CHAPTER 3

MODEL DEVELOPMENT AND SIMULATION

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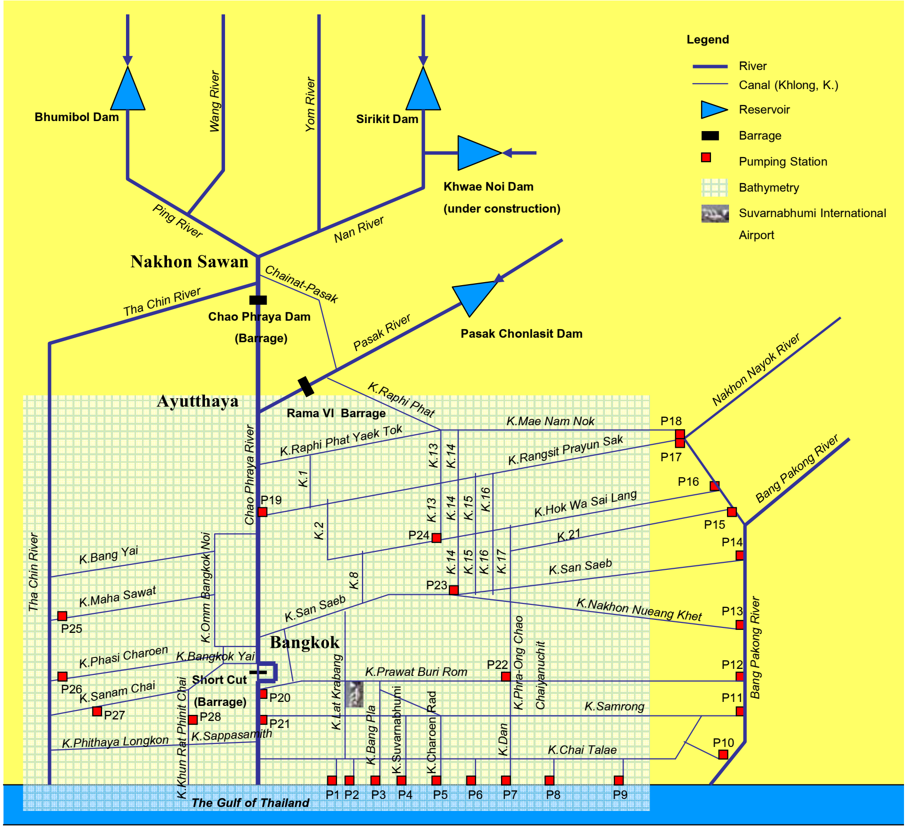
3.1 MODEL DEVELOPMENT

3.1.1 Model Setup

To set up a mathematical model for simulating the flood inundation mechanism caused by rainfall and affected by sea level rise in the delta area of the Lower Chao Phraya River Basin where the BMR is situated, it is necessary to consider the entire Chao Phraya River Basin of about 158,600 km^2 because most of the flood volume comes from the upper basin. The MIKE FLOOD (including MIKE 11 GIS) software package developed by the Danish Hydraulic Institute (DHI) was selected. The MIKE FLOOD is a unique integrated flood modeling package for rivers and flood plains (MIKE 11) and for flows, waves, estuaries, coastal areas and seas (MIKE 21). It dynamically couples well proven one-dimension (MIKE 11) and two-dimension (MIKE 21) modeling techniques into one single powerful tool. The MIKE 11 GIS is an extension for ArcView providing features for catchment/river delineation, cross-sections, and digital elevation model (DEM) data, flood visualization/animation as 2D maps, and result presentation/analysis using the Temporal Analyst.

The developed model generates runoffs from sub-basins and routes through the river/canal network and flood plain that include principal reservoirs, control structures, and pumping stations as shown in **Figure 3.1-1**. It was calibrated and verified based on the observed discharges and water levels at selected stations for the targeted flood years of 1995 and 2002. They were severe floods recorded in the recent past in the Chao Phraya River Basin and had complete observed data sets for rainfall, water level, and discharge at the selected stations. There was also a severe flood in 2006, but unfortunately the observed discharge data in Nakhon Sawan (C.2) is missing during the flooding period (Appendix K, page K-1).



