FAP24

Government of the People's Republic of Bangladesh

Water Resources Planning Organization

European Commission

Delft Hydraulics

Danish Hydraulic Institute

Hydroland

Approtech

Osiris

RIVER SURVEY PROJECT

Special Report No.6

Floodplain levels and bankfull discharge

October 1996

Special Report 6

Floodplain Level and Bankfull Discharge of the Jamuna, Ganges and Padma Rivers

October 1996

Contents

8

Figures

Tables

Acronyms and abbreviations

BWDB	:	Bangladesh Water Development Board
EC	:	The European Commission (formerly the Commission of the European Communities)
FAP	:	Flood Action Plan
FPCO	:	Flood Plan Coordination Organization (today merged with WARPO)
ISPAN	:	Irrigation Support Project for Asia and the Near East
JBS	:	Jamuna Bridge Study
PWD	:	Public Works Department (datum)
RSP	:	The River Survey Project (= FAP24)
WARPO	:	Water Resources Planning Organisation (under the Ministry of Water Resources)

1 Introduction

The River Survey Project (RSP, or FAP24) was initiated in June, 1992, and was completed after 4 years. The project was executed by the Flood Plan Coordination Organisation (FPCO), today merged with the Water Resources Planning Organisation (WARPO), under the Ministry of Water Resources (formerly the Ministry of Irrigation, Water Development and Flood Protection). Funding was granted by the European Commission. The Consultant was DELFT-DHI Joint Venture in association with Osiris, Hydroland and Approtech. Project supervision was undertaken by a Project Management Unit with participation by WARPO/FPCO, a Project Adviser, and a Resident Project Adviser.

The objective of the project was to establish the availability of detailed and accurate field data as a part of the basis for the FAP projects, as well as adding to the basis for any other planning, impact evaluation and design activities within national water resources and river engineering activities.

The project consisted of three categories of activities:

- A survey component, comprising a comprehensive field survey programme of river hydrology, sediment transport, and morphology;
- a study component, comprising investigations of processes and effects within river hydrology, sediment transport and morphology; and
- a training component.

The study programme of the project was developed in a close dialogue with the Client and the Project Adviser. Objectives and scope of the programme were gradually identified and adjusted, and were eventually summarised in a Study Programme submitted to the Client in February 1995.

The present report was prepared within this programme, subject 3: Planform characteristics and channel dimensions, topic 3.1: Planform classification, and meandering and braiding characteristics. Related monographs are *RSP Special Report 7: 'Geomorphology and channel dimensions'*, *RSP Special Report 20: 'Joint BWDB/RSP measurements, morphology'*, and *RSP Special Report 24: 'Morphological processes in Jamuna River'*. For a general presentation of the findings of the morphological studies of the project, please refer to *RSP Final Report Annex 5: 'Morphology'*.

The study was been carried out and reported by Mominul Haque Sarker.

The report was first submitted as RSP Study Report 6 in November, 1995. It was reviewed on behalf of WARPO by the PA, prof. J. J. Peters, and by prof. J. U. Chowdhury, BUET. To the extent practical, the comments received have been incorporated in the present edition. Some more far-reaching professional questions raised by the reviewers have been addressed elsewhere in the final reporting of the RSP.

The author wishes to thank the reviewers for good advice and valuable comments.

2 Background

Natural rivers are generally characterised by a wide variation of discharges and sediment load. The channel formation is determined by the continuous changes of the discharge and the sediment load. In order to determine the channel dimension and the planform characteristics with the help of a single discharge value, the bankfull discharge is often being used. The bankfull discharge is defined by Richards (1980) as *'the flow which just fills the range of the section of the alluvial channel without overtopping the banks'*. He continues that it *'has often been... treated as dominant or formative events controlling channel form'*.

