Hydrological Characteristics of the 1998 Flood in Major Rivers

A. K. M. Saiful Islam and Jahir Uddin Chowdhury
Institute of Water and Flood Management
Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

Abstract

The 1998 flood in the Jamuna, the Padma and the lower Meghna rivers was an extreme event of more than 100-year return period in terms of flow duration. The duration of flood in the Ganges was relatively short, but the return period of peak discharge is greater than 100 years. A numerical hydrodynamic model was used to generate hydrographs of flood discharge in major rivers. The flood flow in 1998 remained above riverbank for nearly 1, 3 and 4 months in the Ganges, the Jamuna and the Padma, respectively. The average flood discharges in these rivers during July to September of 1998 were around 150% of the long-term average discharge for that period. An analysis of inflow and outflow as a function of time indicates that the floodplains stored about 10% of the flow during 1998 flood, and as a result the peak discharge diminished considerably as the flood wave moved downstream. The stage-discharge relationships for flood waves in the Jamuna and the Ganges displayed significant loop characteristics.

INTRODUCTION

The flood of 1998 is a rare hydrological event in the history of Bangladesh. It caused colossal damage to the socio economy and extreme suffering to the people. The main cause of the flood was spill from the major rivers, particularly the Jamuna and the Ganges, which carry about 85% of the flood flow that enter Bangladesh. This paper investigates some hydrological characteristics of flood flow in the major rivers namely the Jamuna, the Ganges, the Padma, the Meghna and the Lower Meghna by analysing the data generated by a numerical hydrodynamic model and making comparison with previous large floods.

MAJOR RIVERS

The flood regimen in Bangladesh is dominated by huge flow carried by three major rivers, namely the Brahmaputra, the Ganges and the Meghna (Fig. 1). The source of floodwater in and around Dhaka city is the Brahmaputra through its distributories. The Brahmaputra has a length of about 2,900 km of which only 270 km lies in Bangladesh, and the reach between offtake of the Old Brahmaputra and confluence with the Ganges is called Jamuna. The catchment of the Brahmaputra at Bahadurabad is approximately 573,500 sq.km. The Ganges has a length of about 2,200 km and the reach in Bangladesh is approximately 230 km long before meeting the Jamuna, and the catchment area at Hardinge Bridge is approximately 1,090,00 sq. km. The travel times of flood waves from the border with India upto the Ganges-Jamuna confluence are approximately 5 and 7 days in the Ganges and the Jamuna, respectively. The reach carrying the combined flow of the Ganges and the Jamuna is called Padma and has a length of about 120 km before meeting the Meghna.

The other major river Meghna, has a length of about 110 km between Bhairabbazar and confluence with Padma. The Meghna receives water flow mainly from 2 big rivers (Fig. 1) and the meeting point of these rivers is approximately 20 km upstream of Bhairabbazar. The catchment area at Bhairabbazar is approximately 77,000 sq.km. The reach carrying the combined flow of Padma and Meghna is called Lower Meghna, which has a length of about 160 km and discharges to the Bay of Bengal. Almost entire flood flow in Bangladesh is drained through the Lower Meghna, which is a tidal river and has a large estuary.

ANALYSIS STATIONS

Stations where the Bangladesh Water Development Board (BWDB) gauges both water level and discharge in the major rivers are at Bahadurabad in the Jamuna, Hardinge Bridge in the Ganges, Bururia in the Padma and Bhairabbazar in the Meghna (Fig. 1). There is no permanent discharge gauging station in the Lower Meghna. There is a water level gage station at Chandpur, which is approximately 22 km downstream from the confluence of the Padma and the Meghna (Fig. 1). This is the most downstream location in the gage network for flood forecasting. Present study utilizes flood data for these stations.