Source: Panya Consultants

Figure 3.1-1 Schematic Diagram of Model Setup

3.1.2 Model Inputs

River/Canal Network and Cross-sections

The river and canal cross-sections surveyed by the Royal Irrigation Department (RID) in different years from 1983 to 2006 were used in the model. Intervals of the cross-sections range from 1 to 5 km. The flood plains outside the bathymetry area were treated as extended river cross-sections and ponds were treated as area-elevation curves obtained from the topographic map scale of 1:50,000 established by the Royal Thai Survey Department (RTSD).

Rainfall and Evaporation

The daily rainfall and pan evaporation data were monitored and gathered by the relevant agencies in Thailand. The rainfall data at 51 selected rainfall gauging stations was obtained from the Meteorological Department (TMD). The pan evaporation data at 9 selected meteorological stations was obtained from the same agency.

Water Level and Discharge

Most of the data was monitored by the RID. The daily water level data at 10 selected gauging stations on the Chao Phraya and Pasak Rivers were collected from RID. The daily discharge data at 8 selected gauging stations on the rivers were also collected from RID. The daily released discharge, water level, and calculated inflow of reservoirs at Bhumibol and Sirikit Dams operated by the Electricity Generating Authority of Thailand (EGAT) and Pasak Chonlasit Dam operated by RID were collected. In addition, hourly sea level data at the Phra Chunlachomklao Fort (Fort Chula) and the Tha Chin River mouth were collected from the Hydrographic Department and the Harbor Department respectively.

Hydraulic Structures

Flood protection dikes have been constructed mainly on the natural levees along both banks of the Chao Phraya, Tha Chin, and lower parts of the Pasak Rivers. The BMA has been constructing polder dike systems together with improvement of drainage systems including pump facilities and diversion tunnels to protect the city core and to drain local flood water along the roads during high intensity rainfall. The RID has been improving and constructing dikes, pumping stations, and diversion canals to protect the eastern and western areas of Bangkok from flooding. These existing and planned flood protection scheme data were obtained from the BMA and RID. The reservoir-capacity curves, operation rules (rule curves), and characteristics of spillways, outlets, and pumping stations were obtained from the agencies concerned (EGAT, RID, and BMA).

DEM

In this study, the Digital Elevation Model (DEM) was prepared from the data obtained from relevant agencies. Ground surface elevations in the eastern area of Bangkok were derived from the topographic maps scale of 1:4,000 surveyed by the BMA in 2006. For other areas, the spot elevations surveyed by the Department of Mineral Resources and the Royal Thai Survey Department in 2002 were used. Accuracy of the simulation depends on that of the DEM. However, the accuracy of the prepared DEM is different from area to area because a series of precise maps covering the whole inundation area is not available and several series of maps of different accuracies were used. Therefore, accurate simulation results are hardly expected for these areas.

Simulations were carried out for the entire flood season (from July to December). To generate flood hydrographs corresponding to 10, 30, and 100-year return periods of rainfall, frequency analysis of basin rainfall over the Chao Phraya River Basin was carried out. The model simulates flood flow along the river/canal network and flood plain covering the study area including Bangkok to identify the inundation area, water depth, and duration of each established scenario.

3.1.3 Model Calibration and Verification

Rainfall-Runoff Model

In this study, the Chao Phraya River Basin has been divided into 15 sub-basins based on major water control structures and the natural distribution of its river system. The NAM model of each sub-basin was calibrated by using the observed discharge from nearby gauging stations, and applying the catchment area proportion. For sub-basins with no nearby gauging station or those in the delta area, the normal parameters of the NAM model were applied. However, all parameters were adjusted again in the HD model calibration. In order to verify the land use change, the calibration was based on two periods: from April 1995 to March 1999 and from April 1999 to March 2003. These periods contain severe flood historical records (Appendix K, page K-12).