Inglis (1968) found that for the Indian rivers, the dominant discharge is nearly the same as the bankfull discharge. Klaassen and Vermeer (1988) derived regime equations for the Jamuna River utilising the 'bankfull discharge' as an independent variable. Besides 'bankfull discharge', there is a number of suggestions in the literature on estimating a channel formative discharge. For a river with multiple braided channels, like the Jamuna, Ganges and Padma, the flow filling up to the banks and above is playing an important role in forming and shaping secondary channels. The flow below the banks and braided bars and chars may not be representative for the channel formation. One of the important parameters for the river training and bank and flood protection work is the bankfull width of a river, and this bankfull width can only be related to the bankfull discharge.

After overtopping the banks of a river, the flow extends over the adjacent land along the river, which can be defined as the floodplain. Due to the relatively shallow depth and the vegetate surface of the floodplain, the flow often loses its sediment carrying capacity, and as a result, sedimentation occurs over the floodplain. In the course of time, such sedimentation can raise the flood plain as well as the bank of the river. Not only the floodplain sedimentation, but also other phenomena: Bank erosion, tectonics and flood spills with a sediment deficit, are the determining factors for the floodplain level adjacent to the river bank. Also, tectonic effect can play a role, but these are beyond the scope of this study. In this study, the floodplain area that is covered by the BWDB standard cross-sections surveying is included. This area ranges from a few kilometres to a few tens of meters from the existing bank of the rivers.

There are mutual relationships between the channel form, the floodplain development, and the bankfull capacity of a section of the river (Keith Richards, 1980). Therefore, the flood-plain level has been included, to a limited extent, in the scope of the present study of the bankfull discharge of the Jamuna, Ganges and Padma.

The present report has been structured in chapters as follows: Objectives of the study, data, and data quality checking (common for the 'floodplain level' and the 'bankfull discharge' analyses). Data analysis, results and discussion are separately presented under the headings of 'floodplain level' and 'bankfull discharge'. Finally, the conclusions of the study are drawn for both topics.

3 Objective

The floodplain level is related with the bankfull discharge, which is utilised as a parameter for the prediction of channel dimensions and plan-form characteristics of the major rivers in Bangladesh. The objectives of this study are as follows:

- To obtain an impression of the variability of the floodplain level and any changes of floodplain level during the last few decades
- To determine the bankfull discharge of the Jamuna, the Ganges and the Padma Rivers
- As different studies on the Jamuna River have reported rather different bankfull discharge rates, one objective of the present study is to estimate the range of variation of the bankfull discharge of the Jamuna River with changes of the definition of the bank level

4 Data

Three types of data are required for this study: (i) floodplain level or bank level data, (ii) hydrological data, and (iii) the chainage line along the rivers, to link the former two types of data. Data utilised in this study and their sources are shown in Figure 1.

In order to estimate the floodplain level, mostly BWDB cross-section survey data for the Jamuna, Ganges and Padma Rivers from 1966 to 1993 were applied. The number of cross-sections utilised in this study is shown in Table 1. FAP1 (1990), and FAP21/22 (1992), surveyed bank and floodplain levels at six location along the Jamuna River (see Figure 2). These data were also analyzed to determine the bank level and to obtain an impression of the variability of the floodplain.

Hydrological data used in the study comprise discharge and water level data. Rating curves and discharge hydrographs estimated by RSP for the discharge gauging stations Bahadurabad, Hardinge Bridge and Baruria (based on discharge measurements by BWDB) were employed for the study. BWDB operates a number of water level gauging stations along the different rivers. Name and chainage of those stations, from which data were used in the present study, are shown in Table 2.

FAP1 derived a chainage line for the Jamuna River based on the conveyance of cross-sections surveyed in 1989, which has been utilised in the study, for the bankfull discharge of the Jamuna River. For the Ganges and the Padma Rivers, chainage lines were derived as a part of the present study on the basis of BWDB 1992-93 cross-section surveys along these rivers.

