in the 2011 flood, but actual slope of water level is slanted. In addition, some part of the parapet wall is lower than DHWL + freeboard (50 cm). Therefore, dike elevation up to DHWL + freeboard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

(2) Evaluation of River Improvement Work

Figure 10.2.40 shows the inundation map of Case0 (Reproduction of 2011yr Flood) and Case0-1 (Road Elevating by DOH/DOR and dyke elevating in lower Chao Phraya River). According to the flood analysis, dyke elevation works protects from overflow of Chao Phraya River, but the protection area is inundated due to overflow from main canal and Tha Chin River. To protect the economic zone completely, countermeasures in Tha Chin River and so on should be carried out.



Case0 :Reproduction of 2011yr Flood



Case0-1 :Road Elevating by DOH/DOR and Dyke Elevating in Lower Chao Phraya River (0 - 141km)

Figure 10.2.40 Inundation Area (w/wo Dyke Elevating Works)

10.2.7 River Improvement Works of Tha Chin River

(1) Outline

Inundation volume and depth at right side of Tha Chin River would increase due to the dyke heightening at the left side for the economically important zone. To prevent the spread of inundation area, the following countermeasures shall be examined.

1) Establishment of shortcut channels in meandering parts of the lower basin

2) Dike Elevation (Left side of Tha Chin River)

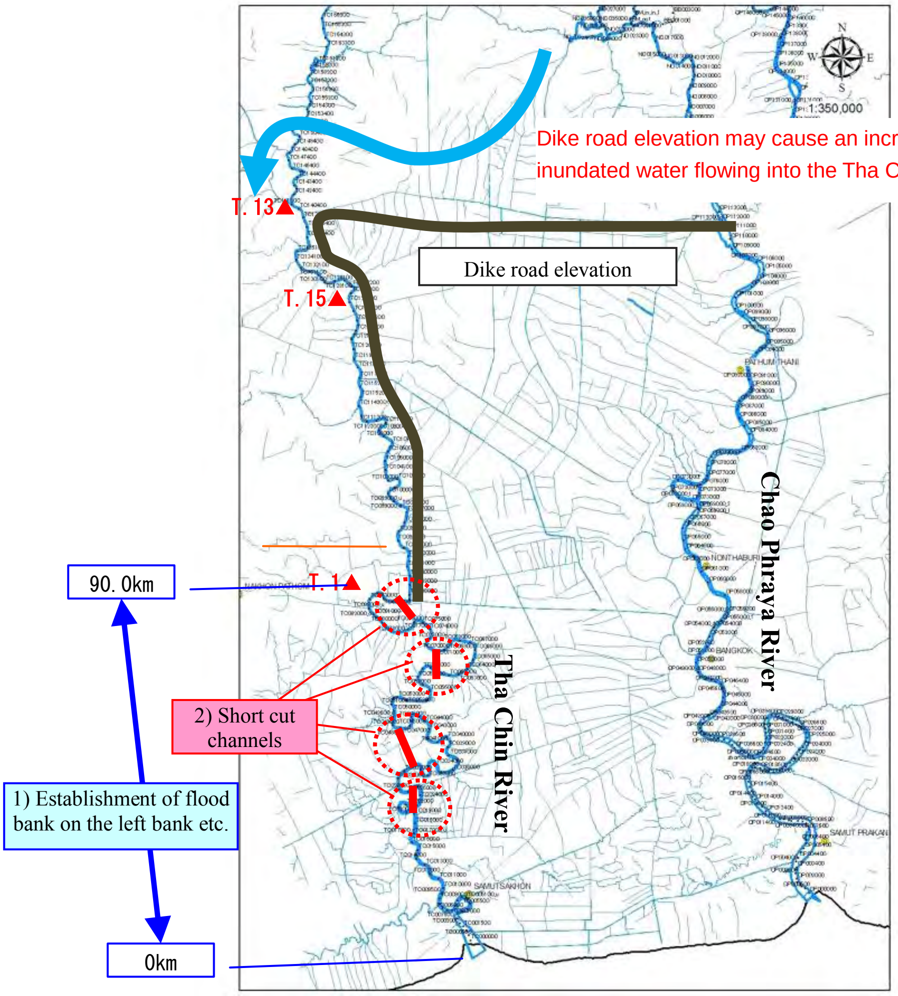


Figure 10.2.41 River Improvement Works in the Tha Chin River

(2) Shortcut Channel

In addition, to increase the drainage capacity of Tha Chin River, four (4) shortcuts are planned 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)

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

(3) Dike Elevation (Left Side of Tha Chin River)

As channel improvement in Tha Chin River, secondary dike at left side should be elevated to "Design High Water Level + Freeboard" from 90 km (Nakhon Pathom Province, Nakhon Chai Si) to 141 km point (Suphan Buri, Song Phi Nong) and primary dyke or concrete parapet wall should be newly constructed from river mouth (Samut Sakhon Province, Mueang Samut Sakhon) to 90 km point. In addition, South side dyke along Bunlue Canal is elevated to "Design High Water Level plus Freeboard".

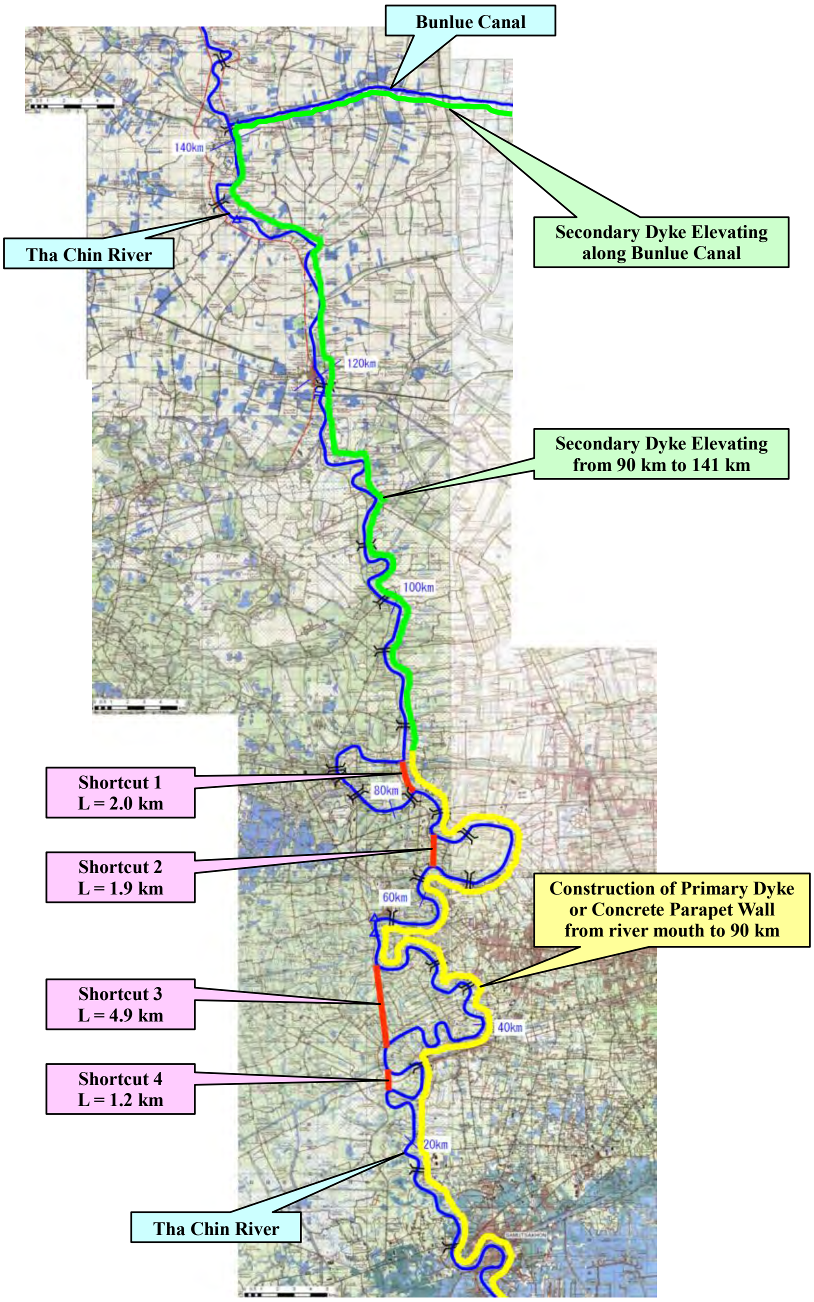


Figure 10.2.42 Location of Shortcut Channels in Tha Chin River

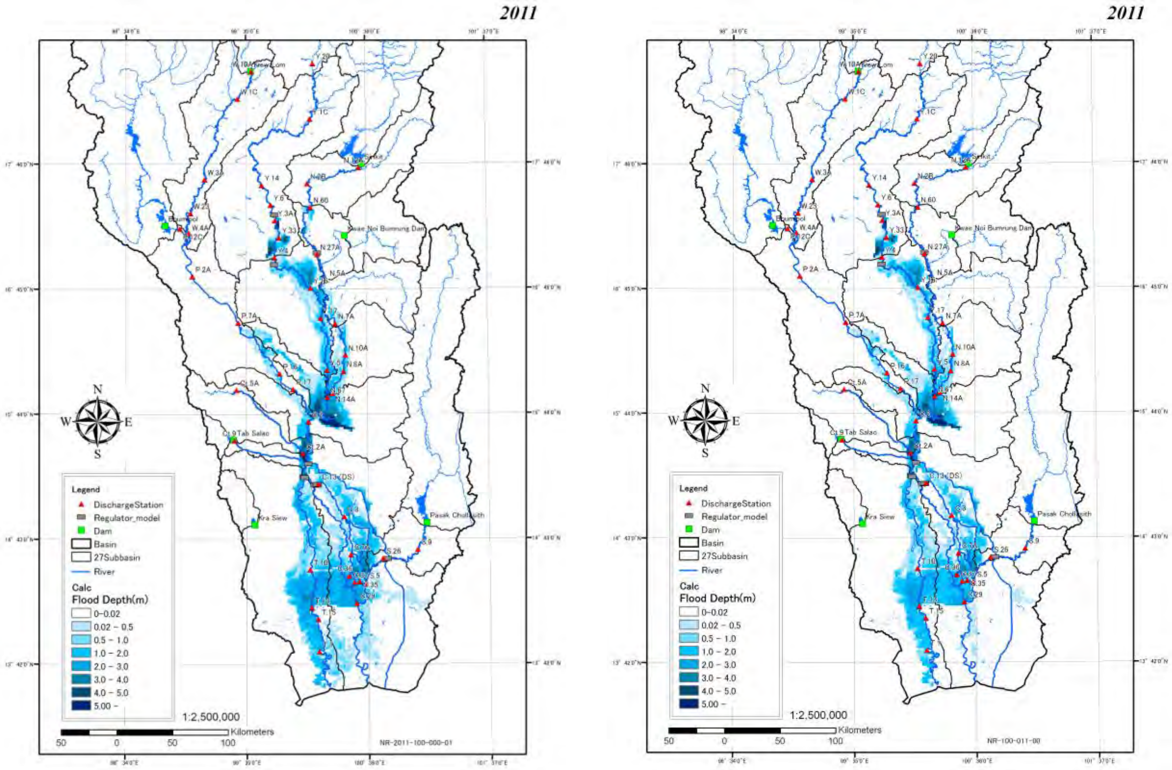
Assumed specifications of shortcut channels are as shown in Table 10.2.37. Values of channel width and river bed level are set with reference to the specification of existing river channels at the diversion point/confluence. To avoid the slope of a shortcut channel from being inverse draft, the river bed level of Shortcut Channel No. 4 in the lowest stream were determined as the deepest value, and the levels of other channels were adjusted.

Table 10.2.37 Specifications of Shortcut Channels – Tha Chin River

No.	Interval	Length	Width	River bed level	Note
1	75.9km - 87.1km	2,170m	120m	Inlet: -6.123 E.L.m Outlet: -7.760 E.L.m Slope: approx. 1/12,000	Roughness coefficient of canal: 0.030 for river bed and 0.020 for embankment slope (assuming bank protection).
2	60.7km - 70.8km	2,200m	Inlet: 125m Outlet: 130m	-7.760 E.L.m Slope: horizontal	
3	29.3km - 48.2km	4,310m	Inlet: 145m Outlet: 190m	Inlet: -7.760 E.L.m Outlet: -7.767 E.L.m Slope: approx. 1/620,000	
4	21.4km - 27.3km	1,930m	230m	-7.767 E.L.m Slope: horizontal	

(4) Effect of River Improvement Works

Figure 10.2.43 shows the estimated inundation area (Case 0-1). It is clear that dike elevation work will prevent overflow from the left side of Tha Chin River.



Without Dike Elevation　　　　With Dike Elevation

Figure 10.2.43 Estimated Inundation Area (With/Without Dike Elevation, Case 0-1)

Figure 10.2.44 shows the flow capacity of Tha Chin River with four shortcut channels. It has been confirmed that installation of shortcut channels will improve the flow capacity at Lower Tha Chin River.

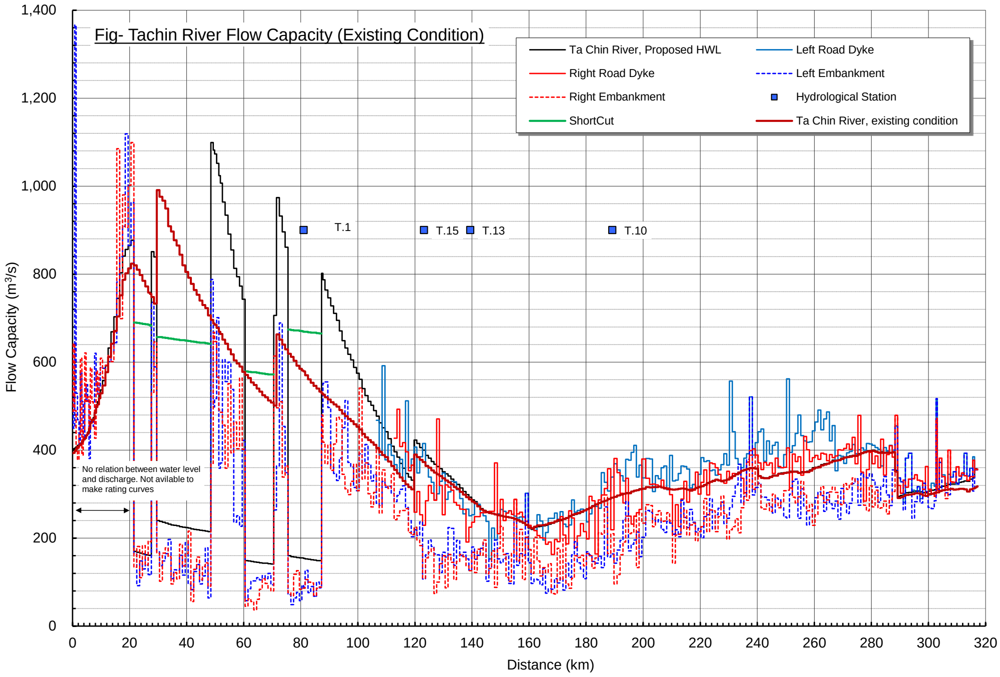


Figure 10.2.44 Flow Capacity of Tha Chin River (Installation of Four Shortcut Channels)

10.2.8 Ayutthaya Bypass Channel

(1) Outline

According to the results of analysis, the discharge capacity of the Chao Phraya River is as graphically shown in the following figure. The discharge capacity at Ayutthaya is very low.

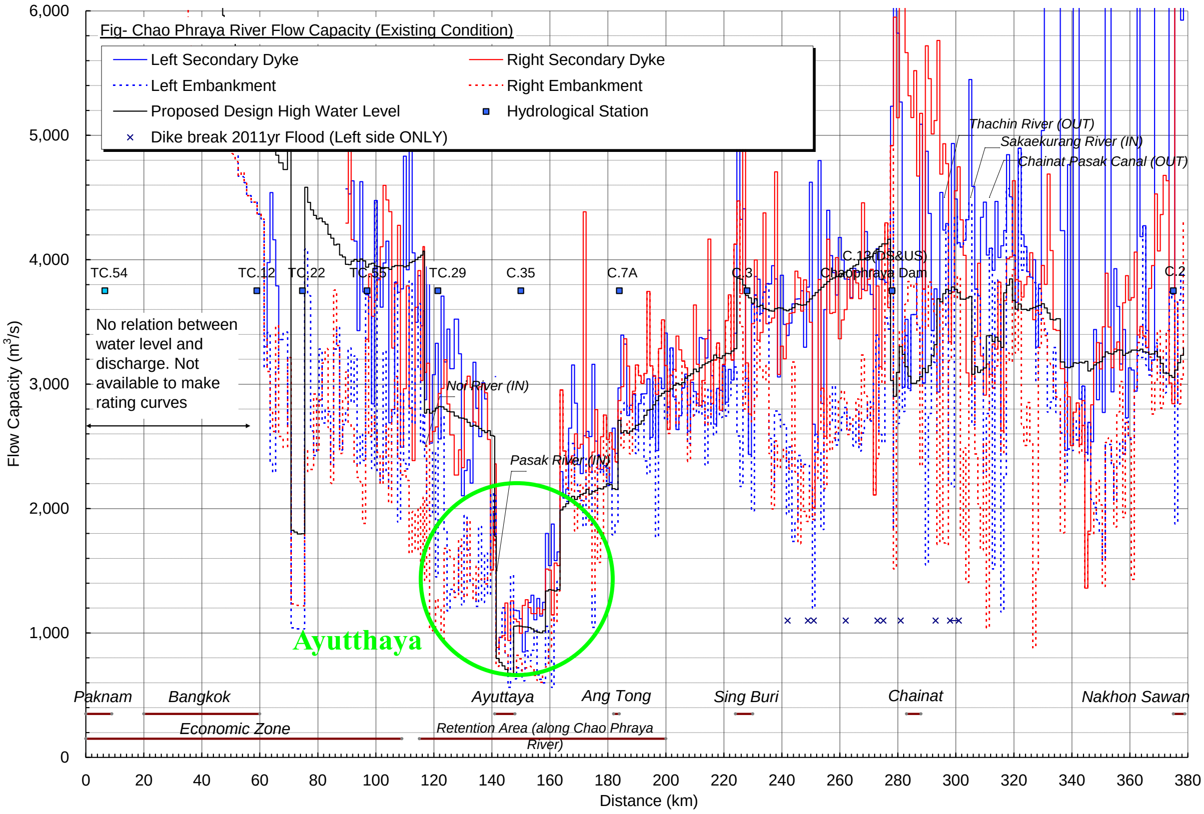


Figure 10.2.45 Present Discharge Capacity of the Chao Phraya River

Ayutthaya Bypass Channel is planned from the upstream of Ayutthaya to just upstream of the confluence of the Noi River and the Chao Phraya River. It 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. Archaeological monuments of World Heritage are scattered along the river and dyke construction is not advisable.

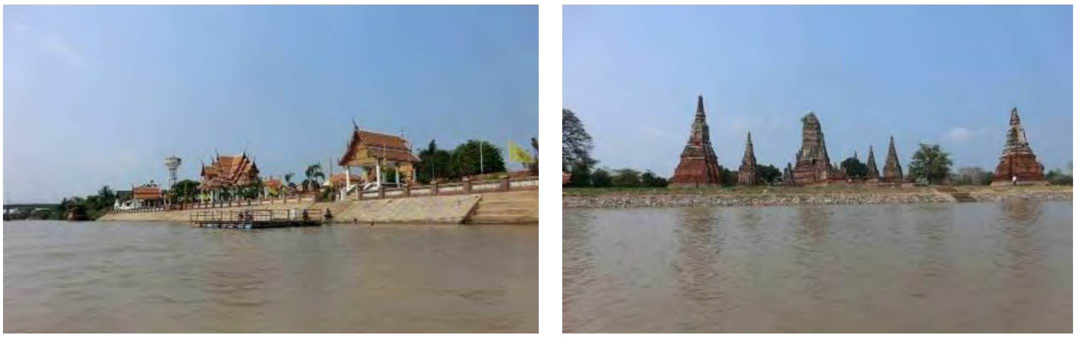


Figure 10.2.46 Scenery of Ayutthaya along the Chao Phraya River

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 can transfer the confluence of the Chao Phraya River and the Pa Sak River, and 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.

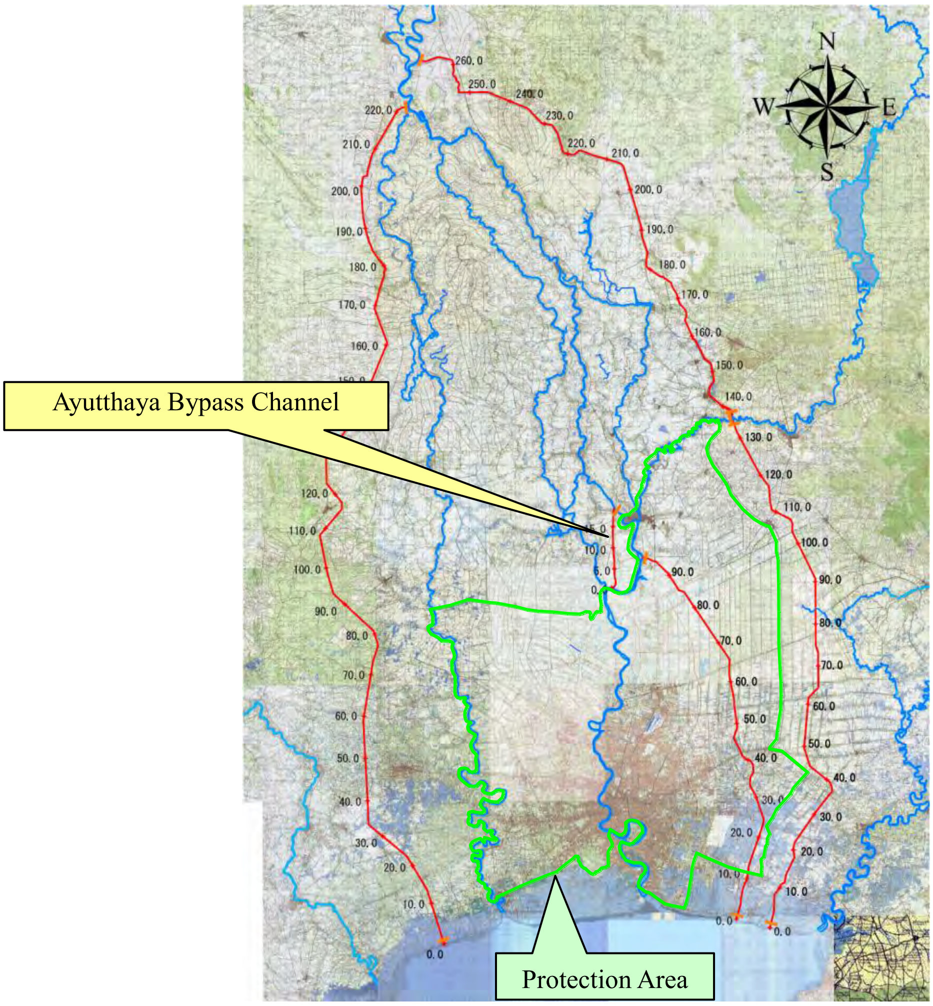


Figure 10.2.47 Location of Ayutthaya Bypass Channel

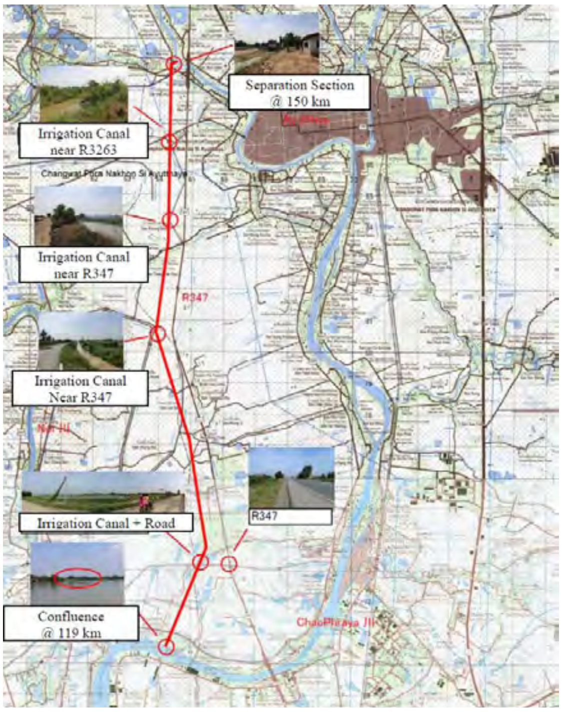


Figure 10.2.48 Bypass Channel Planned along Route 347

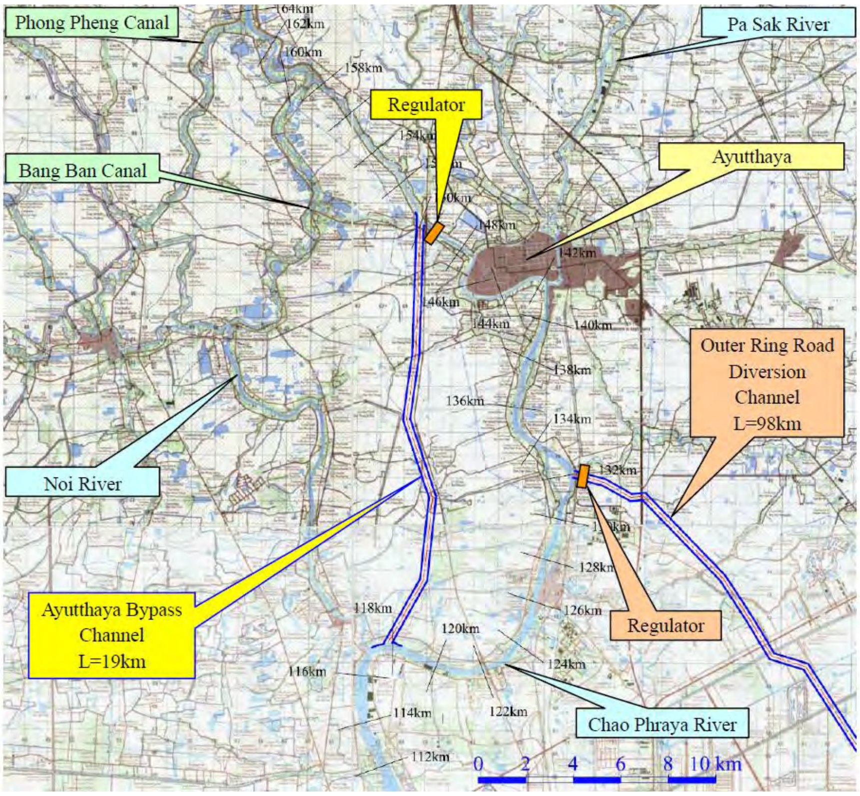


Figure 10.2.49 Proposed Ayutthaya Bypass Channel

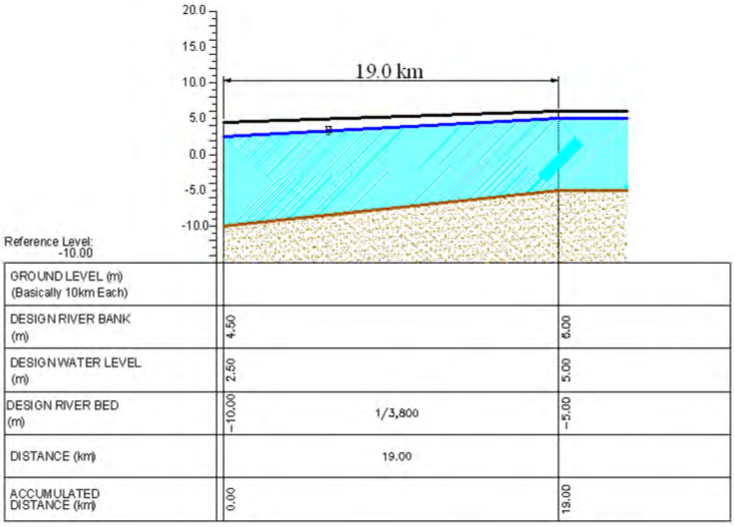


Figure 10.2.50 Longitudinal Section of Ayutthaya Bypass Channel

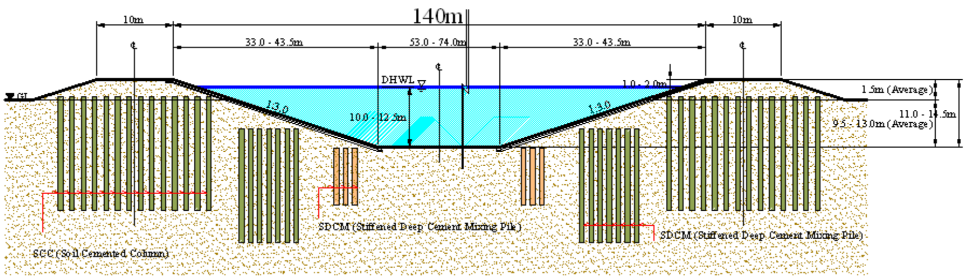


Figure 10.2.51 Channel Cross Section of Ayutthaya Bypass Channel (Capacity: 1,400 m^3/s)

(2) Prioritization of Implementation

It is indispensable to consider the flood safety level of upstream/downstream after flood countermeasures such as river improvement works and installation of flood control facilities etc. when construction schedule is planned. 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 300m^3/s and to be over 4,000m^3/s, according to the flood analysis as shown in Figure 10.2.52, 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.