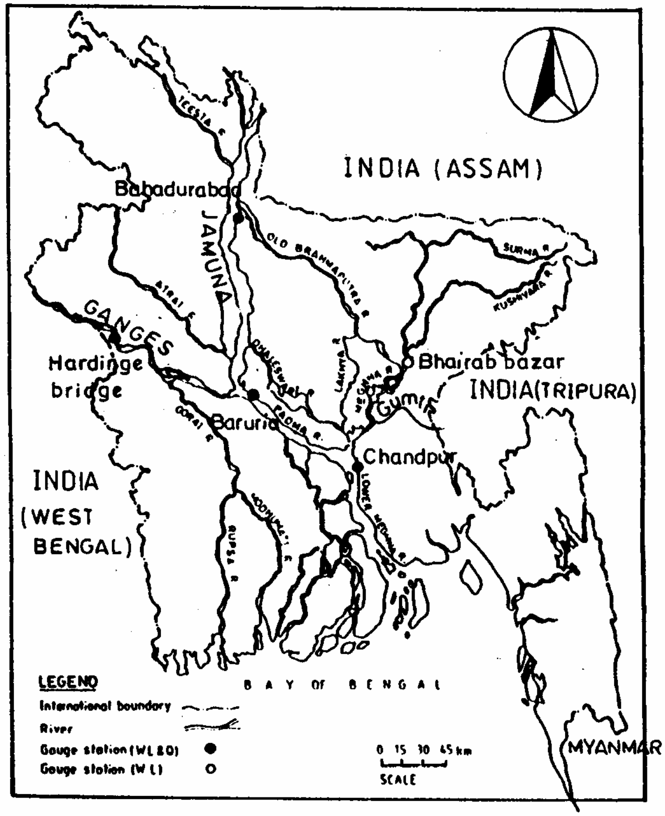

Figure 1: River system of Bangladesh

SIMULATION OF FLOOD DISCHARGE

Gauged discharge data at Bahadurabad, Hardinge Bridge, Baruria and Bhairab bazar are usually available at about two weeks interval during flood season. For the Lower Meghna, discharge data is not available. A numerical model developed by Chowdhury (1986) was used to generate hydrograph of flood discharge in the major river systems. The model is based on an implicit finite difference solution of the gradually varied unsteady flow equation shown below.

$$W\frac{\partial h}{\partial t} + \frac{\partial Q}{\partial x} - q = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + gA\frac{Q\,|\,Q\,|}{k^2} = 0$$

where, W is the total water surface width (m) , h is the elevation of water surface with respect to a common datum, Q is the flow rate (m^3/s), A is the cross-sectional area of flow (conveyance) section (m^2), q is the lateral flow rate per unit length of channel, $k = CA\sqrt{R}$, k is the conveyance of flow section in m^3/s, R is the hydraulic radius of flow section (m), C is the Chezy resistance coefficient ($m^{1/2}$/s) and g is the acceleration due to gravity (m^2/s).

The effective cross-sectional area of flow (conveyance) section is estimated by

$$A = A_r + A_f\sqrt{Y_f / Y_r}$$

where, A_r and A_f are water areas for river section and floodplain section respectively ,and Y_r and Y_f are water depths in river and floodplain respectively.

Hydrodynamic condition during flood flow in the alluvial rivers in Bangladesh is quite different from that during low flow. The cross section changes due to erosion when flow increases from low to high discharge and due to deposition when flood flow recedes. The resistance characteristics also change when low flow changes to high flow in the river –floodplain system. Such changes in the hydraulic condition create difficulty for simulation by numerical model where fixed cross section is assumed. To reduce these difficulties, the simulation was kept confined to the three months period of July to September when about two-thirds of annual discharge occurs.

Schematic representation of the rivers that were included in the model is shown in Fig. 2. It included 1483 km of channels involving 11 rivers, 13 junctions, 4 upstream discharge boundaries and 3 downstream water level boundaries. The rivers were divided into distance steps varying from 1 to 30 km, and the total number of distance steps was 240. A time step of 30 minutes was used in the simulation. The model was calibrated against observed data of previous large flood in 1988 and verified against observed 1998 flood data. Calibrated values of C were in the range 92 to 99 $m^{1/2}$/s among the rivers. A comparison of predicted hydrographs with observed discharge data during 1998 flood is shown in Fig. 3.

FLOOD MAGNITUDE AND DURATION

Simulated hydrographs of 1998 flood at Hardinge Bridge, Bahadurabad, Baruria and Chandpur are shown in Fig. 4. The bankfull discharges (after Delft Hydraulics and Others, 1996) are also shown in the figure. Figure 4 indicates that the long duration of 1998 flood in Bangladesh was mainly due to continuous inflow of high discharge for more than two and half months in the Jamuna. There were four major flood waves in the Jamuna while one in the Ganges. The maximum peak flood discharges at Jamuna and Ganges occurred quite closely at the beginning of September 1998. This feature caused unprecedented high discharge in the Padma and Lower Meghna.