5 Data quality checking

Along the Jamuna River, BWDB standard cross-section surveys cover the reach between the upstream point at the confluence with the Dharla River to the downstream point at the confluence with the Ganges River. Along the Ganges River, BWDB cross-section surveys cover the reach from approximately 60 km upstream of Hardinge Bridge (G#18) to the confluence with the Jamuna River. Along the Padma River, the cross-section surveys extend from Baruria to the confluence with the Upper Meghna River near Chandpur (see Figure 3).

The quality of the BWDB cross-section surveying is discussed in RSP Special Report 20, and by FAP1 (1993, Annex 2). Though a lot of discrepancies and inconsistencies have been detected, the data provide the only information that represents both the channel, the banks, and the floodplain, and both in time and space. Before analysing the BWDB data, a prior quality checking was made, as briefly discussed in the following. The BWDB data used in this study after quality checking are shown in Table 1. FAP1 and FAP21/22 data were assumed to be reliable and no checking has been made before analysis of those data.

River	Type of data	No.	Period	Utilised	Status
Jamuna	Cross-sections	34	1966-1993	16	Checked by JBS, RSP
	Water level	13	1966-1993	8	Checked by RSP
	Discharge	1	1966-1993	1	RSP rating curve
Ganges	Cross-sections	20	1966-1993	18	Checked by RSP
	Water level	7	1966-1993	6	
	Discharge	1	1966-1993	1	RSP rating curve
Padma	Cross-sections	15	1966-1993	11	Checked by RSP
	Water level	5	1966-1993	3	Checked by RSP
	Discharge	2	1966-1993	1	RSP rating curve

Table 1: BWDB data available and utilised in the study, and their status of checking

JBS selected 12 BWDB cross-sections along the Jamuna River for a study of channel dimensions and channel characteristics, and the bench mark histories of the cross-sections were checked by JBS for the purpose. In the present study, those cross-section surveys have been utilised in order to cover the maximum possible reach of the river, see the Table 3.

The standard cross-sections used for the Ganges and the Padma Rivers are listed in Tables 4 and 5, respectively. To verify the horizontal control, the bench mark histories of the pillars/monuments of the cross-sections of the Ganges and Padma Rivers were checked. As mentioned, most of the cross-sections of the Jamuna River were checked by JBS, and checking of the bench mark histories for the rest of the sections has not been done.

Cross-sections of the Ganges and Padma Rivers were used in this study if the bench mark histories were found to be consistent. For a further checking of the horizontal control, cross-sections surveyed by BWDB in 1992-93 for the Ganges and the Padma were superimposed on the SPOT images from the same year by trial and error method, keeping the same azimuth as mentioned in the survey sheets. For details about the quality checking of BWDB standard cross-sections, please refer to a separate working paper.

Name of the river	Station number	Station name	Chainage km
Jamuna	45	Noonkhawa	0.00
	45.5	Chilmari	37
	46.7L	Kholabarirchar	75
	46.9L	Bahadurabad	84.7
	15J	Mathurapara	115
	49A	Kazipur	139
	49	Sirajganj	162
	50.3	Mathura	220
Ganges	89	Sardah	-52
	90	Hardinge Bridge	0
	91	Talbaria	13.5
	91.1	Sengram	37.5
	91.2	Mohendrapur	66
	91.9L	Baruria	98
Padma	91.9L	Baruria	-6
	93.4	Bhagyakul	47
	93.5	Mawa	58.5
	227	Chandpur	79

Table 2: List of BWDB water level gauge stations which were utilized during the study.

The quality checking for the vertical control of the cross-sections comprises a comparison for each standard cross-section between measurements from different years. Those sections that were found inconsistent with respect to vertical control (see Figure 4) were excluded from the analysis.