Hydrodynamic Model

The hydrodynamic model of the Chao Phraya River and its tributaries is separated into the upper and the lower basins. We applied MIKE 11 to the Upper Chao Phraya River Basin to simulate the flood hydrograph of each climate change scenario in Nakhon Sawan province. The observed water level data at Nakhon Sawan (C.2) is used as the end boundary condition of the Upper Model and the simulated result is used as the upstream boundary condition of the Lower Model. The generated discharge hydrographs from the NAM model of sub-basins are also the boundary conditions of both upper and lower models, taking into account the proportion of their catchment areas.

We used MIKE FLOOD (a coupling of MIKE 21 and MIKE 11) and MIKE 11 GIS for the Lower Chao Phraya River Basin to simulate flood inundation in the delta area of the river basin. The river/canal network in this area is so complicated that only the major components of the flood protection system are included in the model. The discharge from the drainage area of sub-polder dikes is treated to drain directly into the river or canal as it is. The end boundary conditions of MIKE 11 are the sea level at the river mouths and the pumping operations at the end of major drainage canals. The boundary conditions of MIKE 21 are the calculated discharge and water level from MIKE 11 and the sea level fluctuation at about 5 km from the shore, approximately equaling the water level at the river mouths. The calculated results at each time step are adjusted automatically to be the same values at the same locations in both MIKE 11 and MIKE 21 and then carried on in the next time step (Appendix K, page K-23).

The calibration results are generally good enough (Appendix K, page K-24). For the 1995 and 2002 floods, in particular, the hydrographs and the inundation maps show a good match with the observed ones. However, considerable gaps between the estimated and observed discharges, water levels, and inundation areas are found. These gaps might be attributed to the racking and accuracy of obtained data. In conclusion, the developed model is considered to be acceptable and applicable to the simulation study of the established scenarios.

3.2 SIMULATION

3.2.1 Return Periods

A return period, also known as a recurrence interval, is an estimate of the interval of time between events of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time or the inverse of the probability that the event will be exceeded in any one year. For example, a 10-year flood has a 1 / 10 = 0.1 or 10% chance of being exceeded in any one year. It is important to remember that a return period is an average frequency, not a schedule.

In the study, 10, 30 and 100-year return periods of rainfall are considered. A 30-year return period of rainfall is a frequency of rainfall events occurring with a magnitude similar to the flood of 1995.

3.2.2 Scenarios

In developing the scenarios, the future changes of precipitation, sea level rise, land subsidence and storm surge were determined as follows:

1) ***Precipitation:***
   (1) Based on past precipitation records; 10, 30 and 100-year return period basin precipitation as determined by the Consultant.
   (2) The future basin precipitation was determined by multiplying the precipitation by a factor provided by JBIC for climate change of A1FI and B1 scenarios.
   (3) The basin precipitation was distributed at rainfall stations according to the rainfall distribution pattern in 1995.
2) ***Land subsidence:*** The future land subsidence was analyzed using past data by the Consultant.
3) ***Sea level rise:*** The future sea level rise was provided by JBIC for climate change in A1FI and B1 scenarios.
4) ***Storm surge:*** The storm surge was based on the historical data collected and analyzed by the Consultant.

Scenarios for infrastructure were considered as follows:

1) Current condition (2008), existing and nearly completed flood protection infrastructures;
2) Future condition (2050) with land subsidence, assuming the planned flood protection infrastructures will have been implemented;
3) Future condition mentioned in 2) with climate change A1FI and B1 scenarios; and
4) Future condition mentioned in 3) with storm surge.

The combination scenarios were considered and summarized as shown in **Table 3.2-1**.