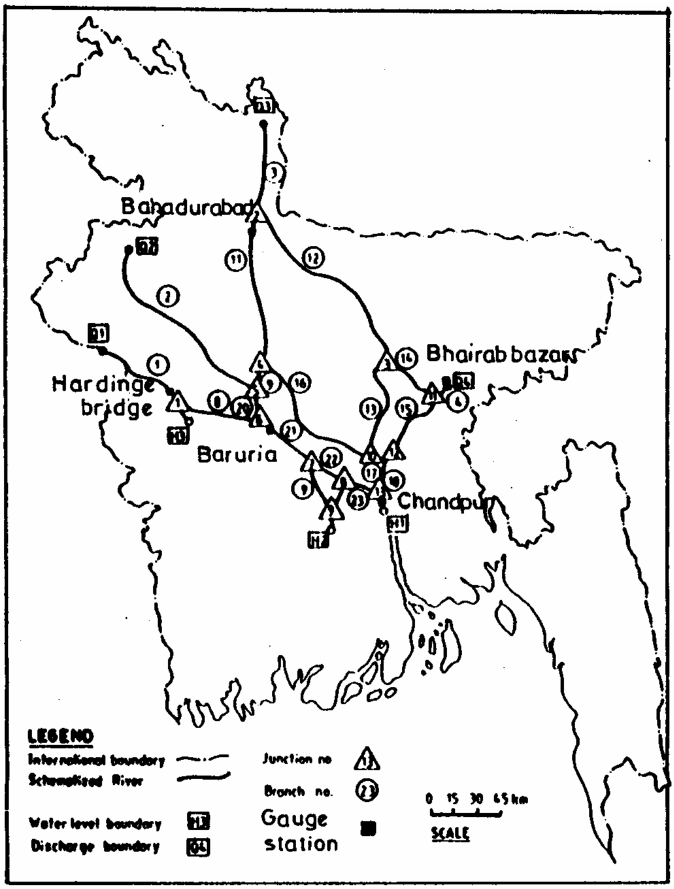

Figure 2: Schematization of river system used in the numerical model

Table 1 shows comparison of three-month (July-September) average discharge and annual maximum discharge during 1998, 1988 and long-term. It is seen from Table 1 that the average flood discharge at all stations except Bahirabbazar during 1998 was much higher than that during 1988, and around 150% of the long-term average discharge. Data in Table 1 indicates that approximately 55% of total flood discharge during July to September 1998 was carried by the Jamuna while approximately 34% by the Ganges.

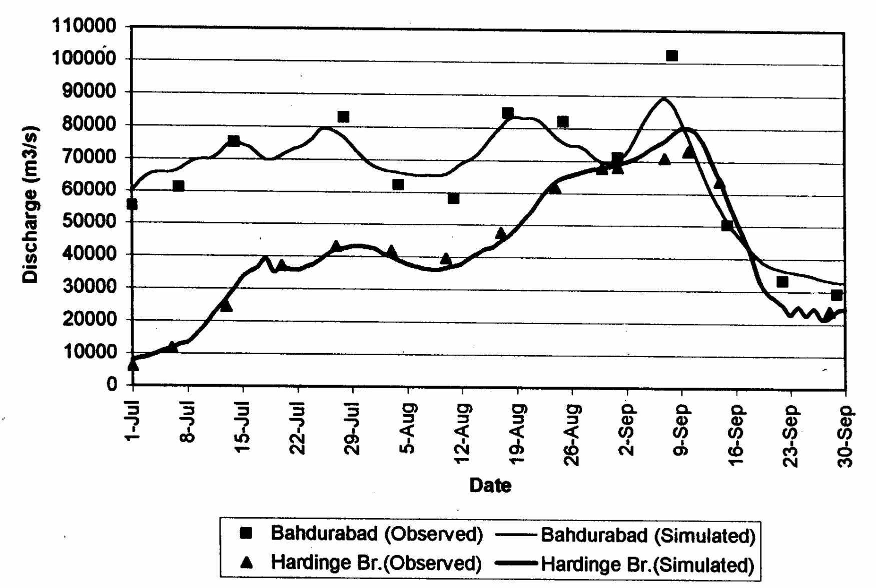

Figure 3: Comparison of predicted discharge with observed discharge during the 1998 flood

