10.3 Hydraulic Examination on Combination of Countermeasures

10.3.1 Simulation Case

To find the best combination of countermeasures and evaluate its effectiveness on flood control, flood simulation with flood analysis model explained in CHAPTER 8 shall be conducted. Simulation case is shown in Table 10.3.1.

Table 10.3.1 Flood Simulation Condition in Chao Phraya River

No.	Case	Countermeasures
1	Case 0-1: Existing Condition	- 2011 Flood without dyke breaches, - Dyke elevating around the protection area by DOH, DOR near Bangkok area.
2	Case 1-1: SCWRM M/P Full Menu	- 2011 Flood without dyke breaches, - Dyke elevating around the protection area by DOH, DOR near Bangkok area, C2: Flood control by new dams, C4: Flood control by retention ponds, C5-1: Dyke elevating up to DHWL + freeboard of 0.5m (The Chao Phraya River), C6-1: East or west diversion channels (1,500 m^3/s), C6-2: Outer ring road diversion channels (500 m^3/s), C7: Effective operation of existing dams.
3	Case 11-0: Proposed Combination 1	- 2011 Flood without dyke breaches, - Dyke elevating around the protection area by DOH, DOR near Bangkok area, C5-1: Dyke elevating up to DHWL + freeboard of 0.5m (Lower Reaches of the Chao Phraya River), C5-1: Dyke elevating up to DHWL + freeboard of 0.5m (Lower Reaches of the Tha Chin River), C5-1: 4 Shortcut channels (Lower reaches of the Tha Chin River), C5-2: Ayutthaya bypass channel (1,400m^3/s), C6-2: Outer ring road diversion channel (500 m^3/s), C7: Effective operation of existing dams.
4	Case 11-1 Proposed Combination 2	- 2011 Flood without dyke breaches, - Dyke elevating around the protection area by DOH, DOR near Bangkok area, C5-1: Dyke elevating up to DHWL + freeboard of 0.5m (Lower Reaches of the Chao Phraya River), C5-1: Dyke elevating up to DHWL + freeboard of 0.5m (Lower Reaches of the Tha Chin River), C5-1: 4 Shortcut channels (Lower reaches of the Tha Chin River), C5-2: Ayutthaya bypass channel (1,400m^3/s), C6-2: Outer ring road diversion channel (500 m^3/s), C7: Effective operation of existing dams.

10.3.2 Result

(1) Calculation Results (Case 0-1: Existing Condition)

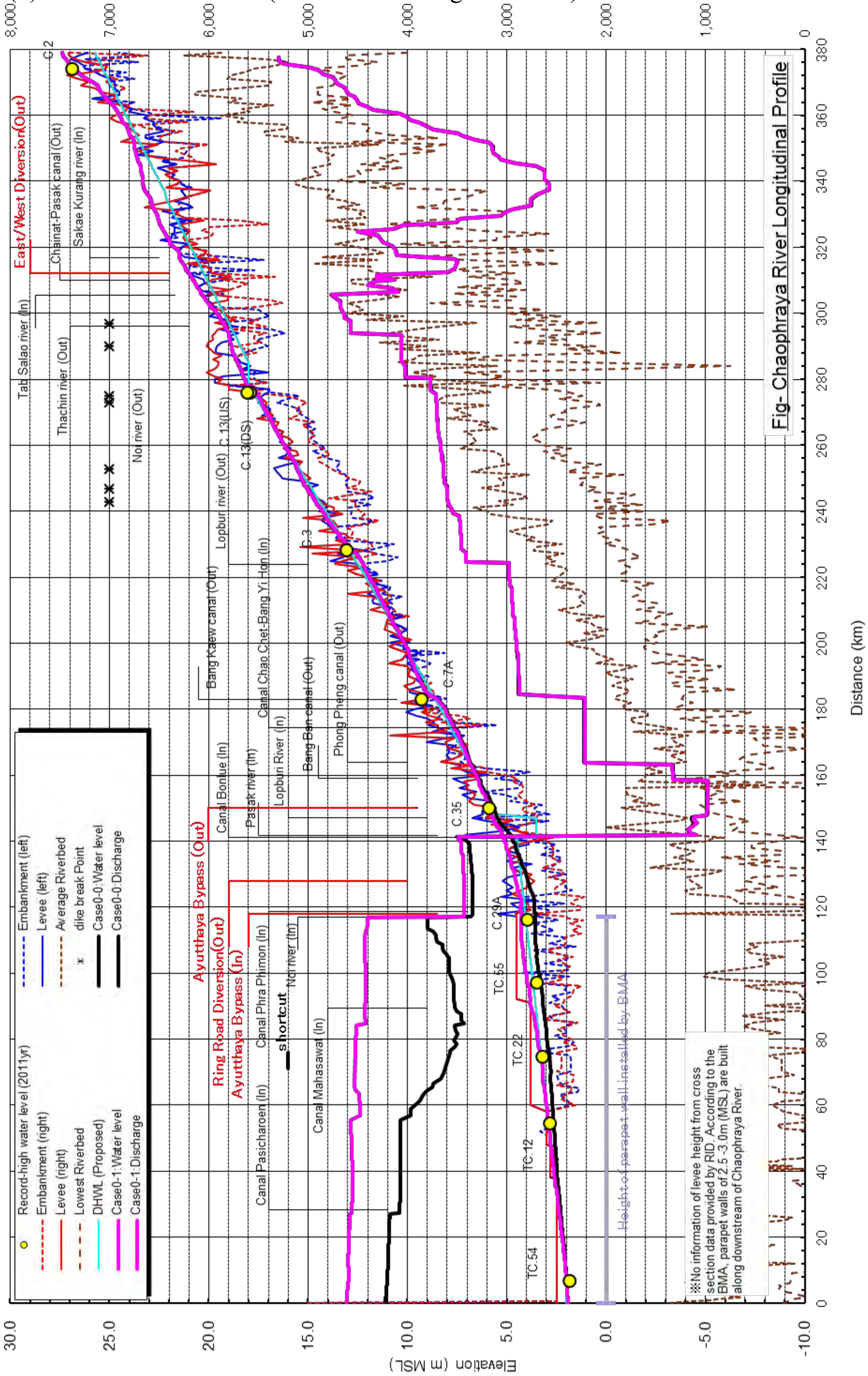


Figure 10.3.1 Longitudinal Section of Chao Phraya River (Case 0-1: Existing Condition)
(Dyke elevating around the protection area by DOH, DOR near Bangkok area)

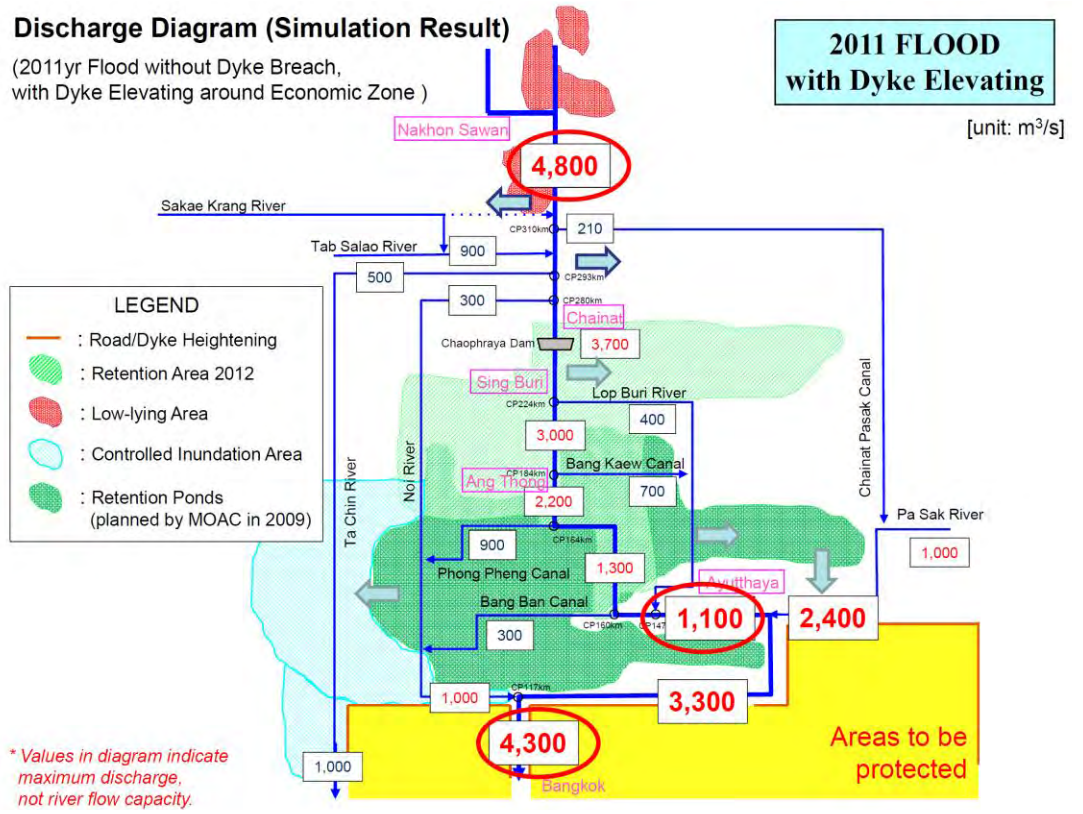


Figure 10.3.2 Maximum Flood Discharge Diagram (Case 0-1: Existing Condition)
(Dyke Elevating around the Protection Area by DOH, DOR near Bangkok Area)

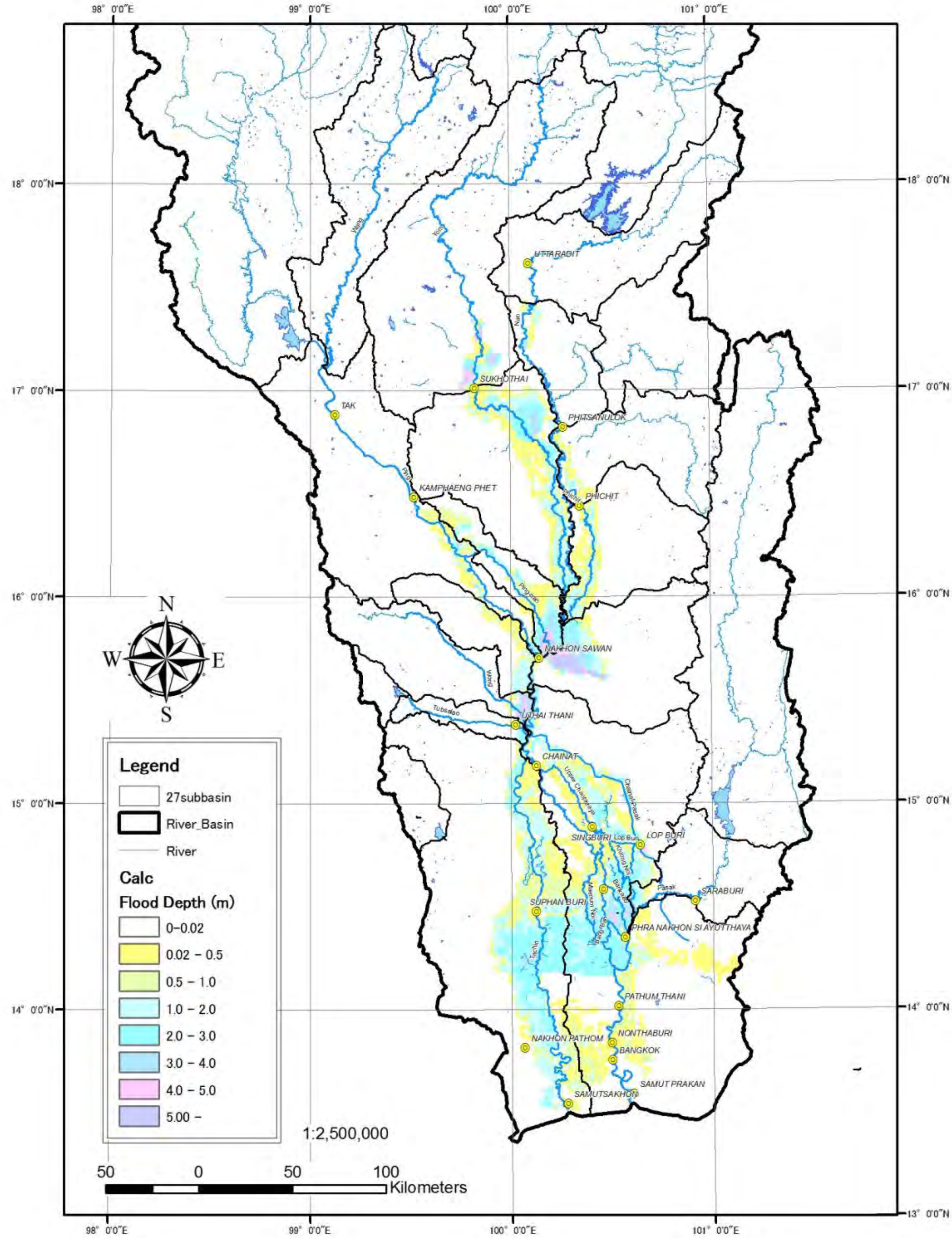


Figure 10.3.3 Flood Inundation Area and Depth (Case 0-1: Existing Condition)
(Dyke Elevating around the Protection Area by DOH, DOR near Bangkok Area)

(2) Calculation Results (Case 1-1: SCWRM M/P Full Menu)

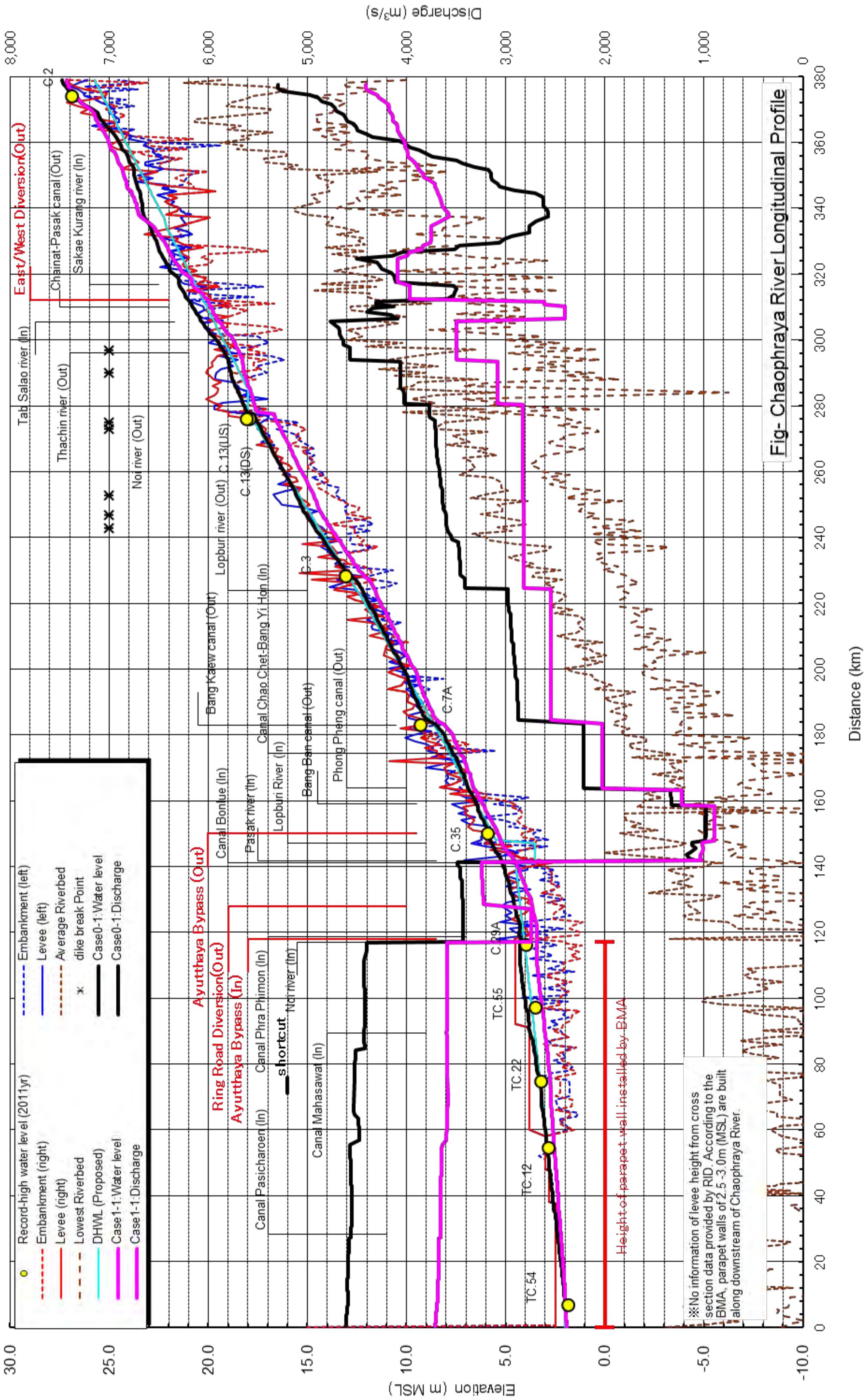


Figure 10.3.4 Longitudinal Section of Chao Phraya River (Case 1-1: SCWRM M/P Full Menu)

(C2: New Dams, C4 : Retention Ponds, C5-1: Dyke DHWL+0.5m - Chao Phraya River, C6-1: Diversion Channel 1,500 m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s, C7: Effective Dam Operation)

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

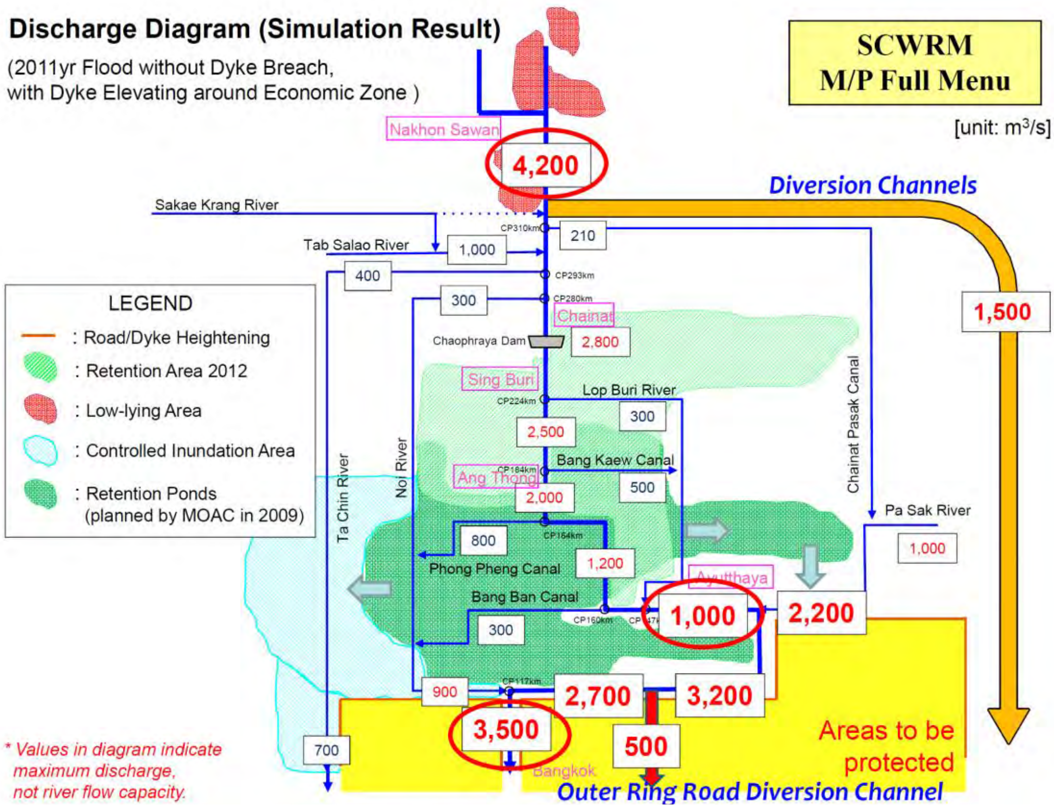


Figure 10.3.5 Maximum Flood Discharge Diagram (Case 1-1: SCWRM M/P Full Menu)

(C2: New Dams, C4 : Retention Ponds, C5-1: Dyke DHWL+0.5m - Chao Phraya River, C6-1: Diversion Channel 1,500 m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s, C7: Effective Dam Operation)

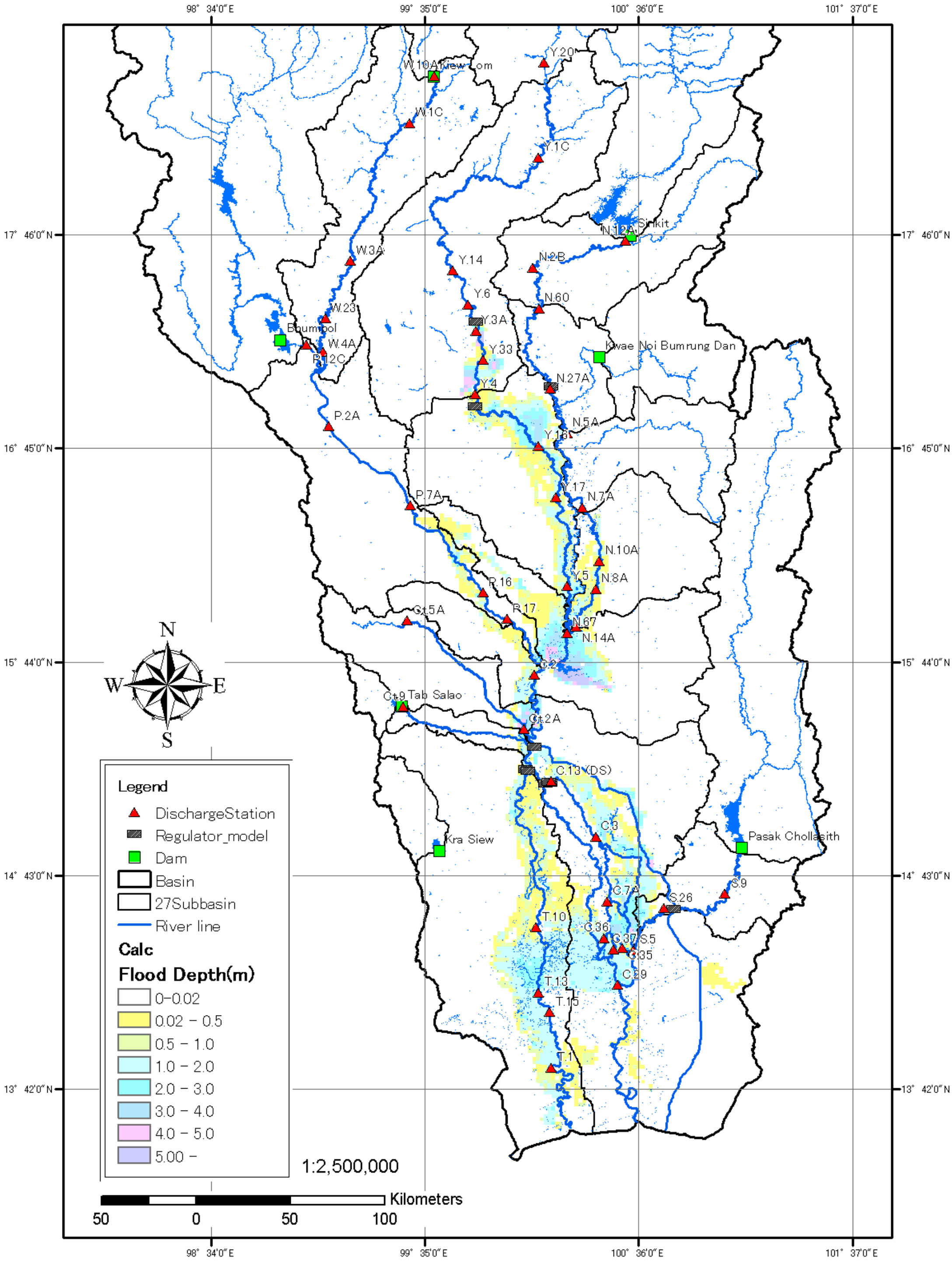


Figure 10.3.6 Flood Inundation Area and Depth (Case 1-1: SCWRM M/P Full Menu)

(C2: New Dams, C4 : Retention Ponds, C5-1: Dyke DHWL+0.5m - Chao Phraya River, C6-1: Diversion Channel 1,500 m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s, C7: Effective Dam Operation)

(3) Calculation Results (Case 11-0: Proposed Combination 1)

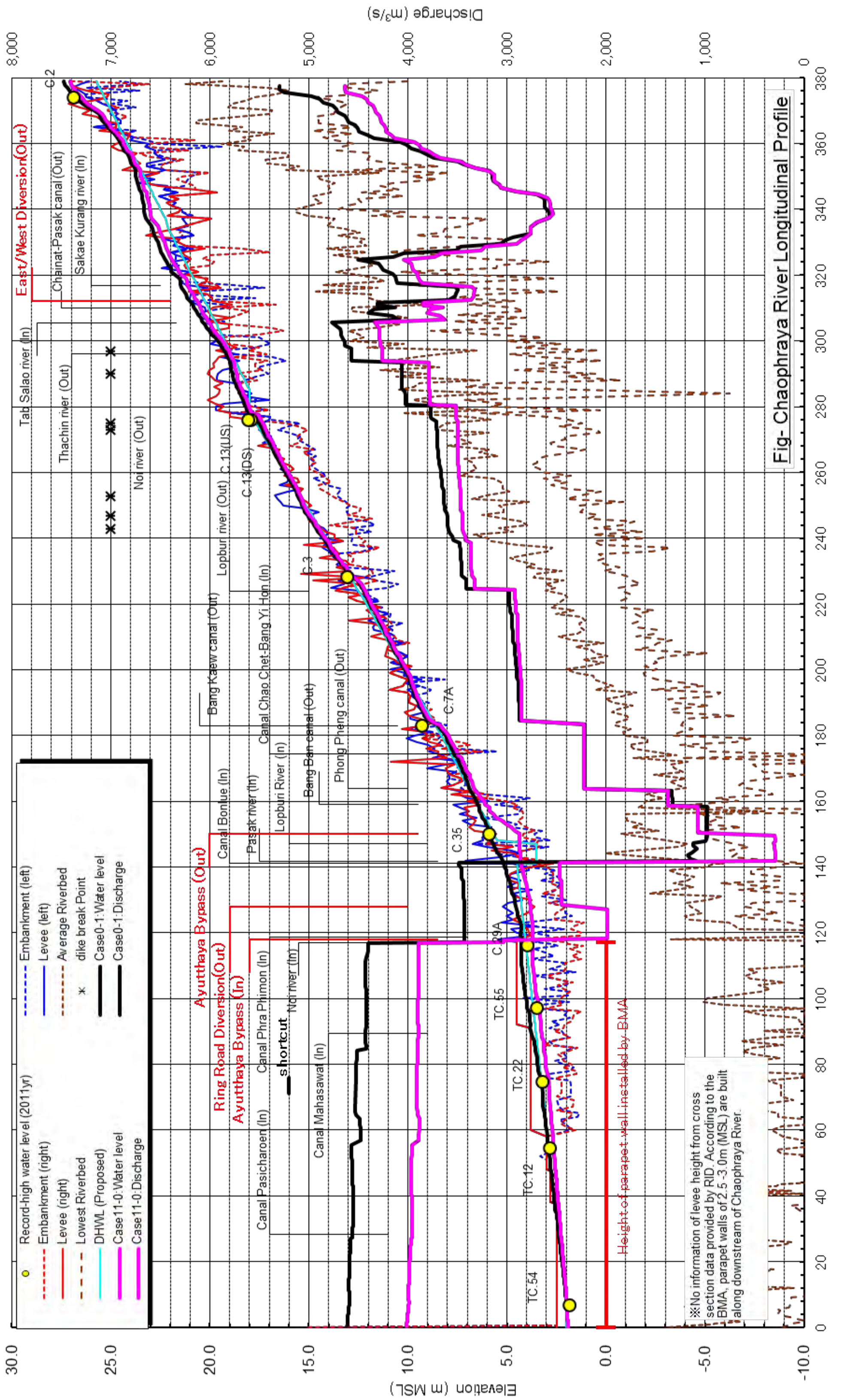


Figure 10.3.7 Longitudinal Section of Chao Phraya River (Case 11-0: Proposed Combination 1)

(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches, C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin, C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s, C7: Effective Dam Operation)

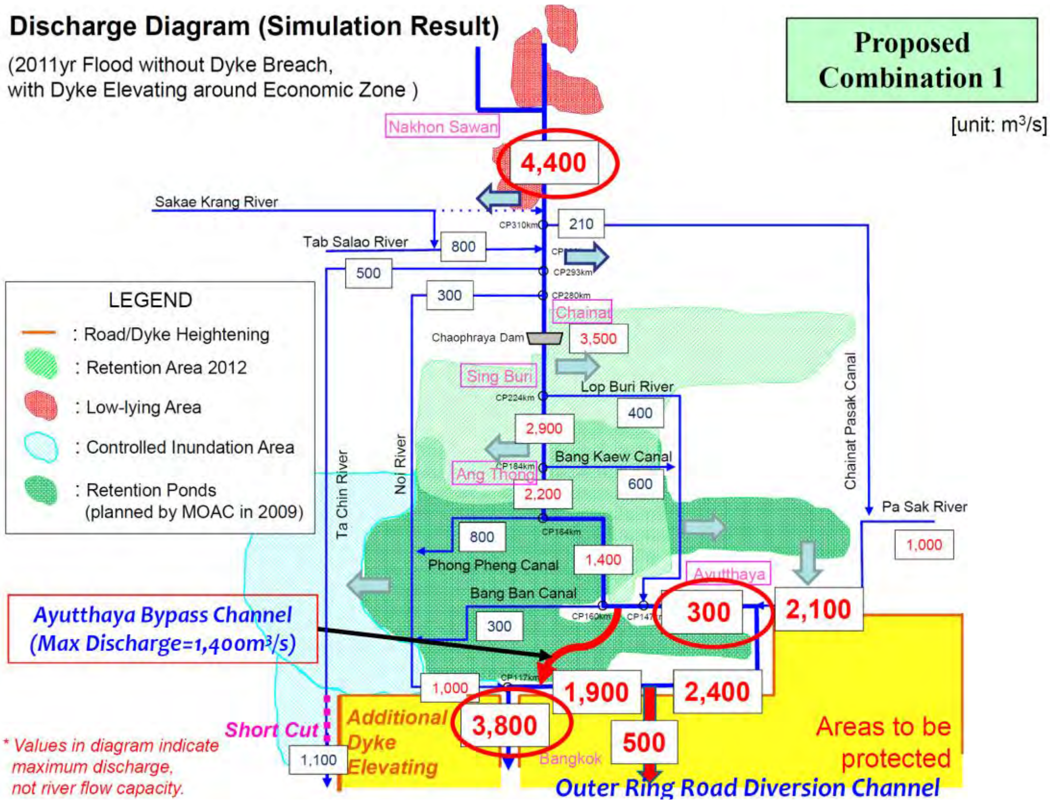


Figure 10.3.8 Maximum Flood Discharge Diagram (Case 11-0: Proposed Combination 1)

(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches,
C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin,
C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s,
C7: Effective Dam Operation)

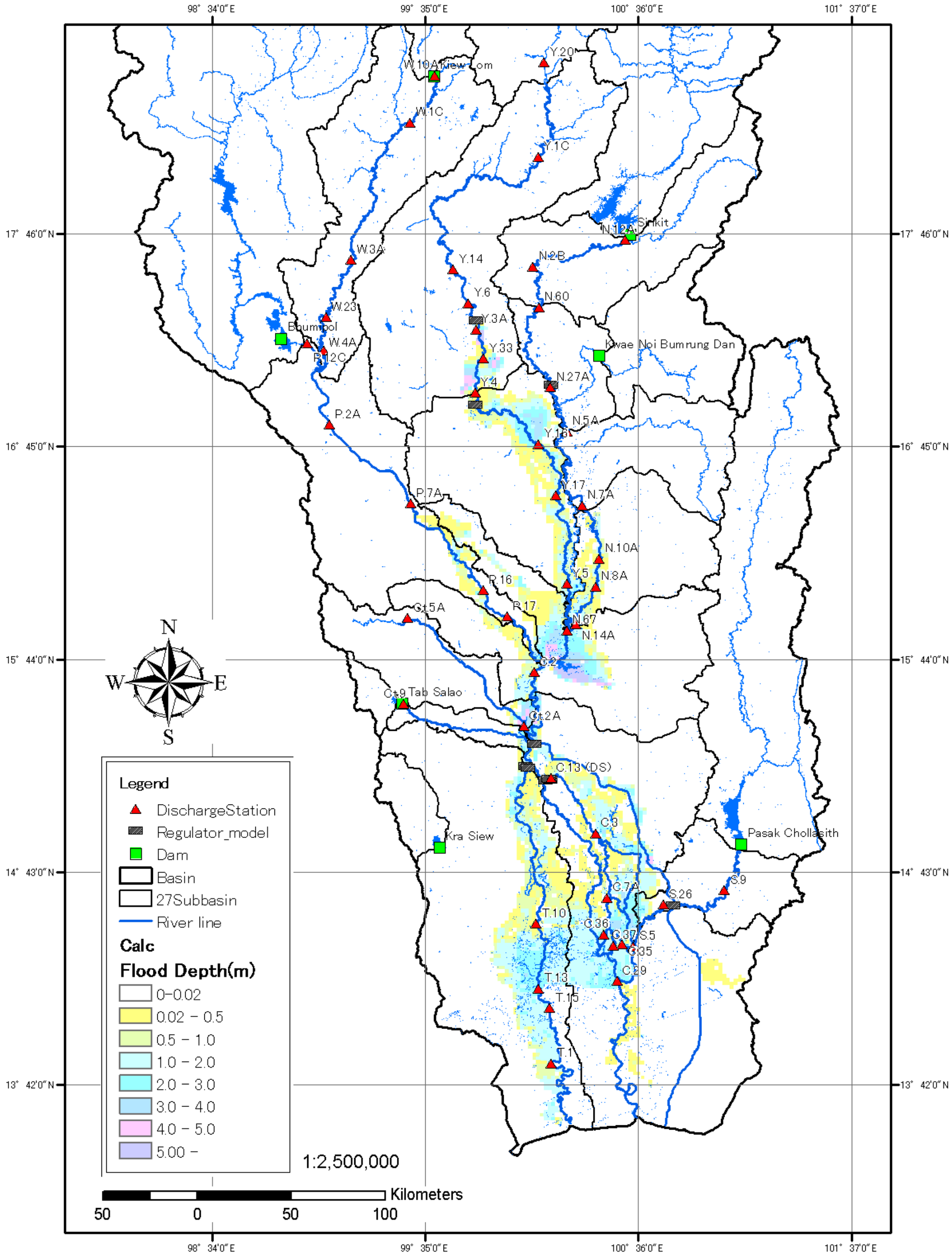


Figure 10.3.9 Flood Inundation Area and Depth (Case 11-0: Proposed Combination 1)

(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches, C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin, C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s, C7: Effective Dam Operation)

(4) Calculation Results (Case 11-1: Proposed Combination 2)

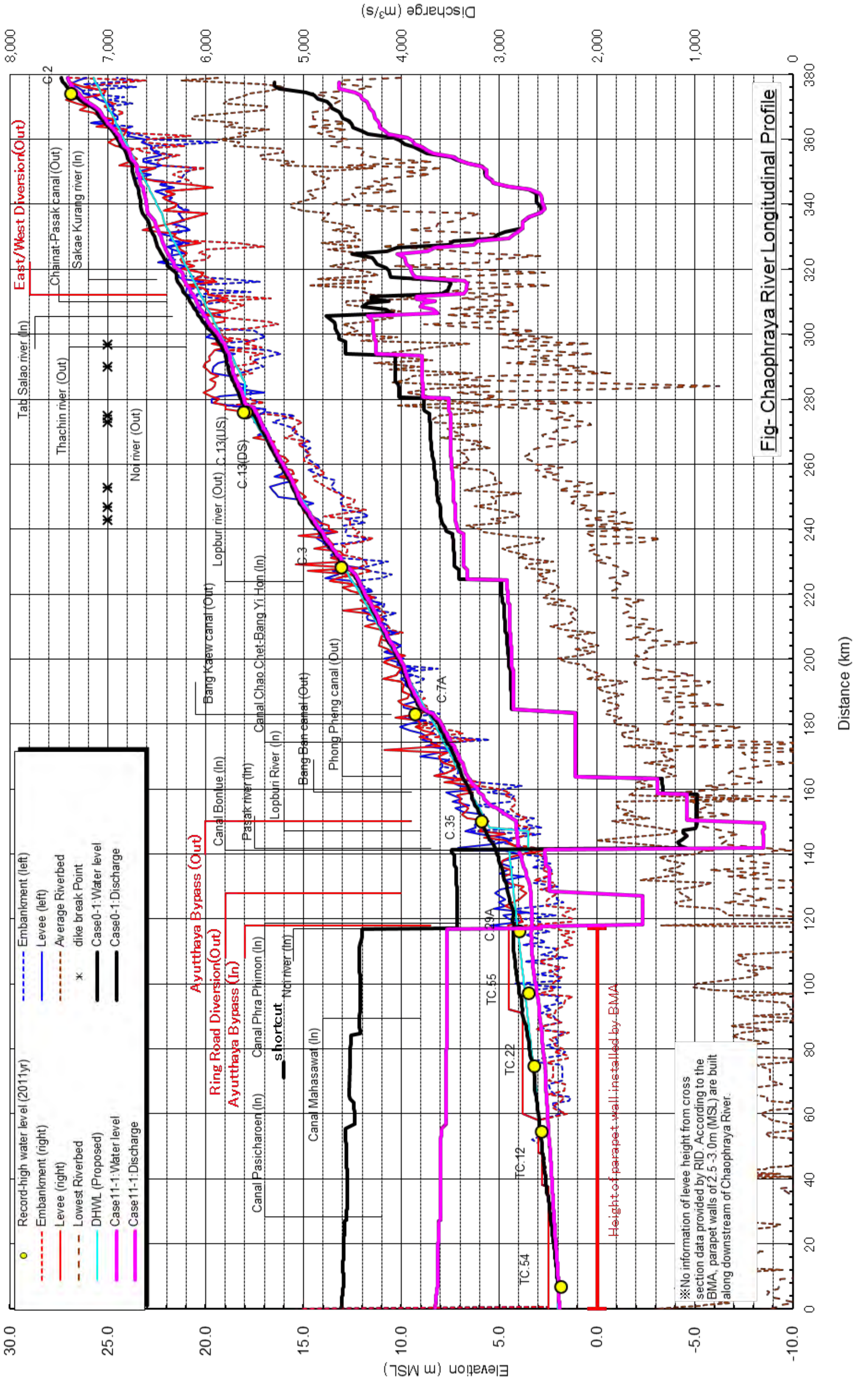


Figure 10.3.10 Longitudinal Section of Chao Phraya River(Case 11-1: Proposed Combination 2)

(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches, C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin, C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 1,000 m^3/s, C7: Effective Dam Operation)