Table 3.2-1 Scenarios for Simulation Study

Description	**Flood from Precipitation at Return Period**		
	10 year	**30 year**	**100 year**
1. Current 2008	C2008-T10	C2008-T30	C2008-T100
2. Future in 2050 with land subsidence	C2050-LS-T10	C2050-LS-T30	C2050-LS-T100
3. Future in 2050 with land subsidence, sea level rise, and A1FI	C2050-LS-SR-A1F1-T10	C2050-LS-SR-A1F1-T30	C2050-LS-SR-A1F1-T100
4. Future in 2050 with land subsidence, sea level rise, and B1	C2050-LS-SR-B1-T10	C2050-LS-SR-B1-T30	C2050-LS-SR-B1-T100
5. Future in 2050 with land subsidence, sea level rise, storm surge, and A1FI	C2050-LS-SR-SS-A1F1-T10	C2050-LS-SR-SS-A1F1-T30	C2050-LS-SR-SS-A1F1-T100
6. Future in 2050 with land subsidence, sea level rise, storm surge, and B1			C2050-LS-SR-SS-B1-T100

Source: Panya Consultants

3.2.3 Flood from the Upper Chao Phraya River Basin

In the Upper Chao Phraya River Basin in its current condition and in the future, it is assumed that the Khwae Noi Dam is operated apart from the existing Bhumibol and Sirikit Dams. The Upper Model was applied to simulate the flood hydrographs in Nakhon Sawan (C.2) which were used to be the upper boundary conditions of the Lower Model. The Upper Chao Phraya River Basin will be affected by climate change only on increasing of precipitation. Sea level rise and storm surge will not be influent up to the upper basin. As a result of increasing precipitation of 3 and 2% of climate change A1FI and B1 scenarios, the flood volume of each return period is increased at about the same percentage but the increase in flood peak discharge is different due to the unequal travel times of flood hydrographs from sub-basins as shown in **Table 3.2-2**.

Table 3.2-2 Volume and Peak Discharge of Flood at C.2 and C.13 Gauging Stations

Description	1995	10-Year Return Period			30-Year Return Period			100-Year Return Period		
		T10	T10A1FI	T10B1	T30	T30A1FI	T30B1	T100	T100A1FI	T100B1
C.2 Gauging Station										
Flood Volume (MCM)	28,307	24,480	25,101	24,953	31,258	32,200	31,965	39,960	41,150	40,839
Factor Increase		1.00	1.03	1.02	1.00	1.03	1.02	1.00	1.03	1.02
Flood Peak (m^3/sec)	4,820	3,143	3,212	3,196	4,801	5,054	4,976	6,853	7,146	7,065
Factor Increase		1.00	1.02	1.02	1.00	1.05	1.04	1.00	1.04	1.03
C.13 Gauging Station										
Flood Volume (MCM)	24,744	20,320	20,795	20,695	27,756	28,485	28,235	36,997	38,378	38,019
Factor Increase		1.00	1.02	1.02	1.00	1.03	1.02	1.00	1.04	1.03
Flood Peak (m^3/sec)	4,501	2,935	3,000	2,984	4,484	4,720	4,646	6,399	6,673	6,598
Factor Increase		1.00	1.02	1.02	1.00	1.05	1.04	1.00	1.04	1.03

Remark: Flood volume is accumulated from July to December
Source: Recorded data in 1995 by RID and Panya Consultants' calculation

The runoff in Nakhon Sawan (C.2) flows to the Chao Phraya Barrage in Chai Nat province for 102 km and some of it is diverted into the Tha Chin River and Khlong Chai Nat-Pasak by the head regulators controlled by the RID. Therefore, the released discharge downstream of the Chao Phraya Barrage is controlled by the RID. The C.13 gauging station is located downstream of the barrage and the recorded runoffs are normally less than that at C.2 because of the diversion upstream, but the shape of the discharge hydrograph is close to that at C.2.