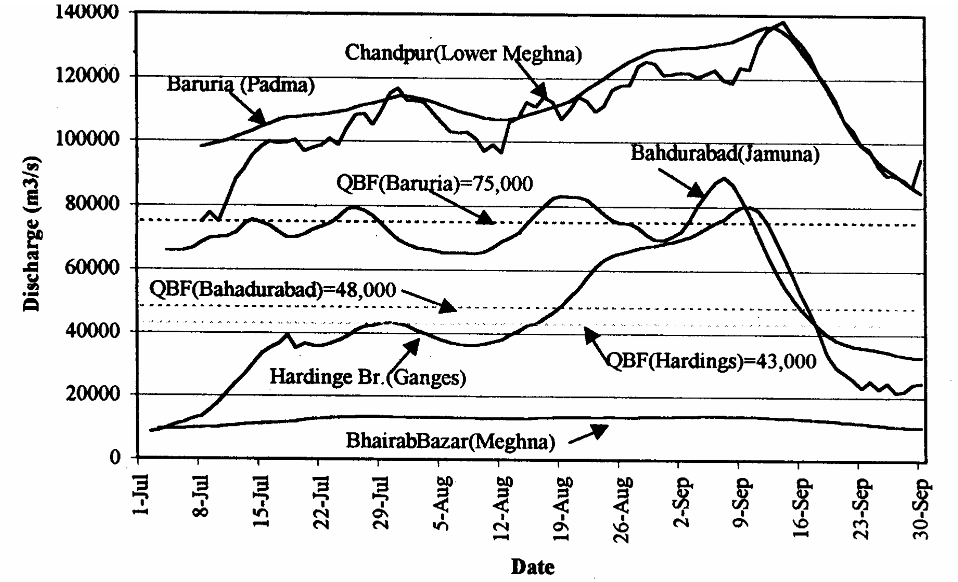

Figure 4: Predicted hydrographs of flood discharge in major rivers during the 1998 flood

Table 1: Comparison of three-monthsaverage flood discharge (July to September) at gauge stations of major rivers

Parameter	Year	Hardinge Bridge	Bahadurabad	Baruria	Bhairab Bazar	Chandpur
Average flood Discharge (m^3/s)	1998	42,808	67,100	1,04,177	12,601	1,06,665
	1988	37,844	52,358	82,499	15,513	81,458
	28 yrs. Avg.	30,764	43,025	65,900	11,060	
Peak flood Discharge (m^3/s)	1998	80,330	93,658	1,36,481	14,037	1,38,283
	1988	71,800	98,300	1,32,000	17,900	1,19,464
	28 yrs. Avg.	52,358	67,100	89,742	13,946	

Duration of 1998 flood is compared with previous large floods as well as long-term average values. By analyzing data since 1966, the previous floods having large magnitude or long duration have been identified. The duration has been assessed in terms of flow above mean bank level (MBL) and bank-full discharge (BFD). Values of MBL and BFD were determined by Delft Hydraulics (1996). Results for flood level analysis are summarized in Table 2 while discharge analysis is presented in Table 3. It is seen from Tables 2 and 3 that peak flood level and discharge of 1998 flood exceeded previous records for the Ganges and the Lower Meghna but not for the Jamuna and the Meghna. However magnitudes of peak floods in Jamuna and Meghna rivers are quite close to the previous records. Using the results of frequency analysis in IFCDR (1995), the estimated return period of the peak of 1998 flood are 100 years and much greater than 100 years for annual maximum water level at Bahadurabad (Jamuna) and Hardinge Bridge (Ganges), respectively; and 75 years and greater than 100 years for annual maximum discharge.