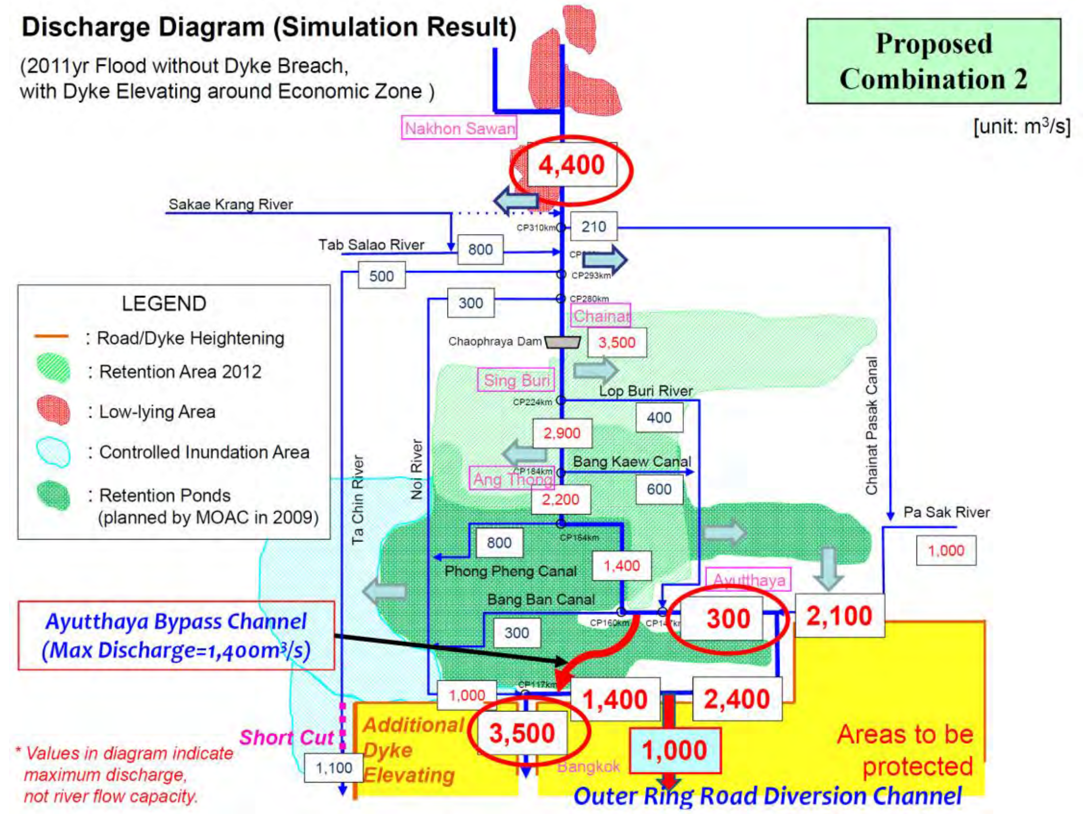


Figure 10.3.11 Maximum Flood Discharge Diagram (Case 11-1: Proposed Combination 2)

**(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches,
C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin,
C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s,
C7: Effective Dam Operation)**

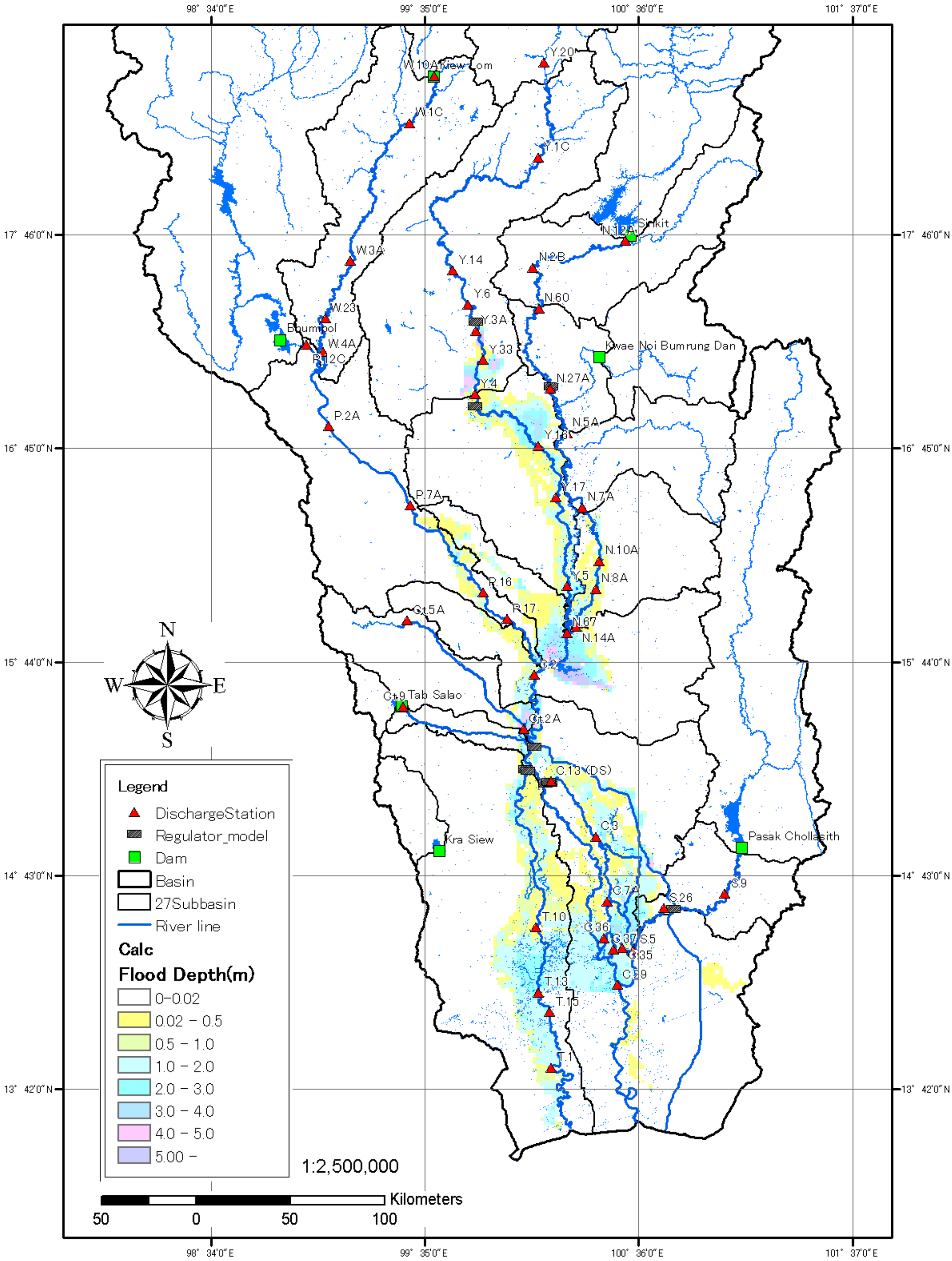


Figure 10.3.12 Flood Inundation Area and Depth (Case 11-1: Proposed Combination 2)

(C5-1: Dyke DHWL + 0.5m – Chao Phraya Lower Reaches,
C5-1: Dyke DHWL + 0.5m – Tha Chin Lower Leaches, C5-1: 4 Shortcut Channels – Tha Chin,
C5-2: Ayutthaya Bypass 1,400m^3/s, C6-2: Outer Ring Road Diversion Channel 500 m^3/s,
C7: Effective Dam Operation)

(5) Calculation Results (New TOR)

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

<u>Combination of New TOR</u>

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

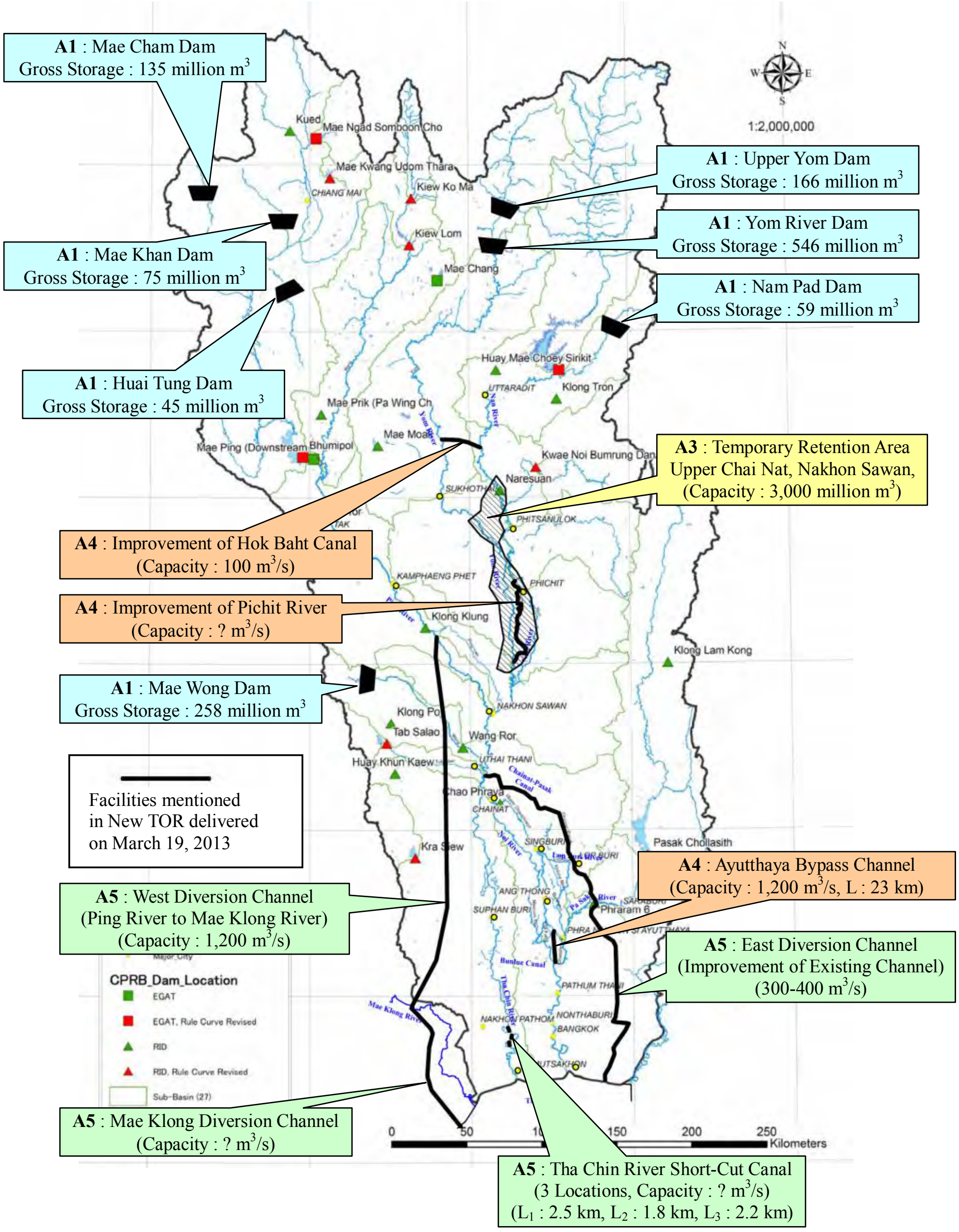


Figure 10.3.13 Combination of Structural Measures (New TOR)

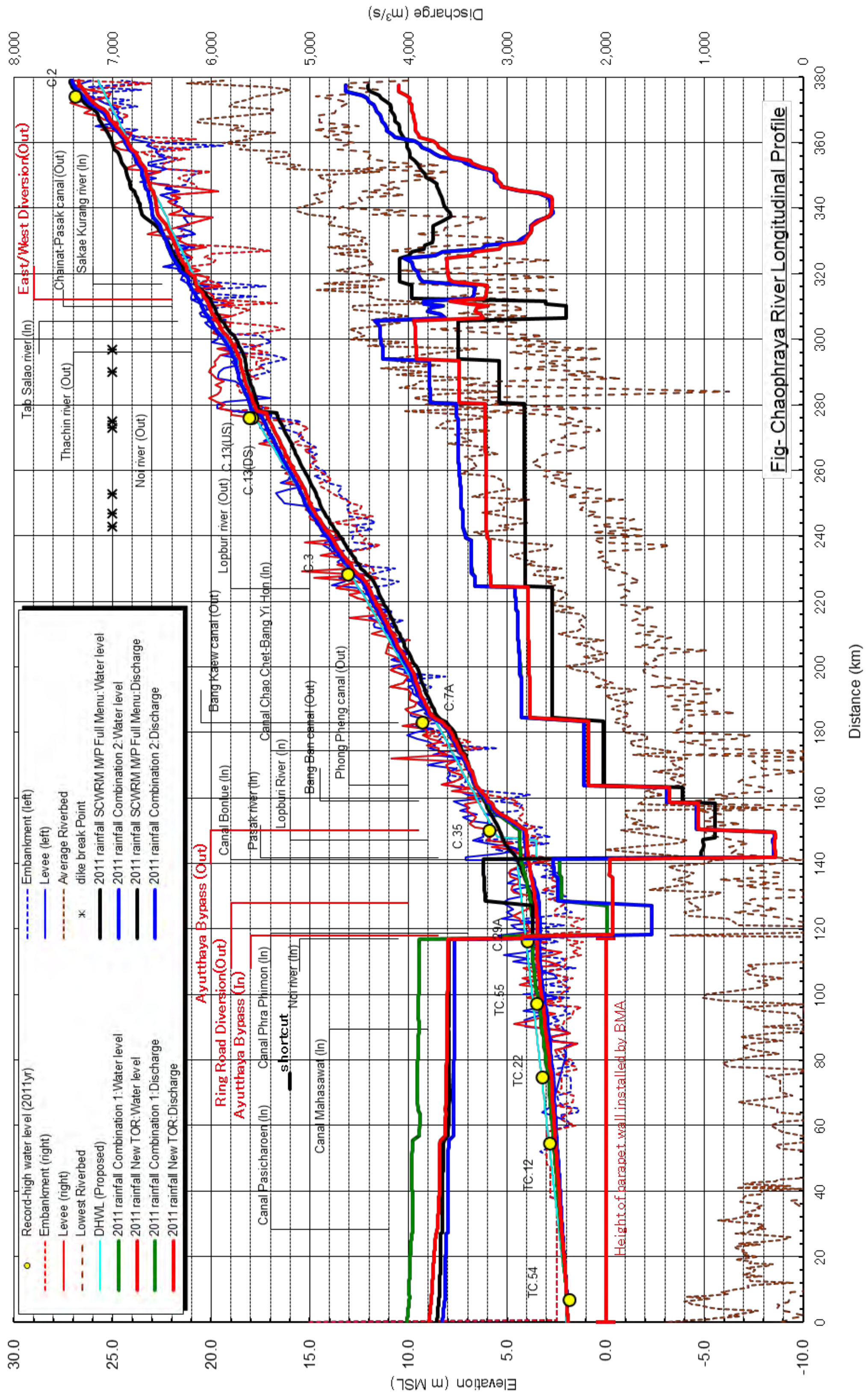


Figure 10.3.14 Longitudinal Section of Chao Phraya River(New TOR)

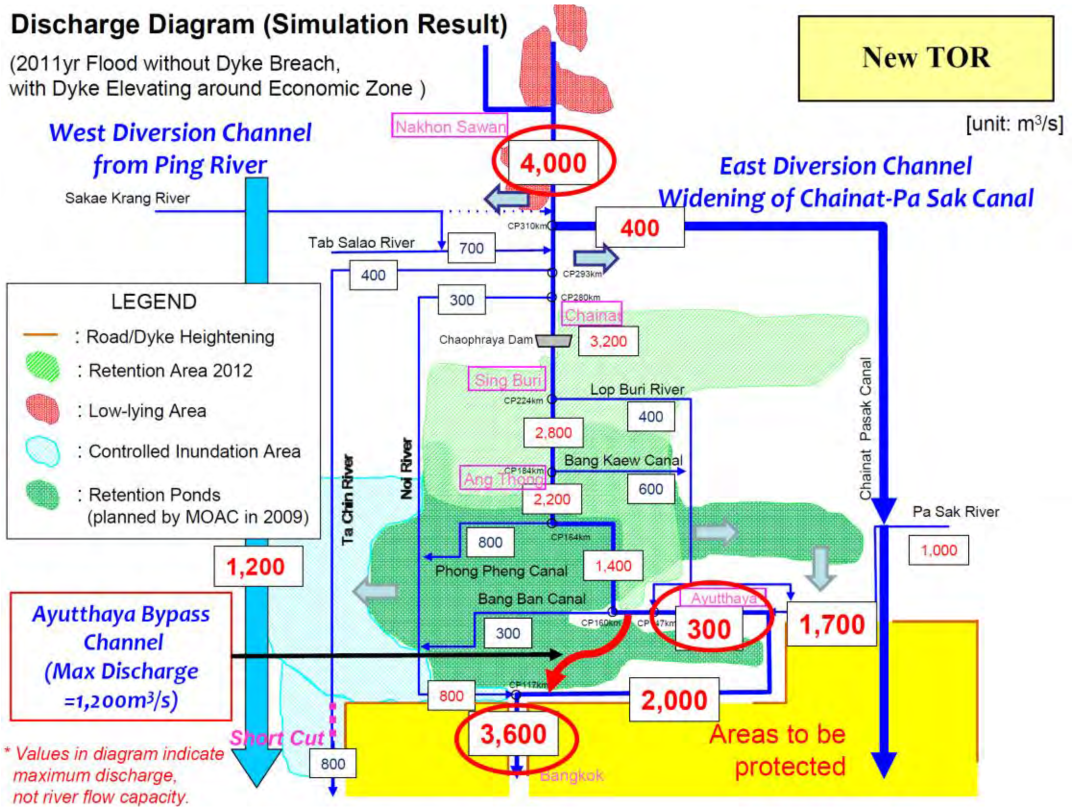


Figure 10.3.15 Maximum Flood Discharge Diagram (New TOR)

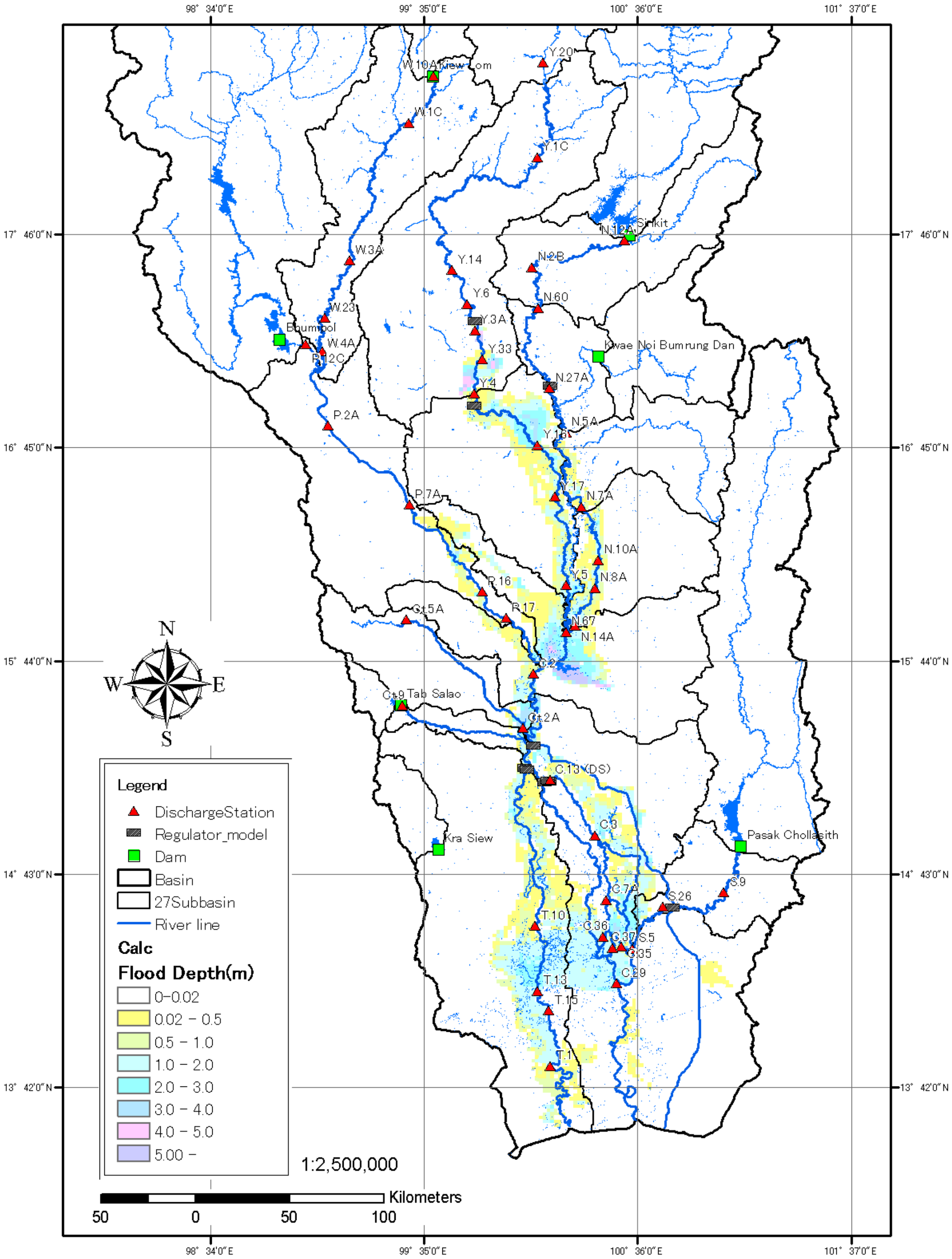


Figure 10.3.16 Flood Inundation Area and Depth (New TOR)

(6) Calculation Results (Flow Capacity)

Figure 10.3.18 shows river flow capacity considering secondary dykes (refer to Figure 10.3.17) with river improvement works under proposed Combination 1 or Combination 2.

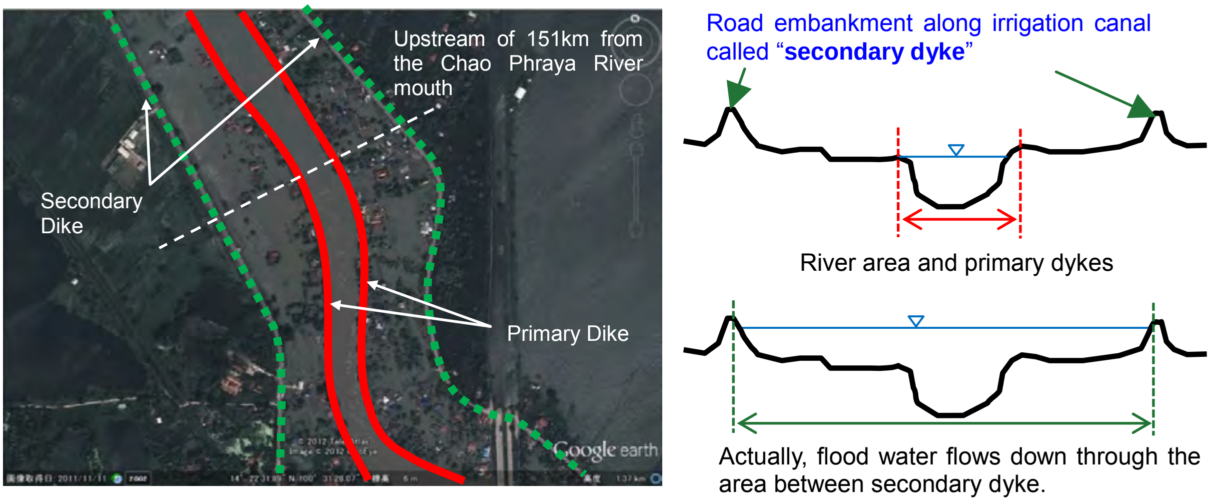


Figure 10.3.17 River Flow Section considering Secondary Dykes

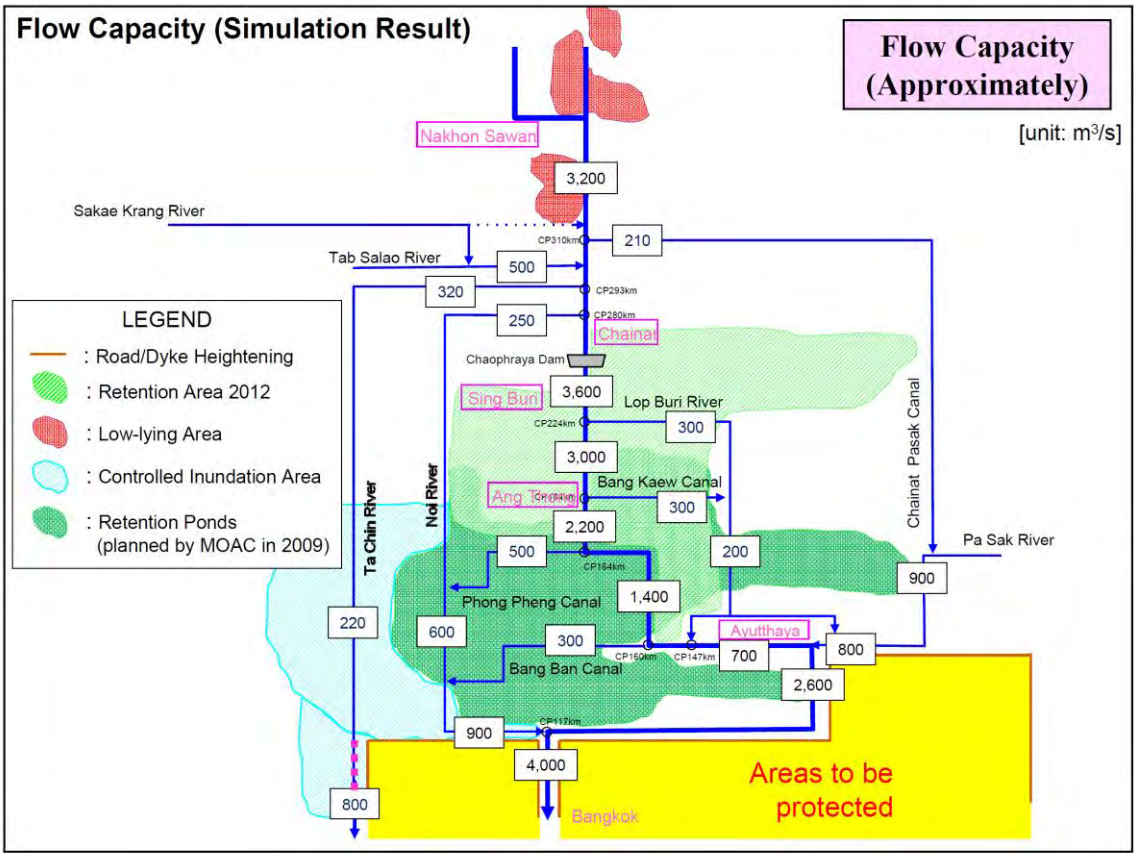


Figure 10.3.18 River Flow Capacity Diagram
(Simulation Result, with River Improvement Works under Combination 1 or 2)

10.4 Hydraulic Examination by Selected Six Types of Flood

10.4.1 Outline of the Six Representative Floods

(1) Flow of Selection of Six Representative Floods

Although the actual rainfall of the 2011 flood is set as the Target Design Force, it is also desirable to check capacities of proposed flood regulation facilities against several different rainfalls from the 2011 flood in terms of spatial and temporal rainfall distributions. An image of the determination method of target floods of design scale is illustrated in Figure 10.4.1, and its concrete determination flow is presented in Figure 10.4.2.

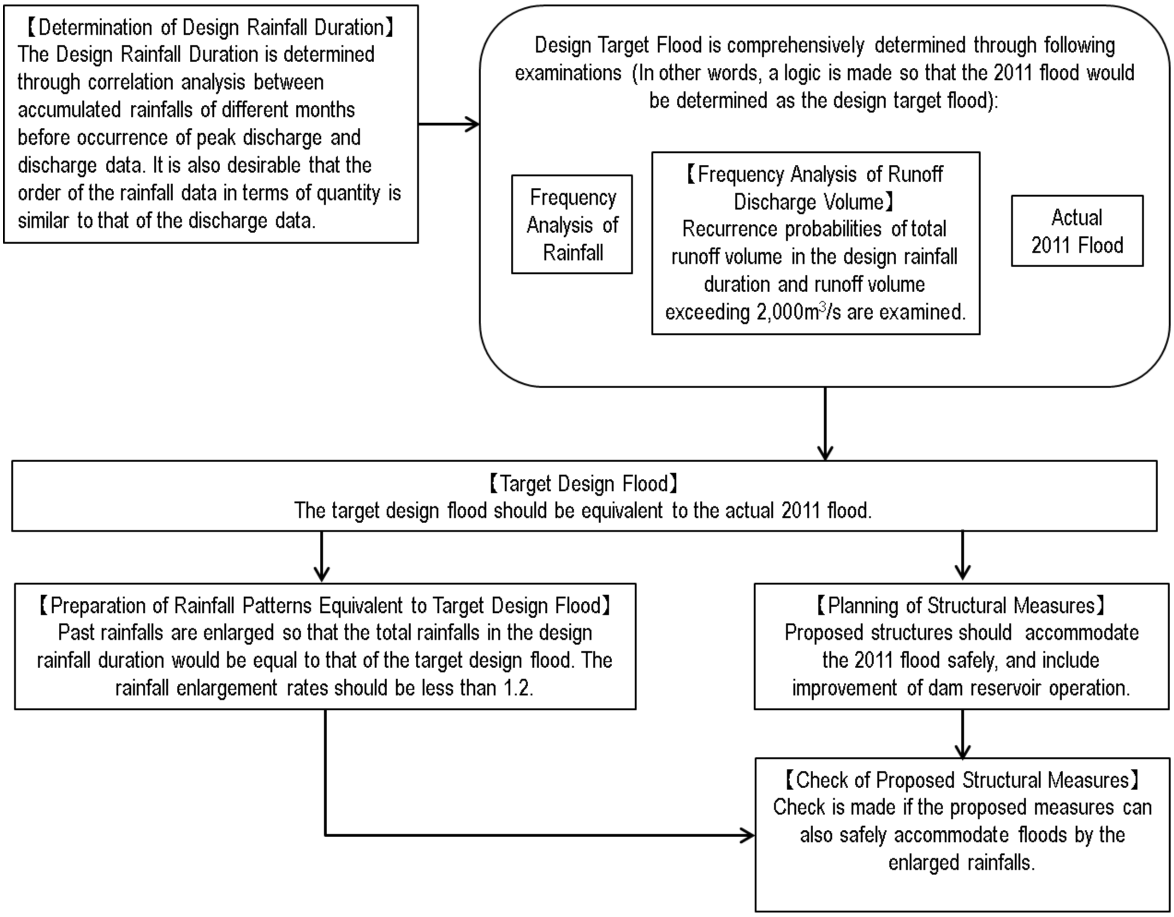


Figure 10.4.1 Image of Determination Method of Target Flood of Design Scale

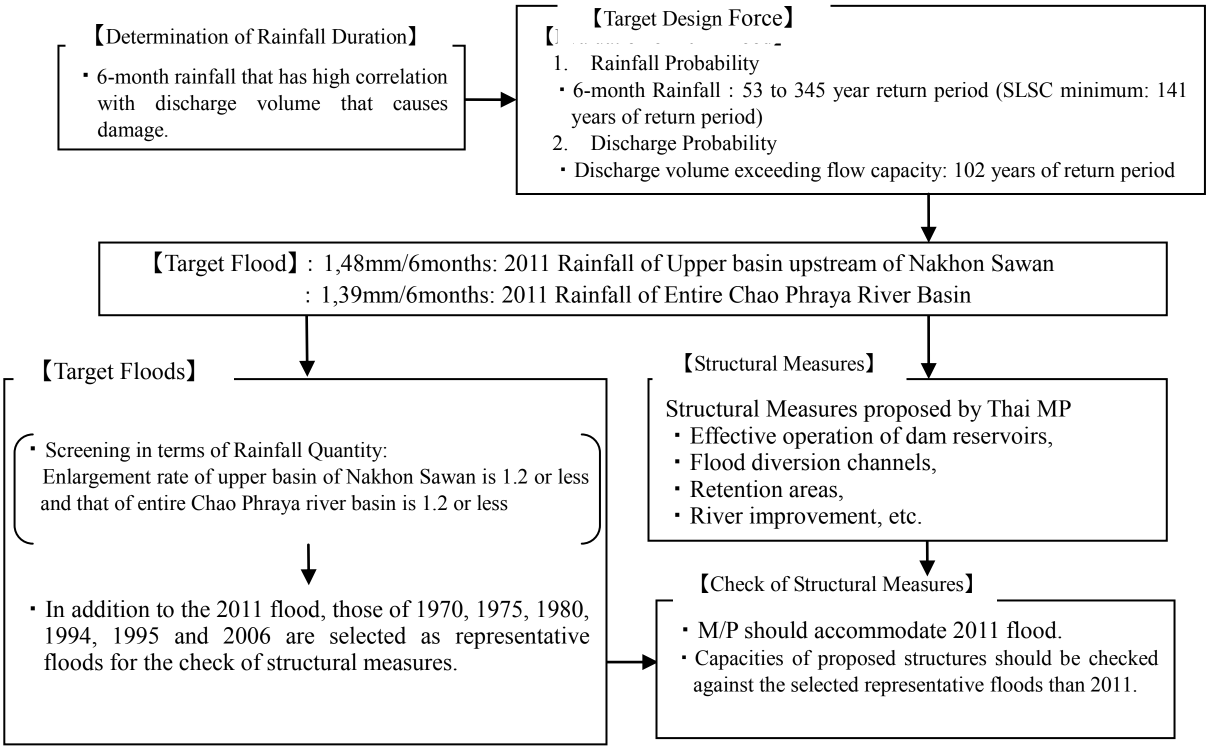


Figure 10.4.2 Concrete Flow of Determination of Target Flood of Design Scale

(2) Rainfall Enlargement Rates (Upstream of C.2 and Entire Chao Phraya River Basin)

Enlargement rates of 6-month rainfalls of 51 years from 1960 to those of the Upper Basin upstream of Nakhon Sawan (1,483mm) and the entire Chao Phraya River Basin (1,390mm) of the 2011 Flood are presented in Table 10.4.1, and summarized in the histograms of Figure 10.4.3 and Figure 10.4.4. From them, the following are considered:

- There are seven years, including 2011, of which enlargement rates of the Upper Basin upstream of Nakhon Sawan are 1.2 or less.
- As for the entire Chao Phraya River Basin there are 14 years, including 2011, of which enlargement rates are 1.2 or less. These 14 years include the seven years of the Upper Basin to 2011.
- For both of the Upper Basin and the entire Chao Phraya River Basin, the years of enlargement rates of 1.2 or less are 1970, 1975, 1980, 1994, 1995 and 2006, in addition to 2011.

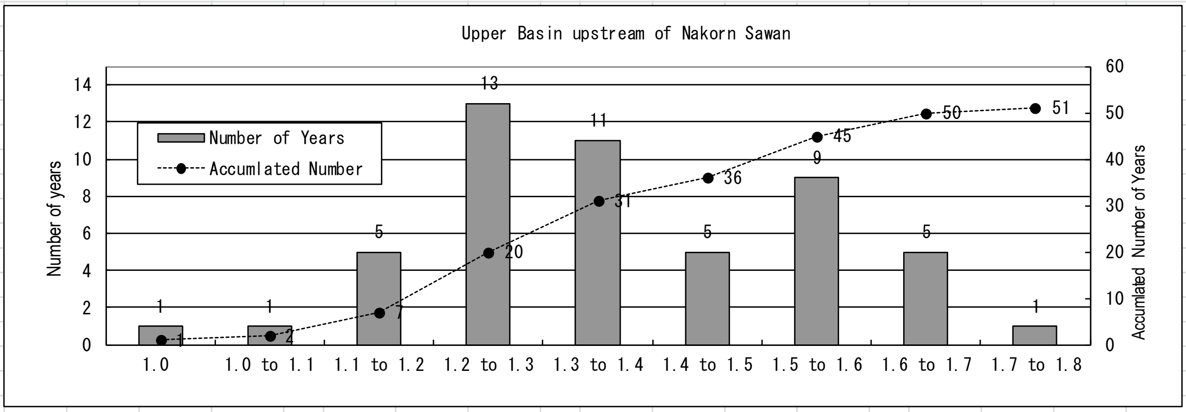


Figure 10.4.3 Histogram of Enlargement Rates (Upstream of Nakhon Sawan)

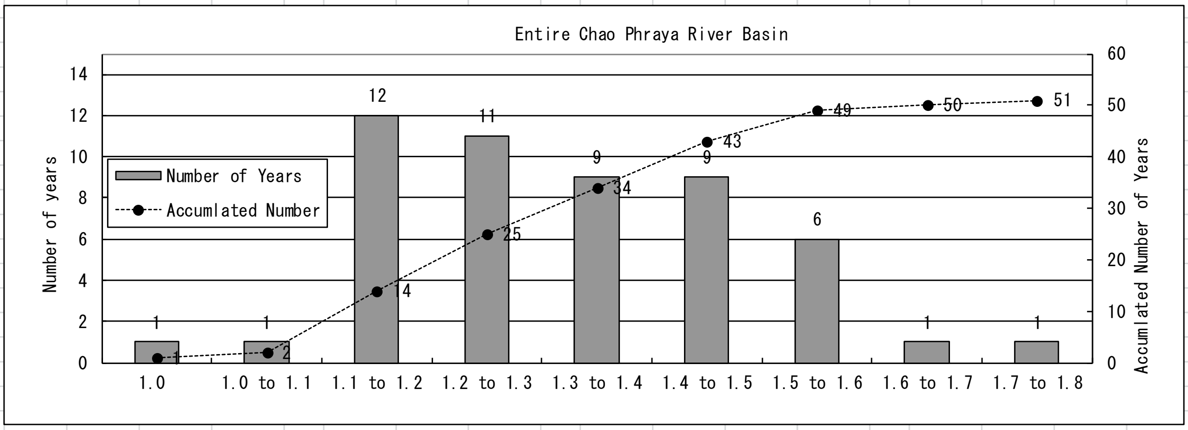


Figure 10.4.4 Histogram of Enlargement Rates (Entire Chao Phraya River Basin)

Table 10.4.1 Enlargement Rates of Rainfalls

Year	6-month rainfall of Upper Basin (1,483mm)				6-month rainfall of Entire Chao Phraya River Basin(1,390mm)				Enlargement rate		Selected as Representative Floods	Actual Discharge	Ranking	Estimated discharge without dam reservoirs			Remarks
	2011 rainfall	1,483	(mm)		2011 rainfall	1,390	(mm)		Hatching: year of 1.2 or less					Maximum Discharge	Annual Volume	Discharge Volume exceeting flow	
	Rainfall (mm)	Enlargement Rate	Judgement	ranking	Rainfall (mm)	Enlargement Rate	Judgement	ranking	UpperBasin	Entire Basin		(m³/s)		(m³/s)	(MCM)	(MCM)	
1961	1,208	1.228	> 1.2	11	1,135	1.225	> 1.2	17	1961	1961		4,712	2	4,712	33,006	6,534	
1962	1,117	1.328	> 1.2	22	1,124	1.237	> 1.2	18	1962	1962		3,812	9	3,812	24,096	2,989	
1963	1,235	1.201	> 1.2	8	1,209	1.150	○	5	1963	1963		2,935	13	2,935	23,717	339	
1964	1,163	1.275	> 1.2	19	1,186	1.172	○	7	1964	1964		3,825	8	5,170	30,419	5,367	Bhumipol Dam
1965	979	1.514	> 1.2	38	991	1.402	> 1.2	35	1965	1965		1,531	39	2,004	18,657	0	started operation
1966	1,065	1.392	> 1.2	31	1,113	1.250	> 1.2	21	1966	1966		2,930	14	3,919	24,115	1,494	in 1964.
1967	974	1.522	> 1.2	40	943	1.475	> 1.2	40	1967	1967		2,768	17	4,200	18,446	1,339	
1968	911	1.628	> 1.2	46	891	1.560	> 1.2	47	1968	1968		1,263	47	1,642	12,963	0	
1969	1,055	1.406	> 1.2	33	1,040	1.337	> 1.2	28	1969	1969		2,827	15	4,300	23,212	1,797	
1970	1,266	1.172	○	4	1,232	1.128	○	3	1970	1970	○	4,420	4	5,830	38,524	7,291	
1971	1,144	1.296	> 1.2	20	1,076	1.293	> 1.2	25	1971	1971		2,370	23	3,356	25,320	1,080	
1972	888	1.669	> 1.2	48	930	1.495	> 1.2	42	1972	1972		1,301	45	2,000	14,596	0	
1973	1,207	1.228	> 1.2	12	1,101	1.263	> 1.2	23	1973	1973		2,590	19	4,539	24,164	2,029	
1974	1,058	1.402	> 1.2	32	1,061	1.311	> 1.2	26	1974	1974		1,925	31	2,672	22,551	21	Sirikitl Dam
1975	1,254	1.183	○	7	1,166	1.193	○	13	1975	1975	○	4,336	5	5,535	40,180	10,518	started operation
1976	1,174	1.263	> 1.2	16	1,150	1.209	> 1.2	16	1976	1976		2,605	18	4,285	28,786	2,669	in 1974.
1977	948	1.564	> 1.2	42	876	1.587	> 1.2	49	1977	1977		1,967	29	3,532	18,486	1,002	
1978	1,214	1.222	> 1.2	10	1,179	1.180	○	9	1978	1978		3,540	11	4,700	34,990	5,585	
1979	949	1.563	> 1.2	41	893	1.556	> 1.2	46	1979	1979		1,390	43	1,784	13,013	0	
1980	1,255	1.181	○	6	1,207	1.152	○	6	1980	1980	○	4,320	6	5,839	35,623	7,112	
1981	1,083	1.369	> 1.2	30	1,030	1.351	> 1.2	31	1981	1981		1,663	35	3,943	27,166	490	
1982	938	1.580	> 1.2	45	915	1.519	> 1.2	45	1982	1982		1,596	37	3,362	19,236	474	
1983	1,099	1.349	> 1.2	24	1,163	1.196	○	14	1983	1983		2,290	25	3,763	25,294	1,386	
1984	1,015	1.461	> 1.2	35	960	1.448	> 1.2	38	1984	1984		1,249	48	2,442	19,200	0	
1985	1,093	1.357	> 1.2	26	1,031	1.349	> 1.2	30	1985	1985		2,137	26	3,068	26,208	561	
1986	1,001	1.481	> 1.2	36	975	1.426	> 1.2	37	1986	1986		1,456	40	2,251	16,839	0	
1987	975	1.520	> 1.2	39	929	1.497	> 1.2	43	1987	1987		1,633	36	3,109	16,605	134	
1988	1,166	1.271	> 1.2	17	1,177	1.182	○	10	1988	1988		1,907	32	3,980	23,528	632	
1989	1,024	1.448	> 1.2	34	980	1.419	> 1.2	36	1989	1989		1,447	41	2,347	15,325	0	
1990	983	1.508	> 1.2	37	995	1.397	> 1.2	34	1990	1990		1,141	49	1,688	14,909	0	
1991	906	1.637	> 1.2	47	882	1.576	> 1.2	48	1991	1991		1,427	42	2,602	15,308	9	
1992	947	1.566	> 1.2	44	954	1.458	> 1.2	39	1992	1992		1,379	44	2,343	13,691	0	
1993	842	1.761	> 1.2	51	817	1.702	> 1.2	51	1993	1993		1,066	50	1,900	8,539	0	
1994	1,313	1.130	○	3	1,168	1.191	○	12	1994	1994	○	2,533	20	4,268	33,587	4,877	
1995	1,262	1.175	○	5	1,230	1.130	○	4	1995	1995	○	4,820	1	5,612	38,741	10,144	
1996	1,166	1.272	> 1.2	18	1,116	1.246	> 1.2	20	1996	1996		3,002	12	4,109	31,211	3,008	
1997	884	1.678	> 1.2	50	838	1.659	> 1.2	50	1997	1997		1,300	46	2,550	13,625	4	
1998	884	1.678	> 1.2	49	926	1.502	> 1.2	44	1998	1998		973	51	2,297	10,027	0	
1999	1,196	1.240	> 1.2	14	1,176	1.182	○	11	1999	1999		2,317	24	3,912	30,476	1,721	
2000	1,093	1.356	> 1.2	25	1,053	1.320	> 1.2	27	2000	2000		1,928	30	3,017	27,314	293	
2001	1,185	1.252	> 1.2	15	1,092	1.274	> 1.2	24	2001	2001		2,072	27	4,215	28,587	1,170	
2002	1,201	1.234	> 1.2	13	1,110	1.253	> 1.2	22	2002	2002		3,997	7	5,547	35,129	7,199	
2003	947	1.565	> 1.2	43	938	1.482	> 1.2	41	2003	2003		1,736	34	3,403	15,513	444	
2004	1,091	1.360	> 1.2	27	1,007	1.381	> 1.2	32	2004	2004		1,575	38	3,450	20,655	758	
2005	1,085	1.366	> 1.2	29	999	1.392	> 1.2	33	2005	2005		1,818	33	3,869	22,229	2,313	
2006	1,375	1.078	○	2	1,266	1.099	○	2	2006	2006	○	3,808	10	6,385	44,332	12,244	
2007	1,214	1.221	> 1.2	9	1,154	1.205	> 1.2	15	2007	2007		2,457	22	4,032	23,304	1,180	
2008	1,114	1.331	> 1.2	23	1,122	1.240	> 1.2	19	2008	2008		2,517	21	3,728	27,243	1,200	
2009	1,090	1.360	> 1.2	28	1,031	1.348	> 1.2	29	2009	2009		2,008	28	4,559	19,077	890	
2010	1,135	1.306	> 1.2	21	1,180	1.178	○	8	2010	2010		2,815	16	5,077	26,630	3,810	
2011	1,483	1.000	○	1	1,390	1.000	○	1	2011	2011	○	4,686	3	6,857	55,570	15,154	
					Number of years of 1.2 or less (including 2011)				7	14	7						

※ The maximum discharge of the year 2006 is an estimated value based on the rating curve of the year 2011
(The raw observed data provided by RID is 5,450m³/s.)

