Appendix-6 Hydrology and Hydraulics

6.1 INTRODUCTION

The river study in 2003 first clarified the river conditions such as physical features of the river and basin, meteorological and hydrological situations, historical changes of river channel, flood and sediment flow conditions. Then, based on the understanding on the river conditions, the alternative crossing locations were identified and screened, and hydraulic parameters for the conceptual designs of relevant facilities were established for the comparative study to select an optimum crossing location. Finally, the crossing location at Mawa-Janjira was selected as an optimum site for construction of the Padma Bridge.

For the river study in 2003, the study on hydrology and hydraulics was elaborated mainly for collection and analysis of basic information and data including climate, hydrology, and river morphological observations. Based on the data analysis, the hydraulic design values for the screening and selection of an optimum site for construction of the Padma Bridge were worked out.

Based on the findings in the river engineering study in 2003, further detail investigations and studies of the river channel and river bank characteristics at Mawa-Janjira were carried out for the purpose of appropriate design of the river works relevant the Padma Bridge in 2004. The study on river works was a key issue for planning of bridge across the Padma River.

The study on hydrology and hydraulics in 2004 was carried out mainly for verifying the preliminary designs for the river works by using the mathematical modeling. Impacts to river flow conditions and river morphology by construction of the project were also assessed through the mathematical modeling.

6.2 HYDROLOGICAL AND HYDRAULIC FEATURES

6.2.1 Hydro-meteorological Overview

(1) Climate

The climate in Bangladesh is classified as a sub-tropical monsoon characterized with high temperature, heavy rainfall, and excessive humidity. The seasonal variations of the climate occur due to exchange of air mass flows between the Central Asia and Indian Ocean. Bangladesh is located at the edge of the vast high pressure area of the continent during the cool months between November and February. Due to higher pressures in China and Siberia, cool air mass flows from the northeast is predominant during this period. Meanwhile, warm and humid air mass from the Indian Ocean prevails during the wet months between June and September when the Inter-Tropical Convergence Zone moves in the north of Bangladesh. The reversal of winds corresponding with the change of pressures in the transitional seasons (May-June and October-November) causes violent storms in Bangladesh.

In Bangladesh, there are six seasons in a year. Of these, ‘Summer’, ‘Rain’, and ‘Winter’ are the major distinctive seasons and others are recognized to be transitional in between.

The season of Summer starts in March and lasts until May. The average maximum temperatures vary from 30°C to 35°C by region within this period. The highest peak of the temperature takes place in April. The maximum temperature exceeds 40°C occasionally.

The season of Rain takes place between June to October when the southwest trade winds known as the monsoons from the Indian Ocean bring the warm and humid air mass resulting in the abundant rainfall in Bangladesh. The average maximum temperatures are a little less than those in Summer. Meanwhile, the average minimum temperatures become more or less 25°C.

The climate becomes dry and cool after October and moves to the season of Winter lasting from November to February. The average maximum temperatures are in the range of 25°C to 30°C by region within this period. The average minimum temperatures are less than 20°C and the lowest takes place in January, ranging from 10°C to 15°C by region and going down less than 10°C in some places.

The rainfall in Bangladesh shows great temporal and spatial variations as shown in Figure 6.2.1. The rainfall in the monsoon season amounts to 70% to 80% of the annual total rainfall. The average annual rainfall varies from 1,200 mm in the west to 5,000 mm or more in the northeast. The warm and humid air mass of the monsoons sweeps up the Bay of Bengal from the Indian Ocean and produces some of the highest recorded rainfalls in the world, particularly in Meghalaya and Assam in India and the northeast regions in Bangladesh.

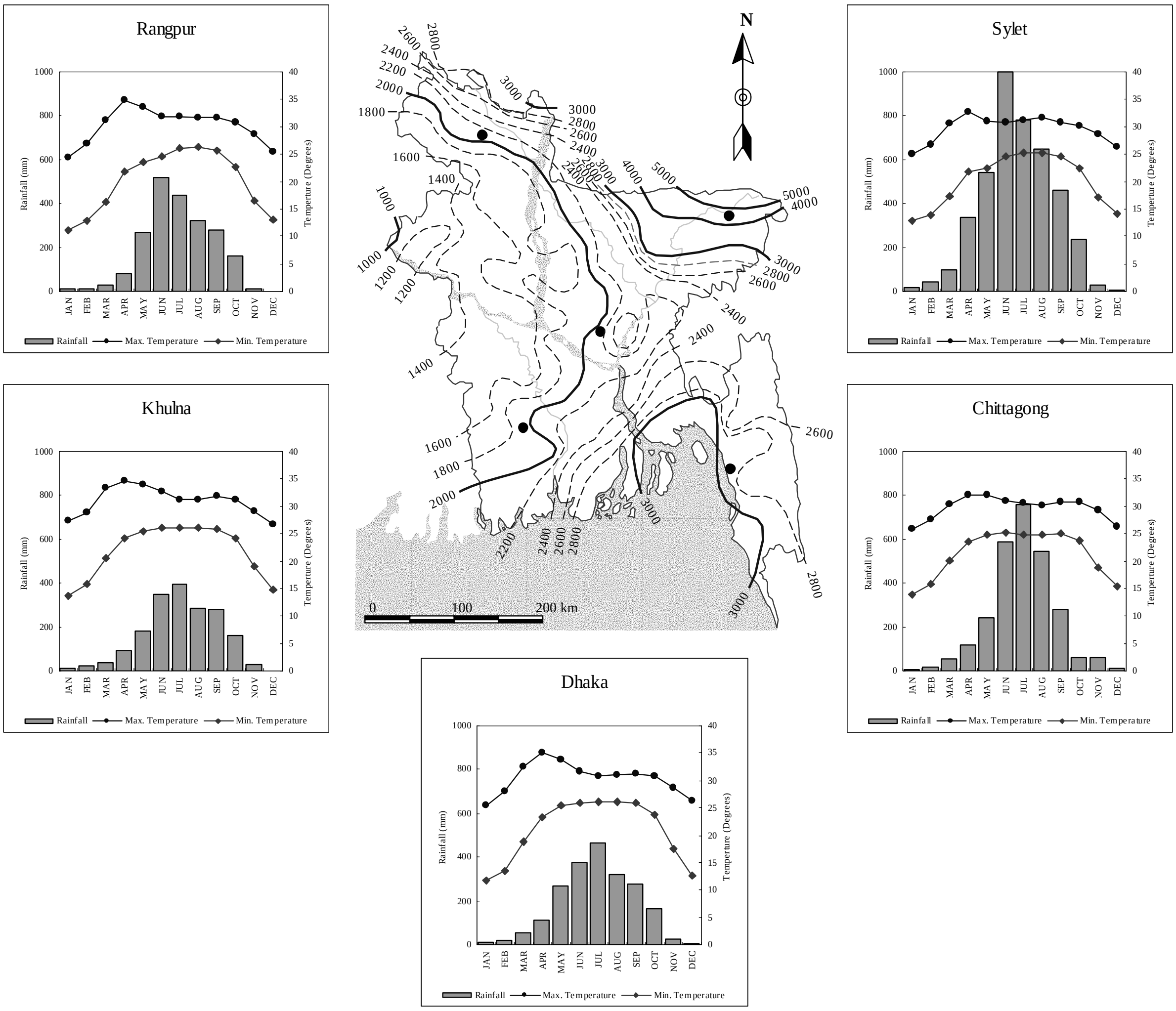


Figure 6.2.1 Rainfall and Temperature in Bangladesh

(2) Flow Regimes

The average water levels and discharges of the Brahmaputra-Jamuna at Bahadurabad, the Ganges-Padma at Hardinge Bridge, and the Padma at Baruia Transit are illustrated in Figure 6.2.2. Some differences in flow regimes are observed between the Jamuna and Ganges. The Jamuna begins rising in May-April and increases its flow gradually until the peak in July-August. Meanwhile, the Ganges become to rise in May-June and peaks in August-September. The peak of the Ganges is one to two months later than that of the Jamuna.

This difference between the peaks of two rivers is explained by the main cause of runoff during the period of rising. The Jamuna rises earlier due to the snowmelt runoff in the Himalayas at first and reaches the peaks in combination with the monsoon runoff. On the other hand, the monsoon runoff is predominant to the increase of flow in the Ganges. The annual total runoff volume of the Jamuna is much larger than that of the Ganges as seen in the discharge hydrographs. The Padma rises together with the Jamuna and reaches the peak almost corresponding with the Ganges.

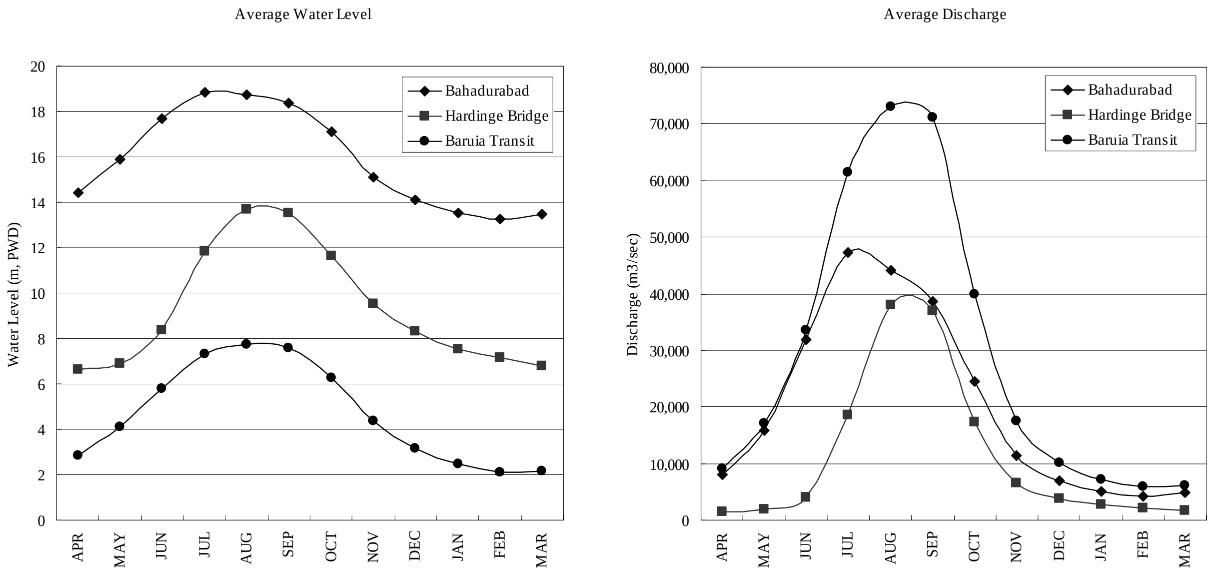
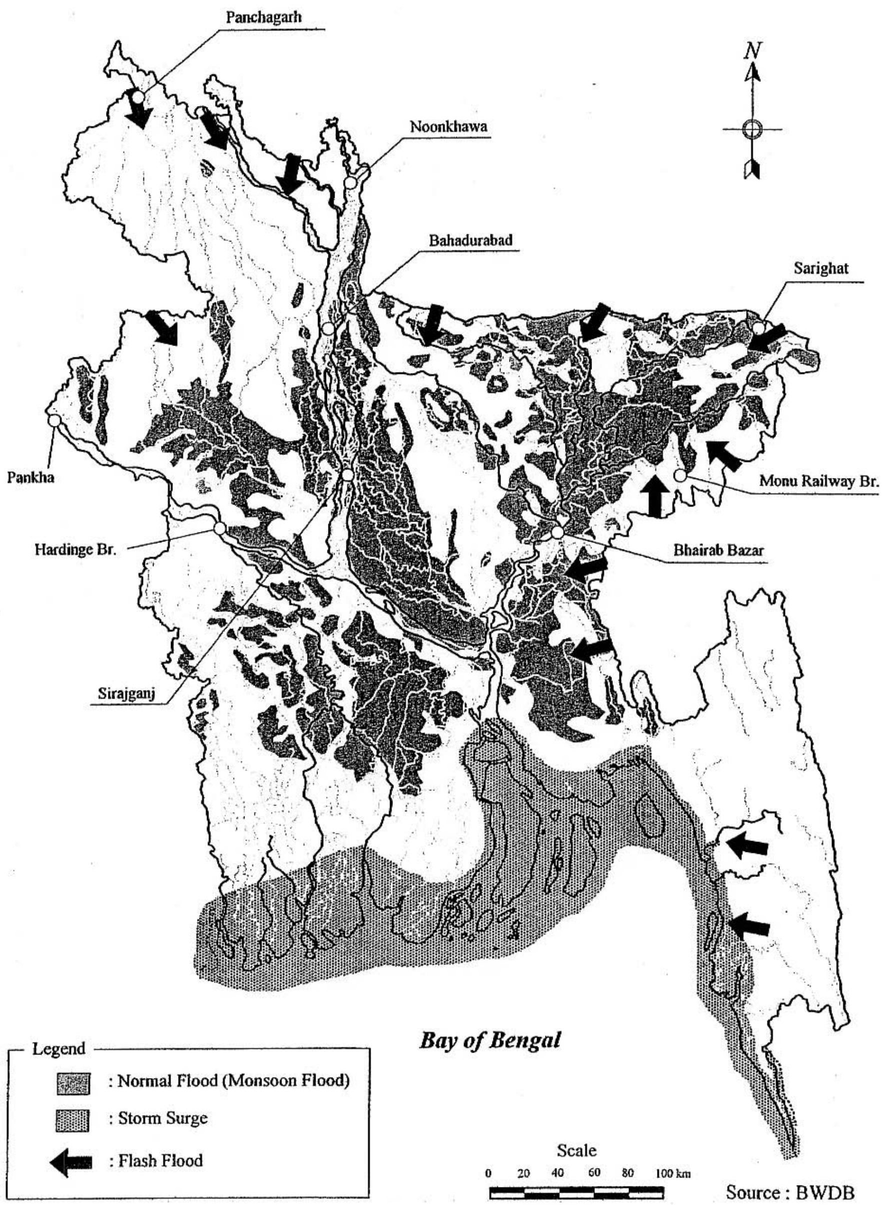


Figure 6.2.2 Flow Regimes of the Major Rivers

(3) Flood

The territory of Bangladesh is a largely low-lying flood plain. The physical characteristics of land, geographic location, multiplicity of rivers, and monsoonal climate attribute to the floods annually taking place and causing frequently serious social and economic damages in Bangladesh. Meanwhile, the annual flood contributes to the traditional agriculture practices depending on the replenishment of soil and water required for the cultivations in the country.

Bangladesh is prone to three main types of flooding, i.e. monsoon floods, flash floods, and cyclonic floods. Flood-affected areas in Bangladesh by the type of flood are classified as shown in Figure 6.2.3.



Source: JICA/BWDB, Feasibility Study for Improvement of Flood Forecasting and Warning Services in the People's Republic of Bangladesh, Interim Report, June 2003

Figure 6.2.3 Flood-affected Areas in Bangladesh by Type of Flood

The monsoon flood occurs annually because of heavy and incessant rainfalls in the upper catchments of the cross-border rivers as well as inside the country during June to October when over 80% of the annual rainfall takes place within this period.

The severe monsoon floods occurred recently in 1987, 1988 and 1998. According to the annual flood reports by BWDB, the flood affected areas were estimated at 100,250 km^2 by the 1998 flood (accounting for 68% of the territory), 89,970 km2 by the 1988 flood (61%), and 57,300 km^2 by the 1987 flood (39%).

The flush flood occurs in the northeastern, southeastern, and extreme northern areas of Bangladesh, where the hilly or mountainous topographies are observed. The major cause of the flush flood is extremely high rainfall intensity occurring locally during the monsoon and transitional seasons. The concentration of flood runoff is quite rapid within several hours at the shortest and results in inundation as well as destructive damages to agricultural crops and properties.

The cyclonic flood causes the most serious and widespread disasters in Bangladesh. Cyclones form in the Bay of Bengal and often hit the southern and southeastern coastal areas. Cyclones bring heavy rainstorms causing flood as well as storm surges due to accompanying strong winds. The coastal areas are prone to flooding by the heavy rainstorms coupled with water level rises in the lower reaches affected by the storm surges. The dangerous situations by cyclones are not only floods but also strong winds and storm surges that attack destructively the coastal areas.

6.2.2 Characteristics of Rainfall

(1) Climate in the Study Area

The objective river stretch for the present study extends between the Padma-Jamuna confluence and Chandpur. In view of the traffic and highway network planning with a Padma crossing, the meteorological records at Dhaka, Faridpur, Khulna, and Barisal were collected for the period from 1973 to 2002 (30 years) and analyzed (Figure 6.2.4). In general, the records indicate that the climatologic characteristics are not different much by location (Figure 6.2.5).

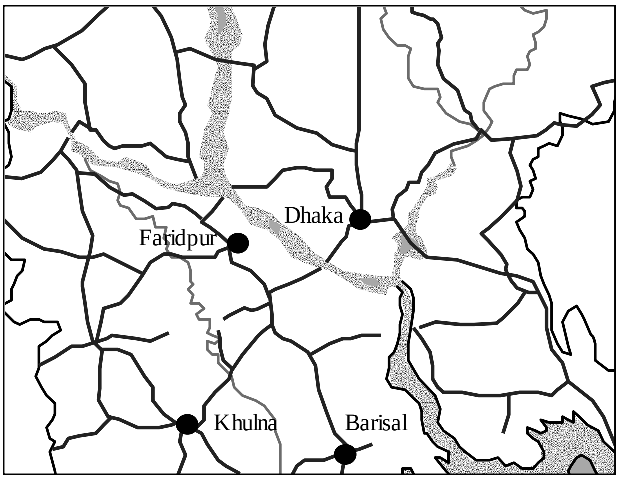


Figure 6.2.4 Padma River and Neighboring Area (Study Area)

The average annual rainfall by location varies from 1,876 mm at Khulna and 2,167 mm at Barisal and indicates that the rainfall is a little less in the west of the study area and gradually increases in the east. The peak of monthly rainfall is observed in June or July and varies from 349 mm at Faridpur to 434 mm at Barisal. The monthly rainfall at Dhaka exceeds 300 mm between May and October (for five months). Meanwhile, the monthly rainfalls exceeding 400 mm are observed in June and July at Barisal. The average rainy days in a year are in a range of 113 days at Dhaka and 123 days at Faridpur. The average number of rainy days in July exceeds 20 days at every location.

The average maximum temperature by location becomes highest in July in the range of 32.8°C at Dhaka and 34.3°C at Khulna. The average minimum temperature takes place in January and varies from 11.8°C at Barisal and 12.8°C at Dhaka.

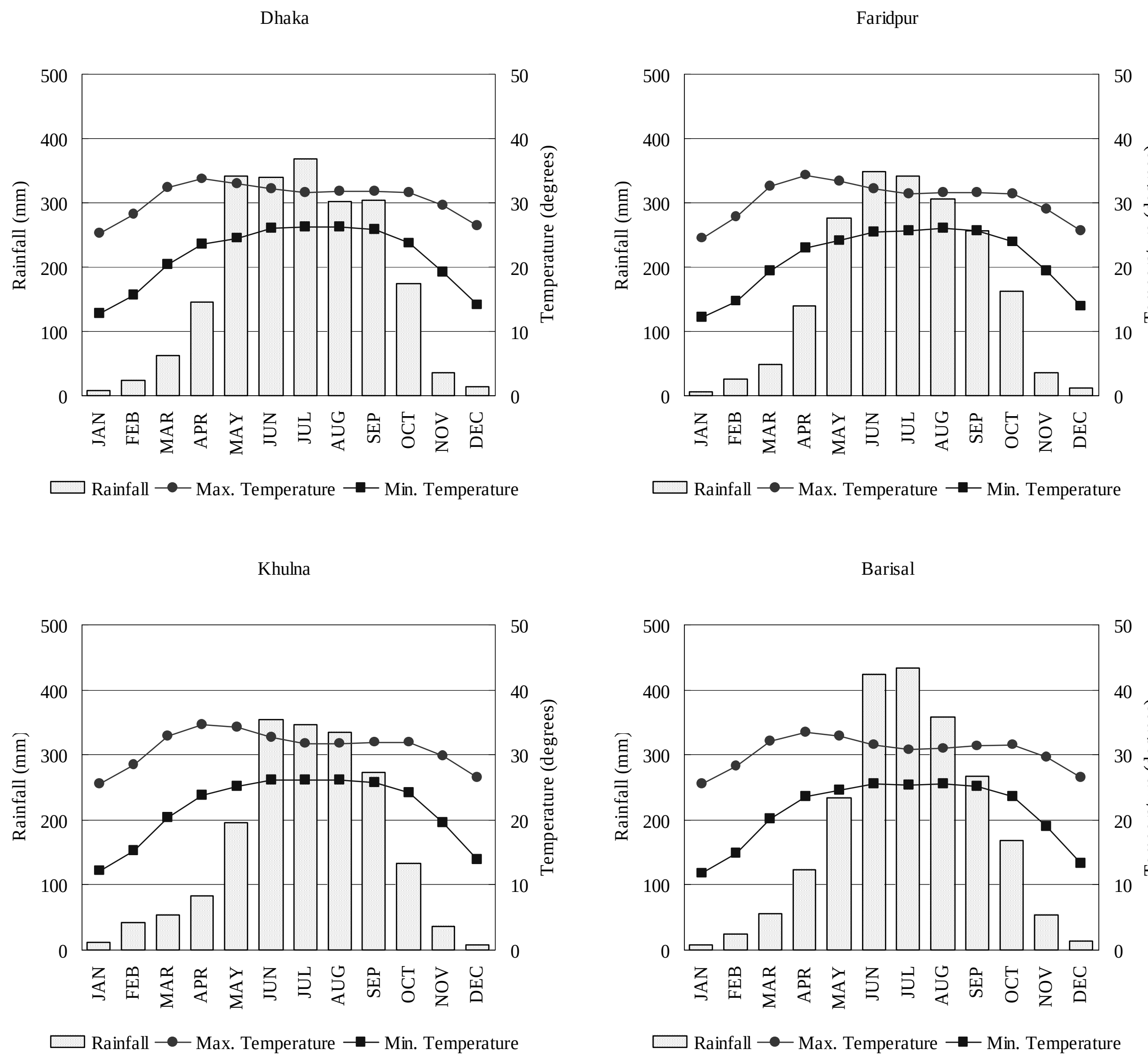


Figure 6.2.5 Monthly Rainfall and Temperature around the Study Area

The average maximum relative humidity at Dhaka exceeds 90% except in February and March. Faridpur shows more than 90% throughout a year. Barisal and Khulna are more humid locations showing 95% or more in every month. The average minimum relative humidity becomes lowest in March and highest in July and exceeds 70% for four months from June to September at every location. The average minimum relative humidity by location ranges from 75% at Dhaka and 80% at Barisal in July, and from 38% at Dhaka and 47% at Barisal in March.

The average sunshine hours in a day become minimum in July and maximum during the dry months between February and April. The average sunshine hours by location range from 3.6 hours at Khulna and 4.2 hours at Faridpur and Dhaka in July, and from 8.1 hours (at Faridpur in February) to 8.6 hours (at Khulna in April) during the dry months.

The average wind speed becomes high in the monsoon season and lowers in the dry season. The south or southwest wind prevails in the monsoon season.

(2) Regional Distribution and Duration of Rainfall

The rainfall records around the study area suggest the tropical features of rainfall characterized with local variations during a heavy rainstorm event. Meanwhile, a series of daily rainfalls within a heavy rainfall event indicate large variations by location.

(3) Rainfall Intensity

The relationships of rainfall intensity, duration, and frequency (IDF) for short duration rainfall were developed by FAP8A Greater Dhaka Protection Project (JICA, 1992). IDF curves by FAP8A are shown in Figure 6.2.6. From IDF curves, the rainfall depths for one hour duration are 64, 82, 95, 107, and 123 mm for 2-, 5-, 10-, 20-, and 50-year return period, respectively.

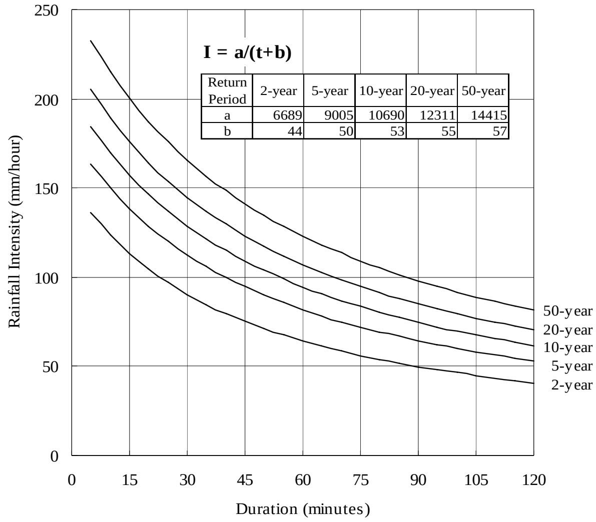


Figure 6.2.6 Rainfall Intensity, Duration, Frequency Curves

(4) Probable Rainfall

The annual maximum series of daily rainfall at each observatory were extracted from the daily rainfall records as shown in Table 6.2.1. The extreme value analyses were carried out to examine the application of three different probability distributions, i.e. Gumbel, Log Pearson Type III, and Log Normal Three Parameters, by using EVA (Extreme Value Analysis) developed by Danish Hydraulic Institute (DHI). Table 6.2.2 shows the calculation result of probable daily rainfall for the return periods of 2-, 5-, 10-, 25-, 50-, and 100-year.