Table 2: Flood level and duration in major rivers

River	Gauge Station	Mean Bank Level MBL (PWD) (m)	Maximum flood level in specified years (PWD) (m)				Continuous duration of flood in days above MBL		Flood of longest continuous duration above MBL before 1998	
			Year 1998	Year 1988	Year 1987	28 yrs. Avg	Year 1998	28 yrs. Avg	Year	Duration in days
Jamuna	Bahdura-bad	18.93	20.41	20.61	19.68	19.74	87	23	1977	59
Ganges	Hardinge Bridge	14.01	15.19	14.87	14.79	14.28	28	12	1980	42
Padma	Baruria	7.05	10.74	9.8	9.5	8.89	118	84	1990	119

Table 3: Flood discharge and duration in major rivers

River	**Gauge Station**	**Bank-full discharge (BFD) (10^3 m^3/s)**	**Maximum discharge in specified years (10^3 m3/s)**				**Continuous duration of flood in days above BFD**		**Flood of longest continuous duration above BFD before 1998**	
			Year 1998	Year 1988	Year 1987	28 yrs. Avg.	Year 1998	28 yrs. Avg.	Year	Duration in days
Jamuna	Bahdurabad	48.0	93.6	98.3	73.0	67.1	77	21	1966	46
Ganges	Hardinge Bridge	43.0	80.3	71.8	75.8	52.3	34	14	1980	40
Padma	Baruria	75.0	136.5	132.0	113.0	89.7	115	21	1980	57

The most remarkable feature of 1998 flood is its very long duration as can be seen from Tables 2 and 3. The long duration of high discharge during 1998 flood in the Jamuna, Padma and Lower Meghna is unprecedented. The flow duration graphs for 1998 flood at Bahadurabad and Chandpur are superimposed on the stage-duration-frequency graphs given in IFCDR (1995) as shown in Fig. 5. The 1998 flood level at Bahadurabad corresponding to duration of 30 days or more has a return period of greater than 100 years. At Chandpur, the return period of both peak magnitude and duration for 1998 flood has exceeded 100 years.

STORAGE FUNCTION OF FLOODPLAIN

Simulation results show that the flood waves attenuated substantially in a quite short distance as it travelled down the Jamuna river as can be seen from the Fig. 6, where the hydrographs are at two locations of approximately 92 km apart. Large decrease in the peak discharge while increase in the trough discharge indicates that substantial volume of floodwater was retained in the floodplain and river. The floodwater was stored during rising flood level and released during falling flood level. To investigate the retention function of floodplain, an analysis of inflow and outflow using the data generated by the numerical model was made. The analysis was based on integration of the following equation.

$$I - O = \frac{dS}{dt}$$

where, I is the inflow (m3/s), O is the outflow (m^3/s) and S is the storage (m^3).