(3) Maximum Discharge and Runoff Volumes of 6 Representative Floods

The maximum discharges at Nakhon Sawan, estimated discharges at Nakhon Sawan without dam reservoirs, total volumes of the estimated discharges at Nakhon Sawan without dam reservoirs and total volume of the estimated discharges exceeding flow capacity at Nakhon Sawan without dam reservoirs for the 51 years from 1961 to 2011 are presented in Figure 10.4.5, Figure 10.4.6, Figure 10.4.7 and Figure 10.4.8. Following are considered from the figure:

- Years of which the maximum discharges at Nakhon Sawan are large are included in the 6 representative years. This tendency is clearer in the case of the estimated discharges without dam reservoirs.
- The 6 representative years are the largest or larger in terms of total discharge volume and total volume of discharge exceeding flow capacity, too.

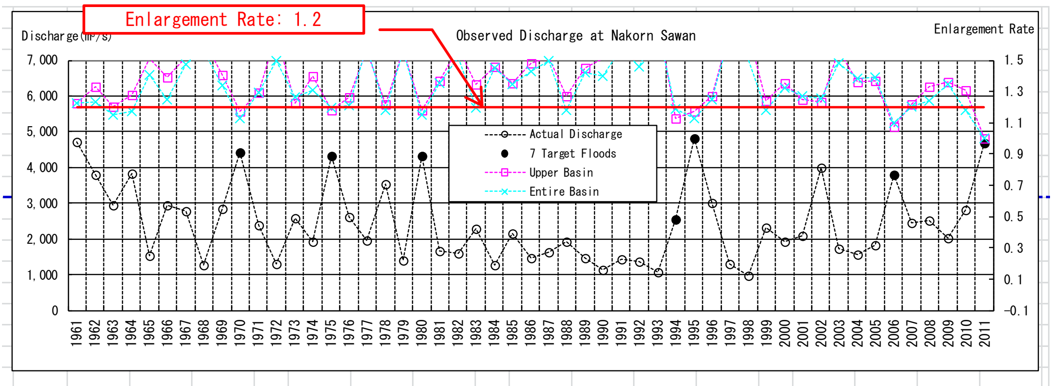


Figure 10.4.5 Observed Discharge at Nakhon Sawan

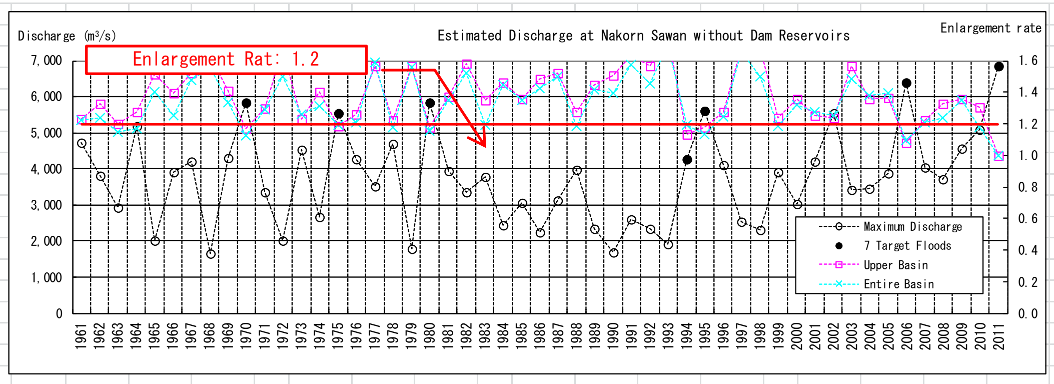


Figure 10.4.6 Estimated Discharge at Nakhon Sawan without Dam Reservoirs

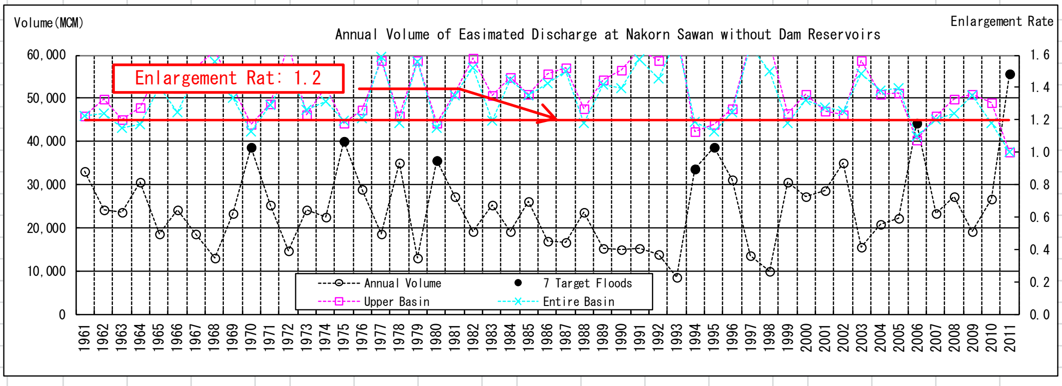
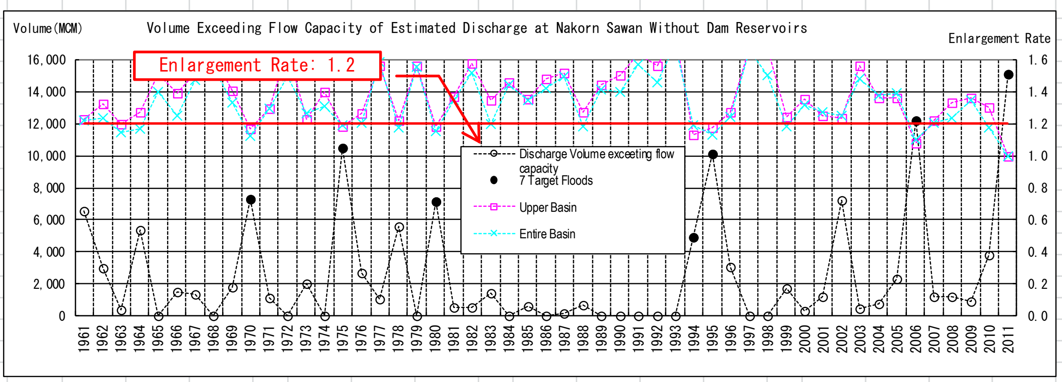


Figure 10.4.7 Estimated Annual Discharge Volume at Nakhon Sawan without Dam Reservoirs



Note: Flow capacity near Nakhon Sawan is assumed to be 2,500m^3/s.

Figure 10.4.8 Estimated Annual Discharge Volume Exceeding Flow Capacity at Nakhon Sawan without Dam Reservoirs

(4) Frequency Evaluation of the Rainfalls (6-month rainfalls) of the Representative Six Floods

Table 10.4.2 shows the results of the frequency analysis on the rainfalls of the representative 6 floods. It is outlined as follows:

- According to the results of the frequency analysis, the rainfall (1,390 mm) of the 2011 flood is analyzed as the probability of 1/90 ~1/200.
- Except the 2011 flood, the maximum rainfall was 1,266 mm in 2006, which is analyzed as a probability of 1/20. The minimum rainfall among the 6 representative floods was 1,166 mm in 1975, evaluated as a probability of 1/6.

Table 10.4.2 Evaluation of Six Representative Floods (6-month rainfall)

Year	Upper Basin upstream of Nakhon Sawan						Entire Chao Playa River Basin					
	6- month Rainfall	Range of Probability by Different Analysis methods			Adopted Method		6-month Rainfall	Range of Probability by Different Analysis Methods			Adopted Method	
	(mm)	SLSC<=0.04			Probability	Method	(mm)	SLSC<=0.04			Probability	method
2011Flood	1,483	1/53	～	1/173	1/141	LN2PM	1,390	1/90	～	1/207	1/101	LN2PM
1970Flood	1,266	1/9	～	1/9	1/9		1,232	1/11	～	1/12	1/11	
1975Flood	1,254	1/9	～	1/9	1/9		1,166	1/5	～	1/6	1/6	
1980Flood	1,255	1/8	～	1/8	1/8		1,207	1/8	～	1/8	1/8	
1994Flood	1,313	1/15	～	1/19	1/19		1,168	1/7	～	1/7	1/7	
1995Flood	1,262	1/8	～	1/9	1/9		1,230	1/10	～	1/11	1/11	
2006Flood	1,375	1/21	～	1/34	1/32		1,266	1/15	～	1/19	1/16	

※ Probability values of flood are estimated by interpolation.

※ For the method for the upper basin of Nakhon Sawan the smallest SLSC method, five methods give SLSC=0.28 (Smallest Value) and LN2PM is adopted because of its smallest Jackknife error in a narrow margin.

※ For the method for the entire river basin, the method of the smallest SLSC method showed low adaptability for the large floods like the 2011 flood, and LN2PM is adopted, because it gives SLSC value below 0.004 and shows a high adaptability for large floods.

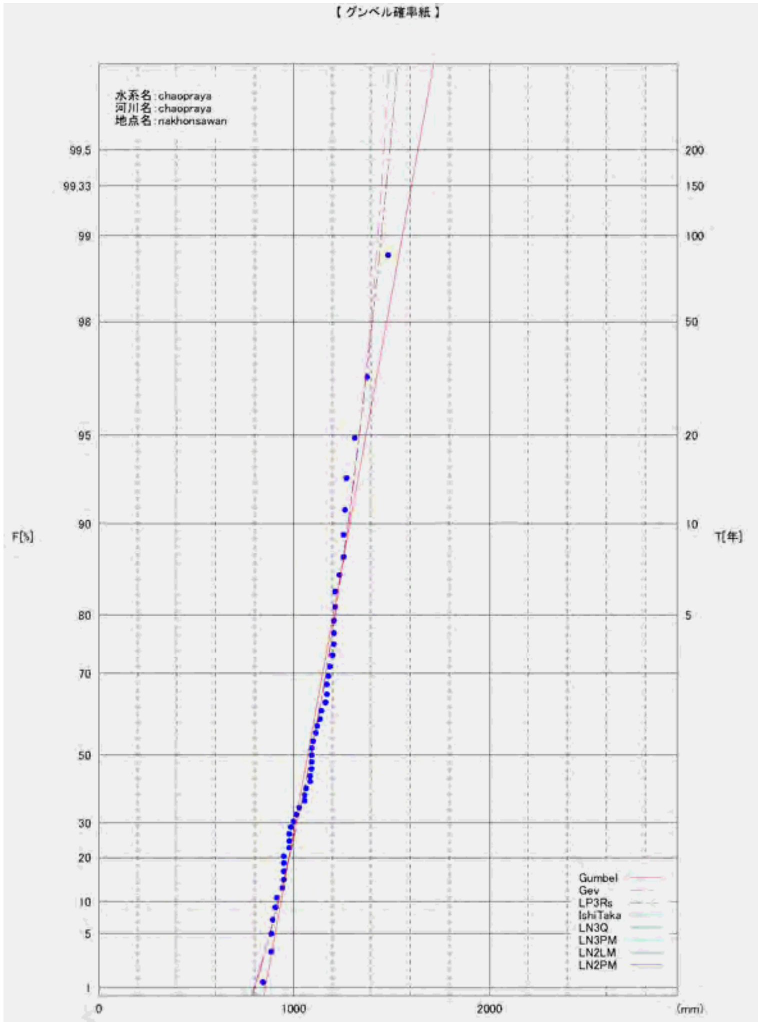


Figure 10.4.9 Probability Distribution (Gumbel Probability Paper)

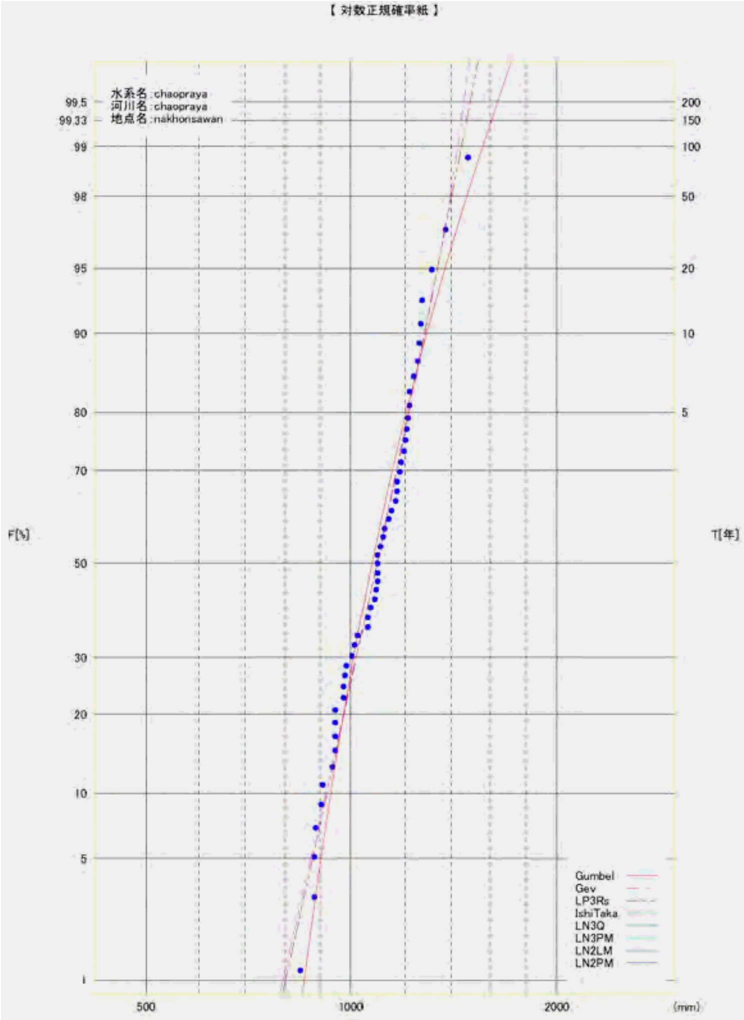


Figure 10.4.10 Probability Distribution (Lognormal Distribution Probability Paper)

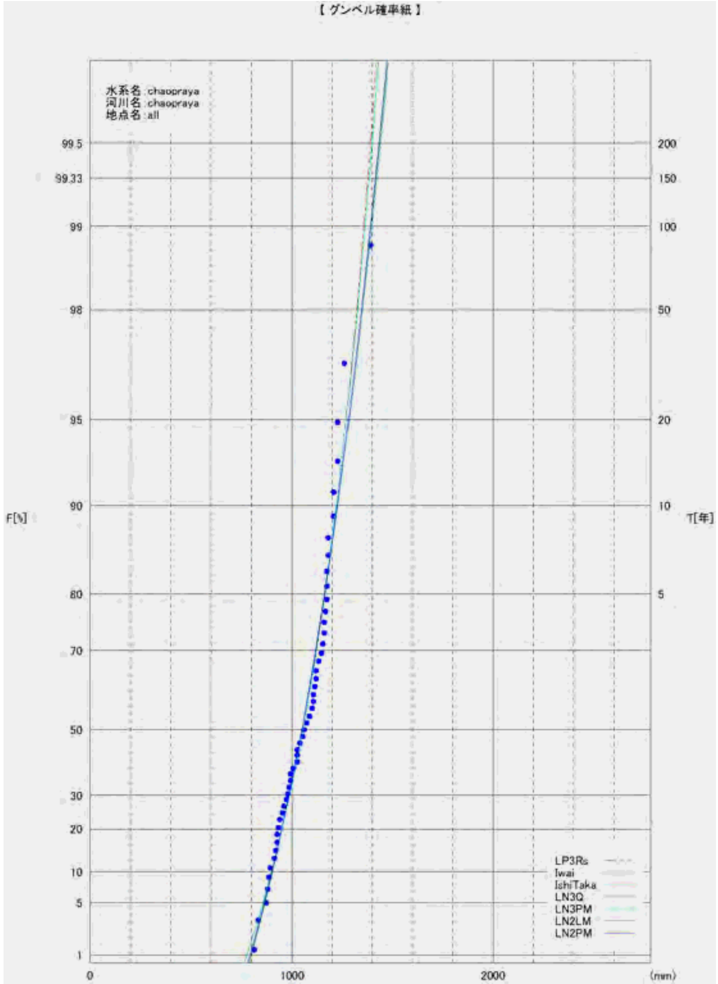


Figure 10.4.11 Probability Distribution
(Gumbel Probability Paper)

<Whole Chao Playa River Basin 6 months (183days)>

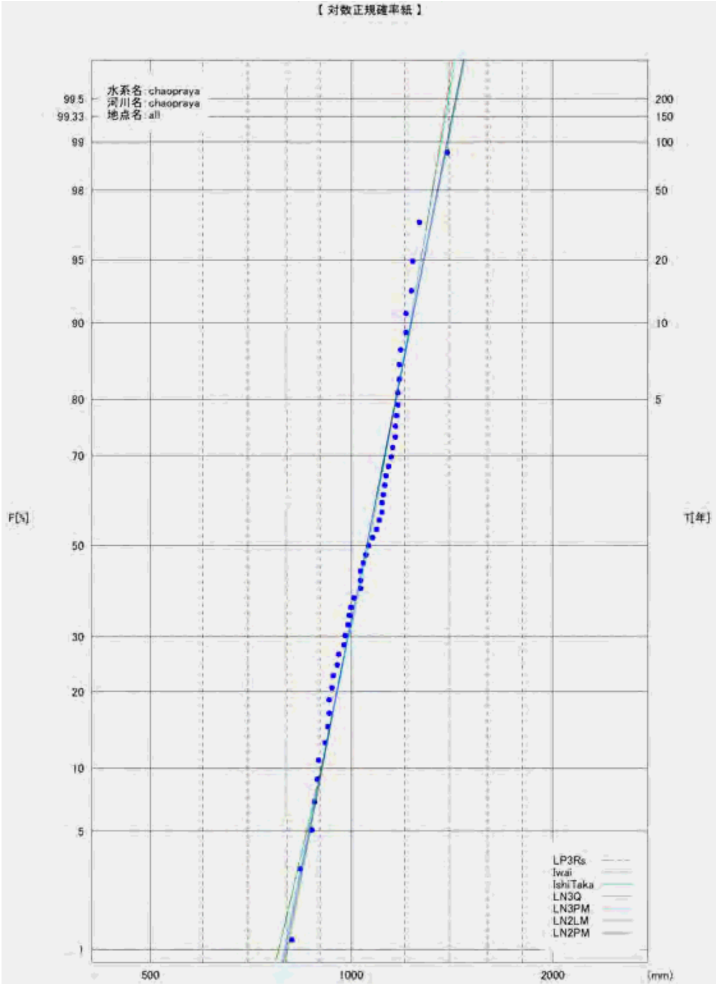


Figure 10.4.12 Probability Distribution
(Lognormal Distribution Probability Paper)

<Whole Chao Playa River Basin, Rainfall duration, 6months>

Table 10.4.3 Results of Probability Analysis by Different Methods (Upper Basin of Nakhon Sawan, 6-month rainfall)

	annual rainfall series (sumple size N=51)											
	exponential distribution	Gumbel Distribution	squre-root expotential type maximum distribution	extrame value distribution	Peason type Ⅲ distribution (real-space)	Peason type Ⅲ distribution	log-nomal distribution				two-parameter log-nomal distribution	
							Iwai	ishihara・takase	quantile	product moment	L-moments	product moment
	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
X-COR(99%)	0.936	0.981	0.974	0.991	0.992	—	—	0.992	0.991	0.992	0.992	0.992
P-COR(99%)	0.920	0.986	0.986	0.995	0.994	—	—	0.994	0.992	0.994	0.994	0.994
SLSC(99%)	0.072	0.039	0.048	0.040	0.028	—	—	0.028	0.029	0.028	0.028	0.028
log likelihood	-309.500	-324.300	-324.700	-323.200	—	—	—	-323.100	-323.100	-323.100	-323.100	-323.100
pAIC	622.900	652.700	653.500	652.400	0.000	—	—	652.200	652.200	652.200	650.200	650.200
X-COR(50%)	0.983	0.986	0.986	0.976	0.981	—	—	0.982	0.984	0.982	0.982	0.982
P-COR(50%)	0.980	0.982	0.982	0.988	0.987	—	—	0.986	0.985	0.986	0.986	0.986
SLSC(50%)	0.098	0.066	0.089	0.077	0.048	—	—	0.048	0.053	0.048	0.048	0.048

	return period (year)	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
	2	1,046	1,071	1,069	1,090	1,089	—	—	1,087	1,082	1,087	1,087	1,087
	3	1,111	1,133	1,137	1,153	1,150	—	—	1,148	1,143	1,148	1,149	1,148
	5	1,192	1,201	1,214	1,215	1,210	—	—	1,209	1,207	1,209	1,211	1,209
	10	1,302	1,287	1,315	1,282	1,277	—	—	1,278	1,281	1,277	1,282	1,278
	20	1,412	1,369	1,415	1,336	1,335	—	—	1,337	1,347	1,337	1,344	1,339
	30	1,477	1,417	1,474	1,363	1,366	—	—	1,369	1,384	1,368	1,377	1,371
	50	1,558	1,476	1,550	1,394	1,402	—	—	1,407	1,428	1,406	1,416	1,410
	80	1,633	1,531	1,620	1,420	1,434	—	—	1,440	1,467	1,439	1,451	1,444
	100	1,668	1,556	1,654	1,431	1,448	—	—	1,455	1,485	1,454	1,467	1,459
	120	1,697	1,577	1,682	1,439	1,460	—	—	1,467	1,500	1,467	1,480	1,472
	140	1,721	1,595	1,706	1,446	1,470	—	—	1,477	1,512	1,477	1,491	1,482
	150	1,732	1,603	1,717	1,449	1,474	—	—	1,482	1,518	1,481	1,495	1,487
	160	1,743	1,610	1,727	1,452	1,478	—	—	1,486	1,523	1,485	1,500	1,491
	180	1,761	1,624	1,745	1,457	1,485	—	—	1,494	1,532	1,493	1,508	1,499
	200	1,778	1,636	1,762	1,462	1,492	—	—	1,501	1,540	1,500	1,515	1,506
	300	1,843	1,683	1,826	1,477	1,516	—	—	1,526	1,572	1,525	1,542	1,533
	400	1,888	1,716	1,873	1,488	1,533	—	—	1,544	1,594	1,543	1,561	1,551
	600	1,953	1,762	1,939	1,501	1,556	—	—	1,569	1,625	1,568	1,587	1,577
2011Flood	1,483	—	1/53	—	—	1/173	—	—	1/153	1/98	1/154	1/126	1/141
1970Flood	1,266	—	1/9	—	—	1/9	—	—	1/9	1/9	1/9	1/9	1/9
1975Flood	1,254	—	1/9	—	—	1/9	—	—	1/9	1/9	1/9	1/9	1/9
1980Flood	1,255	—	1/8	—	—	1/8	—	—	1/8	1/8	1/8	1/8	1/8
1994Flood	1,313	—	1/15	—	—	1/19	—	—	1/19	1/16	1/19	1/16	1/19
1995Flood	1,262	—	1/8	—	—	1/9	—	—	1/9	1/8	1/9	1/8	1/9
2006Flood	1,375	—	1/21	—	—	1/34	—	—	1/33	1/27	1/33	1/30	1/32

(grey) flood scale occurred in 2011
(green) less than 0.04(SLSC)

Jackknife	return period (year)	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
estimate standard errors	2	19	19	20	24	22	—	—	22	18	22	19	19
	3	20	21	23	24	22	—	—	22	19	22	21	21
	5	23	24	27	25	24	—	—	25	24	25	24	24
	10	30	29	35	30	31	—	—	31	36	31	29	29
	20	39	35	43	41	42	—	—	42	52	41	34	34
	30	44	39	48	49	49	—	—	49	63	48	37	37
	50	51	44	55	59	59	—	—	58	78	58	41	41
	80	58	49	61	70	69	—	—	68	92	67	44	44
	100	61	51	64	75	74	—	—	72	99	72	46	46
	120	63	53	67	79	78	—	—	76	105	75	47	47
	140	66	54	69	83	81	—	—	79	110	79	48	48
	150	67	55	70	84	83	—	—	81	112	80	49	49
	160	67	56	71	86	84	—	—	82	114	81	49	49
	180	69	57	73	88	87	—	—	85	118	84	50	50
	200	71	58	75	91	90	—	—	87	122	86	51	51
	300	76	62	81	100	99	—	—	96	136	95	54	53
	400	81	65	86	106	106	—	—	103	146	101	56	56
	600	87	69	92	115	116	—	—	112	161	110	59	58

※ As for the smallest SLSC method, five methods give SLSC=0.028 (Smallest Value), but LN2PM is adopted because of its smallest Jackknife error in a narrow margin.

Table 10.4.4 A Summary of Probability Analysis by Different Methods (Chao Playa River Basin, 6-Month Rainfall)

	annual rainfall series (sumple size N=51)											
	exponential distribution	Gumbel Distribution	squre-root expotential type maximum distribution	extrame value distribution	Peason type Ⅲ distribution (real-space)	Peason type Ⅲ distribution	log-nomal distribution				two-parameter log-nomal distribution	
							Iwai	ishihara・takase	quantile	product moment	L-moments	product moment
	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
X-COR(99%)	0.913	0.968	0.959	0.989	0.990	—	0.989	0.989	0.987	0.989	0.988	0.988
P-COR(99%)	0.903	0.985	0.986	0.994	0.993	—	0.992	0.992	0.991	0.992	0.992	0.991
SLSC(99%)	0.084	0.050	0.058	0.060	0.030	—	0.031	0.031	0.032	0.031	0.031	0.031
log likelihood	-304.500	-320.600	-320.800	-318.400	-318.100	—	-318.200	-318.200	-318.300	-318.200	-318.300	-318.300
pAIC	613.000	645.100	645.600	642.800	642.300	—	642.400	642.400	642.700	642.400	640.700	640.600
X-COR(50%)	0.971	0.974	0.975	0.960	0.968	—	0.969	0.969	0.972	0.969	0.971	0.971
P-COR(50%)	0.971	0.973	0.974	0.983	0.981	—	0.981	0.981	0.978	0.981	0.979	0.979
SLSC(50%)	0.122	0.095	0.116	0.119	0.070	—	0.070	0.070	0.078	0.070	0.076	0.076

	return period (year)	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	Iwai	IshiTaka	LN3Q	LN3PM	LN2LM	LN2PM
	2	1,017	1,039	1,038	1,061	1,060	—	1,059	1,058	1,053	1,059	1,054	1,054
	3	1,075	1,095	1,101	1,118	1,114	—	1,113	1,113	1,108	1,113	1,110	1,109
	5	1,149	1,157	1,174	1,172	1,167	—	1,166	1,166	1,163	1,166	1,167	1,165
	10	1,249	1,235	1,268	1,227	1,223	—	1,223	1,223	1,226	1,223	1,231	1,227
	20	1,348	1,310	1,361	1,270	1,270	—	1,271	1,271	1,281	1,271	1,286	1,282
	30	1,407	1,353	1,416	1,291	1,294	—	1,296	1,297	1,311	1,297	1,316	1,311
	50	1,480	1,406	1,486	1,313	1,322	—	1,326	1,327	1,346	1,326	1,352	1,346
	80	1,548	1,456	1,552	1,331	1,346	—	1,351	1,352	1,377	1,352	1,383	1,376
	100	1,580	1,479	1,584	1,339	1,357	—	1,362	1,364	1,392	1,364	1,397	1,390
	120	1,607	1,498	1,610	1,345	1,366	—	1,372	1,373	1,403	1,373	1,409	1,401
	140	1,629	1,514	1,632	1,350	1,373	—	1,379	1,381	1,413	1,381	1,418	1,411
	150	1,639	1,521	1,642	1,352	1,376	—	1,383	1,384	1,417	1,384	1,423	1,415
	160	1,648	1,528	1,651	1,354	1,379	—	1,386	1,387	1,421	1,387	1,427	1,419
	180	1,665	1,540	1,669	1,357	1,384	—	1,392	1,393	1,428	1,393	1,434	1,426
	200	1,680	1,551	1,684	1,360	1,389	—	1,397	1,398	1,435	1,398	1,440	1,432
	300	1,739	1,594	1,744	1,370	1,406	—	1,415	1,417	1,459	1,417	1,464	1,455
	400	1,780	1,623	1,787	1,377	1,418	—	1,428	1,431	1,476	1,430	1,481	1,472
	600	1,838	1,666	1,848	1,385	1,434	—	1,446	1,449	1,499	1,448	1,504	1,494
2011Flood	1,390	—	—	—	—	1/207	—	1/176	1/170	1/98	1/171	1/90	1/101
1970Flood	1,232	—	—	—	—	1/12	—	1/12	1/12	1/11	1/12	1/11	1/11
1975Flood	1,166	—	—	—	—	1/5	—	1/6	1/6	1/6	1/6	1/5	1/6
1980Flood	1,207	—	—	—	—	1/8	—	1/8	1/8	1/8	1/8	1/8	1/8
1994Flood	1,168	—	—	—	—	1/7	—	1/7	1/7	1/7	1/7	1/7	1/7
1995Flood	1,230	—	—	—	—	1/11	—	1/11	1/11	1/11	1/11	1/10	1/11
2006Flood	1,266	—	—	—	—	1/19	—	1/19	1/18	1/16	1/18	1/15	1/16

(grey) flood scale occurred in 2011
(green) less than 0.04(SLSC)

Jackknife estimate standard errors	return	Exp	Gumbel	SqrtEt	Gev	LP3Rs	LogP3	iwai※	ishitaka※	LN3Q※	LN3PM	LN2LM	LN2PM
	2	18	18	18	23	20	-	-	-	-	22	18	18
	3	18	18	21	22	20	-	-	-	-	22	18	19
	5	19	20	25	21	21	-	-	-	-	22	20	21
	10	24	23	32	24	25	-	-	-	-	22	24	24
	20	31	28	40	31	33	-	-	-	-	22	27	28
	30	35	31	45	37	39	-	-	-	-	23	30	30
	50	40	35	51	45	47	-	-	-	-	24	33	33
	80	46	39	58	53	54	-	-	-	-	26	35	36
	100	48	40	61	57	58	-	-	-	-	27	37	37
	120	50	42	63	60	61	-	-	-	-	28	38	38
	140	52	43	65	62	64	-	-	-	-	29	39	39
	150	53	44	66	63	65	-	-	-	-	30	39	40
	160	54	44	67	64	66	-	-	-	-	30	39	40
	180	55	45	69	66	68	-	-	-	-	31	40	41
	200	56	46	71	68	70	-	-	-	-	32	41	41
	300	61	49	77	74	77	-	-	-	-	34	43	44
	400	64	52	81	79	83	-	-	-	-	37	45	45
	600	69	55	88	84	90	-	-	-	-	40	47	47

※ No evaluation errors, because Jackknife error could not be properly calculated.

(5) Reference: About the 2002 flood

The peak discharge and the volume of the 2002 flood are comparatively large, but not selected as representative six (6) large floods. Because the 6-month rainfall at the upper basin of Nakhon Sawan was 1,201 mm, which is ranked 13th among the 51 floods and the enlargement rates of the flood exceeded 1.2.

Figure 10.4.13 shows actual rainfalls during the fixed periods (One year, 2 months, 1 month and a half month)

- About the 6-month rainfall, the 2002 flood is ranked 13th among the 51 years and not an exceptional large rainfall.
- However, about the rainfalls of short period (half a month, one month and two months), the 2002 flood is the largest among the 51 years.
- The large peak discharge and volume of the 2002 flood are estimated to be caused by the rainfall concentrated in a short period.

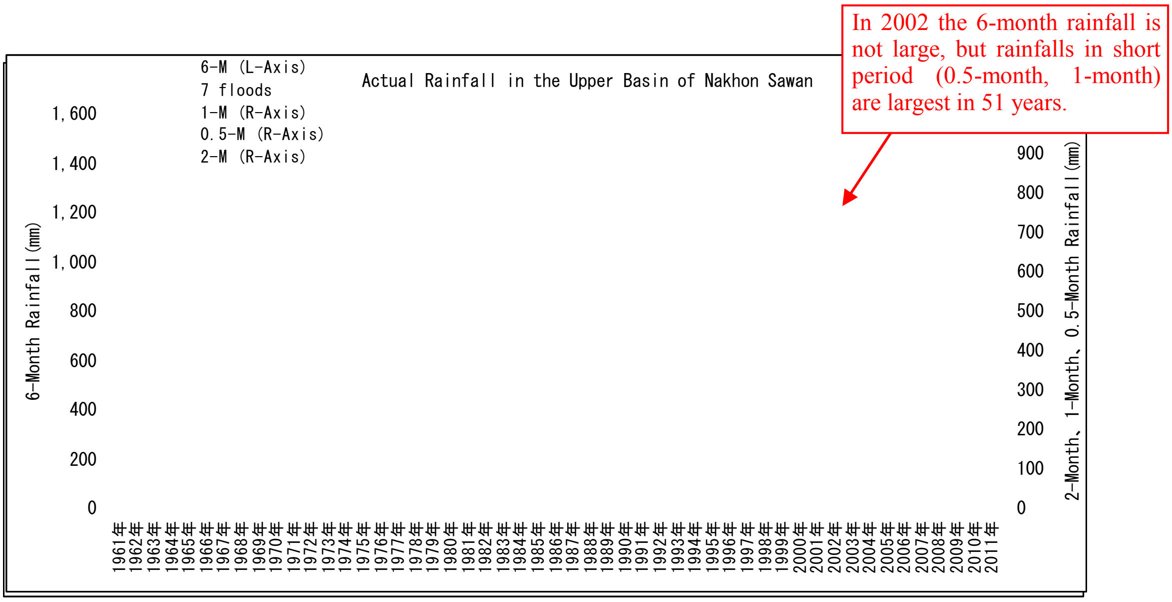


Figure 10.4.13 Rainfalls of Short Periods in the Upper Basin of Nakhon Sawan

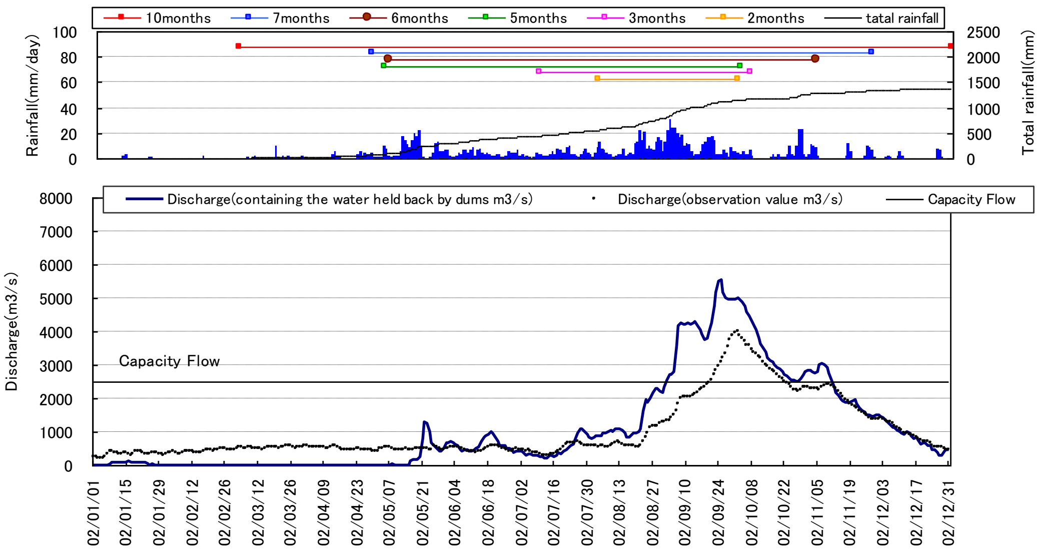


Figure 10.4.14 Actual Discharge without Dams at Nakhon Sawan (in 2002)

10.4.2 Study Case

The list of calculation case and condition are shown in following table.