Table 6.2.1 Annual Maximum Daily Rainfall

Year	Dhaka	Faridpur	Khulna	Barisal	Year	Dhaka	Faridpur	Khulna	Barisal
1971	251	94	62	174	1987	138	191	186	142
1972	231	103	60	110	1988	135	164	129	124
1973	168	148	127	140	1989	118	108	103	209
1974		127	174	133	1990	94	115	83	153
1975	143	101		84	1991	123	86	59	181
1976	163	335	89	72	1992	90	76	64	59
1977	100	330	93	75	1993	140	143	185	123
1978	128	123	132	162	1994	74	115	52	101
1979	108	150	391	152	1995	83	193	113	134
1980	91	70	89	104	1996	150	146	115	137
1981	81	150	122	86	1997	121	93	112	183
1982	146	76	131	216	1998	122	91	103	251
1983	133	109	121	114	1999	141	185	112	95
1984	151	148	216	153	2000	158	80	117	82
1985	92	89	92	145	2001	71	94	82	123
1986	176	370	430	221					

Table 6.2.2 Probable Daily Rainfall

Dhaka

Return Period	GUMBEL	LP-III	LN
2-year	124	124	123
5-year	161	161	160
10-year	185	186	185
25-year	216	217	217
50-year	239	240	242
100-year	262	263	267

Faridpur

Return Period	GUMBEL	LP-III	LN
2-year	130	118	120
5-year	197	176	178
10-year	241	229	226
25-year	297	316	299
50-year	339	399	363
100-year	380	501	434

Khulna

Return Period	GUMBEL	LP-III	LN
2-year	117	105	106
5-year	193	165	157
10-year	243	222	207
25-year	306	319	292
50-year	353	415	373
100-year	400	535	471

Barisal

Return Period	GUMBEL	LP-III	LN
2-year	129	131	132
5-year	171	174	174
10-year	198	201	199
25-year	233	233	229
50-year	259	256	250
100-year	285	277	270

(5) Rainy Days

The number of rainy days is related to workable days for construction works at bridge site. The average number of rainy days was estimated by month for four observatories. The rainy days were counted by daily rainfall depth exceeding 5, 10, and 20 mm, respectively, and shown in Table 6.2.3.

The average number of rainy days becomes maximum in July and minimum in December or January. The rainfall exceeding 5 mm takes place nearly half of the month in July. About 80% of rainy days (rainfall depth exceeding 5 mm) in a year concentrate in the monsoon period from May to September.

Table 6.2.3 Number of Rainy Days

Daily Rainfall > 5 mm

Observatory	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Dhaka	0.4	1.5	2.3	6.0	11.2	12.3	13.9	13.0	11.3	6.1	1.2	0.6	79.9
Faridpur	0.3	1.5	2.2	5.5	9.5	11.1	13.8	12.3	10.7	5.4	1.0	0.5	73.7
Khulna	0.5	1.8	1.8	3.9	7.5	11.3	13.6	12.3	9.4	4.7	1.0	0.3	68.1
Barisal	0.4	1.6	2.2	4.9	9.0	13.8	16.6	15.3	10.9	6.0	1.9	0.4	83.0

Daily Rainfall > 10 mm

Observatory	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Dhaka	0.2	0.9	1.7	4.6	8.8	9.2	9.7	8.7	7.9	4.4	0.8	0.4	57.2
Faridpur	0.2	0.9	1.5	4.2	7.6	8.7	9.8	8.4	7.4	4.1	0.7	0.3	53.7
Khulna	0.3	1.1	1.4	2.5	5.8	8.0	9.2	8.5	6.7	3.3	0.7	0.1	47.8
Barisal	0.2	0.9	1.6	3.7	7.1	10.4	12.0	10.4	7.8	4.6	1.3	0.2	60.2

Daily Rainfall > 20 mm

Observatory	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Dhaka	0.1	0.3	1.1	2.6	6.2	5.4	5.7	4.6	4.9	2.9	0.5	0.3	34.6
Faridpur	0.0	0.3	0.8	2.5	4.7	5.0	5.0	4.4	4.4	2.6	0.5	0.2	30.4
Khulna	0.2	0.7	0.8	1.1	3.3	4.8	4.6	4.5	3.4	1.9	0.3	0.1	25.8
Barisal	0.1	0.3	0.9	2.2	4.3	7.1	7.4	5.8	4.6	2.6	0.6	0.2	36.1

6.2.3 Characteristics of Runoff

(1) Daily Mean Water Levels and Discharges

A summary of the water level records around the study area is shown in Table 6.2.4. The records were retrieved on daily mean basis for all the gauges. For the tidal water level gauges, the daily high and low water levels were derived and summarized as well.

Table 6.2.4 Summary of Water Levels

River	Code	Name of Gauge	Daily Mean Water Level		Tidal Water Level	
			Average HWL	Average LWL	Average HWL	Average LWL
Brhamaputra-Jamuna	50.3	Mathura	10.20	3.03		
Brhamaputra-Jamuna	50.6	Aricha	9.49	2.56		
Ganges-Padma	91.2	Mohendrapur	10.67	3.23		
Padma	91.9L	Baruria Transit	8.34	1.92		
Padma	91.9R	Goalundo Transit	8.99	2.49		
Padma	93.4L	Bhagyakul	6.54	1.28	6.57	1.21
Padma	93.5L	Mawa	6.13	1.12	6.17	1.02
Arial Khan	4A	Chowdhury Char	6.45	0.93	6.48	0.86
Padma	94	Tarpasa	5.73	1.12	5.79	1.02
Meghna	276	Satnal	5.03	0.72	5.14	0.50
Meghna	277	Chandpur	4.46	0.88	4.82	0.60

（NOTE）: Average HWL/LWL are the average values of the annual maximum/minimum water levels.

The daily mean discharge data are available along the Padma at Baruria Transit and Mawa and the off-take of the Arial Khan at Chowdury Char. A summary of the daily mean discharges is shown in Table 6.2.5.

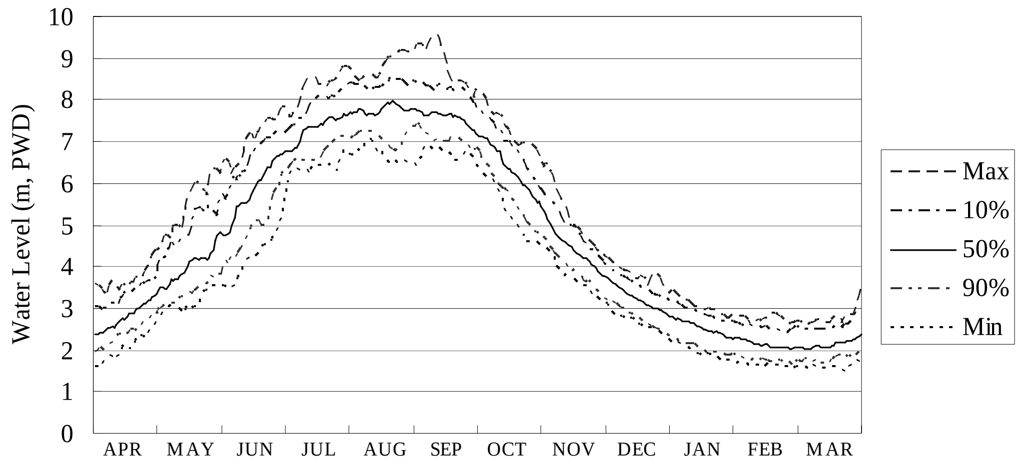
Table 6.2.5 Summary of Daily Mean Discharges

River	Code	Name of Gauge	Daily Mean Discharge (m^3/sec)		
			Average Maximum	Average	Average Minimum
Padma	91.9L	Baruria Transit	92,100	29,500	5,080
Padma	93.5L	Mawa	90,000	28,600	4,730
Arial Khan	4A	Chowdhury Char	2,970	780	70

(2) Frequency and Duration

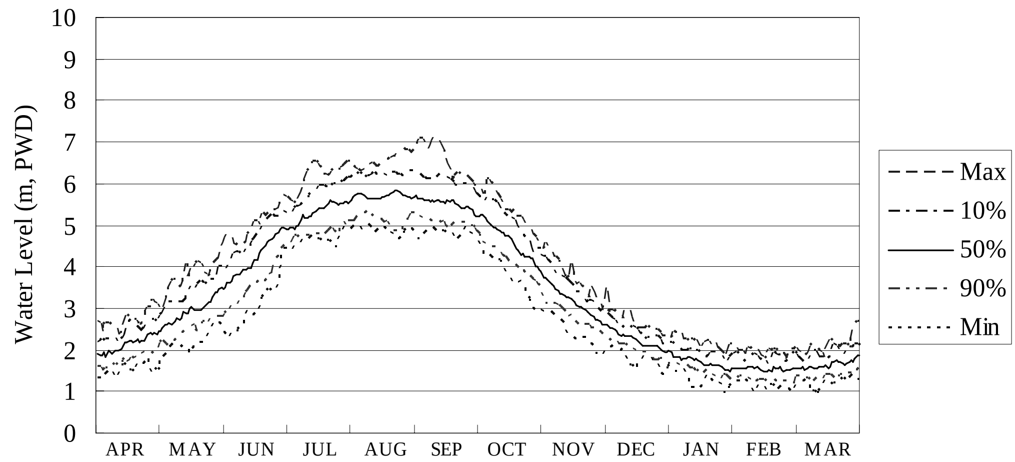
The frequency curves of the water levels were prepared for the selected gauges such as Baruria Transit and Mawa as shown in Figure 6.2.7. The frequency curves for the maximum, the exceeded probabilities of 10%, 50%, and 90%, and the minimum were developed with a time-step of one day on the basis of the daily mean discharge data. The average duration curves indicating the average number of days exceeding a given value were also prepared for the two water level gauges as show in Figure 6.2.8.

Baruria Transit



Month

Mawa



Month

Figure 6.2.7 Water Level Frequency Curves

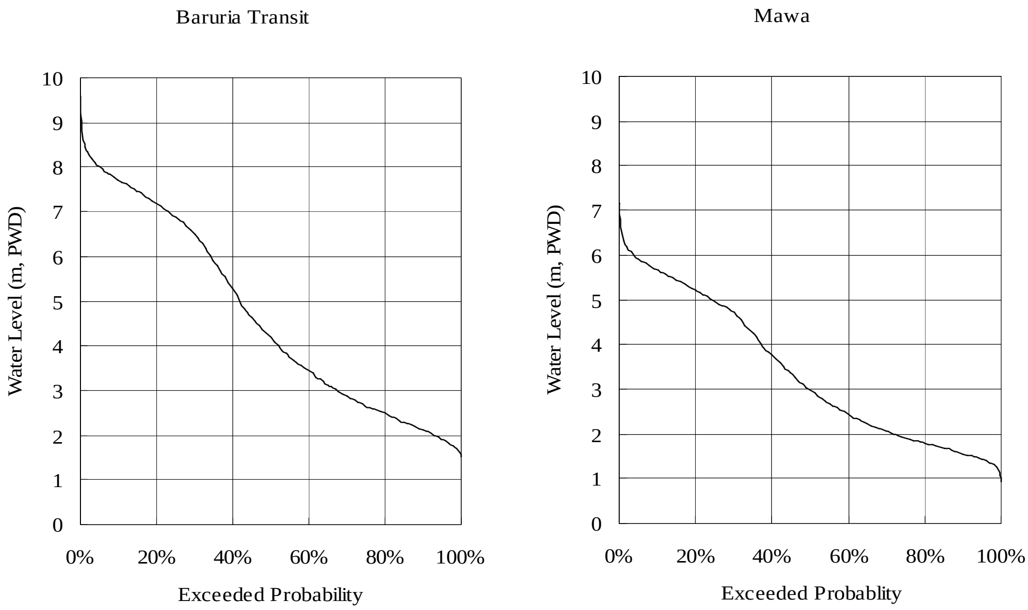


Figure 6.2.8 Water Level Duration Curves

(3) Probable Water Levels

The probable water levels were estimated for the six water level gauges shown in Figure 6.2.9 in and around the Padma. The extreme values year by year were extracted from the daily mean water levels for the non-tidal gauges and from the daily high water levels for the tidal gauges as shown in Table 6.2.6. As seen in the table, the highest recorded took place in 1998/99 for all the six gauges.

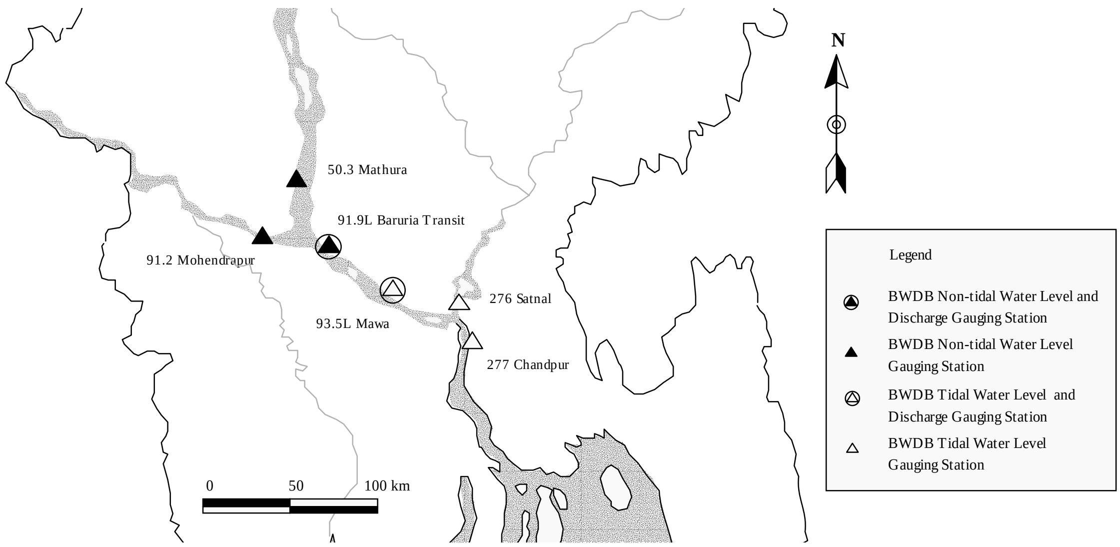


Figure 6.2.9 Locations of Gauges for Probability Analysis

Table 6.2.6 Annual Highest Water Levels

Year	Brahmaputra-Jamuna 50.3 Mathura	Ganges-Padma 91.2 Mohendrapur	Padma 91.9L Baruria Transit	Padma 93.5L Mawa	Meghna 276 Satnal	Meghna 277 Chandpur
1947/48						4.92
1948/49						4.83
1949/50					5.34	4.86
1950/51					4.92	5.10
1951/52					5.01	4.58
1952/53					5.10	4.80
1953/54					5.22	4.92
1954/55					5.86	5.29
1955/56					5.98	5.35
1956/57					4.67	4.83
1957/58					4.52	4.65
1958/59					5.10	4.98
1959/60					4.88	4.71
1960/61					4.97	4.71
1961/62					4.94	4.60
1962/63						
1963/64		10.48				
1964/65	10.07	10.91				
1965/66	9.45	10.13	8.10			
1966/67	9.83	10.76	8.45			
1967/68	9.90	10.38	7.86			
1968/69	10.27	10.57	8.42	6.23	5.49	4.83
1969/70	10.07	10.72	8.18	6.32	5.21	4.85
1970/71	10.67	10.65	8.40	5.76	5.46	4.97
1971/72			8.53	6.34	5.70	5.17
1972/73	9.98	10.33	7.78	5.79	4.82	4.59
1973/74	10.48			6.14	5.24	4.97
1974/75	10.86	11.34	8.61	6.48	5.67	5.24
1975/76	10.01	10.79		5.93	5.05	4.92
1976/77	9.60	10.67			4.83	4.45
1977/78	9.96	10.76		5.97	5.20	4.82
1978/79	9.52	10.79				4.61
1979/80	9.35	10.28			5.15	4.78
1980/81	10.67	11.59	8.65		5.49	4.87
1981/82	9.63	10.62	7.96		5.24	4.57
1982/83	9.73	10.82	7.98		4.81	4.57
1983/84	10.36	11.34	8.47	5.95	5.26	4.68
1984/85	10.24		8.36	6.19	5.62	4.96
1985/86	9.92	10.74	8.06	5.97	4.99	4.72
1986/87	9.70	10.23	7.87	5.78	4.71	4.41
1987/88	10.88	11.29	9.03	6.67	5.61	4.77
1988/89	11.35	11.58	9.35	7.07	6.04	5.16
1989/90	9.70	10.08	7.74	5.76	4.91	
1990/91	10.28	10.48	8.26	5.91	4.98	4.96
1991/92	10.49	10.84	8.49	6.29	5.11	4.81
1992/93	9.72	9.81	7.74	5.55	4.35	4.40
1993/94	10.09	10.09	8.13	6.03	5.03	4.75
1994/95	9.71	10.30	8.05	5.93	4.75	4.33
1995/96	10.69	10.46	8.60	6.52		5.00
1996/97	10.60	10.10	8.45	6.34	5.47	4.94
1997/98	10.43	9.58	8.00	5.86	5.10	4.95
1998/99	**11.62**	**11.90**	**9.58**	**7.14**	**6.40**	**5.62**
1999/00	10.70	10.82	8.53	6.24	3.97	4.95
2000/01	10.61	10.69	8.52	6.28	5.35	4.79
2001/02	10.10	10.91	8.23	6.16	4.97	4.57
2002/03	10.44	11.05	8.65	6.46	4.11	4.07
Average	10.20	10.67	8.34	6.17	5.14	4.82
Max	**11.62**	**11.90**	**9.58**	**7.14**	**6.40**	**5.62**

The extreme value analyses were carried out applying different probability distributions. Finally Log Normal Three Parameters was selected to estimate the probable water levels in conformity with FAP24 adopting the same probability distribution. The estimated probable water levels are shown in Table 6.2.7.

Table 6.2.7 Probable Water Levels

Return Period (years)	Brahmaputra-Jamuna	Ganges-Padma	Padma	Padma	Meghna	Meghna
	50.3	91.2	91.9L	93.5L	276	277
	Mathura	Mohendrapur	Baruria Transit	Mawa	Satnal	Chandpur
2	10.14	10.64	8.27	6.11	5.15	4.81
5	10.60	11.08	8.65	6.44	5.54	5.05
10	10.89	11.32	8.90	6.66	5.75	5.18
25	11.22	11.60	9.23	6.94	5.96	5.32
50	11.46	11.79	9.47	7.14	6.10	5.41
100	11.70	11.97	9.72	7.35	6.22	5.49

(4) Probable Discharges

The probable discharges at Baruria Transit and Mawa were estimated by the following two alternative methods.

- Probability analysis for the annual maximum series of the daily mean discharges on the basis of BWDB data
- Probability analysis for the annual maximum series of the daily mean discharges computed from the corresponding water levels by using the stage-discharge rating equations by FAP24 and IWM

Comparison of the annual maximum series of the daily mean discharges is shown in Table 6.2.8. The extreme value analyses for both series were carried out by the same manner as the water levels, applying Log Normal Three Parameters. The estimated probable discharges are shown in Table 6.2.9.

The estimated probable discharges from the annual maximum series of daily mean water level and stage-discharge rating equations are somewhat larger than the probable discharges based on the BWDB data. Such differences are likely to occur due to the differences in the coverage of years and usage of the stage-discharge rating curves between two discharge series. Within the present study, it is not possible to conclude the suitability of the probable discharges in terms of the accuracy of two discharge series. For the purpose of the present study, the latter alternative method giving the larger values of the probable discharges is regarded as acceptable practically in view of conservative considerations on the facility planning.

Table 6.2.8 Comparison of Annual Maximum Series of Daily Mean Discharges

Baruria Trasit (91.9L)				Mawa (93.5L)			
Year	BWDB Data	Use of HWL and H-Q		Year	BWDB Data	Use of HWL and H-Q	
	Q (m^3/sec)	Q (m^3/sec)	H-Q Used		Q (m^3/sec)	Q (m^3/sec)	H-Q Used
1965/66				1965/66	85,700		
1966/67	81,300	84,000	FAP24	1966/67	85,200		
1967/68	84,700	63,400	FAP24	1967/68	69,200	73,900	FAP24
1968/69	80,200	80,600	FAP24	1968/69	91,000	89,400	FAP24
1969/70	72,700	74,100	FAP24	1969/70	98,200	93,300	FAP24
1970/71	84,200	83,800	FAP24	1970/71	85,200	77,200	FAP24
1971/72				1971/72			
1972/73	84,700	75,900	FAP24	1972/73	78,600	79,900	FAP24
1973/74	90,900	95,500	FAP24	1973/74	100,000	97,800	FAP24
1974/75	113,000	117,400	FAP24	1974/75	111,000	104,600	FAP24
1975/76	93,300	87,400	FAP24	1975/76			
1976/77	83,500			1976/77	84,400	77,900	FAP24
1977/78	81,800			1977/78	99,900	99,900	FAP24
1978/79	80,400			1978/79			
1979/80				1979/80			
1980/81	109,000			1980/81		100,900	FAP24
1981/82	88,200	89,400	FAP24	1981/82	77,300		
1982/83	89,600	86,500	FAP24	1982/83	65,400	86,800	FAP24
1983/84	101,000	102,000	FAP24	1983/84	84,600	83,500	FAP24
1984/85	107,000	100,000	FAP24	1984/85	110,000	109,100	FAP24
1985/86	90,200	92,900	FAP24	1985/86	73,300	75,300	FAP24
1986/87	81,100	81,400	FAP24	1986/87	85,400	111,600	FAP24
1987/88	113,000	111,800	FAP24	1987/88	118,000	119,300	FAP24
1988/89	132,000	138,200	FAP24	1988/89	87,300	105,500	FAP24
1989/90	79,800	73,200	FAP24	1989/90	78,900	76,900	FAP24
1990/91	83,700	87,900	FAP24	1990/91	80,300	80,100	FAP24
1991/92	100,000	104,400	FAP24	1991/92	99,900	99,900	FAP24
1992/93	72,500	74,100	FAP24	1992/93	91,200	91,600	FAP24
1993/94	84,700	87,900	FAP24	1993/94	102,000	99,100	FAP24
1994/95		81,000	FAP24	1994/95		89,400	FAP24
1995/96		97,600	FAP24	1995/96		108,700	FAP24
1996/97	92,600	104,700	IWM	1996/97	87,000	89,100	JICA Study Team
1997/98	86,000	85,100	IWM	1997/98	77,200	75,100	JICA Study Team
1998/99	141,900	150,400	IWM	1998/99	115,700	106,400	JICA Study Team
1999/00	89,700	108,400	IWM	1999/00	102,500	99,900	JICA Study Team
2000/01	83,800	89,200	IWM	2000/01	84,200	82,000	JICA Study Team
2001/02		94,800	IWM	2001/02		78,100	JICA Study Team
Average	92,100	93,400		Average	90,000	92,100	

Table 6.2.9 Estimated Probable Discharges

Baruria Transit

Return Period	Discharge Series	
	BWDB Data	Use of HWL and H-Q
2-year	89,200	90,300
5-year	103,800	106,600
10-year	113,100	117,400
25-year	124,700	131,000
50-year	133,200	141,200
100-year	141,600	151,400

Mawa

Return Period	Discharge Series	
	BWDB Data	Use of HWL and H-Q
2-year	88,500	90,100
5-year	100,800	102,400
10-year	108,300	110,300
25-year	117,100	120,100
50-year	123,400	127,300
100-year	129,400	134,400

(5) Comparison of Probable Water Levels and Discharges with Previous Studies

Tables 6.2.10 and 6.2.11 show the comparison of the probable discharges by FAP24, Padma Bridge Study Phase 1 - Pre-feasibility Study (Pre-F/S, RPT-NEDECO-BCL, 2000), and the present study. The present study estimated the larger values than those by the previous studies for both water levels and discharges. The larger values by the present study are explained by the data series used for the analyses. The data series used by FAP24 and Pre-F/S covered 1966/67-1995/96 and 1965/66-1993/94, respectively. The results by the present study are based on the updated data series from 1965/66-2000/01 inclusive of the 1998 flood giving the historically maximum water levels and discharges.

Table 6.2.10 Comparison of Probable Water Levels with Previous Studies

Baruria Transit

Return Period	FAP24	Pre-FS	Present Study
2-year	8.18	8.23	8.27
5-year	8.52	8.59	8.65
10-year	8.75	8.82	8.90
25-year	9.03	9.04	9.23
50-year	9.23	9.31	9.47
100-year	-	9.52	9.72

Mawa

Return Period	FAP24	Pre-FS	Present Study
2-year	5.93	6.06	6.11
5-year	6.24	6.38	6.44
10-year	6.45	6.59	6.66
25-year	6.70	6.78	6.94
50-year	6.88	7.03	7.14
100-year	-	7.22	7.35

Table 6.2.11 Comparison of Probable Discharges with Previous Studies

Baruria Transit

Return Period	FAP24	Pre-FS	Present Study
2-year	90,000	87,689	90,300
5-year	103,500	100,314	106,600
10-year	112,000	109,464	117,400
25-year	123,500	121,840	131,000
50-year	132,000	131,595	141,200
100-year	140,500	141,783	151,400

Mawa

Return Period	FAP24	Pre-FS	Present Study
2-year	90,000	88,219	90,100
5-year	100,500	100,081	102,400
10-year	106,000	106,960	110,300
25-year	112,000	114,858	120,100
50-year	116,000	120,291	127,300
100-year	120,000	125,412	134,400

(6) Probable Water Levels and Discharges at Alternative Bridge Sites

The probable water levels and discharge at the alternative bridge sites were prepared on the basis of the results of the probable water levels and discharges discussed above. The alternative bridge sites are:

- Site 1: Paturia – Goalundo,
- Site 2: Dohar – Charbhadrasan,
- Site 3: Mawa – Janjira, and
- Site 4: Chandpur – Bhedarganj

The probable water levels and discharges estimated for the alternative bridge sites are shown in Tables 6.2.12 and 6.2.13.

Table 6.2.12 Probable Water Levels at Alternative Bridge Sites

Return Period	Probable Water Levels (m PWD)			
	Site-1	Site-2	Site-3	Site-4
2-year	8.27	6.98	6.11	4.81
5-year	8.65	7.36	6.44	5.05
10-year	8.90	7.62	6.66	5.18
25-year	9.23	7.94	6.94	5.32
50-year	9.47	8.19	7.14	5.41
100-year	9.72	8.43	7.35	5.49

Table 6.2.13 Probable Discharges at Alternative Bridge Sites

Return Period	Probable Discharges (m^3/sec)			
	Site-1	Site-2	Site-3	Site-4
2-year	90,300	(89,100)	90,100	(97,300)
5-year	106,600	(102,600)	102,400	(116,000)
10-year	117,400	(112,300)	110,300	(126,500)
25-year	131,000	(125,500)	120,100	(139,200)
50-year	141,200	(135,900)	127,300	(150,300)
100-year	151,400	(147,000)	134,400	(162,400)

Note: The probable discharges at the site-2 and -4 (figures in parenthesis) were estimated by rough approximations because of the absence of discharge data near these sites.

The water levels at Baruia Transit (91.9L), Mawa (93.5L) and Chandpur (276) are regarded corresponding with the site-1, -3, and -4, respectively. There is no water level gauge in the vicinity of the site-2. The probable water level at the site-2 is therefore derived from the simple interpolation of the probable water levels at Baruia Transit and Mawa. This simple interpolation is regarded as acceptable because the annual highest water levels took place almost simultaneously at Baruria Transit and Mawa

The site-1 and -3 refer to the probable discharges at Baruria Transit and Mawa, respectively. The estimations of the probable discharges at the site-2 and -4 were made by rough approximations because of the absence of discharge data nearby.