3.2.4 Flood in the Lower Chao Phraya River Basin

In the Lower Chao Phraya River Basin at current conditions, it is assumed that dikes along both banks of the Chao Phraya River, Khlong Maha Sawat and Khlong Bangkok Noi are completed and in the eastern area of Bangkok are protected by extending the flood protection system including the Suvarnabhumi drainage system. In the future, it is assumed that the diversion system that consists of the improvement of Khlong Raphi Phat, Khlong 13, 14, 17 and others, and pumping stations is completed. The Lower Model was applied to simulate the flood flow in the delta area to identify the inundation area, flood depth, and flood duration of each established scenario. The inundation area of each flood depth from the simulation results of all scenarios is shown in **Table 3.2-3**.

Current Condition (2008)

The total inundation areas of Bangkok and Samut Prakarn are 359.06, 550.37, and 736.68 km^2 for the flood at 10, 30, and 100-year return period respectively. The dike along both banks of the Chao Phraya River directly affects the water level in the river. Considering the same discharge, the water level with the dike is higher than that without. Therefore, the water level in the Chao Phraya River will be higher when a flood at a higher return period occurs. The tide from the Gulf of Thailand affects the water level in the Chao Phraya River but only in high tide periods from October to December.

Future with Land Subsidence (2050)

Land subsidence will increase the inundation area. For a flood at the 30-year return period that has the probability to occur as did the one in 1995, the total inundation area increases from 550.37 km^2 in 2008 to 568.80 km^2 in 2050 or about 3.35%.

Future with Climate Change

The increase in precipitation and sea level rise from climate change A1FI and B1 scenarios will result in increasing inundation areas. For example, for a flood at the 30-year return period, the total inundation area will increase from 550.37 km^2 in 2008 to 733.92 km^2 in 2050 or 33.35% for A1FI and to 718.53 km^2 or 30.55% for B1.

Future with Storm Surge and Climate Change

The increase in sea level from storm surge plus climate change scenarios will result in an increased inundation area. It is found that for a 30-year return period flood, the total inundation area will increase from 550.37 km^2 in 2008 to 744.34 km^2 in 2050 or 35.24% for A1FI (1.89% by storm surge).

Table 3.2-3 The Inundation Area in Different Flood Depths from Simulation Results