Table 10.4.5 List of Calculation Case

Table- Calculation Case on Chao Phraya River Basin

Study Case	Protection dike around the economic zone	Dike elevating on Chao Phraya River and Pasak River by BMA and DOH	Improved existing dam operation	Construction of dams(new)	Improvement of the retention areas (monkey cheeks)	Dike elevating to DHWH + freeboard of 0.5m (all river/canal)	Construction of floodways(east and/or west) Location upstream 316km from river mouth	Dike elevating along primary dike up to DHWL + freeboard of 0.5m(all river/canal)	Ayutthaya Bypass (1,400m³/s)	Construction of central floodway (capacity 500m³/s) Location upstream 128km from river mouth	Short cut of Tha Chin River shortcut channel	Widening of Tha Chin River 90k - 200k	Flood protection wall of Tha Chin River 0k - 90k	Remarks
case0														Reproduction calculation 2011yr flood, with rainfall Considering dike breaks
case0-0														Without dike breaks
case0-1	●	●												
case1	●	●	●	●	●	●	● (1,500m³/s)							
case1-1	●	●	●	●	●	●	● (1,500m³/s)			● (500m³/s)				
case2	●	●	●	●	●	●	● (1,500m³/s)		●					
case2-1	●	●	●	●	●	●	● (1,500m³/s)		●	● (500m³/s)				
case5	●	●				●								
case7	●	●				●	● (1,500m³/s)							
case8	●	●						●						
case8-1	●	●	●	●	●	●		●						
case9-1	●	●	●											
case9-2	●	●		●										
case9-3	●	●			●									
case9-4	●	●							●					
case9-5	●	●								● (500m³/s)				
case9-6	●	●					● (1,500m³/s)							
case9-6-1	●	●					● (3,000m³/s)							Additional 22 Jan 2013
case9-7	●	●	●				● (1,500m³/s)							
case10-0	●	●	●						●	● (500m³/s)				
case10-1	●	●	●						●	● (1,000m³/s)				
case10-2-4sc-ng	●	●	●						●	● (1,000m³/s)	● (4 shortcut /no gate) *1)			
case10-2-2sc-ng	●	●	●						●	● (1,000m³/s)	● (2 shortcut /no gate) *2)			
case10-2-4sc-wg	●	●	●						●	● (1,000m³/s)	● (4 shortcut /with gate) *1)			
case10-3-4sc-ng	●	●	●						●	● (1,000m³/s)	● (4 shortcut /no gate) *1)	●		
case10-4-4sc-ng	●	●	●						●	● (1,000m³/s)	● (4 shortcut /no gate) *1)	●	● (Left Embankment)	
case10-6	●	●	●						●	● (1,000m³/s)			● (Right and Left embankment)	
case10-7-4sc-ng	●	●	●						●	● (1,000m³/s)	● (4 shortcut /no gate) *1)		● (Right and Left embankment)	
case11-0	●	●	●						●	● (500m³/s)	● (4 shortcut /no gate) *1)		● (Left Embankment)	
case11-1	●	●	●						●	● (1,000m³/s)	● (4 shortcut /no gate) *1)		● (Left Embankment)	

*1) 4 shortcut: No.1(75.9-87.1k), No.2(60.7-70.8k), No.3(29.3-48.2k), No.4(21.4-27.3k)

*2) 2 shortcut: No.1(75.9-87.1k), No.2(60.7-70.8k)

Table 10.4.6 Calculation Condition

Target Flood	Item		Study conditions for 2011 proposed measures	(Enlarged) Calculation conditions for the 6 typical floods (1970,1975,1980,1994,1995,2006)
Runoff calculation	Evapotranspiration		0.8 times the observed values in 2011 (TMD)	0.8 times the averages of observed values during 1980-2011 (TMD)
	Rainfall		Observed values in 2011	Enlarged rate of representative 6 months 1970yr: x 1.128 1975yr: x 1.192 1980yr: x 1.152 1994yr: x 1.190 1995yr: x 1.130 2006yr: x 1.098
	Initial values for calculation		Water level on Jan 1, 2011 in the sequential calculation for the past 30 years.	Averages on Jan 1 for the past 30 years (Each average on Jan 1 during 1981-2011).
Inundation calculation	Runoff at the end of upstream	WANG	Observed discharges (W.10A)	Calculated runoff in Basin 5+6
		PING	Water volume discharged from Bhumibol Dam (Discharges with current & modified operations)	
		YOM	Observed discharges (Y.20)	Calculated runoff in Basin 8
		NAN	Water volume discharged from Sirikit Dam (Discharges with current & modified operations)	
		TAB SALAO	Observed water volume discharged from Tab Salao Dam	Calculated runoff in Basin 22
		KRA SIEW	Observed water volume discharged from Kra Siew Dam	Calculated runoff in Basin 26
		MAE WANG	Observed discharges (Ct.5A)	Calculated runoff in Basin 21
		KWAE NOI	Water volume discharged from Kwae Noi Dam (Discharges with current & modified operations)	
		PASAK	Water volume discharged from Pasak Dam (Discharges with current & modified operations)	
	Tidal level		Observed values in 2011 ・Chao Phraya: Pomprachul Station (16cm below the observed after correcting std. height) ・Tha Chin: Samut Sakhon Station (34cm below the observed after correcting std. height)	
	Evapotranspiration & Under seepage		Considering penetration and un-modeled discharge system, to set the average of pan evaporation for the past 30 years deriving from inundation meshes plus 10mm/day at most.	

10.4.3 Result of the Study

The effectiveness of countermeasures proposed in M/P study against 2011 flood is examined. The evaluation items is discharge, water level, inundation area/depth and inundated volume in flood plain.

The other rainfall patterns to be evaluated age shown below:

Table 10.4.7 Other Rainfall Patterns to be evaluated

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

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

About effectiveness of "Proposed Combination 1 and 2" against other rainfall patterns, Table 10.4.8 shows calculation results against actual rainfalls of other years. On the other hand, Table 10.4.9 shows calculation results against rainfalls which are enlarged to the same quantity as the design external force (2011's 6-month rainfall). As the result of the flood analysis mentioned-above, it could be said that proposed countermeasures, "Proposed Combination 1 (Case 11-0)" or "Proposed Combination 2 (Case 11-1)" is effective against the six representative floods (rainfall scale is 100-year return period) and could protect the protection area including the Bangkok Metropolitan Area from inundation damage.

The longitudinal profile including calculated discharge and water level is shown in Supporting Report Sector E.

Table 10.4.8 Verification Results of Project Effectiveness against Other Actual Rainfalls

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

Table 10.4.9 Verification Results of Project Effectiveness against Rainfalls enlarged to Same Quantity as 2011's 6-month Rainfall

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

10.5 Proposed Combination of Countermeasures

Effective combination of countermeasures have been selected and compared with the combination of SCWRM M/P. To effectively protect the national economic center of Bangkok and its vicinity from floods, it is necessary to select countermeasures for reducing the flood stage:

1) To reduce the flood peak discharge of 400 m^3/s at Nakhon Sawan from the upper basin by the effective operation of Bhumibol and Sirikit dams.
2) To reduce flood stage of the river stretch between Ayutthaya and Bang Sai including the confluence of the Pasak River, the New Bypass Channel has been proposed as river channel improvement, because it is very difficult for the stretch to conduct river improvement works such as rising river banks and widening river channel.
3) To reduce flood volume of the Chao Phraya River after the confluence of the Pasak River, the Outer Ring Road Diversion Channel has been proposed.
4) To protect the economic zone (Protection Area), the dyke improvement of lower reaches of the Chao Phraya River has been proposed.
5) To increase discharge capacity of the Tha Chin River and eliminate the negative impact of the left side dyke heightening for protection of the economic zone, the dyke improvement at left side of lower reaches of the Tha Chin River and four (4) shortcut channels have been proposed.

The proposed combination of structural and nonstructural measures are the following two alternatives.

Proposed Combination 1

1) Effective Operation of Existing Dams;
2) Outer Ring Road Diversion Channel (Capacity 500m^3/s);
3) River Channel Improvement Works and
4) Ayutthaya Bypass Channel (Capacity 1,400m^3/s).

Proposed Combination 2

1) Effective Operation of Existing Dams;
2) Outer Ring Road Diversion Channel (Capacity 1,000m^3/s);
3) River Channel Improvement Works; and
4) Ayutthaya Bypass Channel (Capacity 1,400m^3/s).

Effectiveness of each proposed combinations is compared with the proposed combination of SCWRM. The combination of SCWRM M/P is shown as follows:

Combination of SCWRM M/P

1) Effective Operation of Existing Dams;
2) Construction of New Dams;
3) Improvement of Retarding/Retention Areas;
4) East/West Diversion Channel (Capacity 1,500m^3/s); and
5) Outer Ring Road Diversion Channel (Capacity 500m^3/s); and
6) River Channel Improvement Works.

Together with the proposed combinations, the following measures for sustainable development in the basin are proposed in the Master Plan:

- Reforestation and restoration of the degraded forest area in the upper basin.
- Promotion of controlled inundation in the central plain including land use control and supplemental structural measures.

10.6 Hydraulic Examination (Different Flood Scale)

To understand the flood condition in different flood scale including discharge, inundated area, inundation depth and so on, additional flood analysis is done. In this study, the flood analysis under 5-year, 10-year, 30-year, 50-year and 100-year return period is conducted.
Table 10.6.2 and Table 10.6.3 show the discharge at major point in Chao Phraya River, and the longitudinal profiles of discharge and water level are shown from Figure 10.6.1 to Figure 10.6.4. The inundation maps are as shown in *Supporting Report (1/2), Sector D*.

Table 10.6.1 Probable Rainfall in Chao Phraya River Basin

Return Period	Rainfall (mm/6month)	
	Upper Nakhon Sawan (C.2)	Whole Basin
	Area: 105,000km^2	Area:163,000km^2
5	1,209	1,165
10	1,278	1,227
30	1,371	1,311
50	1,410	1,346
100	1,459	1,390

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

Table 10.6.2 Discharge in Different Flood Scale (1/2)

Return Period	Peak Discharge (m^3/s)						Remarks
	Case 0-1: Existing Condition			Case 1-1: SCWRM M/P Full Menu			
	Nakhon Sawan	Ayutthaya	Bang Sai	Nakhon Sawan	Ayutthaya	Bang Sai	
M/P Study	4,800	1,100	4,300	4,200	1,000	3,500	
5	3,800	900	3,000	3,200	700	1,800	Different flood scale
10	4,000	900	3,400	3,500	750	2,100	
30	4,500	1,000	3,800	3,800	800	2,400	
50	4,700	1,050	4,100	4,000	900	3,000	
100	4,800	1,100	4,300	4,200	1,000	3,500	

Table 10.6.3 Discharge in Different Flood Scale (2/2)

Return Period	Peak Discharge (m^3/s)						Remarks
	Case 11-0: Proposed Combination 1			Case 11-1: Proposed Combination 2			
	Nakhon Sawan	Ayutthaya	Bang Sai	Nakhon Sawan	Ayutthaya	Bang Sai	
M/P Study	4,400	300	3,800	4,400	300	3,500	Design flood
5	3,400	300	2,300	3,400	300	1,900	Different flood scale
10	3,600	300	2,900	3,600	300	2,300	
30	4,000	300	3,300	4,000	300	2,800	
50	4,200	300	3,600	4,200	300	3,200	
100	4,400	300	3,800	4,400	300	3,500	

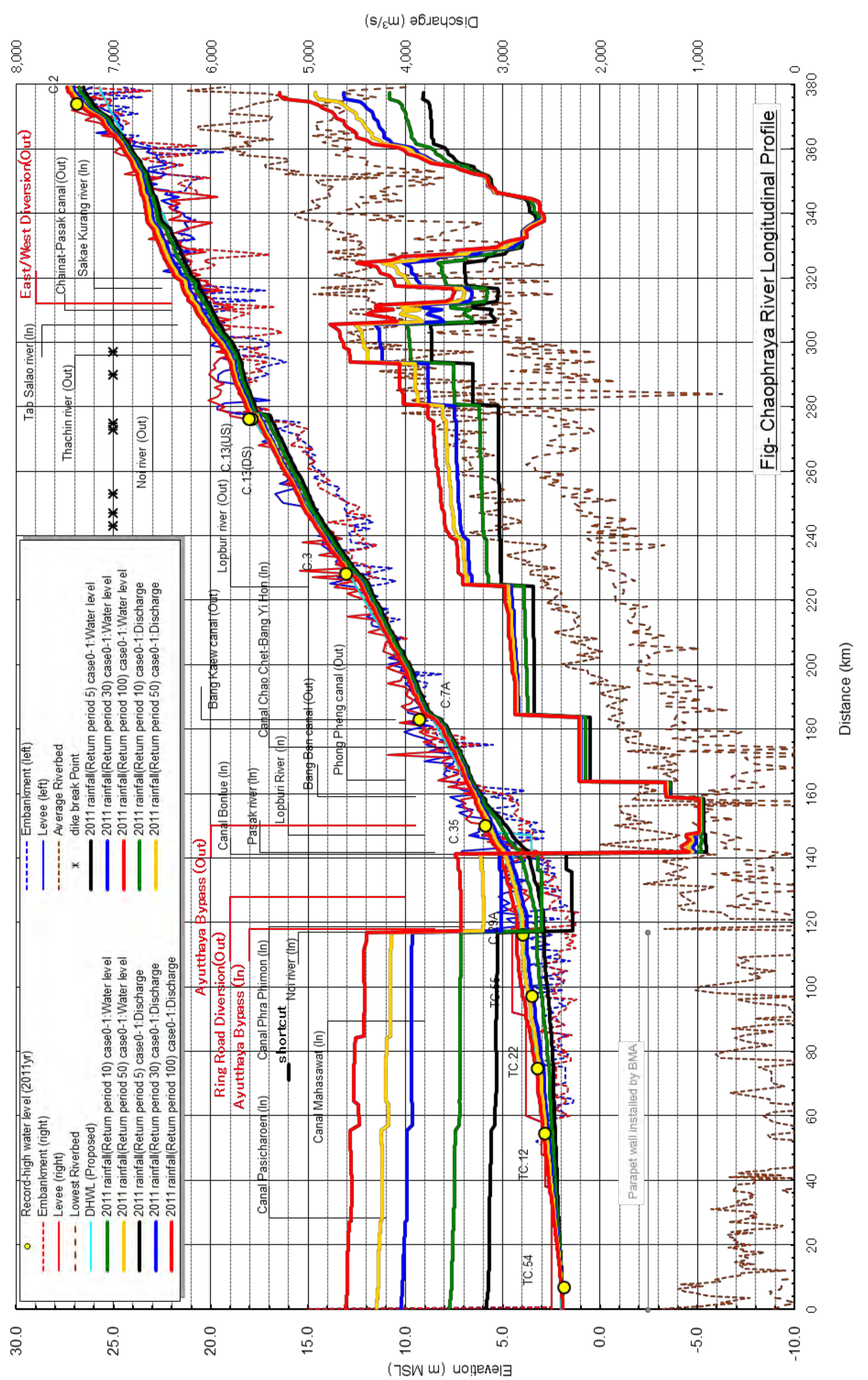


Figure 10.6.1 Longitudinal Profiles of River Discharge and Water Level with Different Flood Scale (Case 0-1)

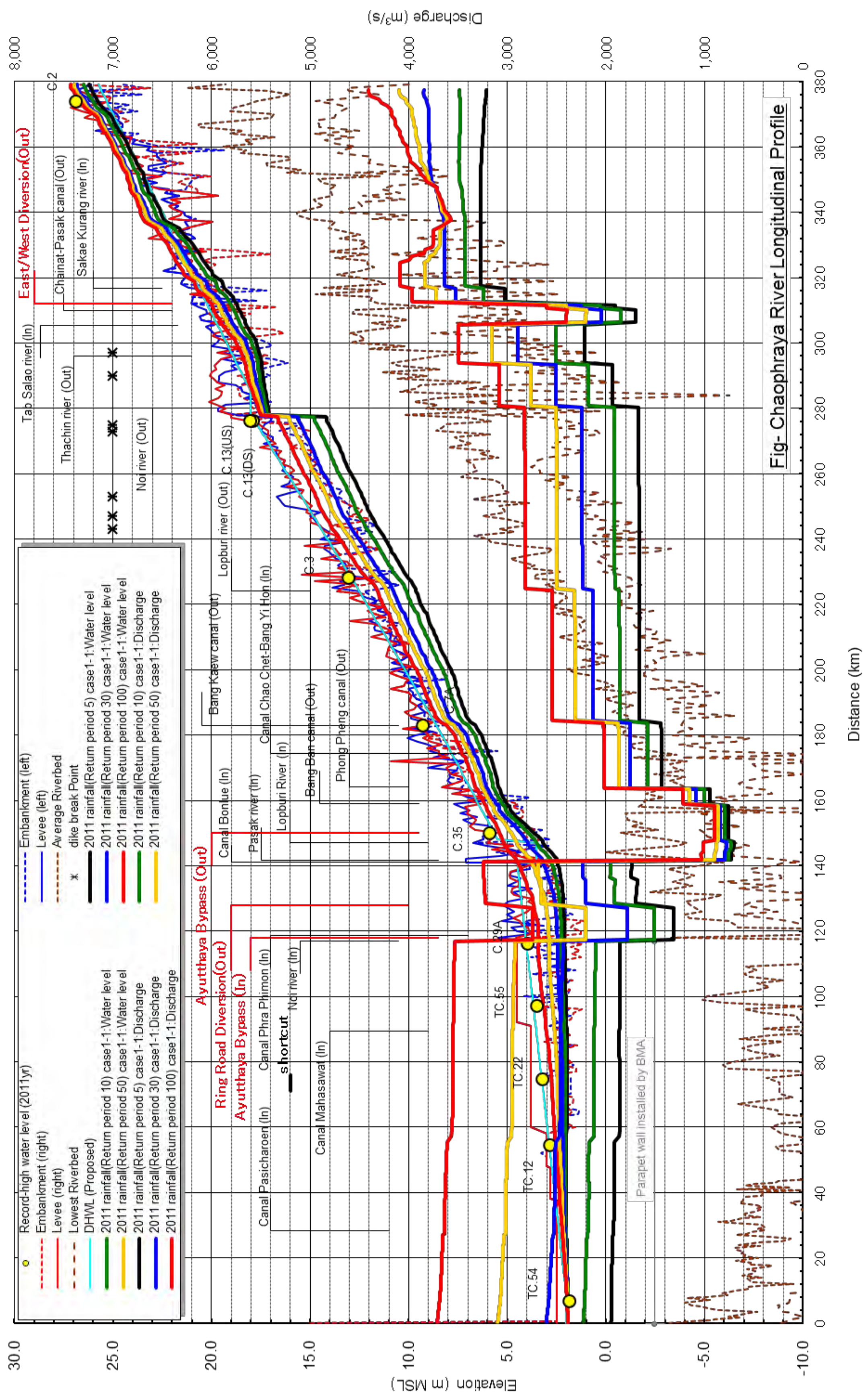


Figure 10.6.2 Longitudinal Profiles of River Discharge and Water Level with Different Flood Scale (Case 1-1)

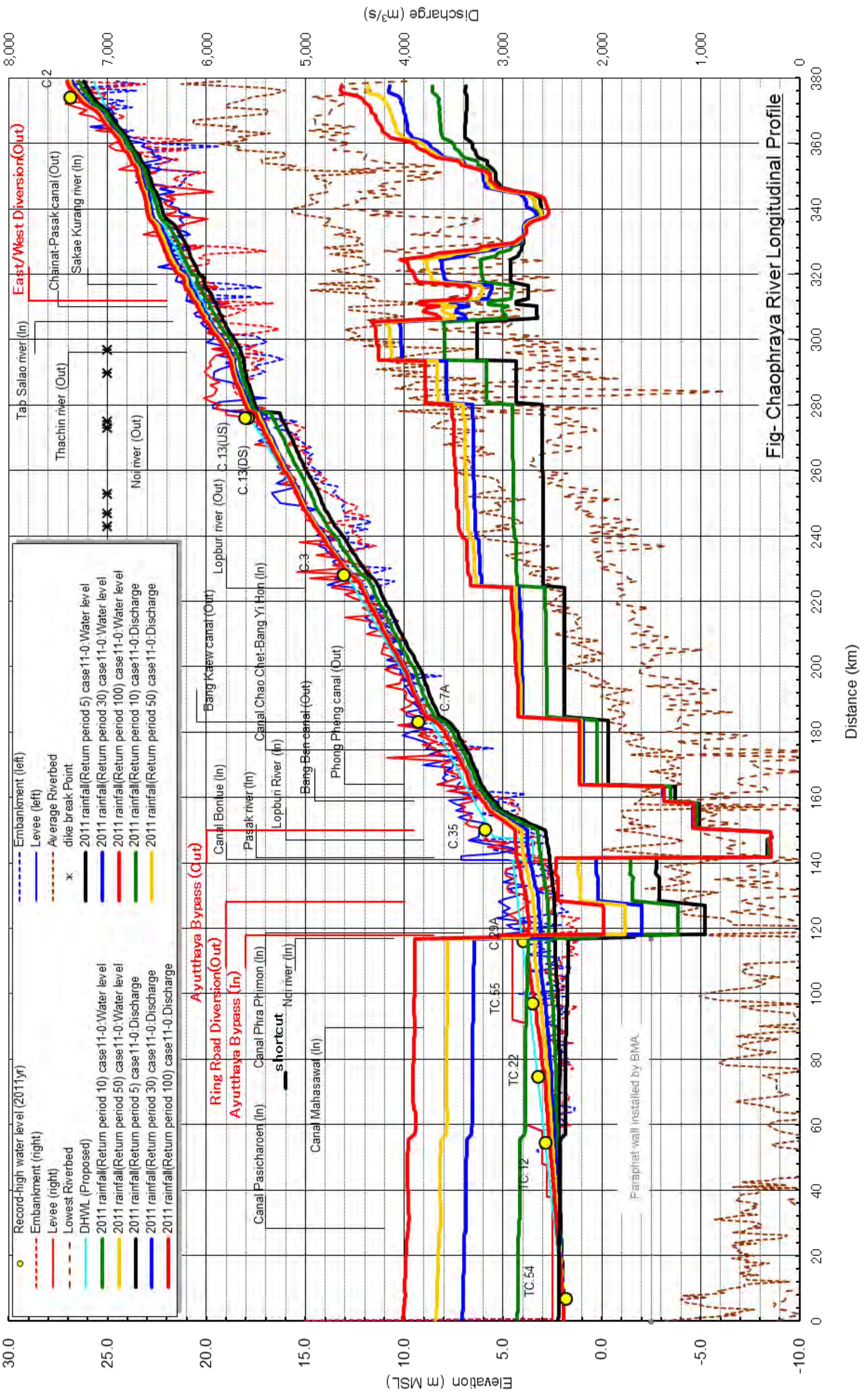


Figure 10.6.3 Longitudinal Profiles of River Discharge and Water Level with Different Flood Scale (Case 11-0)

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

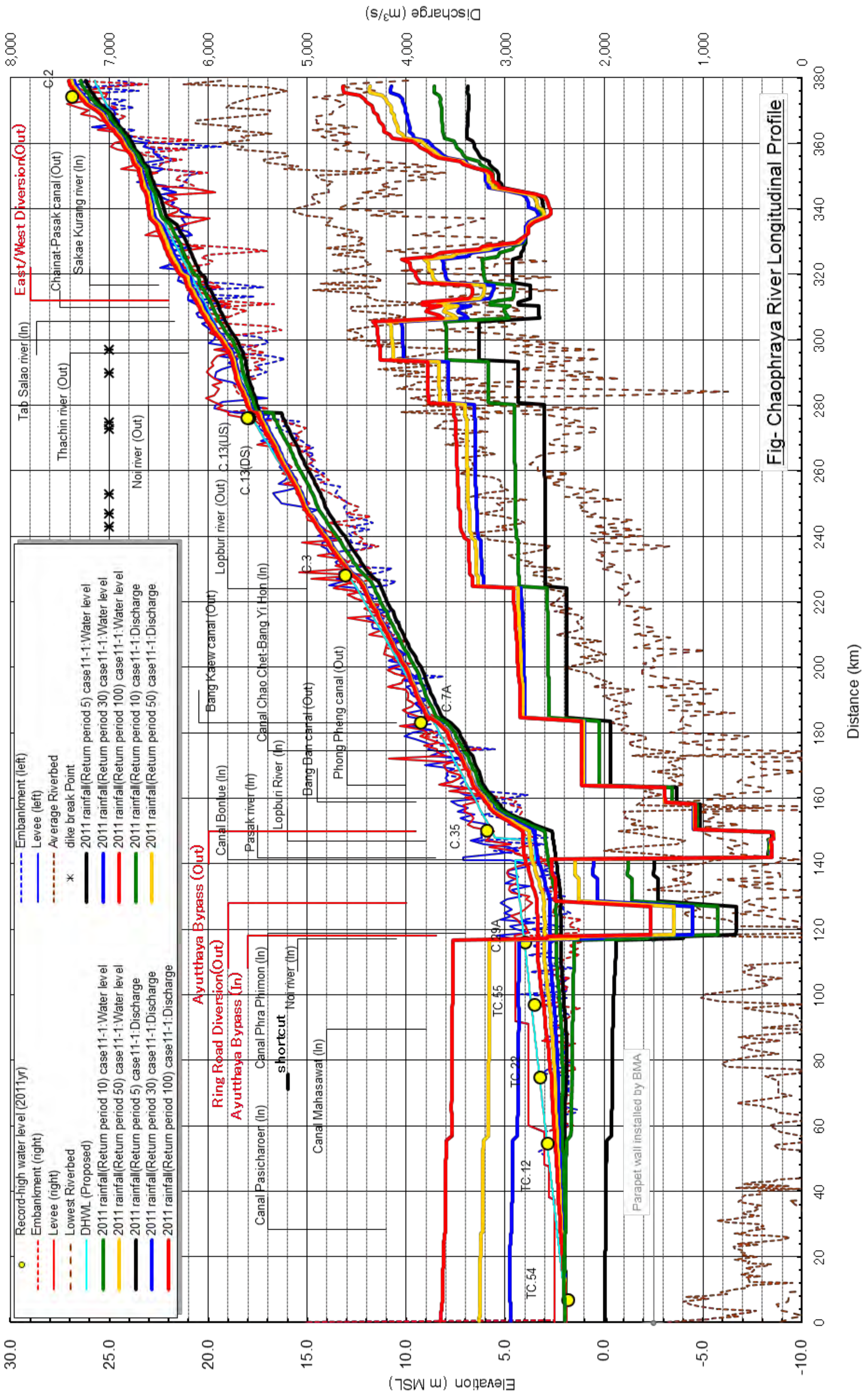


Figure 10.6.4 Longitudinal Profiles of River Discharge and Water Level with Different Flood Scale (Case 11-1)

10.7 Consideration on Climate Change and Storm Surge

10.7.1 Sea Level Rise Caused by Climate Change

This master plan study focuses on the estimation of change of runoff discharge due to climate change. Judgment whether to change design discharges according to the projected impacts is left to the Thai side. If characteristics of the Chao Phraya River Basin are taken into consideration, countermeasures should be sought separately for the upper basin (upstream of Nakhon Sawan), the middle basin (Ayutthaya to Nakhon Sawan) and the lower basin (the river mouth to Ayutthaya).

The upper basin, in which frequency of large floods will increase, will not be affected since planned structural measures will be changed. On the other hand, the lower basin, which is under the tidal effects, will likely be affected by flood inundation risk augmented by sea level rise and storm surges in addition to rainfall increase. If the impact is very much, the basic specifications of the structural countermeasures including DHWL (Design High Water Level) should be modified.

10.7.2 Previous Studies on Climate Change

(1) Study in Thailand

There are three available study reports on Climate Change in Thailand as shown in Table 10.7.1. The first and second reports are the same in terms of contents. Projection results of the WB (The World Bank) Study[1] and the START Study[2] are summarized in Table 10.7.2 and Table 10.7.3.

Table 10.7.1 Study Report in Thailand on Climate Change

No.	Report	Outline
1	Climate Risks and Adaptation in Asian Coastal Megacities, A Synthesis Report	Released in 2010, this report provided impact projection data to the 2009 WB study published in March 2009.
2	Climate Change Impact and Adaptation Study for Bangkok Metropolitan Region (Final Report)	This is the 2009 WB study by Panya Consultant.
3	Preparation of climate Change Scenarios for Climate Change Impact Assessment in Thailand, Southeast Asia START Regional Center, 2010 (START Study)	Projection of 4 variables, maximum and minimum temperature, annual precipitation and sea level rise

Table 10.7.2 Climate Change Impact Projection in 2050 (WB Study)

IPCC Scenario	Temperature increase (ºC)	Mean Seasonal Precipitation Increase (%)	Sea Level Rise (m)	Storm Surge (m)
B1	1.2	2	0.19	0.61
A1FI	1.9	3	0.29	0.61

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

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

Table 10.7.3 Summary of Climate Change Impact Projection by START

Scenario		Prediction	Note
Maximum Temperature	SRES A1B (2045-2065)	Rise by 3-4 degrees	In the Chao Phraya River Basin, 3-month estimated temperature, esp. March to May was largely out of the median.
	SRES A2 (21st Century)	Upward tendency	Current temperature (33-35 degrees) may rise up to 37-39 degrees in the end of 21st Century.
	SRES B2 (21st Century)	Upward tendency	Upward tendency in temperature, but without large changes.
Minimum Temperature	SRES A1B (2045-2065)	Rise by 4 degrees	In the Chao Phraya River Basin, 23.74 deg. of current temperature may rise up to 27.76 deg.
	SRES A2 (21st Century)	Upward tendency	Current temperature (22-26 deg.) may rise up to 26-28 deg. in the end of 21st Century.
	SRES B2 (21st Century)	Upward tendency	Upward tendency in temperature, but without large changes.
Precipitation	SRES A1B (2045-2065)	Rise by 10 %	Upward tendency in the rainy season, namely 1,095 to 1,210mm/y.
	SRES A2 (21st Century)	Upward tendency	A remarkable rise in precipitation to be observed in the Gulf of Thailand in later 21st Century.
	SRES B2 (21st Century)	Upward tendency	Upward tendency in precipitation, but without large changes.
Sea Level Rise	DIVA & POM (2010-2029)	Rise by 5-10 cm	The coastal area of the Gulf of Thailand including the estuary of Chao Phraya River may be affected most. Effects on the sea level rise vary by season because of affection of monsoon seasons.
	DIVA & POM (2030-2049)	Rise by 10-20 cm	

(2) Projection of Rainfall

It is very important for flood mitigation planners to know how precipitation will change due to climate change. In the Chao Phraya River Basin where evaporation is much, evaporation is also very important. According to the WB report, precipitation will increase by 2 to 3%. Since the design rainfall duration is assumed to be 6 months in this JICA Study, it is desirable that impact projection results for monthly rainfall are available, at least. However, they have not been found yet as of January 201). Neither have been projection results of evaporation.

According to the START Study in Table 10.7.3, future trends in precipitation are predicted as follows:

- The Central Plain and Chao Phraya River Basin: There will be higher precipitation throughout the rainy season. Annual precipitation in the future may increase from the present level by approximately 10%, from 1,095mm to 1,210mm.
- The Gulf of Thailand Coastal Zone: There will be significantly higher precipitation throughout the year. Total annual precipitation could change from 1,857mm to 2,603mm, approximately 40% up. Results from climate models show that precipitation will be significantly increased during the north-east monsoon season during November to February.

(3) Projection of Sea Level Rise

For the Chao Phraya River Basin which has the capital, Bangkok in the lowest tidal area, sea level rise is a very serious issue. According to the WB report, the sea level rise of the Gulf of Thailand will be 19 to 29 cm in 2050. The sea level rise in the global level was presented with a map in the IPCC Fourth Assessment Report (AR4) in 2007 as shown in Figure 10.7.1. The adopted scenario is A1B, and a rise of 21 to 48cm is projected all over the globe. However, there is no information (Blank) in the Gulf of Thailand. Due to the previous studies on Climate Change, the sea level rise in the Gulf of Thailand is not much different from the average of global sea level rise.

It is generally said that the sea level rise is significant where an ocean current is strong. In the Gulf of Thailand where no strong current is flowing, the sea level rise might be not so large.

The Southeast Asia START Regional Center developed the sea level rise scenario for the Gulf of Thailand, which was projected by combining the effects of sea level rise and changing sea surface fluctuations. Changes in sea level in the Inner Gulf of Thailand were predicted for two periods (2010-2029 and 2030-2049) in comparison to average sea level of 1985-2000.

- 2010-2029: Ranging from 6.8 to 12.2 cm rise. Maximum sea level rise will be marked in June and minimum in August instead.
- 2030-2049: Ranging from 17.8 to 22.4 cm rise. Maximum sea level rise will be marked in August and minimum in December. This trend is different from those to be predicted during 2010-2029.

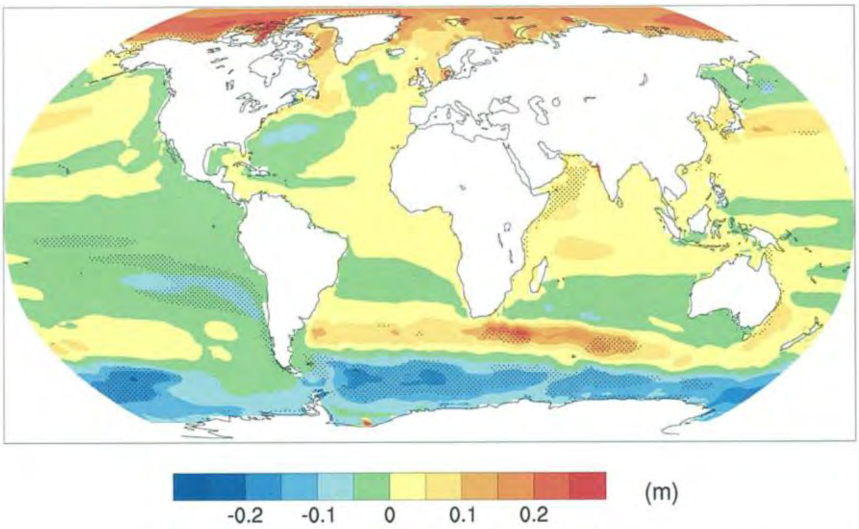


Figure 10.32. *Local sea level change (m) due to ocean density and circulation change relative to the global average (i.e., positive values indicate greater local sea level change than global) during the 21st century, calculated as the difference between averages for 2080 to 2099 and 1980 to 1999, as an ensemble mean over 16 AOGCMs forced with the SRES A1B scenario. Stippling denotes regions where the magnitude of the multi-model ensemble mean divided by the multi-model standard deviation exceeds 1.0.*

Figure 10.7.1 Projection of Sea Level Rise (Global Model)

(4) Projection of Storm Surge

Since storm surge is a short-term phenomenon as short as one day, its influence on the flood of the Chao Phraya River that continues a few months is very limited. However, the rise of the sea level by storm surge is very important to determine the level of the dikes in the downstream stretches.

In Thailand 61cm of the sea level rise by storm surge that was estimated for Typhoon Linda (1997) has been adopted. It is necessary to ask experts if typhoon paths and atmospheric pressure will be changed due to climate change. In this JICA Study a preliminarily examination has been conducted on the changed typhoon path and its storm surge and impacts by using a storm surge simulation model.

JICA conducted interviews to JAMSTEC (Japan Agency for Marine-Earth Science and Technology) and MRI, JMA (Meteorological Research Institute, Japan Meteorological Agency) about typhoons and cyclones in November 2012. Results are summarized as follows:

- According to results of ensemble average of various simulation models, the global tendency is that the number of typhoons and cyclones will decrease but their strength will increase.
- Many simulation results show a unique tendency but the range of values is very wide.
- Even for specific areas like the east or west pacific, differences among the simulation models are big.

- If the smaller area like the Gulf of Thailand is focused, the bigger is uncertainty.
- Information is too scarce to determine concrete measures.
- The number of typhoons and cyclones will decrease by 20 to 30% in the north pacific, and decrease by 15 to 20% at the global level.

Although uncertainty is still large for local areas as mentioned above, the following could be said, at least:

- The number of typhoons will not change or decrease by as little as one or two in 25 years.
- The strength of typhoons will hardly change.

10.7.3 Projection of Impact on Rainfall by Climate Change

In this JICA Study the duration of the design rainfall is 6 months. Therefore, monthly projection data of rainfall and evaporation are necessary, at least, although monthly evaporation might be estimated from temperature data. The monthly data will also make it possible to examine influence on drought. Following are conditions of the impact projection and method of data arrangement:

(1) Green House Gas Emissions Scenario

There are emission scenarios, A1 (very rapid economic growth scenario: A1FI, A1T, A1B); A2 (very heterogeneous world scenario); B1 (convergent world scenario with an emphasis on global solutions to economic, social, and environmental sustainability); and B2 (world scenario with an emphasis on local solutions to economic, social, and environmental sustainability). Generally, an average scenario, A1B is adopted. There are also cases that adopt both of the most conservative scenarios (A1FI) and the most optimistic scenario (B1).

(2) Climate Change Simulation Model

There are available data of GCM (Global Climate Model) and AGCM (Atmospheric General Circulation Models by MRI, JMA). The Calculation grid sizes are $100km^2$ for GCM and $20km^2$ for AGCM, respectively.

(3) Method for Projection Data Arrangement

A method to arrange projection data is proposed as follows:

Arrangement of change quantity: extent of change is assessed by statistical analysis. For example, there are available 20C3M (reproduction data for 20 years from 1981 to 2000), mid-term projection data for 20 years from 2046 to 2065 and long-term projection data for 20 years from 2081 to 2100. Statistical analysis will be made for each data set to extract significant changes among them.

Seasonal characteristics: In order to examine seasonal characteristics (for example rainfall of April to June will increase, that of July to September will increases, etc.) projection data will be treated separately for every 3 months.

Regional characteristics: Since the Chao Phraya River Basin is very wide, regional characteristics will be also examined. For example, 2-division case (upstream and downstream of Nakhon Sawan) or 5-division case (downstream of Nakhon Sawan, Ping, Wang, Yom and Nan River Basins).

10.7.4 Study on Sea Level Rise Caused by Climate Change

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

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

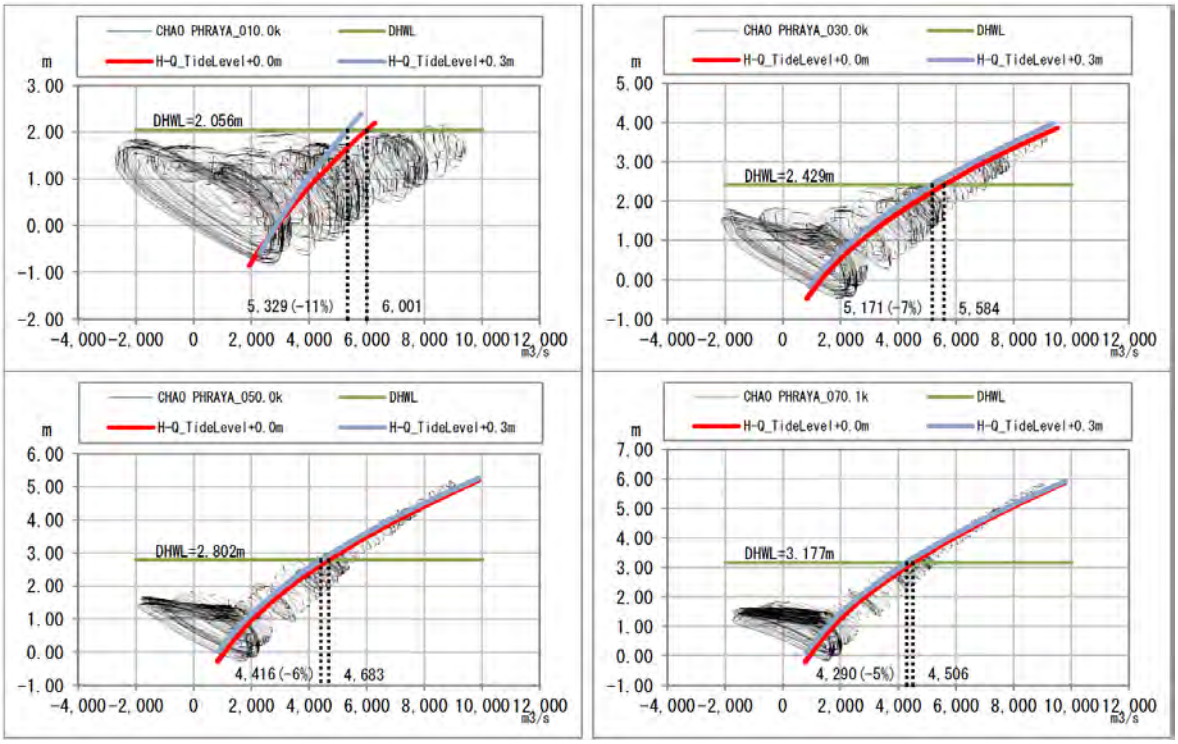


Figure 10.7.2 Discharge Capacity in Case of Sea Level Rise of 30 cm

10.7.5 Study on Storm Surge

A storm surge is an offshore rise of sea level associated with a low pressure weather system, typically typhoons. Coastal areas along the Gulf of Thailand have been historically affected by storm surges.