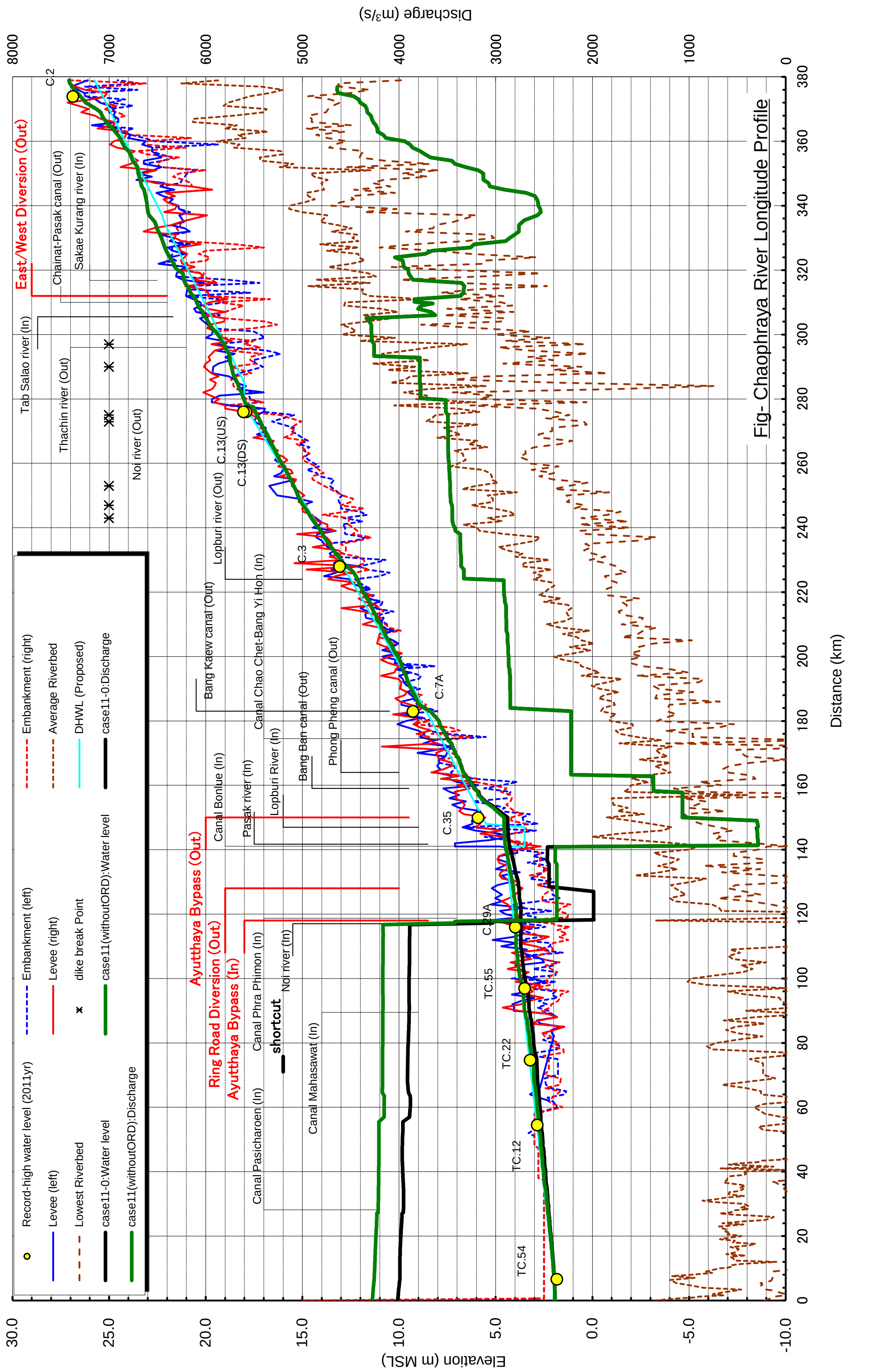


Figure 10.2.52 Longitudinal Section of Chao Phraya River (Ayutthaya Bypass ONLY, without Outer Ring Road Diversion Channel)

10.2.9 Forest Restoration

(1) Introduction

Forest management in Thailand is conducted by the Royal Forest Department (RFD). The forest area of the country was reduced from 53.33% to 30.92% between 1960 and 2006. As the result, the watersheds of the Chao Phraya River Basin have been devastated and the capacity for water absorption has diminished. In addition, surface erosion, slope failures, landslides, flash floods and drought have increased.

The 10th National Economic, Social and Development Plan (NESDP 2007 – 2011) has set a target of 40% forest cover or forest area of 204,800 km². The present forest area is 171,585.65 km², covering 33.44% of the country.

The present five year plan (2012-2016) of the RFD was prepared due to the Master Plan for Water Resources Management by the Strategic Committee for Water Resources Management (SCWRM). The Master Plan aims to solve problems and reduce flood damages.

The important actions are the forest area restoration and ecosystem conservation in order to stabilize the forest area upstream, which is an essential source for water absorption and delay runoff at mid-streams and downstreams.

It is necessary for the eight (8) river basins: the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krang, Pasak and Tha Chin Rivers to restore the degraded forest areas from flood management aspects.

The RFD has prepared an action plan for restoration of the degraded forest area in the Chao Phraya River Basin.

(2) Restoration of Degraded Forest Area

As for the eight tributaries of the Chao Phraya River Basin (Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krang, Pasak and Tha Chin rivers), the forest area is estimated to be 66,034 km², of which 13,500 km² is classified as degraded forest. In the upper reaches of the four (4) rivers (the Ping, Wang, Yom and Nan rivers) the forest area is 59,970 km², of which 9,524 km² is classified as degraded forest area. The forest area and degraded forest are as summarized in the following table.

Table 10.2.38 Forest Area and Degraded Forest Area

No.	Sub Basin	Basin Area (km²)	Forest Area (km²)	%	Degraded Forest Area (Km²)			
					Conservation Forest	Reserved Forest	Total	%
1	Ping River	34,537	23,369	67.66	1,678.40	2,057.60	3,736.00	15.99
2	Wang River	10,793	7,951	73.67	265.60	388.80	654.40	8.23
3	Yom River	24,047	11,194	46.55	555.20	1,272.00	1,827.20	16.32
4	Nan River	34,682	17,456	50.33	931.20	2,376.00	3,307.20	18.95
5	Chao Phraya	23,873	846	3.55	80.00	510.40	590.40	69.79
6	Sakae Krang River	4,907	1,556	31.72	766.40	550.40	1,316.80	84.63
7	Pasak River	15,626	2,522	16.14	126.40	1,236.80	1,363.20	54.05
8	Tha Chin	14,196	1,140	8.04	73.60	670.40	744.00	65.26
Chao Phraya River Basin		162,661	66,034	40.60	4,476.80	9,062.40	13,539.20	20.50

Upper River Basin (Nakhon	104,059
Chao Phraya River Basin	162,661

The RFD has set a target for the restoration of the degraded forest area of 8.46 million km² of the eight (8) river basins in the Chao Phraya River Basin by the restoration of forest resources and ecosystem within five (5) years. The implementation requires the participation of provincial governments and communities in the forest area.

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<u>In Thailand, numerous communities are living with forest</u>

- More than 1,000 recorded species of plants contain medicinal properties and 30,000-40,000 households harvest them on a full-time basis.
- About 60% of the rural population or roughly 30,000 communities living near forests rely on edible plants for their daily needs and 500 species of these plants are sold in local markets throughout the country.
- Currently more than one (1) million households are living within the Thailand's National Forest Reserve. The forest dwellers depend on the forest mainly for non-timber forest products.

(a) Measures for Restoration of Forest

The restoration project is composed of reforestation, soil conservation, and weir construction in the National Reserved Forest as follows:

(i) Preparation of Seedling Plantation

Seedling plantation is carried out by the RFD, communities and educational institutions. The total amount of seedling for ecosystem restoration was 82,600,000 in 2012. Seedlings of large wood have been prepared for planting in 2013.

(ii) Reforestation for Restoration of Ecosystem

- Reforestation in the surveyed degraded forest of 580,000 Rai (928 km², which is suitable for ecosystem restoration.
- Reforestation for restoration of ecosystem by communities totaling 99,500 Rai (159.2 km²): slow growing trees, fast growing trees and edible wildwood.

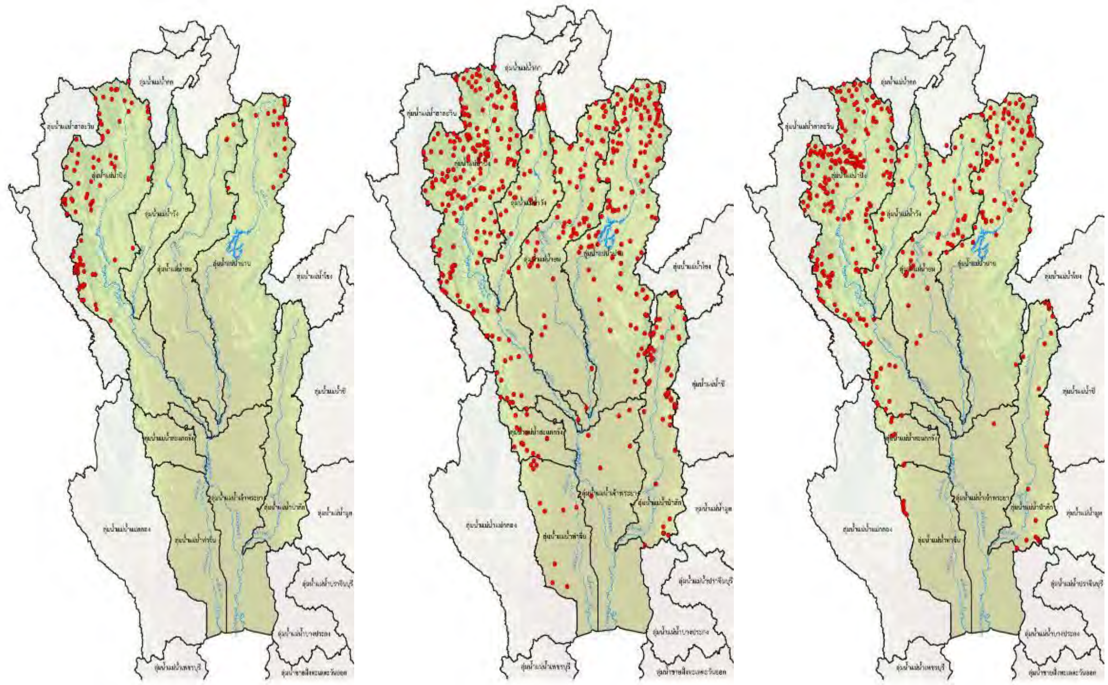
(iii) Rattan Planting

Rattan seedlings were planted in 100,000 Rai (160 km²) in 2012. A total of 24,000,000 rattan seedlings have been prepared for planting in 2013.

(iv) Vetiver Planting for Soil Conservation

Some 100,000,000 Vetiver seedlings will be planted in horizontal lines transversing the slope of areas.

(v) Community Participation in Reforestation and Sustainable Nourishment Promotion: 8 areas



Paddy Field to Forest Area Reforestation Area Vetiver Planting Area

Figure 10.2.53 Location Maps of Forest Restoration Measures for Degraded Forest Area

(b) Check Dam Construction

The following check dams are planned to be implemented after the survey of area conditions:

- 11,000 semi-permanent check dams
- 3,050 permanent check dams
- 15,000 small check dams

Location of check dam construction sites are shown in the following figure.

Check Dam Types

Semi-Permanent Check Dam

Semi-permanent check dam is made of reinforced concrete or brick and cement. Dam crest is 3-5 m long, and constructed in canal 3-5 m wide to strengthen the canal that is expecting a great water volume cluster descending from the integrated check dams. This type of check dam shall be constructed around the second order stream since it is able to trap small sediment and suspended sediment and store some water.

Permanent Check Dam

Permanent check dam is made of reinforced concrete. Its crest is no longer than 5 m and constructed in a canal no wider than 5 m. Due to wider size of canal and greater volume of water, this type of check dam has to be even stronger to delay severity and store a large water volume to take advantage of it as long as possible. Suspended sediment can be trapped and water can be stored, serving as a water source for the community.

Source: "Check Dam Construction Manual" by Public Forestation Division, Forestation Promotion Office, Department of Forestry, MONRE

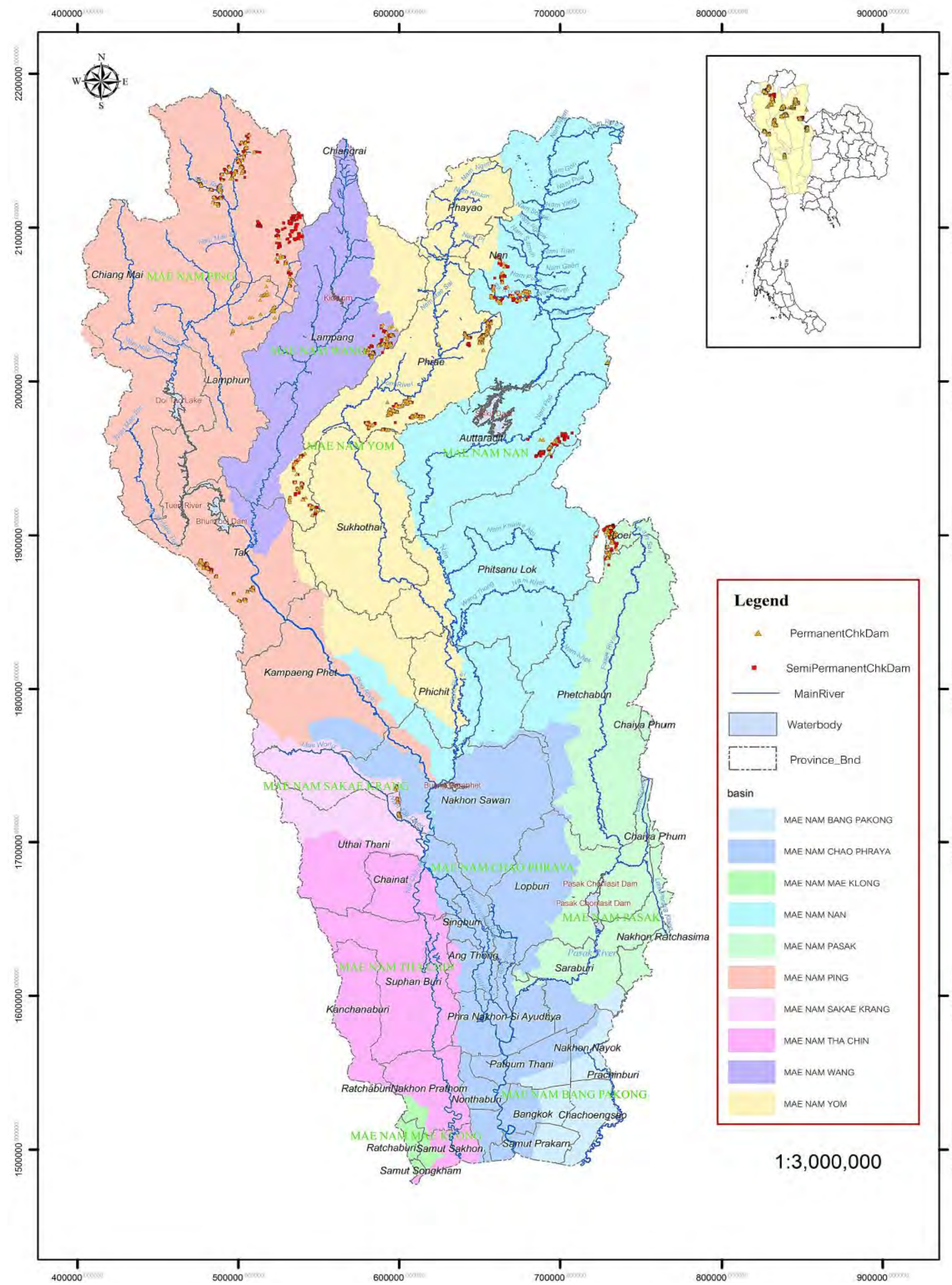


Figure 10.2.54 Location Map of Check Dam Construction

(c) Implementation Plan

The implementation plan for 2012-2013 and five years are shown in the following Table 10.2.39 and Table 10.2.40.

Table 10.2.39 Restoration of Forest for Planting and Construction in 2012-2013

No.	Main Basin	Seedling Plantation	Vetiver Planting for Soil and Water Conservation	Paddy Field to Change for Forest Land	Semi-Weir	Permanent Weir
		Quantity (Million Seedling)	Quantity (Million Seedling)	Quantity (Rai)	Number of Weire	Number of Weir
1	Ping River	28.88	3.00	900.00	662	175
2	Wang River	7.00	3.75	300.00	289	90
3	Yom River	17.98	7.00	900.00	525	162
4	Nan River	15.21	4.00	600.00	336	95
6	Sakae Krang River	2.77	0.50	300.00	92	31
7	Pasak River	10.76	1.75	300.00	296	57
Total		82.60	20.00	3,300.00	2,200	610

Source : Action Plan and Budget Restoration Project, Forest and Soil Conservation, Weir Construction in National Reserved Forest

Table 10.2.40 Five-Year Implementation Plan

Activity	Unit	Implementation Year					
		Year 1	Year 2	Year 3	Year 4	year 5	Total
1. Seedling plantation to support reforestation	Million seedling	82.6	43	44	44	44	257.6
2. Plantation for reforestation	Million rai	0.060	0.300	0.140	0.140	0.140	0.780
3. Vetiver planting	Million seedling	20	20	20	20	20	100
4. Paddy field to exchange forest land	Rai	3,300	3,300	3,300	3,300	3,300	16,500
5. Weir construction	Number of Weir	5,810	5,810	5,810	5,810	5,810	29,050

Source : Action Plan and Budget Restoration Project, Forest and Soil Conservation, Weir Construction in National Reserved Forest

(3) Effects of Forest Restoration

To restore the forest in the Chao Phraya River Basin, the RFD has been conducting restoration of the degraded forest area of 13,500 km^2 by reforestation, vetiver planting, rattan planting and construction of check dams. By restoring the degraded forest area which is about 20% of the forest area in the Chao Phraya River Basin, the upper reaches of the Ping, Wang, Yom and Nan rivers will increase their water holding capacity and the stability of slopes with the reduction of surface soil erosion and sediment disasters.

The water holding capacity of forests depend on thickness of surface soil and forest type covering ground. The Royal Forest Department (RFD) has estimated 687.84 m^3/m^2 (0.43 m^3/m^2) in average based on the maximum water storage capacity of the forest area in the upper basin. The water holding capacity in the forest area will increase by restoration of the degraded forest area (13,500 km^2) because the forest area will expand from 66,000 km^2 to 80,000 km^2. Naturally the water holding capacity of forest area is expected to increase, and also the potential of sediment discharge caused by surface erosion is expected to decrease.

(4) Required Further Study

The RFD aims to restore the degraded forest area within 5 years, and after 2017 it shall be necessary to implement a reforestation project and a forest ecosystem conservation project in order to attain the target of 40% forest cover. The RFD has to formulate the long-term plan.

Accordingly, the Project for the Comprehensive Flood Management Plan for the Chao Phraya River Basin should require the restoration and conservation of the forest area and ecosystem from 2017 onwards as a part of the comprehensive flood management plan. According to the report of the RFD, in the upper reaches of the Chao Phraya River Basin, flood and sediment disasters such as slope failure, landslide, debris flow and flash flood have often occurred in the rainy season, so that reforestation and simultaneously, the soil conservation plan are important.

Currently the RFD has adapted vetiver planting for prevention of slope erosion, and permanent and semi-permanent check dams as forest and ecosystem conservation measures. To stabilize the watersheds, it is necessary to promote reforestation and forest conservation in order to attain the goal of the flood disaster risk management.

10.2.10 Controlled Inundation Area

(1) Introduction

After implementation of the facilities proposed in the Master Plan, the protection area will be safe from floods, but inundation areas may still remain. In this section the current inundation area is studied on the regional variation of flood depth and duration and required measures for controlled inundation area from flood disaster risk management aspects.

(2) Inundation Area

(a) Inundation Area in the 2011 Flood

A reproduction of the 2011 flood inundation area and an assumed inundation area after implementation of the Master Plan are shown in the following Figures.

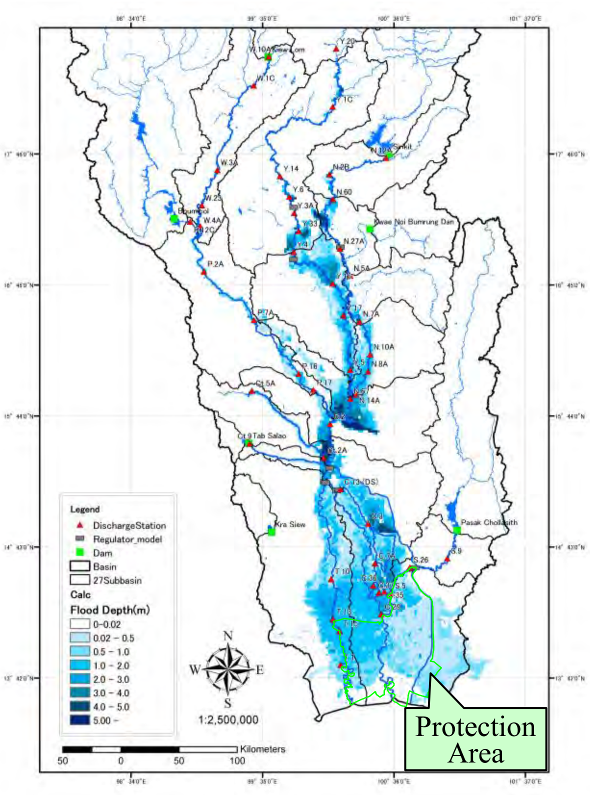


Figure 10.2.55 Reproduction of the 2011 Flood Inundation Area

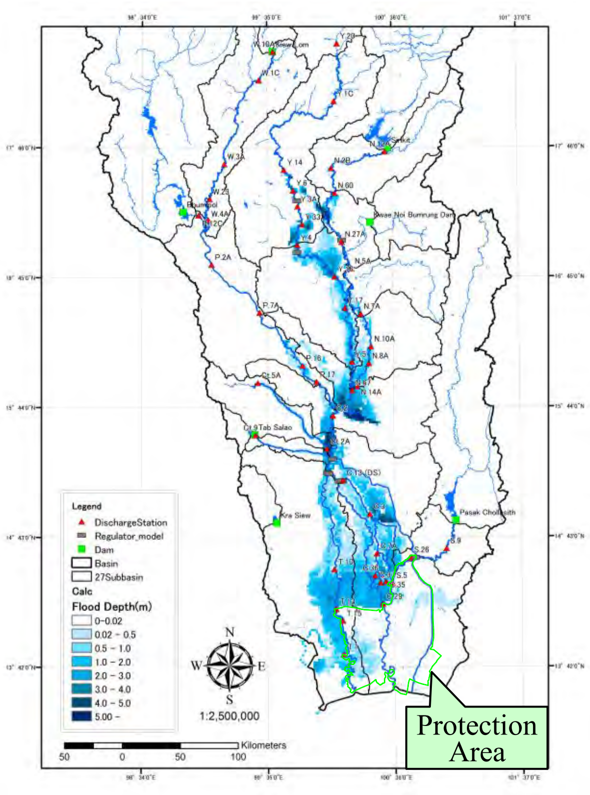


Figure 10.2.56 Assumed Inundation Area after Implementation of Structural Measures proposed in the M/P

As shown in Figure 10.2.55 and Figure 10.2.56, Bangkok and its Vicinities (Special Economic Zone), which are planned as the Protection Area is able to be protected from the design flood by implementation of the facilities proposed in the Master Plan. However, it is difficult to protect the whole low-lying areas along the Yom and Nan rivers at Upper Nakhon Sawan and the low-lying area at Lower Nakhon Sawan from floods. Besides, these low-lying areas have an important function as the natural retarding basin reducing flood peaks downstream.

From the good reason it is necessary for these low-lying areas, considering coexistence with floods, to discuss required countermeasures as "Controlled Inundation Area" like land use plans and effective agricultural methods on the assumption of habitual inundation.

The situations of low-lying areas at upper and lower Nakhon Sawan are outlined below.

(i) Upper Nakhon Sawan

The inundation area in the upper central plain in the Yom and Nan River basins has old river channels, lakes and swamps along the two rivers. The low-lying and swamp areas also function as natural retarding basins. The floods from the basins inundate the low-lying and swampy areas as well as the adjacent agricultural lands or irrigation areas depending on the scale of flood.

The central part of the inundation area at the low-lying/marsh and agricultural land has been selected by RID and the Government of Thailand as the Retention Area (see Figure 10.2.57), and the rest of the inundation area requires measures for promotion of the controlled inundation.

(ii) Lower Nakhon Sawan

The inundation areas in the lower central plain in the Chao Phraya River Basin are caused by the floods from the main stream of Chao Phraya River and branch rivers (Tha Chin, Noi River and Lopburi River). The flood waters inundated in natural levee areas, back swamp and neighboring agricultural areas along the rivers. The inundation area is mostly composed of irrigation area and the ratio of mash area is very low.

The central part of the inundation area with low-lying marsh and agricultural land has been proposed by RID and the Government of Thailand as the Retention Area (see Figure 10.2.57). The rest of the inundation area requires measures for the promotion of controlled inundation.

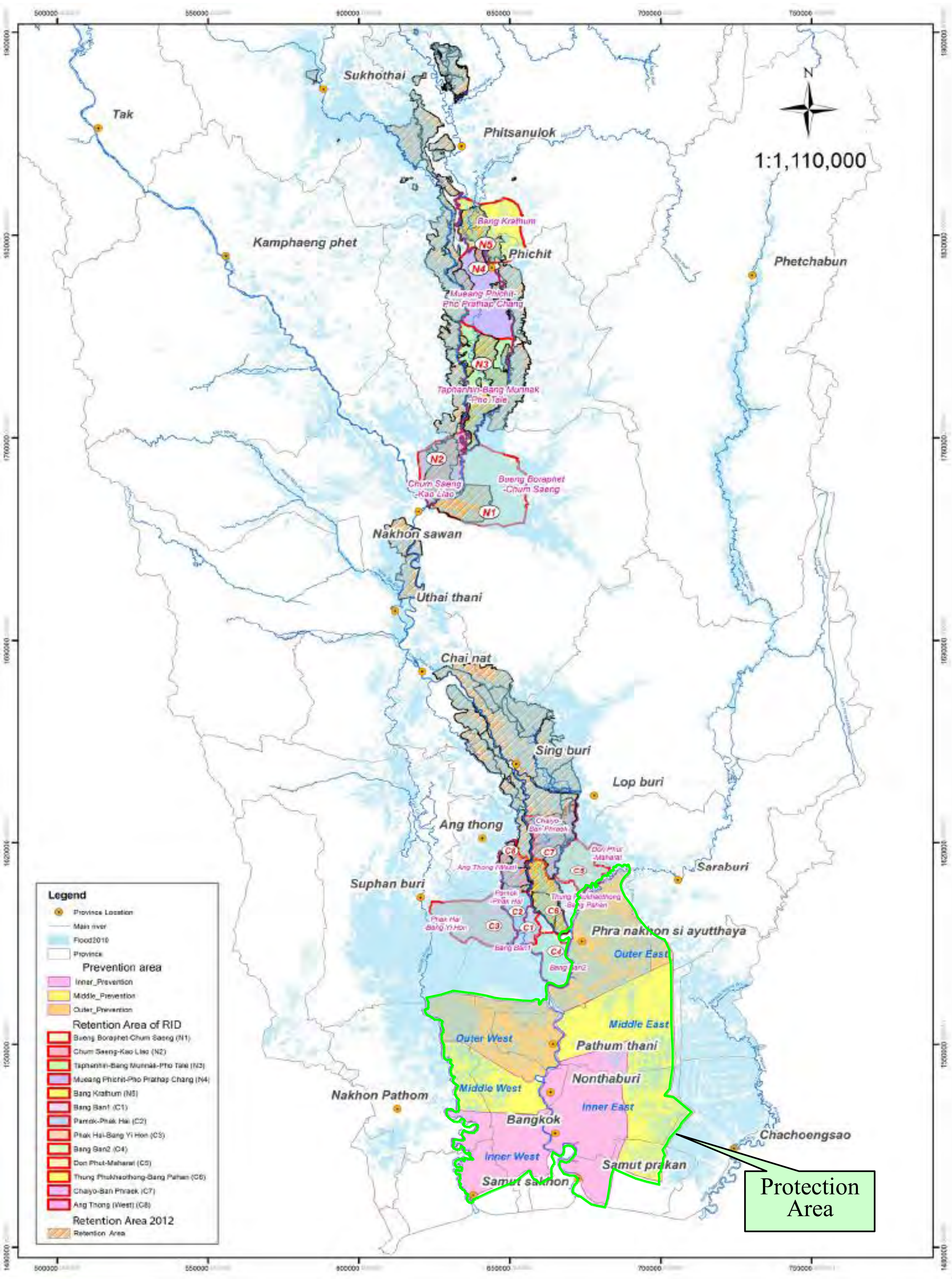


Figure 10.2.57 Location of Retention Area Planned by RID and the Government of Thailand

(b) Study on Characteristics of Inundation Area

The inundation areas at upper and lower Nakhon Sawan are divided into typical subdivisions as shown in Figure 10.2.58, Figure 10.2.59 and Figure 10.2.60. The characteristics of each subdivision have been investigated.