Among 13 BWDB water level gauging stations along the Jamuna River, 8 stations were found to be consistent (see Table 2) during the water surface slope analysis by RSP (see Hydrological Study Phase 1, 1993). The same method has been applied for the water level gauges along the Ganges and the Padma Rivers. For the Padma River, three water level gauges were used, along with the gauge station at Chandpur in the Lower Meghna. The water level gauges of Sureswar and Tarpasha, situated at opposite banks of the Padma at chainage about 65 km, showed a water level difference of about 1 m for same the date for the higher discharges. Therefore, both of these gauges were excluded from the analysis.

6 Floodplain level

6.1 Description

6.1.1 Floodplain

According to Volker (1981), the floodplain can be classified into three zones: Natural levee, transition zone, and backswamp. During flood flow, the river spills over the banks and flows over a strip of land along the river. This strip of land is known as natural levee. It is topographically elevated, due to the relatively coarser fraction of sediments depositing over this area. The natural levee accretes both laterally and vertically. The width of natural levees vary within a range of one-half to four times of the width of the river (Allen 1970) and the height may be as much as 3 to 4 m (Volker, 1981). Along the Jamuna, Ganges and Padma Rivers, backswamp is not a common feature, except for a few places. Rather, the flood basin is wide, see Figure 5.

Coleman (1969) observed the formation of the natural levee of the Jamuna and the Padma Rivers. He noted that flood spills occur in two ways. One (the predominant way) is diversion of the flood water into the basin through distinct funnel-shaped flood channels, which also convey the sediment from the river. This type of diversion of flood water has little influence on the formation or change of the floodplain level adjacent to the river. The second type of spill of flood water over the bank results in well-defined crevasse splays, which lead the water into the adjacent basin. Such crevasse splays account for the vertical accretion and irregularities in the vertical and the lateral direction of the natural levee. Crevasse splays mostly consist of fine sand capped with finer deposits, see Coleman (1969). It is not so that over-bank flow always contributes to aggrading the floodplain. Leopold et. al. (1964) pointed out that irregularly distributed flood flows over a floodplain sometimes could induce scour, rather than deposition.

Leopold et. al. (1964) classified the floodplain sedimentation into two types: One is the over-bank deposition, and the other is the lateral deposition within the river. They noticed that the lateral accretion dominates the process of the sediment deposition over the floodplain. For rivers like the Jamuna, Ganges and Padma, where the rates of bank erosion and migration of the channels are relatively high, it is evident that the lateral accretion will be the dominating process.

6.1.2 River dynamics

Jamuna River has followed its present course for the last 200 years, and Ganges for approximately 500 years (ISPAN, 1993), while the Padma, carrying the joint volumes of water of the Jamuna and Ganges, has followed its present course since the avulsion of the Jamuna River.

During the last few centuries, the rivers have been in the process of adjusting their floodplain and plan-form. The Jamuna River, after its avulsion, has oscillated within a 20 km wide sand body (Bristow, 1987), which is known as the active corridor. The Jamuna as a highly active braided river, continuously eroding and depositing its secondary and tertiary channels.

The Ganges and the Padma are wandering rivers (ISPAN, 1993). They are in a transition between meandering and braiding, and are often changing their plan-form locally within the different river stretches.

The banks of all these three rivers are highly erodible, the erosion rate exceeding 1000 m/year in extreme cases (Klaassen and Masselink, 1992). The near-bank floodplain of these river are in a process of continuous lateral deposition and erosion. FAP4 found that the Ganges and Padma Rivers, while shifting laterally, confine their migration within an active corridor (FAP4, Final Report, Volume 3, 1993).

6.1.3 Limitation of data used

The standard cross-sections surveys of BWDB follow a fixed alignment, and the length of each section is limited by a fixed monument or by pillars. The length of the floodplain covered by BWDB cross-section surveys is mainly determined by the eroding or receding bank of the river. In most of the cases, it was observed that if any one bank of a cross-section is stable for a few years, BWDB reduces their length of the survey over the floodplain from a few km to a few tens or hundreds of meters. Hence, the BWDB data only represent the bank level and a part of the developing floodplain adjacent to the existing bank. However, in a few cases, the characteristic shapes of floodplain features, such as the natural levee with its depressed flood basin, or a part of the backswamp, can also be observed from the data, when the bank is stable for a period of time (see Figure 6).