6.2.4 Tide

(1) Tidal Variations by Season

The water level gauges of BWDB are classified into the non-tidal and tidal water level gauges. The tidal water level gauges are located in the coastal areas as well as in the inland reaches. The number of the tidal water level gauges is 128. The water levels at the BWDB gauges are measured six times a day by three hours interval from 6:00 to 18:00. In addition, the measurements of highest and lowest water levels taking place within the daily observation hours (6:00-18:00) are also measured at the tidal water level gauges.

Figure 6.2.10 shows the annual variations of daily highest and lowest water levels in the year 1995/96 at Daultkhan (BWDB tidal water level gauge, 278) located about 70 km upstream from the river mouth. The water level varies seasonally by runoff from upstream as seen in the hydrographs of the daily highest and lowest water levels. Meanwhile, the seasonal variations of tide can also be seen in the daily water level ranges derived from the daily highest and lowest water levels. The maximum daily variation of 3.55 m took place in the middle of May and the minimum of 0.74 was observed in the late February.

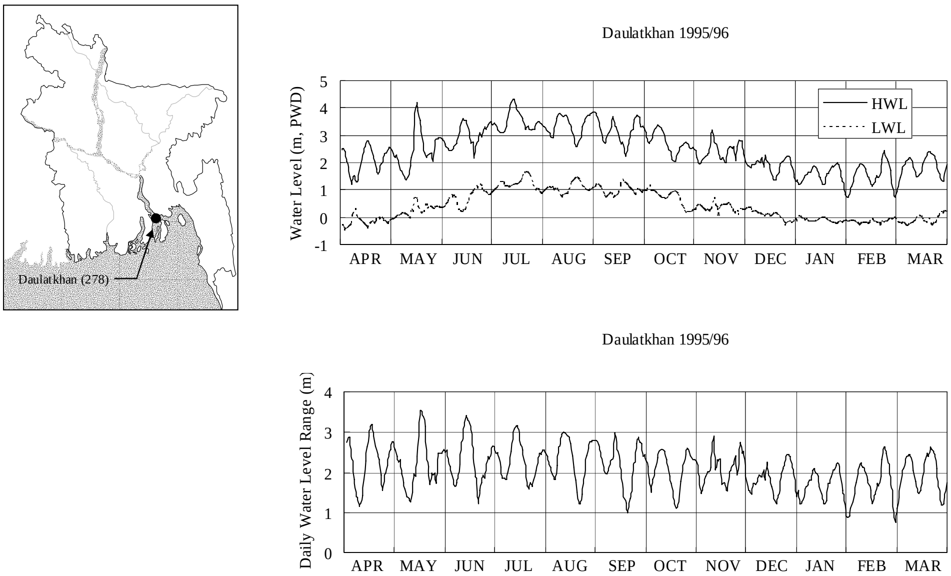


Figure 6.2.10 Water Level Variations at Daulatkhan (1995/96)

(2) Tidal Influences

Tidal influences to the rivers reach around Malkuli in the Meghna and Goalundo in the Padma located about 390 and 230 km from the river mouth, respectively. The average daily water level ranges by month at the BWDB tidal gauges of Daulatkhan, Chandpur, and Mawa are summarized in Table 6.2.14. Seasonal variations of tidal range in a day are different depending on the locations of the gauges. Chandpur is located about 160 km from the estuary and shows the maximum water level range varying from 1.28 m in May and 0.88 m in September. At Mawa the maximum water level range varies from 0.51 m in March and 0.20 m in August.

Table 6.2.14 Average Daily Water Level Ranges at BWDB Tidal Water Level Gauges

Month	Daulatkhan (278)			Chandpur (277)			Mawa (93.5L)		
	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min
April	3.02	2.18	1.14	1.25	0.84	0.43	0.48	0.28	0.12
May	3.10	2.30	1.40	1.28	0.85	0.43	0.41	0.22	0.11
June	3.08	2.35	1.51	1.17	0.81	0.46	0.36	0.19	0.09
July	3.08	2.35	1.56	0.97	0.67	0.42	0.24	0.14	0.06
August	3.08	2.34	1.43	0.89	0.61	0.34	0.20	0.11	0.05
September	2.95	2.20	1.21	0.88	0.59	0.30	0.21	0.11	0.04
October	2.84	2.06	1.13	1.04	0.66	0.29	0.35	0.18	0.06
November	2.69	1.94	1.20	1.14	0.73	0.33	0.36	0.20	0.08
December	2.40	1.74	1.13	1.07	0.70	0.37	0.35	0.20	0.08
January	2.37	1.68	1.01	1.09	0.73	0.37	0.42	0.24	0.09
February	2.53	1.75	0.92	1.13	0.78	0.39	0.50	0.28	0.11
March	2.76	1.92	1.00	1.21	0.82	0.41	0.51	0.30	0.13

Figure 6.2.11 shows the examples of the relationships between daily mean water levels and daily water level ranges at Mawa, and Baruria Transit in the year 2000/01. At Mawa, the daily water level range varies from 0.2 to 0.6 m for the daily mean water levels from 6 to 2 m PWD as a whole. Baruria Transit is located around the border of tidal influences to the Padma. The majority of the plots at Baruria Transit are shown within the daily water level range of 0.1 m for any daily mean water level at Baruria Transit.

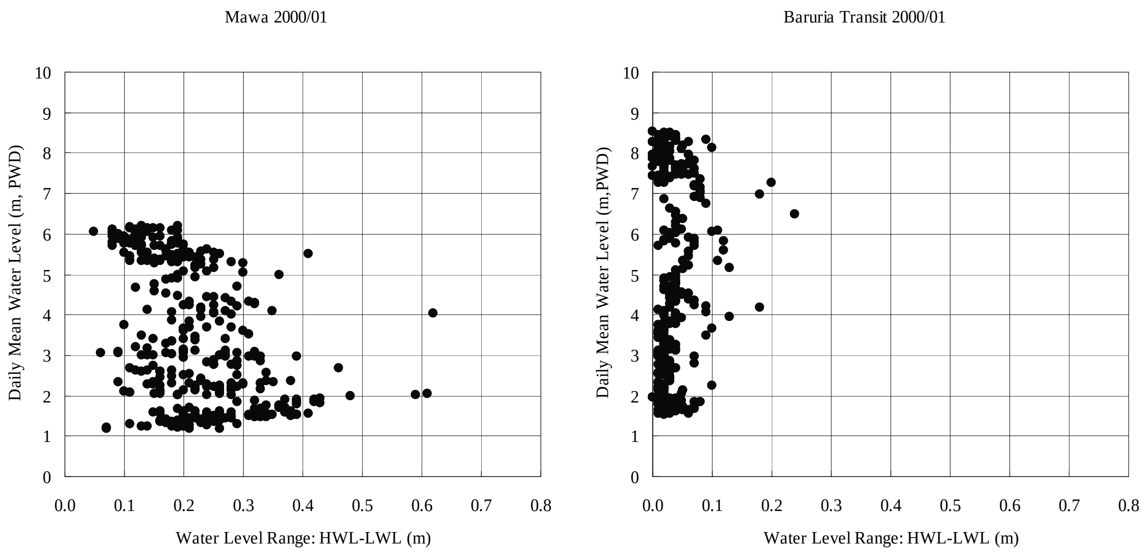


Figure 6.2.11 Relationships between Daily Mean Water Levels and Daily Water Level Ranges

6.2.5 Flood Flow and Inundation Conditions

(1) Past Major Floods

The major floods occurred in 1987, 1988, and 1998 are the historically severe events in Bangladesh in the light of the available flood statistics since 1954. 'Annual Flood Report, 1998' issued by BWDB describes the situations of the flood levels at the monitoring stations of the flood forecasting and warning services (FFWS). Around the study area, the historically highest water levels were recorded at FFWS monitoring stations of Aricha (50.3), Goalundo Transit (91.9R), Chandpur (277) and the second highest was observed at Bhagyakul (93.4L) during the 1998 flood event. The highest peaks and days above danger level are summarized in Table 6.2.15.

Table 6.2.15 Records of Major Flood Events around the Study Area

River	Code	BWDB Monitoring Station	Highest Peak Level (m PWD)			Days above Danger Level		
			1998	1988	1987	1998	1988	1987
Jamuna	50.3	Aricha	10.76	10.58	10.13	68	31	48
Padma	91.9R	Goalundo Transit	10.21	9.83	9.52	68	41	54
Padma	93.4L	Bhagyakul	7.50	7.43	6.99	72	47	56
Meghna	277	Chandpur	5.62	5.16	4.77	49	29	19

The water level hydrographs at Aricha, Goalundo Transit, Bhagyakul, and Chandpur during the flood events in 1987, 1988, and 1998 are shown in Figures 6.2.12 and 6.2.13. The hydrographs show that the 1998 flood caused the long lasting water levels exceeding the danger level over the historically highest peak.

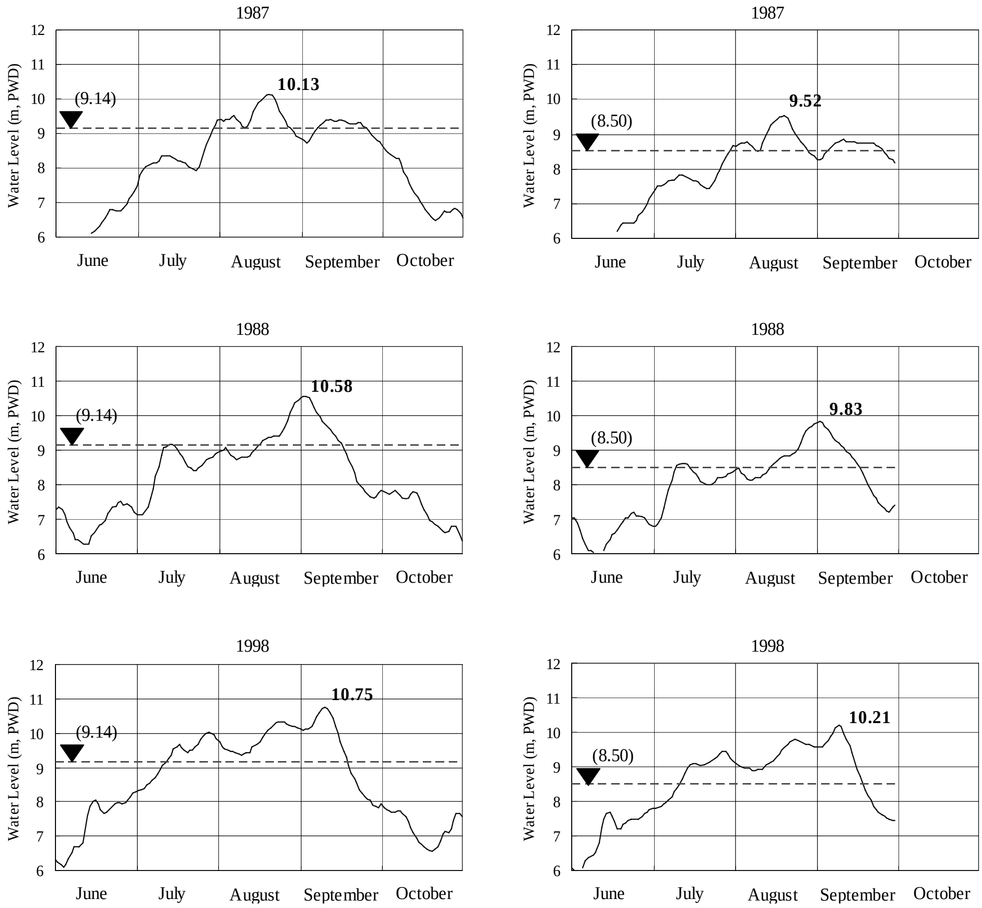


Figure 6.2.12 Water Level Hydrographs during 1987, 1988, and 1998 Flood Events (Aricha and Goalundo Transit)

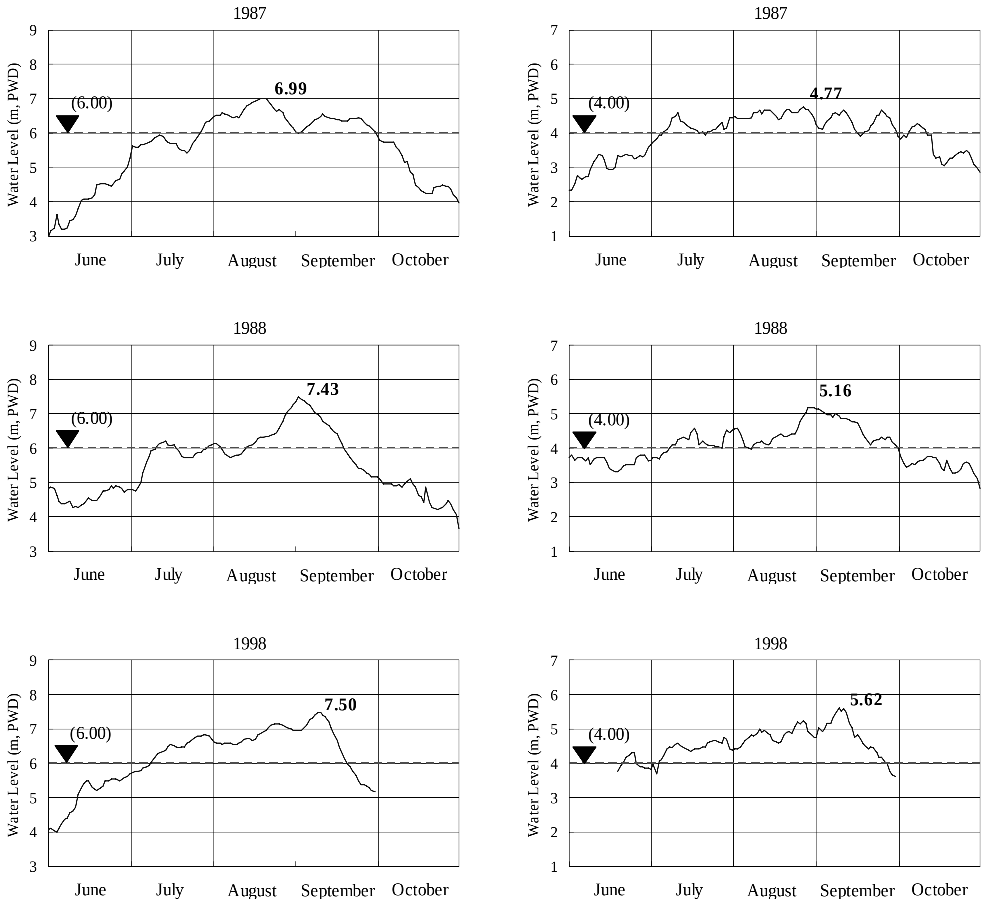


Figure 6.2.13 Water Level Hydrographs during 1987, 1988, and 1998 Flood Events (Bhagyakul and Chandpur)

(2) Characteristics of Flood and Inundation

The flood and inundation in Bangladesh is highly dependent on the runoff from the Ganges-Brahmaputra-Meghna drainage basin expanding over India, Nepal, Bhutan, China, and Bangladesh. The territory of Bangladesh covers only 8% of the drainage basin and a most amount of runoff is brought from the outside of the territory. The Ganges-Padma, Brahmaputra-Jamuna, Padma, and Meghna rivers increase discharges to bankfull amounts or more continuously due to the heavy rainfalls widely taking place in the upper drainage basin during the monsoon season. The rivers overflow and inundate the riverine areas when the discharge exceeds the bankfull capacity.

The water levels of the rivers rise up 4 to 7 m higher than those in the dry season. During the monsoon season, the drainage area within Bangladesh also gets the heavy rainfalls amounting to some 80% of the annual rainfall varying from 1,200 to 5,000 mm by region. The runoff caused by such rainfalls eventually concentrates into the major rivers through the tributaries. But the runoff is hardly drained when the major rivers keep the high water levels. As a result, the runoff inundates topographically lower areas along the tributaries.

About 80% of the territory is the low-lying flood plain of the Ganges-Padma, Brahmaputra-Jamuna, and Meghna rivers. Therefore, the inundation spreads over a vast extent on the flood plain as a result of the overflow from the major rivers in combination with the stagnant runoff from the drainage area within the country. In the case of the large scale flood, the flood plain is almost totally covered with water. A limited extent of elevated lands (natural levees, vegetated chars, embankments, reclaimed lands etc.) remains free from inundation in the flood plain.

Photo 6.2.1
Overbank flooding, left bank of the Padma, view from the south to Paturia Ferry Ghat, 8th July 2003

Photo 6.2.2
Inundation, an area to the west of Dhaka, view from helicopter, 10th July 2003

(3) Inundation Areas

Because of the vast extent of flood and inundation in Bangladesh, the extent of inundation areas was assessed by the approaches of GIS using the satellite images. The Center for Environmental and Geographic Information Services (CEGIS, former EGIS: Environment and GIS Support Project for Water Sector Planning) carried out the assessment of the inundation areas in the 1998 flood. The results were compiled into EGIS Technical Note Series: Mapping of the 1998 Floods (EGIS, 1999).

CEGIS analyzed the RADARSAT satellite images on 26th August, 10th September, and 17th September during the 1998 flood. The ground resolutions of the RADARSAT images were 100 m x 100 m for 26th August and 17th September and 50 m x 50 m for 10th September. The images were classified into ‘Open Water Flood’ and ‘Others’ defined as follows:

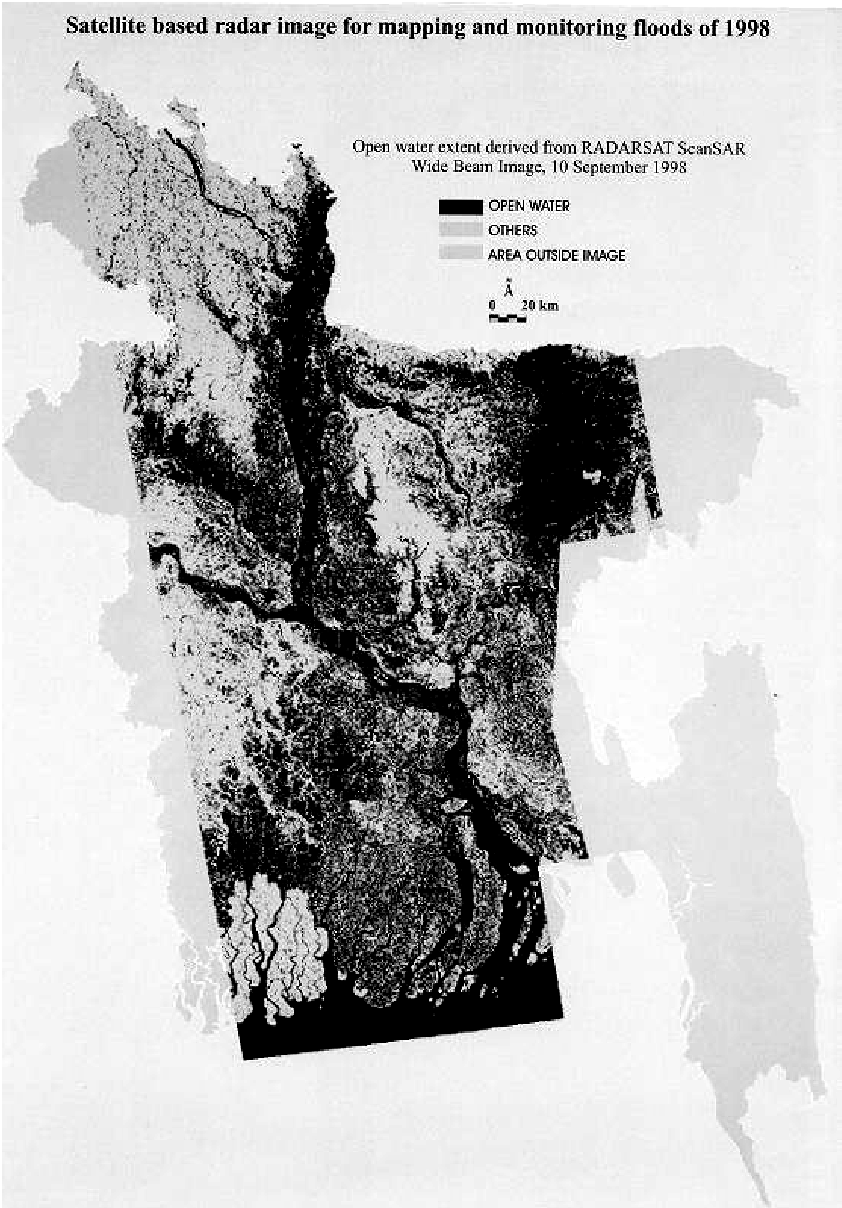
- Open Water Flood: including water areas with little or no crop canopy
- Others: including non-flooded lands, flooded/inundated agricultural crops with high canopy and aquatic weeds, dense settlements with high canopy trees

The three satellite images cover the different extents due to the constraints at the time of data acquisition. The extent of each classification was retrieved on the basis of the common area that was commonly covered by all the images as given in Table 6.2.16.

Table 6.2.16 Extent of Open Water Flooding from RADARSAT Images for Common Area, 1998

Image Class	26th August		10th September		17th September	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Open Water Flooding	3,026,899	55	3,123,136	57	2,367,955	43
Others	2,480,057	45	2,383,830	43	3,139,001	56
Total	5,506,956	100	5,506,956	100	5,506,956	100

The classified flood map from RADARSAT image of 10th September 1998 is shown in Figure 6.2.17. The highest recorded water levels in the Padma were recorded on 7th September, three days before the date of the image.



Source: CEGIS

Figure 6.2.14 Classified Flood Map from RADARSAT Image of 10th September 1998

The analysis of the flood mapping of the 1998 flood by CEGIS also covered the flooded area (open water flooding) by Thana (Upzila). Table 6.2.17 shows the flooded areas in the selected Thanas in the neighboring districts (Zila) along the Padma river. Figure 6.2.15 shows the locations of the districts along the Padma River.

During the flood peaking period, Thanas covered with more than 70% of Open Water Flood are mainly observed around the left bank of the Jamuna-Ganges confluence. It is suggested that these areas may be likely to suffer from the overbank flooding of the Jamua and Padma from the early period of the flood due to the riverine topographic conditions.

Table 6.2.17 Percentages of Open Water Flood by Thana during 1998 Flood

Districts on Left Bank

District	Thana	Area (ha)	Percent of Area Flooded		
			26-Aug	10-Sep	17-Sep
Dhaka	Dhaka Metro	30,292	46%	42%	38%
	Dhamrai	30,742	78%	74%	52%
	Dohar	16,150	62%	67%	53%
	Keraniganj	16,688	64%	57%	47%
	Nawabganji	24,481	69%	71%	62%
	Savar	28,013	48%	48%	40%
	Total Area	146,366			
Manikganj	Daulatpur	21,624	80%	85%	77%
	Ghior	14,596	76%	77%	77%
	Hariampur	24,544	73%	70%	70%
	Manikganj	21,481	63%	49%	49%
	Saturia	14,011	75%	52%	52%
	Sibalay	19,908	72%	71%	71%
	Singair	21,740	62%	47%	47%
	Total Area	137,904			
Munshiganj	Gozaria	13,091	63%	60%	56%
	Lohajang	13,012	62%	66%	60%
	Munshiganji	16,079	42%	43%	38%
	Serajdikhan	18,020	49%	48%	44%
	Srinagar	20,299	67%	67%	60%
	Tongibari	14,997	25%	29%	22%
	Total Area	95,498			
Chandpur	Chandpur	30,880	53%	58%	52%
	Faridganj	23,115	30%	30%	22%
	Haimchar	17,449	74%	76%	68%
	Hajiganji	18,991	55%	47%	37%
	Kachua	23,582	71%	56%	36%
	Matlab	40,924	49%	54%	47%
	Shahrasti	15,431	72%	58%	49%
	Total Area	170,372			

Districts on Right Bank

District	Thana	Area (ha)	Percent of Area Flooded		
			26-Aug	10-Sep	17-Sep
Rajbari	Baliakandi	24,254	22%	28%	27%
	Goalanda	14,902	75%	79%	64%
	Pangsha	41,427	36%	41%	40%
	Rajibari	31,300	24%	30%	24%
	Total Area	111,883			
Faridpur	Alfadanga	13,601	60%	77%	49%
	Bhanga	21,636	67%	66%	54%
	Boalmari	27,236	37%	55%	46%
	Char Bhadrasan	14,160	83%	84%	76%
	Faridpur	40,704	41%	49%	38%
	Madhukhali	23,019	18%	31%	33%
	Nagarkanda	37,903	58%	62%	40%
	Sadarpur	29,021	59%	62%	47%
	Total Area	207,280			
Madaripur	Kalkini	28,000	62%	60%	34%
	Madaripur	31,382	52%	54%	34%
	Rajoir	22,928	71%	69%	49%
	Sibchar	32,189	63%	66%	52%
	Total Area	114,499			
Shariatpur	Bhedarganj	26,729	72%	69%	48%
	Damudya	9,175	68%	58%	31%
	Goshairhat	16,787	68%	62%	34%
	Janjira	23,954	81%	77%	70%
	Naria	24,002	69%	66%	58%
	Palong	17,510	49%	39%	19%
	Total Area	118,157			

Source: Mapping of the 1998 Floods
EGIS Technical Note 14, 1999

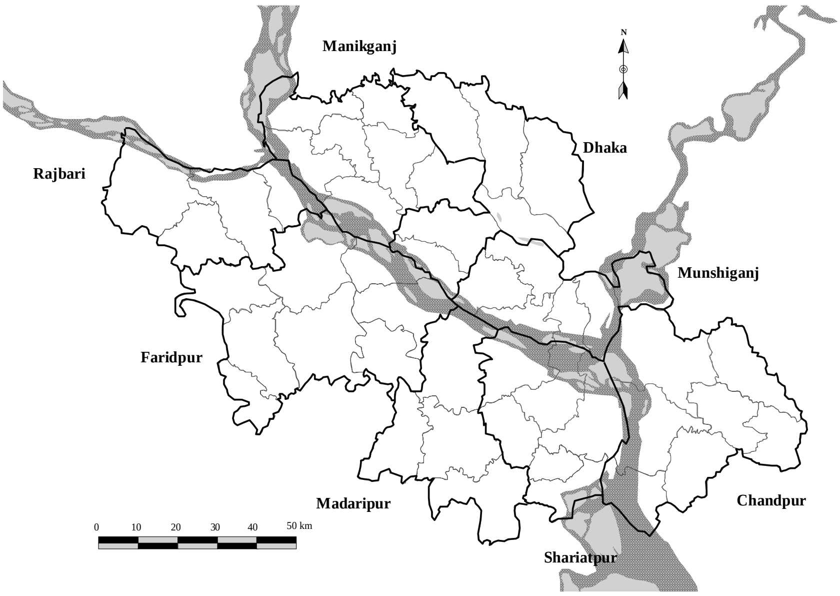


Figure 6.2.15 Neighboring Districts (Zilas) along the Padma River

6.3 HYDRO-METEOROLOGICAL OBSERVATIONS

6.3.1 Relevant Agencies and Activities

(1) Bangladesh Meteorological Department

Bangladesh Meteorological Department (BMD) is responsible for the meteorological observations including surface observation, atmospheric observation, and satellite image acquisition. There are 35 surface observatories of BMD within the country to observe the meteorological items listed in Table 6.3.1. The locations of the surface observatories are shown in Figure 6.3.1.