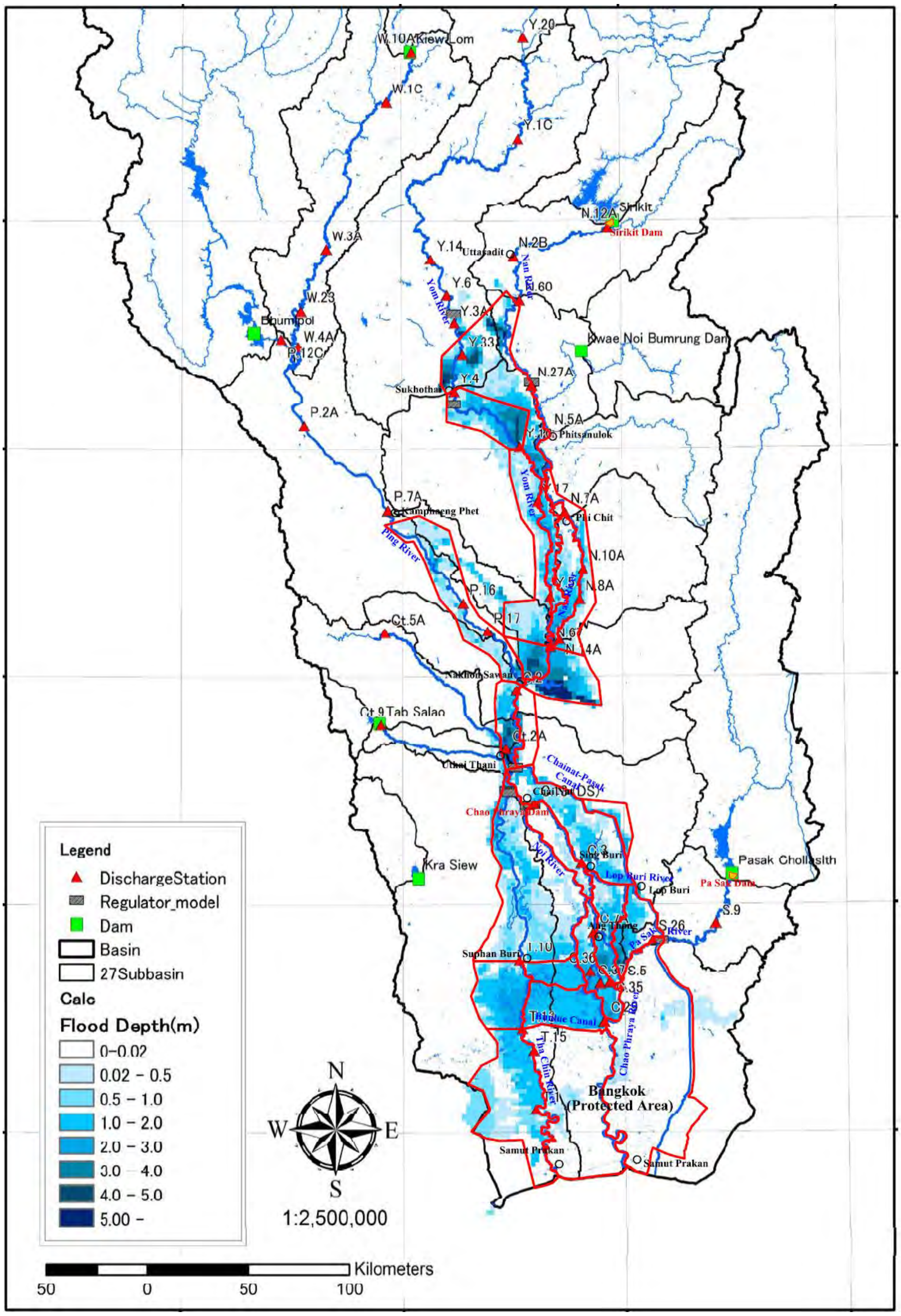


Figure 10.2.58 Subdivisions at the Assumed Inundation Area after Implementation of the M/P

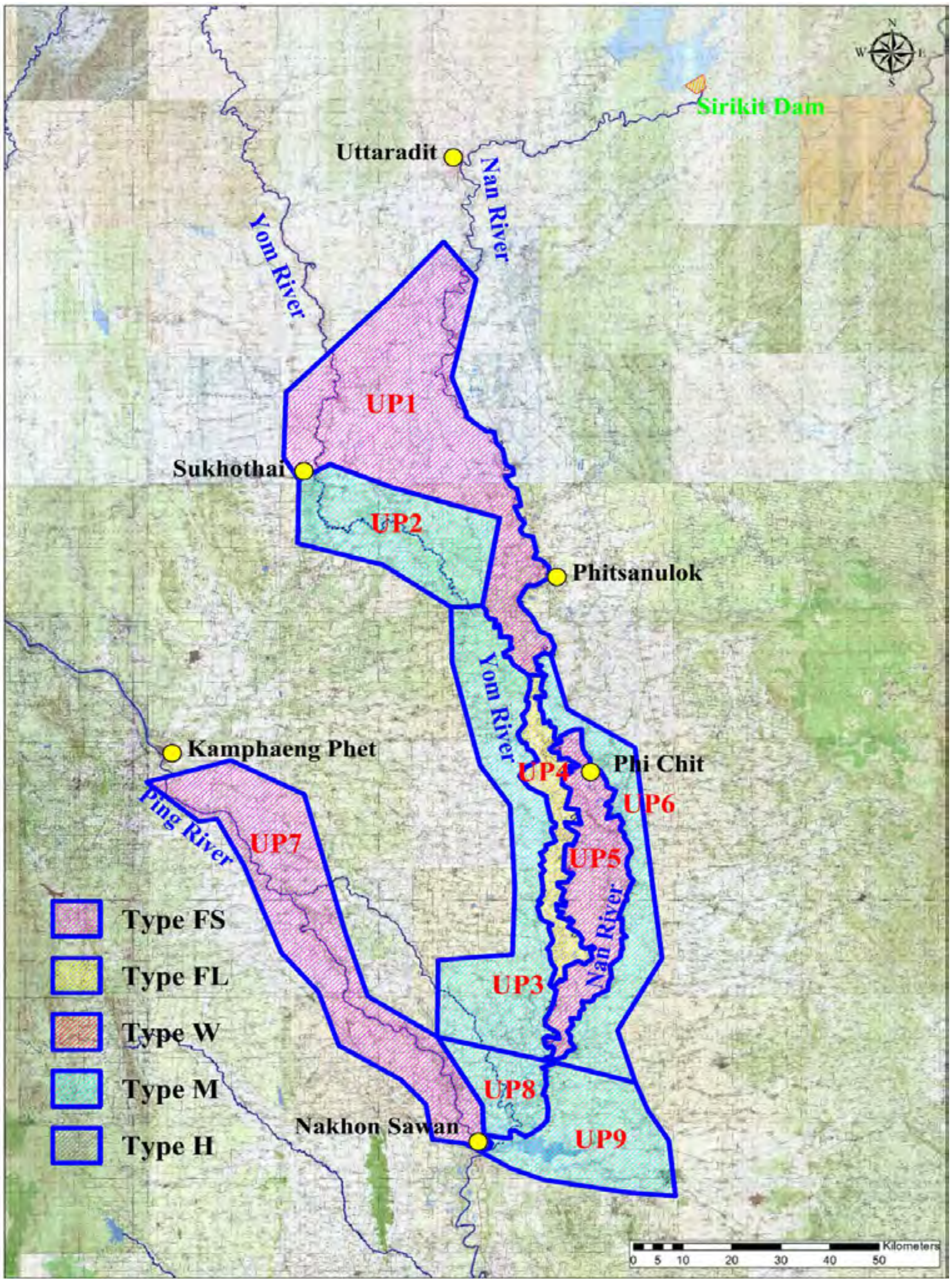


Figure 10.2.59 Subdivisions at the Assumed Inundation Area in Upper Nakhon Sawan (Based on Topographic Map in 1/50,000 Scale)

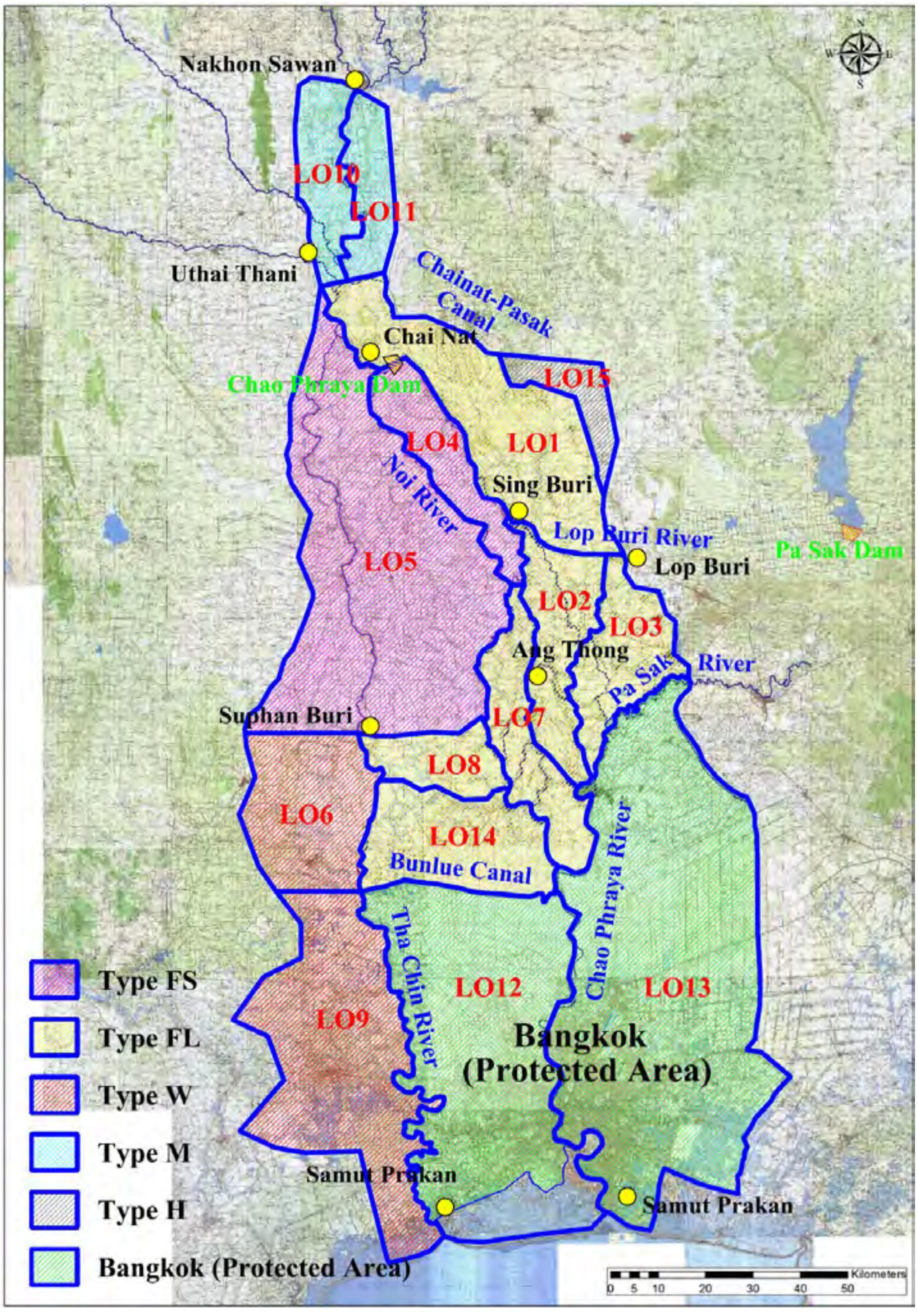


Figure 10.2.60 Subdivisions at the Assumed Inundation Area in Lower Nakhon Sawan (Based on Topographic Map in 1/50,000 Scale)

The inundation area is categorized into the following 5 types:

Type FS:

Agricultural area. Overflow water from the river spreads and flows towards downstream resulting in relatively shallow and shorter inundation. The west side is also affected by runoff from the river's own basin.

Type FL:

Agricultural area. Flood water flows over 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 area.

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

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

Type H:
Agricultural area. The area is affected by small scale floods from the east hill side in the basin. The inundation depth and duration are very shallow and short.

Subdivision Nos.12 and 13 belong to the protection area of Bangkok and its vicinity. The characteristics of each division of the Control Inundation Area are listed as follows:

Table 10.2.41 Land Use Types of the Inundation Area at Upper Nakhon Sawan

Type	Subdivision Number	Area (km^2)		Name of Irrigation Project	Land Use Type
FS	UP 1	1,800	3,710	Phai Chum Phon	Rainfed, floodplain
	UP 5	610		Tha Bua, Tum Sam, Bueng Mai	Irrigation area, rai-fed paddy land, floodplain
	UP 7	1,300		-	Rainfed area
FL	UP 4	330	330	Yom-East, Nan-West	Rainfed paddy land, floodplain
W	-	-	-		
M	UP 2	750	3,540	Phai Chum Phon	Irrigation area, floodplain
	UP 3	1,200		Yom West	Rainfed paddy land, floodplain
	UP 6	650		Tha Bua, Dong Setti	Irrigation area, floodplain
	UP 8	270		Nan-West, Chum Saeng	Rainfed paddy land, floodplain
	UP 9	670		Nan East, Bung Boraphet	Irrigation area, rainfed paddy land, floodplain
H	-	-	-		
Total		7,580			

The inundation areas in Upper Nakhon Sawan are characterized as: Area of each subdivision is narrow; Ratio of rainfed paddy field is higher and ratio of irrigation area is lower; and Land is inclined and there are vertical drops between subdivisions.

Table 10.2.42 Characteristic Features of Subdivisions in Controlled Inundation Area at Upper Nakhon Sawan under 10-Year Probable Flood

Type	Sub-division No.	Area (km^2)		Maximum Inundation Volume (MCM)					Maximum Average Depth (m)					Maximum Inundation Area (km^2)				
				Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1
FS	UP1	1,800	3,710	790	790	750	750	750	1.4	1.4	1.4	1.4	1.4	540	540	510	510	510
	UP5	610		220	220	90	100	100	0.6	0.6	0.5	0.5	0.5	350	350	180	180	180
	UP7	1,300		380	380	310	310	310	0.5	0.5	0.5	0.5	0.5	690	690	600	600	600
FL	UP4	330	330	300	290	260	260	260	1.0	1.0	1.0	1.0	1.0	280	280	270	270	270
W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	UP2	750	3,540	900	900	900	900	900	1.3	1.3	1.3	1.3	1.3	690	690	690	690	690
	UP3	1,200		420	410	370	370	370	0.6	0.5	0.5	0.5	0.5	740	740	720	720	700
	UP6	650		280	280	80	90	90	0.7	0.7	0.5	0.5	0.5	420	420	160	180	180
	UP8	270		630	630	570	570	570	2.5	2.5	2.3	2.3	2.3	250	250	250	250	250
	UP9	670		2000	2000	1700	1700	1700	3.6	3.5	3.4	3.4	3.4	570	570	510	510	510
H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	7,580		5920	5900	5030	5050	5050	-	-	-	-	-	4530	4530	3890	3910	3890

Table 10.2.43 Characteristic Features of Subdivisions in Controlled Inundation Area at Upper Nakhon Sawan under 100-Year Probable Flood

Type	Sub-division No.	Area (km^2)		Maximum Inundation Volume (MCM)					Maximum Average Depth (m)					Maximum Inundation Area (km^2)				
				Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1
FS	UP1	1,800	3,710	1000	1000	910	910	910	1.5	1.5	1.5	1.5	1.5	670	680	590	590	590
	UP5	610		260	260	180	190	190	0.7	0.7	0.6	0.6	0.6	360	360	300	320	320
	UP7	1,300		610	610	480	480	480	0.7	0.7	0.6	0.6	0.6	830	830	770	780	770
FL	UP4	330	330	400	400	310	310	310	1.3	1.3	1.1	1.1	1.1	310	310	280	280	280
W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	UP2	750	3,540	1100	1100	1100	1100	1100	1.5	1.5	1.5	1.5	1.5	710	710	710	710	710
	UP3	1,200		750	750	630	630	630	0.7	0.7	0.6	0.6	0.6	1100	1100	1100	1100	1100
	UP6	650		370	370	210	230	230	0.8	0.8	0.6	0.7	0.7	460	460	330	340	340
	UP8	270		780	780	690	690	690	3.0	3.0	2.7	2.7	2.7	260	260	260	260	260
	UP9	670		2400	2400	2200	2200	2200	3.8	3.8	3.7	3.7	3.7	640	640	610	610	610
H	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	-	7,580		7670	7670	6710	6740	6740	-	-	-	-	-	5340	5350	4950	4990	4980

Table 10.2.44 Land Use Types of Inundation Area at Lower Nakhon Sawan

Type	Subdivision Number	Area (km²)		Name of Irrigation Project	Land Use Type
FS	LO4	480	3,280	Tha Bot, Donchedee, Krasao	Irrigation area, floodplain
	LO5	2,800		Chao Chet, Bang Yi-hon	Irrigation area, floodplain
FL	LO1	1,300	4,100	Manorom	Irrigation area, floodplain
	LO2	580		Maharaj, Tu Ban Kum, Tung Chang	Irrigation area, floodplain
	LO3	550		Kok Kra Tiam, Loeng Rang	Irrigation area, floodplain
	LO7	560		Pho-Phraya, Song Phi-Nong	Irrigation area, floodplain
	LO8	330		Yang Mane, Bang Ban	Irrigation area, floodplain
	LO14	780		Phakhai	Irrigation area, floodplain
W	LO6	810	2,510	Borom That, Channasut	Irrigation area, floodplain
	LO9	1,700		Bang Lane, KPS, Nak-Pat, DNSD etc	Irrigation area
M	LO10	420	760	Grot Pra Payuha	Irrigation area, rainfed paddy land, floodplain
	LO11	340		-	Rainfed paddy land
H	LO15	230	230	Chong-kae	Irrigation area, floodplain
Total			10,880		

The characteristic features of the inundation area in Lower Nakhon Sawan are summarized as follows:

- Area of each subdivision is large; mostly irrigation area.
- Land is flat with only small vertical drops between subdivisions.
- The south side of downstream agricultural area changes gradually to industrial area.
- The low-lying area has a large function as natural retarding basin

Table 10.2.45 Characteristic Features of Subdivisions in Controlled Inundation Area at Lower Nakhon Sawan under 10-Year Probable Flood

Type	Sub-division No.	Area (km^2)		Maximum Inundation Volume (MCM)					Maximum Average Depth (m)					Maximum Inundation Area (km^2)				
				Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1
FS	LO4	480	3,280	10	10	0	0	0	0.1	0.1	0.0	0.0	0.0	50	50	0	0	0
	LO5	2,800		1100	1100	450	890	890	0.6	0.6	0.3	0.5	0.5	1800	1800	1300	1600	1600
FL	LO1	1,300	4,100	600	600	420	430	430	0.7	0.7	0.6	0.6	0.6	770	760	650	660	660
	LO2	580		550	560	160	370	360	1.3	1.3	0.9	1.2	1.2	400	410	170	300	300
	LO3	550		580	590	290	430	420	1.5	1.5	0.9	1.2	1.2	390	390	320	360	350
	LO7	560		360	520	180	320	260	0.9	1.2	0.7	0.9	0.8	380	410	260	340	310
	LO8	330		270	410	220	310	310	0.9	1.3	0.7	1.0	1.0	310	310	300	310	310
	LO14	780		610	1200	690	930	910	0.8	1.6	0.9	1.2	1.2	760	760	760	760	760
W	LO6	810	2,510	620	980	560	730	720	1.0	1.4	0.9	1.1	1.1	640	710	590	650	650
	LO9	1,700		550	1300	470	640	620	0.6	0.9	0.7	0.7	0.7	810	1300	670	830	800
M	LO10	420	760	640	640	420	550	550	1.8	1.8	1.3	1.6	1.6	350	350	320	340	340
	LO11	340		210	210	40	150	150	2.0	2.0	0.7	1.9	1.9	110	110	30	80	80
H	LO15	230	230	190	190	190	190	190	1.6	1.6	1.6	1.6	1.6	120	120	120	120	120
Total	-	10,880		6290	8310	4090	5940	5810	-	-	-	-	-	6890	7480	5490	6350	6280

Table 10.2.46 Characteristic Features of Subdivisions in Controlled Inundation Area at Lower Nakhon Sawan under 100-Year Probable Flood

Type	Sub-division No.	Area (km²)		Maximum Inundation Volume (MCM)					Maximum Average Depth (m)					Maximum Inundation Area (km²)				
				Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1	Case 0	Case 0-1	Case 1-1	Case 11	Case 11-1
FS	LO4	480	3,280	70	70	0	30	30	0.3	0.3	0.0	0.3	0.3	250	250	0	110	110
	LO5	2,800		1800	1800	1000	1400	1400	0.9	0.9	0.6	0.7	0.7	2100	2100	1800	2000	2000
FL	LO1	1,300	4,100	1100	1100	860	860	860	1.0	1.1	0.9	0.9	0.9	1000	1000	940	940	940
	LO2	580		860	900	700	700	690	1.6	1.6	1.4	1.4	1.4	540	550	440	480	480
	LO3	550		900	930	760	760	750	1.9	2.0	1.7	1.7	1.7	460	470	440	440	440
	LO7	560		580	990	520	640	590	1.2	1.9	1.3	1.3	1.2	490	520	380	480	480
	LO8	330		380	620	420	500	480	1.2	1.9	1.3	1.6	1.5	320	330	310	320	320
	LO14	780		880	1700	1200	1400	1400	1.1	2.3	1.6	1.9	1.8	760	760	760	760	760
W	LO6	810	2,510	880	1500	1000	1200	1200	1.2	1.9	1.4	1.5	1.5	730	800	730	770	760
	LO9	1,700		1400	2700	1400	1600	1500	0.9	1.6	0.9	1.0	1.0	1500	1600	1500	1500	1500
M	LO10	420	760	840	840	720	730	730	2.3	2.3	1.9	2.0	2.0	370	370	370	360	360
	LO11	340		270	270	190	230	230	2.3	2.3	2.4	2.0	2.0	120	120	80	120	120
H	LO15	230	230	230	230	230	230	230	1.8	1.8	1.8	1.8	1.8	130	130	130	130	130
Total	-	10,880		10190	13650	9000	10280	10090	-	-	-	-	-	8770	9000	7880	8410	8400

(3) Required Measures for Flood Disaster Management

(a) Type FS Inundation Area

After implementation of the facilities proposed in the Master Plan, structural and nonstructural measures are required for the inundation area in order to reduce flood disaster risks and enhance people's living conditions. The following measures are required.

<u>Regional Characteristics</u>

Mainly agricultural land use. Floodwater flows downward. Inundation depth and duration are comparatively shallow and short. In case of the 100-year probable flood, the inundation depth becomes deeper in the middle of September, the maximum average depth is about 0.7 m and the duration, about one month in case of average depth over 0.5m. Also, the west side is affected by the runoff from its own basin.

<u>Structural Measures</u>

- 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.
- Installation of drainage pumps.
- Optimum management of irrigation canals.
- Water conservation works at the west hilly area.

<u>Nonstructural Measures</u>

- Compensation for farmland damaged by inundation.
- Preparation of community-based hazard map and land use control.
- Preparation of floodplain management.

- Agricultural guidance like changing forms of farming schedule.
- Measures to secure feed for livestock.
- Improvement of flood information communication and education system.

(b) Type FL Inundation Area

Regional Characteristics

Mainly agricultural areas. Floodwater flows downward, but retained at the area, which is classified as the lower area in the central plain. Even in the future, the inundation depth and duration in the area are deep and long. In case of the 100-year probable flood, the inundation depth becomes deep in the middle of September, the maximum average depth is from 1.3 m to 2.2 m, and the duration is 1.7 to 3.5 months in case of average depth over 1.0 m.

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 assure 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.
- Preparation of flood plain management.
- Improvement of flood information, communication and education system.

(c) Type W Inundation Area

Regional Characteristics

Mainly agricultural. The area is located at the west side of the protection area and the passage of floodwater flowing down southward. Also this area is affected by floods from the west hill side in its own basin.

In case of the 100-year probable flood the inundation depth becomes deep early in October, the maximum average depth is from 1.3 m to 1.9 m, and the duration is 2.0 to 2.5 months in case of the average depth over 1.0 m.

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 of 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).
- Water conservation works at the west hilly area.

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 in inundation period.
- Measures to secure feed for livestock.
- Preparation of community-based hazard map and land use control.
- Improvement of flood information, communication and education system.

(d) Type M Inundation Area

Regional Characteristics

Low-lying mashes and habitual inundation area. The flood depth and duration are deep and long. The area is located at just downstream of Nakhon Sawan and inundation starts early. In case of the 100-year probable flood the inundation depth becomes deep in August and the maximum average depth is from 2.3 m to 3.0 m, and the duration is 3.8 to 5.0 months in case of the average depth over 1.0 m.

Structural Measures

- Strengthening of the existing levee surrounding the low-lying marsh area.

Nonstructural Measures

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

(e) Type H Inundation Area

Regional Characteristics

Agricultural area. Small-scale inundation occurs brought by floods from the hillside in its own basin. The inundation depth and duration are very shallow and short.

Structural Measures

- Construction of community-based small-scale retention ponds (controlled intake and discharge facilities, irrigation water supply in dry season).
- Strengthening of the existing levees.
- Water conservation works at the east hilly area.

Nonstructural Measures

- Improvement of flood information, communication and education system.

(4) Inundation Volume, Average Depth and Area

To find out and confirm the characteristic of each inundation block in Chao Phraya River, time-series inundation volume, average depth and inundation area for each probability were calculated as shown in Figure 10.2.61 to Figure 10.2.78.