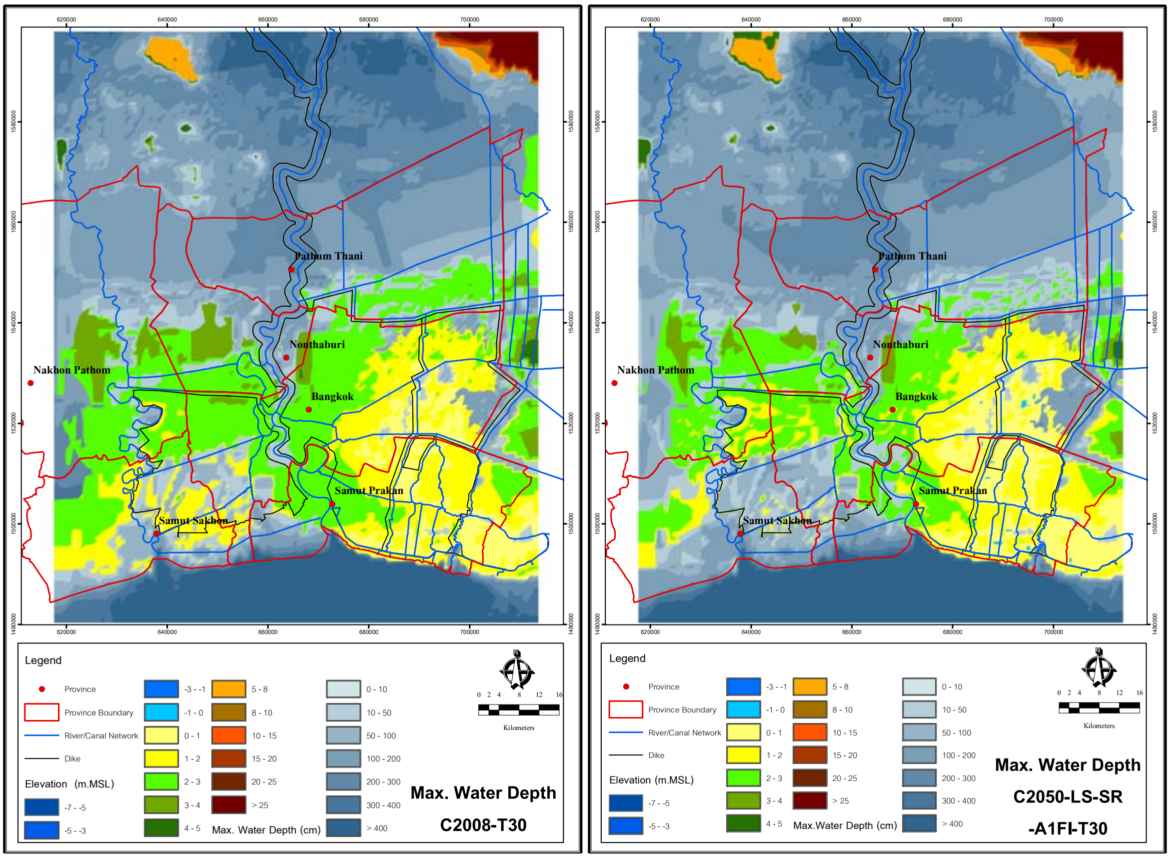
Unit: km^2

Depth of Flood (cm)	C2008-T10	C2050-LS-T10	C2050-LS-SR-B1-T10	C2050-LS-SR-A1FI-T10	C2050-LS-SR-SS-A1FI-T10	C2008-T30	C2050-LS-T30	C2050-LS-SR-B1-T30	C2050-LS-SR-A1FI-T30	C2050-LS-SR-SS-A1FI-T30	C2008-T100	C2050-LS-T100	C2050-LS-SR-B1-T100	C2050-LS-SR-SS-B1-T100	C2050-LS-SR-A1FI-T100	C2050-LS-SR-SS-A1FI-T100
Bangkok (BMA)																
0-10	1.71	2.01	1.88	1.99	1.89	1.71	1.49	2.12	2.02	2.01	3.49	2.41	2.13	2.12	2.05	1.89
10-50	123.34	136.84	151.35	158.37	161.18	180.27	176.36	176.91	170.06	163.14	166.23	157.02	164.03	161.73	156.54	154.27
50-100	55.63	89.05	116.42	128.91	133.44	121.65	154.66	181.13	191.99	201.96	203.56	211.38	225.87	229.17	236.94	240.29
100-200	7.72	13.78	17.96	22.69	21.28	66.61	47.24	137.05	138.80	137.70	147.76	226.69	239.21	238.41	251.38	249.89
>200	7.43	8.12	8.99	9.46	11.11	7.51	9.20	11.71	11.31	12.98	17.33	20.97	23.76	25.11	25.96	27.62
Sub-total	195.84	249.81	296.60	321.42	328.90	377.74	388.95	508.92	514.18	517.79	538.36	618.46	655.01	656.54	672.87	673.97
Samut Prakarn (SPK)																
0-10	0.32	0.39	1.02	1.06	1.18	0.97	0.68	1.41	1.59	1.45	1.09	1.29	1.04	1.00	1.19	1.15
10-50	31.70	30.26	35.57	41.63	40.97	34.52	32.18	53.22	56.93	54.97	52.83	61.83	75.55	74.05	81.85	78.91