Table 6.3.1 Surface Observation at 35 Observatories of BMD

Every 3 Hours Observation	Daily Basis Observation
• Precipitation • Air Temperature • Relative Humidity • Atmospheric Pressure • Wind Speed and Direction	• Maximum Air Temperature • Minimum Air Temperature • Sunlight Hours

BMD has the meteorological radar system including the radars at four locations such as Dhaka, Rangpur, Cox's Bazar, and Khepupara. The observation range of these radars is a radius of 400 km to cover the entire territory of Bangladesh as shown in Figure 6.3.1. The meteorological radar system contributes to the prediction of cyclone movement and real-time estimation of rainstorm intensity.

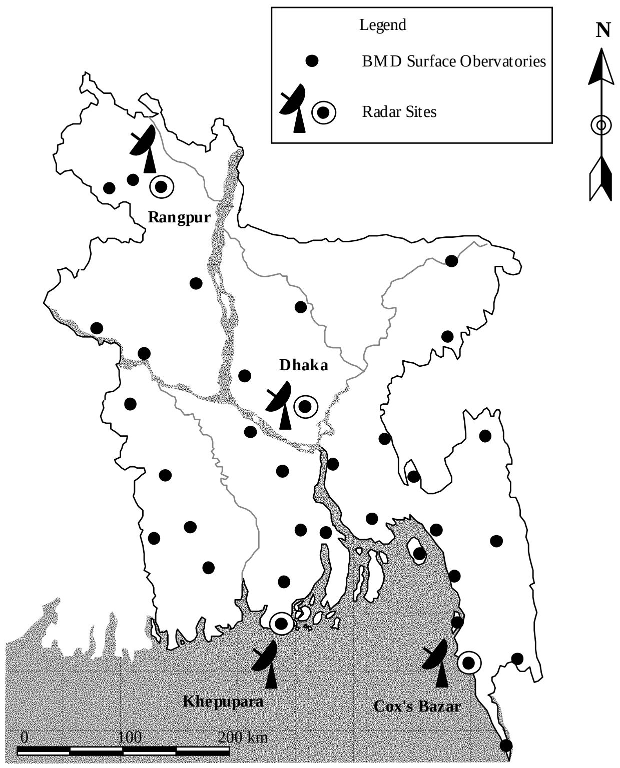


Figure 6.3.1 Locations of BMD Surface Observatories and Radars

(2) Bangladesh Water Development Board

Bangladesh Water Development Board (BWDB) is carrying out comprehensive hydrological observations and data management for the entire country. The observed records are utilized for the various purposes of the roles of BWDB including water resources development, flood forecasting, river training works, drainage, and irrigation. The observation network of BWDB is broadly classified into four, i.e. Surface Water Hydrology (SW), Ground Water Hydrology (GW), Climate, and River Morphology. The number of observatories by each category is listed in Table 6.3.2.

Table 6.3.2 BWDB Hydro-meteorological Observatories

Category	Observation	Number of Observatories
Surface Water Hydrology (SW)	Non-tidal Surface Water Level	214
	Tidal Surface Water Level	128
	Discharge	108
	Tidal Discharge	2
	Surface Water Quality	13
	Salinity	46
Ground Water Hydrology (GW)	Ground Water Table	20
	Ground Water Quality	119
	Aquifer Test	278
Climate	Rainfall	269
	Evaporation	39
River Morphology	River Cross Section	1,023
	Sediment	26

The different Circles of BWDB such as Surface Water Hydrology Circle-1, Ground Water Hydrology Circle, and River Morphology and Research Circle elaborate the hydro-meteorological observations for their responsible fields. All the observed records are gathered and accumulated into the database managed by Surface Water Hydrology Circle-2 of BWDB in Dhaka. BWDB provides the data stored in the database for other organizations on request.

(3) Flood Forecasting and Warning Center

Flood Forecasting and Warning Center (FFWC) was established within BWDB in 1972. The present system of FFWC was strengthened through the project funded by Danish International Development Agency (DANIDA) in 1990s. The observation system of FFWC is composed of the following observatories within the territory of Bangladesh:

- 91 manually operated water level stations
- 13 automatic water level stations
- 56 manually operated rainfall stations
- 6 automatic rainfall stations

(4) Bangladesh Inland Water Transport Authority

Bangladesh Inland Transport Authority (BIWTA) practices the bathymetric surveys to monitor the available depth for the inland navigations in the major rivers in Bangladesh. The bathymetric surveys are carried out once in a year in general.

In the bathymetric surveys, the Dhaka navigation system is used for positioning. The depth of water is measured by an echo sounder mounted on the survey vessel. The measured depths are charted as depth from average lowest low water level (ALLW), which is determined on the basis of water level observations at BIWTA or BWDB gauges located in the vicinity of the bathymetric survey area. The measured depths are drawn on maps together with contour lines, submerged and exposed char (sandbar) lines, bank lines and some permanent features on the riverbanks (ferry ghats, bazars, mosques, etc.). The scales of the maps rage from 1:5,000 to 1:50,000 depending on the scales of surveyed rivers.

BIWTA also carries out the tidal level observations at 17 locations around the coast along Bay of Bengal as well as the locations of the inland ports. The water levels are observed by half an hour interval.

(5) Project Based Activities

In addition to the routine practices, the hydro-meteorological observations including hydrographic surveys have been carried out under the different projects for the respective purposes.

A series of Flood Action Plan (FAP) were initiated after the serious flood event experienced in 1988. FAP comprised the various component studies as shown in Table 6.3.3 to tackle with the flood in Bangladesh. Through the FAP component studies, the extensive data collection and analysis had been elaborated together with the hydrographic surveys required for the respective purposes. Of those, the River Survey Project (FAP24) from 1992 to 1996 elaborated the extensive baseline measurements, surveys and studies for the hydrographic features in Bangladesh. The River Survey Project also developed a database named PSD24 for storing the data collected in the past as well as the data resulting from the measurements and surveys during the period of the project.

The Jamuna Multipurpose Bridge Authority (JMBA) entrusts the operation and maintenance of the Jamuna Bridge, which was completed in 1998 to the Jamuna Operation and Maintenance Contractor (JOMAC). JOMAC is carrying out the hydrographic surveys since 1998 including the river cross section surveys in upstream and downstream of the bridge and the bathymetric surveys along the guide bunds on both banks.

These surveys are conducted every two week during the monsoon season and every one month during the rest of the year. JMBA envisages utilizing the hydrographic surveys by JOMAC for deciding the need of maintenance work for the bridge substructures and guide bunds before the monsoon season.

Table 6.3.3 Flood Action Plan (FAP)

FAP No.	Activities	Funding Source
	Main Components	
1	Brahmaputra Right Embankment Strengthening	IDA
2	Northwest Regional Study	UK, Japan
3	North Central Regional Study	EU, France
3-1	Jamalpur Priority Project	France, EU
4	Southwest Area Study	UNDP, ADB
5	Southwest Regional Study	UNDP
6	Northeast Regional Study	Canada
7	Cyclone Protection Project	EU, IDA
8A	Greater Dhaka Protection Project	Japan
8B	Dhaka Integrated Flood Protection Project	ADB
9A	Secondary Town Integrated Protection Project	ADB
9B	Meghna River Bank Protection Project	IDA
10	Flood Forecasting and Warning Expansion	UNDP, Japan
11	Disaster Preparedness Project	UNDP, Japan, Demark
	Supporting Studies	
12	FCD/1 Review	UK, Japan
13	Operation and Maintenance Study	UK, Japan
14	Flood Response Study	USA
15	Land Acquisition and Resettlement Study	Sweden
16	Environmental Study	USA
17	Fisheries Study and Pilot Project	UK
18	Topographic Mapping	Finland, France, Switzerland
19	Geographic Information System	USA
20	Compartmentalization Pilot Project	Netherlands, Germany
21/22	Bank Protection, River Training and Active Flood Control Management	Germany, France
23	Flood Proofing Pilot Project	USA
24	River Survey Program	EU
25	Flood Modeling and Management	Denmark, France, Netherlands, UK
26	Institutional Development Program	UNDP, France
	Macro-economic Study (Special Study)	France

6.3.2 Data Availability for the Study

(1) Climatology

The climatologic records in and around the study area were collected from BMD. The records for the period from 1971 to 2002 are available at four meteorological stations, i.e. Dhaka, Khulna, Brisal, and Faridpur. The records cover rainfall, temperature, relative humidity, evaporation, sunshine hours, and wind speed and direction for each station. The locations of these observatories are shown in Figure 6.3.2.

(2) Hydrology

The daily water level records at the selected gauging stations along the Jamuna, Ganges-Padma, and Meghna were collected from BWDB. The records are available for different periods depending on the gauging stations as shown in Table 6.3.4. The periods of the records are more than 30 years with several intermittent in general as shown in Figure 6.3.3.

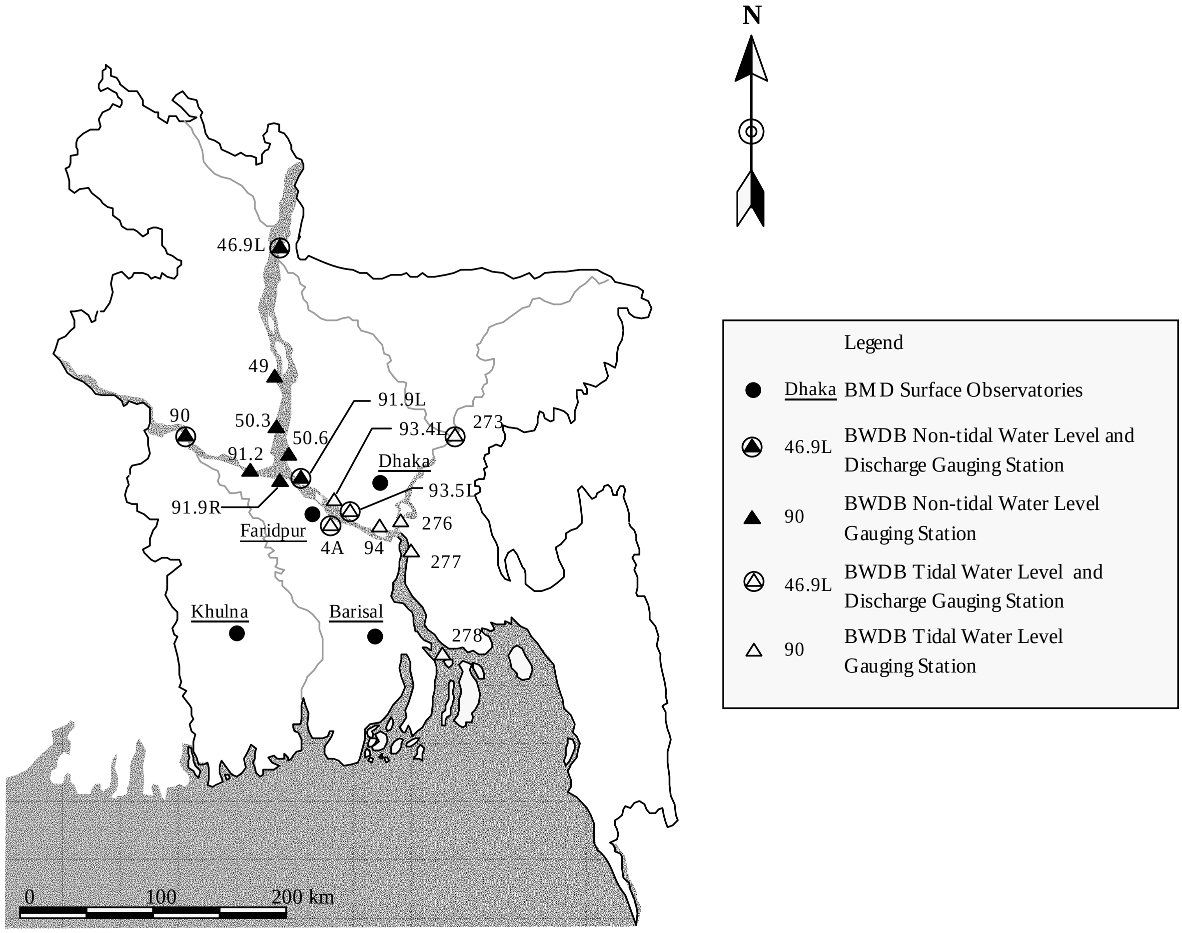


Figure 6.3.2 Locations of Selected BMD Surface Observatories and BWDB Hydrological Stations for Data Collection

Table 6.3.4 Water Level Records Collected

River	Code	Name of Station	Type of Data	Period
Brahmaputra-Jamuna	46.9L	Bahadurabad	Non-tidal Water Level	1960/61-2002/03
Brahmaputra-Jamuna	49	Sirajganj	Non-tidal Water Level	1945/46-2001/02
Brahmaputra-Jamuna	50.3	Mathura	Non-tidal Water Level	1964/65-2002/03
Brahmaputra-Jamuna	50.6	Aricha	Non-tidal Water Level	1964/65-2002/03
Ganges-Padma	90	Hardinge Bridge	Non-tidal Water Level	1910/11-2002/03
Ganges-Padma	91.2	Mohendarpur	Non-tidal Water Level	1962/63-2002/03
Padma	91.9L	Baruia Transit	Non-tidal Water Level	1965/66-2002/03
Padma	91.9R	Goalundo Transit	Non-tidal Water Level	1964/65-2002/03
Padma	93.4L	Bhagyakul	Tidal Water Level	1968/69-2002/03
Padma	93.5L	Mawa	Tidal Water Level	1968/69-2002/03
Arial Khan	4A	Chowdhury Char	Tidal Water Level	1965/66-2002/03
Padma	94	Tarpasa	Tidal Water Level	1928/29-2002/03
Meghna	273	Bhairab Bazar	Tidal Water Level	1959/60-2000/01
Meghna	276	Satnal	Tidal Water Level	1961/62-2002/03
Meghna	277	Chandpur	Tidal Water Level	1947/48-2002-03
Meghna	278	Daulatkhan	Tidal Water Level	1950/60-1995/96

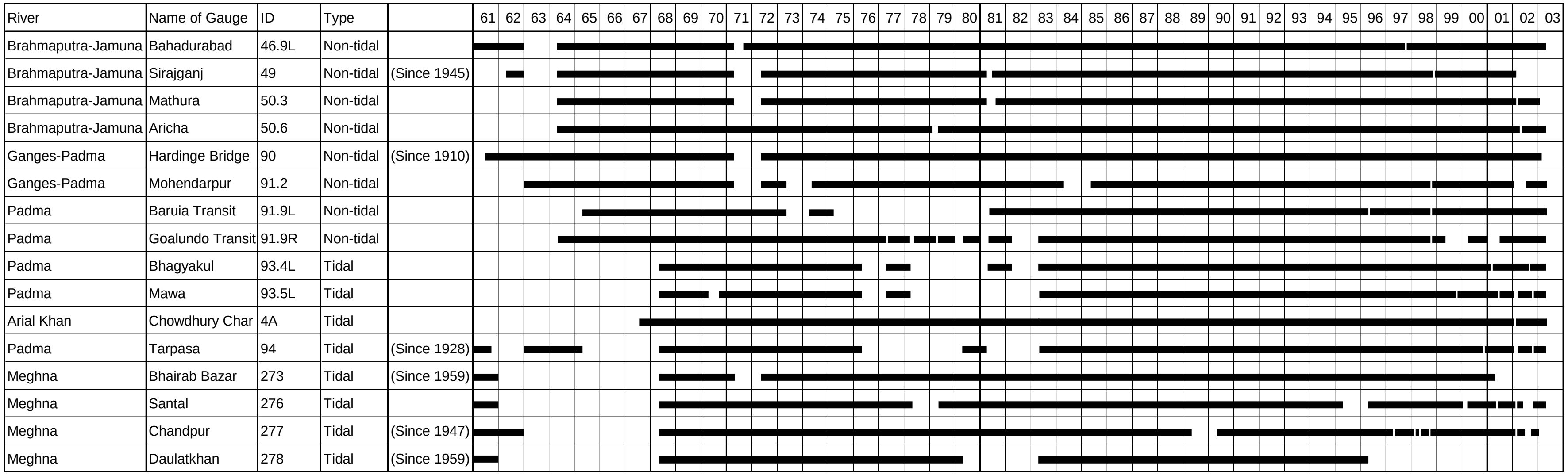
Of the stations listed above, the daily mean discharges converted by stage-discharge (H-Q) rating curve are also available at Bahadurabad (46.9L), Hardinge Bridge (90), Baruia Transit (91.9L), Mawa (93.5L), and Chowdhury Char (4A). The periods of the records are more than 30 years with several intermittent and are different by station, i.e.

1956/57-2002/03 at Bahadurabad, 1934/35-2001/02 at Harding Bridge, 1966/67-2000/01 at Baruia Transit, 1964/65-1999/00 at Mawa, and 1965/66-2000/01 at Chowdhury Char, respectively. At Mawa, the converted dischages are available only for the monsoon periods after 1987.

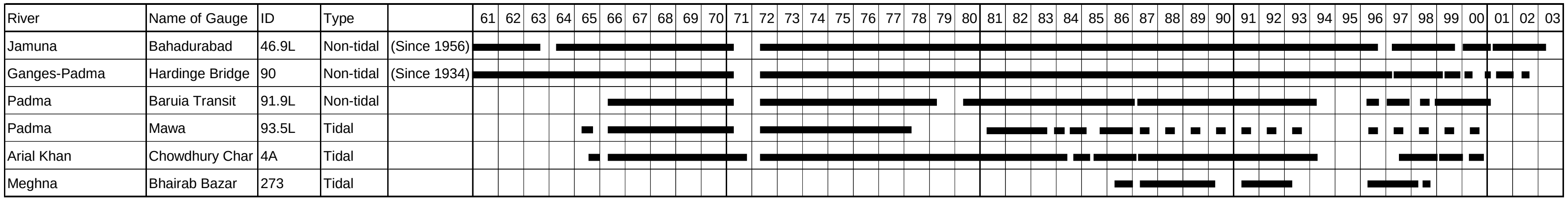
The discharge measurement records were collected for two stations along the Padma river at Baruia Transit (91.9L) and Mawa (93.5L) for the period of the recent 13 years (1990/91 to 2002/03). The sediment transport converted into the daily values is also available at Baruia Transit for the recent 10 years (1992/93-2001/02).

Figure 6.3.3 Water Level and Discharge Records Collected

Water Level



Discharge



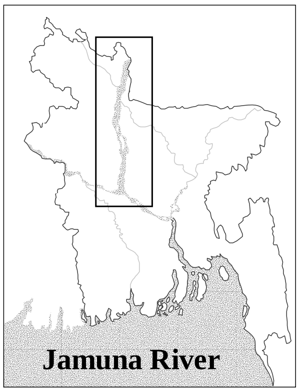
(3) River Morphology

BWDB carries out the river cross section surveys throughout the country. The main purpose of the river cross section surveys is to monitor the morphological changes. The surveys were initiated in 1964 along the Jamuna river and have been extended over the major rivers and tributaries/distributaries. The surveys are conducted annually for the major rivers such as the Jamuna, Padma, and Meghna (including the Meghna Lower) and once in two or three years for the tributaries and distributaries. A location map of the surveyed cross sections is issued by BWDB. The cross sections are identified with the code and sequential numbers by river. The numbers of the BWDB standard cross sections along the major rivers are identified on the location map as shown in Table 6.3.5.

Table 6.3.5 BWDB Standard Cross Sections along the Major Rivers

River	Code	Approx. Length of Reaches Surveyed (km)	Number of Cross Section
Brahmaputra-Jamuna	J	210	39
Ganges-Padma	G	120	25
Padma	P	100	15
Meghna	M	240	45
Meghna Lower	ML	90	13
Total		760	137

The locations of the cross sections along the Jamuna, Ganges-Padma, and Meghna are shown in Figures 6.3.4, 6.3.5, and 6.3.6, respectively. Of these river cross sections, the historical cross section data were collected mainly for the Padma river between the Jamuana-Gauges confluence and the Padma-Meghna confluence. The data of other rivers were also collected partly for the selected stretches covering the Jamuna and Ganges upstream of the confluence and the Meghna upstream and downstream of the confluence of the Padma. Complete set of the cross section data for all the major rivers were obtained for some recent years.



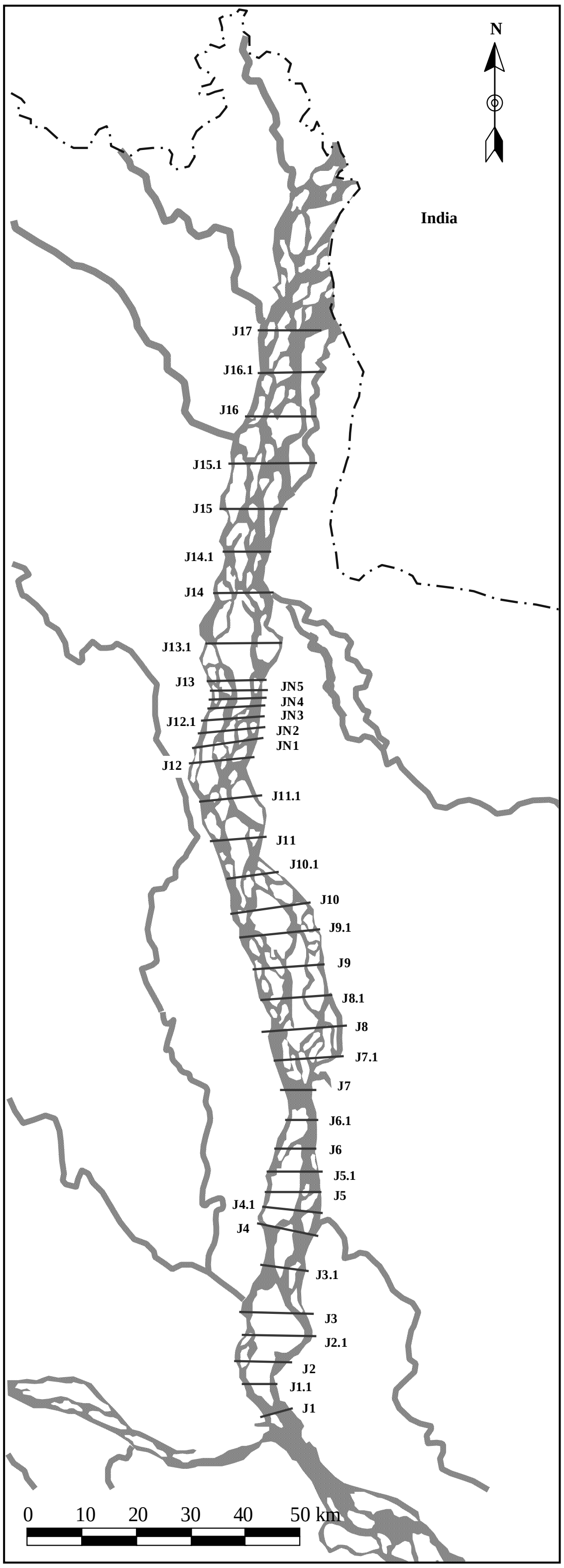


Figure 6.3.4 Locations of BWDB Standard Cross Sections along the Major Rivers (Jamuna River)

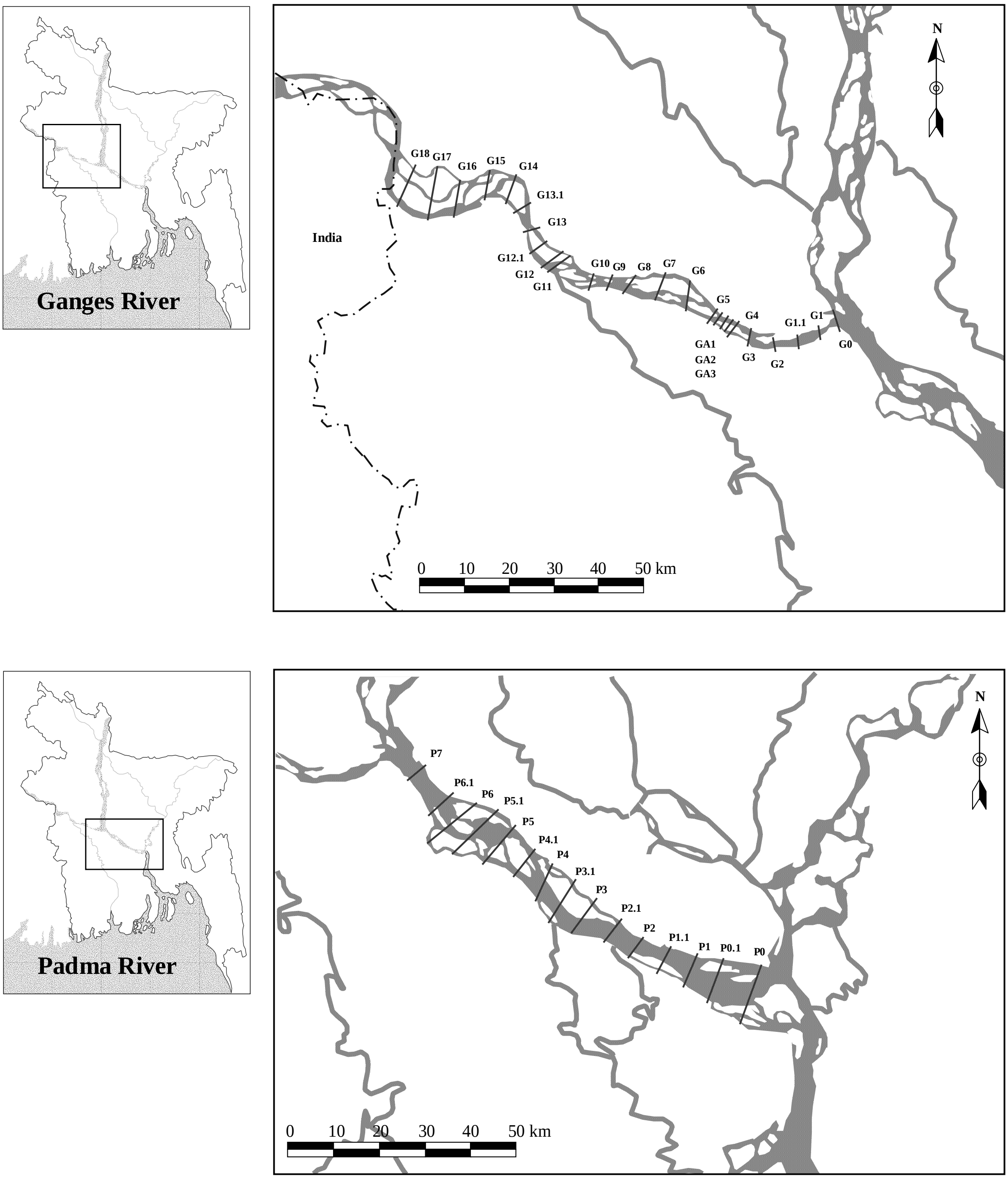


Figure 6.3.5 Locations of BWDB Standard Cross Sections along the Major Rivers (Ganges River and Padma River)