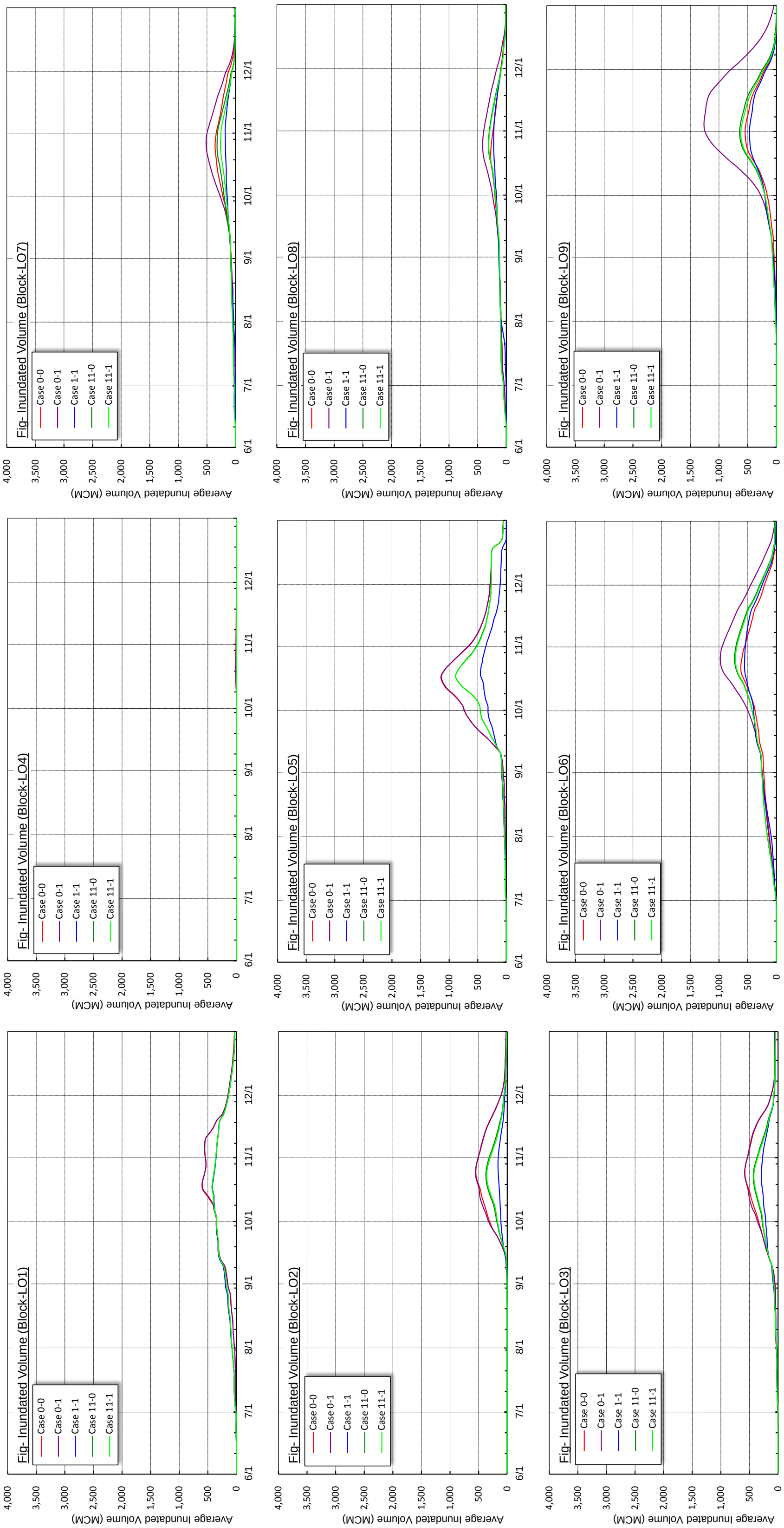


Figure 10.2.61 Inundation Volume in Chao Phraya River (10-year Return Period) (1/3)

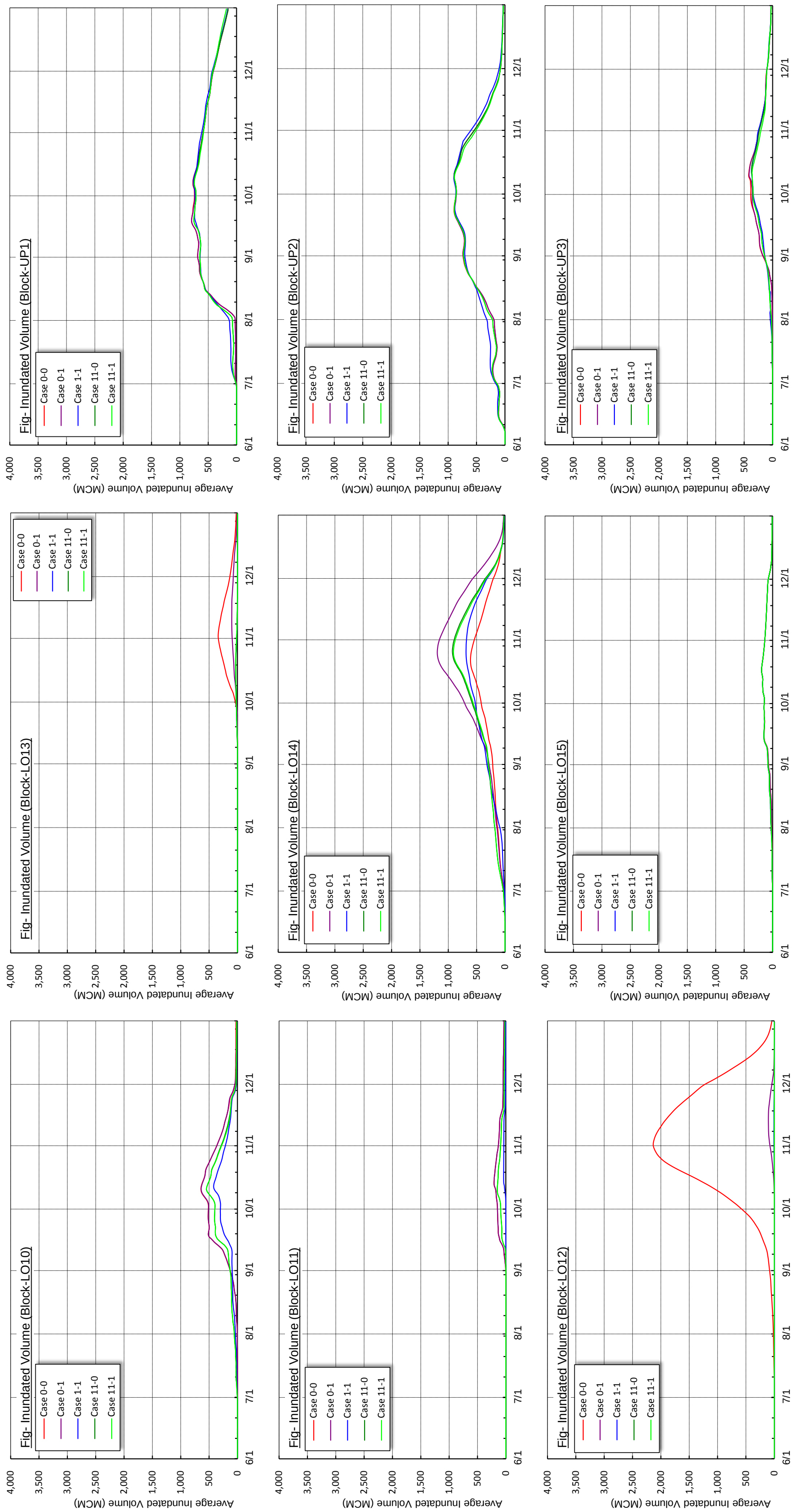


Figure 10.2.62 Inundation Volume in Chao Phraya River (10-year Return Period) (2/3)

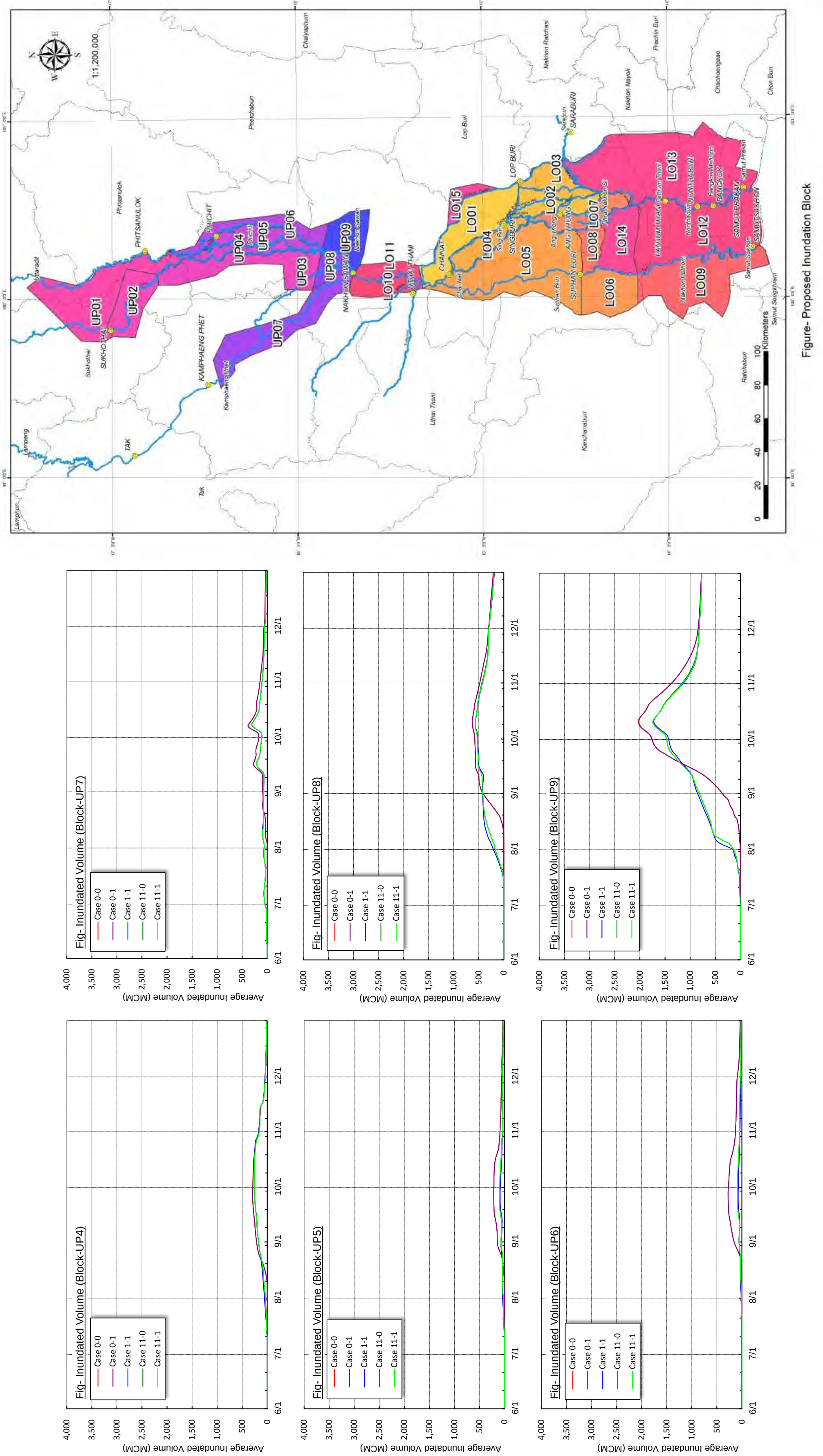


Figure 10.2.63 Inundation Volume in Chao Phraya River (10-year Return Period) (3/3)

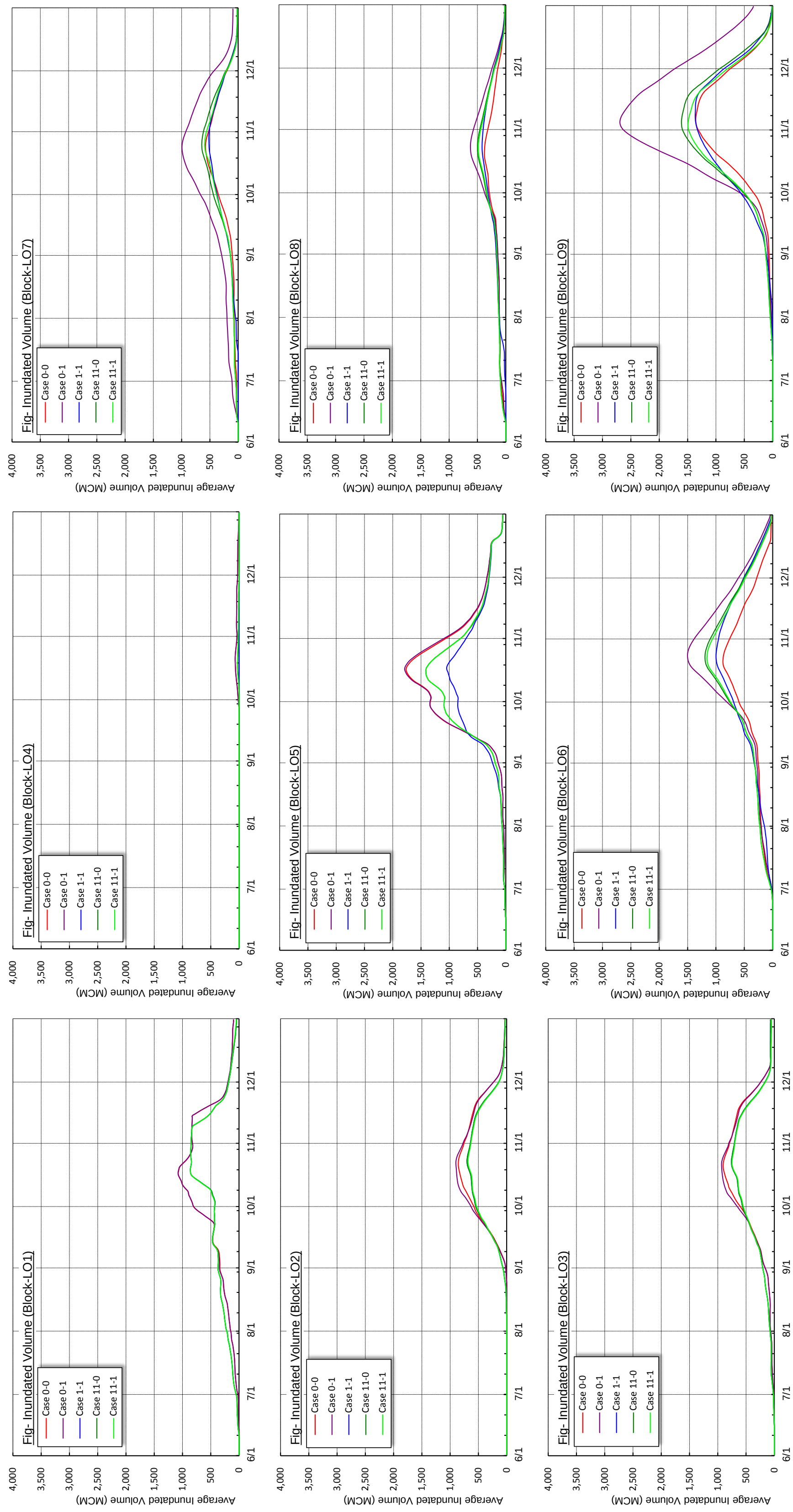


Figure 10.2.64 Inundation Volume in Chao Phraya River (100-year Return Period) (1/3)

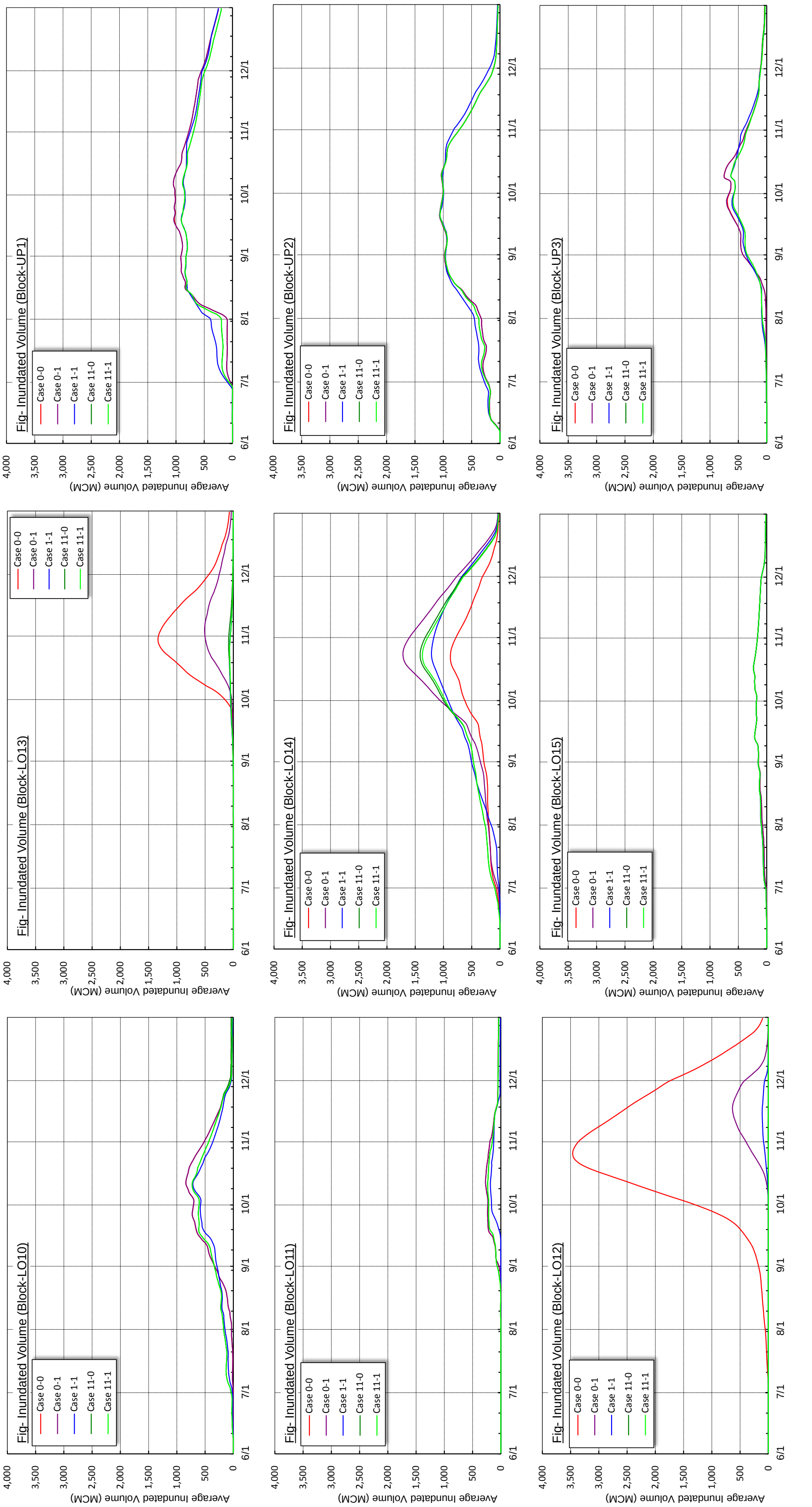


Figure 10.2.65 Inundation Volume in Chao Phraya River (100-year Return Period) (2/3)

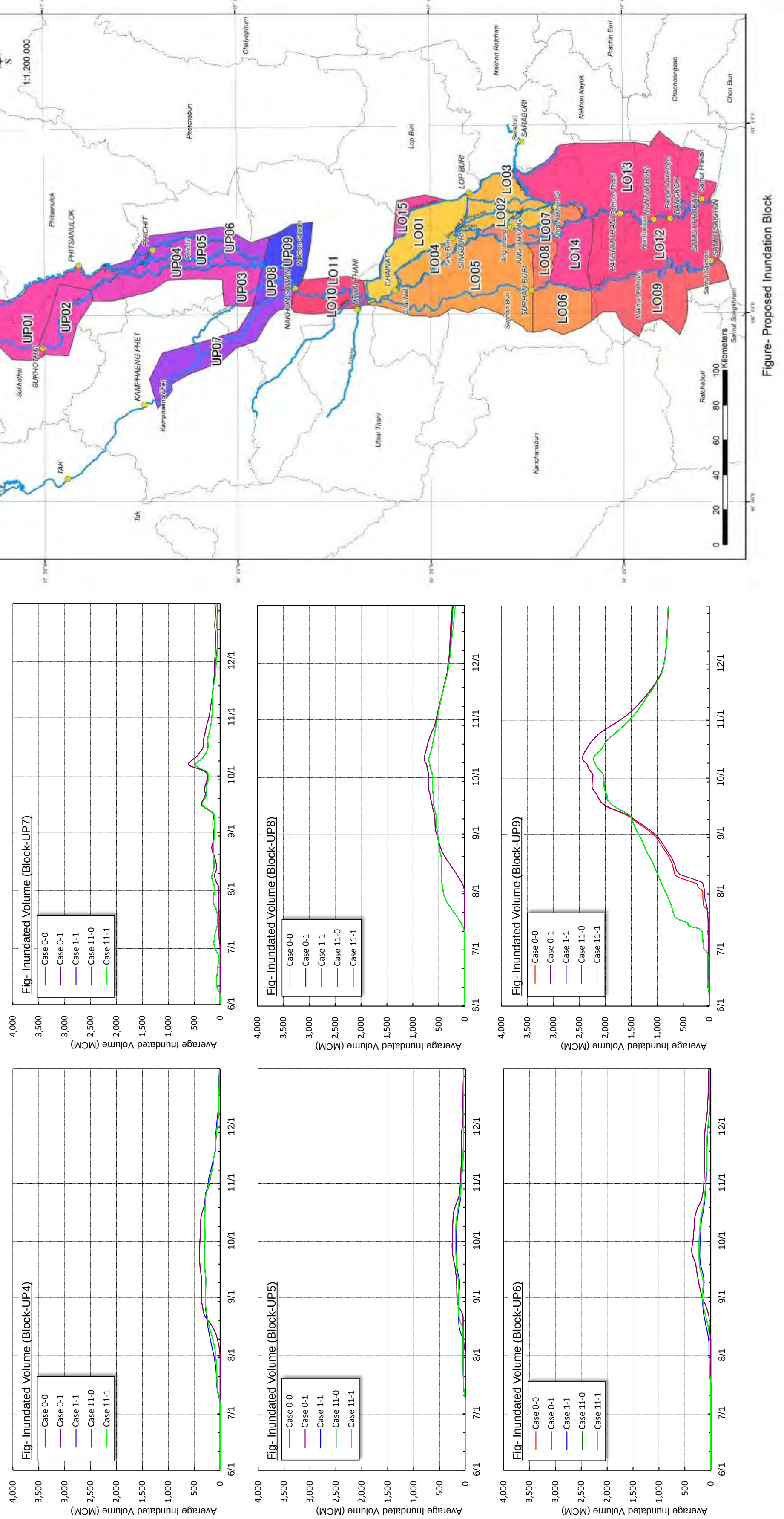


Figure 10.2.66 Inundation Volume in Chao Phraya River (100-year Return Period) (3/3)

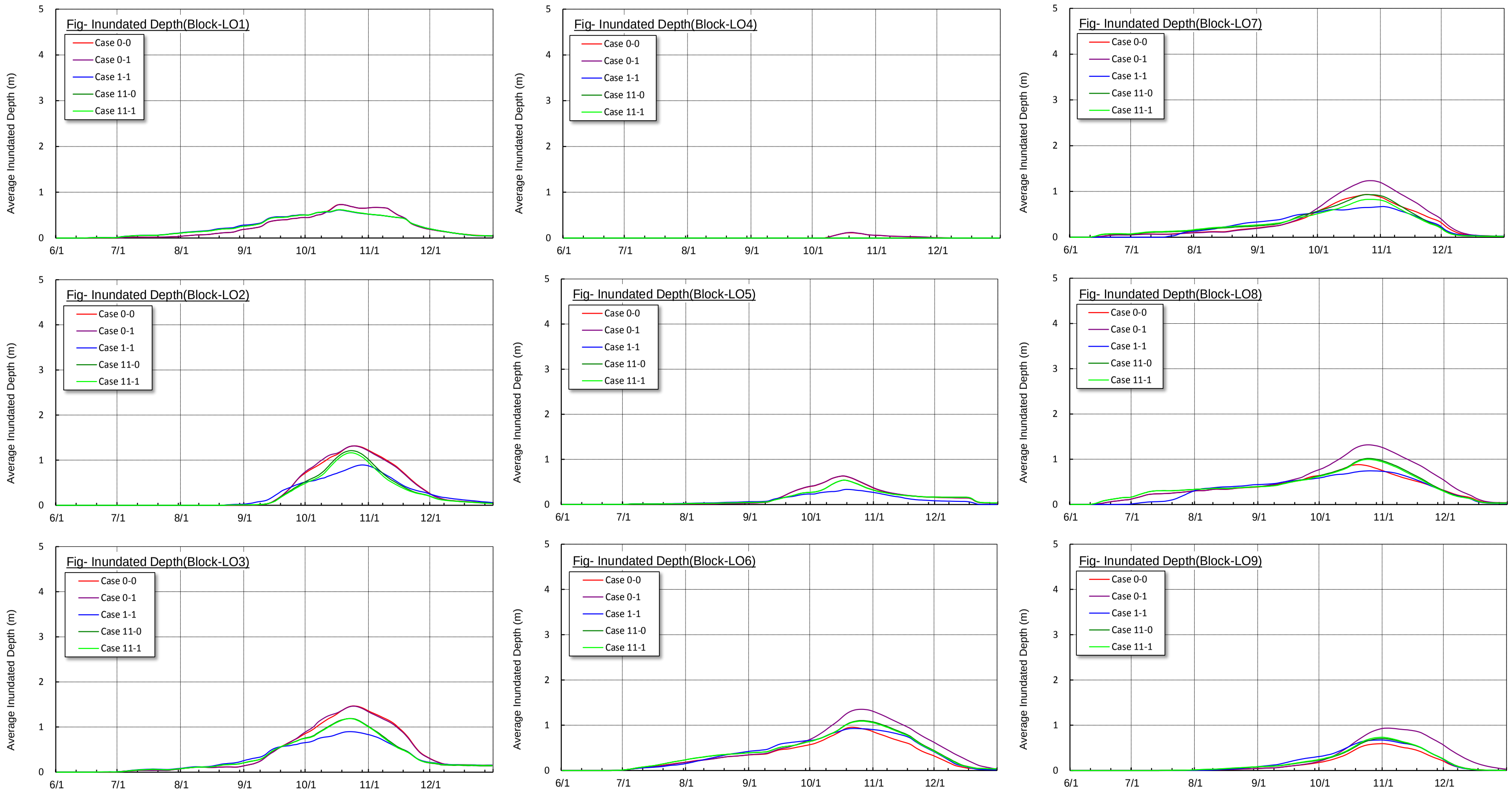


Figure 10.2.67 Average Inundation Depth in Chao Phraya River (10-year Return Period) (1/3)

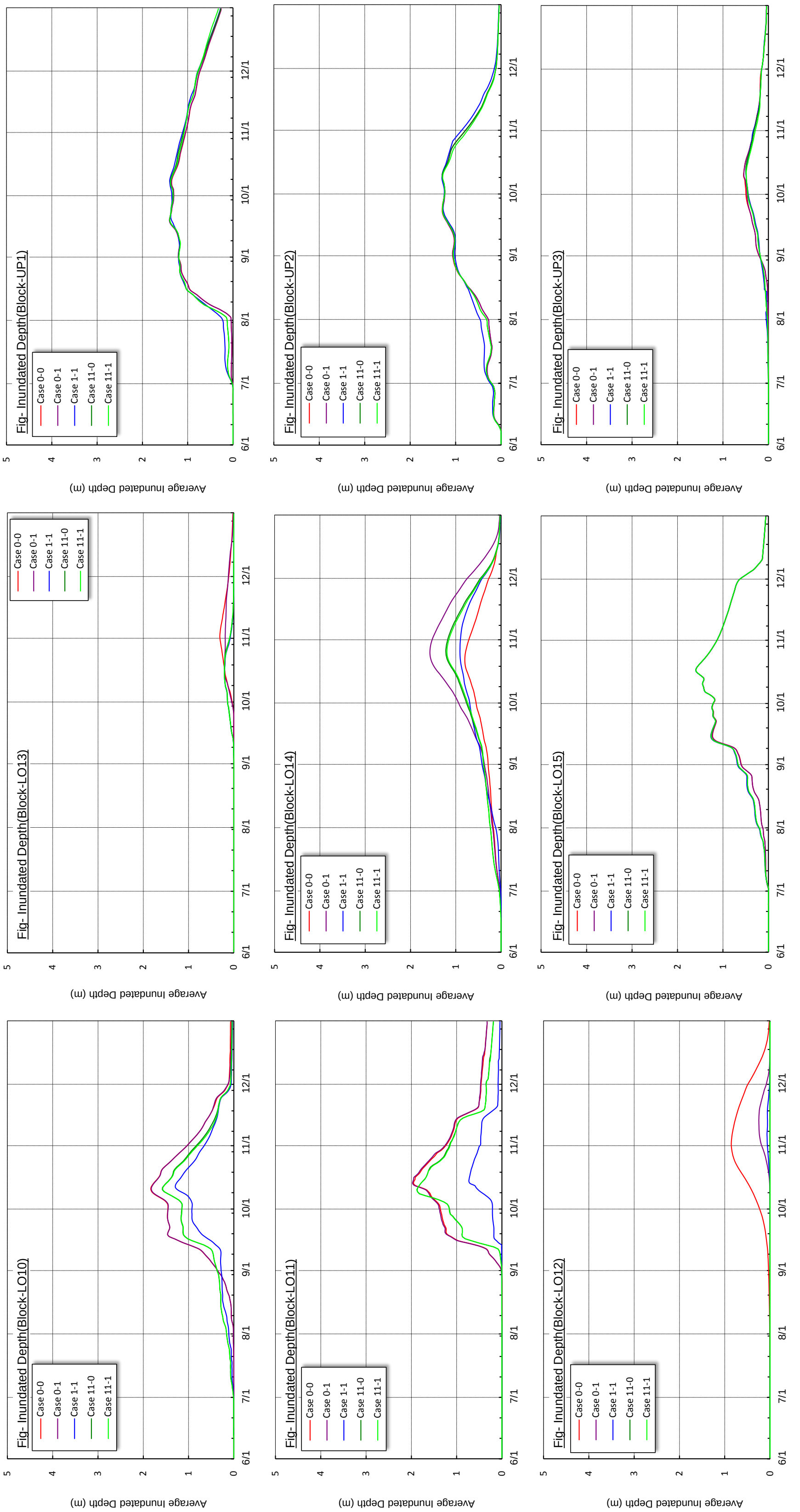


Figure 10.2.68 Average Inundation Depth in Chao Phraya River (10-year Return Period) (2/3)

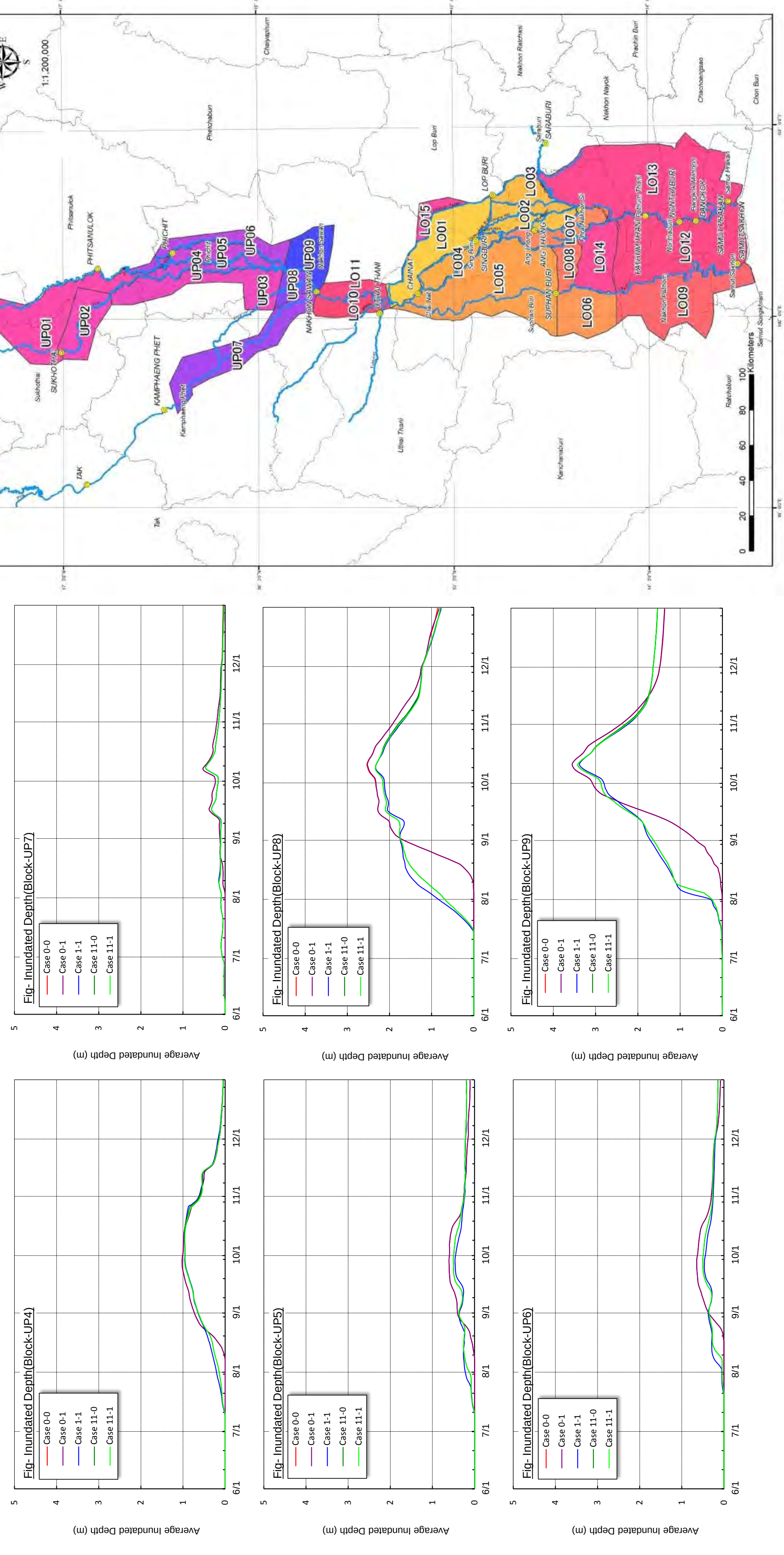


Figure 10.2.69 Average Inundation Depth in Chao Phraya River (10-year Return Period) (3/3)