An analysis is being made to assess a risk of storm surge in the coastal area of the Chao Phraya River Basin including Bangkok.

Firstly, a storm surge simulation model was established through model validation using observation data of Typhoon Gay (1989) and Typhoon Linda (1997).

Then a storm surge simulation was conducted under a scenario that a typhoon similar to Typhoon Linda hits the river mouth of the Chao Phraya River (refer to Figure 10.7.4).

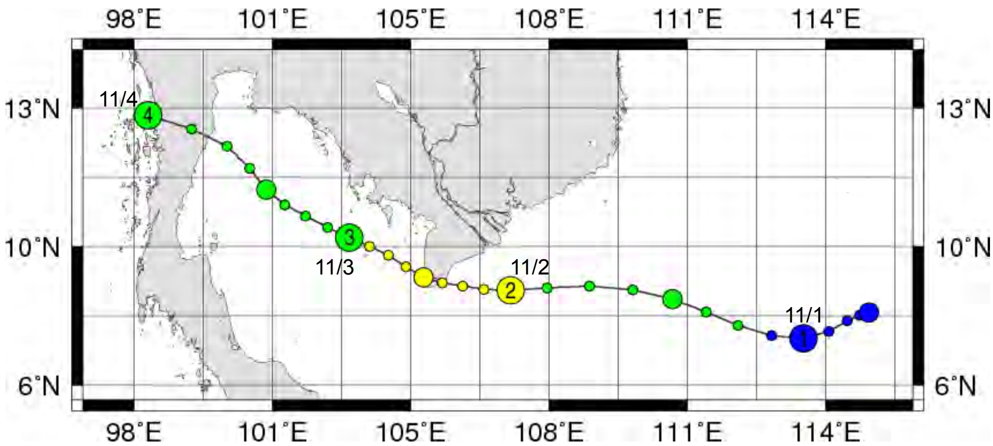
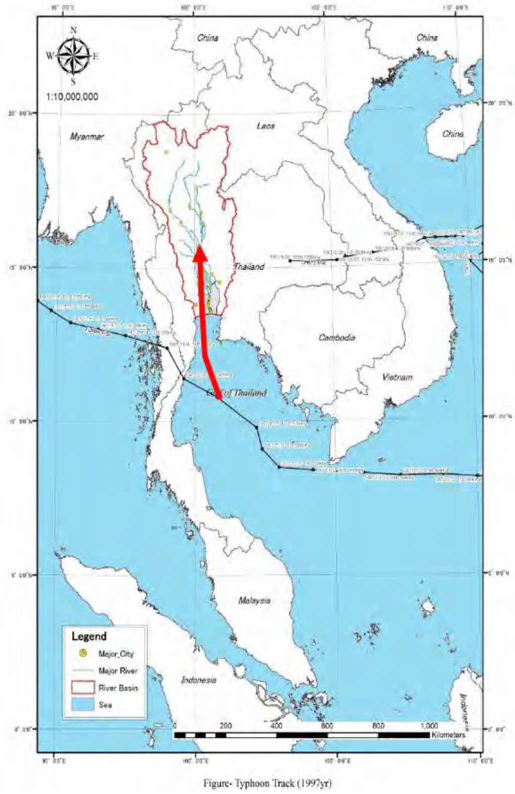


Figure 10.7.3 Track of Typhoon Linda in 1997



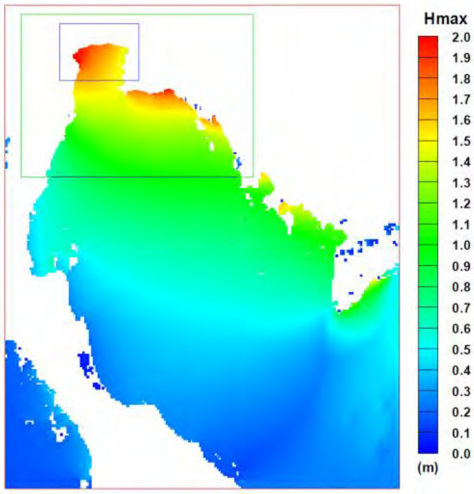


Figure 10.7.4 Modified Typhoon Route **Figure 10.7.5 Simulated Maximum Surge**

Moreover, a flood inundation simulation for the 2011 flood was also conducted with water level rise at river mouth by the estimated storm surge as the boundary condition at the river end. The following conditions were set.

- The storm surge with the highest sea water rise occurred in October 30, 2011 at the time of the highest river water level;
- The seawater rise was max. 2.0m (refer to Figure 10.7.5) and lasted for 24 hours (refer to Figure 10.7.6); and
- The simulation on the reproduction of the 2011 Flood is executed with i) the dyke elevation around the economic zone along the Chao Phraya River and Pa Sak River, ii) Effective Operation of Existing Dams, iii) Ayutthaya Bypass and iv) Outer Ring Road Diversion Channel.

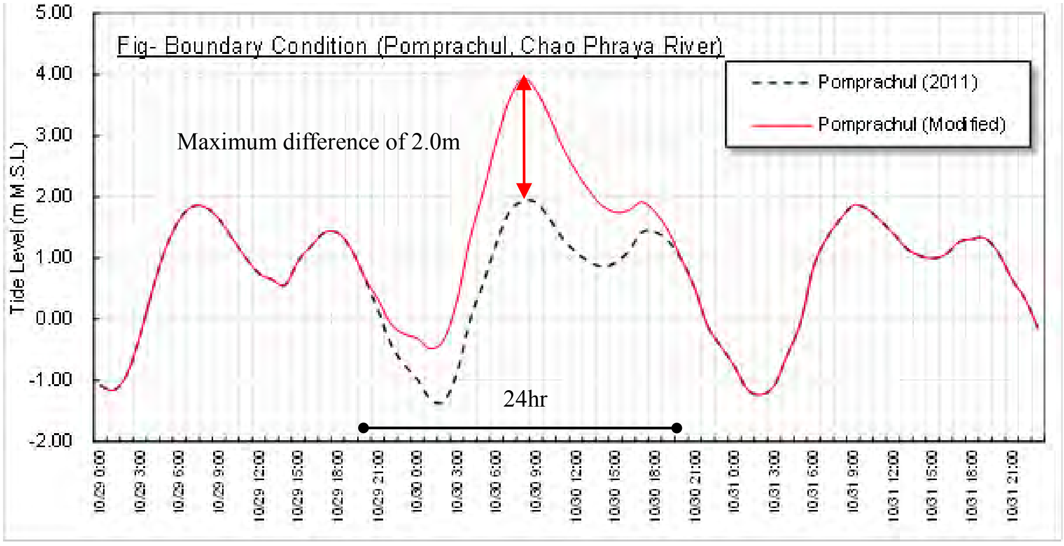
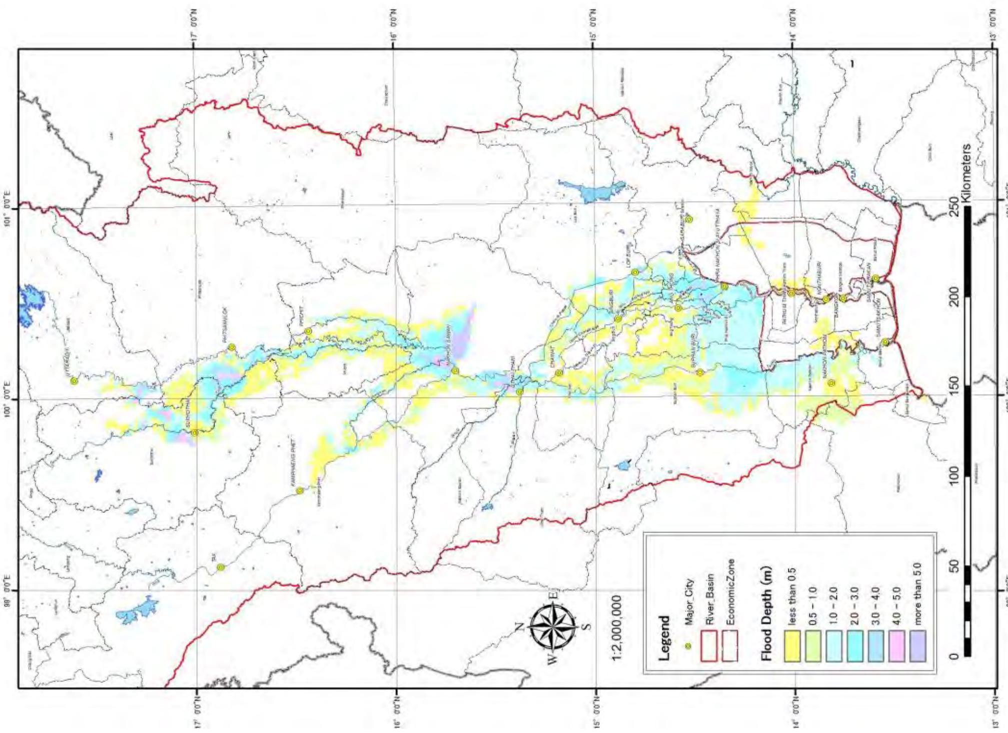
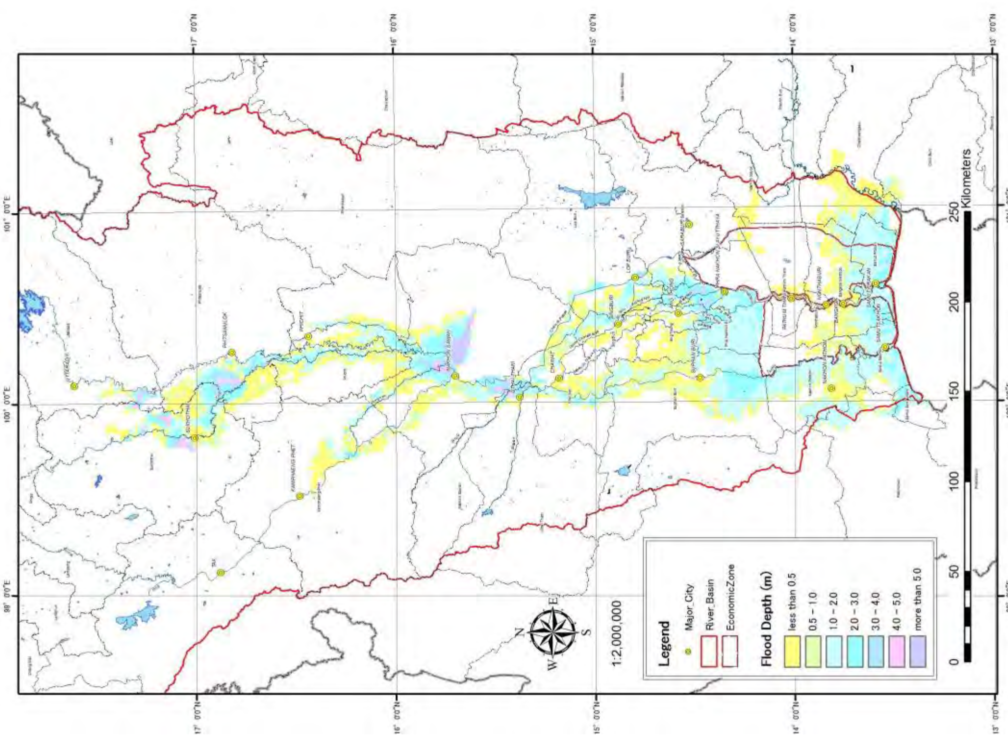


Figure 10.7.6 Application of Sea Level at Estuary of the Chao Phraya River and Tha Chin River

Estimated inundation area is shown in Figure 10.7.7 and Figure 10.7.8. These figures show that the effect of storm surge to floods in Chao Phraya River Basin is not negligible. Inundated volume to the flood plain was estimated as 3,600 MCM due to storm surge. In case of a huge storm surge, countermeasures including road elevation along the coastline, river improvement works, construction of tide wall etc., would be necessary.



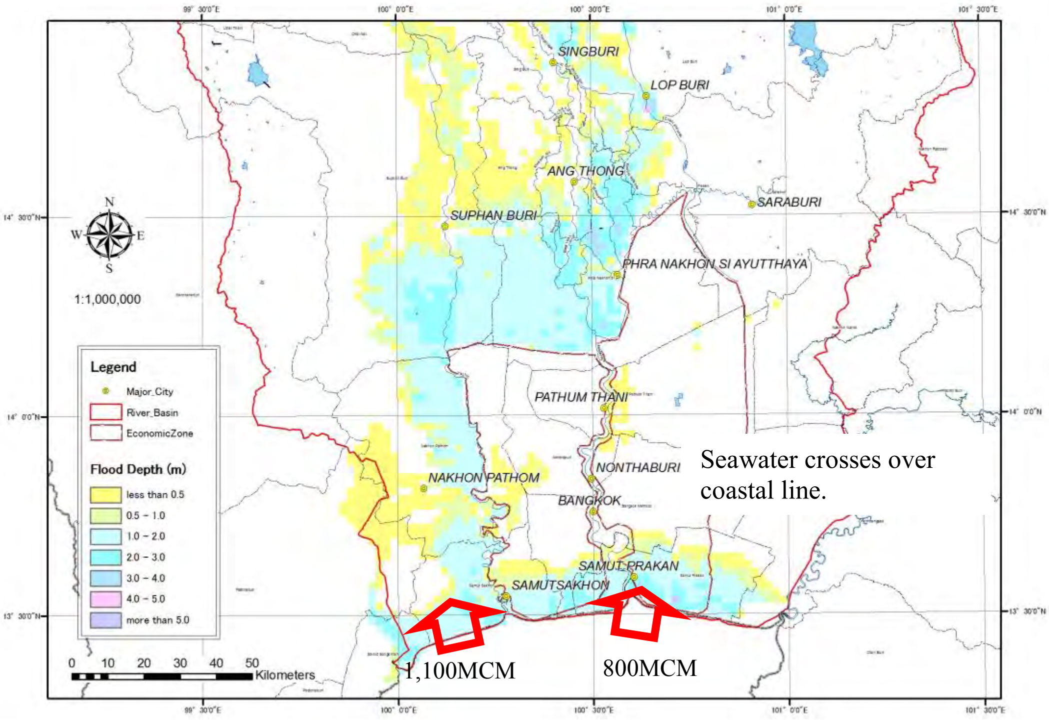
Without Storm Surge



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

Figure 10.7.7 Estimated Inundation Area in Chao Phraya River Basin

(October 30)



(October 31)

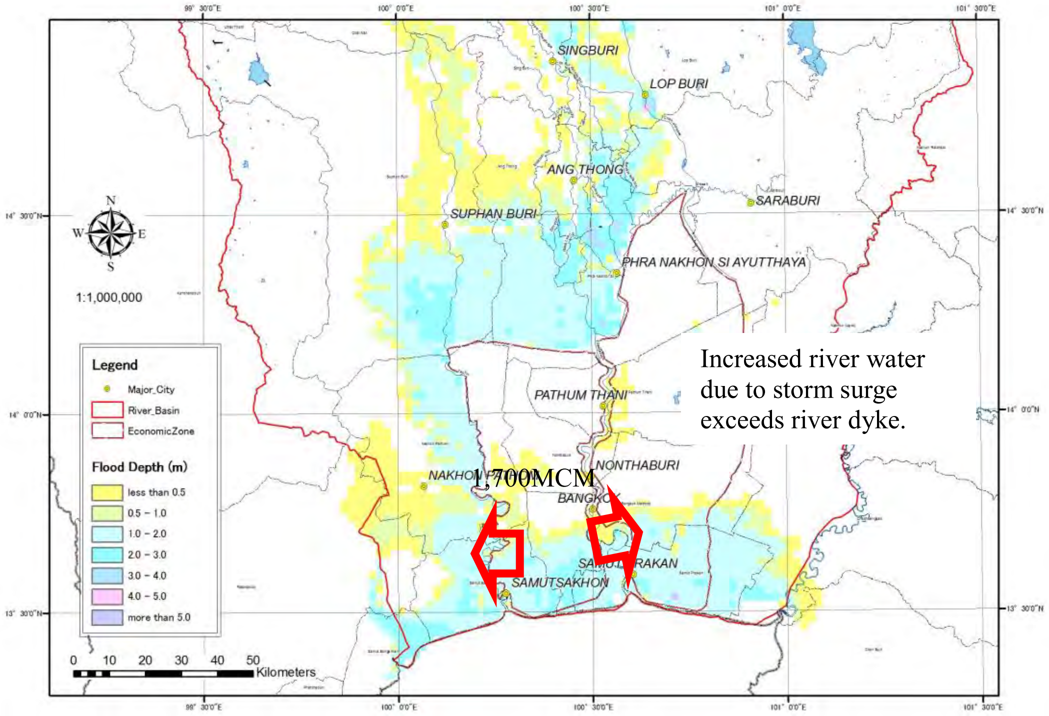


Figure 10.7.8 Simulation on 2m of Storm Surge with 2011 Flood

10.8 Cost Estimation and Implementation Plan for the Master Plan

10.8.1 General

(1) Components of Measures

In the master plan, several countermeasures as shown in Figure 10.8.1 have been studied. Among them, this chapter deals with the cost estimate for the following measures.

1) River Improvement (Ayutthaya Bypass Channel and Dyke Improvement) (C5);
2) Construction of new dams (C2);
3) Construction of flood diversion channel (C6);
4) Improvement of retarding/retention areas (C4); and

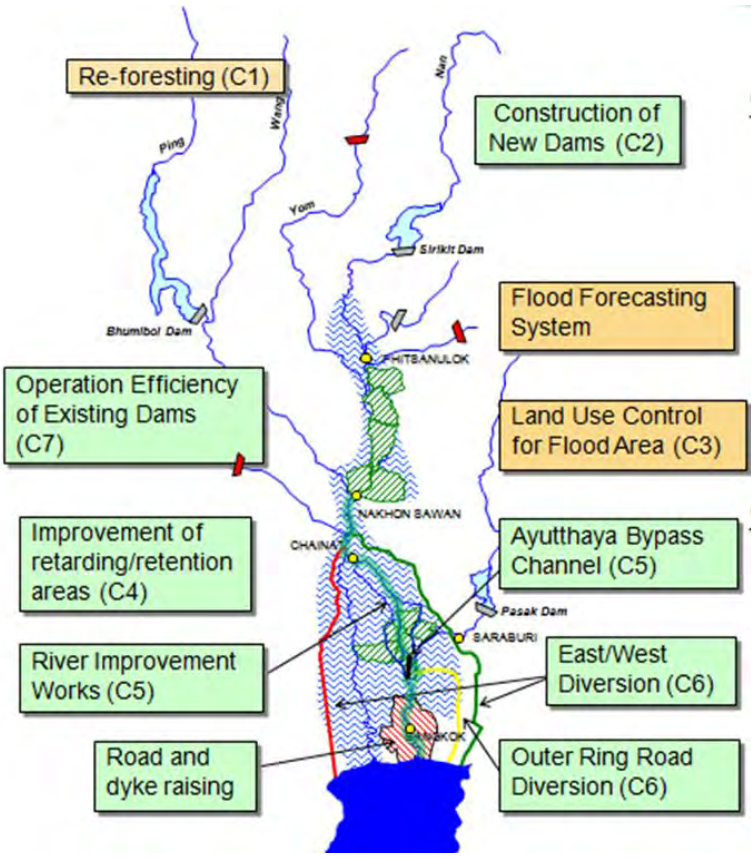


Figure 10.8.1 Location of Master Plan Countermeasures

(2) Conditions of Cost Estimate

(a) Price Level and Currency

Price level of the project cost is the domestic price level as of December, 2012 indicated in Thai Baht. The applied exchange rate is as follows:

- 1 USD = 30.7775 Baht (1 Baht = 0.032 USD)
- 100 JPY = 35.7960 Baht (1 Baht = 2.794 JPY)
  [Bank of Thailand Selling Rate as of 28 December, 2012]

(b) Composition of Project Cost and Estimation Method

The project cost (financial cost) of each component is composed of the following items:

- Construction Cost
- Engineering Cost (cost for survey and design)
- Other Costs (costs for EIA and government administration)
- Physical Contingency
- VAT
- Land Cost
- Compensation Cost
- Price Escalation

Item 1) is composed of direct construction cost and indirect construction cost. Direct construction cost was estimated multiplying the work quantity of the major work item based on the preliminary facility design by the unit cost of such work item. The unit cost was set based on the collected cost information such as cost estimation report in the feasibility study by RID and contract document of the previous relevant project by RID, as shown in Table 10.8.1.

Table 10.8.1 Reference Cost Information provided by RID

Document	Prepared by
Feasibility Study Report	
Water Management Project East of Chao Phraya River (West Diversion Channel), 2012	Panya Consultant, etc.
Feasibility Study on the Development of Flood Prone Low-Land in Chao Phraya River Basin, 2009	Team Consultant, etc.
Contract Document	
Mae Kuang Irrigated Agriculture Development Project Phase II (contract signed in 1987)	Consultant: Sanyu Consultants, etc.; Contractor: Vianini Lavori
Pasak Irrigation Project (Kaeng Khoi – Ban Mo Pumping Irrigation) (contract signed in 2001)	Consultant: Sanyu Consultants, etc.; Contractor: See Sang Karn Yotah

Indirect construction cost was estimated to be 15% to the direct construction cost, based on the instance of feasibility study and previous construction contract. Item 2) to Item 5) was estimated by the ratio to Item 1) and/or sum of other items. The ratio is as shown in Table 10.8.2.

Table 10.8.2 Ratio for Cost Estimation of Items 2), 3), 4) and 5)

Item	Ratio to Item 1)
2) Engineering Cost	
Site survey (Topographic, Geotechnical, etc.)	5% of 1)
Design work	5% of 1)
3) Other Costs	
EIA	5% of [1) + 2)]
Government administration	10% of [1) + 2)]
4) Contingency	10% of [1) + 2) + 3)]
5) VAT	7% of [1) + 2) + 3) + 4)]

Items 6) and 7) were estimated on the basis of necessary land to be acquired and houses/factories to be relocated worked out based on the preliminary design and the unit cost. The unit cost was set based on the data in the feasibility study.

Item 8) was set on the assumption that the annual price escalation is 2.5%, based on the IMF estimate of inflation 2012–2017.

10.8.2 River Improvement

(1) Project Features

(a) Improvement of Chao Phraya River

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

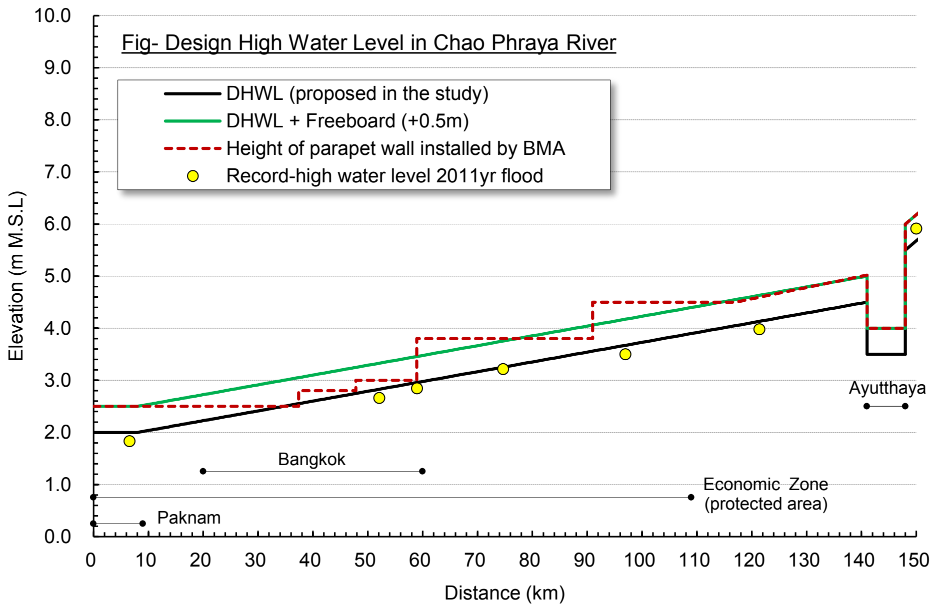


Figure 10.8.2 Installation of Parapet Wall along the Lower Chao Phraya River

(b) Improvement of Tha Chin River

To increase discharge capacity at lower reaches of the Tha Chin River and to protect the economic zone, the following countermeasures are adopted:

i) Four (4) shortcuts are installed;

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

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

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

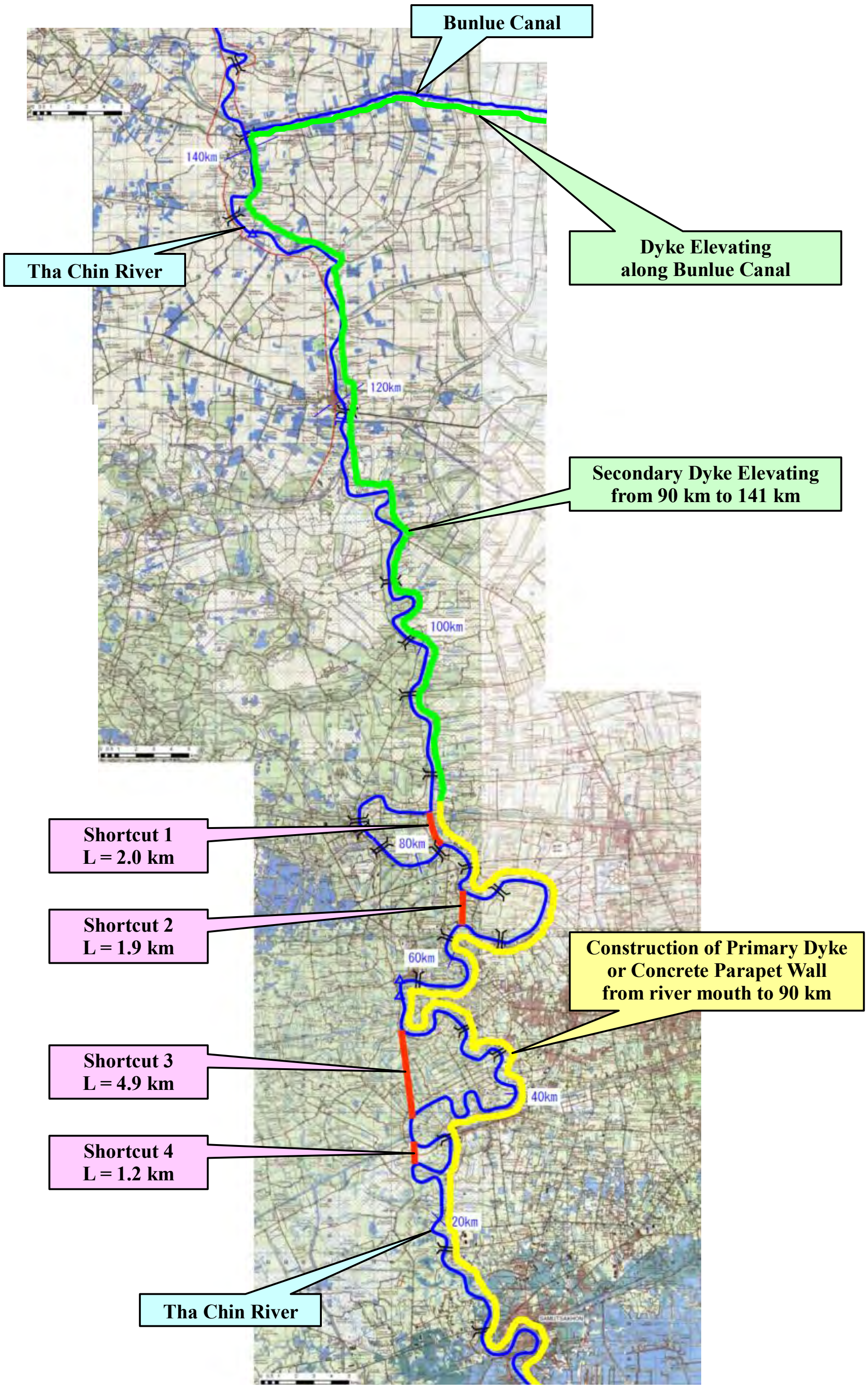


Figure 10.8.3 River Improvement in Tha Chin River

(c) Ayutthaya Bypass Channel

(i) Location

This countermeasure is to construct a bypass channel from upstream side of Ayutthaya urban area to the confluence with Noi River on the Chao Phraya River. The location of the channel is shown in Figure 10.8.4.

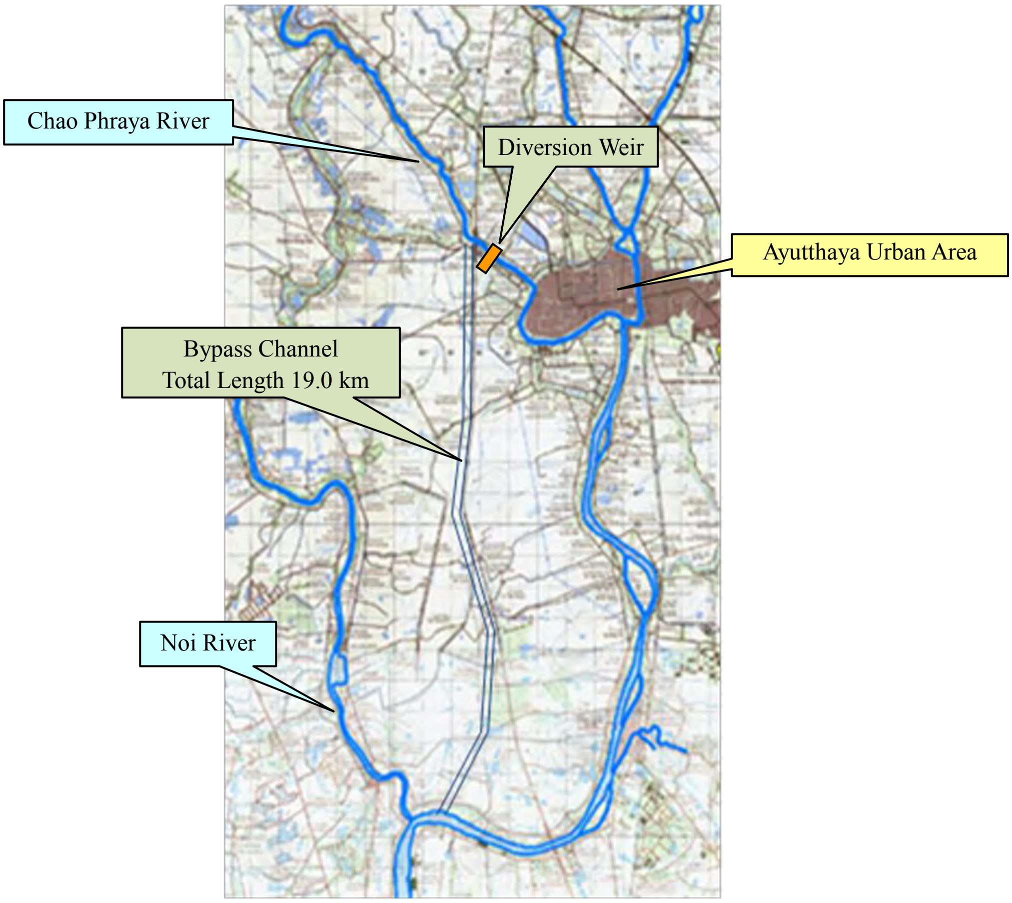
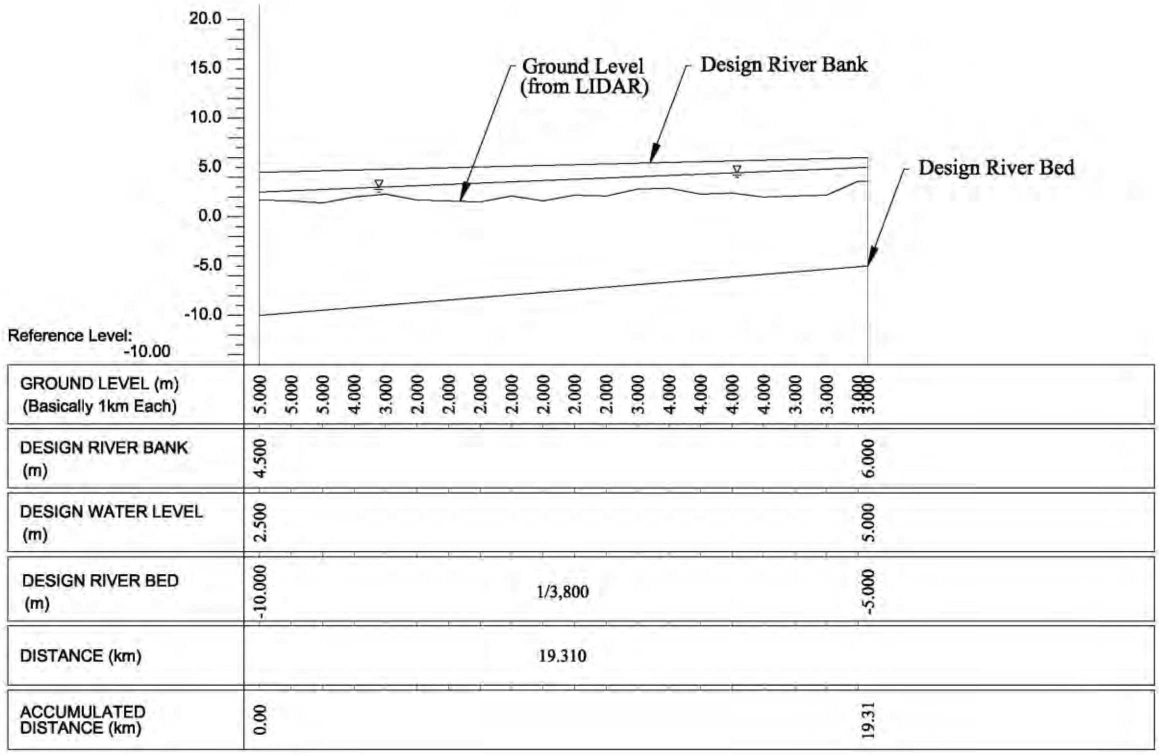


Figure 10.8.4 Location of Ayutthaya Bypass Channel

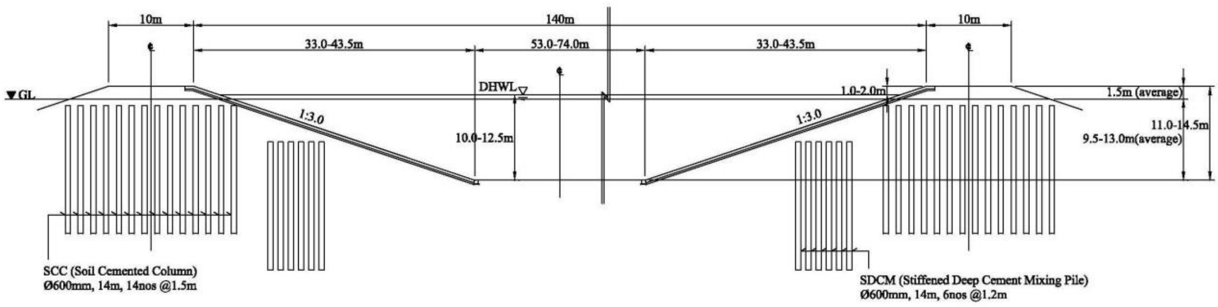
(ii) Project Feature

The design capacity of diversion channel is 1,400 m^3/s. The profile and cross section of the channel is shown in Figure 10.8.5 and Figure 10.8.6.



Source: JICA study team

Figure 10.8.5 Profile of Ayutthaya Bypass Channel



Source: JICA study team

Figure 10.8.6 Standard Cross Section of Ayutthaya Bypass Channel

The construction work is composed of the following major work item:

- Earth Works (including ground improvement works)
- Road Works
- Concrete Works (Canal lining concrete)
- Crossing Facilities (Bridge, Gate, Siphon)

(2) Cost Estimate for River Improvement

(a) Unit Cost of Major Work Item

The unit cost of earthworks and ground improvement work was built-up with unit prices of construction resources such as equipment rental cost and fuel price. Regarding the other work item, the unit cost was calculated in reference to the cost estimation for the previous feasibility study report. The unit cost for land acquisition and compensation was also set in reference to the feasibility study report. The price level of the said reports was 2011, thus the price escalation in 2011–2012, that is 5%, was considered for working out the unit cost for this study.

(b) Project Cost

The estimated project cost is summarized in Table 10.8.3.

Table 10.8.3 Project Cost for River Improvement

Unit: million baht

Item		Ayutthaya Bypass	Dyke Improvement	
			SCWRM M/P	Combination 1 or 2
1.	Construction Cost	9,407	6,364	6,903
2.	Engineering Cost	941	636	690
3.	Other Costs (EIA, Admin.)	1,552	1,050	1,139
4.	Physical Contingency	1,190	805	873
5.	VAT	916	620	672
6.	Land Cost	4,208	1,800	2,646
7.	Compensation Cost	66	0	1,010
Total Cost		18,279	11,275	13,933

10.8.3 Construction of New Dam

(1) Location

Figure 10.8.7 shows the location of the three (3) proposed dams in the Chao Phraya River Basin: Kaeng Sua Ten Dam, Nam Kheg Dam, and Mae Wong Dam.

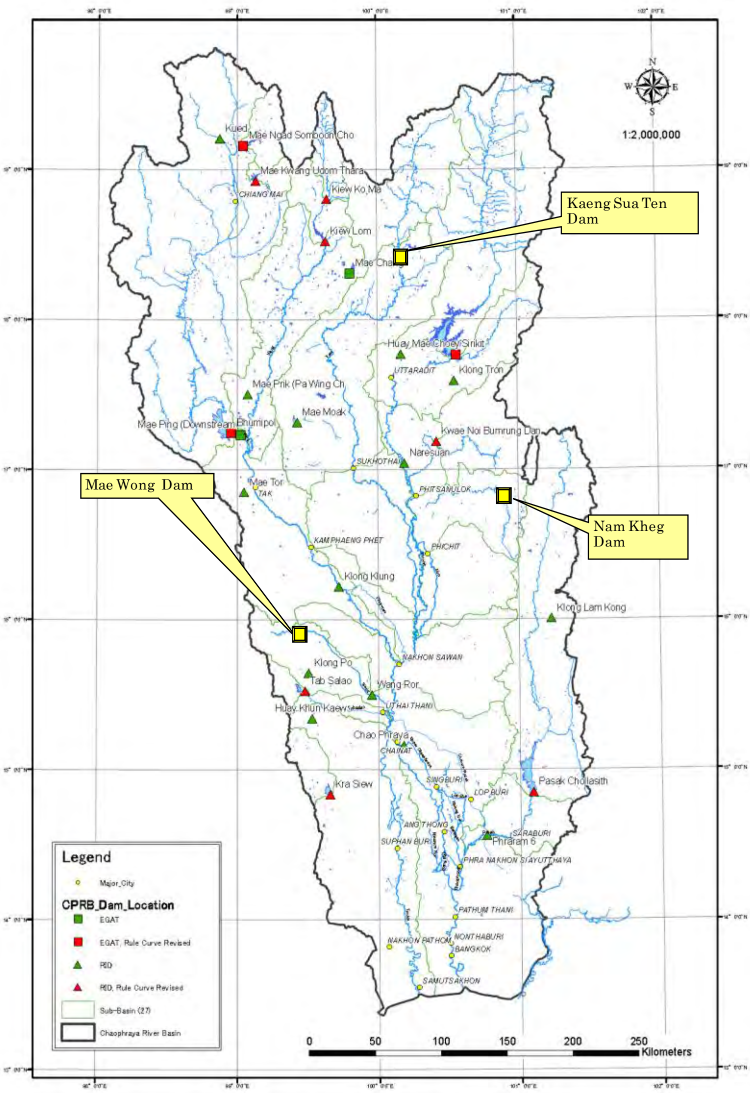


Figure 10.8.7 Location Map of New Dams Proposed in the Chao Phraya River Basin

(2) Project Feature

Table 10.8.4 shows the project feature of the three dams, based on the feasibility study by RID. The design feature of Nam Kheg and Mae Wong dam were determined by analogy to the design of Kaeng Sua Ten Dam.