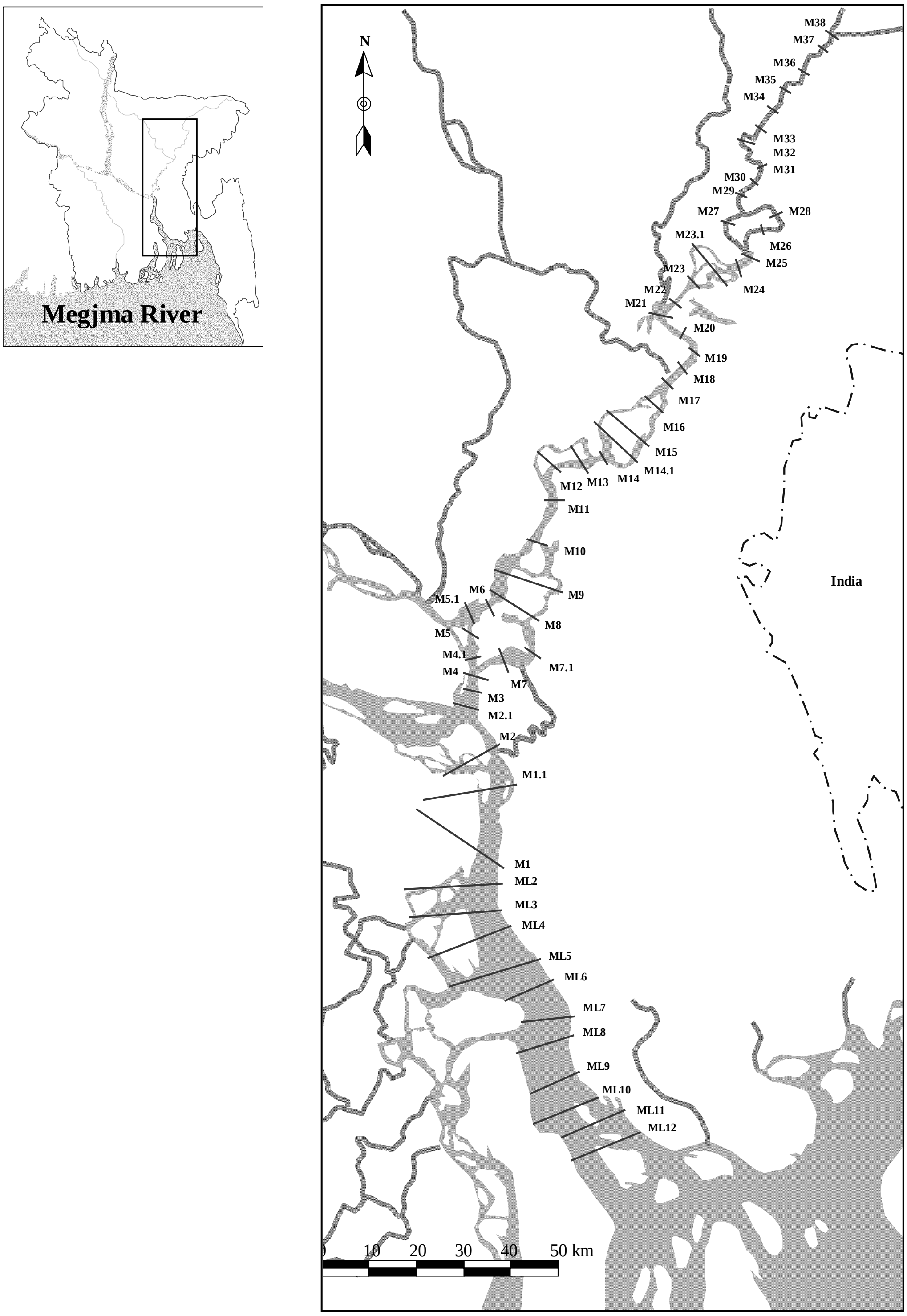


Figure 6.3.6 Locations of BWDB Standard Cross Sections along the Major Rivers (Meghna River)

6.3.3 Evaluation of Data

(1) Water Levels

The water levels of at the BWDB gauges are measured from wooden staff-gauges as a whole. The water level readings are taken five times a day at 6:00, 9:00, 12:00, 15:00 and 18:00. The automatic water level gauges are limited in number and are installed around the border areas and in the vicinity of Dhaka only.

The water level observations in Bangladesh face the difficulties in reducing errors due to the frequent shifts of the staff gauges against the seasonal variation of water level in the rivers, flood/inundation, and river bank erosion. Possible errors in the water level records were pointed out by FAP24 (1996) and FAP25 (1992) under the practices of the water level observations by BWDB.

The seasonal variations of water level in the rivers range approximately from 4 to 7 m exceeding the reading range of a staff gauge. To cope with the seasonal variations, another staff gauge is installed at a higher place nearby during the high flow season. A relation of water levels between the original gauge and new one is obtained by simultaneous readings before check-leveling of the gauge.

The staff gauge is shifted to some distance way from the original location due to river bank erosion or non-accessibility of the gauge during the high flow season. It was reported that the distance between the original gauge and new one was about 1 km upstream or downstream in some cases. Such a large shift of the gauge causes possible errors in readings because of the water surface slopes that were estimated about 5 to 8 cm in the main river (FAP24).

Possible errors in relation to the staff gauges were also pointed out due to inadequate location of gauge at side-branches sometimes disconnected with the main river and at bridge piers or abutments where the water levels are affected by local flow variations.

According to FAP24, the possible errors caused in relation to the field operation practices in Bangladesh are broadly classified into the following:

- Measurement errors: errors made in reading the water level from the staff gauge
- Errors related to the location of the gauge: errors refer to the poor representative of the readings at disconnected side-branches, bridge piers, abutments, etc.
- Errors related to the vertical position of the gauge: errors in the zero of the gauge

Measurement errors and errors related to the location of the gauge cause a temporary bias in the gauge readings in an order of some decimeters. Regarding errors in the zero of the gage, FAP24 revealed an average difference between BWDB zero values and FAP 24 surveys at 47 gauges in the main rivers was 5 cm but a few gauges showed the differences over 25 cm. FAP24 also compared the levels of BWDB bench marks and those established by FINNMAP (FAP24, 1993) at 20 gauges. An average difference was found to be 16 cm and the differences over 30 cm were observed at six gauges.

In the light of the FAP24 results, most of the water level gauges for the data collection in the present study shows the differences within 12 cm resulting from the leveling from BWDB bench marks to corresponding gauges (Table 6.3.6). Meanwhile, the comparison of the bench mark levels covers only a limited number of the gauges in the Jamuna and Ganges and the results are not shown for the important water level gauges along the Padma.

Table 6.3.6 Difference of Zero Value of Gauge (FAP24, 1993)

River	Code	Name of Station	Difference in Zero Value of Gauge (BWDB Zero Value) – (FAP24 Surveyed Zero Value)	
			Leveling from BWDB Bench Mark	Leveling from FINNMAP Bench Mark
Brahmaputra-Jamuna	46.9L	Bahadurabad	-0.02	-0.04
Brahmaputra-Jamuna	49	Sirajganj	-0.05	-0.39
Brahmaputra-Jamuna	50.3	Mathura	-0.04	-0.05
Brahmaputra-Jamuna	50.6	Aricha	-0.07	-0.12
Ganges-Padma	90	Hardinge Bridge	+0.03	-0.06
Ganges-Padma	91.2	Mohendarpur	+0.12	-0.02
Padma	91.9L	Baruia Transit	-0.03	NA
Padma	91.9R	Goalundo Transit	NA	NA
Padma	93.4L	Bhagyakul	-0.03	NA
Padma	93.5L	Mawa	+0.06	NA
Arial Khan	4A	Chowdhury Char	+0.11	NA
Padma	94	Tarpasa	-0.01	NA
Meghna	273	Bhairab Bazar	-0.01	NA
Meghna	276	Satnal	0.00	NA
Meghna	277	Chandpur	-0.01	NA
Meghna	277	Daulatkhan	NA	NA

The data collected in the present study shows a bias of some decimeters which may be caused by measurement error. Some data imply errors in the zero level of the gauge, including a partial period that shows the differences in the low water levels from the other period. Inaccuracy of zero value of gauge at its shifting in combined with the absence of proper check leveling may attribute to such errors.

Implications of errors in relation to inaccuracy of the bench mark levels could not find as far as the checks simply made on the basis of the collected data. This type of errors will affect the studies and succeeding designs for Padma bridge if a range of errors are not negligible. Checks of the bench mark levels of the water level gauges, especially along the Padma and Meghna, need to be carried out in the progress of further studies and designs together with the periodical check-leveling for ensuring the accuracy of vertical position of the staff gauge.

(2) Discharges

BWDB conducts the discharge measurements by the conventional velocity-area method. Because of the large scale of the rivers, the discharge measurements by the velocity-area method include the several sources of errors. FAP24 investigated and pointed out the possible sources of error in the discharge measurements with reference to ISO (1983) as follows.

► Instrumental Errors
- Errors in calibration of propeller type current meter
- Incorrect flow angles in measurements by non-directional current meter

► Exposure Time of the Local Point Velocity
- Errors dependent on measuring time

► Number of Points in the Vertical
- Poor performance of the two-point flow measurement
- Dynamic positioning of the survey vessel

► Number of Verticals in the Cross Section
  - Errors dependent on the number of verticals
  - Inaccurate measurement of depths by suspension cable
  - Inaccurate measurement of distances between verticals

► Others
  - Time duration of discharge measurement taking about two days for one measurement coupled with water level fluctuation
  - Error in water level reading

FAP24 also analyzed differences between discharge measurements by Acoustic Doppler Current Profiler in combination with an Electromagnetic Flow Meter (ADCP-EMF) and the conventional velocity-area method. It was found that the discharges measured by ADCP-EMF were some 10% less than those measured by the conventional velocity-area method.

For the study of Padma bridge, Baruria Transit (91.9R) and Mawa (93.5L) are the important gauges. Both water level and discharge measurements are undertaken at these gauges. The plots of discharge measurements at Baruria Transit are fairly grouped and indicate well-fitness to the stage-discharge rating curves annually updated. Meanwhile, the plots at Mawa show a larger scatter because of the tidal influence (Figure 6.3.7). FAP24 describes a conclusion that the combination of discharge measurements in the Padma at Baruria Transit and in the Arial Khan off-take at Chowdhury Char (A4) is likely to provide more accurate discharges in the Padma River including Mawa.

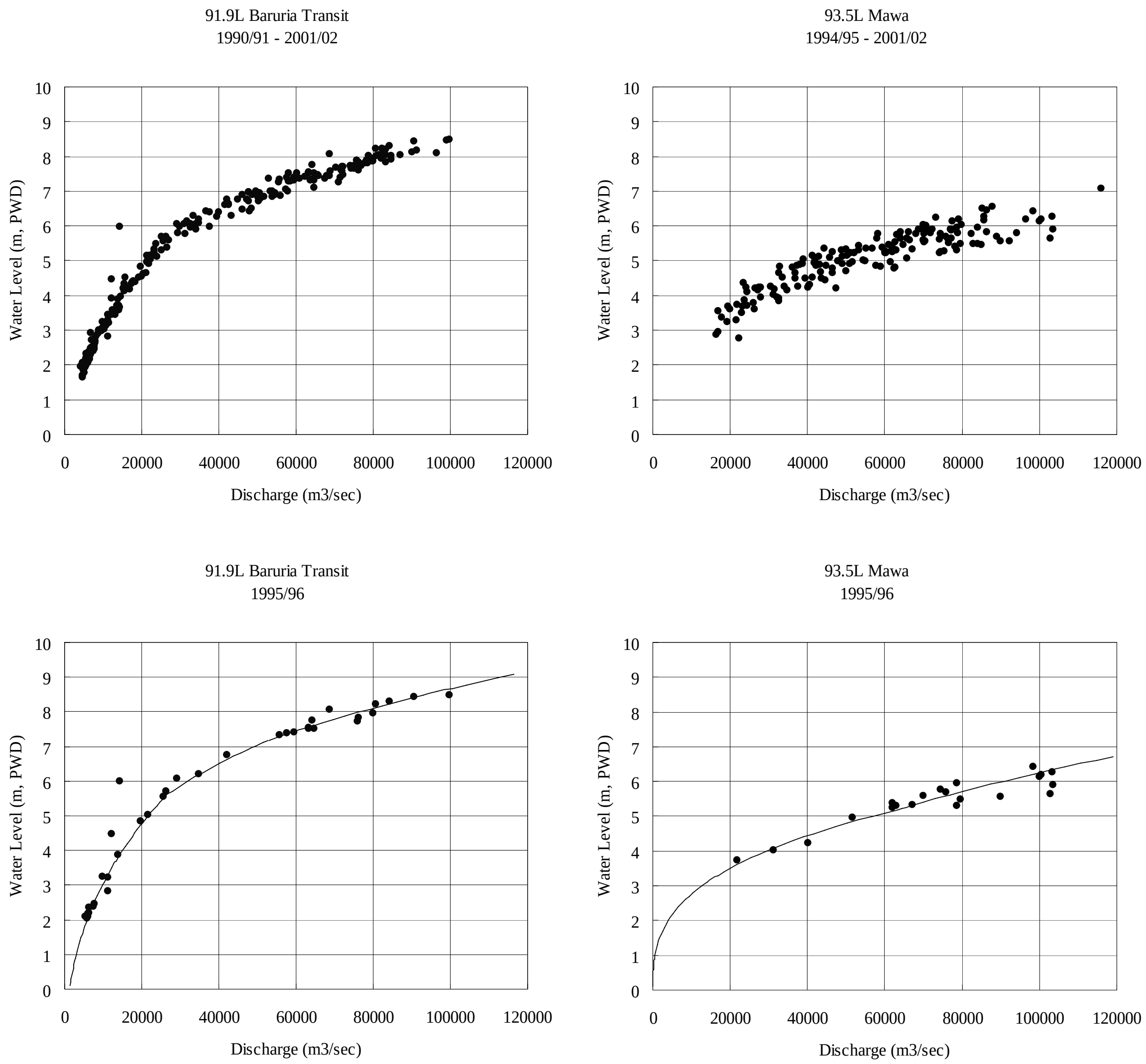


Figure 6.3.7 Examples of Discharge Measurement Plots and Rating Curves

(3) River Cross Sections

The Padma cross sections surveyed by BWDB are available since 1969 to date. There are 15 standard cross sections are assigned along the Padma and these cross sections have been surveyed annually. However, the data obtained from the BWDB data base generally cover eight cross sections i.e. P0, P1, P2, P3, P4, P5, P6, and P7 by year and the remaining seven in between such as P0.1, P1.1, P2.1, P3.1, P4.1, P5.1, P6.1 are missing for most of the years. Therefore, such cross sections for some years were supplemented from the data provided by Institution of Hydraulic Modeling (IWM).

The historical survey data of the Padma show several gaps since 1969 to date, i.e. 1979/80, 1983/84, 1986/87, 1987/88, 1989/90, 1990/91, and 1991/92. A large difference in the position of the maximum depth is observed before and after the gap from 1989/90 to 1991/92 at P2 where all the available data were collected. A similar difference is also observed at P2 between 2000 and 2001 (Figure 6.3.8). Even though these differences may be possible due to the river changing its planform dynamically, the data validation should be checked in the light of the horizontal position of the surveyed cross section.

It was informed by BWDB that the monuments or pillars for positioning the BWDB standard cross sections were defined with the coordinate system. However, the data of coordinates at each monument or pillar were made available only for the latest year. Due to significant planform changes, it is supposed that relocations of the monuments or pillars resulting in horizontal shifts of the cross section took place in the past. But such horizontal shifts could not be confirmed so far because of the absence of data for exact positioning of the cross sections survey in the past.

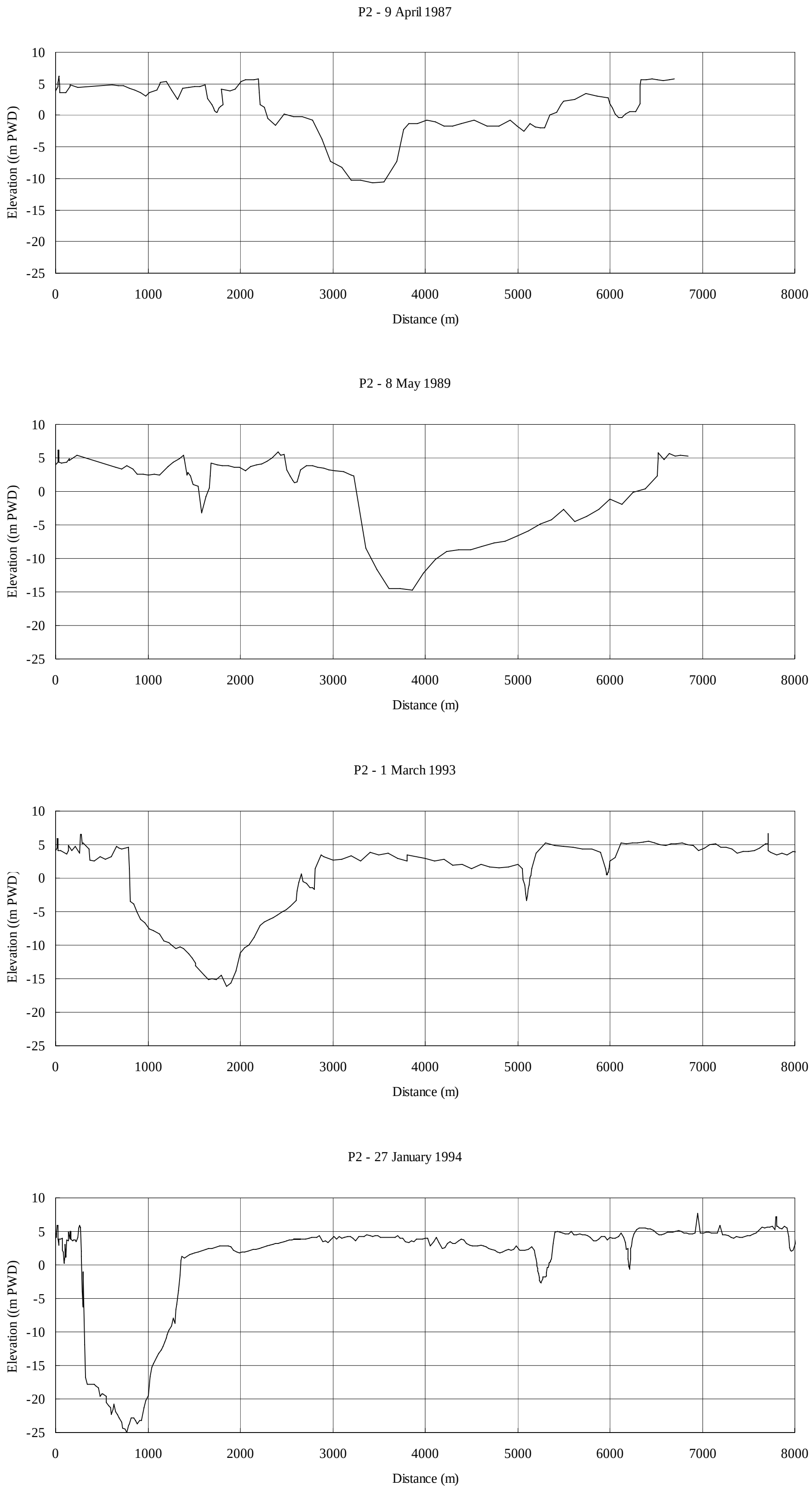


Figure 6.3.8 Examples of River Cross Section Changes (P2)

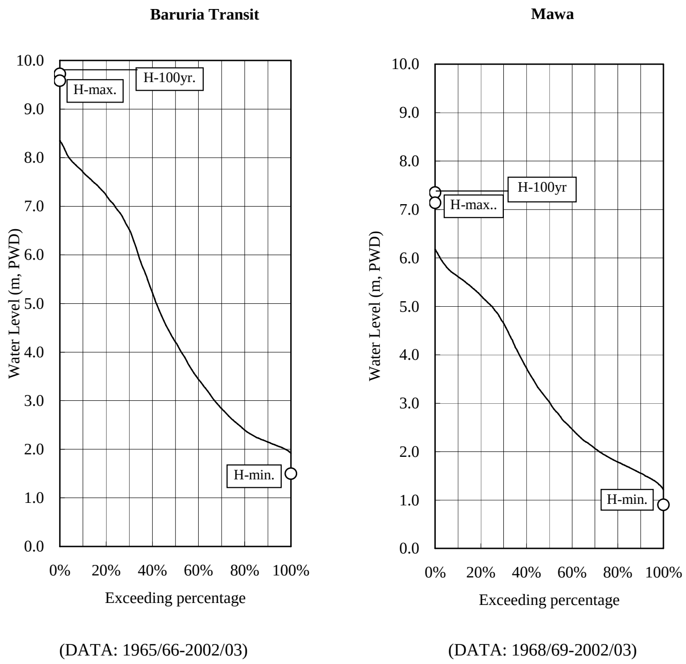
6.4 ADDITIONAL HYDROLOGICAL AND HYDRAULIC STUDIES FOR TWO ALTERNATIVE SITES

6.4.1 Standard Water Levels

Standard High Water Level (SHWL) is a reference water level to decide the navigation clearance under the river crossing structures like bridge, and Standard Low Water Level (SLWL) is a reference water level for judging the navigability. SHWL and SLWL are also referred to the discussions on the construction method and implementation program of the project works.

SHWL and SLWL are defined by BIWTA as average water levels of 5% and 95% exceedance in the respective years. According to the definition, SHWL and SLWL were worked out using the water level records at Baruria Transit from 1965/66 to 2002/03 hydrological year, and Mawa Station from 1968/69 to 2002/03. Results are shown in Figure 6.4.1. The hydrological year starts in April and ends in March next year.

Exeeding percentage (%)	W.L.at Baruria (m,PWD)	
H-100yr.	9.72	
Max.	9.58	
1	8.28	
2	8.18	
3	8.08	
4	8.00	
5	7.94	SHWL
6	7.89	
7	7.85	
8	7.80	
9	7.75	
10	7.70	
15	7.48	
20	7.23	
25	6.92	
30	6.52	
40	5.22	
50	4.21	MWL
60	3.44	
70	2.84	
75	2.60	
80	2.40	
85	2.25	
90	2.15	
91	2.13	
92	2.11	
93	2.09	
94	2.07	
95	2.05	SLWL
96	2.04	
97	2.01	
98	1.99	
99	1.96	
Min.	1.50	



	Exeeding percentage (%)	W.L.at Mawa (m,PWD)
	H-100yr.	7.35
	Max.	7.14
	1	6.10
	2	6.02
	3	5.94
	4	5.87
SHWL	5	5.81
	6	5.76
	7	5.72
	8	5.69
	9	5.65
	10	5.61
	15	5.44
	20	5.22
	25	4.99
	30	4.65
	40	3.72
MWL	50	3.02
	60	2.46
	70	2.06
	75	1.91
	80	1.79
	85	1.67
	90	1.55
	91	1.53
	92	1.50
	93	1.48
	94	1.45
SLWL	95	1.43
	96	1.40
	97	1.36
	98	1.32
	99	1.28
	Min.	0.90

Figure 6.4.1 Standard Water Levels at Baruria Transit and Mawa

The Baruria Transit and Mawa stations are located near PG-site and MJ-site, respectively. Since the slope of the Padma River is as mild as 4 to 6 cm/km, water level records at these stations can be regarded as those at the crossing sites.

6.4.2 Hydraulic Design Values

According to the studies in the previous chapters and sections, hydraulic design values are summarized for the convenience of preliminary facility plan and design as listed hereunder.

(1) Design Flood

Design flood of 100-year return period was adopted for the facility plan at the crossing location of Padma bridge taking the same design scale as that of Jamuna bridge.

		(PG-site)	(MJ-site)
1)	Reference station:	Baruria Transit Station	Mawa Station
2)	Design discharge (Q_{100}):	151,400 m^3/s	134,400 m^3/s
3)	Design High Water Level (DHWL):	9.72 m,PWD	7.35 m,PWD

(2) Standard Water Levels

According to the definition of BIWTA, Standard High Water Level (SHWL) and Standard Low Water Level (SLWL) were calculated as water levels at 5% and 95% exceedance, respectively.)