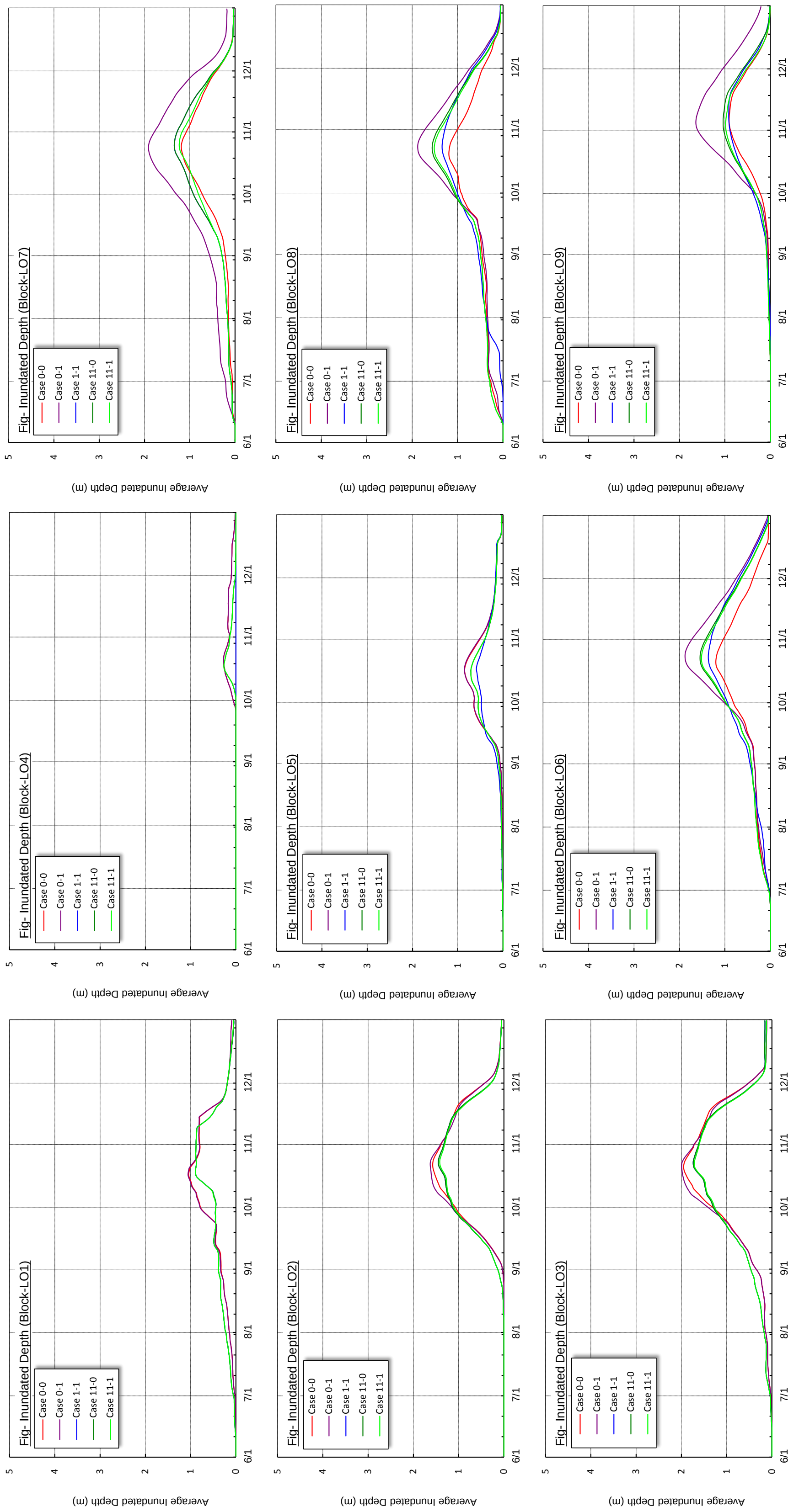


Figure 10.2.70 Average Inundation Depth in Chao Phraya River (100-year Return Period) (1/3)

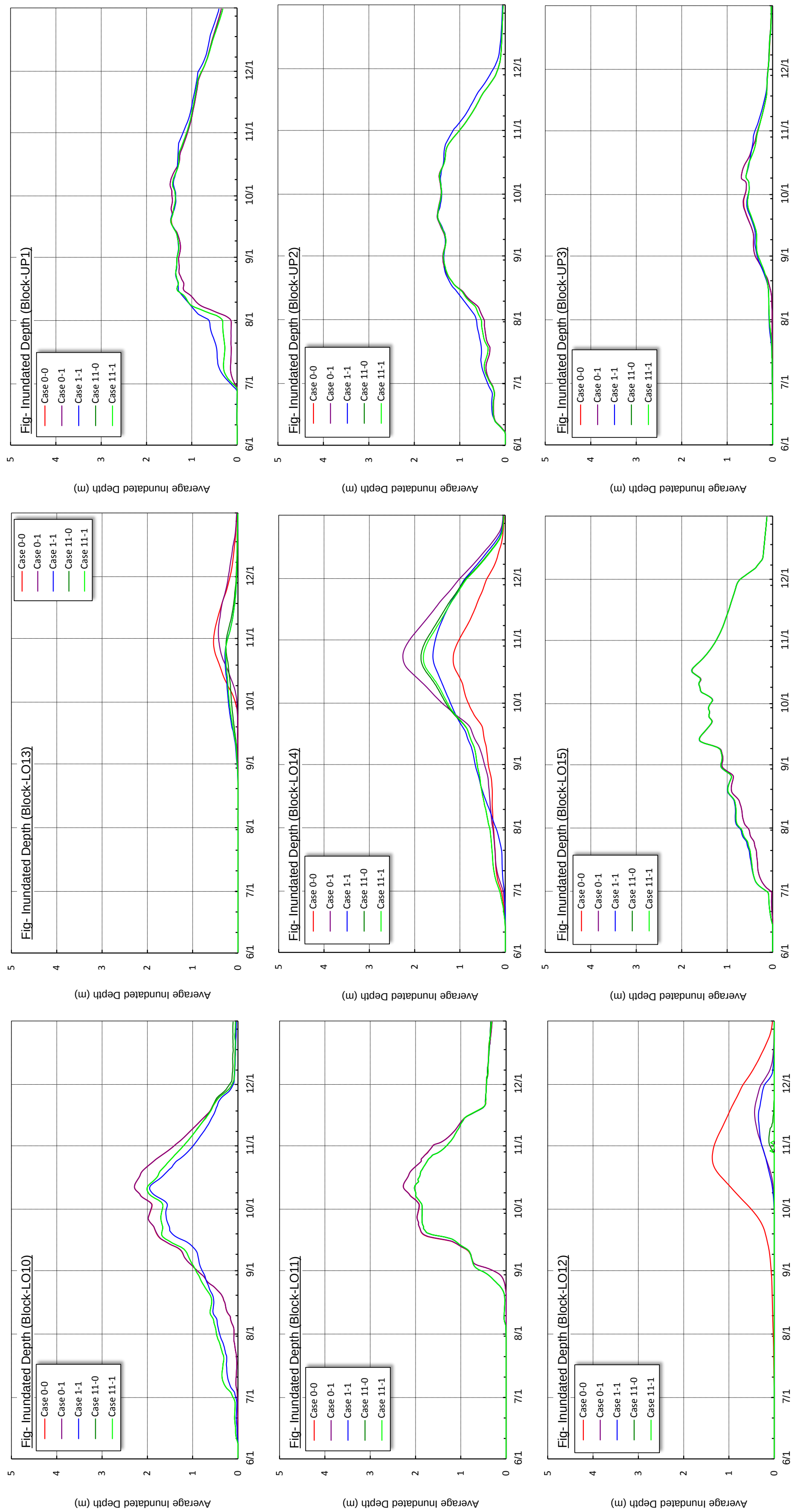
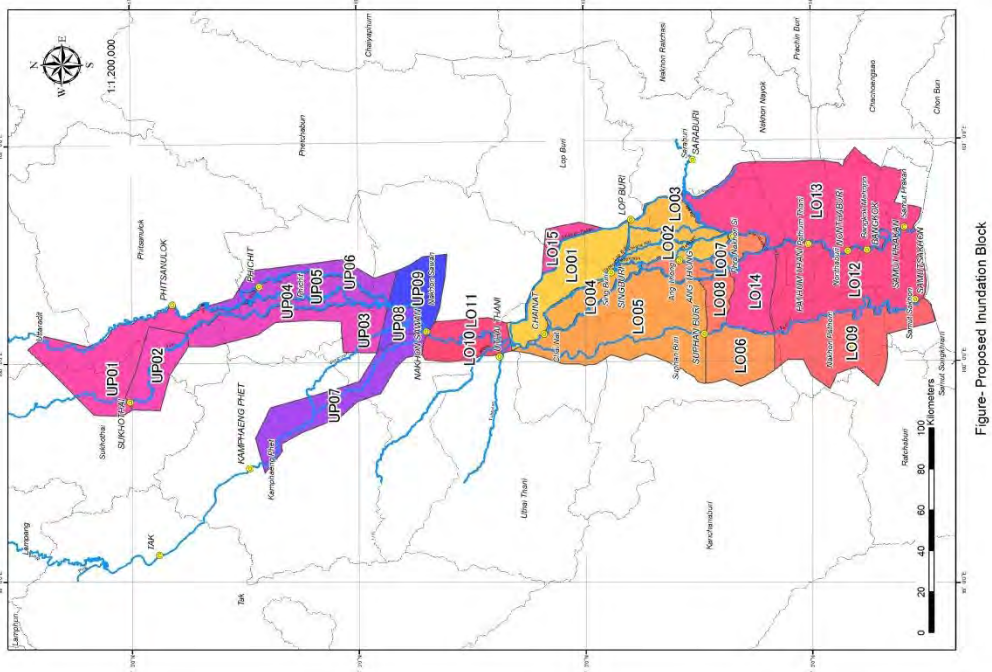


Figure 10.2.71 Average Inundation Depth in Chao Phraya River (100-year Return Period) (2/3)



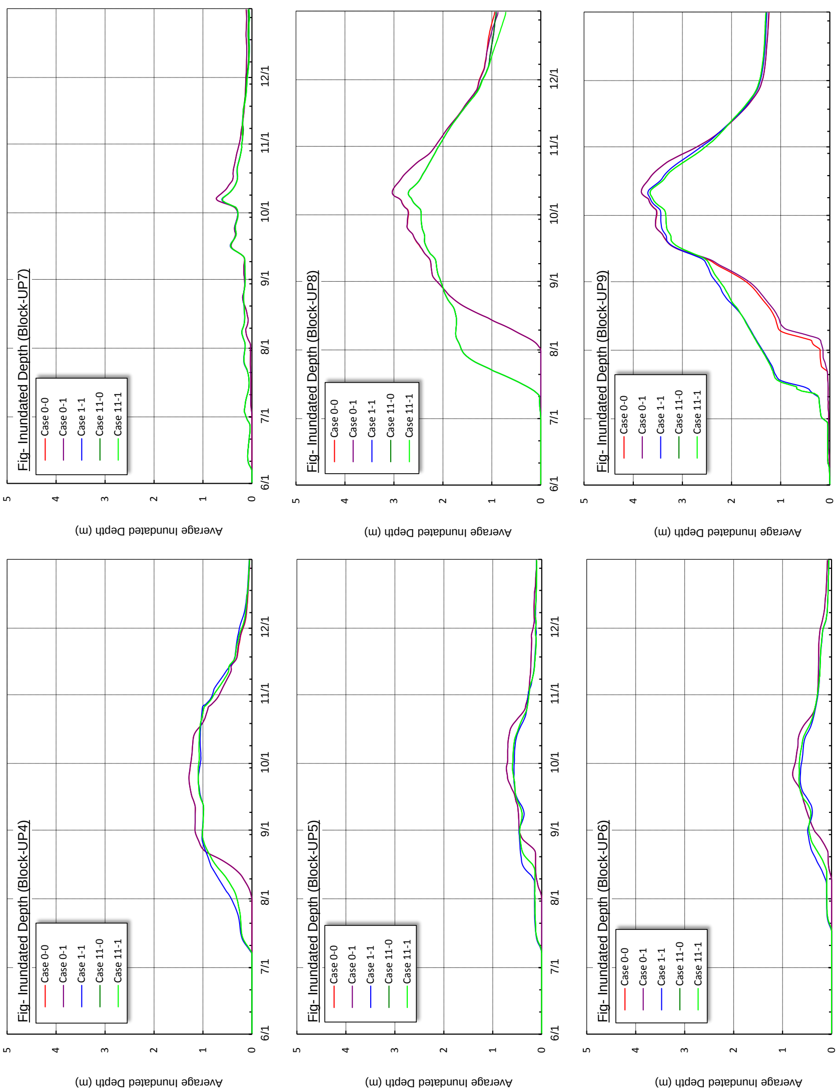


Figure 10.2.72 Average Inundation Depth in Chao Phraya River (100-year Return Period) (3/3)

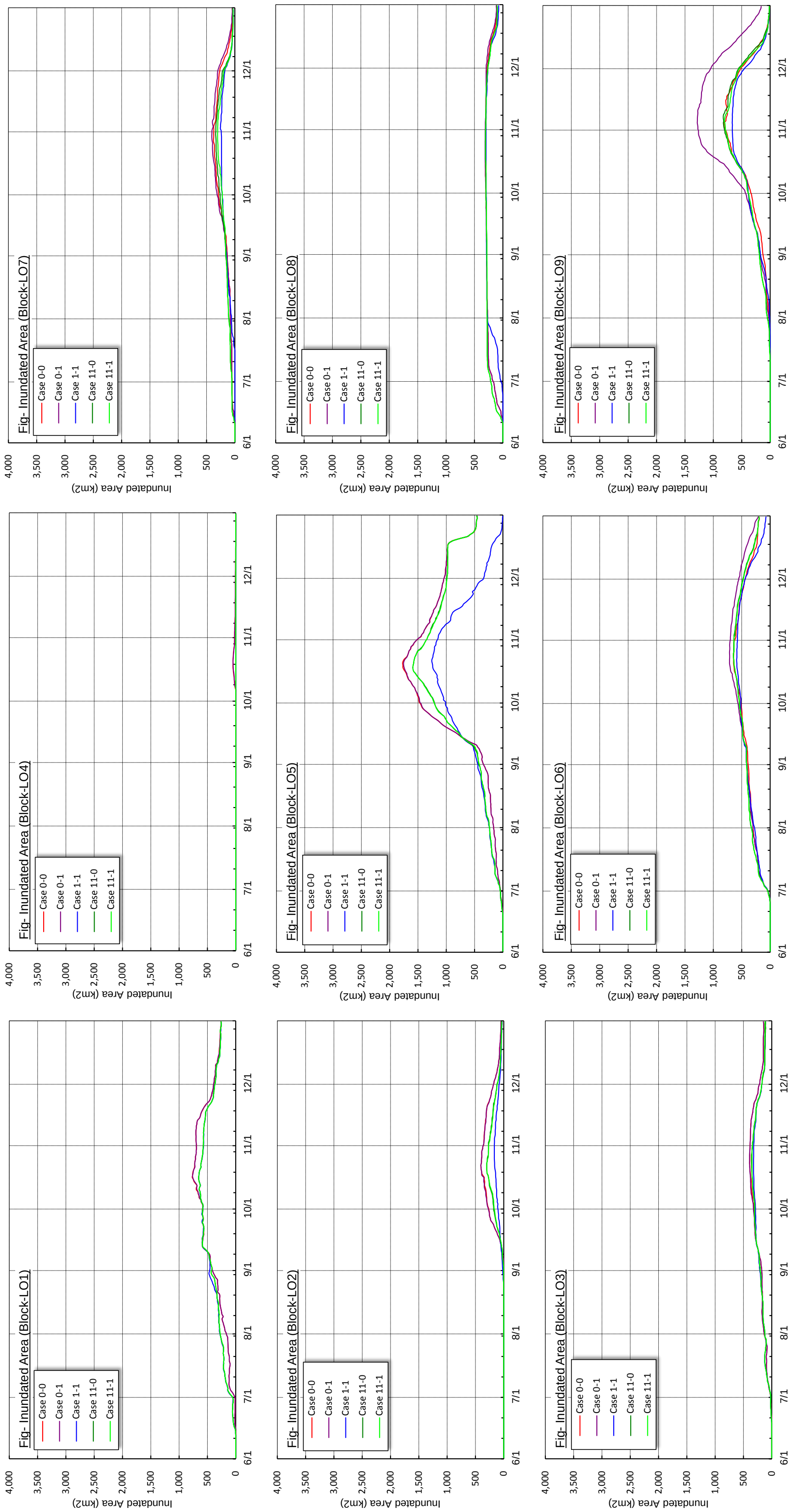


Figure 10.2.73 Inundation Area in Chao Phraya River (10-year Return Period) (1/3)

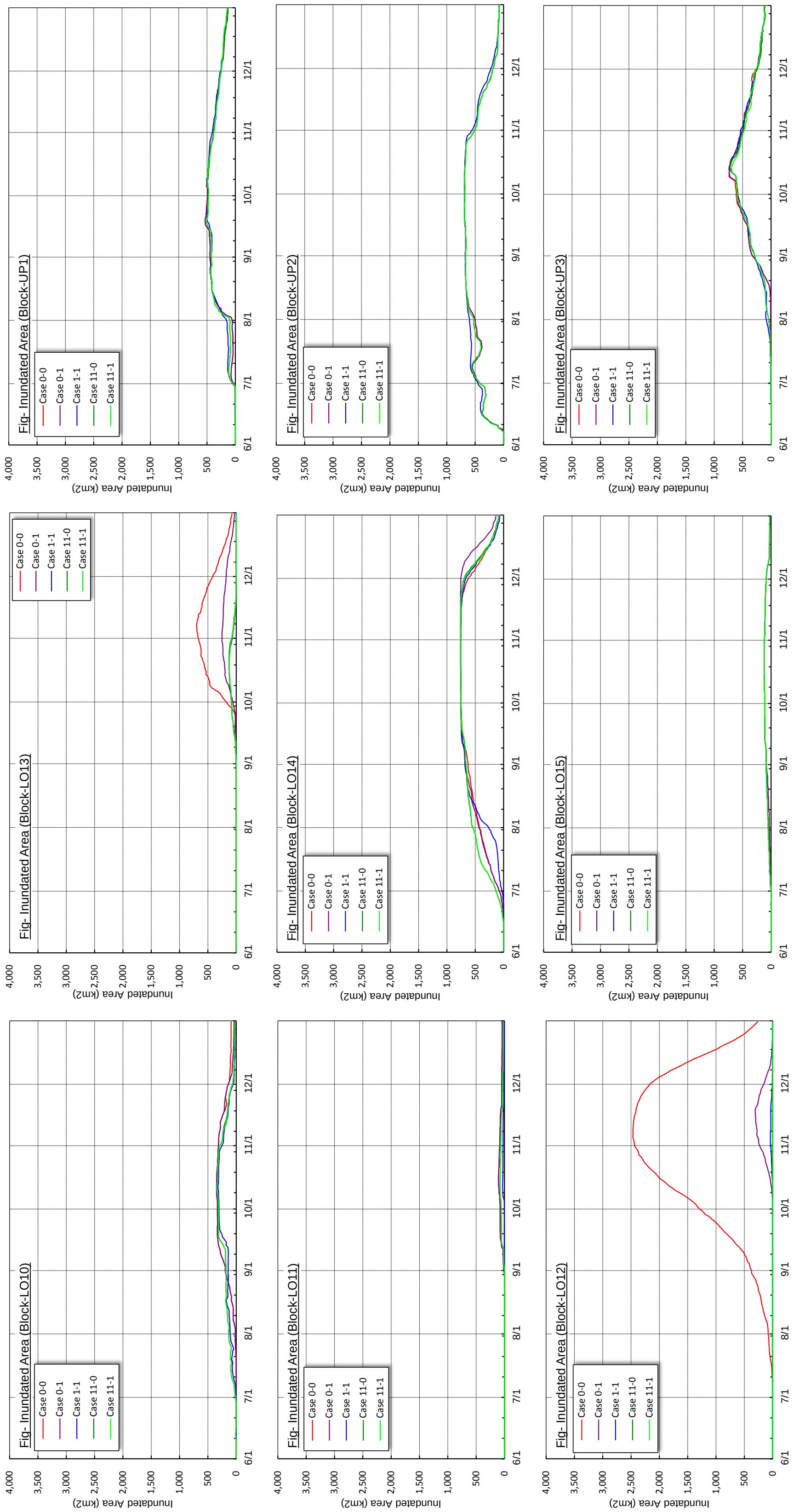


Figure 10.2.74 Inundation Area in Chao Phraya River (10-year Return Period) (2/3)

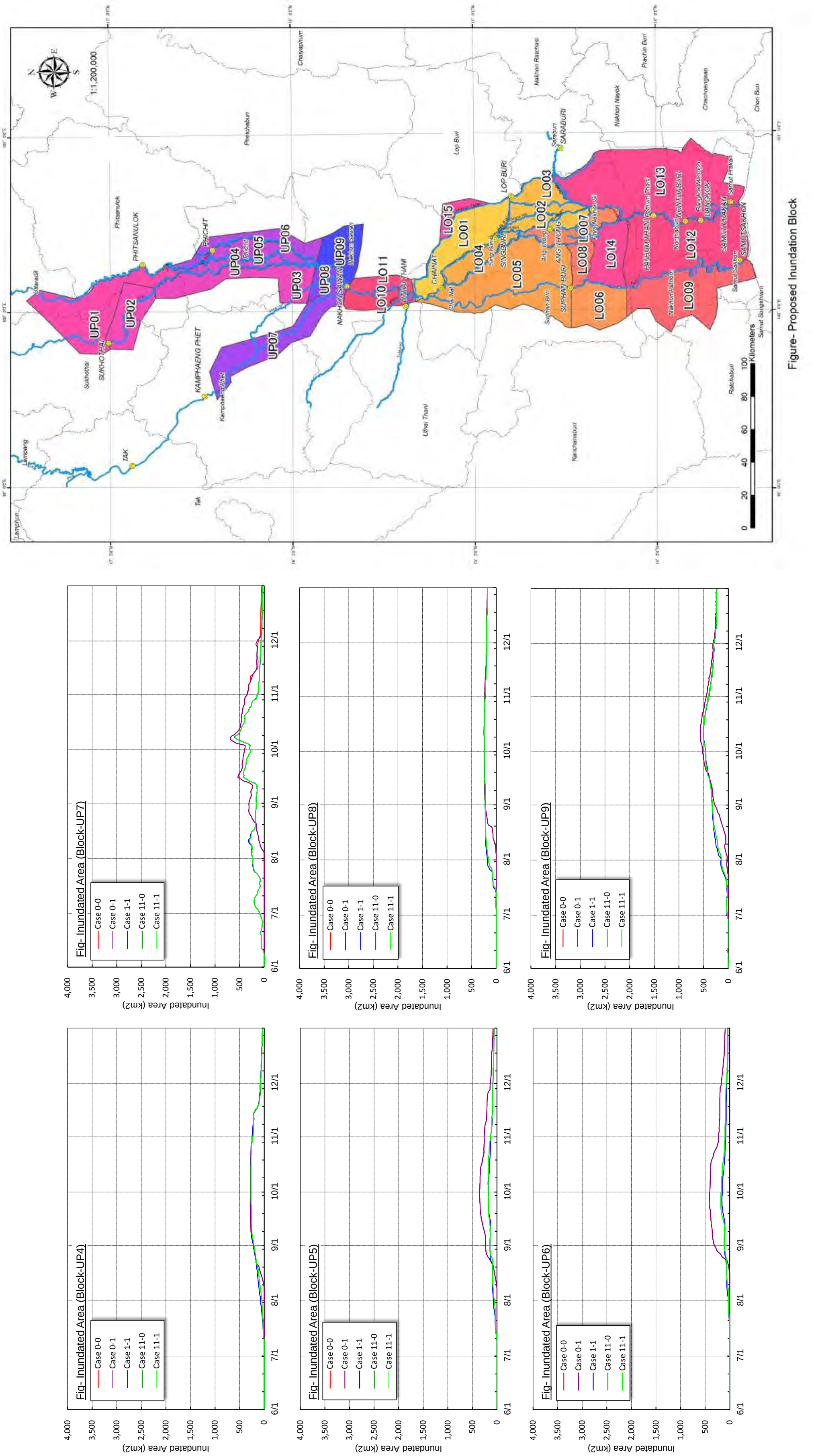


Figure 10.2.75 Inundation Area in Chao Phraya River (10-year Return Period) (3/3)

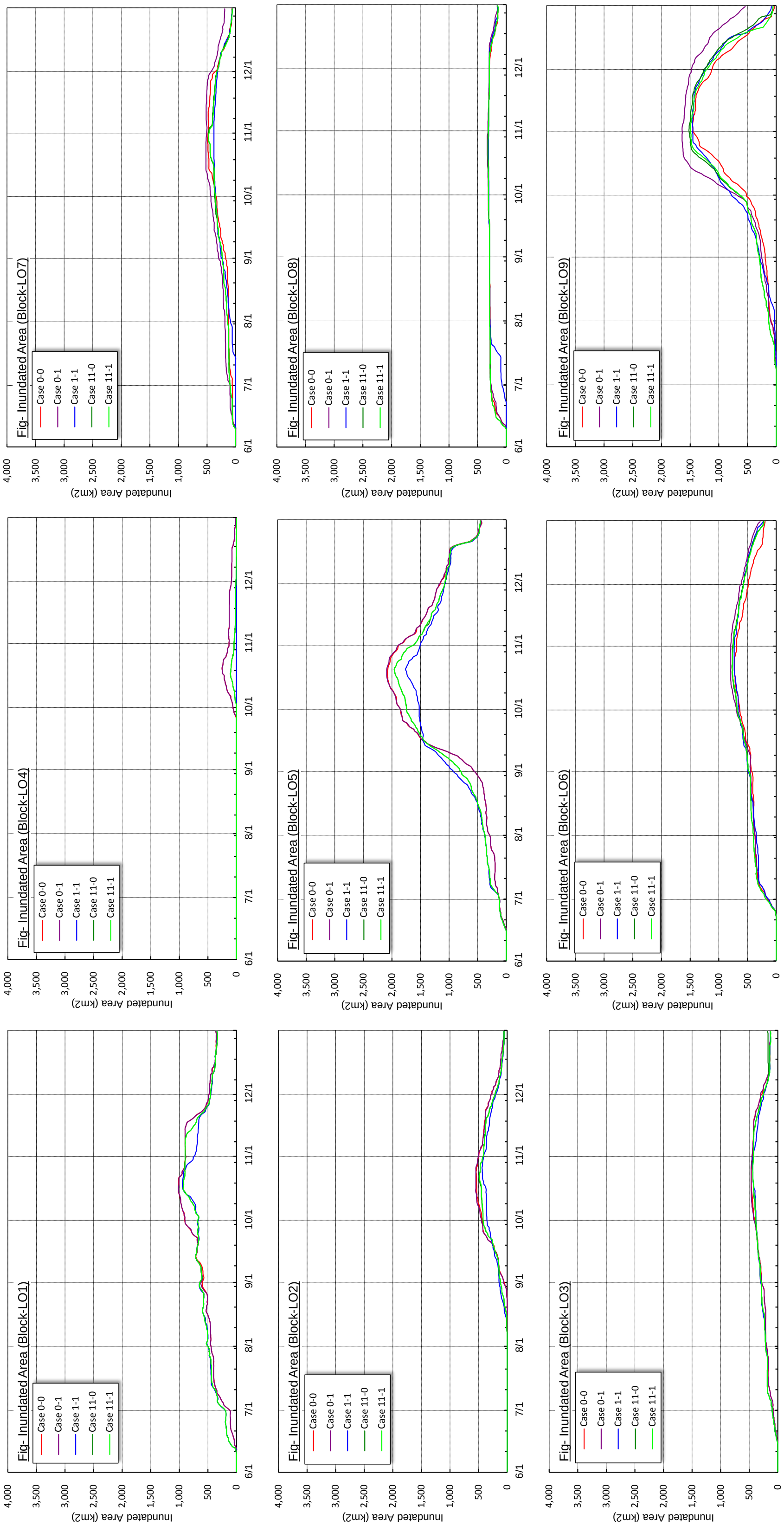


Figure 10.2.76 Inundation Area in Chao Phraya River (100-year Return Period) (1/3)