6.2 Data analysis and discussion

The floodplain and river surveys of FAP21/22 in the Jamuna River are shown with a 0.5 m contour interval. An example has been reproduced as Figure 7. From this figure it is observed that within a distance like 5 km, the level differs more than 2 m. Local irregularities of the floodplain level are observed both along and in the transverse direction of the river, see Figure 8. As mentioned earlier, Coleman (1969) pointed out that crevasse splays account for the irregular boundary of the toe of the natural levee. Also, formation and dying of spill flood channels and irregular flow over the floodplain may contribute to these irregularities.

Due to the instability of the bank of these rivers, the existence of a matured natural levee (developed over a long period of time) is not possible along the existing bank of the river. For banks which are free from erosion or deposition for a period of time, for example the left bank of cross-sections G#2 and G#3 of Ganges River, the shape and size of the developing natural levee can be observed clearly. For section G#2, the surveys of 1965 and 1969 were compared. At this section, the natural levee eroded with time, and, at the same time, a lateral accretion occurred during the four years period, so that little change can be observed at the toe of the levee or flood basin, see Figure 6a. For cross-section G#3, the BWDB surveys of 1968, 1972 and 1976 were compared. No large changes of the natural levee of this section were observed in the eight years period, only a few decimeter vertical accretion at the toe of the natural levee is seen, Figure 6b. Figure 6 shows that the width of the natural levee is 1.50 km, and that the relative height of the levee is more than one meter for section G#3, while the width is 1 km and the relative height is nearly two meters for section G#2. The widths of both levees are smaller than the range described by Allen (1970). The continuous migration of the river course, restricting the development of the natural levee, may be one of the causes of the difference in width as compared with Allen (1970).

In Figure 9, the time variation of the floodplain/bank level is shown for different BWDB cross-sections from the Jamuna, Ganges and Padma Rivers. No significant changes of floodplain/bank level is observed from this figure, though the year-to-year variation is considerable, especially at sections G#7 and G#10 (which are both at the left bank of the Ganges) and at sections P#3_1 and P#7 (at the right bank of the Padma), and at both banks of section P# 1 of the Padma. Changes of floodplain/bank level within two to four year are in the range of 0.5 to 1 m. These changes are associated either with bank erosion or with bank recedence. For the former case, see for example Figure 10a, at section P#3_1. Here, after 1975, erosion of the right bank continues until 1984. Erosion of the higher part of the natural levee shifted the bank at the toe of the previous levee from 1975 to 1979, and the right bank level continues to decrease as the erosion proceeds, see Figure 10a. The section of 1984 shows that after ceasing of the erosion, the right bank raised nearly up to the position of 1975. For the latter case, see for example Figure 10b, at section P#7, where the right bank receded towards the river. A raising of the attached bar from 1974 continued up to 1989, till the level nearly reached the bank level of 1974.

Figures 9 and 10 show examples where bank erosion or deposition into the river have changed the level of the near-bank floodplain, but within a few years, the level raised again nearly up to its previous level. More often, overtopping of flood water result in a rapid sedimentation over the low-laying floodplain. Another reason of apparent small year-to-year variations of the floodplain, as seen in Figure 9, is related to the survey procedure, as the length of the survey over the floodplain is the not same, and also, the levelling points during the survey are not same every year. This can influence the average impression of the level of a highly irregular floodplain.

For banks that are free from erosion or deposition for a long time, almost no change in the level is observed from Figures 9 and 10. This suggests that if any net aggradation or degradation phenomena occur on the matured floodplain, they cannot be detected from the applied type of data, neither with respect to time scale nor quality. The analysis shows that the processes of lateral deposition and erosion are predominant in these rivers, without any net aggradation or degradation trend of the floodplain.