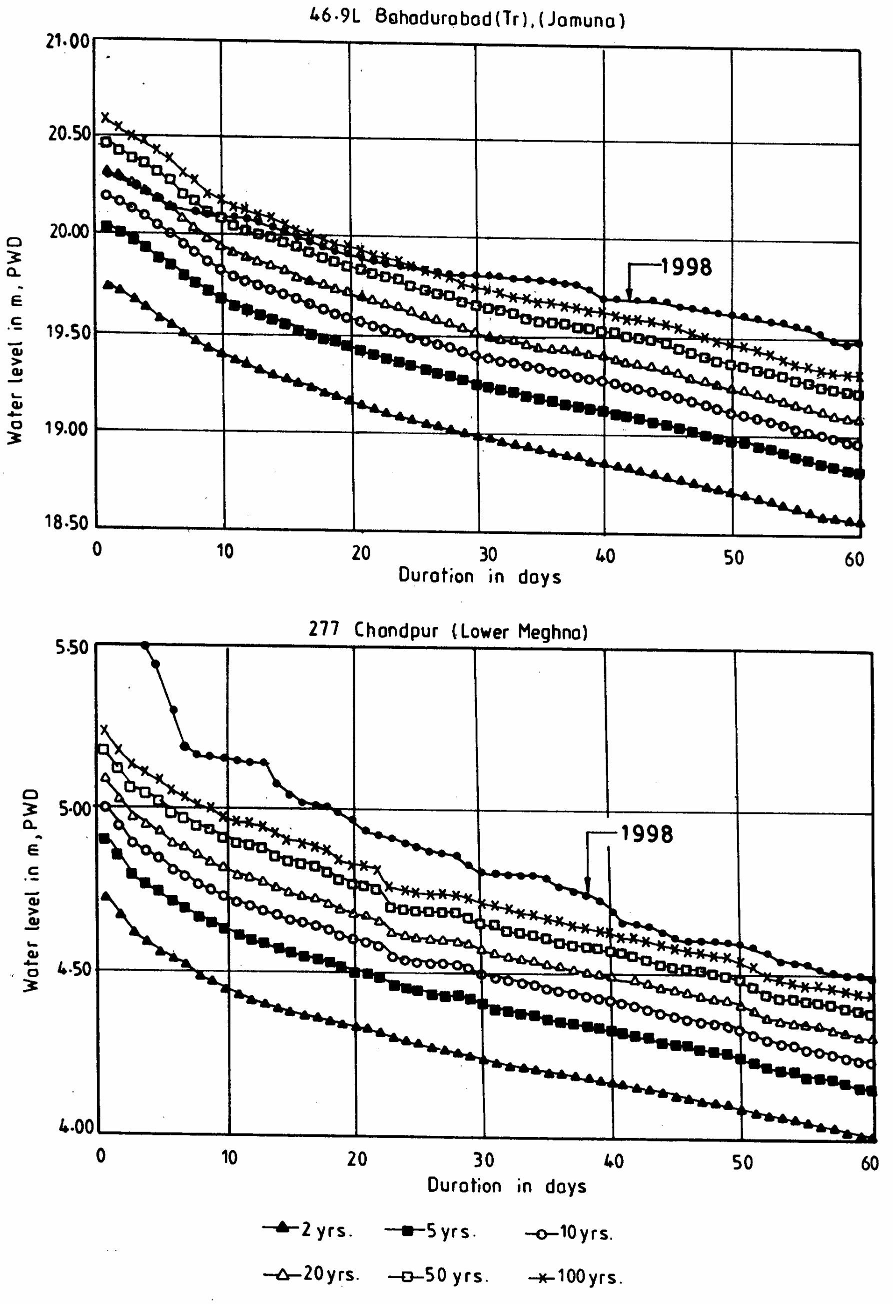

Figure 5: Comparison of daily water level of 1998 flood with stage-duration-frequency curves at Bahdurabad and Chandpur

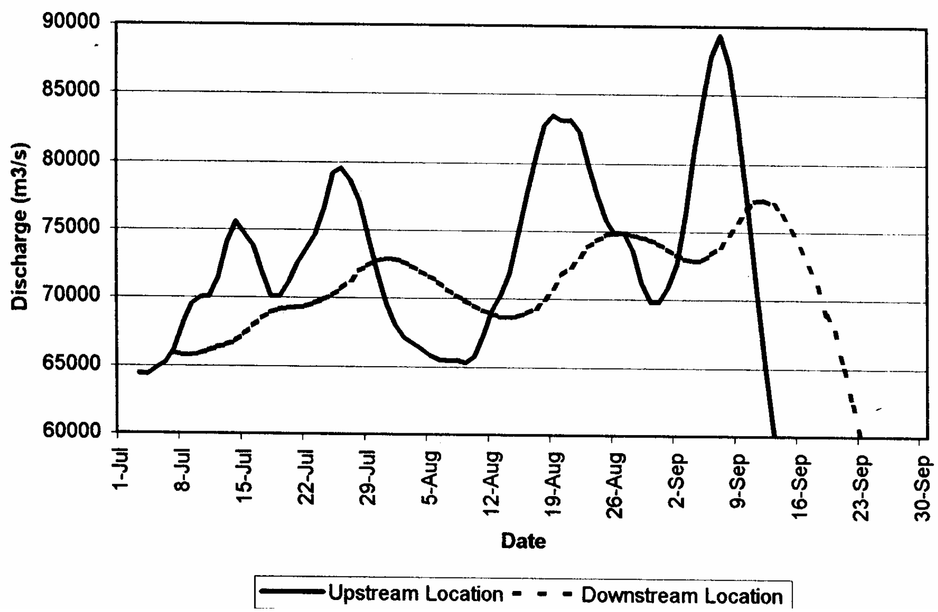

Figure 6: Simulated flood discharges during 1998 at two locations 92 km apart along Jamuna River