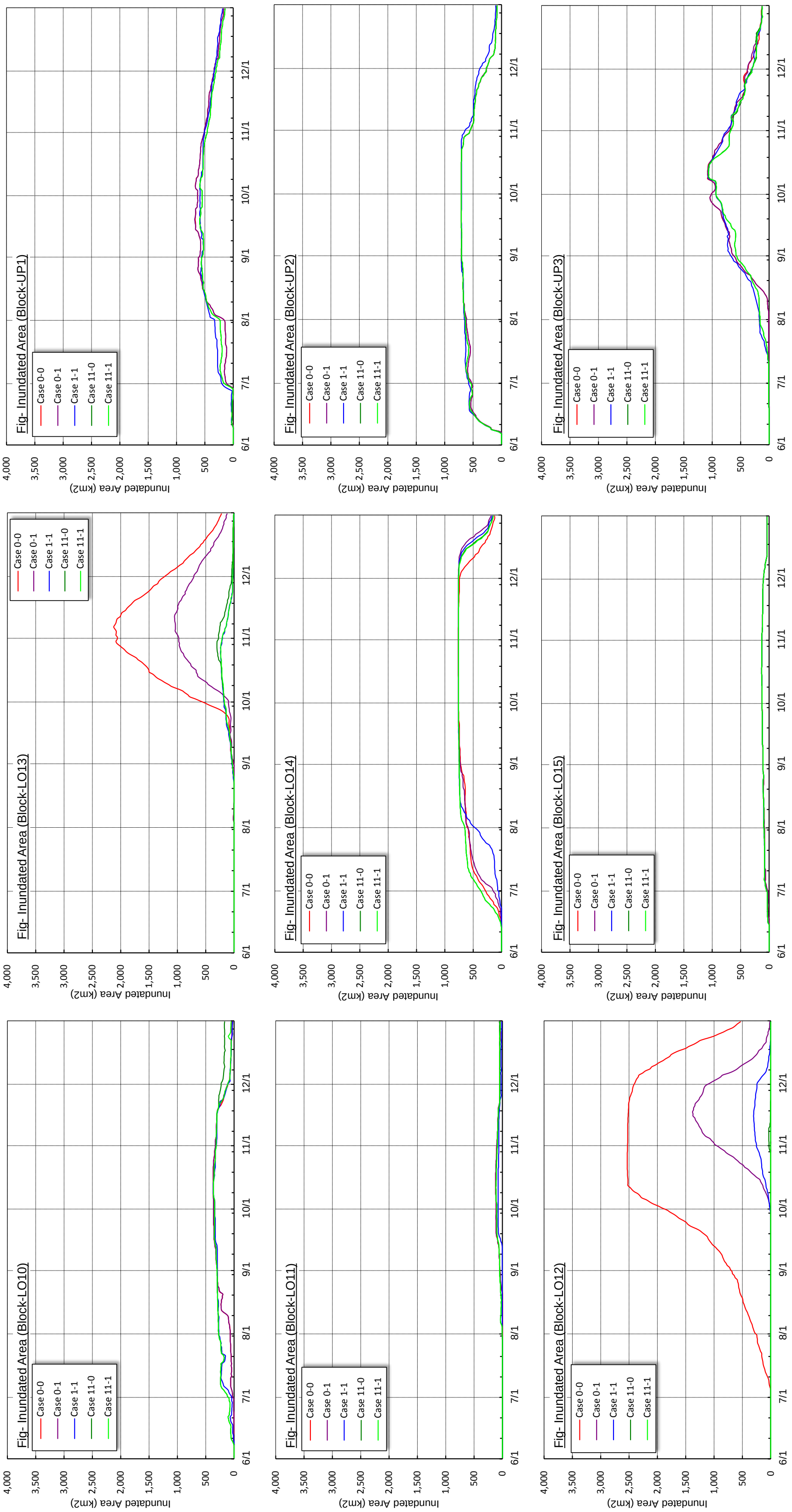
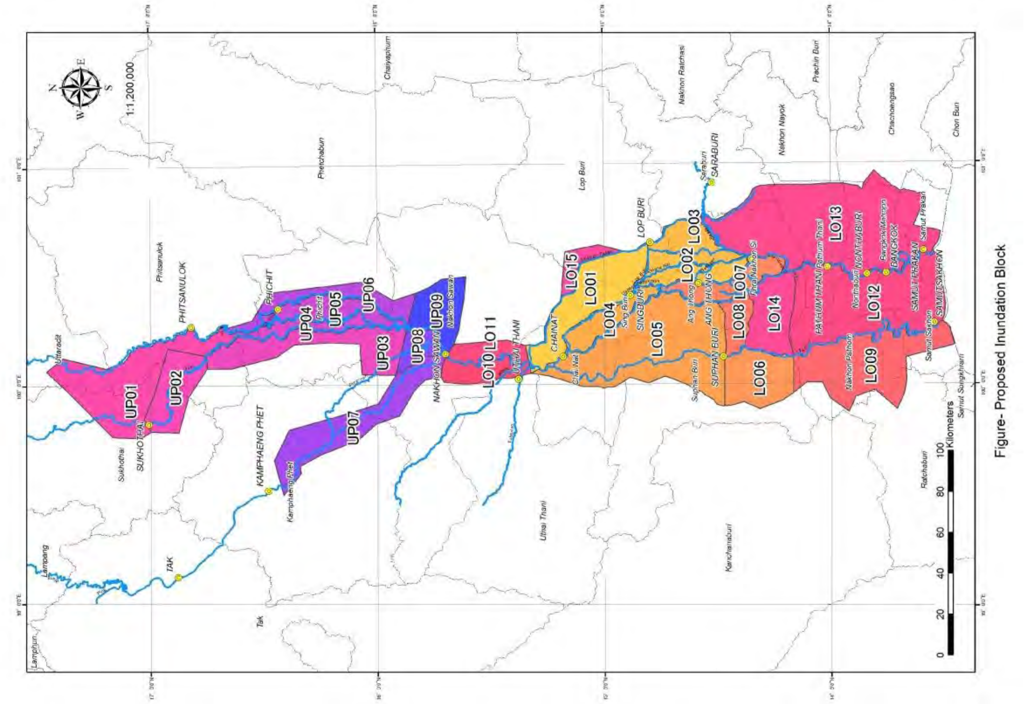


Figure 10.2.77 Inundation Area in Chao Phraya River (100-year Return Period) (2/3)



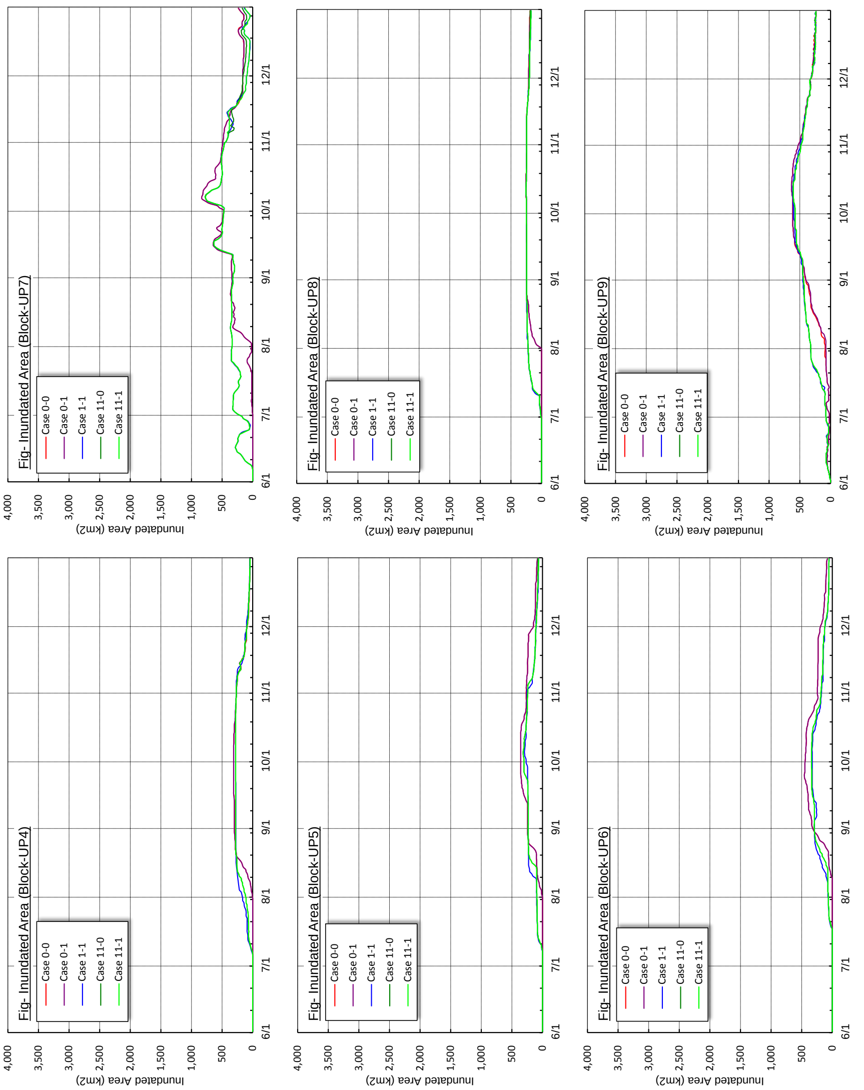


Figure 10.2.78 Inundation Area in Chao Phraya River (100-year Return Period) (3/3)

10.2.11 Land Use Control in Inundation Area

(1) Case Study for Land Use Control

(a) Selection of Case Study Area

To deliberate on the countermeasure of land use for flood management of Chao Phraya River Basin, the situation of the area with high potential for flooding should be investigated in the local level. For this purpose, the case study area is to be selected from the point of view of regional disaster prevention.

The selection of the area is carried out by considering the pattern of agricultural land use with potential of inundation height from simulation and situation of specified retention area.

Table 10.2.47 Target Area of the Case Study

	Height of Inundation by Simulation		Retention Area	Land Use					
				Build-up Areas Zone	Agricultural Land Uses				Environ-mental Conserva tion Zone
	Less than 2m	2m or more			Rural and Agricultu-ral Area	Conservation for Rural and Agricultural Area	Land Reform for Agricultural Area	Land Consoli-dation for Agriculture	
Taphan Hin-Bang Mun Nak, Pichit			○	○	○	○		○	○
Bang Ban, Ayutthaya			○	○	○			○	
(Nakhon Sawan – flood protecting city)									
(Suburb of BKK)									

(b) Ayutthaya Province

(i) Overview

Five (5) industrial parks are located adjacent to the Bangkok Metropolitan Area, the transportation hub. Factories are prominent in the agricultural zone along R9 and along the national roads running from north to south and from east to west in the regions such as R32. Factories are also found along R3111, 3263 in Bang Ban, and Bag Chai located to the northwest of Ayutthaya.

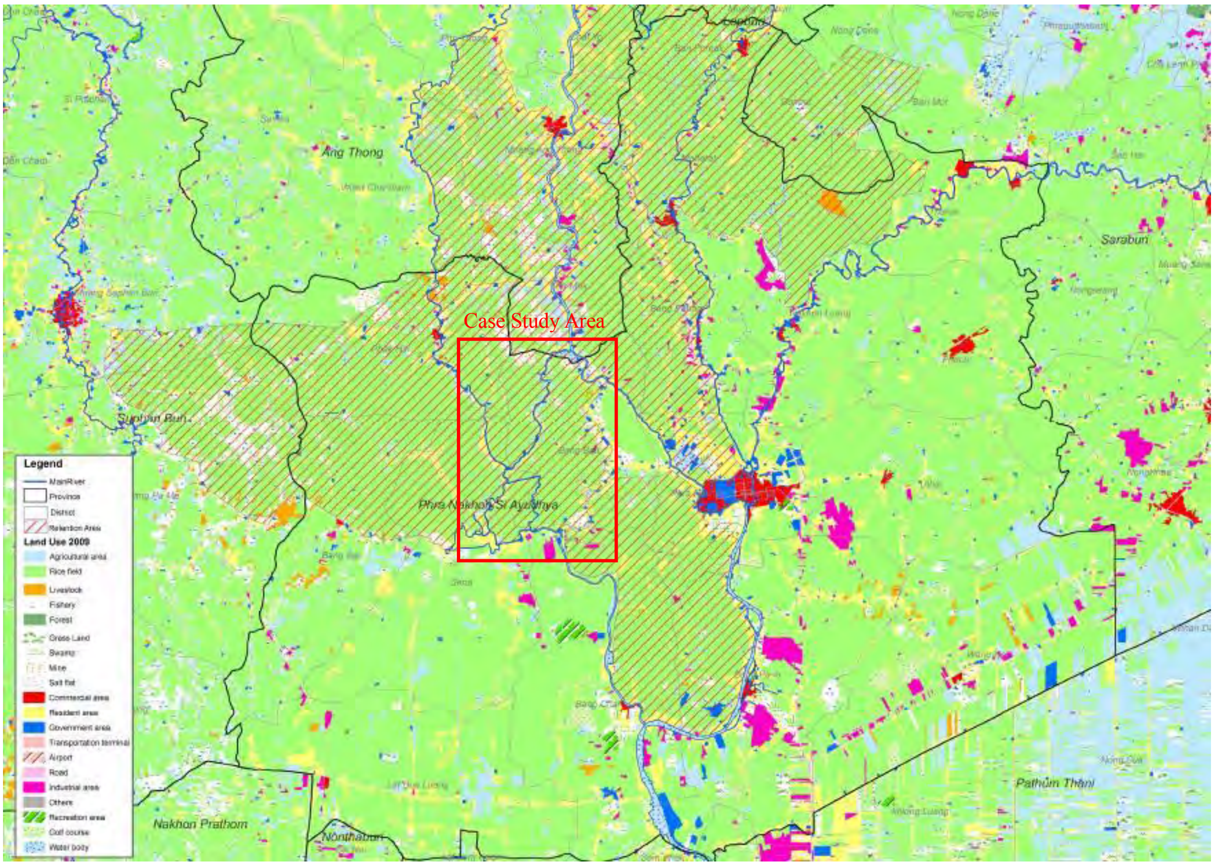
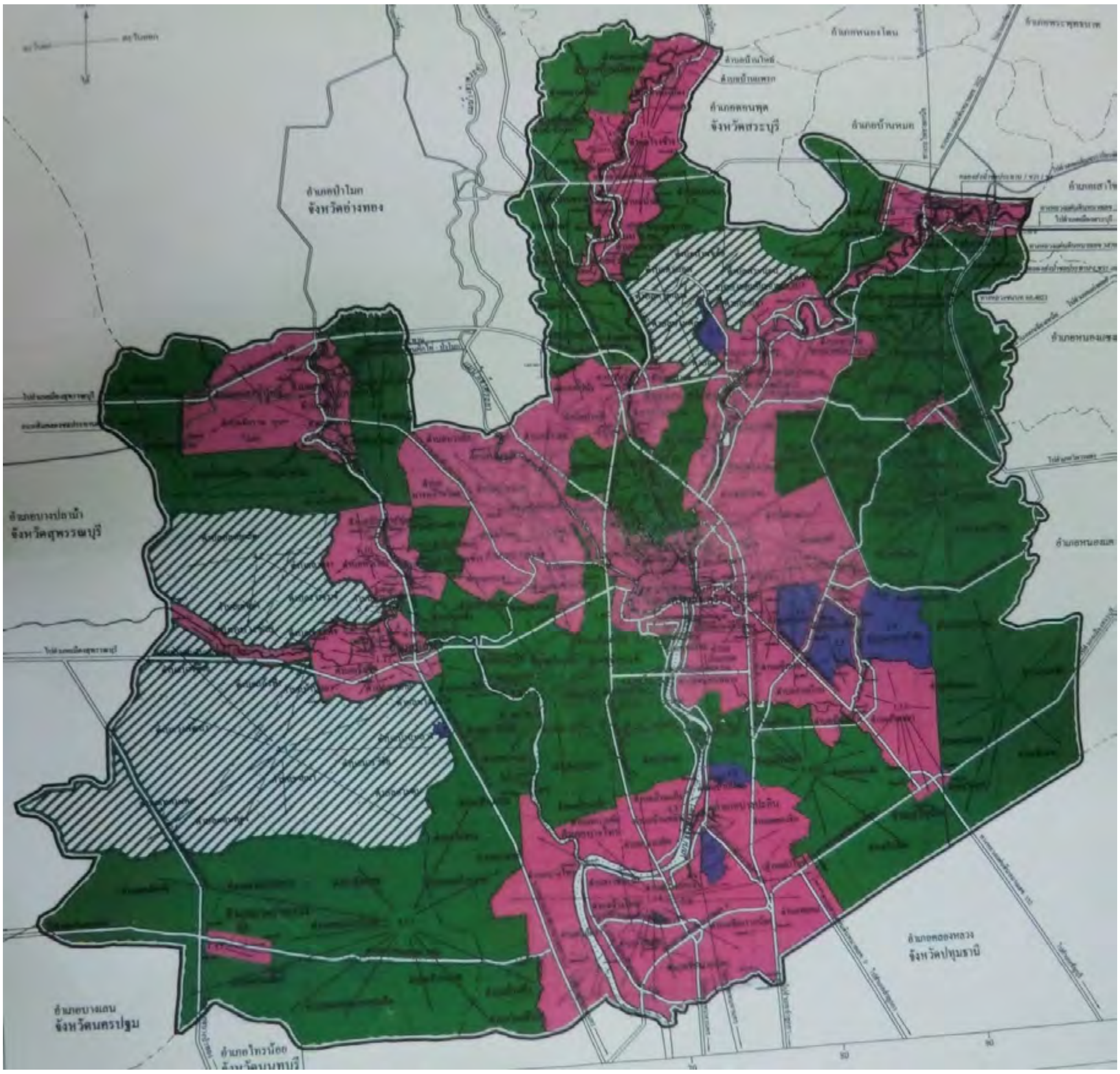


Figure 10.2.79 Situation of Ayutthaya Province (2009)

Most districts in the province have their town planned with fertile paddy fields which receive the blessing of the Chao Phraya River. The urban area and farmlands are distinguished clearly as seen in the condition of land use. Non-agricultural land use is in progress along the main road.



Residential, Commercial and farmland around （Town Planning Area)
Specific Industrial
Rural and Agriculture Area
Land consolidation for agriculture

Figure 10.2.80 Land Use Plan of Ayutthaya (Under Process for Approval)

(ii) Bang Ban District

The area is located in the northwestern part of the City of Ayutthaya. The entire area is irrigated, and almost all were affected by the 2011 flood. The hospital and commercial area in the town center are protected by temporary earth dyke on the outer perimeter road. Almost all farmlands are designated as flood retention area with facilities constructed partially. A significant part of the area along R3111, 3263 and 3412 has been converted into non-agricultural use such as factory with roadside expansion as the economic land use. These areas are designated as rural and agriculture areas, but allow the location of non-agricultural land use such as certain factories with low environmental impact. Additionally, since the ratio of minor use exemption of Bang Ban and the adjacent Sena district is 20%, the location of non-agricultural appears to be promoted in good condition for access. There appear few non-agricultural land uses in the area of land consolidation for agriculture partially exempt from the rule.

The area outside of Bang Ban is designated as rural and agricultural area under the provincial land use plan of Ayutthaya. It appears that more locations of non-agricultural land use are being promoted as minor use exemption of 10%.

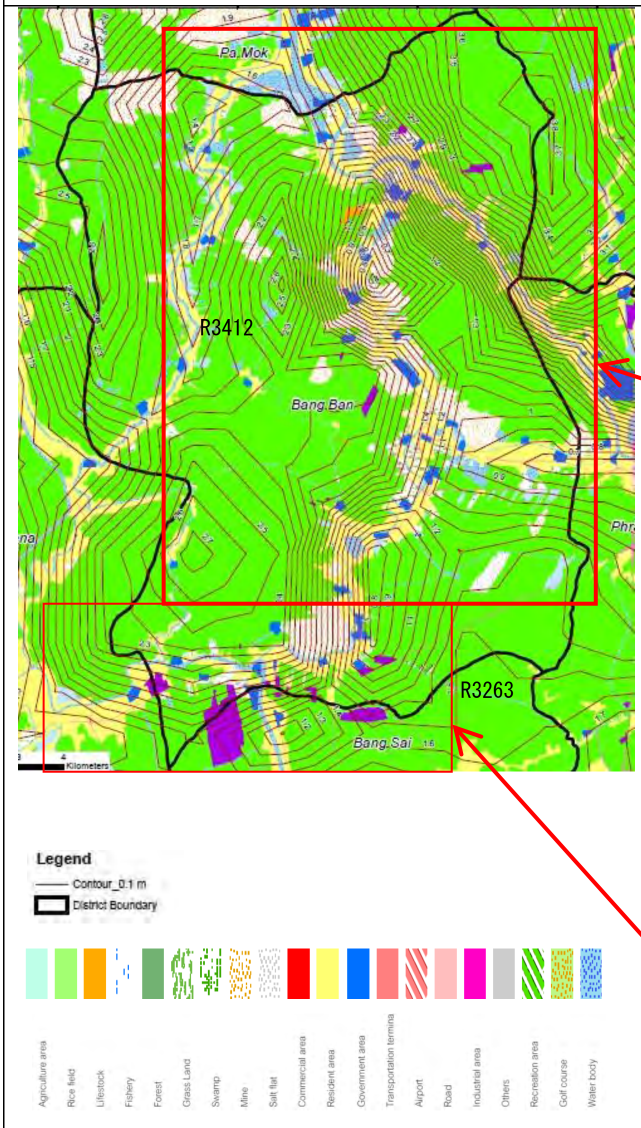
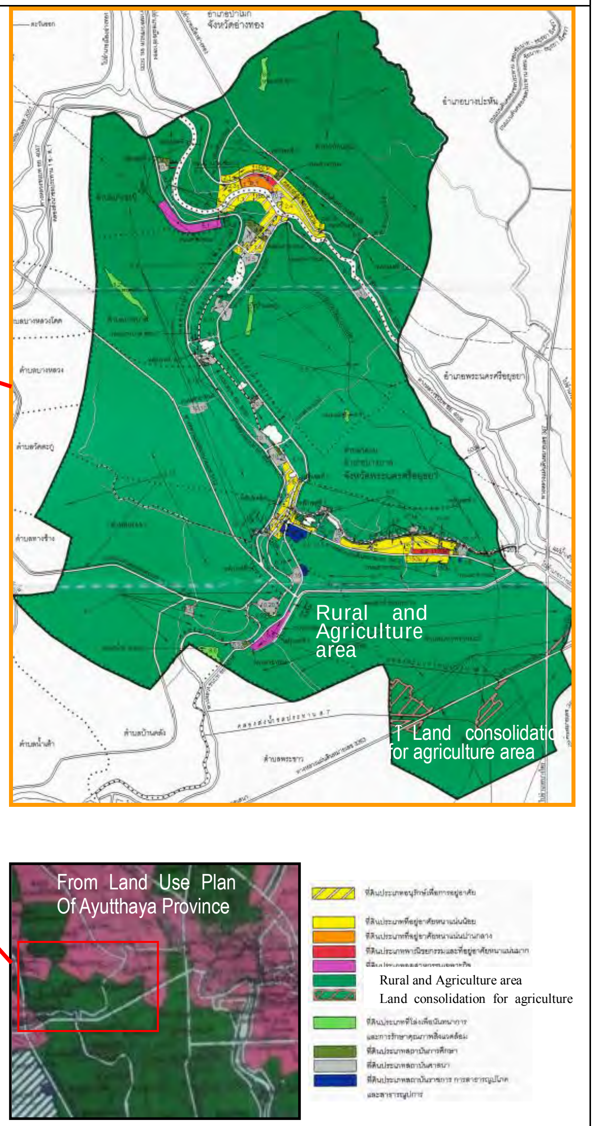
Land Use in 2009	Land Use Plan of Bang Ban District
	

Figure 10.2.81 Land Use and Town Planning of Bang Ban District, Ayutthaya

Table 10.2.48 Control of Land Use of Bang Ban District, Ayutthaya

		Rural and Agricultural Area	Conservation for Rural and Agricultural Area	Land Reform for Agricultural Area	Land Consolidation for Agriculture
Province Ayutthaya	Purpose	Agriculture or agricultural related purpose, educational institutions, religious institutions, government institutions, infrastructure and public assistance.	Agriculture or agricultural related purpose, educational institutions, religious institutions, government institutions, infrastructure and public assistance mainly for environmental preservation and maintenance. Land use for other businesses shall not be allowed for large buildings.		
	Land use not permitted	All types of factories apart from low impact; Gas filling facilities; Fuel oil storage; Hotels more than 9m high; Dwelling and commerce in large building; Golf course	All types of factories apart from low impact; Hazardous objects; Gas filling facilities; Fuel oil storage; Hotels more than 9m high; Dwelling and commerce in large building; Golf course ; Amusement park, etc		
		※Minor use exemption, 10% ※Provision of absolute height, some open space	※Provision of setback		
Bang Ban District	Purpose	Agriculture or agricultural related purpose, educational institutions, religious institutions, government institutions, infrastructure and public assistance.			Land consolidated area based on legislations.
	Land use not permitted	All types of factories apart from low impact; Gas filling facilities; Fuel oil storage; Hotels more than 9m high; Dwelling and commerce in large building;			
		※Minor use exemption: 20%			

(c) Pichit Province

(i) Overview

Yon and Nan rivers flow through the center of the region where paddy fields spread forming the floodplain. Most of the area is affected by inundation, but the slightly elevated area on the alluvial fan bordering the Pin River retards flooding. A large portion of the area near Yom and Nan River Basin is considered to be a water retention area.

Dominant land use in this area is paddy and truck farm; non-agricultural land use does not appear to spread. Along the national road such as R1118 from north to south, R111, 113, and 1118 west to east, residential and commercial areas are sporadically seen. A large scale development area appears to be located along R104.

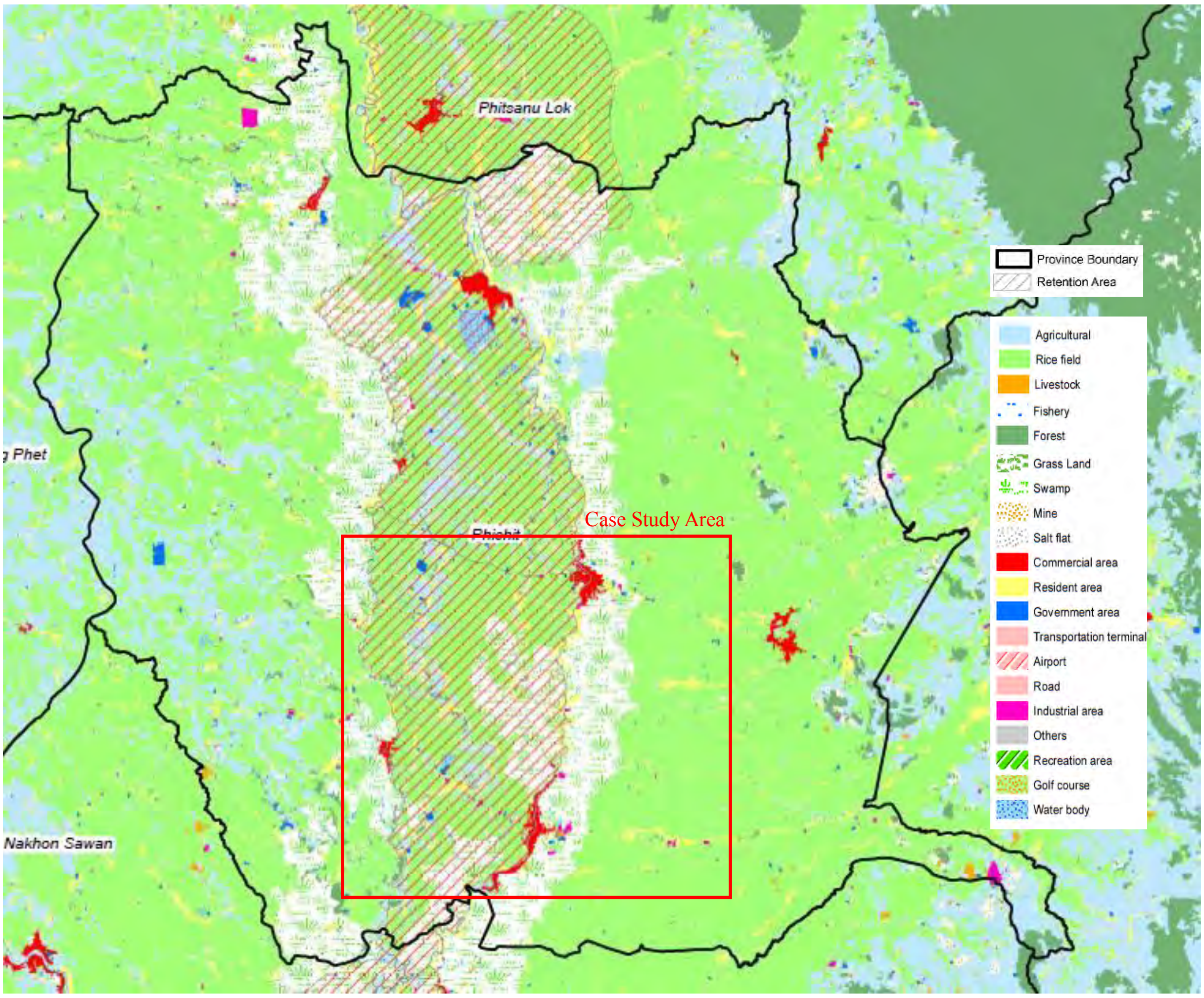


Figure 10.2.82 Current Situation of Pichit Province (2009)

The town planning being defined in all cities and community areas in the province has been proposed and is expected to be approved within this year 2013.