7 Bankfull discharge

7.1 Methodology

7.1.1 Method to determine the bankfull discharge

The bankfull discharge can be estimated by an indirect method based on the breaking point of the rating curve at high stages. This method is best suited for a primary estimate. Drawbacks of this method are as follows: (i) the breaking point of the rating curve may reflect the 'char' level rather than the bank level; (ii) the range of variation of the breaking point is quite high, and may reflect both the local morphological changes and changes of the char level. A bankfull discharge estimated by this method represents only the specific section of the discharge gauging station for which the rating curve was made, as the bank level profile may not conform with water level profile for the whole river reach.

The method that was used in the present study is to estimate the bank level over a certain river stretch, and to compare this bank level with the water level profile at different discharges. Estimation of the bank level is based on the bank elevation at a number of fixed locations distributed at a fixed distance along the river, and for estimation of the water level profile, the same procedure is followed. Drawbacks of this method are as follows: First, the bank level along the river is not a regular feature, and the water level profile, though not as irregular as the bank level, still does not maintain a fixed slope over a long distance, but varies with time and space. Secondly, the bankfull discharge derived by this method is sensitive to the estimation of the bank and water level. Still, this method can provide a better estimate than the former, which is highly influenced by the local morphological features.

7.1.2 Definition of the parameters

In order to determine the bankfull discharge, two parameters are significant. One is the bank level, and the other is the longitudinal water level profile at different discharges. For the purpose of this study, the bank level is defined as the average of the bank level as estimated from BWDB survey data for about the last three decades. For the Jamuna River, the bank level data have been analyzed in a slightly different way than for the Ganges and the Padma Rivers. The reason for this is an aim to examine range of variation of the bankfull discharge of the Jamuna River due to changes of the definition of the bank level. Hence, for the Jamuna River, two levels, high and low level, were marked at both banks of each of the BWDB cross-sections, see Figure 11. High points, like roads or embankments, were not considered, and low depressed points on the floodplain were also neglected. The mean bank level is defined as the average of the high and low levels (1966-1993), while the average high bank level is defined as the average high levels from the period. The 'high' and 'mean' bank levels of the lower bank of a section (see Table 3) are then compared with the water level profile.

For the Ganges and Padma Rivers, the bank level is defined as the average of the mean level (1966-1993) of the near-bank floodplain (see Tables 4 and 5). Unlike the Jamuna River, the mean bank level is directly estimated from the BWDB cross-section, without estimating the low and the high level. For comparing the water level profile at different discharges with the bank level, both bank levels were plotted for these two rivers.

Estimates of the water level profile along a river were based on the discharge gauging stations Bahadurabad, Hardinge Bridge and Mawa (representing Jamuna, Ganges, and Padma, respectively). For a particular discharge, occurring on a given date, the profile was estimated by connecting the concurrent water levels at gauging stations among the ones listed in Table 2.

Cross-section	Chainage,(1989) km	Average bank level (m PWD)		
		High level	Low level	Mean level
J#17	25	25.27	23.77	24.40
J#16	37	23.74	22.70	23.22
J#15	56	22.16	21.55	21.85
J#14_1	63	21.58	20.74	21.17
J#13	85	19.36	18.51	18.93
J#12_1	84	18.90	17.72	18.31
J#11	118	16.73	15.89	16.32
J#10_1	127	15.73	15.07	15.43
J#9	142	15.23	13.97	14.65
J#8	150	14.01	13.52	13.77
J#7	162	13.88	12.85	13.35
J#6_1	171	12.76	12.03	12.39
J#6	178	12.75	11.88	12.31
J#5	188	11.87	10.75	11.27
J#4	201	11.04	10.11	10.57
J#2_1	220	9.17	8.44	8.80

Table 3: Average (1966-1993) high, low and mean level of the lower bank of a section of the Jamuna River