Table 10.8.4 Project Feature of Proposed New Dams

Item	Kaeng Sua Ten Dam	Nam Kheg Dam	Mae Wong Dam
River Basin	Yom River	Nam River	Sakae Krang River
Planning Feature			
Catchment Area	3,538 km^2	937 km^2	612 km^2
Crest Elevation	261m MSL	538 m MSL	210 m MSL
Crest Length	540 m	757 m	903 m
Reservoir Area	66.8 km^2	11.2 km^2	17.6 km^2
HWL/LWL	258 m/218 m	530 m/421 m	205 m/180 m
Effective Storage	1,125 MCM	542 MCM	238 MCM
Maximum Design Discharge	5,360 m^3/s	3,030 m^3/s	2,470 m^3/s
Design Feature			
Dam Type	Rock Fill Type	Rock Fill Type	Rock Fill Type
Dam Hight	69 m	128 m	56 m
Dam Slope (Up/Down stream)	1 : 3.0 / 1 :2.0	1 : 3.0 / 1 : 2.0	1 : 3.0 / 1 : 2.0
Dam Crest Width	10.0 m	8.0 m	12.0 m
Dam Bottom Width	355.0 m	648.0 m	292.0 m
Dam Embankment Volume	3,910,000 m^3	18,275,000 m^3	4,420,000 m^3
Diversion Tunnel	D 10.0m, L=455m	D 7.5m, L=748 m	D 6.8m, L=392m
Grouting	L=35m x 722 nos.	L=65m x 1011 nos.	L=30m x 1206 nos.

The construction work is composed of the following major work item:

- Construction of diversion tunnel
- Excavation and transportation for dam foundation and spillway
- Quarry excavation and transportation (spoil)
- Quarry excavation (rock) and transportation for dam embankment
- Dam embankment (core)
- Dam embankment (rock)
- Grouting
- Spillway concrete
- Spillway gate

The work volume was calculated based on the preliminary design for the said feasibility study and with several assumptions.

(3) Cost Estimate for Construction of New Dam

(a) Unit Cost of Major Work Items

The unit costs of major work items were worked out in reference to the Contract BQ (Bill of Quantities) of a previous and relevant project, the Mae Kuang Project conducted by RID, and converted to the 2012 price level.

(b) Project Cost

The estimated project cost is summarized in Table 10.8.5.

Table 10.8.5 Project Cost for New Dam

Unit: million baht

Item		Kaeng Sua Ten Dam	Nam Kheg Dam	Mae Wong Dam	Total of Three Dams
1.	Construction Cost	12,944	21,182	6,945	41,071
2.	Engineering Cost	1,294	2,118	695	4,107
3.	Other Cost (EIA, Admin.)	2,136	3,495	1,146	6,777
4.	Physical Contingency	1,637	2,680	879	5,196
5.	VAT	1,261	2,063	677	4,001
6.	Land Cost	5,460	874	1,373	7,706
7.	Compensation Cost	647	1,059	347	2,054
Total Cost		25,379	33,471	12,061	70,911

10.8.4 Construction of Flood Diversion Channels

(1) Location

Figure 10.8.8 shows the planned route of three diversion channels: (i) West Diversion Channel; (ii) East Diversion Channel; and (iii) Outer Ring Road Diversion Channel.

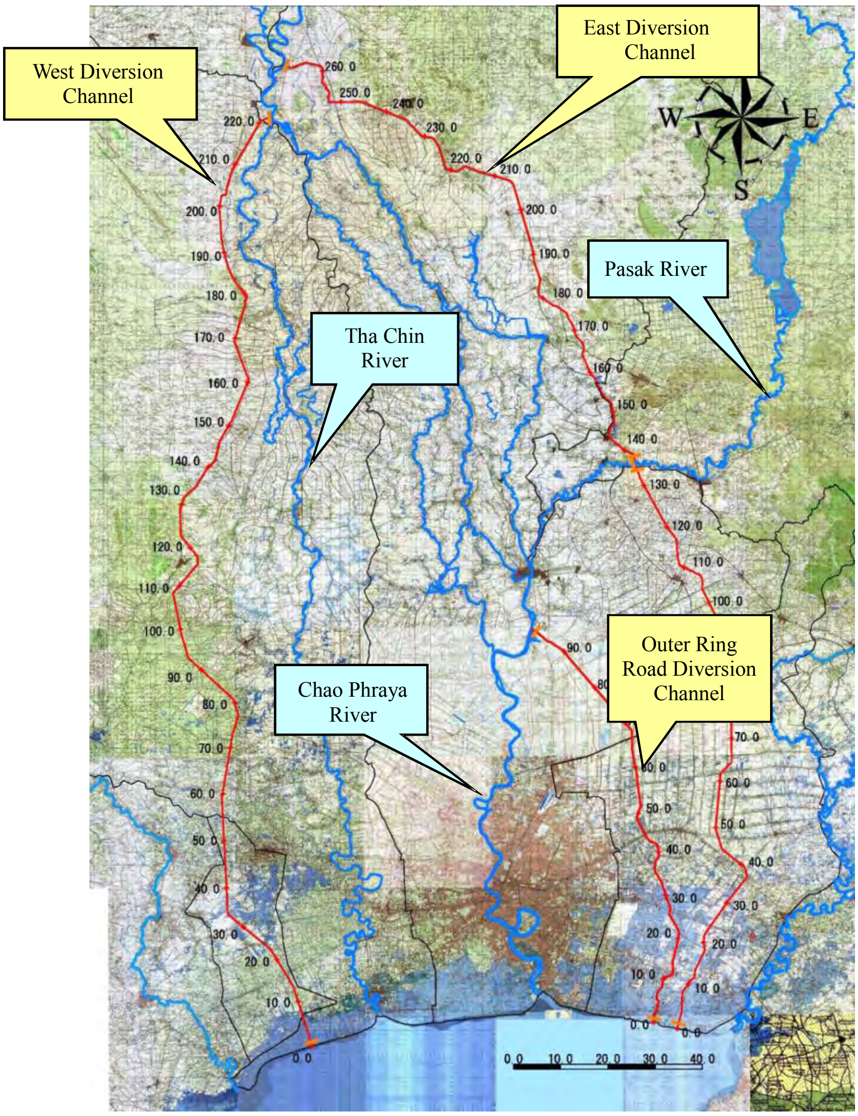


Figure 10.8.8 Location Map of Three New Diversion Channels

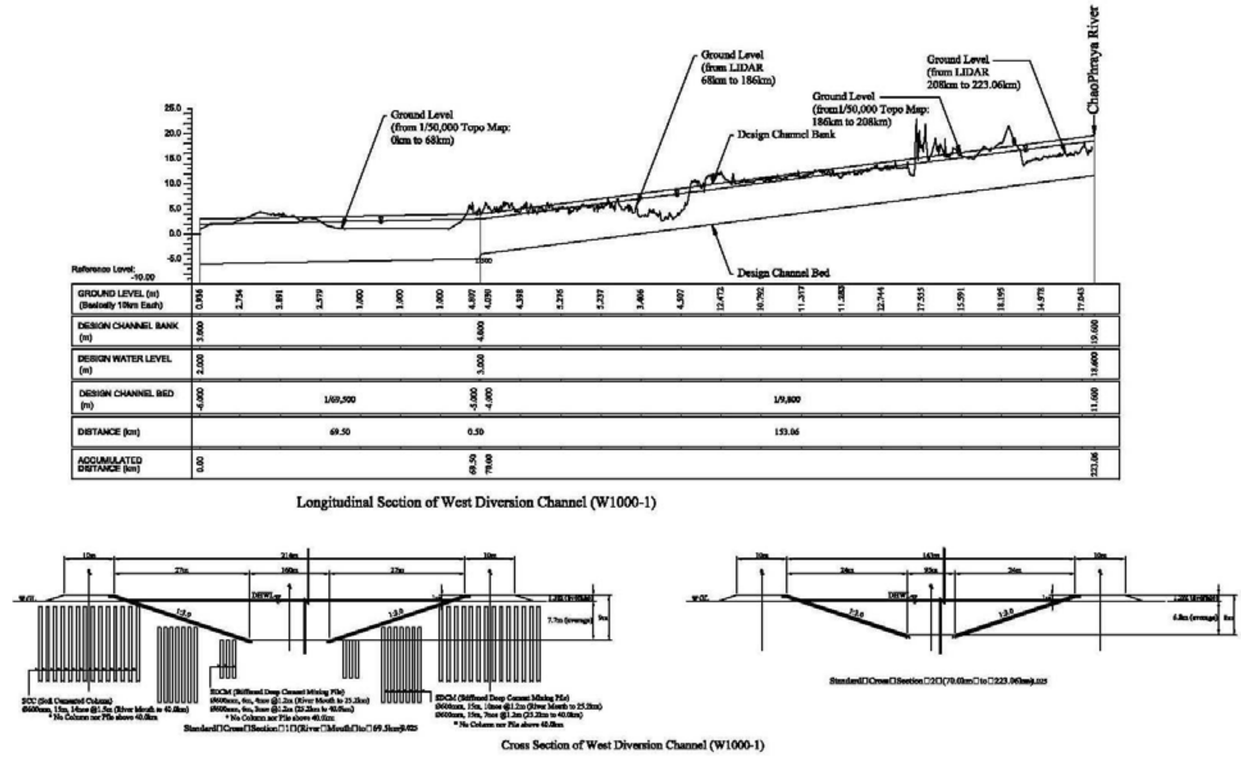
(2) Project Features

Alternatives to the diversion channel as shown in Table 10.8.6 were studied and cost for each alternative was worked out.

Table 10.8.6 Alternatives to Diversion Channels

Alternative	Design Capacity	Type of Channel	Concrete Lining
West Diversion Channel			
W1500-1	1,500 m^3/s	Excavated channel	Lining on slope portion
Outer Ring Road Diversion Channel			
O500-1	500 m^3/s	Excavated channel	Lining on slope portion
O1000-1	1,000 m^3/s	Excavated channel	Lining on slope portion

The profile and cross section of W1000-1 and O500-1 are shown in Figure 10.8.9 and Figure 10.8.10, respectively.



Source: JICA study team

Figure 10.8.9 Profile and Cross Section of West Diversion Channel (W1000-1)

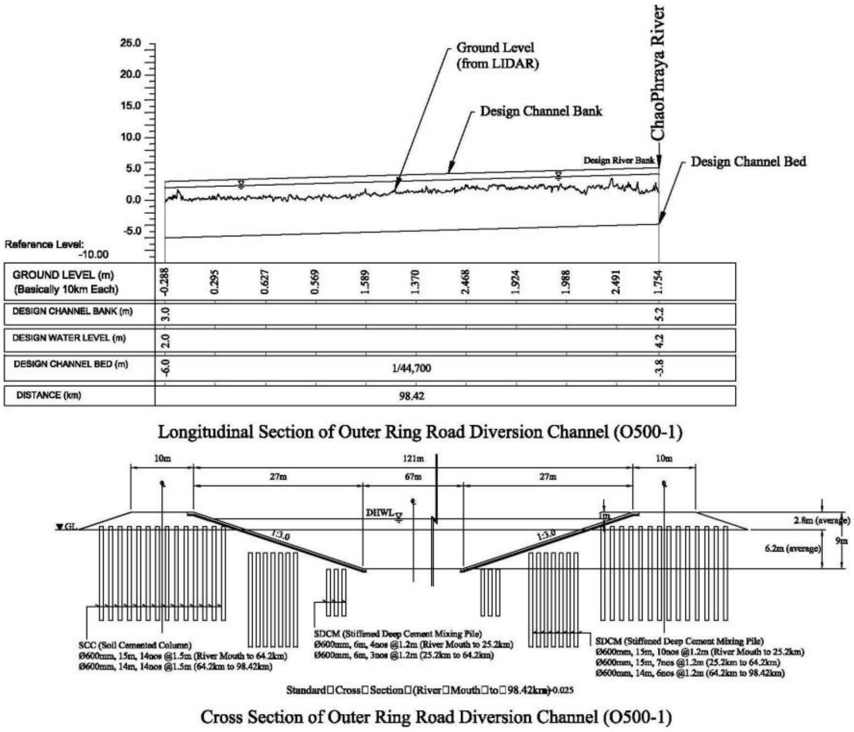


Figure 10.8.10 Profile and Cross Section of Outer Ring Road Diversion Channel (O500-1)

The construction work is composed of the following major work item:

- Earth Works (including ground improvement works)
- Road Works
- Concrete Works (Canal lining concrete)
- Crossing Facilities (Bridge, Gate, Siphon)

(3) Cost Estimate for Flood Diversion Channel

(a) Unit Cost of Major Work Items

The same unit costs as of "2. River Improvement" has been applied as unit costs of major work items.

(b) Project Cost

Estimated project cost for each of the alternatives is summarized in Table 10.8.7.

Table 10.8.7 Project Cost for Flood Diversion Channel

Unit: million baht

Item		W1500-1	O500-1	O1000-1
1.	Construction Cost	119,733	47,908	68,187
2.	Engineering Cost	11,973	4,791	6,819
3.	Other Cost (EIA, Adm.)	19,756	7,905	11,251
4.	Physical Contingency	15,146	6,060	8,626
5.	VAT	11,663	4,667	6,642
6.	Land Cost	30,776	18,821	29,701
7.	Compensation Cost	1,910	482	772
Total Cost		210,956	90,634	131,996

10.8.5 Improvement of Flood Retarding Area

(1) Location

Improvements for the 13 retarding areas (5 in the north of Nakhon Sawan and 8 in the north of Ayutthaya) were planned by RID based on the "Feasibility Study on the Development of Flood Low Lands in Chao Phraya Basin (2009)." Location of the retarding area is shown in Figure 10.8.11 and Figure 10.8.12.

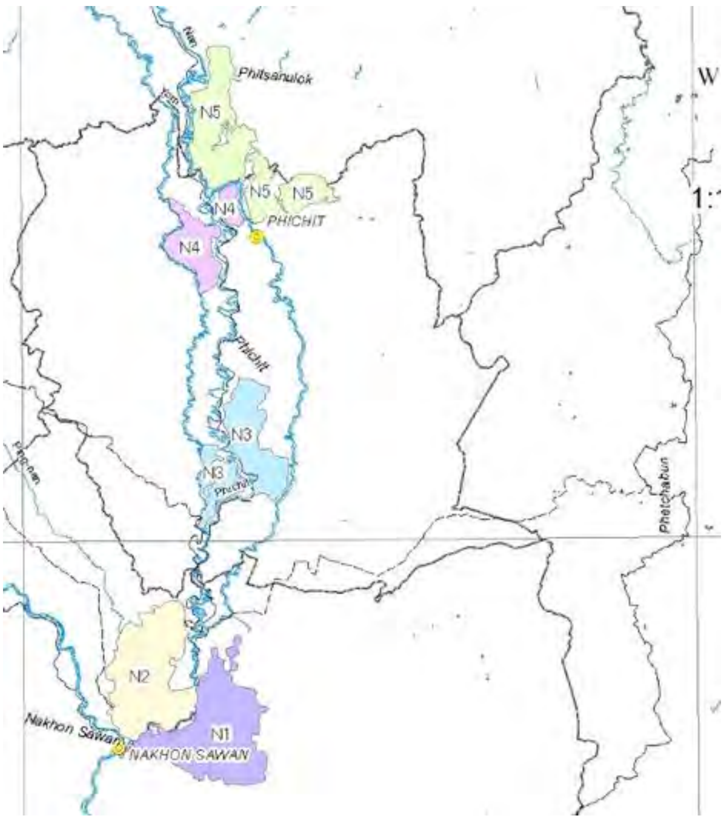


Figure 10.8.11 Location Map of Retarding Area (North of Nakhon Sawan)

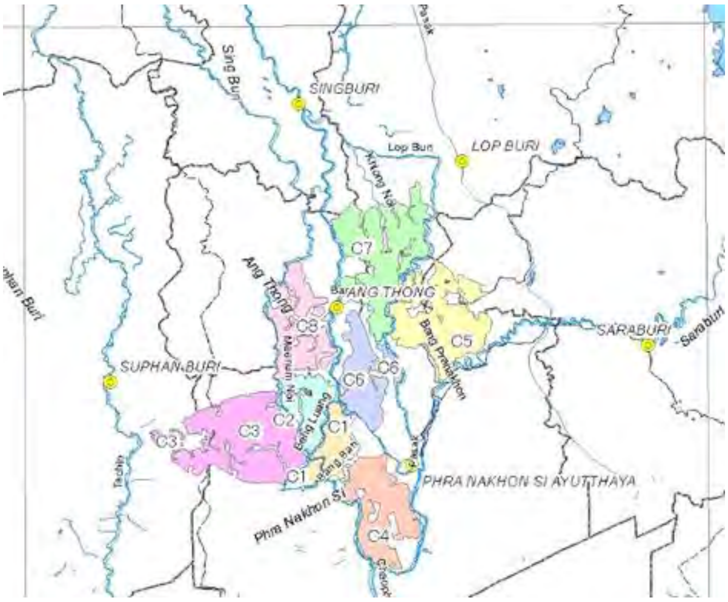


Figure 10.8.12 Location Map of Retarding Area (North of Ayutthaya)

(2) Project Feature

The feature of the retarding area to be improved is shown in Table 10.8.8.

Table 10.8.8 Feature of Retarding Area

Name		Retention Area (km^2)	Capacity (MCM)	Ave. Water Depth (m)
North of Nakhon Sawan				
N1	Borapetch Swamp – Chum Sang	219	233	1.1
N2	Chum Sang – Gao Liao	165	238	1.4
N3	Tapan Hin – Bang Moon Nak – Po Talay	147	240	1.6
N4	Mueang PhitchitPhichit – Po Tab Chang	86	147	1.7
N5	Bang Kratum	209	303	1.2
North of Ayutthaya				
C1	Bang Ban 1	52	126	2.4
C2	Pa Moke – Phak Hai	190	125	0.7
C3	Phak Hai – Bang Yeehon	190	257	1.4
C4	Bang Ban 2	117	279	2.4
C5	Don Pud - Maharaj	152	257	1.7
C6	Tung Pookhao Thong – Bang Pahun	89	249	2.8
C7	Chaiyo – Baan Prak	166	259	1.6
C8	Angthong (West side)	99	186	1.9

The works for improvement of the above of each retarding area is composed of construction /restoration of the following facilities:

- Pumping stations
- Gate
- Siphon, Culvert canal
- Natural canal, Irrigation canal
- Bridge
- Dyke embankment, Road

The amount of the above works for each of the retarding area was set according to the facility plan presented in the said feasibility study report.

(3) Cost Estimate for Improvement of Flood Retarding Area

(a) Unit Cost

The unit cost of the above work was worked out in reference to the said feasibility study report and converted to 2012 price level.

(b) Project Cost

The estimated project cost for each retarding basin is summarized in Table 10.8.9.

Table 10.8.9 Project Cost for Improvement of Flood Retarding Area

Unit: million baht

Item		N1 – N5	C1 – C8	Total
1.	Construction Cost	8,855	21,710	30,564
2.	Engineering Cost	885	2,171	3,056
3.	Other Costs (EIA, Admin.)	1,461	3,582	5,043
4.	Physical Contingency	1,120	2,746	3,866
5.	VAT	862	2,115	2,977
6.	Land Cost	11	1,072	1,083
7.	Compensation Cost	-	-	-
Total Cost		13,195	33,396	46,590

10.8.6 Flood Forecasting System

Estimated project cost for the flood forecasting system is summarized in Table 10.8.10.

Table 10.8.10 Summary of Project Cost for Flood Forecasting System

Unit: million baht

Item		Flood Forecasting System
1.	Construction Cost	2,727
2.	Engineering Cost	273
3.	Other Costs (EIA, Admin.)	450
4.	Physical Contingency	345
5.	VAT	266
6.	Land Cost	0
7.	Compensation Cost	0
Total Cost		4,061

10.8.7 Project Cost without Price Escalation

(1) Alternative Combination Cases

Three alternative combination cases as shown in Table 10.8.11 were studied for comparison.

Table 10.8.11 Alternative Combination Cases

Cases	Measures	
SCWRM M/P	C2: New Dams	Kaeng Sua Ten, Nam Kheg and Mae Wong Dam
	C4: Improvement of Retarding Area	Total of N1 to N5 and C1 to C8
	C5: River Improvement	Dyke Improvement
	C6: Diversion Channel	West Diversion Channel (W1500-1)
		Outer Ring Road Diversion Channel (O500-1)
	C8: Flood Forecasting System	Forecasting System
Proposed Combination 1	C5: River Improvement	Dyke Improvement
		Ayutthaya Bypass Channel
	C6: Diversion Channel	Outer Ring Road Diversion Channel (O500-1)
	C8: Flood Forecasting System	Forecasting System
Proposed Combination 2	C5: River Improvement	Dyke Improvement
		Ayutthaya Bypass Channel
	C6: Diversion Channel	Outer Ring Road Diversion Channel (O1000-1)
	C8: Flood Forecasting System	Forecasting System

(2) Project Cost without Price Escalation

Estimated project cost without price escalation is summarized in the following table.

Table 10.8.12 Project Cost without Price Escalation

SCWRM M/P Module		Description	Capacity (m^3/s)	Project Cost (million baht)		
				SCWRM M/P	Proposed Combination 1	Proposed Combination 2
C1	Reforestation	-	-	*NE* *	*NI* **	*NI*
C2	Construction of New Dams	3 dams	-	70,911	*NI*	*NI*
C3	Land Use Control for Flood Area	-	-	NE	*NI*	*NI*
C4	Improvement of Retarding / Retention Areas	13 retention ponds	-	46,590	*NI*	*NI*
C5	River Improvement	River channel improvement	-	11,275	13,933 ****	13,933 ****
		Ayutthaya Bypass Channel (L=19km)	1,400	*NI*	18,279	18,279
C6	Flood Diversion Channel	West diversion channel (L=223km)	1,500	210,956	*NI*	*NI*
		Outer ring road diversion channel (L=98km)	500	90,634	90,634	-
			1,000	-	-	131,996
C7	Operation Efficiency of Existing Dams	Bhumibol, Sirikit, Kwae Noi, Pa Sak dams	-	*NB* ***	*NB*	*NB*
C8	Flood Forecasting System	-	-	4,061	4,061	4,061
Total		-	-	**434,428**	**126,907**	**168,270**

* *NE*: Not estimated (included in SCWRM M/P)
** *NI* : Not included in the proposed combinations
*** *NB*: Budget allocation is not necessary
**** Including river improvement of the Tha Chin River
Note 1: The costs in the respective columns include construction, engineering service, administration, land acquisition, resettlement, physical contingency, price escalation and valued added tax.
Note 2: Nonstructural measures proposed in the study are not included in the cost estimate.

10.8.8 Disbursement Schedule

(1) SCWRM Master Plan

(a) Implementation Schedule

Figure 10.8.13 shows the implementation schedule for SCWRM Master Plan.

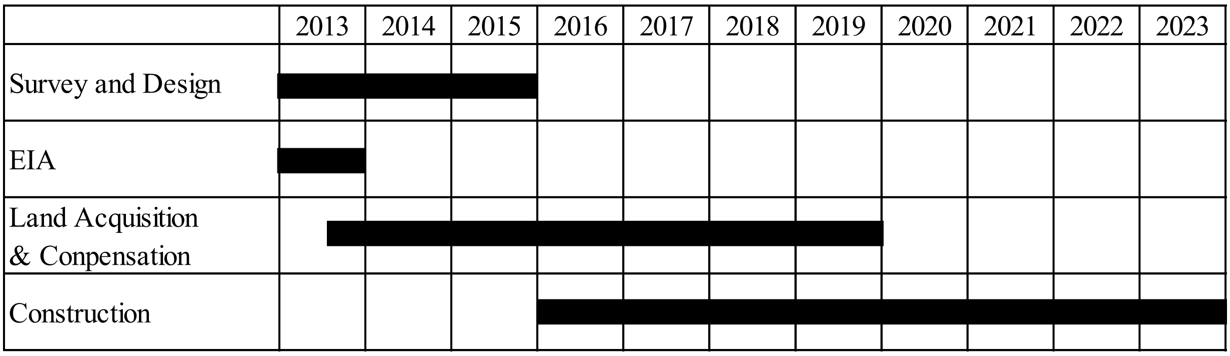


Figure 10.8.13 Implementation Schedule for SCWRM Master Plan

As shown above, prior to commencement of the construction works, EIA, land acquisition and compensation will be commenced. The construction period is estimated to be at least 8 years.

(b) Disbursement Schedule

Based on the above implementation schedule, the disbursement schedule for SCWRM M/P was worked out. The disbursement schedule is summarized in Table 10.8.13.

Table 10.8.13 Disbursement Schedule for SCWRM Master Plan

Unit: million baht

Item	Total	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Base Cost	434,428	28,420	28,478	28,478	39,555	39,555	54,171	68,788	47,708	33,092	33,092	33,092
Price Escalation	73,527	710	1,442	2,190	4,106	5,198	8,651	12,979	10,420	8,235	9,268	10,327
Total	507,955	29,130	29,920	30,668	43,661	44,753	62,822	81,767	58,128	41,327	42,360	43,419

(2) Proposed Combination 1 and Combination 2

(a) Implementation Schedule

Figure 10.8.14 shows the implementation schedule for the proposed Combination 1 and Combination 2.

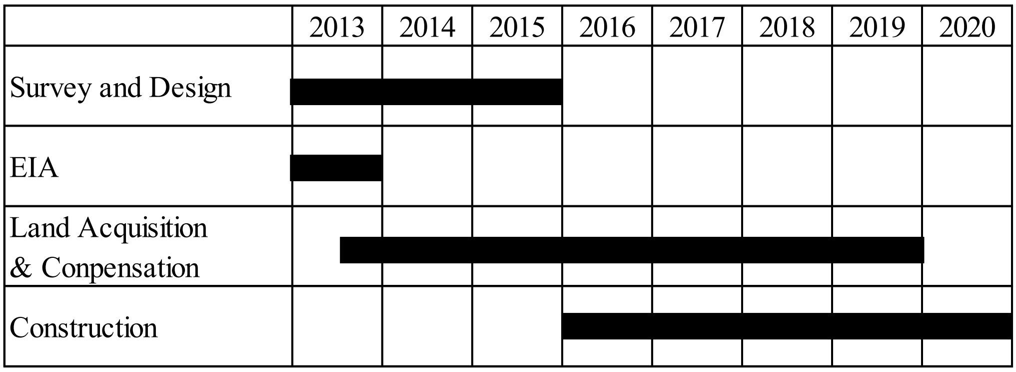


Figure 10.8.14 Implementation Schedule for Proposed Combination 1 and Combination 2

As shown above, prior to commencement of the construction works, EIA, land acquisition and compensation will be commenced. The construction period is estimated to be at least 5 years.

(b) Disbursement Schedule

Based on the above implementation schedule, the disbursement schedule for the proposed Combination 1 and Combination 2 were worked out. The disbursement schedule is summarized in Table 10.8.14 and Table 10.8.15.

Table 10.8.14 Disbursement Schedule for Proposed Combination 1

Unit: million baht

Item	Total	2013	2014	2015	2016	2017	2018	2019	2020
Base Cost	126,907	9,623	11,199	11,199	11,643	27,402	27,402	19,522	8,919
Price Escalation	16,485	241	567	861	1,209	3,601	4,376	3,684	1,948
Total	143,393	9,863	11,765	12,060	12,851	31,002	31,777	23,206	10,868

Table 10.8.15 Disbursement Schedule for Proposed Combination 2

Unit: million baht

Item	Total	2013	2014	2015	2016	2017	2018	2019	2020
Base Cost	168,270	13,122	15,175	15,175	15,462	35,994	35,994	25,728	11,621
Price Escalation	21,739	328	768	1,167	1,605	4,730	5,748	4,854	2,538
Total	190,009	13,450	15,943	16,342	17,067	40,724	41,742	30,582	14,159

(3) Project Cost with Price Escalation

Estimated project cost with price escalation is summarized in the following table.

Table 10.8.16 Project Cost with Price Escalation

SCWRM M/P Module		Description	Capacity (m^3/s)	Project Cost (million baht)		
				SCWRM M/P	Proposed Combination 1	Proposed Combination 2
C1	Reforestation	-	-	*NE* *	*NI* **	*NI*
C2	Construction of New Dams	3 dams	-	70,911	*NI*	*NI*
C3	Land Use Control for Flood Area	-	-	NE	*NI*	*NI*
C4	Improvement of Retarding / Retention Areas	13 retention ponds	-	46,590	*NI*	*NI*
C5	River Improvement	River channel improvement	-	11,275	13,933 ****	13,933 ****
		Ayutthaya Bypass Channel (L=19km)	1,400	*NI*	18,279	18,279
C6	Flood Diversion Channel	West diversion channel (L=223km)	1,500	210,956	*NI*	*NI*
		Outer ring road diversion channel (L=98km)	500	90,634	90,634	-
			1,000	-	-	131,996
C7	Operation Efficiency of Existing Dams	Bhumibol, Sirikit, Kwae Noi, Pa Sak dams	-	*NB* ***	*NB*	*NB*
C8	Flood Forecasting System	-	-	4,061	4,061	4,061
Price Escalation (2013 to 2020 or 2023)		-	-	73,527	16,485	21,739
Total		-	-	**507,955**	**143,393**	**190,009**

* *NE*: Not estimated (included in SCWRM M/P)
** *NI* : Not included in the proposed combinations
*** *NB*: Budget allocation is not necessary
**** Including river improvement of the Tha Chin River
Note 1: The costs in the respective columns include construction, engineering service, administration, land acquisition, resettlement, physical contingency, price escalation and valued added tax.
Note 2: Nonstructural measures proposed in the study are not included in the cost estimate.

CHAPTER 11 PROJECT EVALUATION

11.1 Economic Evaluation

11.1.1 Methodology

(1) General

The main objective of the economic evaluation here is to examine the investment efficiency of the component of the Master Plan from the viewpoint of national economy using cost-benefit analysis in cases where it can be applied. Market prices have been converted to economic ones where the influence of market distortion is removed, (the so-called shadow prices). Opportunity costs are used for the costs of goods and services whose markets do not exist. Economic Internal Rate of Return (EIRR) is used here as the indicator of efficiency of project investment.

(2) Preconditions

The following preconditions are assumed in the economic evaluation. Additional preconditions will be clarified as necessary.

(a) With-Project and Without-Project

"Without-Project" is the case where flood is managed by the currently existing systems. "With-Project" is the case where the project component is implemented into the currently existing systems.

(b) Evaluation Period

Evaluation period covers the whole project life from the preparation of construction. It is decided as 2013 to 2050 (38 years after the commencement of the project).

(c) Standard Conversion Factor (SCF)

A conversion factor is the ratio between the economic price value and the financial price value for a project output or input. When it is calculated for the economy as a whole, it is called as Standard Conversion Factor (SCF) or an average conversion factor. Since border prices are regarded as economic prices, SCF is used for bringing such goods that are valued in domestic price level and those that are valued in border price level to a common base. In addition, SCF is simply the inverse of the Shadow Exchange Rate Factor (SERF), which is the ratio of the shadow exchange rate to the official exchange rate by definition. SCF of Thailand is estimated as 1 (one).

(d) Shadow Wage Rate Factor

Considering the low unemployment rate and its downward trend in Thailand, Shadow Wage Rate Factor (SWRF) or the ratio between its shadow wage rate and its price for unskilled labor can be estimated as 1 (one).

(e) Price Level

Price level is set at 2012. Price data before 2012 is adjusted to the 2012 level by applying the inflation rate.

(f) Social Discount Rate

Twelve percent (12%) is employed as the social discount rate for this economic analysis.

(3) Costs

Incremental costs are included in the evaluation by comparing "with-project" and "without-project situations." Costs are calculated in the form of cash flow of each year during the evaluation period. The following cost items are considered:

(a) Capital Cost

Capital cost includes costs of construction of facilities and equipment, and consulting services. Economic evaluation includes physical contingencies but excludes price escalations.

(b) Operation and Maintenance Cost

Operation and maintenance cost for each year is included. Price escalation is not included.

(c) Depreciation

Since the money allocated and subject to depreciation is not actually spent at that time, it is not included in the cost items.

(4) Benefits

Incremental benefits are included in the evaluation by comparing with-project and without-project situations. The benefits are calculated in the form of cash flow of each year during the evaluation period. Benefits of a flood management project are the reduction or mitigation of damages caused by floods.

As for the direct damage caused by flood, generally, it can be calculated by the following formula:

[Direct Damage in the Area (Baht)] = [Area Size (km^2)] × [Damageable Value (Baht/km^2)] × [Damage Rate by Inundation Depth]

The damageable value is the maximum amount of asset value that will be damaged by the inundation. It is assumed that damage rate is a function of inundation depth (m) and the function should be estimated. Since the flood causing inundation is a probability event, the damage value to be calculated is the yearly expected value based on the probability of flood occurrence (sum of damages multiplied by each flood probability). In this project, the flood analysis in different five flood scales, 2-year, 10-year, 30-year, 50-year and 100-year return period, are conducted. In the economic evaluation, conceivable flood risk has to be considered even after completion of the project and the flood analysis considering the dike breaches is done. The assumed dike break points are selected according to the following conditions,

i) Flood analysis counting dike breaches is done for Chao Phraya River and Pasak River. The dike breaches in the both rivers would damage the economic zone.
ii) Relative elevation between embankment and dike exceeds more than 2.0m and, duration that water level is higher than DHWL in Chao Phraya River, and the average dike height minus 50cm in Pasak River, is more than thirty days. In 2011yr, dike breaches occurred intensively in the sections with high relative elevation (refer to *Chapter 2, 2.1.4 River System*) and the longer duration of water lever keeping high, the more risk of dike breach due to seepage failure of dike body increases.

The Inundation maps in different flood scales and assumed dike breach points are shown in *Supporting Report*, *Sector P: Economic Evaluation*.

Estimation of indirect damages varies for each category. It will be discussed later in actual calculation for each category.

11.2 Economic Evaluation of Master Plan

11.2.1 Conditions of Evaluation

(1) Economic Prospects of Thailand

One of the Japanese prestigious commercial banks, the Bank of Tokyo-Mitsubishi UFJ, published a report on the middle-term economic prospects of Thailand in January 2013. Following is the scenario of the economic growth of Thailand up to 2022.

(a) 2012 to 2014: Average growth rate is 4.5% to 4.9%.

The growth rate in 2012 would increase to the middle of 5% level due to the rebound from flood damage in 2011 but that in 2013 will lower again due to the rebound by high growth in 2012. Investment for flood management by the Government as well as increase in direct investment with the expectation of ASEAN Economic Community (AEC) establishment will keep a steady growth. Significant increase in minimum wage in 2012-2013 will increase consumption and support the growth.

(b) 2015 to 2018: Average growth rate is the middle of 4% level.

Thailand will strengthen its role as a production center of ASEAN taking advantage of the AEC establishment. Expansion of consumption as well as increase in export within ASEAN will speed up the growth gradually and the growth rate will reach 5% level in 2018.

(c) 2019 to 2022: Average growth rate is 4.0% to 4.4%.

Growth rate will lower gradually as Thailand will enter a population onus period and the effect of transition of Chinese economy to stable growth economy will materialize. Production of low value-added products will shift to CLM countries due to the increase in labor costs in Thailand. Its dependence on export will lower relatively although it is still a driving force of growth. On the other hand, increase in urbanization as well as increase in per capita GDP to 8,000 USD will pull up the growth by expanding mature consumption such as services.

[Reference]

Oxford Economics, an economic forecasting company in UK, made the following forecast for the Thai economy in the "County Economic Forecast" dated May 24, 2012. It forecasted higher growth than that of the Bank of Tokyo-Mitsubishi UFJ for a few years after the flood recovery.

Year	2011	2012	2013	2014	2015	2016
GDP Growth (%)	0.1	5.3	6.5	5.6	5.4	4.9

Source: Oxford Economics, "Country Economic Forecast," May 24, 2012.

(2) Analysis of Questionnaire Survey on Flood Damage

(a) Manufacturing

In order to examine economic impacts by the 2011 flood, flood damage analysis is conducted with data obtained from a questionnaire survey in manufacturing factories of the seven flooded industrial estates (Aug-Oct 2012). Examinations, results and evaluation of the analysis are as follows:

(i) Relationship between Inundation Depth and Damage Rate of Assets (Whole Sectors)

Examinations are done with all effective data on relationship between inundation depth above the floor and damage rate of assets such as fixed and inventory assets. Data show that lots of damage rate values are scattered at the same depth, indicating no statistically significant relations. The determination coefficients (R^2), 0.0042 for fixed assets and 0.015 for inventory assets also support the results.

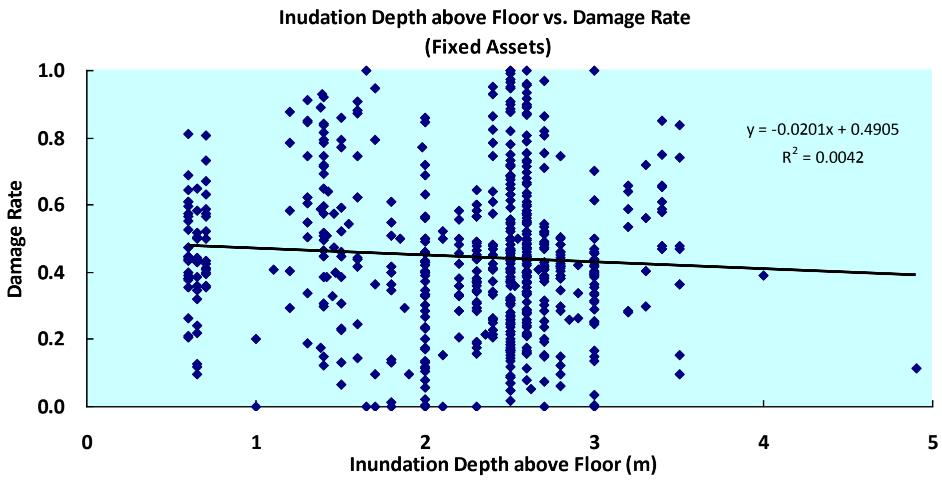


Figure 11.2.1 Relationship between Inundation Depth and Damage Rate (Fixed Assets)

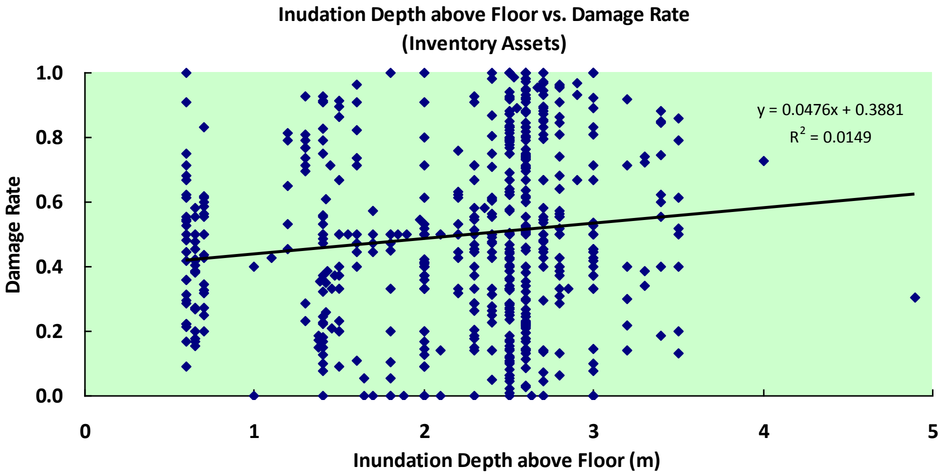


Figure 11.2.2 Relationship between Inundation Depth and Damage Rate (Inventory Assets)

(ii) Relationship between Inundation Depth and Damage Rate of Assets (by Sector)

Considering no relations using the data in whole sectors, another examination is conducted by dividing the data by sector such as: I) Food & Textile; II) Chemical & Metals; III) General Machinery; IV) Electronic Machinery; and V) Others. They indicate that all determination correlations are much lower than those for statistical significance in both assets.