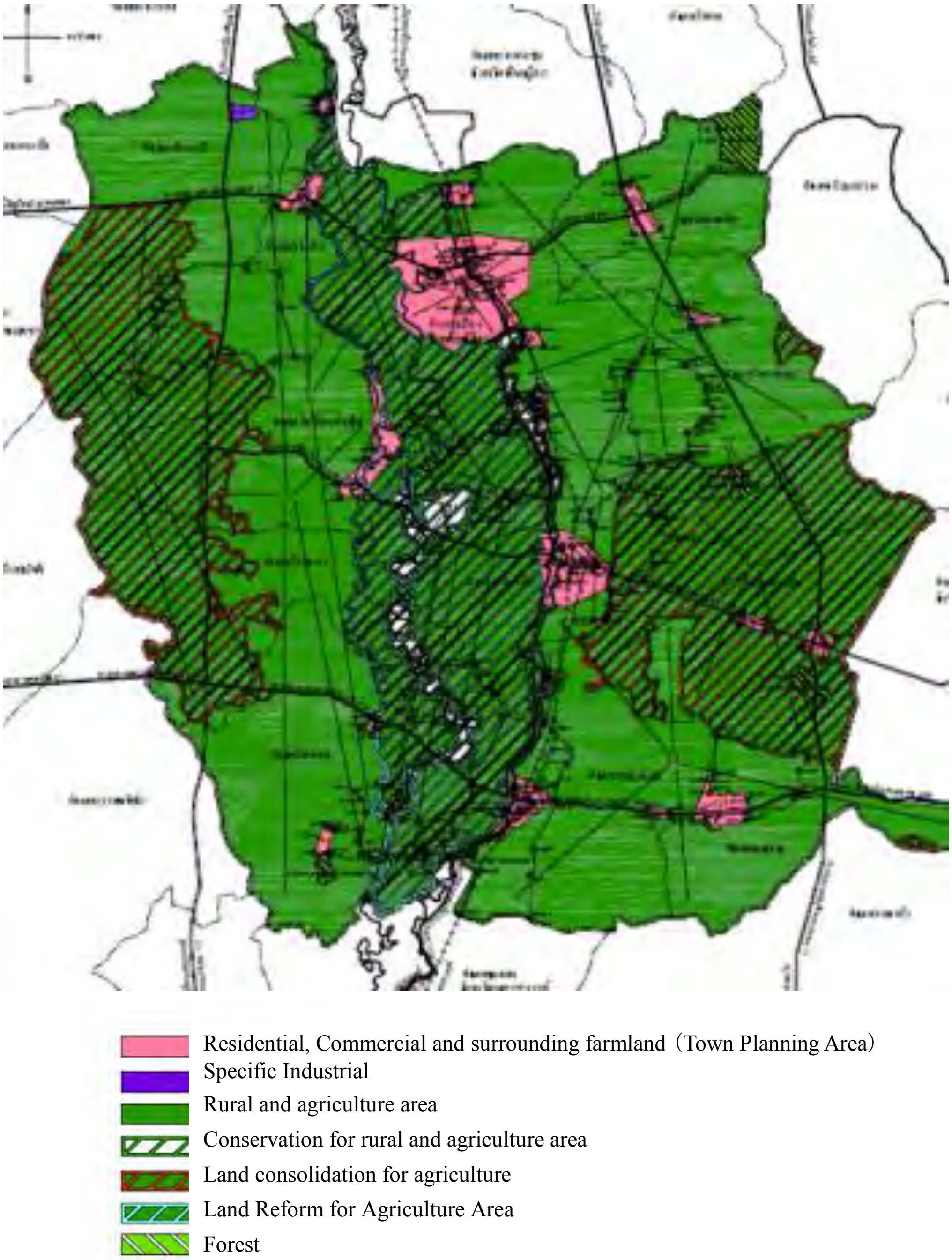


Figure 10.2.83 Land Use Plan of Pichit Province (Under Process for Approval)

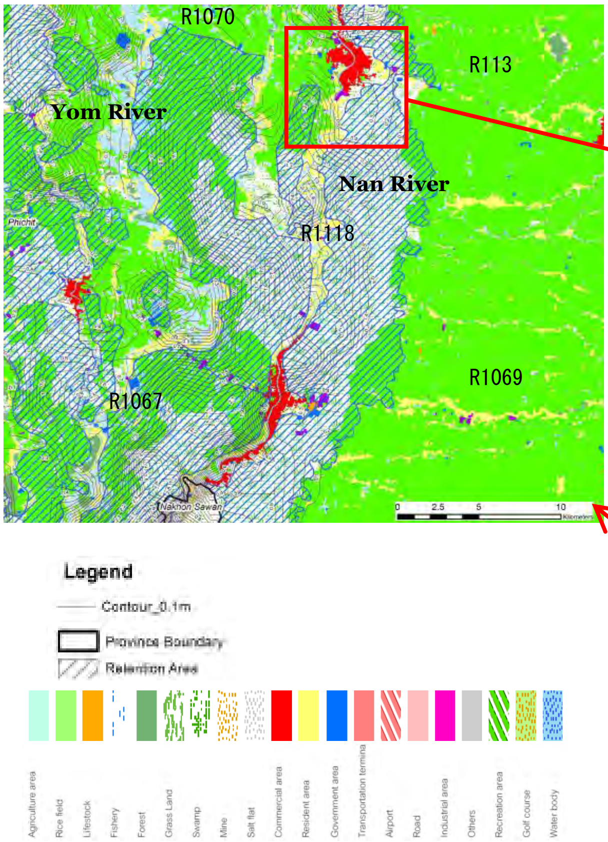
(ii) Tahan Hin, Ban Mun Nak District

Tahan Hin, Bang Mun District located in the hub of traffic where R1118 and R113 intersect 1067 along Nan River. Although most of this area was inundated in the 2011 flood, the township on the river levee was not affected. The area between Yom and Nan rivers is considered to be a water retention area apart from township.

There appears to be an exudation of residential land use along R113 from the township of Taphan Hin and along R1067 from the township of Bang Mun Nak. Most of the area of farm lands is designated as rural and agriculture area and it appears that dwellings and factories with low environmental impact are located. As to the area between Yom and Nan rivers designated for rural and agricultural area, there is little non-agricultural land use. There seems to be no non-agricultural land use also in the area designated as land consolidation for agriculture.

Since the ratio of exemption of minor land use in rural and agriculture is 10% in Taphan Hin and 25% in Bang Mun Nak, non-agriculture land use may be promoted especially along the main road even in low urbanization impact areas.

Land Use in 2009	Land Use Plan of Tahan Hin, Ban Mun Nak



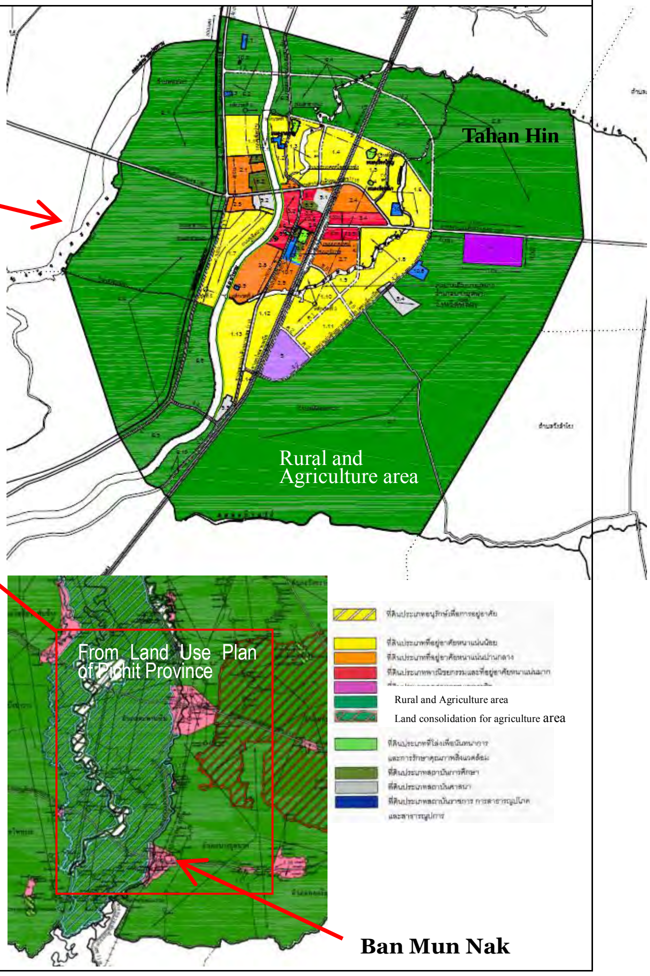


Figure 10.2.84 Land Use and Town Planning of Tahan Hin, Ban Mun Nak District, Pichit

Table 10.2.49 Control of Land Use of Tahan Hin, Ban Mun Nak District, Pichit

		Rural and Agriculture area	Conservation for Rural and Agriculture area	Land Reform for Agriculture Area	Land Consolidation for agriculture
Pichit province	(Not disclosed yet)	(Not disclosed yet)	(Not disclosed yet)	(Not disclosed yet)	(Not disclosed yet)
Taphun Hin District	Purpose	Agriculture or agricultural related purpose, educational institutions, religious institutions, government institutions, infrastructure and public assistance.			Land consolidated area based on legislation
	Land use not permitted	All types of factories apart from low impact			
		*Minor use exemption, 10%			
Bang Mun Nak District	Purpose	Agriculture or agricultural related purpose, educational institutions, religious institutions, government institutions, infrastructure and public assistance.			
	Land use not permitted	All types of factories apart from low impact; Dwelling and commerce in large building			
		*Minor use exemption, 25%			

(2) Issues of Land Use Control

(a) Study on New Land Use Measures for Retention Area

Most of the retention areas considered in the master plan are designated for agricultural land use such as “Rural and Agriculture Area,” “Conservation for rural and agriculture area,” partially, “Land Reform for Agriculture Area” and “Land consolidation for agriculture area.” Residents of small scale and factory of low environmental impact are permitted to locate in the area of “Rural and Agriculture area” and “Conservation for rural and agriculture area.” On the other hand, almost all buildings are not permitted, basically. Since the exemption rule for minor land use has been defined in the range of 5% to 25% of each area in the above-mentioned agricultural land use apart from “Land consolidation for agriculture area,” the control on buildings has become ineffective.

It is indispensable that the new strict land use or review of regulations on exemption is to be introduced to control location of buildings in the retention area. Since “Land consolidation for agriculture area” and “Land Reform for Agriculture Area” are target areas of land development for agriculture, these two areas should be excluded from the target area for retention.

(3) Introduction for Interim Regulation for Land Use Control to the Area protected by Ring Levee in the Future

In high potential areas for flooding that are taking protective measures against inundation such as ring levee and waterside land, the introduction of strict regulations to building construction is needed. Since there is no regulation such as "Disaster Risk Area," a new system to specify the hazardous area of flooding is also needed.

(a) Enhance Coordination System of Land Use

To increase the effectiveness of land use policy, cooperation between related organizations is required. The fact that in addition to the Department of Town and Country Planning and the organization for building permits there are organizations that serve to enhance the value of land use such as agricultural land use may give rise to mutual contradiction to each other. Considering the situation that cooperation has not been fully operated, it is necessary to establish the system to ensure the cooperation of relevant organizations for land use control.

(4) Proposed Solution to the Issue

(a) Policies for Land Use Control

(i) Basic Policy

To set up countermeasures of land use as a part of the management of Chao Phraya River Basin, the result of study such as past flooding feature, flood control under the MP, and historical and social background of land use in Thailand must be considered. The policy direction of management of land use control of the basin is to be set up as follows:

To take into account the direction of policy on the basis of mitigation:
The characteristics of the flood and land use primary use paddy of the Chao Phraya River Basin are summarized as follows.

It is assumed that this master plan responds to a disaster of 100-year probability such as the 2011 flood, but it is also inevitable that flooding will occur during heavy rain of 100-year probability even if flood control measures were implemented. To cope with flood damage, the basic concept of mitigation is that flood damage is to be reduced as much as possible in frequent flood in several years and is to be reduced to a certain level of damage in the event of a disaster of once in several decades to one hundred years.

To promote guidelines of land use that respects social and historical background:
Social and economic activities are a day-to-day life of ordinary people which communities have cultivated over a long period. Although mitigation is a basic policy, it is inevitably reproachable to put the cart before the horse if the measures appear to act as impediment to people's daily life and economic activities.
Measures of land use for mitigation should lead to improving the quality of life of the people that respects social environment and historical background taking account of inheritance of land use in the current situation and existing system.

Enhancement of land use coordination system
At the time of construction of large-scale land development, improvement, and property, it is required to make effective use of land that took into consideration the potential flooding from the point of view of the Chao Phraya river basin management.
If an application of this large-scale land use has been made, a project shall be implemented on the basis of sufficient cooperation of related organizations with consideration for flood as a part of river management.

(ii) Concept of Land Use

The concept of land use management is set as follows based on the basic policy:

The concept 1:
To implement effective land use regulation as a minimum corresponding to the frequent floods in order to maintain and improve people's daily life and economic activities.

The concept 2:
To promote land use in order to minimize flood damage in several decades to a hundred years in terms of mitigation.

Table 10.2.50 Direction to Response of Flooding

Frequency of disaster	Direction	Concept
Several decades to one hundred years	Reduce damage as much as possible	Concept 2
Several years	Minimize damage	Concept 1

The concept 3:
To implement measures to improve the quality of life for the people live in a serious flood-prone area.

The concept 4:
To create a system of performance under the full coordination of related organizations for implementation of the following measures. The relationship between concept and measures of land use is as follows.

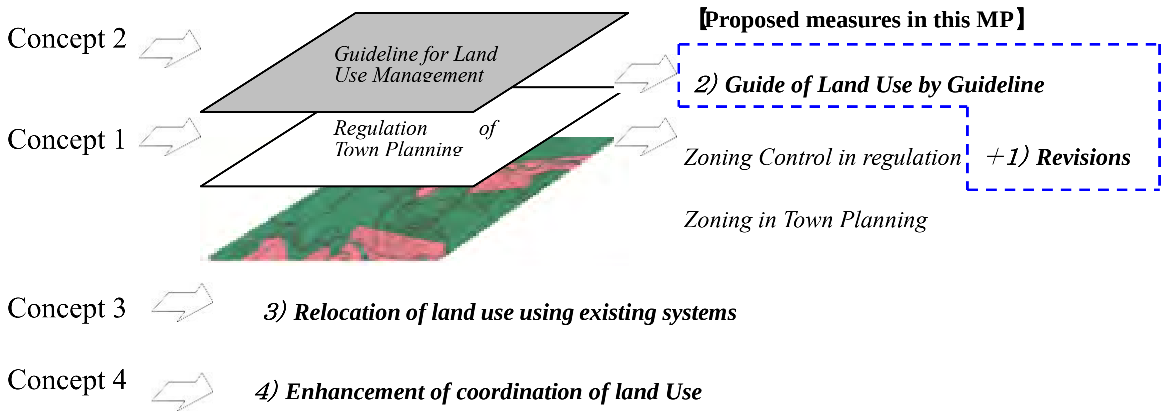


Figure 10.2.85 Image of Land Use Management Based on Concept

(b) Specific measures of Land Use Management

(i) 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. The risk analysis results of flood analysis are to be used as an appraisal of flood vulnerability.

From the fact that Town Planning has been set up in Chanwat, Amphoe level in the flood prone area on the Chao Phraya River Basin, 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. The new regulation is applied on the occasion of proposal of building permission after promulgation.

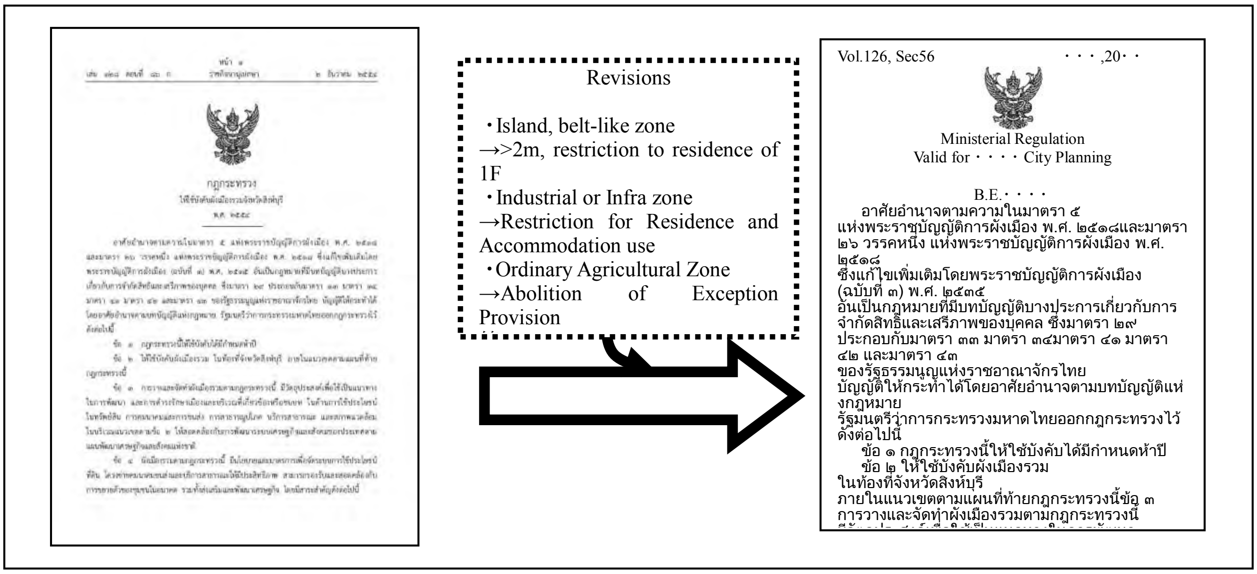
Basic policy and contents of application is as follows:

- In coherent area of high density township of Town Planning Area, protection of town is a basic policy so that new land use control should not be implemented.
- In area designated as residential use zone[*1] in island-like or belt-like zone along the highway, residence on the first floor is subject to restriction in the area where inundation depth is predicted to exceed 2m.
- In area designated as industrial or infrastructure use zone[*2] in individual zone, protection of the area is a basic measure and is subject to restriction for residence and accommodation use other than factory, warehouse, etc.
- In area designated as ordinary agricultural use zone[*3], buildings related to agriculture are permitted. Of course, every building is supposed to be permitted in a certain percentage in accordance with the provisions of exception. Since this situation leads to the expansion of flood damage, exception rule is not to be applied to the regulation in the area where inundation depth is predicted to exceed 2m.

*1 Residential use zone:
Zone with residence such as Conservation for Residential Area, Low density residential area, Medium density residential area, High density residential and commercial area, Commercial area.

*2 Industrial or infrastructure use zone:
Zone located by industrial facilities such as Industrial and warehouse area, Specific Industrial, Warehouse, Storage and Godown, General Industrial Non-pollution industrial and ware house, Conservation for tourism, Public service and utilities area.

*3 Ordinary agricultural use zone:
Zone with agricultural land use, such as Rural and Agriculture area, Conservation for rural and agriculture area.



Existing Regulation for Land Use | Regulation in the Future

Figure 10.2.86 Image of Revision of Existing Land Use Regulations

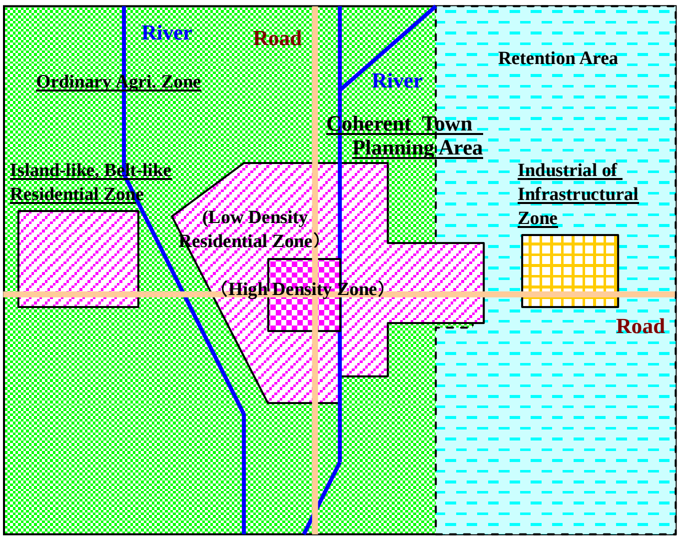


Figure 10.2.87 Image of Location of Town Planning Area

Table 10.2.51 Contents of Specific Measures of Land Use Management (Tentative)

Category of Flood Area	Flood Depth	Retention Area	Features	Land Use Zoning				
				Town Planning Area	Island-like, Belt-like Residential Zone	Industrial, Infrastructure Zone	Ordinary Agricultural Zone	New Designation
			Example		Nakhon Chai Sri	Nakhon Chai Sri, Ayutthaya	All area	-
FS	—		Relatively shallow inundation and shorter duration		-	Continuation of Current System	Continuation of Current System	Continuation of Current System
FSR	—	○	Relatively shallow inundation and shorter duration. Water level is controlled.	Basically Protection ------------ Continuation of Current System	-	-	-	-
FL	>2m		Deeper inundation and longer duration.		-	Basically Protection	Basically Protection	Not allowed
						Not allowed to residential and commercial	Abolition of Exception Provision	
FLR	>2m	○	Deeper inundation and longer duration. Water level is controlled.		-	Basically Protection	Inundation control	Not allowed
						Residential and accommodation not allowed	Abolition of Exception Provision	
W	>2m		Flood ways for overflowed water located in west of protection area		Allowed to flood	Basically Protection	Allowed to flood	Allowed with uninhabitable to ground floor
					Uninhabitable to ground floor	Residential and accommodation not allowed	Uninhabitable to ground floor	
M	>2m		Swamp, deep inundation and long duration		-	Basically Protection	Allowed to flood	Not allow
						Residential and accommodation not allowed	Abolition of Exception Provision	
MR	>2m	○	Swamp, deep inundation and long duration. Water level is controlled.		-	Basically Protection	Inundation control	Not allowed
						Residential and accommodation not allowed	Abolition of Exception Provision	
H	—		Small scale floods from the east hilly		Continuation of Current System	Continuation of Current System	Continuation of Current System	Continuation of Current System

Upper : Land Use Policy

Under : Land Use Control Measure

(ii) New Measure for Guide of Land Use – Creation of Land Use Guideline -

To further reduce flood damage, the induction of land use is to be introduced in flood prone area. It is proposed that this induction of land use is implemented under the "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.

The contents of the guidelines are proposed as follows.

- Induction of land use is carried out by applying the guidelines to new construction or renovation of buildings.
- The basic policy of induction is to reduce flood damage as much as possible taking into account the features of building use, flood area and its position as a Retention Area.
- Induction contents is indicated by a matrix chart of regional flooding features and building use.
- As for a building use as Residential and Commercial, not buildable or uninhabitable to ground floor are to be induced depending on the depth of inundation to reduce human and economic damage.

- As for a building use of Industrial and Infrastructural, not buildable or installation of facilities for flooding are to be induced depending on the depth of inundation.
- As for a building use of Religion, Cultural and Educational, the raising of the ground or the height of first floor considering the high water flooding besides flood wall or levee are to be induced for the functions responsible for emergency measures such as shelter during flooding.
- As for a building use for Agricultural, installation of flood protection such as raising ground level are to be induced to ensure an environment of agricultural production.
- As for a building use for Public Service, the raising of the ground or flood wall or levee are to be induced in view of its important function for restoration, saving victims and shelters in flooding.
- As for a building use of Tourism and Recreation, the raising of the ground or flood wall or levee are to be induced in view of ensuring the safety of visitors.

This guideline shall serve to supplement the provisions of the Town Planning Regulation described above. It is assumed that the Building Control Bureau of DTP is responsible for the promulgation and publicity of this guideline. The Building Permission Office of the local government is expected to refer to this guideline on the occasion of pre-consultation of building permit application.

<u>Residential, Commercial</u>：Detached Houses, Housing Complex, Store, Shophouse, Office, Theater, Hotel, etc.

<u>Industrial and Infrastructural</u>：Factory, Auto-repair Shop, Warehouse, etc.

<u>Religion, Cultural and Educational</u>：Museum, Reference Library, School, Vocational College, College, University, Wat, etc.

<u>Agricultural</u>：Farm Product Storage, Processing Facilities

<u>Public Service</u>：Administrative Facilities

<u>Tourism and Recreation</u>：Resort Facilities, Tourist Facilities, Local Product Shop、Golf Club House, etc.

Table 10.2.52 Scheme of Building Control in accordance with the Features of Flooding (Tentative)

Features of flooding Area			Building Use					
Category of Flood Area	Retention Area	Features	Residential/ Commercial	Industrial Infrastructure	Religion Cultural Education	Agriculture	Public Service	Tourism・Recreational
FS		Relatively shallow inundation and shorter duration	△1	△1	○	○	○	○
FSR	○	Relatively shallow inundation and shorter duration. Water level is controlled.	△2	△1	△1	○	○	○
FL		Deeper inundation and longer duration.	×	△1	△1	△1	△1	△1
FLR	○	Deeper inundation and longer duration; Water level is controlled.	×	×	△1	△1	△1	△1
W		Floodways for overflow water located in west of protection area	△2	△1	△1	△1	△1	△1
M		Swamp, deep inundation and long duration	×	×	△1	△1	△1	△1
MR	○	Swamp, deep inundation and long duration. Water level is controlled.	×	×	△1	△1	△1	△1
H		Small scale floods from the east hill	△1	△1	○	○	○	○

Policy of Land Use restriction :○: Buildable as usual △: Buildable conditionally (Condition 1: With levee or raising of the ground level; 2: Uninhabitable to ground floor) ×: Not buildable newly, renovation

(iii) Relocation of Land Use by Using Existing Systems

The flood area covers most of the Chao Phraya River Basin and high dense residential areas extend linearly along the river. Although flood water depth at the flood will continue to decline because of measures for flood, it is expected that more than 1m inundation occurs in the area of FL, W and M.

Since measures 1) and 2) are applied during new construction and restoration of building, the works will require a considerable amount of year.

It is deemed appropriate that the community works to develop resilient area.

Measures to protect the area from flood are:

・ protection of the area by structure ;

・ levee or flood wall, etc.

・ relocation to the raised land keeping

・ community to reduce the influence of flood

In this case, it is considered that the application of Land Readjustment* as existing systems can be carried out in accordance with the arrangement of parcels of land and the development of roads and other infrastructure.

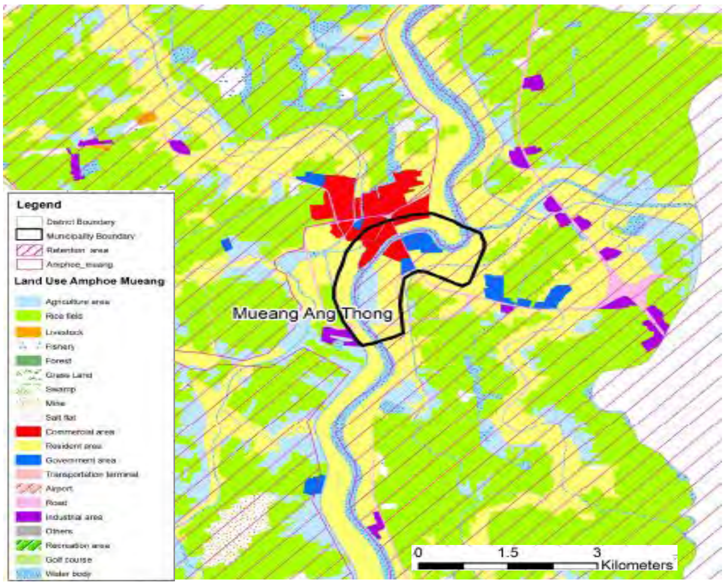
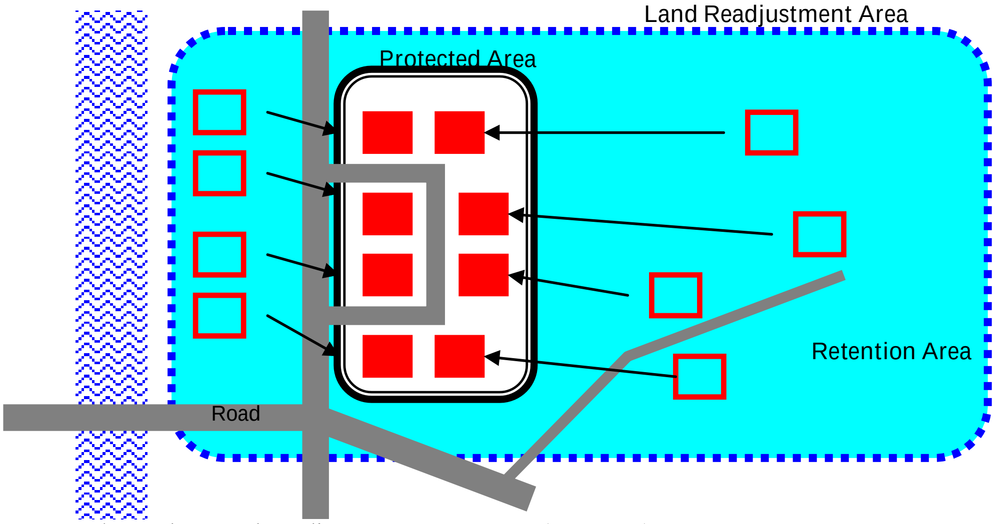


Figure 10.2.88 Map of Land Use around Ang Thong



* Based on Land Readjustment Act B.E.2547 (A.D.2004)

Figure 10.2.89 Image of Land Readjustment by Integrating Land Relocation

(iv) Enhancement of Coordination of Land Use

To secure cooperation in 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 large scale of land use, such as special economic zone and to discuss land use under flood control measures in consideration of potential of flood.