50-100	40.70	37.80	35.69	36.37	34.95	43.54	38.81	40.71	42.21	44.86	46.77	42.21	41.42	43.31	44.53	50.13
100-200	46.72	47.79	54.13	56.82	50.58	48.35	54.64	58.07	59.31	54.02	53.60	58.13	64.93	59.71	66.07	60.66
>200	43.78	50.57	57.84	60.78	69.83	45.25	53.53	56.20	59.69	71.24	44.04	49.52	55.42	67.83	60.59	72.12
Sub-total	163.22	166.81	184.26	196.67	197.51	172.63	179.85	209.61	219.74	226.55	198.32	212.99	238.36	245.91	254.24	262.97
BMA&SPK																
0-10	2.04	2.40	2.90	3.06	3.07	2.68	2.17	3.53	3.61	3.45	4.57	3.70	3.17	3.13	3.24	3.05
10-50	155.04	167.10	186.92	200.00	202.15	214.79	208.54	230.13	226.99	218.11	219.06	218.85	239.58	235.78	238.39	233.18
50-100	96.34	126.85	152.12	165.28	168.38	165.19	193.47	221.84	234.21	246.83	250.33	253.59	267.30	272.49	281.47	290.42
100-200	54.43	61.57	72.09	79.51	71.86	114.96	101.88	195.13	198.11	191.72	201.35	284.82	304.13	298.12	317.46	310.56
>200	51.21	58.70	66.83	70.25	80.94	52.76	62.74	67.91	71.00	84.23	61.36	70.49	79.18	92.94	86.55	99.74
Total	359.06	416.62	480.86	518.09	526.40	550.37	568.80	718.53	733.92	744.34	736.68	831.45	893.36	902.45	927.11	936.94
Difference	-	57.56	121.80	159.03	167.34	-	18.43	168.16	183.55	193.97	-	94.77	156.68	165.76	190.42	200.26