Daily average discharge was used in the integration process and the effect of travel time was incorporated. The estimated storage, as a percentage of cumulative inflow volume since the first of July, is plotted against time in Fig. 7. Water level at Baruria, which is just at the downstream of Ganges-Jamuna confluence, is also shown. It is seen that around 20% and 10 % of total inflow of floodwater were stored in the river-floodplain system during 1988 and 1998 floods, respectively. Smaller percentage for storage in the case of 1998 flood is because of much larger inflow volume. Larger percentage for storage during early part of 1988 flood season was because of smaller inflow. This analysis indicates that the floodplain plays the role of a huge retention reservoir. Therefore complete prevention of flooding of major floodplains by flood control embankments is likely to cause substantial increase in the flood levels in major rivers.

STAGE-DISCHARGE CHARACTERISTICS

Using model-generated data for 1998 flood, stage-discharge plots for Jamuna, Ganges and Padma rivers at Bahadurabad, Hardinge Bridge and Baruria, respectively are shown in Fig. 8. It is seen that there is an anti-clockwise loop in the relationship corresponding to every flood wave. Discharge is larger during rising flood than that during falling flood for a given stage. The loops are distinct and quite wide in the case of Ganges and Jamuna rivers, but not distinct in the case of Padma River. This feature indicates that monotonic stage-discharge relationship (rating curve) may not be appropriate for the Jamuna and the Ganges. Effect of acceleration in flow, resistance from braid-bars and storage function of floodplain are among the main reasons for significant loop characteristic in the stage-discharge relationships.

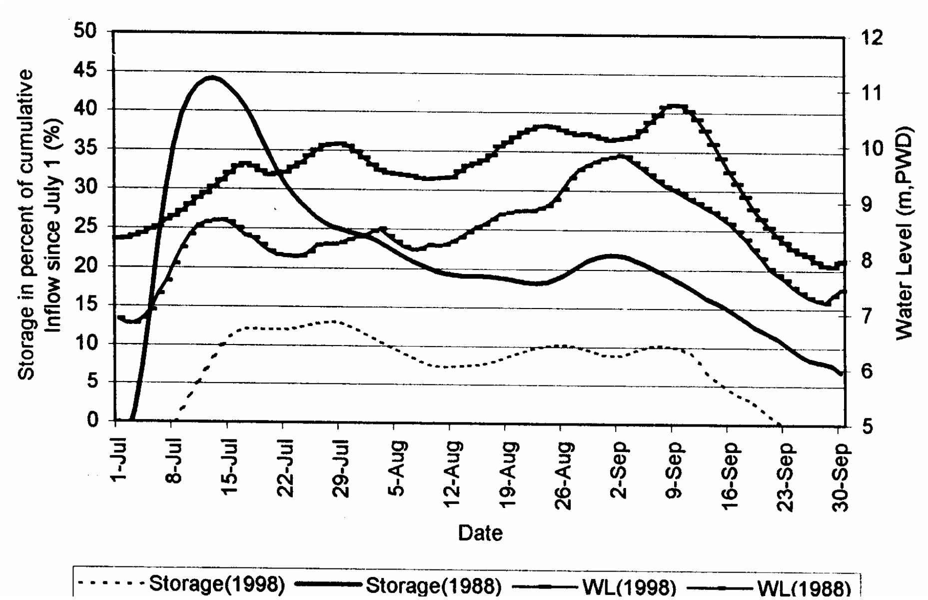

Figure 7: Estimated storage of floodwater in the river-floodplain system and water level at Baruria

CONCLUSIONS

The remarkable feature of 1998 flood was the long duration of very high discharge in the Jamuna, Padma and Lower Meghna. The flood flow remained above the riverbank for nearly 1, 3 and 4 months in the Ganges, the Jamuna and the Padma, respectively. Return periods for the 1998 flood in the Jamuna, Padma and Lower Meghna are greater than 100 years when the flow duration is considered. Close occurrence of peak floods in the Ganges and Jamuna during early September caused very large discharge of around 140,000 m^3/s in the Padma and Lower Meghna.