(b) Households

Like the case in manufacturing, damage analysis on households is conducted with data obtained from a questionnaire survey from the residents living in the flooded areas in the Chao Phraya River Basin (Aug-Oct 2012). Examinations, results and evaluation of the analysis are as follows:

(i) Relationship between Inundation Depth and Damage Rate of Assets (Whole Households)

Similar to the method in Manufacturing, examinations are done with all effective data on relationship between inundation depth above the floor and damage rate of assets such as buildings and household goods.

The determination correlations (R^2) obtained from the graphics indicate little significant relations in statistics with 0.0994 for buildings and 0.1161 for household goods.

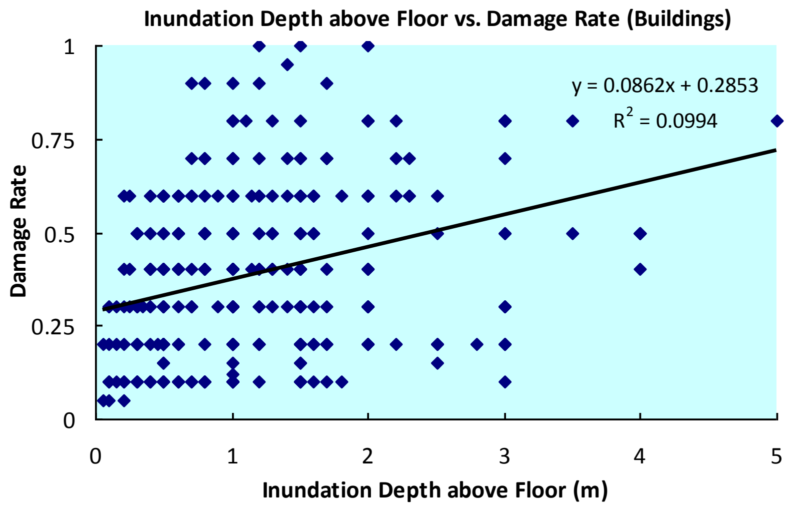


Figure 11.2.3 Relationship between Inundation Depth and Damage Rate (Buildings)

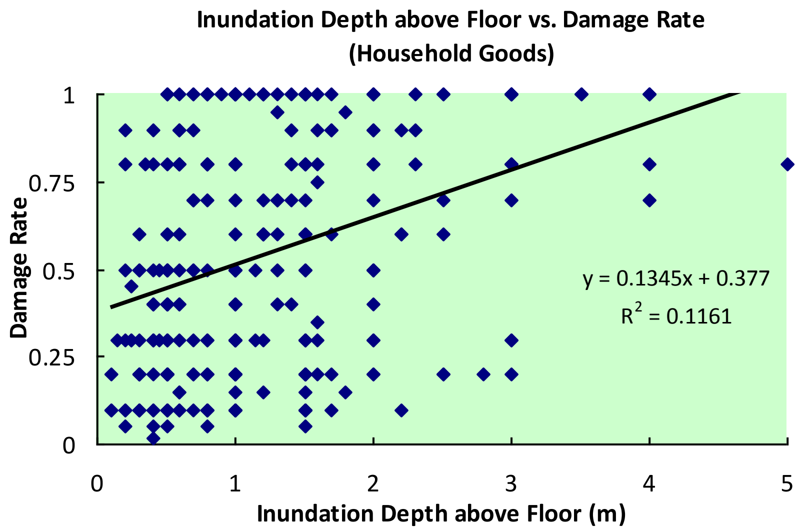


Figure 11.2.4 Relationship between Inundation Depth and Damage Rate (Household Goods)

(ii) Relationship between Inundation Depth and Damage Rate of Assets (by Floor Space)

To examine the scale of damage by living standards, per capita floor space of a house is assumed to be a factor of living standards. Three classifications of floor space are set as: I) less than 30m^2/head; II) 30-100 m^2/head; and III) more than 100m^2/head, considering the balance of data volume. The values of R^2 seem to be better by the classification but all values could not be statistically significant for using flood damage estimation.

(iii) Relationship between Inundation Depth and Damage Rate of Assets (by Story of House)

Based on an assumption that the house structure might give an effect on damages by the flood, the relationship between inundation depth and damage rate of assets by story of house (one- and two-story) is evaluated.

The results show no significant relationships were found between the two parameters, even though a tendency of higher correlations for two-story houses is observed. A negative correlation is seen in the building damage with one-story houses.

11.2.2 Costs

Costs are economic ones where the transfer payments; namely, taxes and duties, are excluded. Following items are included in the cost calculation: (i) Construction; (ii) Engineering; (iii) Other (EIA, admnistration); (iv) Physical contingencies; (v) Land aqiusition; (vi) Compensation; and (vii) O&M. Costs of (i) to (vi) will accrue once as capital costs before and/or in the construction period. O&M cost will accrue every year after the construction is completed and the facilites start to be used. Capital costs are shown in the followint table.

Table 11.2.1 Economic Capital Costs (SCWRM M/P)

(Unit: Million Baht)

Item		New Dams	Retarding Area	River Improve-ment	Diversion Channel		Flood Forecasting System	Total
		Kaeng Sua Ten, Nam Kheg and Mae Wong Dam	Total of N1 - N5, C1 - C8	Dyke Improvement	West Diversion Channel (W1500-1)	Outer Ring Road Diversion Channel (O500-1)		
1.	Construction	41,071	30,564	6,364	119,733	47,908	2,727	248,368
2.	Engineering	4,107	3,056	636	11,973	4,791	273	24,837
3.	Other (EIA, Adm.)	6,777	5,043	1,050	19,756	7,905	450	40,981
4.	Physical Contingency	5,196	3,866	805	15,146	6,060	345	31,419
5.	Land Acquisition	7,706	1,083	1,800	30,776	18,821	0	60,186
6.	Compensation	2,054	0	0	1,910	482	0	4,446
Total		66,911	43,613	10,655	199,294	85,968	3,795	410,236

Table 11.2.2 Economic Capital Costs (Proposed Combination 1)

(Unit: Million Baht)

Item		River Improvement		Diversion Channel	Flood Forecasting System	Total
		Dyke Improvement	Ayutthaya By-Pass	Outer Ring Road Diversion Channel (O500-1)		
1.	Construction	6,903	9,407	47,908	2,727	66,945
2.	Engineering	690	941	4,791	273	6,694
3.	Other (EIA, Adm.)	1,139	1,552	7,905	450	11,046
4.	Physical Contingency	873	1,190	6,060	345	8,469
5.	Land Acquisition	2,646	4,208	18,821	0	25,675
6.	Compensation	1,010	66	482	0	1,558
Total		13,261	17,363	85,968	3,795	120,387

Table 11.2.3 Economic Capital Costs (Proposed Combination 2)

(Unit: Million Baht)

Item		River Improvement		Diversion Channel	Flood Forecasting System	Total
		Dyke Improvement	Ayutthaya By-Pass	Outer Ring Road Diversion Channel (O1000-1)		
1.	Construction	6,903	9,407	68,187	2,727	87,223
2.	Engineering	690	941	6,819	273	8,722
3.	Other (EIA, Adm.)	1,139	1,552	11,251	450	14,392
4.	Physical Contingency	873	1,190	8,626	345	11,034
5.	Land Acquisition	2,646	4,208	29,701	0	36,555
6.	Compensation	1,010	66	772	0	1,848
Total		13,261	17,363	125,355	3,795	159,774

11.2.3 Benefits

As mentioned in the section of methodology, benefits of the project are captured in the form of expected direct/indirect damage reduction. Damages are examined and estimated for each sector including manufacturing, households, agriculture, other industries and infrastructure/public sector below.

(1) Manufacturing Sector

(a) Direct Damages

(i) Damageable Values of Manufacturing Sector

Fixed assets (building, machinery, vehicle, office appliances, equipment, etc.) and inventory assets (materials and components, work in progress, finished goods, goods purchased for resale) of factories are considered as the damageable property of the manufacturing sector.

Available Data

"Factory Data 2011" is available from the website of the Department of Industrial Work (DIW), Ministry of Industry. This data include name, type, address, land area, number of employees, etc., of each factory. There are 40,594 factories included in the data for the 24 provinces that are relevant to the potential inundation areas.

The National Statistical Office (NSO) published "The 2007 Industrial Census," which includes the fixed asset data and inventory asset data in book value in addition to the number of persons engaged by industrial division for each province as of December 31, 2006.

Damageable values are calculated as follows:

(1) Values of fixed assets and inventory assets per person engaged are calculated by the division for each province using 'The 2007 Industrial Census."
(2) Asset values of each factory are calculated by multiplying asset values per person engaged by the number of person engaged in the factory which is included in the "Factory Data 2011."
(3) Since factory data in the "Factory Data 2011" have location data, the location of asset values is identified, which can be utilized to the flood simulation results.

Modification of Calculation Results

Asset values of factories calculated above are modified for the following reasons:

(1) Asset values calculated above are summed up to estimate the total asset value for each Province and compared with the data of "The 2007 Industrial Census" which includes the actual total asset value for each Province, and then the former figures are modified to coincide with the latter data.
(2) Since the values are indicated in 2006 price, they are adjusted to the 2011 price by multiplying with 1.288, which is the wholesale price escalation since 2006.

Table 11.2.4 Wholesale Price Index of Thailand

	2005	2006	2007	2008	2009	2010	2011
Wholesale price index (2005 = 100)	100.0	107.1	110.5	124.3	119.6	130.8	137.9
Comparison with 2006 (times)	–	1.000	1.032	1.160	1.116	1.221	1.288

Source: World Bank

Note: Data is available for years up to 2011

Estimation Result of Damageable Values

Table 11.2.5 presents the damageable values in a potential inundation area of about 35,000 km^2 that is delineated so as to cover inundation areas of past major floods as shown in Figure 11.2.5.

Table 11.2.5 Damageable Values of Factories in Potential Inundation Area

Number	Province	Damageable Values (Million Baht)		
		Fixed Assets	Inventory Assets	Total
1	Bangkok	458,158	213,011	671,169
2	Nonthaburi	36,352	15,324	51,676
3	Pathum Thani	365,725	91,629	457,354
4	Ayutthaya	244,642	57,851	302,493
5	Ang Thong	10,192	2,416	12,608
6	Lopburi	12,830	4,413	17,243
7	Singburi	10,144	5,471	15,615
8	Chainat	2,436	1,036	3,472
9	Saraburi	45,169	14,537	59,706
10	Samut Prakarn	440,810	196,883	637,693
11	Chachoengsao	121,789	47,093	168,882
12	Nakhon Nayok	942	359	1,301
13	Ratchaburi	1,231	551	1,782
14	Suphan Buri	7,040	2,296	9,336
15	Nakhon Pathom	57,889	23,067	80,956
16	Samut Sakhon	136,800	102,835	239,635
17	S. Songkhram	334	124	458
18	Uttaradit	2,146	1,058	3,203
19	Nakhon Sawan	9,841	2,569	12,410
20	Uthai Thani	830	160	990
21	Kampaeng Phet	29	10	39
22	Sukhothai	1,607	615	2,222
23	Phitsanu Lok	5,677	1,222	6,899
24	Phichit	2,499	1,244	3,743
	Total	1,975,112	785,774	2,760,886

(ii) Damage Calculation

Direct damages are estimated by multiplying the damageable values by damage rates that vary according to flood inundation depth. The flood simulation gives inundation depth of each 2km x 2km grid cell in the floodplains. Accordingly the damage calculation is also made on the grid cell basis.

Damageable Values for 2km x 2km Grid Cells

Fortunately, the “Factory Data 2011” of DIW includes the address information at tambon level of factories. By assuming that the density of the damageable values in a tambon is uniform, the values in the tambon are distributed uniformly to grid cells in the tambon. Following figure shows the cell-based damageable values obtained in this way.

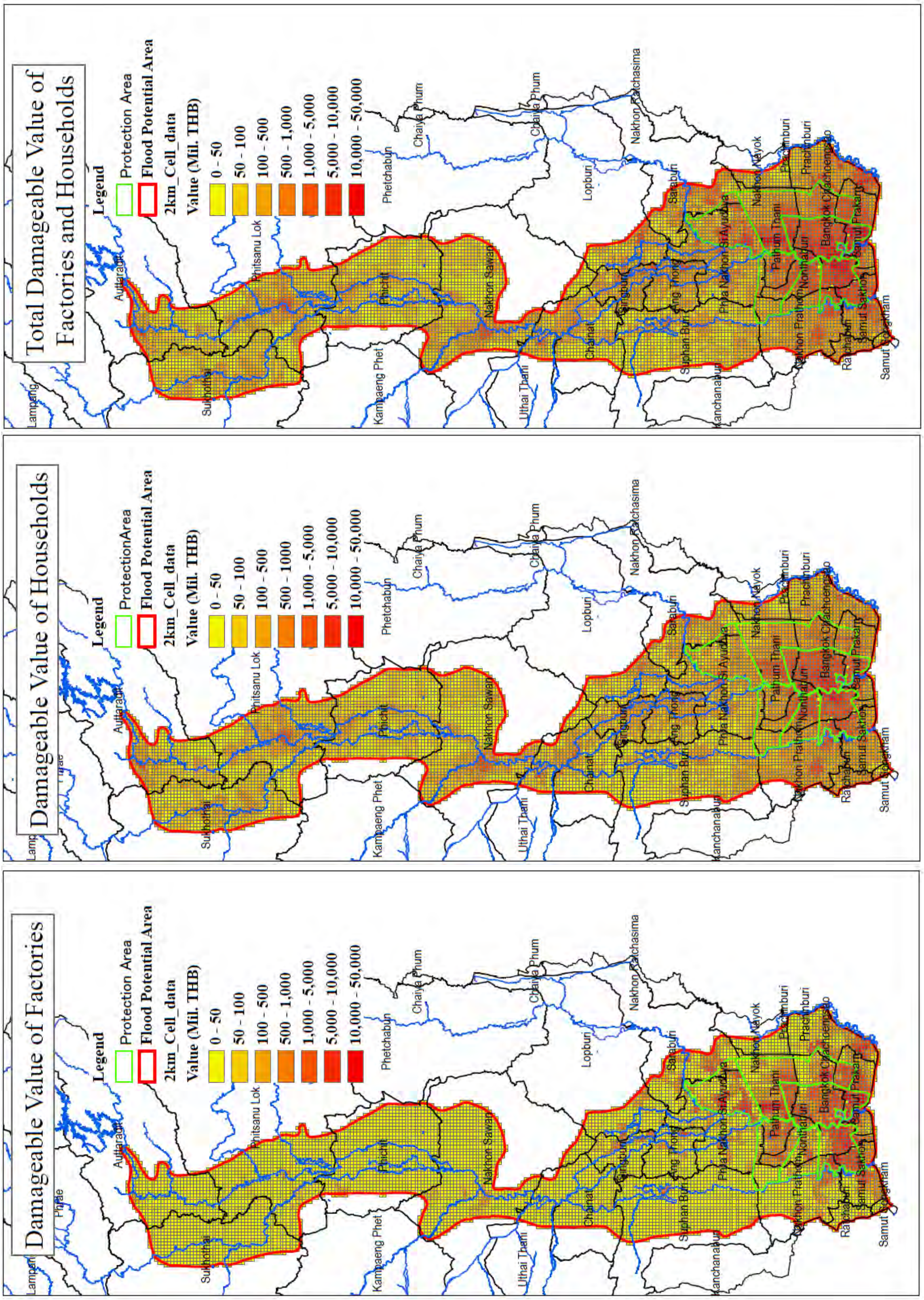


Figure 11.2.5 Distribution of Damageable Values

Floor Level and Damage Rate

To estimate direct damages to fixed and inventory assets, two parameters, floor level and damage rates have to be determined.

The floor level can be defined as the maximum level that generates no damage to the factories. Since Thai people are generally familiar with floods, it might be assumed that factory buildings are built with a certain margin above the habitual flood water level, at the 2-year return period inundation water level, at least, for example, based on past experiences. According to the series of site visits, it is also deemed that industrial estates in the protection area (the economic zone of Bangkok and its vicinity) that were badly affected during the 2011 flood are of lower floor level and more vulnerable. Therefore, it is assumed that the floor level is at the 2-year return period inundation water level in the protection area, and that it is 50cm above the 2-year return period inundation water level in the other areas.

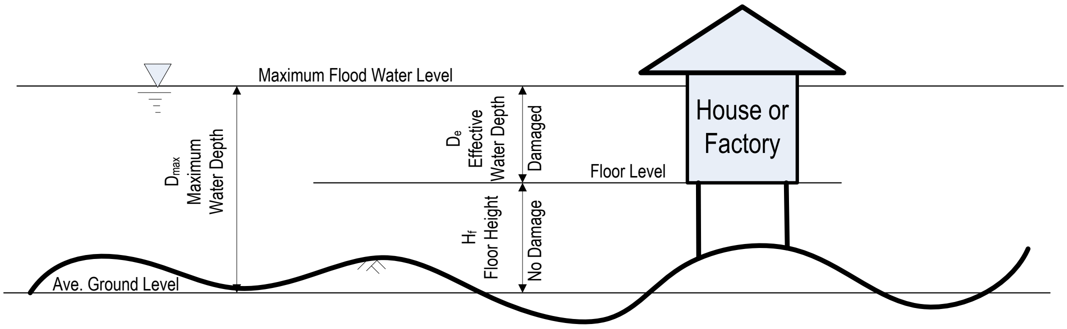


Figure 11.2.6 Floor Level

Regarding the damage rate, there is no significant relationship found between damage and water depth in the interview survey. Therefore, damage rates used in Japan are applied as presented in the following table.

Table 11.2.6 Floor Level and Damage Rates

Floor Level		Damage Rate*					
Protection Area	Other Areas	Damageable Value	Flood Depth over Floor Level				
			0-0.5m	0.5-1m	1-2m	2-3m	Greater than 3m
Flood inundation level of 2-year return period	Flood inundation level of 2-year return period + 50cm	Fixed Assets	0.232	0.453	0.789	0.966	0.995
		Stocks	0.128	0.267	0.586	0.897	0.982

*Source: “Manual for Economic Analysis for Flood Control Projects in Japanese”, Ministry of Infrastructure, Land and Transport, Japan

Estimation of Direct Damages by 2011 Flood

Using the above damageable values, floor levels and damage rates, direct damages are estimated according to flood inundation depths obtained from the flood simulation. The following table compares the estimated direct damages with those estimated by the Ministry of Industry.

According to Table 11.2.7, the total estimated damage is 644 billion THB, which is very close to 514 billion THB by the Ministry of Industry. Especially, those of Bangkok, Nonthaburi, Pathum Thani, and Ayutthaya provinces in the economic zone (Protection Area) are also close to those by the Ministry of Industry, respectively. Therefore, it might be considered that the values of the floor level and damage rates are set properly.

Table 11.2.7 Estimated Direct Damages for 2011 Flood

No.	Province	Estimated by JICA Study Team (Mil. THB)			Estimated by Ministry of Industry (Mil. THB)		
		Fixed Assets	Inventory Assets	Total	7 industrial estates	Others	Total
1	Bangkok	135,123	40,400	175,523		39,100	39,100
2	Nonthaburi	33,768	8,327	42,096		31,200	31,200
3	Pathum Thani	134,925	19,830	154,756	237,400	62,900	391,600
4	Ayutthaya	80,686	11,063	91,749		91,300	
5	Ang Thong	478	65	543		1,400	1,400
6	Lopburi	3,445	889	4,335		37,500	37,500
7	Singburi	458	129	587			
8	Chainat	383	97	480		4,400	4,400
9	Saraburi	748	143	892			
10	Samut Prakarn	44,908	12,918	57,825			
11	Chachoengsao	15,829	3,419	19,248			
12	Nakhon Nayok	18	2	20			
13	Ratchaburi	0	0	0			
14	Suphan Buri	862	139	1,001			
15	Nakhon Pathom	24,567	6,041	30,609			
16	Samut Sakhon	42,038	18,340	60,378			
17	S. Songkhram	0	0	0			
18	Uttaradit	5	4	9			
19	Nakhon Sawan	1,158	202	1,360		8,300	8,300
20	Uthai Thani	115	26	141		200	200
21	Kampaeng Phet	989	38	1,026			
22	Sukhothai	142	37	179			
23	Phitsanu Lok	601	84	686			
24	Phichit	526	52	578			
	Total	521,772	122,248	644,020	237,400	276,400	513,800

<u>Estimation of Direct Damage for Future Scenario</u>

Direct damage for several future development scenario cases are estimated as presented in the following table.

Table 11.2.8 Estimated Direct Damages for Future Scenario Cases

Case No.	Return Period	Direct Damages to Manufacture Sector (Mil. THB)		
		Fixed Assets	Inventory Assets	Total
Reproduction of 2011 Flood		521,772	122,248	644,020
0-1 (Without Project)	2 years	6,327	1,626	7,954
	10 years	155,891	30,764	186,655
	30 years	187,727	36,860	224,587
	50 years	204,844	42,733	247,578
	100 years	303,341	68,661	372,001
1-1 (Master Plan by SCWRM)	2 years	-	-	0
	10 years	138,466	25,952	164,418
	30 years	146,279	28,829	175,108
	50 years	158,943	31,316	190,259
	100 years	183,827	35,441	219,269
11-0 (Proposed Combination-1)	2 years	-	-	0
	10 years	145,928	27,384	173,312
	30 years	170,293	32,722	203,015
	50 years	162,888	32,684	195,572
	100 years	193,114	37,807	230,922
11-1 (Proposed Combination-2)	2 years	-	-	0
	10 years	145,511	27,134	172,645
	30 years	161,781	31,617	193,398
	50 years	163,230	32,441	195,670
	100 years	188,546	36,587	225,133

(b) Indirect Damages

Indirect damages of the manufacturing sector are estimated with the percentages to the total one resulting from the research by the Ministry of Finance and the World Bank in order to get the EIRR and other indicators. Detailed data is shown in (4) Other Sectors and Indirect Damages.

(2) Household Sector

(a) Direct Damages

(i) Damageable Values of Household Sector

Floods cause damages directly on houses and assets of households. Weighted average value of houses and assets per household are estimated and the total value of households in each area is calculated with household number data in the area issued by Department of Provincial Administration (DOPA).

Weighted Average House Value per Household

Weighted average construction cost of house per household is estimated with the following data:

1) Number of houses by type (debouched house, townhouse, condominium, etc.) and by construction material (wood, brick) for each province in "The 2010 Population and Housing Census" by NSO.
2) Construction cost of house by house type and material for each province published by the Ministry of Finance.
3) Standard total floor size by house type by the Ministry of Interior.
4) Average number of stories of highrise buildings such as condominiums and apartments by the City Planning Department of related provinces.

It is assumed that high-rise buildings are directly damaged at their first floor. Hence, the house value of high-rise buildings with *n* stories is reduced to 1/*n*.
Finally, the values were depreciated by 50% because it is assumed that the ratios of houses are all the same for ages after the construction.

Weighted Average Asset Value per Household

Weighted average value of household asset per household is estimated with the following data:

1) Ownership rates of household assets (television, VCD/DVD player, computer, refrigerator, microwave cooker, washing machine, air conditioner, car, motorcycle, etc.) for each province in "The 2010 Population and Housing Census" by NSO.
2) Standard price of commodities published by the Ministry of Commerce.

The asset values of high-rise buildings with *n* stories are reduced to 1/*n* for the same reason as their house value.
Finally, their value is depreciated by 50% because it is assumed that the ratios of commodities are all the same for ages after the purchase.

Estimation Result of Damageable Values

By using the above average values per household and the household number data, the damageable values of the households are estimated as presented in Table 11.2.9.

Table 11.2.9 Damageable Values of Households by Province

Number	Province	Number of Households	Damageable Values (Million THB)		
			House Buildings	Household Assets	Total
1	Bangkok	2,337,074	564,559	381,232	945,791
2	Nonthaburi	556,018	168,451	127,497	295,948
3	Pathum Thani	471,813	131,841	84,800	216,641
4	Ayutthaya	286,925	81,280	38,737	120,017
5	Ang Thong	89,282	24,305	17,623	41,928
6	Lopburi	71,178	20,172	15,009	35,181
7	Singburi	70,306	21,977	13,918	35,895
8	Chainat	74,391	22,206	13,457	35,663
9	Saraburi	100,084	32,134	21,353	53,487
10	Samut Prakarn	531,985	141,410	87,606	229,016
11	Chachoengsao	119,656	36,709	23,874	60,583
12	Nakhon Nayok	19,388	5,849	3,907	9,756
13	Ratchaburi	24,719	8,138	5,372	13,510
14	Suphan Buri	134,367	39,128	27,891	67,019
15	Nakhon Pathom	336,977	112,743	73,062	185,804
16	Samut Sakhon	240,518	73,702	29,339	103,041
17	S. Songkhram	7,022	1,791	1,137	2,928
18	Uttaradit	93,758	25,374	16,200	41,574
19	Nakhon Sawan	209,380	61,871	38,000	99,871
20	Uthai Thani	23,773	7,251	4,065	11,315
21	Kampaeng Phet	526	142	95	236
22	Sukhothai	135,815	31,030	23,186	54,216
23	Phitsanu Lok	208,699	59,324	40,568	99,892
24	Phichit	148,104	35,986	25,937	61,923
	Total	6,291,756	1,707,370	1,113,866	2,821,235

(ii) Damage Calculation

Direct damages are estimated by multiplying the damageable values by damage rates that vary according to flood inundation depth. The flood simulation gives inundation depth of each 2km x 2km grid cell in the flood plains. Accordingly, the damage calculation is also made on the grid cell basis.

Damageable Values for 2km x 2km Grid Cells

Household numbers in 2011 at "tambon" level are available from the Department of Provincial Administration (DOPA). Similar to the industrial sector, by assuming that the density of the damageable values in a tambon is uniform, the values of the tambon are distributed uniformly to grid cells in the tambon. Figure 11.2.5 shows the cell-based damageable values obtained in this way.

Floor Level and Damage Rate

Similar to the manufacturing sector, two parameters, floor level and damage rates have to be determined. According to site surveys, house owners seem to be more careful than those of factories, probably because of inherited memories of past floods. Houses are generally of higher floor levels. Therefore, it is assumed that the floor level is as high as 50cm above the 5-year return period inundation level, regardless of in or out of the Protection Area.

As for the damage rates, there is no significant relationship found between damages and water depths of the interview survey. Therefore, damage rates used in Japan are applied as presented in Table 11.2.10.

Table 11.2.10 Floor Level and Damage Rates

Floor Level	Damage Rate*					
	Damageable Value	Flood Depth over Floor Level				
		0-0.5m	0.5-1m	1-2m	2-3m	Greater than 3m
Flood inundation level of 5-year return period +50cm	House Buildings	0.092	0.119	0.266	0.580	0.834
	Household Assets	0.145	0.326	0.508	0.928	0.991

* Source: "Manual for Economic Analysis for Flood Control Projects in Japanese", Ministry of Infrastructure, Land and Transport, Japan

Estimation of Direct Damages by 2011 Flood

Using the above damageable values, floor level and damage rates, the direct damages are estimated according to flood inundation depths obtained from the flood simulation. Table 11.2.11 compares the estimated direct damages with those estimated under the Post Disaster Needs Assessment (PDNA) by the World Bank and MoF. According to the table, the estimated number of affected houses is very close to that of PDNA. Therefore, the above assumption of the floor level could be regarded reasonable, at least, while the Japanese damage rates generated larger damages than PDNA.

Table 11.2.11 Estimated Direct Damages for 2011 Flood

No.	Province	Estimated by JICA Study Team				Estimated under PDNA			
		Number of Affected Households	Direct Damages (Mil. THB)			Number of Affected Households	Direct Damages (Mil. THB)		
			House buildings	Household Assets	Total		House buildings	Household Assets	Total
1	Bangkok	994,159	22,302	24,454	46,756	761,725	1,954	14,843	16,797
2	Nonthaburi	509,095	14,190	16,927	31,117	204,920	654	3,974	4,628
3	Pathum Thani	243,902	6,270	6,357	12,627	237,394	1,116	4,616	5,732
4	Ayutthaya	128,323	3,383	2,637	6,020	196,929	1,294	3,835	5,129
5	Ang Thong	5,638	141	161	303	50,579	263	981	1,244
6	Lopburi	38,717	1,564	2,177	3,741	33,280	173	645	818
7	Singburi	5,057	145	145	291	21,078	91	408	499
8	Chainat	17,802	759	810	1,569	20,088	106	389	495
9	Saraburi	5,484	162	169	331	23,459	192	455	647
10	Samut Prakarn	17,088	666	694	1,359	-	-	-	-
11	Chachoengsao	84	2	2	5	61,780	326	1,198	1,524
12	Nakhon Nayok	1,414	39	41	81	19,942	199	386	585
13	Ratchaburi	0	0	0	0	-	-	-	-
14	Suphan Buri	30,113	807	907	1,713	84,841	418	1,645	2,063
15	Nakhon Pathom	132,953	4,097	4,202	8,299	89,571	358	1,737	2,095
16	Samut Sakhon	56,188	1,781	1,520	3,300	19,378	31	378	409
17	S. Songkhram	0	0	0	0	-	-	-	-
18	Uttaradit	3,558	264	273	537	-	-	-	-
19	Nakhon Sawan	86,161	2,357	2,328	4,685	51,411	396	1,005	1,401
20	Uthai Thani	10,646	309	302	611	4,440	23	86	109
21	Kampaeng Phet	9,846	305	412	717	-	-	-	-
22	Sukhothai	6,202	438	436	875	-	-	-	-
23	Phitsanu Lok	22,732	728	1,020	1,748	10,946	44	212	256
24	Phichit	21,197	475	544	1,019	14,826	63	287	350
	Total	2,346,359	61,184	66,518	127,702	1,906,587	7,701	37,080	44,781

Estimation of Direct Damages for Future Scenarios

Direct damages for several future development scenario cases are estimated as presented in the following table.

Table 11.2.12 Estimated Direct Damages for Future Scenario Cases

Case No.	Return Period	Number of Affected Households	Direct Damages to Households (Mil. THB)		
			House buildings	Households Assets	Total
Reproduction of 2011 Flood		2,346,359	61,184	66,518	127,702
0-1 (Without Project)	2 years	-	-	-	0
	10 years	230,469	6,749	6,556	13,305
	30 years	418,839	13,477	16,078	29,555
	50 years	521,828	18,437	22,713	41,150
	100 years	656,637	24,187	28,961	53,148
1-1 (Master Plan by SCWRM)	2 years	-	-	-	0
	10 years	22,969	799	732	1,531
	30 years	197,678	5,891	5,584	11,475
	50 years	292,421	8,718	8,635	17,352
	100 years	383,362	11,405	11,702	23,107
11-0 (Proposed Combination-1)	2 years	-	-	-	0
	10 years	96,435	2,832	2,692	5,524
	30 years	270,240	8,241	8,354	16,594
	50 years	306,706	9,433	9,821	19,255
	100 years	436,994	13,768	15,872	29,640
11-1 (Proposed Combination-2)	2 years	-	-	-	0
	10 years	77,137	2,262	2,148	4,410
	30 years	245,635	7,520	7,598	15,118
	50 years	296,099	9,091	9,436	18,527
	100 years	409,633	12,632	14,238	26,869

(b) Indirect Damages

Indirect damages of the household sector are estimated with the percentages to the total which results from the research by the Ministry of Finance and the World Bank in order to get the EIRR and other indicators. Detailed data is shown in (4) Other Sectors and Indirect Damages.

(3) Agricultural Sector

Agricultural damage brought about by the 2011 flood is found as fairly smaller than what had initially been expected from the heaviest disaster with the return period of over 100 years in view of the agricultural policy orientation practiced for years by MOAC and RID before the flood occurrence. However, the population could not get rid of such damages as submergence of their cars, agricultural machinery and cultured fish in their fishponds. Such inevitable damages resulted in per-capita loss of about 1,500 Baht on average.

In this economic context, annual farm income level of farm household is estimated at 249 thousand Baht for north provinces and 381 thousand Baht for southern ones, implying that the flood damage is equivalent to 0.4-0.6% of household income. It follows that such a catastrophic flood actually affected farmers to the same extent as they experience every year as yield fluctuations of their routine crop species. It should be kept in mind that some agricultural damages have not yet been made public, including damages of agricultural machinery, agricultural product-processing units, rice mills, etc. Allowing these invisible damages to additionally count, the actually experienced agricultural damage values would not exceed a few percent of total farm household income.

Table 11.2.13 Total Value of Agricultural Flood Damages

(Unit: Million Baht)

Category / Area	Annual Crop	Fruit Trees	Other Tree Crop	Livestock	Inland Fish Culture	Agri. Prod. Facilities	Farmland Rehabili-tation	Total
Northern CP	488	931	31	44	436	1,445	552	3,927
Central CP	1,465	7,509	254	236	415	2,590	401	12,870
Total	1,953	8,440	285	280	851	4,034	953	16,797
(Share)	(11.6%)	(50.2%)	(1.7%)	(1.7%)	(5.1%)	(24.0%)	(5.7%)	(100.0%)

Source: Ministry of Agriculture and Cooperatives
(Notes)
Annual Crop: maize, cassava, sugar cane, etc.
Fruit Trees: banana, mango, etc.
Other Tree Crop: oil palm, para-rubber, etc.
Livestock: cattle, swine, poultry, etc.

(4) Other Sectors and Indirect Damages

The summary of the research on the flood in 2011 by the Ministry of Finance and the World Bank is shown below. Since damages of the industrial sector and the household sector amount to 88.8% in direct damage and 76.5% in total, these sectors actually dominated the whole damage by the flood in 2011. Considering other industries, tourism is one of the most important industries in Thailand. Its share of direct damages is just 0.8% while that of indirect damages is 11.3%. Further, the share of direct damages of other industries (excluding manufacturing, household and agriculture) in total is 10.3% while that of indirect damages, 28.8%.

Table 11.2.14 Damage by 2011 Flood

(Unit: Million Baht)

	Direct Damage		Indirect Damage		Total	
Infrastructure						
Water Resources Management	8,715	1.4%	-	-	8,715	0.6%
Transport	23,538	3.7%	6,938	0.9%	30,476	2.1%
Telecommunication	1,290	0.2%	2,558	0.3%	3,848	0.3%
Electricity	3,186	0.5%	5,716	0.7%	8,901	0.6%
Water Supply and Sanitation	3,497	0.6%	1,984	0.2%	5,481	0.4%
Productive						
Agriculture, Livestock and Fishery	5,666	0.9%	34,715	4.4%	40,381	2.8%
Manufacturing	513,881	81.5%	493,258	62.0%	1,007,139	70.6%
Tourism	5,134	0.8%	89,673	11.3%	94,808	6.7%
Finance & Banking	-	-	115,276	14.5%	115,276	8.1%
Social						
Health	1,684	0.3%	2,133	0.3%	3,817	0.3%
Social	-	-	-	-	-	-
Education	13,051	2.1%	1,798	0.2%	14,849	1.0%
Housing	45,908	7.3%	37,889	4.8%	83,797	5.9%
Cultural Heritage	4,429	0.7%	3,076	0.4%	7,505	0.5%
Cross Cutting						
Environment	375	0.1%	176	0.0%	551	0.0%
TOTAL	630,354	100.0%	795,191	100.0%	1,425,544	100.0%

Source: Ministry of Finance, Royal Thai Government and World Bank, "Thailand Flooding 2554 Rapid Assessment for Resilient Recovery and Reconstruction Planning

11.2.4 EIRR Calculation

Damages other than direct damages of the manufacturing and household sectors is estimated with the percentages to the total one which resulted from the research by the Ministry of Finance and the World Bank in order to get the EIRR and other indicators. Further, following are assumed in the EIRR calculation:

- Assets are expected to increase with the economic growth. Thus, the benefit is increased in accordance with the forecasted GDP growth rate up to 2022 (end year of GDP forecasting); and
- Benefits of the project will accrue in the construction stage in accordance with its progress after three years of research and design.

Table 11.2.15 Summary of Results

Case	EIRR	B/C	NPV (Billion Baht)
SCWRM M/P	13.0%	1.08	20.46
Proposed Combination 1	29.3%	2.68	137.21
Proposed Combination 2	24.6%	2.17	127.24

11.2.5 Sensitivity Analysis

Sensitivity analysis is carried out for the project on several cases of changes in the benefit or cost as summarized below. Indicators in original case are so high that they are robust to some extent against unfavorable situations (benefit decreasing or cost increasing) in principle. More attention should be paid on benefit decreasing cases since they harm the figures more than cost increasing cases.

Table 11.2.16 Sensitivity Analysis (SCWRM M/P)

	IRR	B/C	NPV (Billion Baht)
Project benefit 10% down	9.1%	0.72	-68.22
Project benefit 20% down	7.3%	0.53	-114.02
Project cost 10% up	11.8%	0.99	-4.04
Project cost 20% up	10.8%	0.90	-28.54

Table 11.2.17 Sensitivity Analysis (Proposed Combination 1)

	IRR	B/C	NPV (Billion Baht)
Project benefit 10% down	21.7%	2.12	91.38
Project benefit 20% down	17.9%	1.71	58.31
Project cost 10% up	27.1%	2.43	129.03
Project cost 20% up	25.2%	2.23	120.84

Table 11.2.18 Sensitivity Analysis (Proposed Combination 2)

	IRR	B/C	NPV (Billion Baht)
Project benefit 10% down	18.7%	1.72	77.84
Project benefit 20% down	15.4%	1.39	42.21
Project cost 10% up	22.6%	1.97	116.35
Project cost 20% up	21.0%	1.81	155.47

11.3 Environmental and Social Considerations

11.3.1 Outline of the Project for Evaluation

(1) Project Name

(a) Ayutthaya Bypass Diversion Channel
(b) Outer Ring Road Diversion Channel
(c) Dike Improvement of the Lower Chao Phraya River
(d) Dike Improvement and Short Cut Channels in the Tha Chin River Basin

(2) Objectives

After several trials to develop an effective countermeasure for flood management in Thailand, establishing two new diversion channels including: (i) Ayutthaya Bypass Diversion Channel (19km in length), and (ii) Outer Ring Road Diversion Channel (100km in length), and (iii) Dike Improvement with other structural/nonstructural measures have been selected as the most cost-efficient and significantly effective for protecting the lower Chao Phraya River Basin where the industrial centers are integrated. In this section, evaluation for the two planning diversion channels is to be conducted from the viewpoint of environmental and social aspects, respectively. In addition, for the flood-prone Tha Chin River Basin, (iv) Dike Improvement and Short Cut Channels were selected to mitigate the future floods in this area.

11.3.2 Activities Requiring Environmental and Social Considerations

In the projects including the two diversion channels and dike improvement in the Chao Phraya River Basin and dike improvement and short cut channels of the Tha Chin River, activities requiring environmental and social considerations are as follows:

(1) Canal work (Earthwork, road, canal lining, and ground improvement)

(2) Facility work (Road Bridge, floodgate)

(3) Riverbank work (Embankment)

(4) Dike work (Wall, elevation)

(5) Material handling (Truck operating)

Outline of the work required is shown in Table 11.3.1

Table 11.3.1 Outline of the Canal and Facility Work

Work Type	Work Items	Outline	Main Equipment
Canal	Earthworks	Excavation, Soil disposal, Embankment	Backhoe, Bulldozer
	Road Works	Basement (sub-base and base course); Finishing (asphalt concrete pavement)	Motor grader, Vibratory roller, Tire roller, Asphalt finisher
	Canal Lining	Lining with concrete	Concrete mixing vehicle, Crane
Facility	Road Bridges	Bridges across canals	Concrete mixing vehicle, Crane, Pile driver
	Floodgates	With both connecting sites of the river	Truck-mounted Crane; Backhoe, Bulldozer, Pile driver, Vibratory hammer
River bank	Embankment	Earthfill to build riverbanks	Backhoe, Bulldozer, Scraper
Dike	Wall Works	Parapet wall installation	Backhoe, Bulldozer, Concrete mixing vehicle, Crane
	Elevation Works	Elevation of walls for enough wall and dike height	Concrete mixing vehicle, Crane

11.3.3 Categories of Project and Environmental Assessment

According the Thai laws[1], 34 project types and activities require Environmental Impact Assessment (EIA) and approval through the national approval process. However, the diversion channels and dike improvement are definitely outside of the scope of the EIA category in accordance with the Thai environmental assessment system at present.