		(PG-site)	(MJ-site)
1)	Reference station:	Baruria Transit Station	Mawa Station
2)	Period of data:	1965/66 –2002/03	1968/69 – 2002/03
3)	SHWL:	7.94 m,PWD	5.81 m,PWD
4)	Mean Water Level (MWL):	4.21 m,PWD	3.02 m,PWD
5)	SLWL:	2.05 m,PWD	1.43 m,PWD

(3) Maximum Scour Depth

PG-site:

1) Recorded lowest riverbed at CS-P7: –13.2 m,PWD surveyed in July 1977
2) Maximum scour depth for design:

	(Scoured bed)	(Depth below DHWL)
Riverbed adjacent to riverbank with RTW (within 300 m from bank)		
• Without local scour:	–33.8 m,PWD	43.5 m
• With local scour (pier ϕ 3m):	–39.3 m,PWD	49.0 m
Other portion of riverbed		
• Without local scour:	–23.1 m,PWD	32.8 m
• With local scour (pier ϕ 3m):	–28.6 m,PWD	38.3 m

MJ-site:

1) Recorded lowest riverbed at CS-P2.1: –28.3 m,PWD surveyed in January 1994.
2) Maximum scour depth for design:

	(Scoured bed)	(Depth below DHWL)
Riverbed adjacent to riverbank with RTW (within 300 m from bank)		
• Without local scour:	–37.5 m,PWD	44.9 m
• With local scour (pier ϕ 3m):	–43.0 m,PWD	50.4 m
Other portion of riverbed		
• Without local scour:	–26.4 m,PWD	33.8 m
• With local scour (pier ϕ 3m):	–31.9 m,PWD	39.3 m

(4) Mean Flow Velocity

Sectional and depth-averaged mean velocities of flood flow were calculated by Manning's uniform flow formula assuming river slope I = 1/15,800 and Manning's coefficient of roughness n = 0.015. Cross sectional and depth averaged mean velocities under the design flow conditions were estimated as follows:

	(PG-site)	(MJ-site)
1) Cross sectional mean velocity	2.37 m/s	2.66 m/s
2) Depth averaged mean velocity	5.44 m/s	5.54 m/s

6.5 MATHEMATICAL MODELING

6.5.1 Outlines

Mathematical modeling was carried out for analyzing hydraulic and river morphological aspects relevant to the preliminary designs of river works for the Padma Bridge.

The objectives of the mathematical modeling are described hereunder.

(a) Simulation of Present Hydraulic Conditions around Proposed Bridge Site

Mathematical simulation models are prepared to understand the present hydraulic and river morphological conditions around the Padma River at Mawa-Janjira. The models are based on data currently available and obtained through the field investigations carried out in relation to this mathematical modeling.

(b) Verification of Hydraulic Design Parameters and Dimensions for Proposed Structures

Hydraulic design parameters and dimensions required for the proposed structures are prepared with reference to analysis of hydrological records, experiences of previous bridge construction projects in India and Bangladesh, available design standards, and other knowledge of river engineering. The preliminary designs for the feasibility study are worked out on the basis of these hydraulic design parameters and dimensions. The mathematical modeling is conducted for verifying the hydraulic design parameters and dimensions of the proposed structures in order to confirm technical appropriateness of the preliminary designs.

(c) Assessment of Impacts by Construction of the Project

Impacts to river flow conditions and/or morphological process by construction of the project are evaluated respectively in the course of the preliminary designs of the individual structures. Meanwhile, the mathematical modeling aims at evaluating integrated impacts through simulations of flooding in the neighboring areas and tendency of morphological developments in order to ensure the layout plan of the proposed structures and their dimensions.

The mathematical modeling was carried out by Institute of Water Modeling (IWM) under the sub-contract with the Study Team.

In the beginning of the mathematical modeling, various data relevant to the Padma river such hydrology, flood and inundation, topography, river morphology, sediment, chars, and river works was analyzed to develop insight on the hydraulic and morphologic process. The interim results of the river study by the Study Team were also reviewed for conducting preparatory studies of the mathematical modeling.

Field measurements for acquiring necessary data for the mathematical modeling were also conducted before development of mathematical models. Bathymetric surveys were carried out for the Padma river reaches upstream and downstream of the Mawa-Janjira site. Geotechnical investigations for researching erosion resistance of riverbank were also conducted to evaluate tendency of river morphology around the Mawa-Janjira site.

A quasi two-dimensional model was developed to cover the main stream and branches of the Padma river and flood plains that may be affected by construction of the project. Impacts by construction of the project were assessed through comparison of the results of simulations between ‘without project’ and ‘with project’ conditions. Main points for assessment were extent of flooding area and distribution of flooding depth in the neighboring flood plains.

A two-dimensional model was developed to cover the main stream of the Padma river and riverbanks that may be affected by construction of the project. Impacts on morphological developments were assessed through comparison of the results of simulations between ‘without project’ and ‘with project’ conditions.

In addition, the simulations by two-dimensional model also were conducted to assess the middle- to long-term (5 to 10 years) impacts on tendency of river morphological process through comparison of simulations between ‘without project’ and ‘with project’ conditions.

6.5.2 Quasi-two Dimensional Modeling and Simulations

(1) Outlines of Model Development

Development of quasi two-dimensional model was conducted by using MIKE11 series. A quasi-two dimensional model was developed to cover the major rivers and principal branches for the reaches between the Jamuna-Ganges confluence and Chandpur. The model was developed by re-organizing the existing hydrodynamic models such as General Model (GM), South West Region Model (SWRM) and North Central Region Model (NCRM), which had been developed and validated by IWM under the funding by BWDB for the hydrological year 2001/02.

Topographic features of a selected extent of flood plain that might be affected by construction of the project was also incorporated into the model in the manner of digital elevation model (DEM) properly linked with the river network. Minor rivers connecting with the major rivers and principal branches of the Padma were also incorporated within the flood plain area of interest.

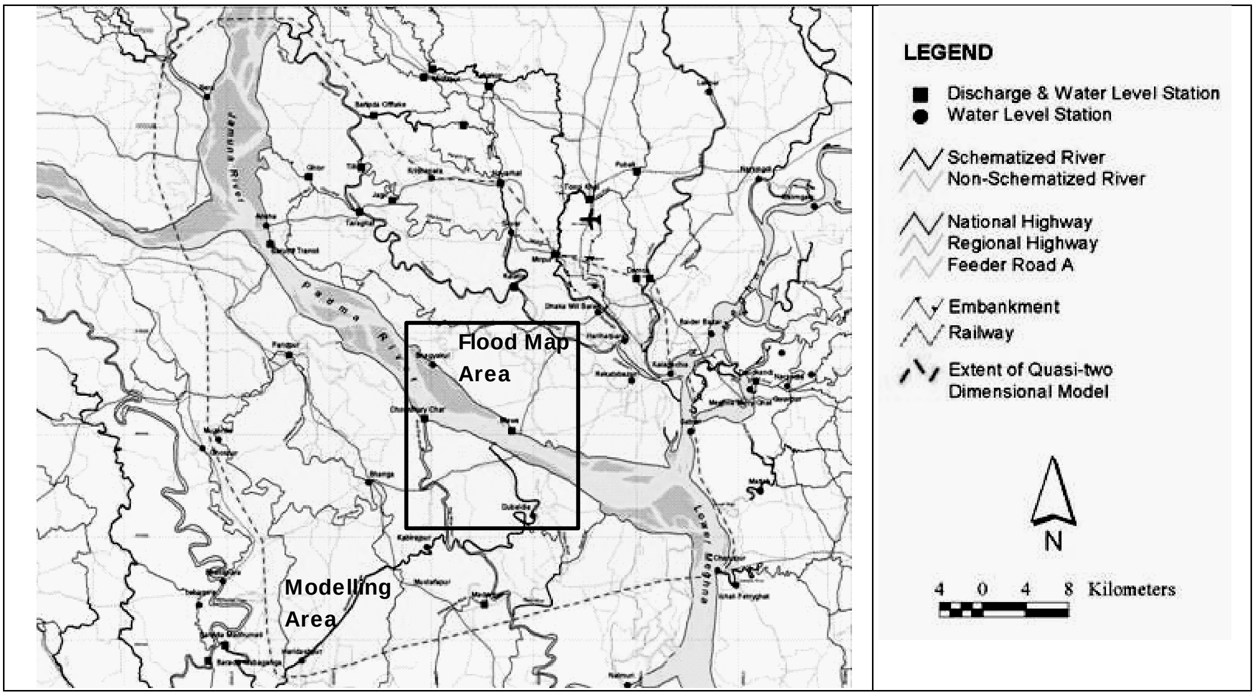


Figure 6.5.1 Extent of Quasi-two Dimensional Model

(2) Simulation by Quasi-two Dimensional Model

(a) Hydrological Settings

The simulation of hydrodynamics requires hydrographs expressed by time series of hydrological data at the different boundaries. For preparation of hydrograph at each boundary, the hydrological year 1998/99 was selected as a typical flood year for generating the probable hydrographs at the respective boundaries. Probable hydrographs for the different return periods such as 25- and 100-year were estimated by reduction or enlargement of 1998/99 hydrograph at each boundary on the basis of probable water levels and discharges at Baruria Transit representing dominantly the hydrological conditions of the Padma.

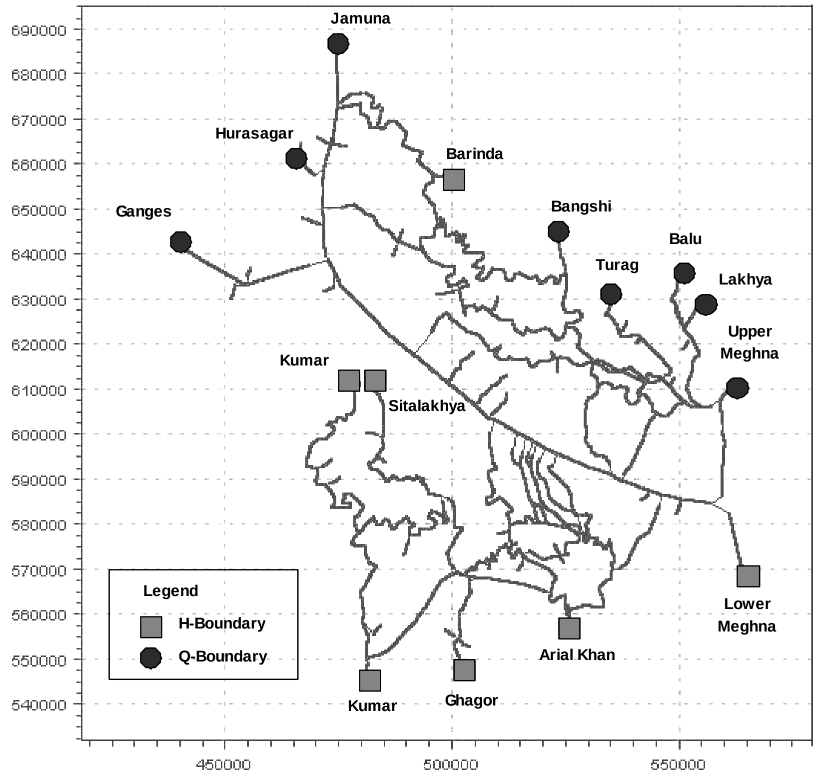


Figure 6.5.2 River Network and Boundaries of Quasi-two Dimensional Model

(b) Simulations for Probable Flood

Based on the hydrological settings for the simulation discussed above, water levels and discharges at Baruria Transit and Mawa were simulated as shown in Table 6.5.1.

Table 6.5.1 Comparison of Extreme Value Analysis and Simulation

Baruria Transit

Return Period	Probable Water Level (m PWD)		Probable Discharge (m^3/sec)	
	Extreme Value Analysis	Simulation	Extreme Value Analysis	Simulation
25-year	9.23	9.21	131,000	122,900
100-year	9.72	9.79	151,400	140,800

Mawa

Return Period	Probable Water Level (m PWD)		Probable Discharge (m^3/sec)	
	Extreme Value Analysis	Simulation	Extreme Value Analysis	Simulation
25-year	6.94	6.93	120,100	117,000
100-year	7.35	7.49	134,400	134,900

Some differences are observed between the values estimated by extreme value analysis (EVA) and the simulated values. Such differences are likely to occur due to the different approaches to estimate the probable flood. In addition, there is a limitation to simulate the different return periods of flood by one simulation model calibrated with a certain selected hydrological year because H-Q relationships of the Padma are changing year by year due to the changes of river morphological features.

For the purpose of the present study, the simulated values for probable flood are regarded as acceptable practically to make the comparative assessment purposes for 'without project' and 'with project' conditions. The differences in the estimated values are observed within a certain small range that is acceptable in the light of the different approaches for estimation and the limitation of the simulation model as mentioned above.

(c) Simulations for 'Without Project' and 'With Project' Conditions

Simulations for 'without project' and 'with project' conditions were conducted for the designed floods of 25- and 100-year return period, respectively. The results of simulations are presented hereunder together with assessment of impacts by construction of the project.

(3) Assessment of Impacts by Construction of the Project

(a) Water Levels and Discharges

Simulated highest water levels and maximum discharges at Mawa and Arial Khan bridge are listed in Table 6.5.2. In general, differences water levels between 'without project' and 'with project' conditions are less than 0.1 m.

Table 6.5.2 Simulated Water Levels and Discharges

Highest Water Level

Return Period	Mawa (m PWD)		Arial Khan Bridge (m PWD)	
	Without Project	With Project	Without Project	With Project
25-year	6.96	7.02	7.25	7.23
100-year	7.47	7.55	7.79	7.78

Maximum Discharge

Return Period	Mawa (m^3/sec)		Arial Khan Bridge (m^3/sec)	
	Without Project	With Project	Without Project	With Project
25-year	117,900	126,200	3,500	3,300
100-year	134,500	134,800	3,700	3,900

(b) Flooding Extent and Depth

The maximum flooding depth in the flood plains around the proposed bridge site were estimated by the highest water level distributions superimposed on DEM for each return period. DEM used for the mathematical modeling was prepared on the basis of National Digital Elevation Model (FAP19, 1995) and was arranged with a finer resolution acceptable for the scale of flood map by interpolation.

Because a large part of the flood plains shown on the extent of flood map lies below 5 m PWD, the flood plains are mostly covered with the water in the flood peaking period as shown in Table 6.5.3. Even though some extent of higher lands may be above the water actually in the flood peaking period, such lands due to micro topographic undulations may not be accurately expressed by the original National Digital Elevation Model with a resolution of 300m x 300m. Therefore, the flooding extent and depth do not represent absolute estimations and are regarded as rather rough estimations for the purpose of relative comparison between 'without' and 'with project' conditions.

The relative comparison of maximum flooding extent by depth between 'without project' and 'with project' conditions is shown in Table 6.5.3. In general, the maximum flooding extent becomes slightly wider in the 'with project' condition. This may be caused by some reduction of openings for local channels crossing the proposed approach road embankment on the right bank.

Table 6.5.3 Comparison of Maximum Flooding Extent by Depth

Without Project

Return Period	Accumulated Flooding Extent by Depth (km^2)				
	Over 2.0m	Over 1.5m	Over 1.0m	Over 0.5m	Over 0.0m
25-year	915	1,090	1,166	1,190	1,197
100-year	1,075	1,157	1,187	1,195	1,197

With Project

Return Period	Accumulated Flooding Extent by Depth (km^2)				
	Over 2.0m	Over 1.5m	Over 1.0m	Over 0.5m	Over 0.0m
25-year	933	1,095	1,169	1,191	1,197
100-year	1,088	1,163	1,190	1,197	1,197

(c) Flooding Conditions near Proposed Approach Road on Right Bank

Some impacts on flooding may be anticipated by the proposed approach road embankment with a length of 12 km running on the flood plain on the left bank. According to the field reconnaissance, available aerial photos and topographic surveys, it was identified that the five major openings by construction of local bridges would be required at least to maintain the present flow conditions of the local channels as much as possible. The width of the major openings ranges from 150 to 310m. The locations of the local channels and major openings by local bridge are shown in Figure 6.5.3.

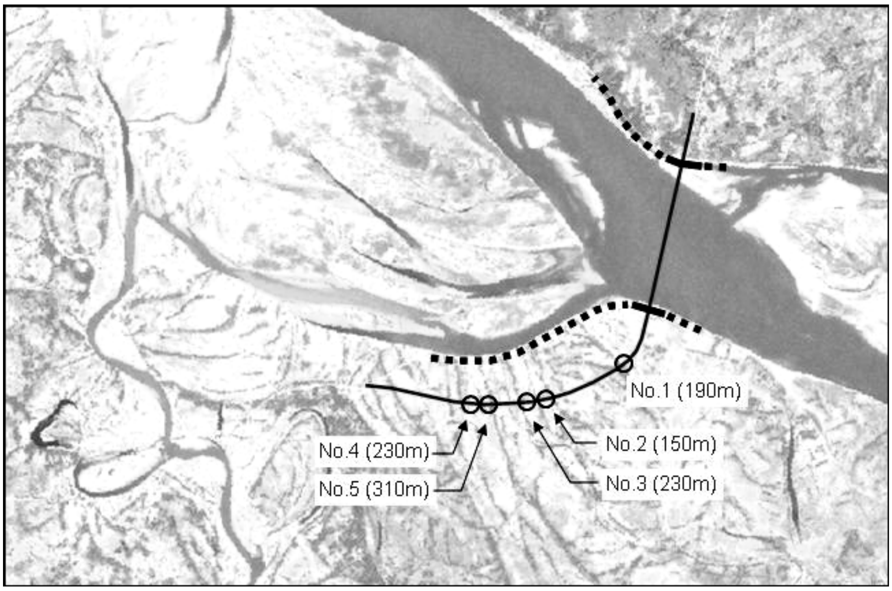


Figure 6.5.3 Crossings of Proposed Approach Road on Right Bank

The impacts on flooding were assessed by the simulations in terms of changes in flooding duration and water level. Table 6.5.4 shows the changes in flooding duration at the selected locations upstream and downstream sides of the proposed approach road on the right bank. Flooding duration is almost not changed between ‘without project’ and ‘with project’ conditions.

Table 6.5.4 Flooding Duration near Proposed Approach Road (Right Bank)

Return Period	Flooding Duration by Days			
	Without project		With project	
	Upstream of Approach Road at No.2 (DEM 4.67 m PWD)	Upstream of Approach Road No.4 (DEM 5.09 m PWD)	Upstream of Approach Road at No.2 (DEM 4.67 m PWD)	Upstream of Approach Road at No.4 (DEM 5.09 m PWD)
25-year	84	78	85	78
100-year	108	87	109	87

Water levels of local channels crossing the proposed approach road embankment on the right bank were also assessed as show in Table 6.5.5. At the proposed major crossings, the highest water levels become slightly higher for the 'with project' condition.

Table 6.5.5 Water Level of Local Channel at Crossing of Proposed Approach Road on Right Bank

Without Project

Return Period	No.1	No.2	No.3	No.4	No.5
25-year	7.14	7.30	7.32	7.43	7.46
100-year	7.66	7.81	7.83	7.94	7.97

With Project

Return Period	No.1	No.2	No.3	No.4	No.5
25-year	7.10	7.33	7.34	7.47	7.48
100-year	7.66	7.87	7.88	8.01	8.02

6.5.3 Two-dimensional Modeling and Simulation: 2003/04 Padma 2-D Core Model

(1) Outlines of Model Development

Development of two-dimensional model was conducted by using software MIKE21C. A two-dimensional model was developed to cover the main stream and branches of the Padma river and riverbanks that may be affected by construction of the project. The model was based on the satellite image in 2003, the available bathymetric data by BIWTA in 2003 and the bathymetric surveys carried out for the mathematical modeling in June and August 2004. This two-dimensional model was therefore named '2003/04 Padma 2-D Core Model' and was calibrated and validated through comparison between simulated and observed hydrodynamics and river morphological process in the years 2003 and 2004.

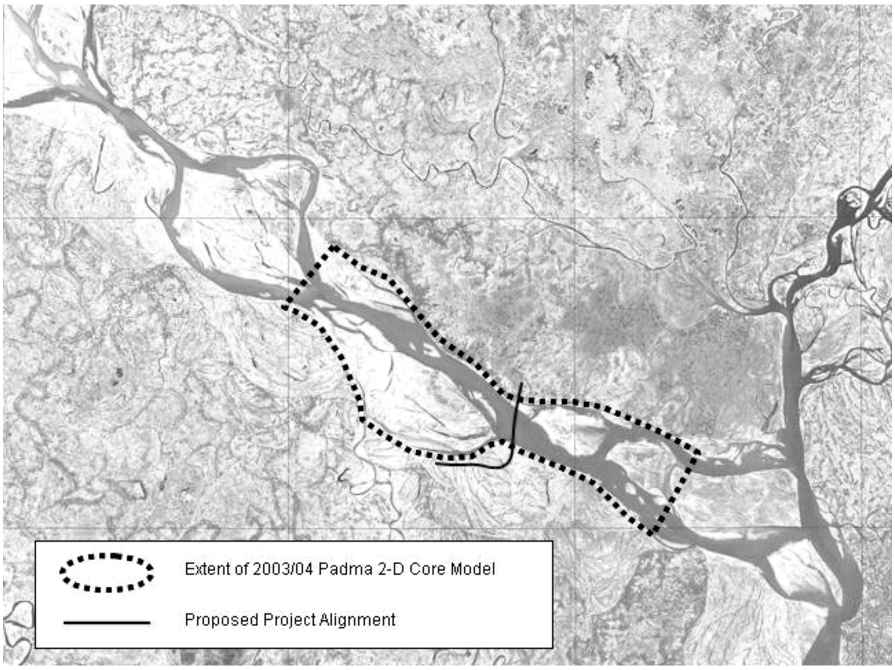


Figure 6.5.4 Extent of 2003/04 Padma 2-D Core Model

(2) Simulations by 2003/04 Padma 2-D Core Model

(a) Hydrological Settings

Hydrological settings for verification of hydraulic design parameters and structural dimensions of the proposed structures were given in the form of a water level hydrograph at the downstream boundary and a discharge hydrograph at the upstream boundary. The probable flood hydrograph at the boundary was generated on the basis of the observed hydrograph in 1998/99.

Based on the analysis of flood magnitude at Baruria Transit, the probable hydrographs for the return periods of 25- and 100-year were estimated by reduction or enlargement of the 1998/99 discharge and water level hydrographs, respectively.

Because of neither bifurcation nor significant riverbank breach between Baruria Transit and the upstream boundary, discharges at the upstream boundary of 2003/04 Padma 2-D Core Model were regarded equivalent to those at Baruria Transit. Meanwhile, discharge distribution by the bifurcation of the Arial Khan was taken into consideration for the model. Downstream water levels for the model were extracted from the water levels simulated by 2003/04 Padma 2-D Long-term Model discussed in the succeeding sub-section 6.5.4.

(b) Simulations for Probable Flood

Simulations for probable were conducted for the design floods for 100- and 25-year return period, respectively. Based on the hydrological settings for the simulation discussed above, water levels and discharges at Mawa were simulated and resulted as shown in Table 6.5.6.

Table 6.5.6 Comparison of Extreme Value Analysis and Simulation

Return Period	Probable Water Level at Mawa (m PWD)		Probable Discharge at Mawa (m^3/sec)	
	Extreme Value Analysis	Simulation	Extreme Value Analysis	Simulation
25-year	6.94	7.04	120,100	119,900
100-year	7.35	7.49	134,400	137,800

Some differences are observed between the values estimated by extreme value analysis (EVA) and the simulated values. Meanwhile, the simulated values for probable flood are regarded as acceptable practically to make the comparative assessment purposes for ‘without project’ and ‘with project’ conditions, because of the same reasons as described in the previous sub-section 6.5.2 regarding the simulations for probable flood for the quasi-two dimensional model.

(c) Simulations for ‘Without Project’ and ‘With Project’ Conditions

For the purpose of the two-dimensional modeling, the types of riverbank depending on erosion resistance were classified as shown in Figure 6.5.5.

For the purpose of simulations for riverbank erosion, the types of riverbank depending on erosion resistance were classified according to the morphologic study by CEGIS (February 2004), which identified that riverbank materials of the Padma into three categories, i.e. highly erosive (erosion rate more than hundreds meter per year), moderately erosive (20 to 50 meter per year) and relatively erosion resistant (0 to 15 m per year). According to the CEGIS classifications and the extent of the proposed bank protection works, the riverbank settings for ‘without project’ and ‘with project’ conditions were defined as follows.

Highly Erosive Bank represents a river bank showing low erosion resistance with an erosion rate of 100 m/year or more because of natural soil characteristics. This type of river bank is identified mostly along the right bank

Moderately Erosive Bank represents a river bank showing moderate erosion resistance with an erosion rate of 20-50 m/year because of natural soil characteristics. This type of river bank is identified along the left bank, extending 25 km from the proposed bridge site to the downstream.

Relatively Erosion Resistant Bank represents a river bank showing erosion resistance with an erosion rate of 0-15 m/year because of natural soil characteristics. This type of river bank is identified along the left bank upstream of the proposed bridge site with an extent of 15 km approximately.

Non-erosive Bank is defined as a river bank protected by permanent or semi-permanent structure. This type is adopted for the extent of the proposed bank protection works.

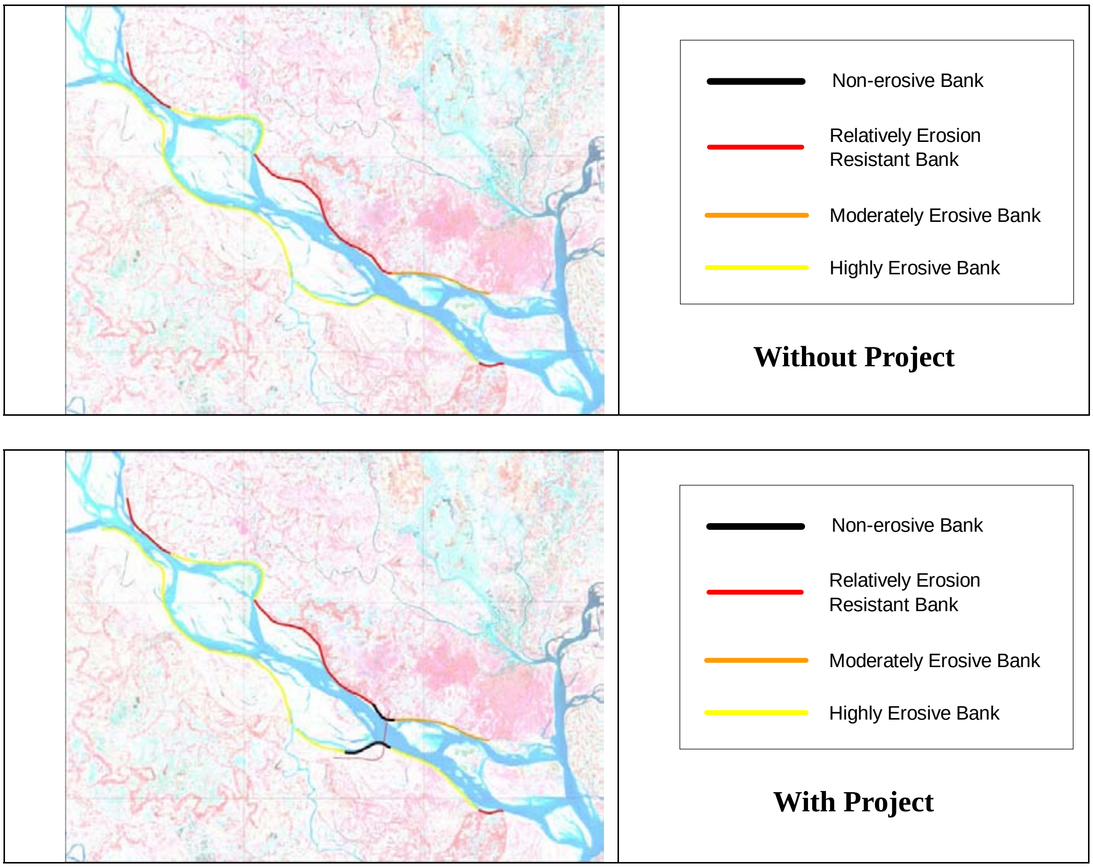


Figure 6.5.5 Riverbank Settings for Simulation

(3) Assessment of Impacts by Construction of the Project

(a) Summary of Hydraulic Design Parameters at Bridge Site

Basic hydraulic parameters at the proposed bridge site were obtained as listed in Table 6.5.7. In general, no significant difference is observed between ‘without project’ and ‘with project’ conditions. The hydraulic design parameters for the preliminary designs are also shown together. The simulated values are generally acceptable, compared with those used for the preliminary designs.