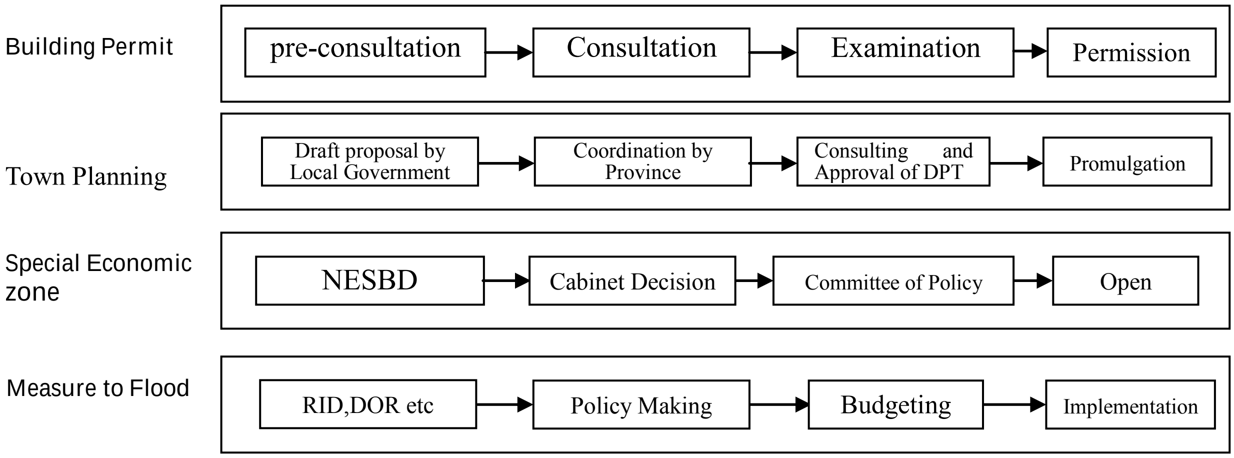
<u>Assumed Members and Matters of coordination</u>

Membership is assumed to consist of the Royal Irrigation Department (RID), the Ministry of Agriculture and Cooperatives, the Department of Public Works and Town & Country Planning (DPT), the Department of Roads (DOR), the Department of Highway (DOH) of the Ministry of

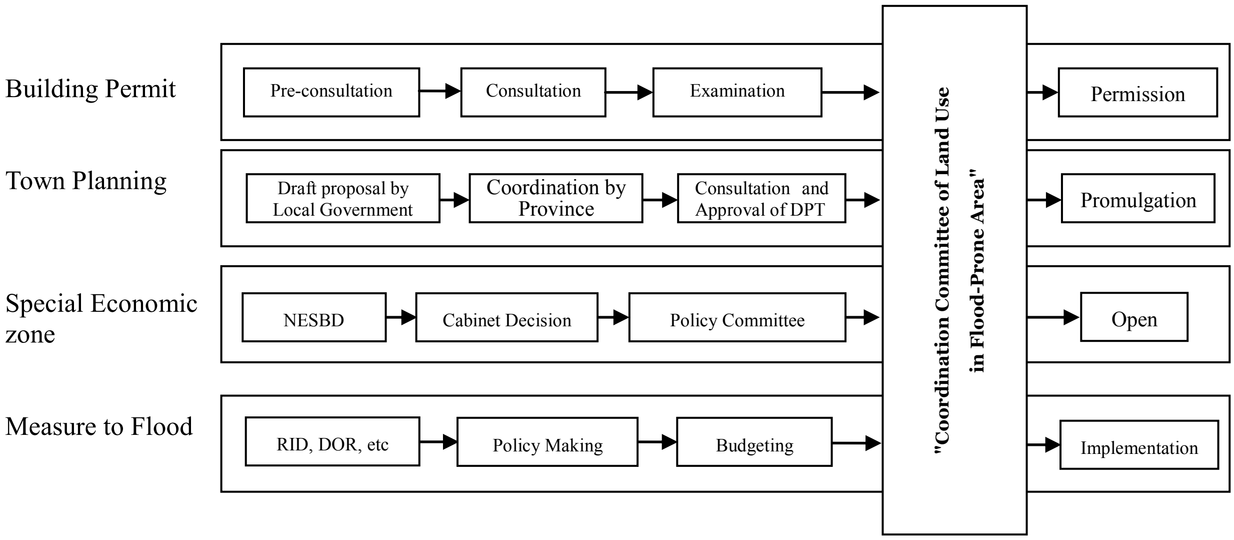
Interior, the National Economic and Social Development Board (NESDB), the Ministry of Industry, etc. Matters of coordination are assumed as the following:

- Positioning of the area based on the flood potential
- Vulnerability assessment in predicted inundation
- Effect for mitigation
- Advice on measures against flood based on the guideline, etc

Existing Process of Related System



Proposed Process of related system



10.2.12 Inland Storm Water Drainage

After the 2011 flood the Thai Government designated as "Flood Protection Area" the most economically important area of some 5,600km^2 that covers Bangkok and 9 industrial estates. The economic area is going to be enclosed by flood walls or heightened roads and canal dikes in order to prevent floodwater from entering the zone. The enclosing works have already started and are expected to be completed by January 2014.

With the enclosing works the protection zones will be much safer against floodwater from the outside that troubled these zones very much in 2011. Instead, management of storm water generated in the zones by local rainfall becomes more important. In this section, a strategy for the inland storm water drainage of the flood protection area is proposed based on a preliminary study.

(1) Existing Flood Protection and Storm Water Drainage Measures

The existing measure for flood protection and storm water drainage in the protection zones is the polder system that is commonly applied in Thailand. Namely, a protection area is surrounded by ring dykes to prevent floodwater from entering into the area of which inland storm water is drained out through a regulator or pumped out depending upon the water level of the outside.

Presently, DOH and DOR are constructing flood walls and heightening roads/dykes along the boundaries of the protection zones. The height of the flood walls and the heightened roads/dykes is the maximum water level of the 2011 flood plus 50 cm. The works have already started and is estimated to be completed by January 2014.

Regarding the inland storm water drainage, RID, BMA and municipalities with support from DPT are developing drainage canals and pump stations for each jurisdiction area.

(a) Agricultural Areas

Most of the protection zones fall in RID Region 11. The drainage outlets are Chao Phraya, Nakhon Nayok River, Bang Pakong Rivers and the sea for the eastern zones, while Tha Chin and Chao Phraya rivers are for the western zones. When the water level of the outside (rivers or the sea) is low, natural drainage is possible but pumping is necessary when it is high. The pumps are operated so as to maintain the water level in the protection zones as high as possible during the irrigation season but as low as possible during the flood season.

During the 2011 flood, pumps of RID Region 11 were operated continuously for 4 months from September to December with about 50 to 80% of working rate. In the southern lower areas near the sea it is very difficult to collect water to the pump stations due to almost horizontal or negative slope. Houses on the canal banks also disturb water flow during a flood. After the 2011 flood, dredging of canals, installation of water pushing machines and installation of semi-permanent pumps were implemented as flood mitigation measure. Especially regarding the installation of the pumps, a total of 240 sets of semi-permanent pumps (120 pumps to each of the eastern and western areas) were added to existing regulators in the RID Region 11. With this installation, the total pumps capacity increased by 75% from 970 m^3/s to 1,690 m^3/s. Since the total drainage area is about 3,800 km^2, the pump capacity increased from 0.25 m^3/s/km^2 to 0.44 m^3/s/km^2.

(b) BMA Areas

Flood walls have been constructed along the Chao Phraya River against water levels of 100-year return period. The existing levels of the walls are 2.5 to 3.0m MSL. During the 2011 flood, overflow took place only in a small uncompleted section, but there was no overflow in the other sections.

Planning scale in terms of return period for inland storm water drainage facilities is three to ten years. BMA has many drainage pumps with a total capacity of 1,584 m^3/s over the 1,568 km^2 of its territory. Out of them 1,032 m^3/s is pumped to Chao Phraya River (East: 695 m^3/s, West: 337 m^3/s). The remainder is for internal drainage between polders.

Since the total drainage area of the pumps to Chao Phraya River is about 1,050 km^2, its specific capacity per 1 km^2 is 1.0$m^3/s/km^2$, almost the same as 1 to 2 $m^3/s/km^2$ of drainage projects for municipalities supported by DPT. During the 2011 flood the pumps were operated 20 to 24 hours a day for about a month continuously according to BMA. When the water level of Chao Phraya River is so high that overflow is about to happen, pumps are stopped by judgment of the pump station.

After the 2011 flood, BMA prepared short-term, mid-term and long-term plans for flood mitigation, as shown in Table 10.2.54. Regarding improvement of drainage system, BMA is planning to dredge drainage channels to increase their flow capacity. Augmentation of the pump capacity has not been planned in five years except for pumps for three drainage tunnels that are planned to be constructed by 2017.

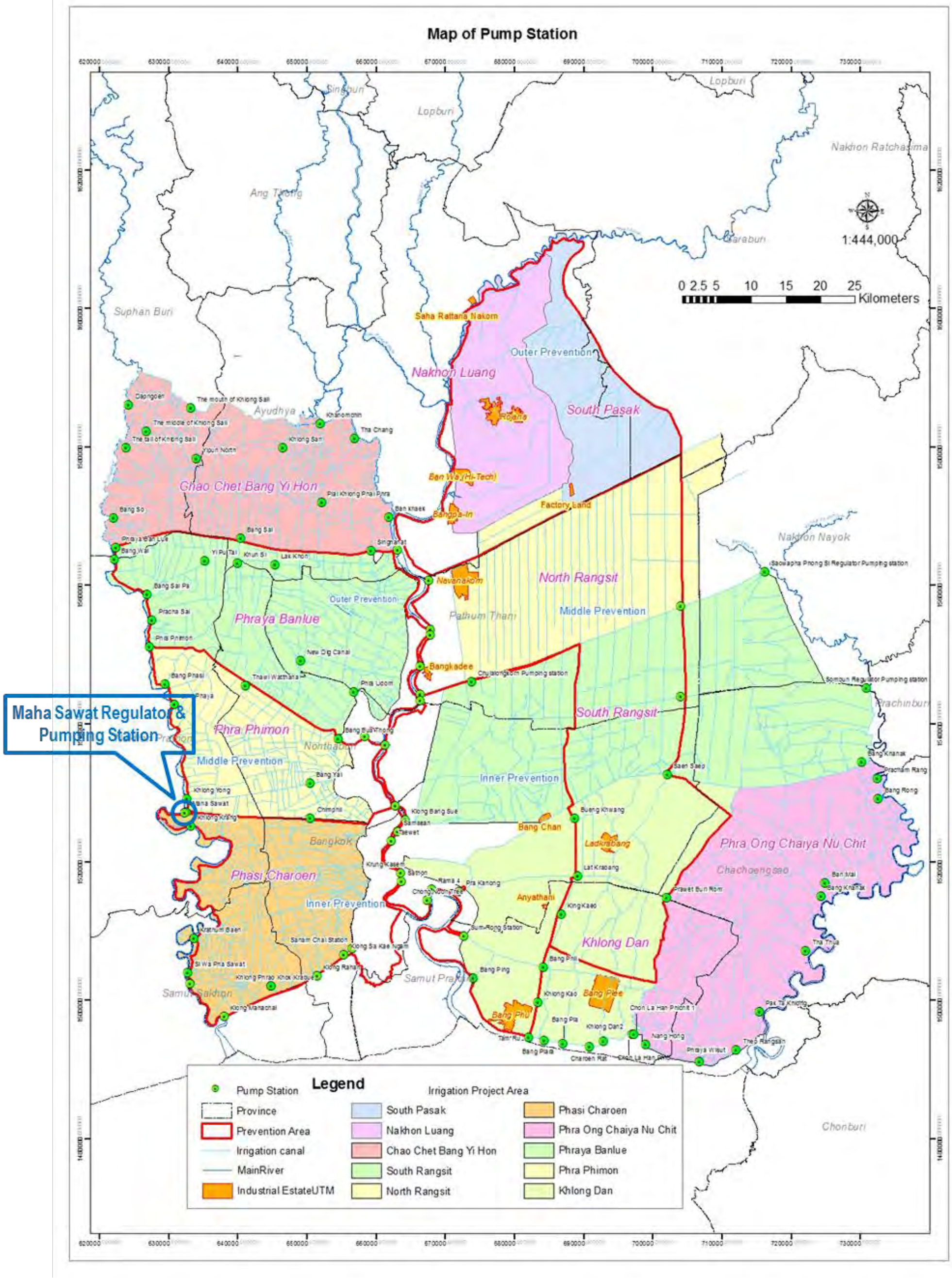


Figure 10.2.90 Location Map of Major Pump Stations

Table 10.2.53 Drainage Pumps in RID Region 11

Location	Outlet	Pump Capacity (m^3/s)			Remarks
		Permanent	Semi-permanent	Total	
East	Chao Phraya R.	167.2	54.0	221.2	
	Nakhon Nayok R.	33.6	54.0	87.6	
	Bang Pakong R.	101.6	90.0	191.6	
	Gulf	336.8	48.0	384.8	
	Internal drain	136.0	114.0	250.0	
	Subtotal	639.2	360.0	999.2	
West	Chao Phraya R.	53.0	93.0	146.0	
	Tha Chin R.	276.4	267.0	543.4	
	Internal Drain	1.6	-	1.6	
	Sub-total	329.4	360.0	689.4	
Total		968.6	720.0	1,688.6	

Table 10.2.54 Flood Mitigation Measures by BMA after the 2011 Flood

Term	Measures	Budget	Remarks
Short-term (3 to 6 months)	Dredging of main drainage canals	1.5 bil. Baht	
	Increase efficiency of drainage system, initiate warning system, setting of flow meter	0.684 bil. Baht	
Mid-term (2012)	Repair of flood wall of Chao Phraya River, Bangkok Noi Canal and Mahasawat Canal.	Not available	
	Heightening of flood walls of Chao Phraya River and the canals	Not available	Lower : 2.5 to 2.8m msl Middle: 2.8 to 3.0m msl Upper: 3.0 to 3.5m msl
	Heightening of King's Dike	Not available	1.5 -2.9 to 3.0m msl
Long term (2013-2017)	Strengthening and elevating of flood walls of Chao Phraya R, Bangkok Noi Canal and Mahasawat Canal and King's Dike.	67.8 billion Baht	
	Developing of canal capacity		
	Increase of flow discharge to the Gulf		Ex. 3 new drainage tunnels
	Development of retention ponds		
	Provision of materials and equipment		
	Development of flood control center		

(2) Preliminary Studies

(a) Verification of Pump Capacity by Simple Water Balance Calculation

After the 2011 flood, the drainage capacity was very much improved by the installation of the semi-permanent pumps as well as canal dredging. According to RID Region 11, the pump capacity is now much enough to cope with at least inland storm water that is generated in the area. In this context, verification of the existing pump capacity in the RID Region 11 area is made by a simple water balance calculation for the west middle protection zone (Phra Pimon Irrigation Project Area) which is a typical pump drainage area in terms of specific pump capacity.

Table 10.2.55 Drainage Pumps in West Middle Protection Areas

Drainage Outlet	Pump Capacity (m^3/s)				Drainage Area (km^2)	Specific Capacity ($m^3/s/km^2$)
	Permanent	Semi-permanent	Total			
Chao Phraya River	22.2	18.0	40.2	193.2	551	0.35
Tha Chin River	78.0	75.0	153.0			

Daily rainfall of five months from August to December 1983 of Bangkok Station of TMD (No. 455201) is used as a model rainfall. The total 5-month rainfall is 1,661mm, which caused serious flood damage over Bangkok and its vicinity, is the maximum in 41 years from 1970 to

2011. The simple water balance calculation assumes that the drainage area is like a pond. It is also assumed that inland storm water is drained only by the pumps during all the calculation period, although in reality natural (gravity) drainage is possible when the river water is low enough.

Calculation results are presented in Figure 10.2.91. As shown in Figure 10.2.91, the maximum water level is 1.27 m MSL and much lower than the maximum allowable water level. This means that the pumps can drain the inland storm water without causing significant damage. Therefore, it can be said that the pump capacity is enough.

The specific pump capacity of this protection zone, 0.35 $m^3/s/km^2$ is smaller than 0.44 $m^3/s/km^2$, the average pump capacity in the RID area excluding the BMA area. Therefore, if it is taken into consideration that even this less pump-equipped zone has enough capacity to cope with the heavy rainfall in 1983, it is natural to consider that the other RID areas also generally have a sufficient capacity. However, it has to be noted that the applied calculation is based on the simple pond model and water flow in canal networks is not considered at all.

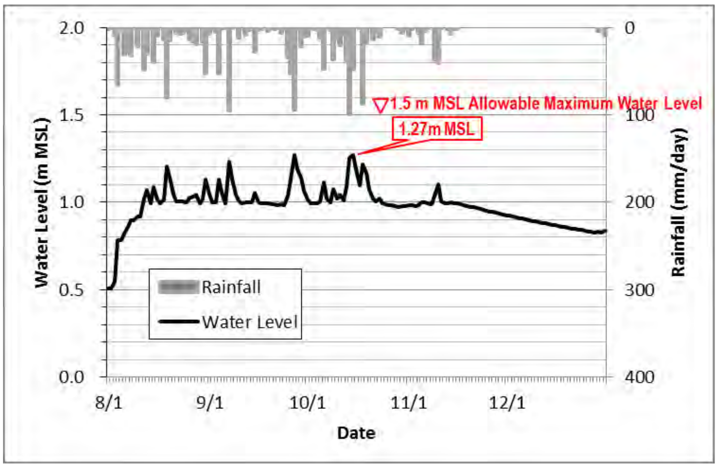


Figure 10.2.91 Calculation Results (Water Level Graph)

(b) Preliminary Study on Water Level Rise by Pump Discharge

There are many pump stations along the lowest stretches of the Chao Phraya River. The total pump capacity is 1,400 m^3/s. If it is taken into account that the flow capacity of the river stretches is about 3,500 m^3/s, the pump capacity can never be ignored. Accordingly, a preliminary study on the effect of the pump discharge on the river water level is made based on a one-dimensional unsteady flow analysis to obtain a hint for a deployment plan and operation of pump stations.

Longitudinal profiles of the calculated maximum water levels are presented in Figure 10.2.92, and calculated hydrographs of water level and discharge are also presented in Figure 10.2.93.

When the pump is the bigger and located the more upstream, the bigger is the water level rise. Therefore, it is not desirable to place a big pump in the upper stretches of Ayutthaya, Pathum Thani and Nonthaburi. If a big pump has to be placed in the upstream due to topographical conditions, the pump discharge should be taken into account when a river discharge allocation plan is made.

In the downstream stretches of Bangkok and Samut Prakan, tidal influence is dominant as characterized by large tidal amplitudes. At the center of Bangkok, 40km from the river mouth, at least 50 cm of tidal amplitude appears even during a big flood discharge. In these lower stretches it might be possible to operate pumps according to the tidal water level fluctuation. For example, a pump is stopped when the water level is as high as the flood wall, but its operation is resumed in a few hours later as the water level is lowered. According to BMA, this is already practiced by BMA operators.

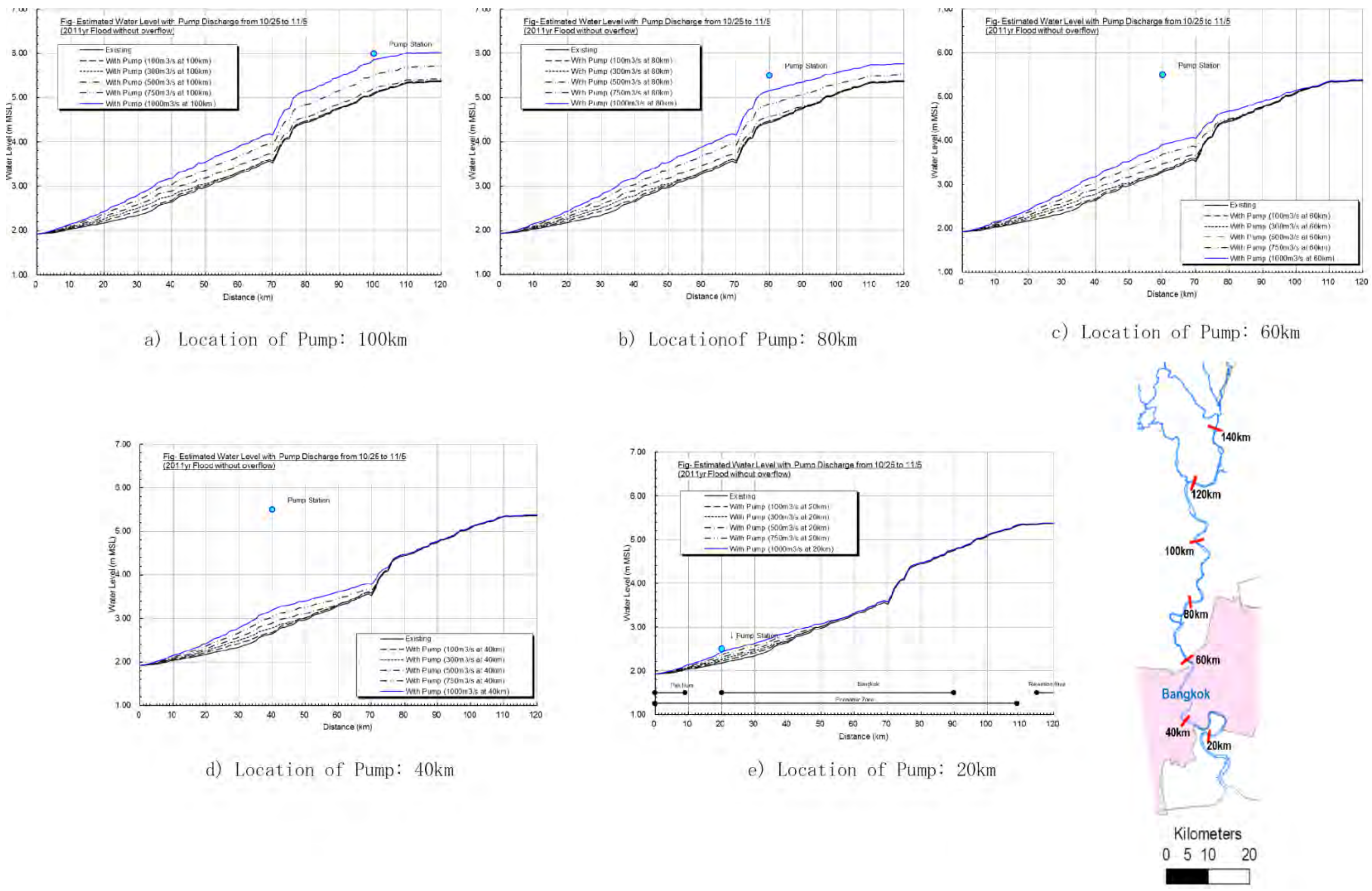


Figure 10.2.92 Longitudinal Profile of Maximum Water Level

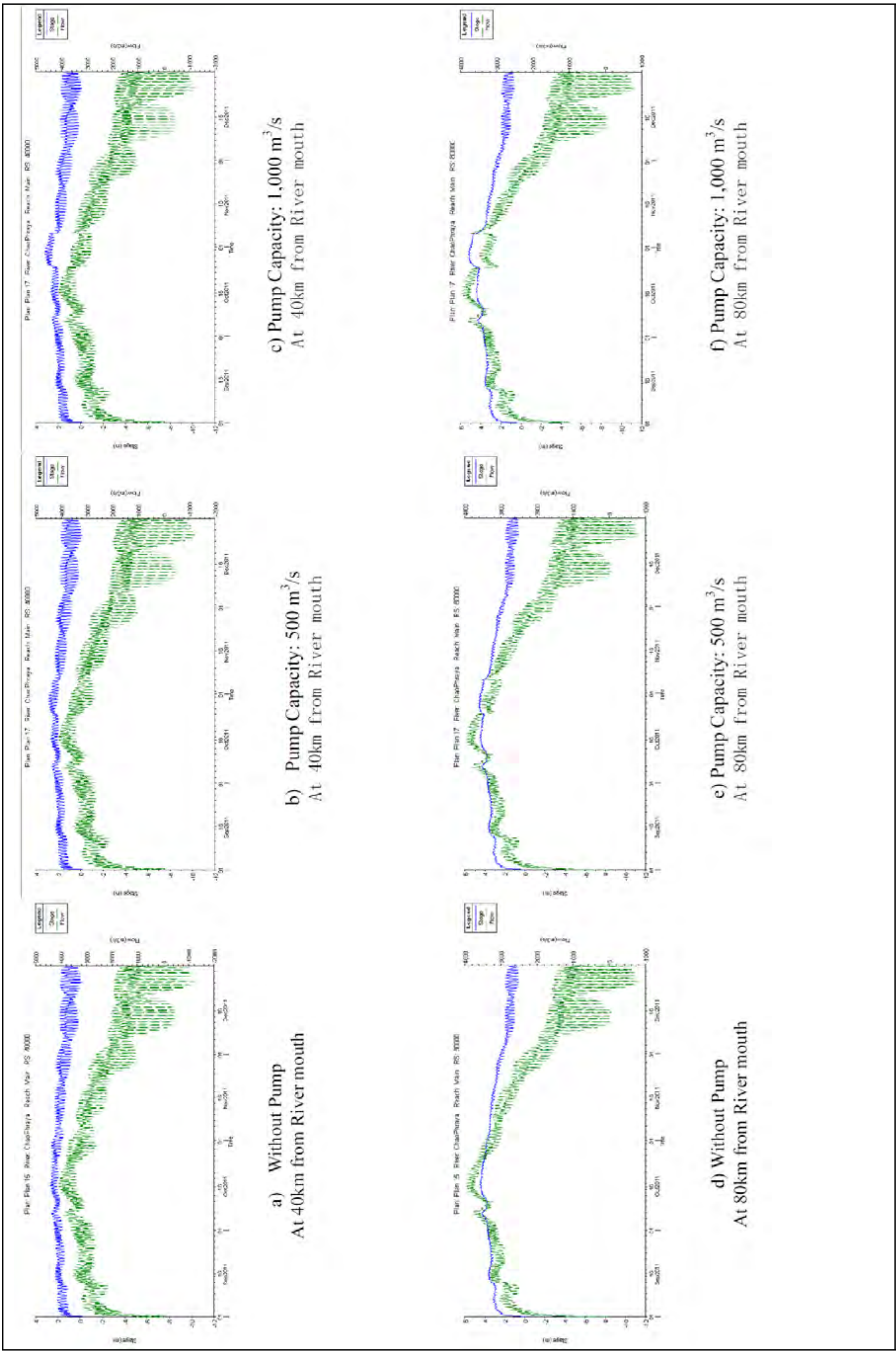


Figure 10.2.93 Hydrographs of Water Level and Discharge

10.2.13 Result of 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. billion cubic meters of floodwater.

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, because the dam 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 very effective to reduce the risk of dyke breach 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 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 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 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 10.2.94, 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.

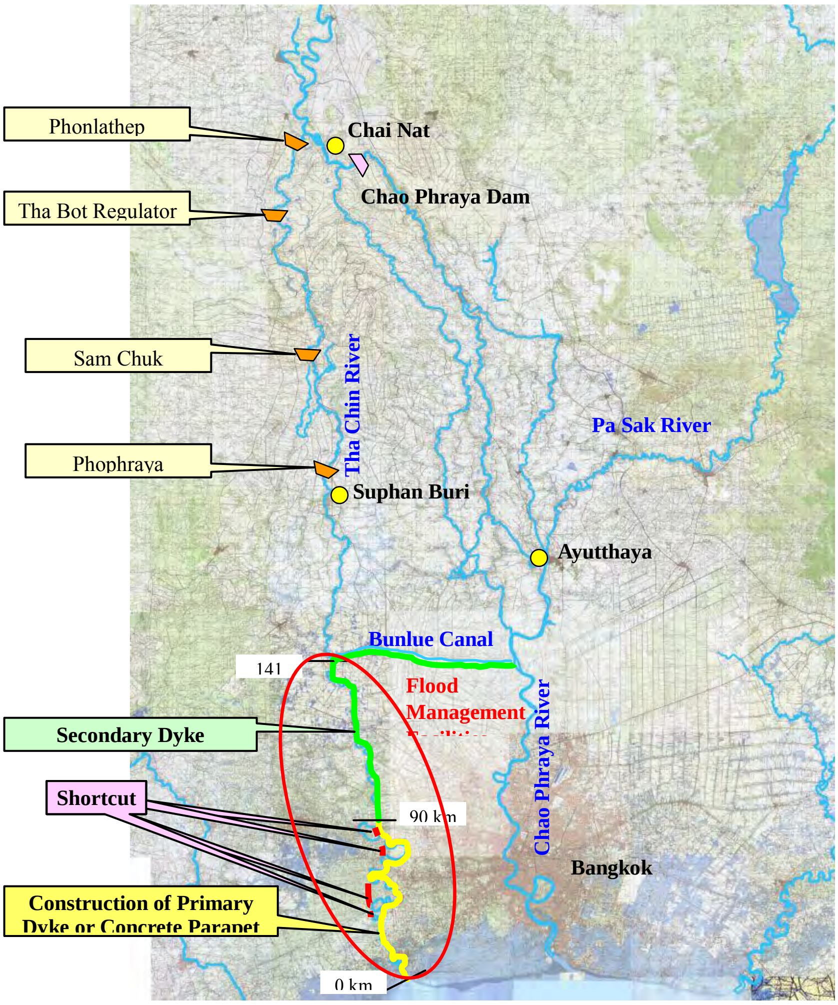


Figure 10.2.94 Location of Regulators for Irrigation on Tha Chin River

(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.