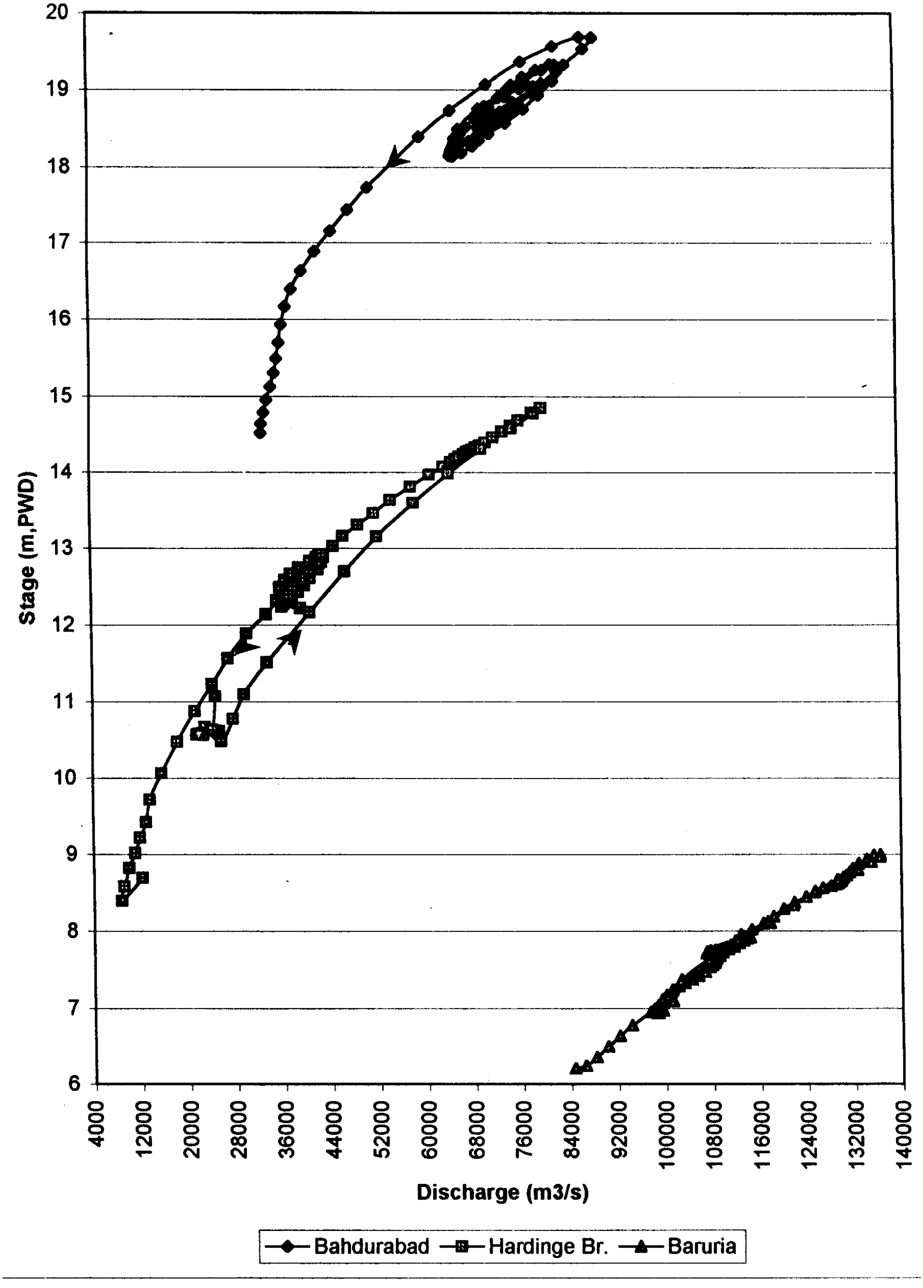

Figure 8: Simulated stage-discharge relationships of flood waves in 1998 for Jamuna, Ganges and Padma rivers

The floodplains played an important role by storing about 10% of the total inflow of flood water through rivers during 1998 flood season, and as a result the peak flood discharge decreased substantially as the flood waves moved downstream. The stage-discharge relationships for flood waves in the Jamuna and the Ganges display significant loop characteristics.

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