On the other hand, impacts on the environment may arise mainly by the construction activities for the project. A case is probable to make the residents or houses resettled in the project area to other location. Taking the situation into account, it is concluded that conducting an Initial Environmental Examination

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

(IEE) should be essential according to the JICA Guidelines for Environmental and Social Considerations.

11.3.4 Project Area Outlook and Scopes of Assessment

(1) Ayutthaya Bypass Diversion Channel

The planning area is located along the west side of Route 347 where both ends intersect with the right banks of the Chao Phraya River between the north area of the central Phra Nakhon Si Ayutthaya (Ayutthaya) and south Bang Sai. The area is mostly occupied with plain arable fields, and houses are found in a few sites such as the intersection of the planned bypass channel with Route 3263. Major industrial centers including an industrial estate developed along the left bank of the Chao Phraya River. Ethnic groups, national or natural parks, precious wild lives and historical memorials are not distributed over the whole planned area. The planning bypass channel also intersects with 14 existing canals and two vehicle roads running through the paddy field.

(2) Outer Ring Road Diversion Channel

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

(3) Dike Improvement of the Lower Chao Phraya River

The target area of the dike improvement is in lower Chao Phraya River from the estuary to approx. 100km upstream. This basin lies in the Chao Phraya Delta where business and industrial activities focus on. Bangkok and its vicinities cover the most area of the project. No specific land acquisition is required for the dike improvement because most works are to add the height of the existing parapet walls (0-60km points, constructed by BMA) and dike roads (constructed by DOH). All the work areas are within the Right-of-way of the RID and authorities concerned. Like the Ayutthaya project, no specific concerns like ethnic groups, national or natural parks, precious wildlife and historical memorials have been observed over the area.

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

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

11.3.5 Natural Environmental Consideration

(1) Common Matter

During the construction, generation of noise and vibration from construction traffic or machinery and increase in traffic volume are possible issues. Treating by-products such as excavated soil can be also a task. In-use period of the channels, considerations should be required as to surface water (turbidity with sand/soil) and groundwater (water level), ground (topography/geographical features, ground subsidence) and landscape. Impacts on rare species of animals and plants are expected minor because most of the planning area is covered with secondary woodland and arable fields. However, the impact on soil organisms by soil excavation is to be considered.

(2) Ayutthaya Bypass Diversion Channel

Some influences on landscape in-use stage may be concerned because few large structures except Route 347 are found near the planning area.

(3) Outer Ring Road Diversion Channel

Salinization of surface water or soil is a possible problem in case the seawater would run up from the mouth at the Gulf of Thailand. Some influences on landscape in-use stage may be concerned though some large structures are found near/in the planning area.

(4) Dike Improvement of the Lower Chao Phraya Rive

There are no specific considerations.

(5) Dike Improvement and Short Cut Channels in the Tha Chin River Basin

Like the case of Ayutthaya Bypass Diversion Channel, landscape after the completion may be a trouble factor by some residents. Short cut channel construction may cause salt water intrusion toward more upstream from the Gulf of Thailand because of shrinking the river length.

11.3.6 Social Environmental Consideration

(1) Common Matter

Land acquisition or expropriation is needed for the channels and roads for trucks used during the construction work. In addition, income compensation due to loss of opportunities of crop production would be necessary because both planning areas stretch out in paddy/arable fields. At the intersections with existing main roads, coordination with competent authorities is essential. For resettlement and compensation for the houses scattered in the planning area, an intensive household survey and compensatory negotiation complying with the Thai legislation will be required for smoother progress.

(2) Ayutthaya Bypass Diversion Channel

More than eighty houses are expected to be eligible even though most project area in arable fields (see Figure 11.3.1 and Figure 11.3.2)

(3) Outer Ring Road Diversion Channel

The expected number of eligible houses or the Project Affected Persons (PAPs) vary depending on the discharge capacity set up: about 600 houses at 500m^3/s capacity and about 900 houses at 1,000m^3/s, respectively. Intersection with existing infrastructures spreads over the project area (see Figure 11.3.3 and Figure 11.3.4).

(4) Dike Improvement of the Lower Chao Phraya River

No involuntary resettlement of people is expected because the target area is already developed (see Figure 11.3.5).

(5) Dike Improvement and Short Cut Channels in the Tha Chin River Basin

For the parapet wall installation, some people in the estuary area are expected to be eligible but the number of PAPs is uncertain. No or little affection in any other project areas is estimated (see Figure 11.3.6 and Figure 11.3.7).

Figure 11.3.1 Planning Area (Overall) - Ayutthaya Bypass Diversion Channel -

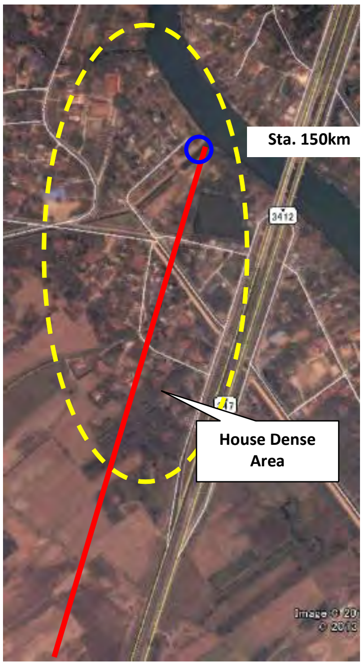


Figure 11.3.2 Planning Area (House Dense Area)

Figure 11.3.3 Planning Area (Overall) - Outer Ring Road Diversion Channel -

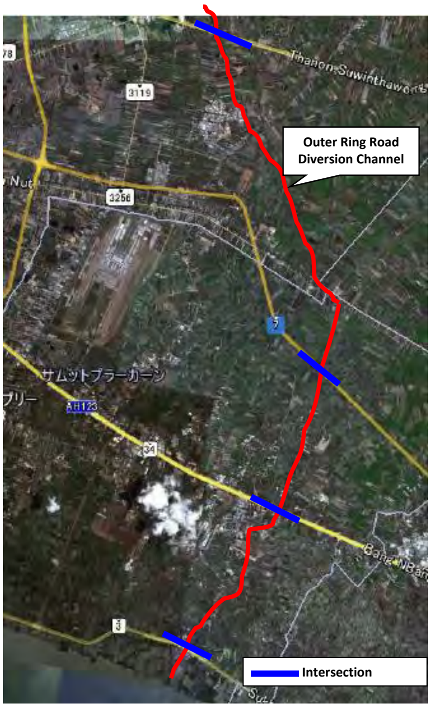


Figure 11.3.4 Planning Area (Lower Area)

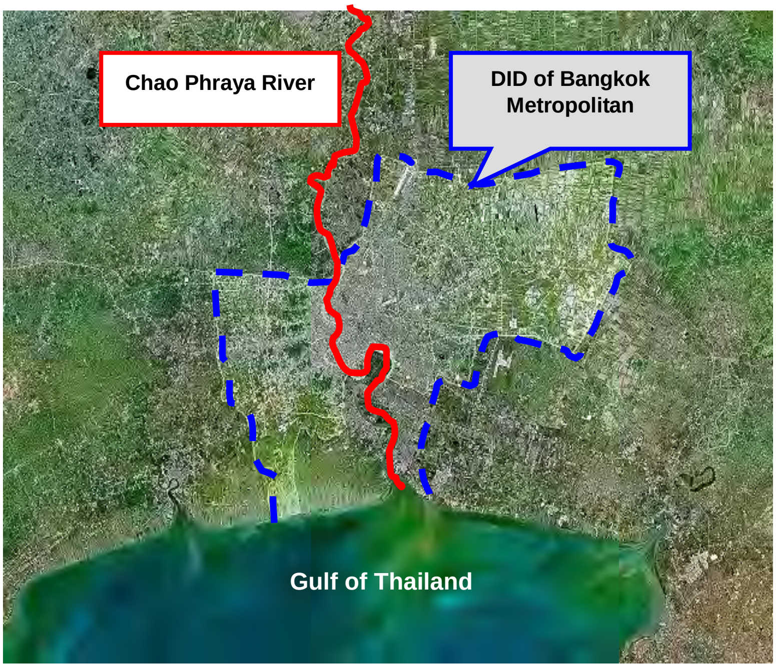


Figure 11.3.5 Planning Area (Overall) - Dike Improvement of the Lower Chao Phraya River -

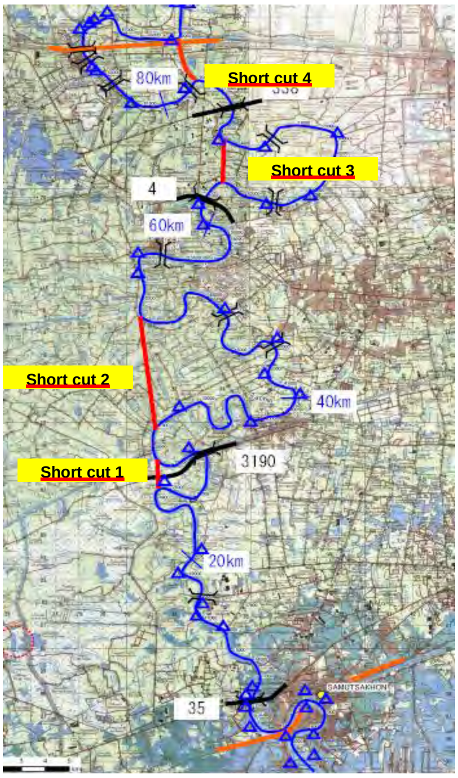


Figure 11.3.6 Planning Area (Short Cut Channels) - Dike Improvement and Short Cut Channels in the Tha Chin River Basin -

Figure 11.3.7 Planning Area (Populated Area at the Estuary) - Dike Improvement and Short Cut Channels in the Tha Chin River Basin -

11.3.7 Influence Factors on Natural and Social Environment

Both projects are expected to give minor impacts on natural and social environment by taking into account the area characteristics. However, the items listed in Table 11.3.2 should be considered and measures taken.

Table 11.3.2 List of Influence Factors on Natural and Social Environment

<table>
<tr><th colspan="3">Project Stage</th><th colspan="3">Pre- / At-work</th><th>In-use</th></tr>
<tr><th colspan="3" rowspan="2">Work Type</th><th rowspan="2">Facility</th><th colspan="2">Canal</th><th rowspan="2">Operation</th></tr>
<tr><th>Excavation</th><th>Levee</th></tr>
<tr><td colspan="7">Natural Environmental Consideration</td></tr>
<tr><td colspan="2" rowspan="3">Air Quality</td><td>Dust</td><td colspan="3">○</td><td>-</td></tr>
<tr><td>Noise/Vibration</td><td colspan="3">○</td><td>-</td></tr>
<tr><td>Offensive Odor</td><td>-</td><td>○</td><td>-</td><td>○</td></tr>
<tr><td rowspan="4">Water Quality</td><td rowspan="2">Surface</td><td>Pollution</td><td colspan="3">○</td><td>○</td></tr>
<tr><td>Salt Intrusion</td><td colspan="3">-</td><td>○</td></tr>
<tr><td rowspan="2">Ground</td><td>Water Level</td><td>-</td><td>○</td><td>-</td><td>○</td></tr>
<tr><td>Salinization</td><td colspan="3">-</td><td>○</td></tr>
<tr><td rowspan="2">Soil Environment</td><td colspan="2">Topographic / Geographic Features</td><td colspan="3">○</td><td>○</td></tr>
<tr><td colspan="2">Ground Subsidence by Lowering Groundwater Level</td><td colspan="3">○</td><td>○</td></tr>
<tr><td colspan="3">Ecology (Fauna & Flora)</td><td colspan="3">○</td><td>○</td></tr>
<tr><td colspan="3">Landscape</td><td colspan="3">○</td><td>○</td></tr>
<tr><td colspan="2">Wastes</td><td>Derived from Construction Work</td><td colspan="2">○</td><td>-</td><td>-</td></tr>
<tr><td colspan="7">Social Environmental Consideration</td></tr>
<tr><td colspan="3">Land Acquisition / Compensation</td><td colspan="3">○</td><td>-</td></tr>
<tr><td colspan="3">Involuntary Relocation</td><td colspan="3">○</td><td>○</td></tr>
<tr><td colspan="3">Effect on Existing Infrastructure (Roads, canals, etc.)</td><td colspan="3">○</td><td>-</td></tr>
</table>

Note: Items marked "○" are considered to have potential impact(s) on natural or social environment.

11.3.8 Comprehensive Evaluation and Mitigation Measures

It is considered feasible in general to avoid or reduce severe impacts derived from construction works or caused by direct reform from the existence of these new diversion channels when conducting the mitigation measures shown in Table 11.3.3. In particular, careful consideration and measures will be essential to implement land acquisition and involuntary resettlement of inhabitants affected by the project progress.

Table 11.3.3 Summary of the Mitigation Measures

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

11.4 Project Evaluation

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

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

Based on the Thai laws, an EIA is not needed for the projects and there is no need to get approval through the national approval process because both the by-pass channel and diversion channel projects are outside the scope of the EIA category in accordance with the Thai environmental assessment system at present.

On the other hand, impacts on the environment may arise mainly due to the project construction activities. However, it is probable that residents or houses in the project area will be resettled to other locations. Taking the situation into account, it is concluded that an Initial Environmental Examination (IEE) is essential according to the JICA Guidelines for Environmental and Social Considerations.

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

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

(1) Effective Operation of Existing Dams;

(2) Outer Ring Road Diversion Channel (Capacity: 500 or 1,000 m^3/s);

(3) River Improvement Works (including Tha Chin River Improvement);

(4) Ayutthaya Bypass Channel (Capacity: 1,400 m^3/s); and

(5) Flood Forecasting.

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

CHAPTER 12 CONCLUSION AND RECOMMENDATION

12.1 Conclusion

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

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

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

<u>Unsteady Flow Analysis</u>

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

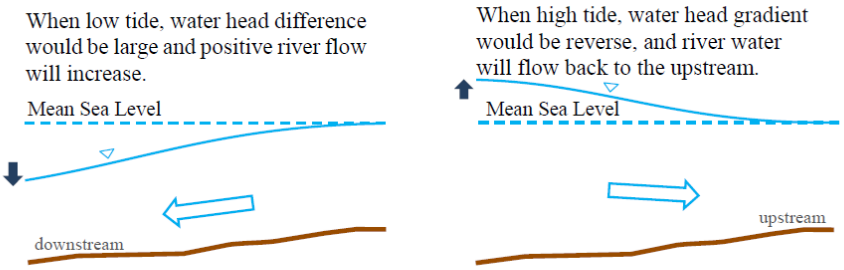
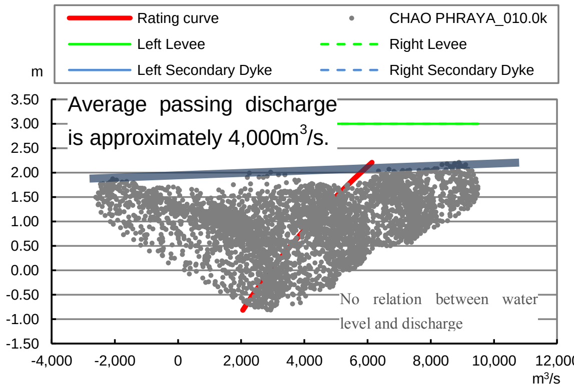
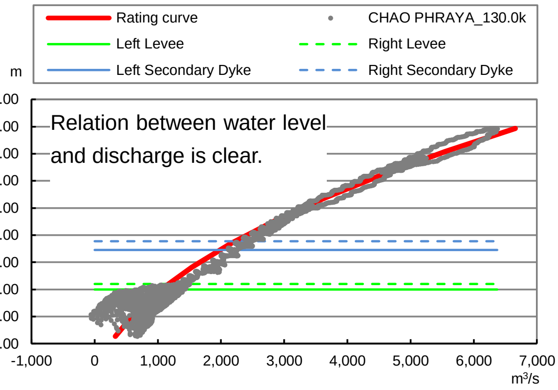


Figure 12.1.1 Influence of Sea Tide

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



Chao Phraya River: 10.0km



Chao Phraya River: 130.0km

Figure 12.1.2 H-Q Plotting Chao Phraya River (without Overflow)

Large Flood Water Volume Compared with River Flow Capacity

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

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

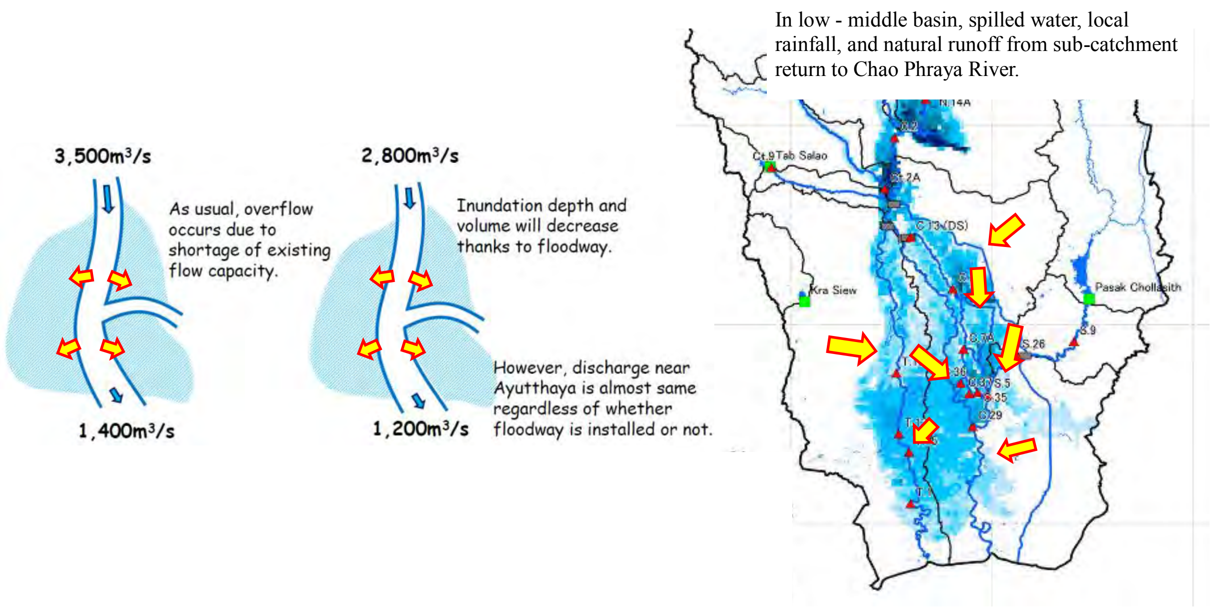


Figure 12.1.3 Overflow from Rivers/Canals and Return Flow to Rivers/Canals

Design High Water Level

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

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

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

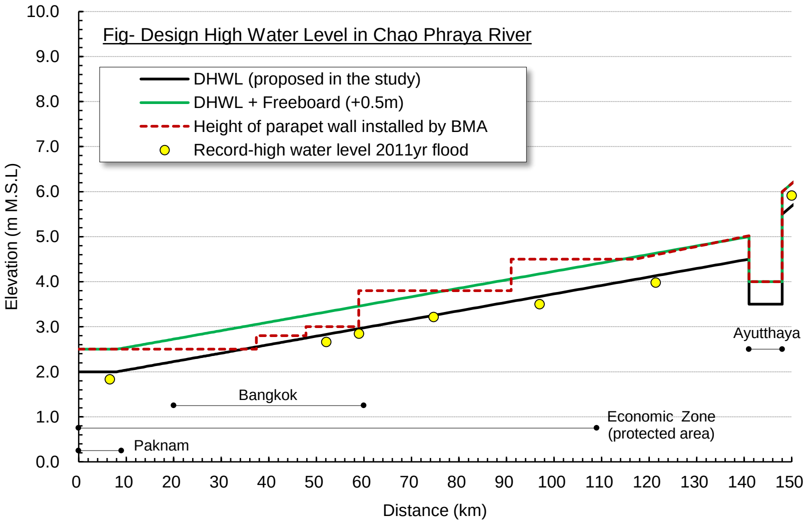


Figure 12.1.4 Proposed Design High Water Level for Lower Reaches of Chao Phraya River

Influence by Road Heightening Works

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

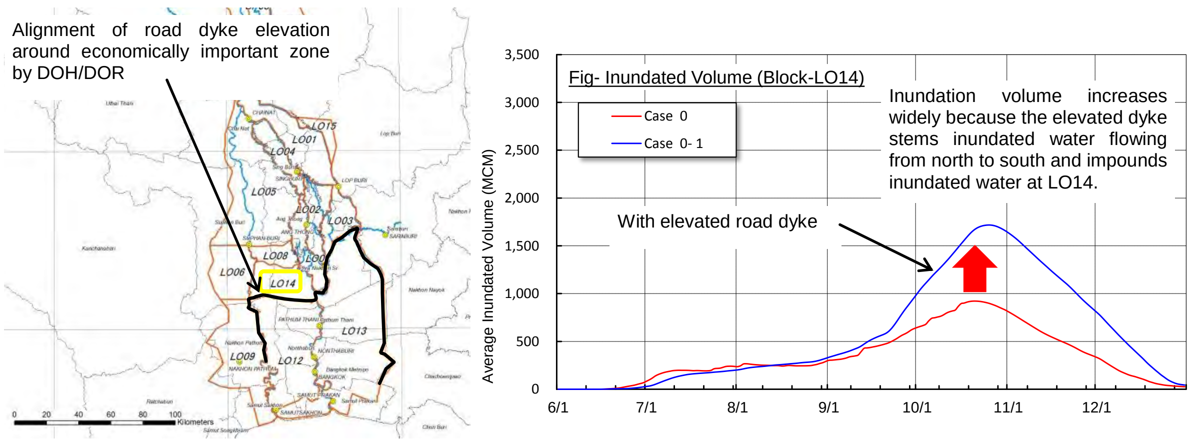


Figure 12.1.5 Inundation Volume (Influence of Road Dyke Elevation)

Current Capacity of Pumps installed in the Protection Area

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

Comprehensive Flood Management Plan

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

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

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

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

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

Proposed combinations of measures are as follows:

(1) Proposed Combination 1

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

(2) Proposed Combination 2

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

(3) Other Nonstructural Measures

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

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

12.2 Recommendation

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

Above all, the following remarks should be recommended.

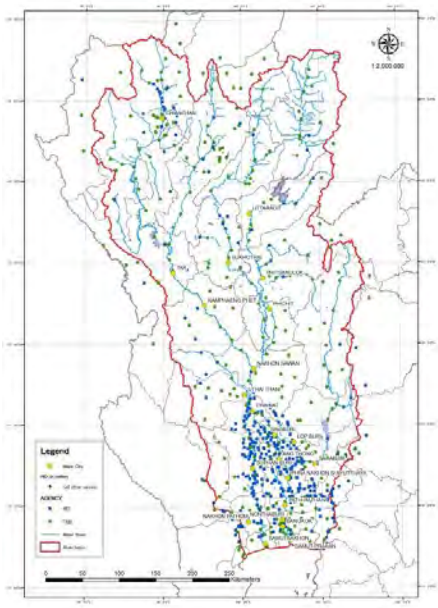
- The precise topographical information obtained in the JICA Study should be distributed immediately to all organizations and agencies concerned. They should carry out the necessary investigations based on it. If this accurate topographical information is not used, any proposal in extremely lowland area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

Recommendation about Comprehensive Flood Management Plan

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

Recommendations on the Hydrological Data Observation System

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

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

Recommendation about Hydrological Data Management

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

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

Recommendation about Hourly and Daily Flow Capacities in the Lower Reaches

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

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

Figure 12.2.1 River Surveyor M9 (V-ADCP) prepared by RID

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

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

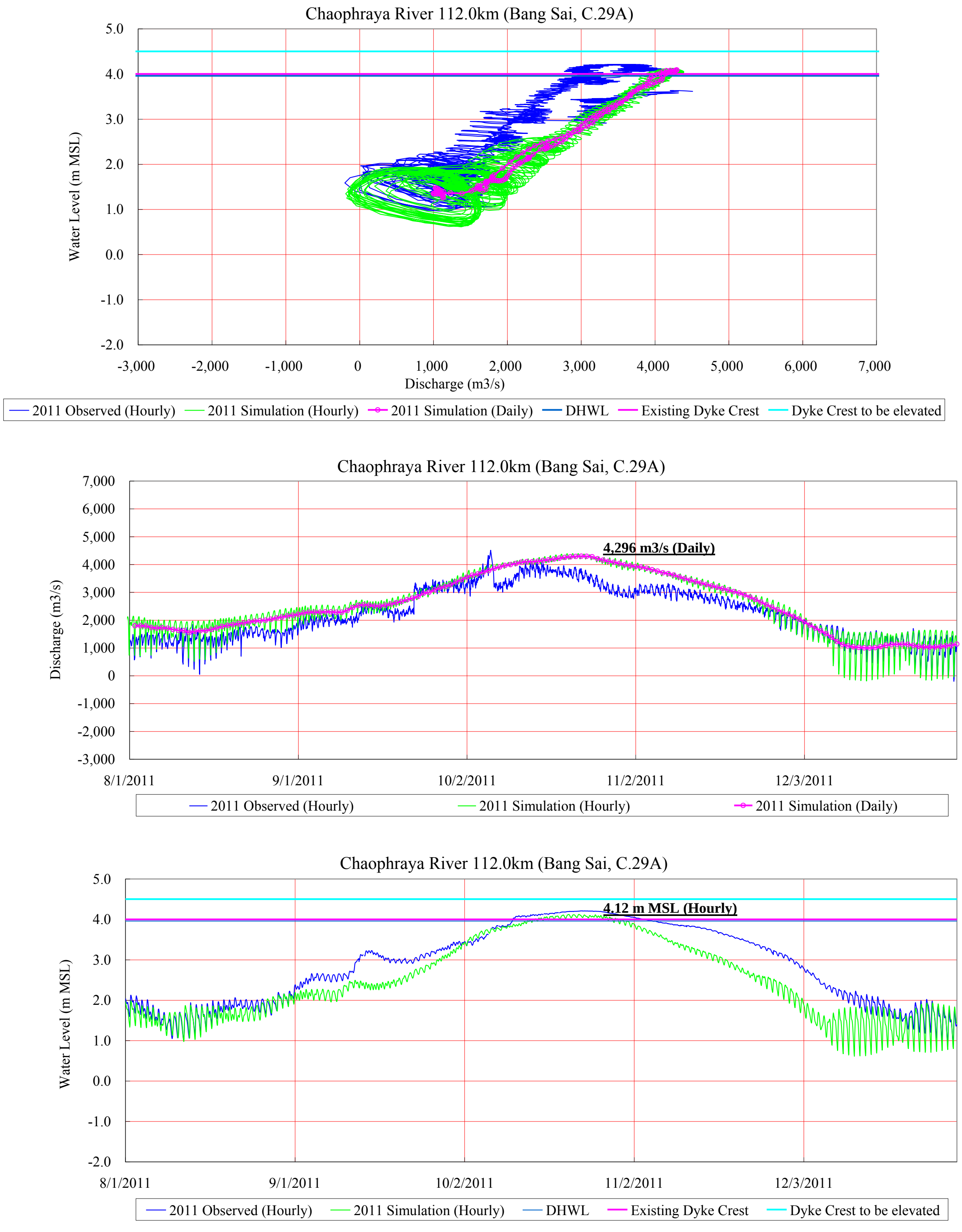


Figure 12.2.2 Water Level and Discharge at 112km Point from River Mouth (Bang Sai, C29A)

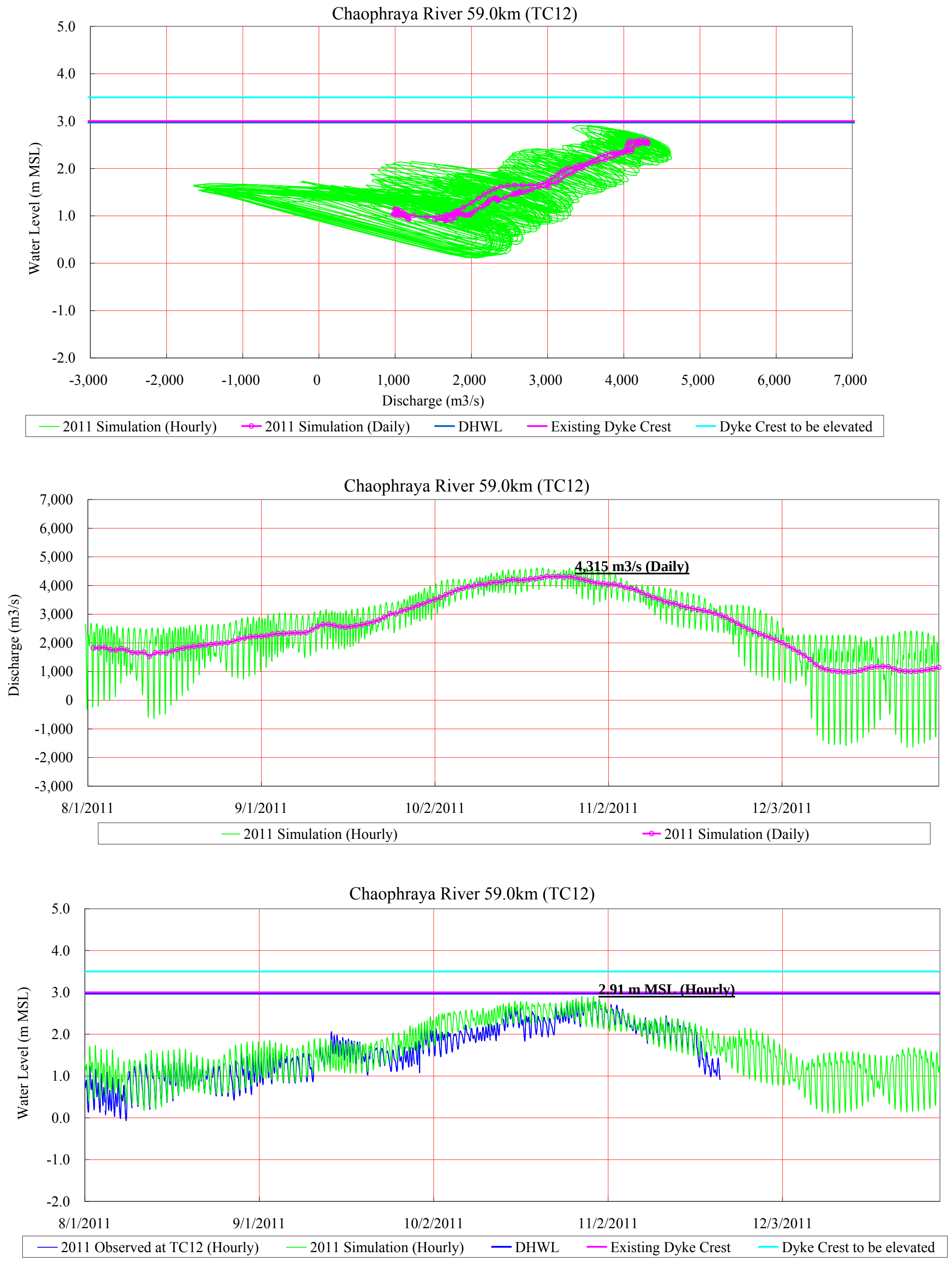


Figure 12.2.3 Water Level and Discharge at 59 km Point from River Mouth (TC12)

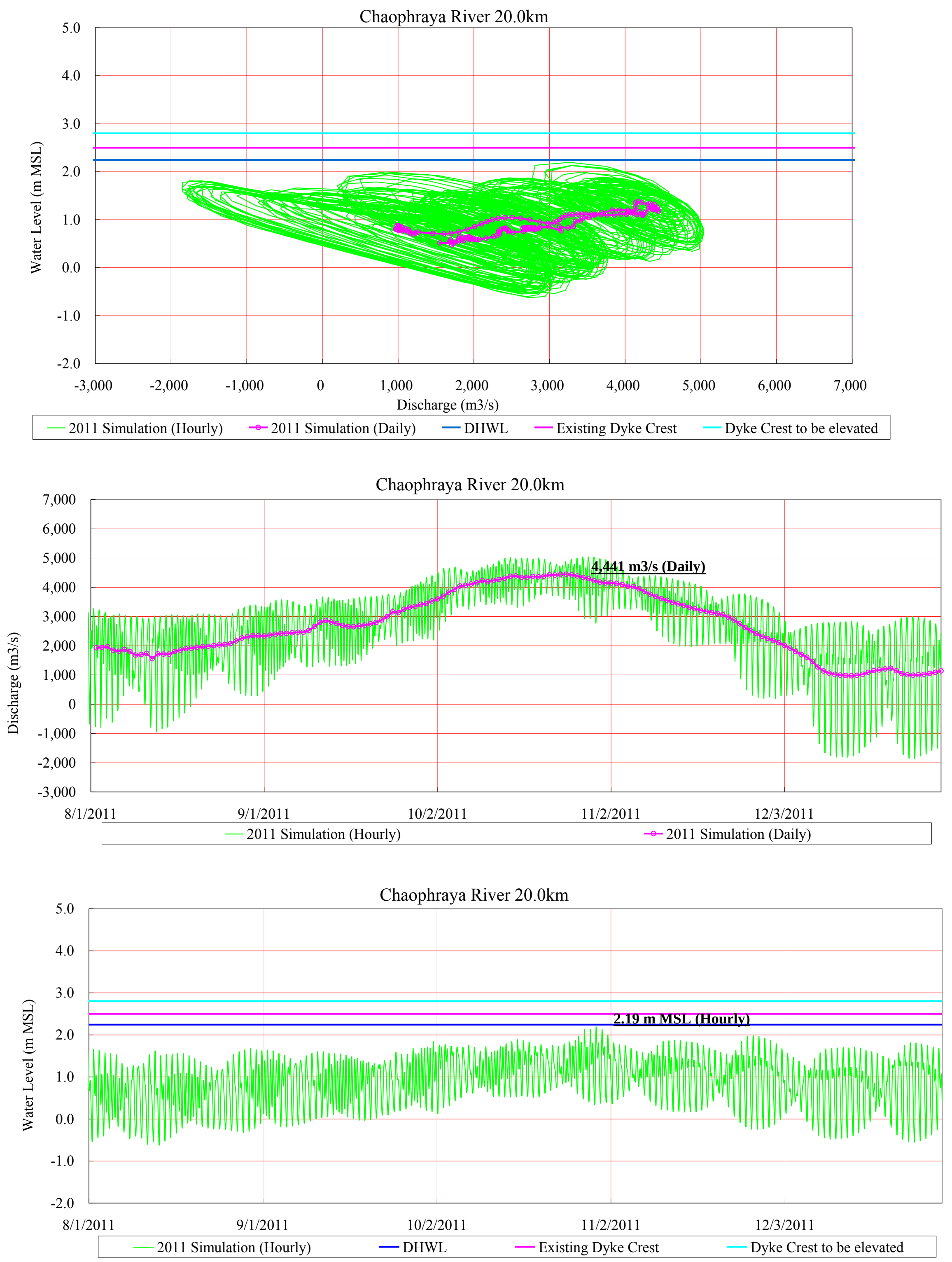
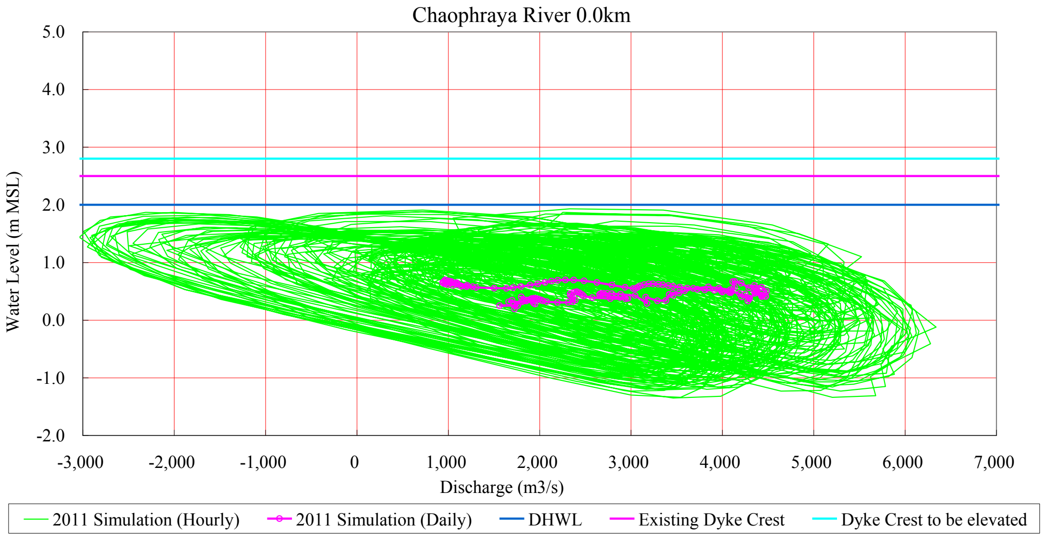
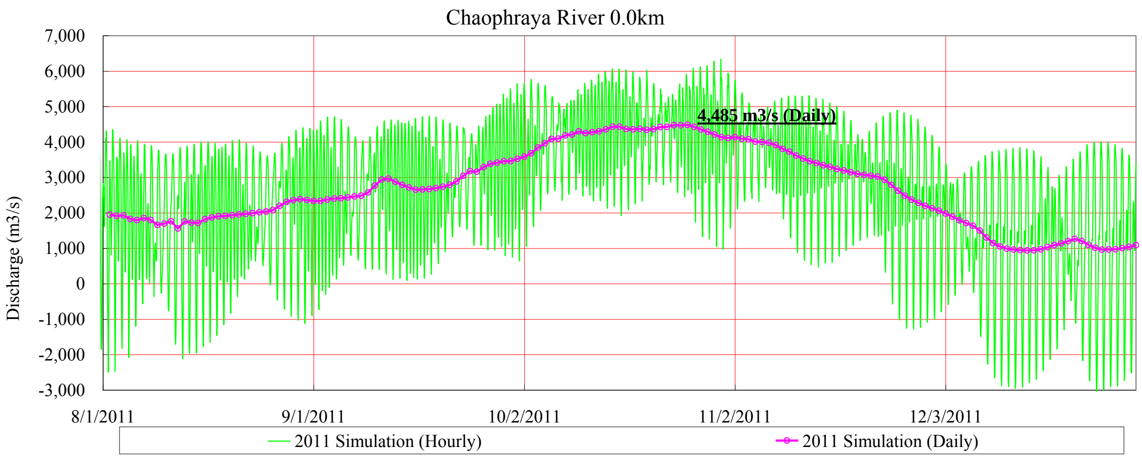


Figure 12.2.4 Water Level and Discharge at 20km Point from River Mouth





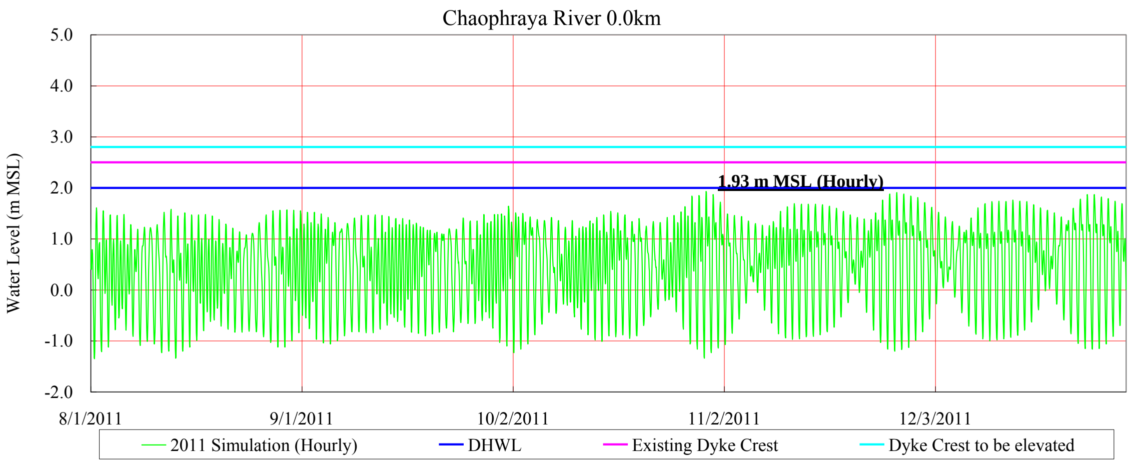


Figure 12.2.5 Water Level and Discharge at River Mouth