The differences observed in the simulated water levels and discharges are explained in the paragraphs of (b) Simulations flood Probable Flood and do not significantly affect the design parameters.

Simulated depth-averaged velocity takes place a certain location on the channel cross section at the proposed bridge site. The simulated values are regarded as acceptable within the design flood velocities for the respective return periods, which may also take place locally on the channel cross section at the proposed bridge site.

The design parameters for riverbed scour were estimated with a combination of natural sours and structure induced scours that are assumed to occur locally together in consideration of the most critical scouring. Meanwhile, the simulated lowest scoured depths are composed of natural scours only. The results of simulation for ‘with project’ condition indicate that some extent of structure induced scours near both riverbanks but do not correspond locally with the natural scours under 2004 riverbed conditions, which are the baseline set-up of the two-dimensional model.

Table 6.5.7 Summary of Simulations for Without/With Project Conditions

Hydraulic Parameters at Bridge Site	Without Project	With Project	Design Parameters
Return Period 100-year			
Highest Water Level (m PWD)	7.49	7.49	7.35
Max. Discharge (m^3/sec)	137,800	137,800	134,400
Max. Flow Velocity (m/sec)	2.9	3.0	4.8
Lowest Scoured Depth (m PWD)	-14	-16	-37.6
Return Period 25-year			
Highest Water Level (m PWD)	7.04	7.15	6.94
Max. Discharge (m^3/sec)	119,900	119,900	120,100
Max. Flow Velocity (m/sec)	2.8	2.8	4.7
Lowest Scoured Depth (m PWD)	-12	-15	-35.3

Note: 'Max. Flow Velocity' means the maximum of depth-averaged velocity.

(b) Flow Conditions

Comparison of the simulated results between 'without project' and 'with project' conditions indicate only minor differences in the highest water levels as shown in Figures 6.5.6 and 6.5.7.

At the proposed bridge site, the water levels simulated under 'with project' condition are slightly higher than those simulated under 'without project condition'. These results may caused by a little constriction of the cross section at the proposed bridge site due to the proposed bank protection works on both banks.

The designs of the banks protection works basically keep the perennial channel width and large extent of channel constriction is not considered. Meanwhile, the bank protection works designed above the Standard Low Water Level (SLWL) effect a little constriction of flow especially during the high flow period. But such a constriction of some 100m is quite minor than 5.3 km width of the river channel.

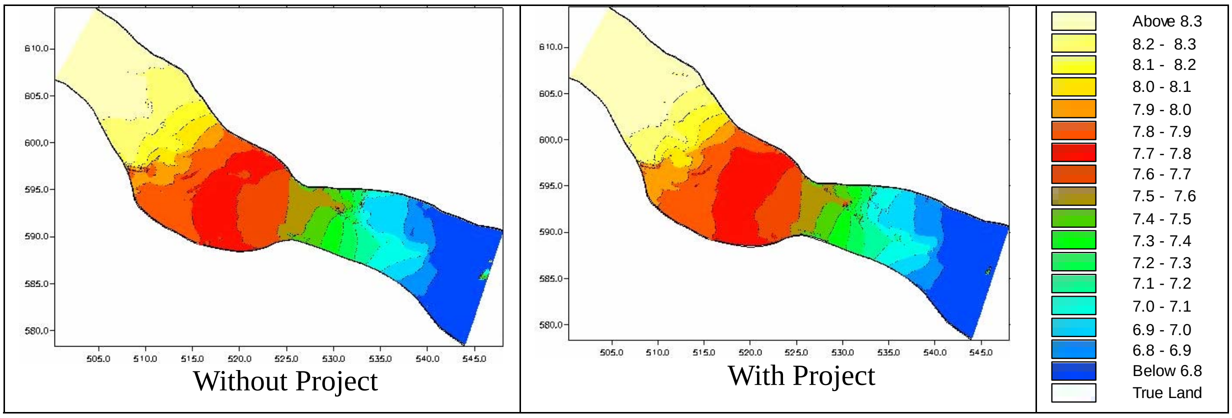


Figure 6.5.6 Comparison of Highest Water Levels (Return Period 100-year)

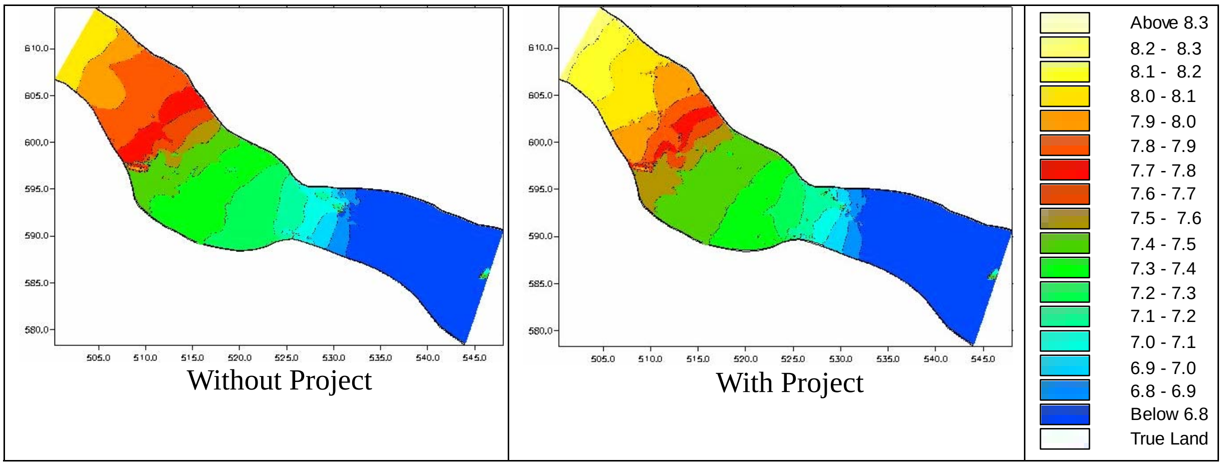


Figure 6.5.7 Comparison of Highest Water Levels (Return Period 25-year)

Similarly to the water levels, comparison of the simulated results between ‘without project’ and ‘with project’ conditions indicate only minor differences in the maximum flow velocities as shown in Figures 6.5.8 and 6.5.9. The flow velocities are depth-averaged at the peak of discharge.

Such minor differences in the flow velocities are also attributed to the bank protection works designed above SLWL effecting a little constriction of flow.

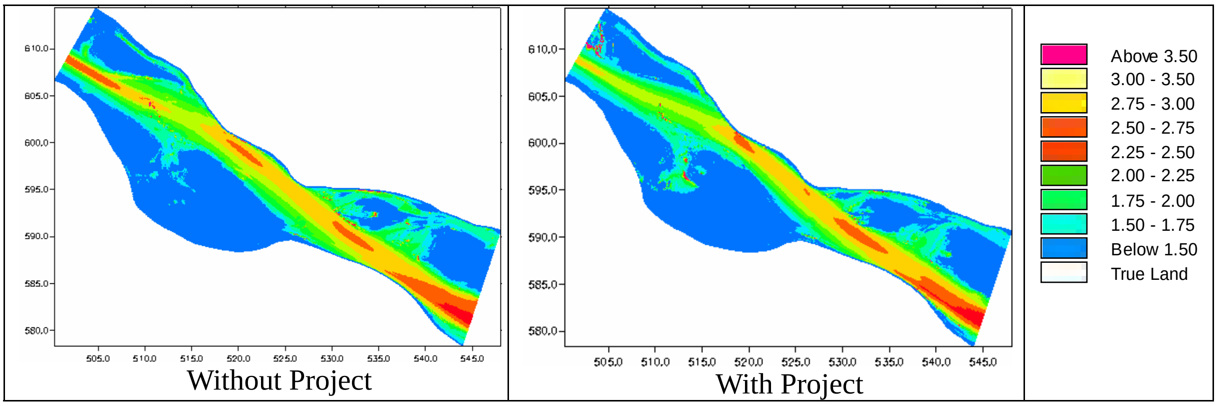


Figure 6.5.8 Comparison of Flow Velocities at Peak of Discharge (Return Period 100-year)

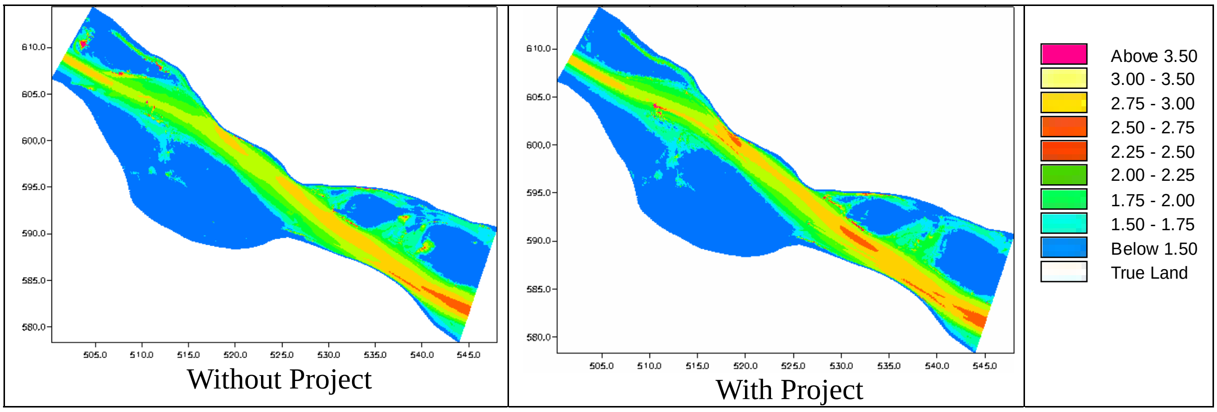


Figure 6.5.9 Comparison of Flow Velocities at Peak of Discharge (Return Period 25-year)

(c) Morphological Developments

Comparison of the simulated results between ‘without project’ and ‘with project’ conditions indicate only minor differences in the riverbed variations as shown in Figures 6.5.10 and 6.5.11.

Relatively deep scours (-12 to -9m PWD) are observed near the upstream end, along left bank upstream of the proposed bridge site and right bank downstream of the proposed bridge site, respectively. No significant difference is visible for the extent of deep scours and main water course in macro-basis view of morphological process.

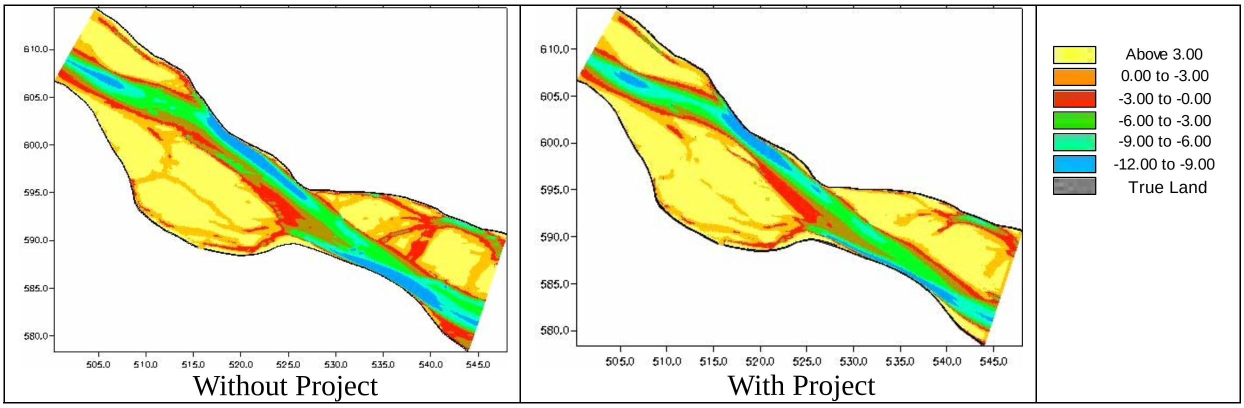


Figure 6.5.10 Comparison of Lowest Riverbed Levels (Return Period 100-year)

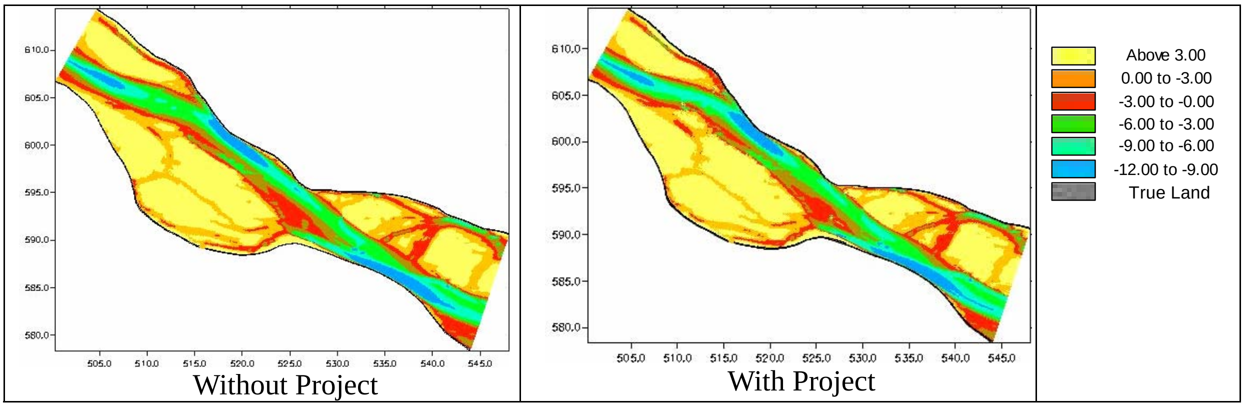


Figure 6.5.11 Comparison of Lowest Riverbed Levels (Return Period 25-year)

The simulated river cross sections near the propose bridge site are shown in Figures 6.5.12 and 6.5.13. The project induced changes between ‘without project’ and ‘with project’ are found to be minor.

The upstream cross sections (J380 and J390) indicate that the deepest riverbed for ‘with project’ condition is higher. Meanwhile, the deepest riverbed for ‘with project’ condition is lower than that for ‘without bridge’ condition at the downstream cross section (J430). These differences in the deepest riverbed may be attributed to the effect of a little constriction of flow by the bank protection works. The structure induced scours are observed in front of riverbank (within some hundreds meters from riverbank) but are not significant in depth, compared with the design scour depth.

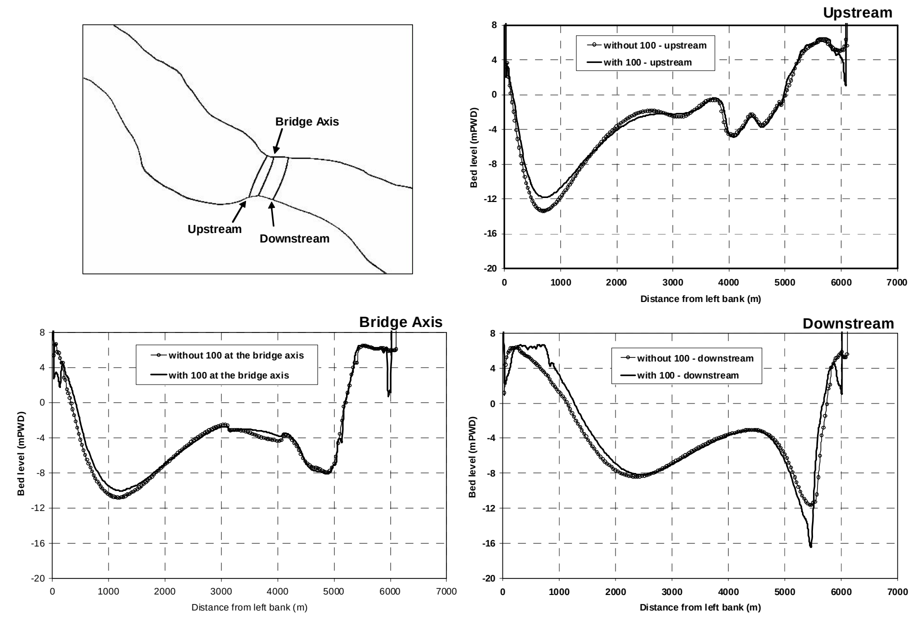


Figure 6.5.12 Comparison of Simulated Riverbed Levels near Bridge Site (Return Period 100-year)

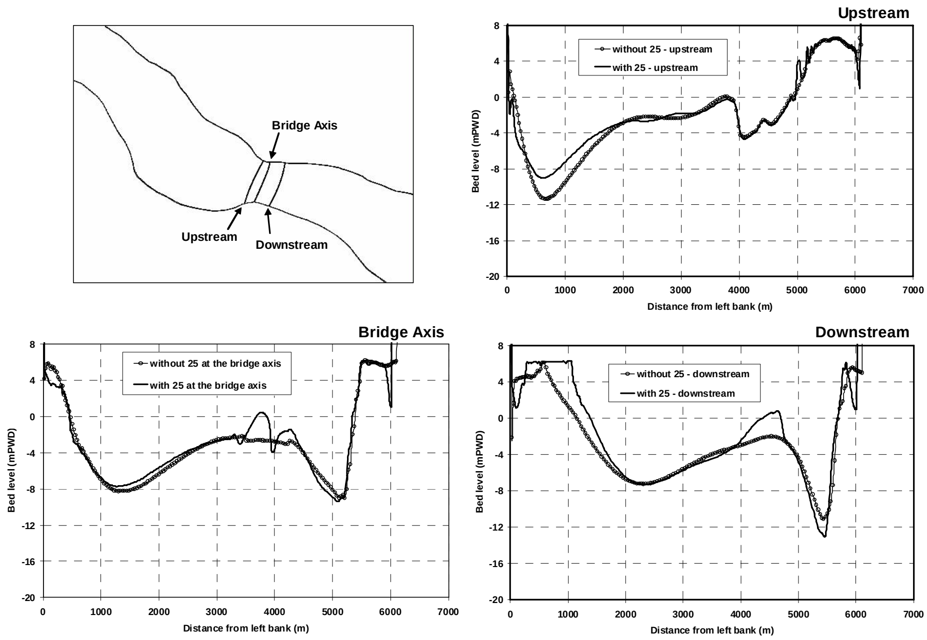


Figure 6.5.13 Comparison of Simulated Riverbed Levels near Bridge Site (Return Period 25-year)

(d) Riverbank Erosion

Comparison of the simulated results between 'without project' and 'with project' conditions indicate only minor differences in the riverbank erosion as shown in Figures 6.5.14 and 6.5.15.

On the left bank, noticeable riverbank erosion of some 150 m for 100-year return period is found around 6 km downstream from the proposed bridge site and may correspond with the area of Louhajang. Similarly on the right bank, noticeable riverbank erosion of 450 m for 100-year return period is found around 9 km downstream from the proposed bridge site.

Comparison of the longitudinal profiles of river bank erosion indicates that effects of the proposed bank protection works to reduce the riverbank erosion are observed along the right bank from the proposed bridge site to the downstream where the maximum riverbank erosion takes place. Meanwhile, there is no significant difference in the simulated maximum riverbank erosion between 'without project' and 'with project' conditions.

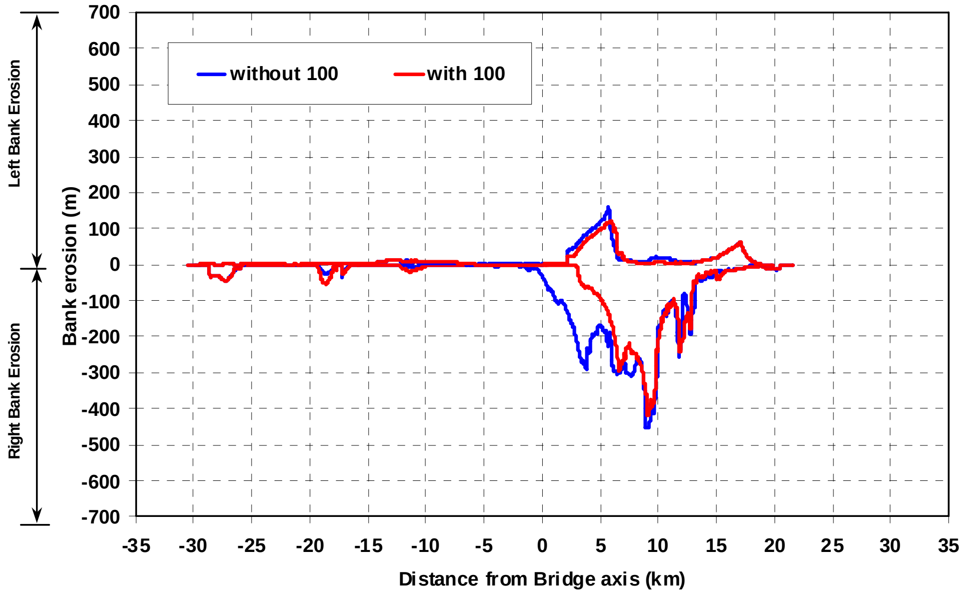


Figure 6.5.14 Comparison of Simulated Riverbank Erosion (Return Period 100-year)

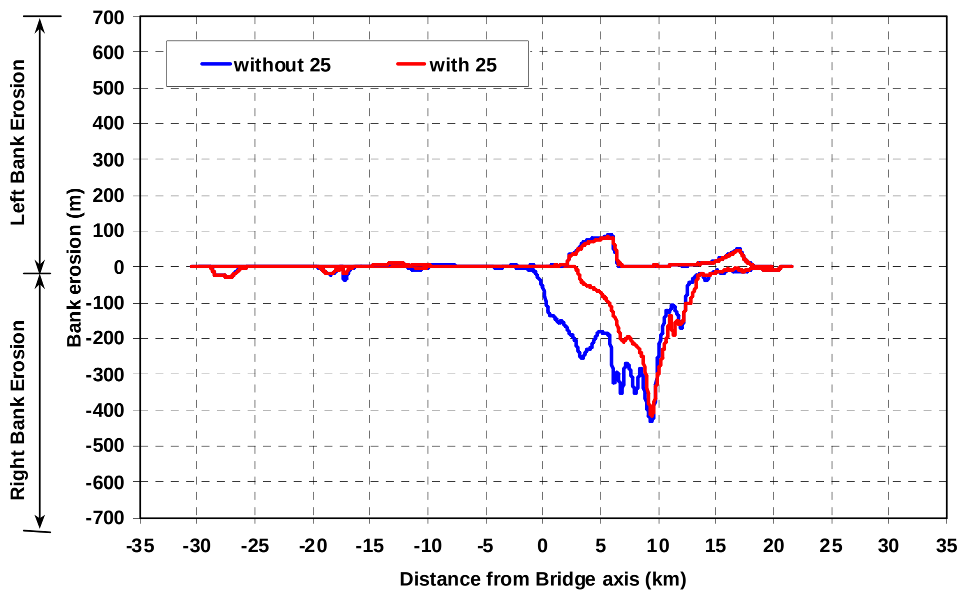


Figure 6.5.15 Comparison of Simulated Riverbank Erosion (Return Period 100-year)

6.5.4 Two Dimensional Modeling and Simulation: 2003/04 Padma 2-D Long Term Model

(1) Outlines of Model Development

Development of two-dimensional model for long-term simulation was conducted by using software MIKE21C. A two-dimensional model was developed to cover the main stream and branches of the Padma river and riverbanks between the Jamuna-Ganges confluence to Chandpur. The model was based on the satellite image in 2003, the river cross sections surveys by BWDB in the pre-monsoon 2003, the available bathymetric data by BIWTA in 2003 and the bathymetric surveys carried out for the mathematical modeling in June and August 2004. This two-dimensional model was therefore named '2003/04 Padma 2-D Long-term Model' and was validated through comparison between simulated and observed hydrodynamics and river morphological process in the years 2003 and 2004.

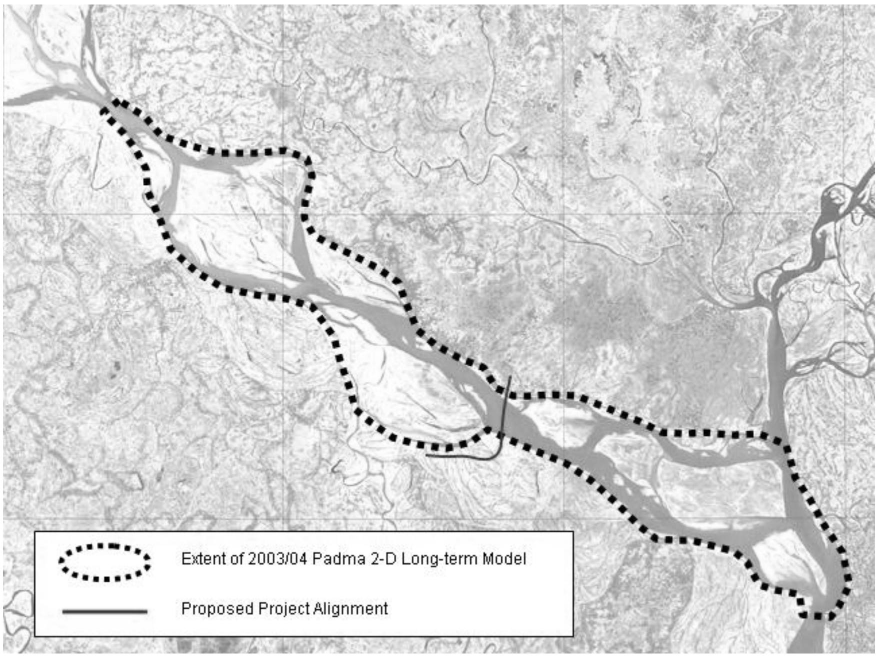


Figure 6.5.16 Extent of 2003/04 Padma 2-D Long-term Model

(2) Simulations by 2003/04 Padma 2-D Long-term Model

(a) Hydrological Settings

Hydrological settings for predictions of the middle- to long-term tendency of river morphology were given in the form of water level and discharge hydrographs in the late 10 years (from 1993/94 to 2003/04) at the respective boundaries.