Remark: Difference from the current condition (C2008)
Source: Panya Consultants' calculation

Figure 3.2-1 illustrates a comparison of maximum flood water depth between the current condition (C2008-T30) and the future with land subsidence, sea level rise, and a precipitation increase of 3% (C2050-LS-SR-A1FI-T30) for floods at the 30-year return period. Because of the flood protection system (polder dike and pumping system), most of the areas east of Bangkok will be protected except some areas where the crest elevations of dikes are not high enough, especially in the north and east of the area. For the western area of Bangkok, the crest elevations of dikes are not high enough to protect against flood and sea level rise, especially in the west and south of the area. In addition, the capacity of pumping stations of Phrasi Charoen, Sanam Chai, and Khun Rat Pinitchai are inadequate to pump the inside flood water out into the Tha Chin River and the Gulf of Thailand.

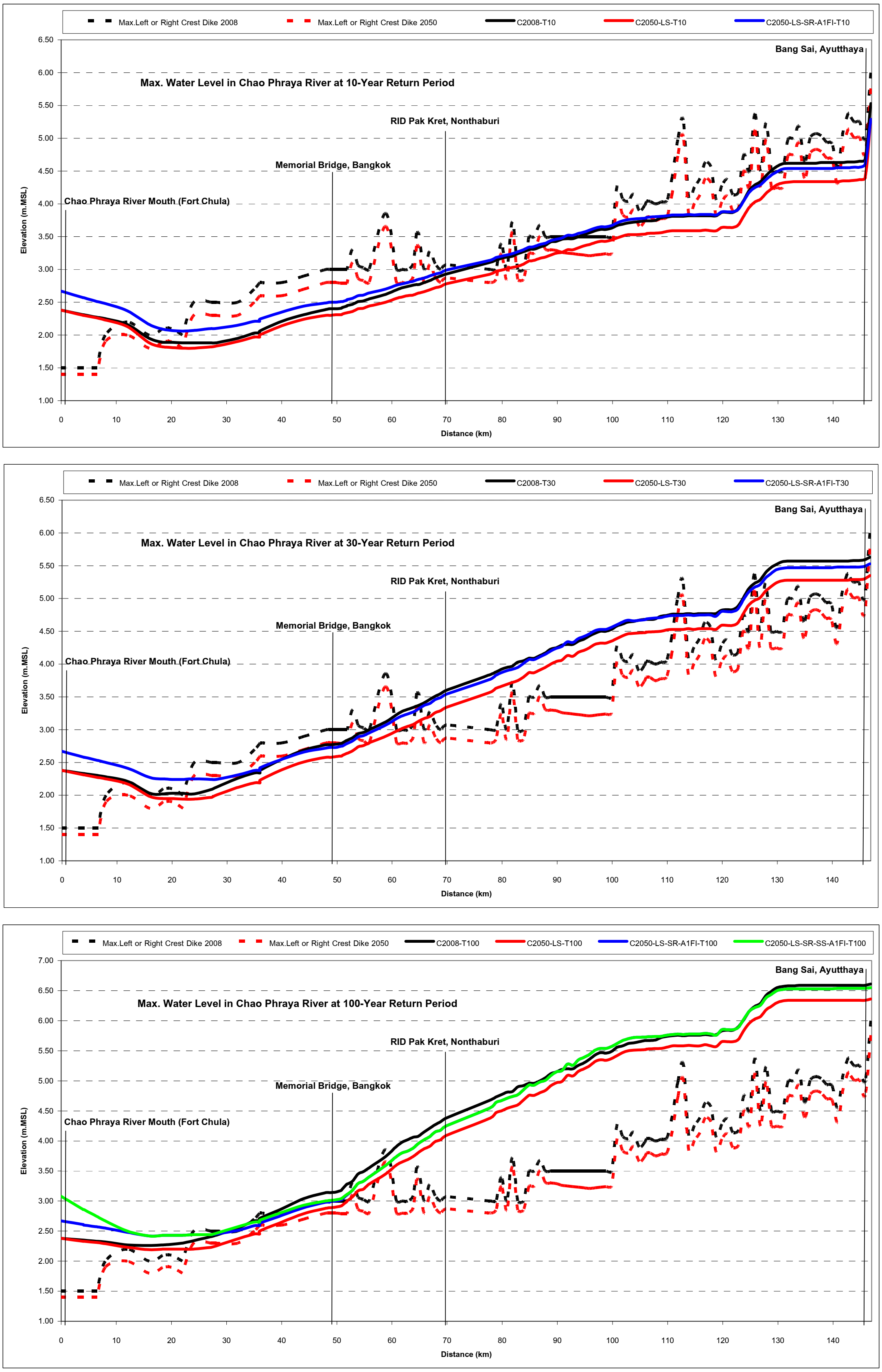
The inundation area on both banks of the Chao Phraya River will expand where the crest elevations of dikes are not high enough. However, the water level will be higher than the crest elevations of dikes along the river banks, but the duration is during the high tide period, so the flood water will not flow into the inner area of Bangkok. Furthermore, the inside drainage system can drain the overflow water into the rivers and the Gulf of Thailand, resulting in less inundation area in the east and the city core of Bangkok.



Source: Panya Consultants' calculation

Figure 3.2-1 Maximum Water Depth of Case C2008-T30 and C2050-LS-SR-A1FI-T30

Figure 3.2-2 illustrates the maximum water surface profile along the Chao Phraya River from the river mouth to Bang Sai district, Ayutthaya at 10, 30 and 100-year flood return periods. Comparing Case C2008-T100 and C2050-LS-T100, it reveals that the maximum water level will be reduced due to land subsidence of about 0.20 m, considering the sea level at the river mouth is not increased. Comparing Case C2050-LS-T100 and C2050-LS-SR-A1FI-T100, the maximum water level will be increased due to the increasing of flood water from the upper basin and the sea level rise. Comparing Case C2050-LS-SR-A1FI-T100 and C2050-LS-SR-SS-A1FI-T100, the maximum water level will be increased at the river mouth due to storm surge, but the effect will appear up to about 50 km from the river mouth.



Source: Panya Consultants' calculation

Figure 3.2-2 Maximum Water Level in the Chao Phraya River at Different Return Periods