The long-term simulations were carried out by using hydrodynamics during the monsoon period in each year and the pre- or post monsoon period are not considered due to difficulties in simulation of morphological developments during the low flow period. This approach was already used in the past for the similar two-dimensional simulations for the Jamuna and Gorai rivers. The morphological process was accordingly simulated as an accumulation of morphological developments in the monsoon period year by year. The results do not exactly represent morphological process for the continuous hydrologic cycle but suggest indicative morphological process for a long period.

(b) Simulations for Prediction of Tendencies of Morphological Process

A simulation for 'without bridge' condition was conducted at first to simulate the tendencies of river morphological process for 5 and 10 years. Succeeding to the simulation for 'without bridge' condition, another simulation for 'with bridge' condition was conducted on the condition that the proposed structures were incorporated into the model in the same manner as described in the sub-section 6.5.3. The results of simulations are presented hereunder together with assessment of long-term impacts by construction of the project.

(3) Assessment of Impacts by Construction of the Project

Comparison of the simulated results between ‘without project’ and ‘with project’ conditions indicate that no significant difference is visible for the main water course in view of macro-basis morphological developments as shown in Figure 6.5.17

Figure 6.5.18 shows the change in simulated riverbed level from the present (2003/04) to after 5- and 10-year for ‘without project’ and ‘with project’ conditions. As explained before, these simulated values do not mean the prediction of riverbed levels since the simulated values give the accumulation of morphological developments within the monsoon period only and those for the pre- or post monsoon period are not taken into consideration. The simulated results accordingly represent indicative tendencies of scour or deposition of riverbed in a certain long period.

From the viewpoint of indicative tendencies of riverbed scour or deposition by location, both ‘without project’ and ‘with project’ conditions indicate no large difference each other in the middle- and long-term tendencies of morphological process.

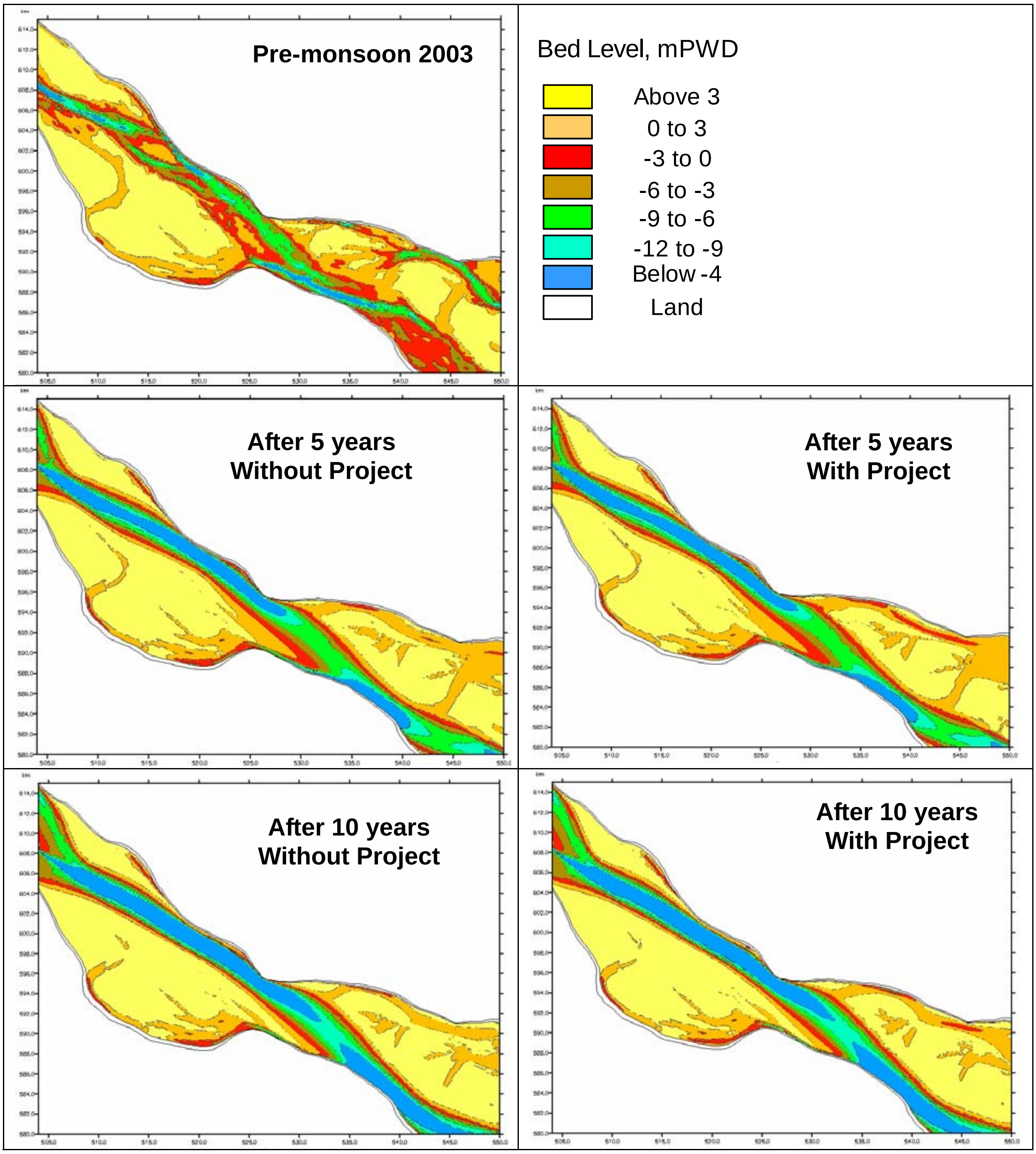


Figure 6.5.17 Riverbed Levels - 'Present (2003/04), After 5 years, and After 10 years

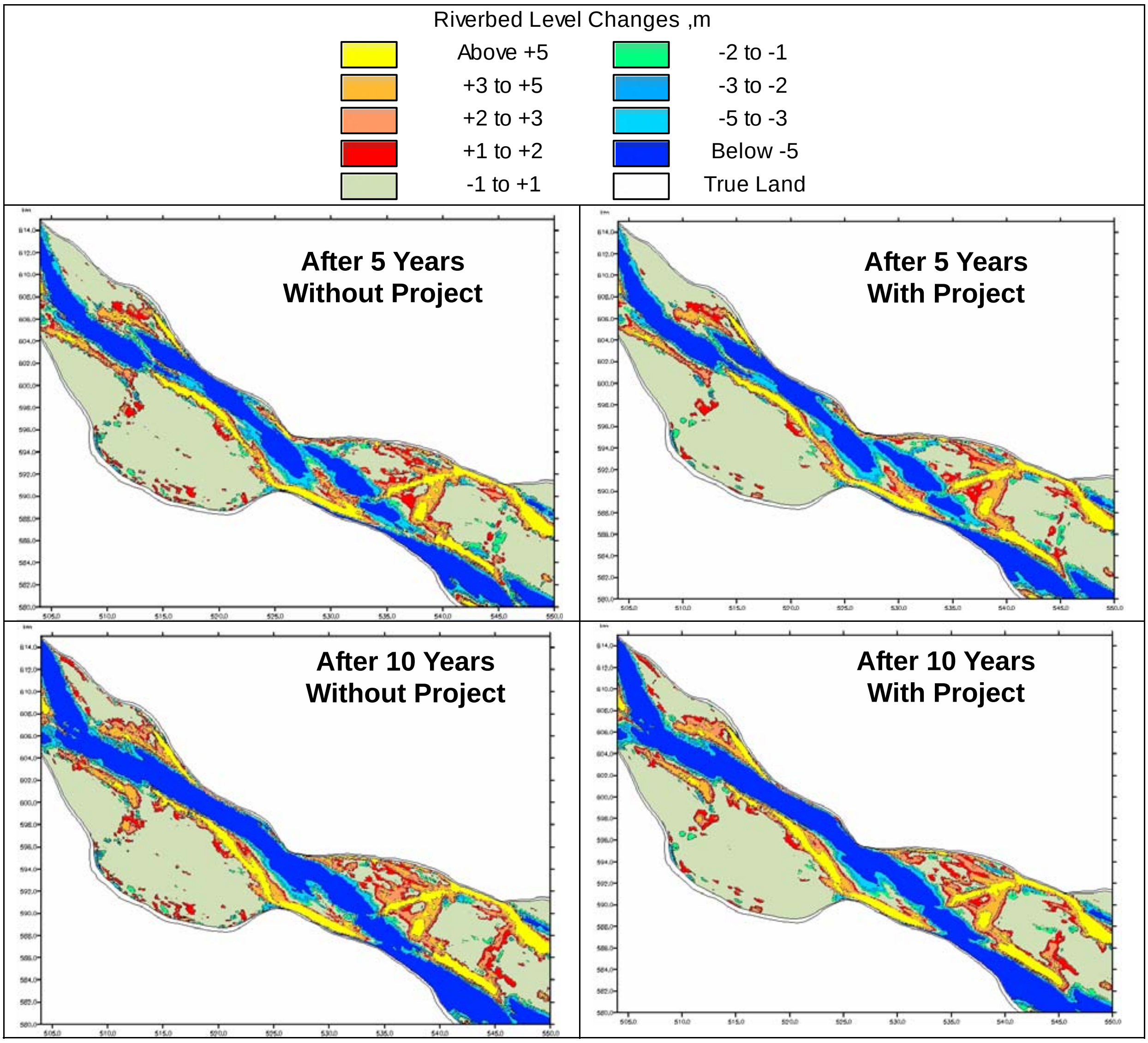


Figure 6.5.18 Comparison of Riverbed Changes - After 5 years and After 10 years

Comparison of the simulated results between 'without project' and 'with project' conditions indicate only minor differences in the riverbank erosion as shown in Figures 6.5.19 to 6.5.23.

Comparison of the simulated results between 'without project' and 'with project' conditions indicate only minor differences in the riverbank erosion. On the left bank, noticeable riverbank erosion of some 300 m after 10 years is found around 7 km downstream from the proposed bridge site. Similar tendencies are also observed on the right bank around 12 km downstream from the proposed bridge site with an erosion of some 700 m after 10 years. Comparison of the longitudinal profiles of river bank erosion, effects of the proposed bank protection work to reduce the riverbank erosion are observed along the right bank from the proposed bridge site to the downstream where the maximum riverbank erosion takes place. Meanwhile, there is no significant difference in the simulated maximum riverbank erosion between 'without project' and 'with project' conditions.

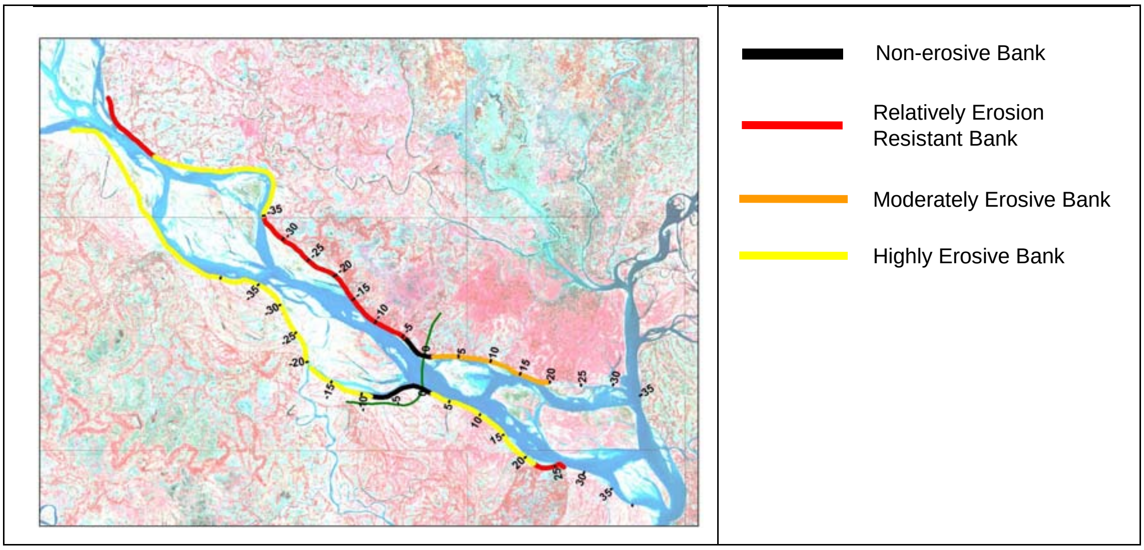


Figure 6.5.19 Classifications of riverbank and Distance from Proposed Bridge Site

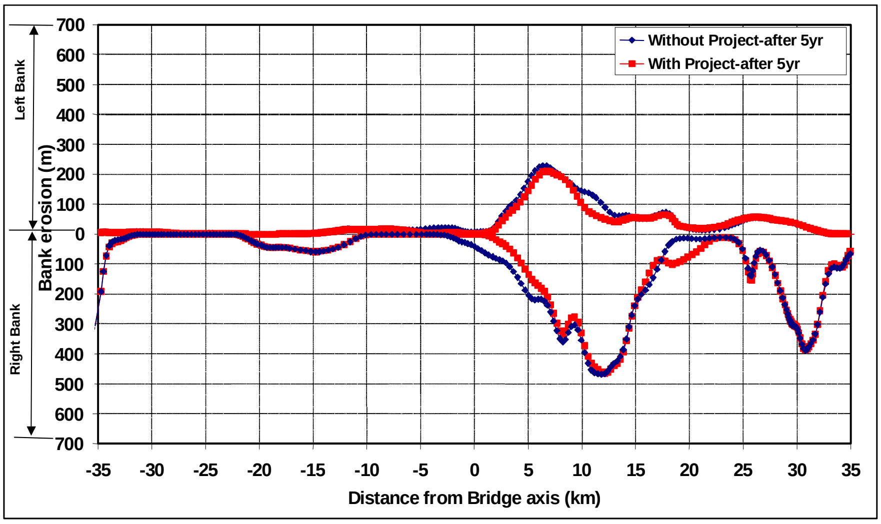


Figure 6.5.20 Comparison of Simulated Riverbank Erosion (After 5-year)

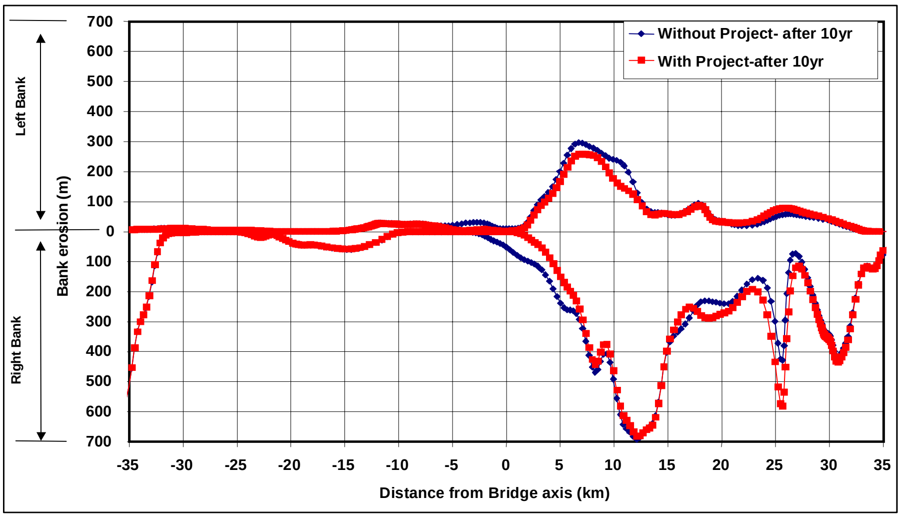


Figure 6.5.21 Comparison of Simulated Riverbank Erosion (After 10-year)

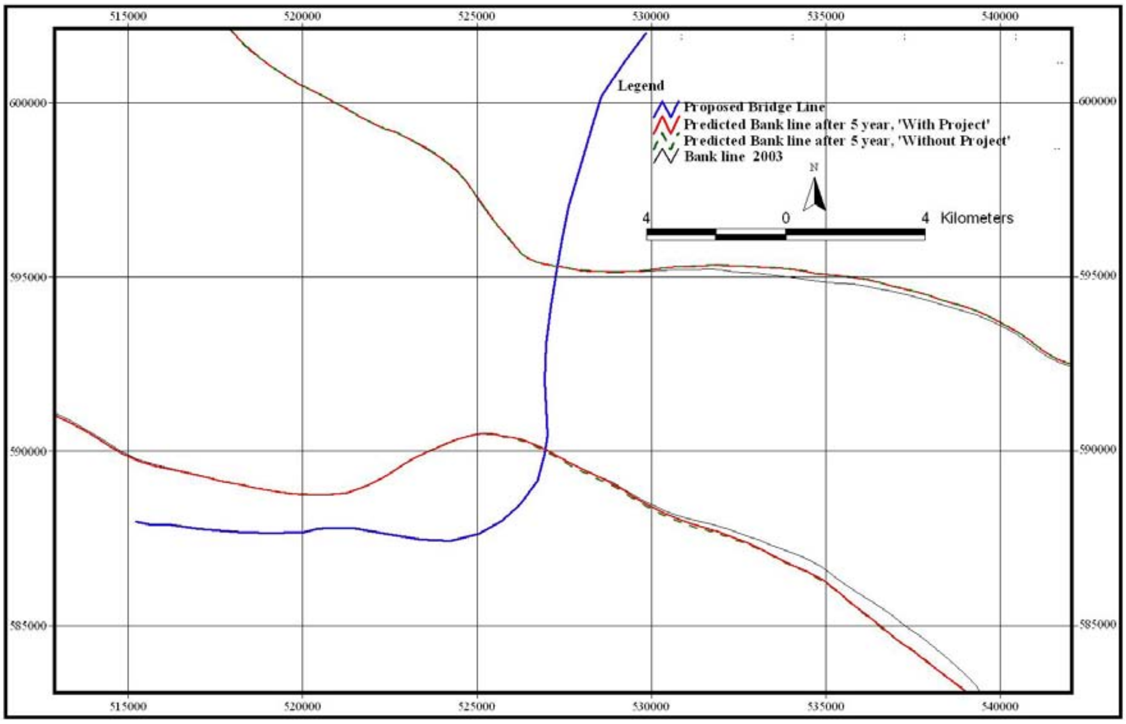


Figure 6.5.22 Comparison of Simulated Bank Line Changes (After 5-year)

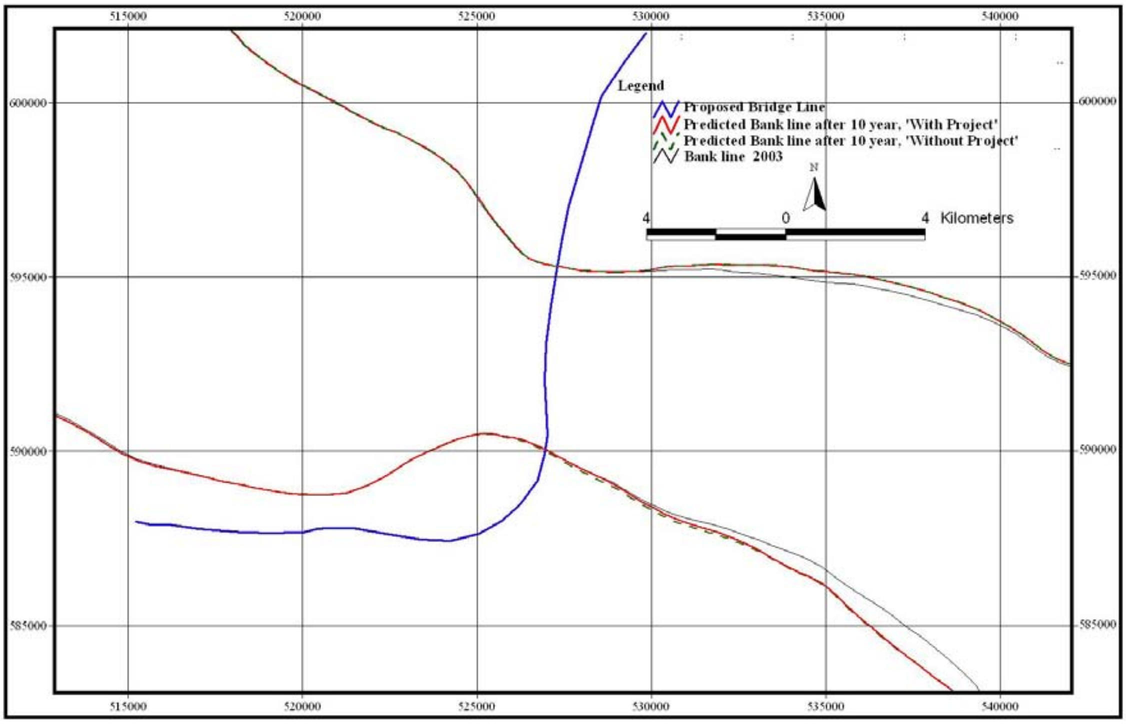


Figure 6.5.23 Comparison of Simulated Bank Line Changes (After 10-year)

6.5.5 Summary of Simulation Results and Impact Assessment

(1) Quasi Two-dimensional Model

The results of simulation by the quasi-two dimensional model indicate that some minor impacts would be anticipated in terms of flooding extent and water level after construction of the project, i.e. some +10 cm increment of the highest water levels at Mawa and locations along the upstream side of the proposed approach road on the right bank.

Impacts on flooding were also assessed by the simulations in terms of changes in flooding duration at the selected locations upstream sides of the proposed approach road on the right bank. Flooding duration is almost not changed between 'without project' and 'with project' conditions.

The simulated flood maps for the selected area around the proposed bridge site indicate that the maximum flooding extent by depth becomes slightly wider in the 'with project' condition. An increment of the flooding area with a flooding depth over 2.0 m is only 2% for 25-year return period and 1% for 100-year return period, respectively.

Meanwhile, it is also necessary to consider the limitations in the mathematical modeling developed on the basis of the currently available data only. Due to the limitation in topographic data of local channels in the flood plains, the simulations considered only five major openings by local bridges with an opening width ranging from 150 to 310 m for the proposed approach road section on the right bank. Besides the major openings, the numbers of small openings by minor bridges and crossing culverts are also proposed. Even though the local effects by such small openings could not be evaluated by the present scale of the mathematical modeling, the small increment of flooding extent and water level for 'with project' condition is expected to be further reduced with the local effects of the minor openings.

With due consideration of the above, it is concluded that the adverse impacts by construction of the project will be miner.

(2) Two-dimensional Model: 2003/04 Padma 2-D Core Model

The results of simulation suggest that the hydraulic design parameters for the preliminary designs are properly given and the adverse impacts by construction of the project will be minor in terms of hydrodynamics and river morphology for the design flood under the 2003/04 conditions.

The hydraulic design parameters of flow velocity and lowest scoured level are given in consideration of a critical condition representing that river flow concentrates into one-side of riverbank and accordingly natural and structural induced scours take place at the same location. Meanwhile, the 2003/04 conditions that are the basis of the present two-dimensional model do not represent such a critical condition and the simulated results indicate less values for both flow velocity and lowest scoured level. The hydraulic design parameters used for the preliminary design are therefore regarded as conservative but should be considered as a possible critical condition for the design purpose.

The observed impacts in the simulated results are attributed to a small extent of channel constriction because of the proposed bank protection works partially designed above Standard High Water Level (SHWL). The extent of such a constriction is some 100 m that is comparatively smaller than the scale of the crossing width of 5.3 km. The impacts indicated as the differences between 'without project' and 'with project' conditions are minor as a whole. For the design flood of 100-year return period, an increment of the highest water level is almost negligible and only a +0.1 m/sec increment occurs in the depth-averaged flow velocity. An increment of +4 m takes place in the lowest scoured level for the design flood of 100-year return period but its elevation is -16 m PWD which is still far above the design scour level of -37.6 m PWD.

On the left bank, noticeable riverbank erosion of some 150 m for 100-year return period is found around 6 km downstream from the proposed bridge site and may correspond with the area of Louhajang. Similarly on the right bank, noticeable riverbank erosion of 450 m for 100-year return period is found around 9 km downstream from the proposed bridge site. Comparison of the longitudinal profiles of river bank erosion indicates that effects of the proposed bank protection works to reduce the riverbank erosion are observed along the right bank from the proposed bridge site to the downstream where the maximum riverbank erosion takes place. Meanwhile, there is no significant difference in the simulated maximum riverbank erosion between ‘without project’ and ‘with project’ conditions. It is therefore concluded that no significant impact in river bank erosion is expected between ‘without project’ and ‘with project’ conditions against the design flood.

(3) Two-dimensional Model: 2003/04 Padma 2-D Long-term Model

The results of simulation suggest that no large impacts in middle- and long-term morphological process will be expected by construction of the project.

Comparison of the simulated results between ‘without project’ and ‘with project’ conditions indicate that no significant difference is visible for the main water course in view of macro-basis morphological developments. From the viewpoint of indicative tendencies of riverbed scour or deposition by location, both ‘without project’ and ‘with project’ conditions indicate no large difference each other in the middle- and long-term tendencies of morphological process.

Comparison of the simulated results between ‘without project’ and ‘with project’ conditions indicate only minor differences in the riverbank erosion. On the left bank, noticeable riverbank erosion of some 300 m after 10 years is found around 7 km downstream from the proposed bridge site. Similar tendencies are also observed on the right bank around 12 km downstream from the proposed bridge site with an erosion of some 700 m after 10 years. Comparison of the longitudinal profiles of river bank erosion, effects of the proposed bank protection work to reduce the riverbank erosion are observed along the right bank from the proposed bridge site to the downstream where the maximum riverbank erosion takes place. Meanwhile, there is no significant difference in the simulated maximum riverbank erosion between ‘without project’ and ‘with project’ conditions. It is therefore concluded that no significant long-term impact in river bank erosion is expected between ‘without project’ and ‘with project’ conditions.