Cross-section	Chainage (1992-93) km	Average bank level (m PWD)	
		Right bank	Left bank
G#17	-32.5	15.71	16.07
G#16	-27.5	15.41	15.71
G#15	-19.5	15.36	15.38
G#14	-10.5	14.90	15.50
G#13	2.9	13.94	14.08
G#12	8.7	12.28	13.54
G#11	13.7	13.22	12.97
G#10	19	12.80	12.69
G#9	26	13.00	12.51
G#8	31.5	12.15	12.10
G#7	36.5	11.75	11.53
G#6	39.5	11.65	11.29
G#5	45	11.39	10.69
G#4	53	10.53	10.67
G#3	58	10.20	10.43
G#2	65	9.85	10.12
G#1	79	10.00	8.70

Table 4: Average (1966-1993) bank level of the Ganges River

Cross-section	Chainage (1992-93) km	Average bank level (m PWD)	
		Left bank	Right bank
P#7	0	8.26	7.56
P#6_1	5.4	7.01	7.10
P#6	11	6.68	6.83
P#5	21.5	6.83	6.98
P#4_1	28.5	6.67	6.66
P#4	36.5	6.67	6.86
P#3_1	49	6.50	5.94
P#3	55.5	5.51	5.69
P#2	67	5.00	5.40
P#1_1	72	4.91	5.38
P#1	77	5.10	5.28

Table 5: Average (1966-1993) bank level of the Padma River

The water level profile for each discharge is not a constant line. It varies from year to year, and also within one single year, due to hydrological and local morphological phenomena. Specific gauge analyses of the discharge stations at Bahadurabad of the Jamuna, at Hardinge Bridge of the Ganges, and at Mawa of the Padma River, were done by RSP, see Figure 12 (from Hydrological study phase 1, 1993). For each of the discharge stations, the year-to-year variation of the stage is considerable, the maximum range of variation being up to 0.50 m. To have an average impression of the stage for the same discharge, two years were selected for each river, where the stage variations were above and below the average line, and with almost the same magnitude for the higher discharges. Years 1990 and 1991 were selected for the Ganges and Padma Rivers, and 1984 and 1985 for the Jamuna, see Figure 12.

7.1.3 Assumption

Within the study reaches of the rivers, the discharge is not the same, due to the presence of tributaries and distributaries (see Figure 3). For simplicity, however, it has been assumed that the discharge at Bahadurabad represents the Jamuna River, Hardinge Bridge the Ganges, and Baruria the Padma River.

8 Data analysis

8.1 Jamuna River

As mentioned earlier, two bank levels, high bank and mean bank level, were estimated for each cross-section, and both were compared with water level profiles in order to asses the range of the bankfull discharge of the Jamuna River. The mean bank level profiles of the left and the right bank of this river are shown in Figure 13. The range of variation of levels between two banks is 0.05 m to 0.35 m. The mean level of the lower bank of a section was compared with discharge profiles of 45,000 m^3/s and 50,000 m^3/s for the years 1984, 1985 and 1990, see Figure 14. This figure indicates that the bankfull discharge varies with time, and that the variation is higher at the downstream reach of the Jamuna, where backwater from the confluence affects the water level profile. The figure suggests that the average bankfull discharge is somewhere in between 45,000 m^3/s and 50,000 m^3/s, if the mean bank level is considered. The high bank level is compared with the water level profile of 55,000 m^3/s in Figure 13c. The average bankfull discharge is around 55,000 m^3/s, if the high bank level is considered.

Bank surveying of FAP21/22 and FAP1 was also utilised to asses the bankfull discharge, see Figure 14d. This figure indicates that the average bankfull discharge is within the range of 45,000 m^3/s and 50,000 m^3/s, a mid value of 48,000 m^3/s would be reasonable, if the mean bank level is considered. It is to be noted here that the mean bank level estimated from the BWDB cross-section surveys complies well with the mean elevation of the FAP21/22 and FAP1 data.

Now, the question arises, what will then be the most relevant bankfull discharge of the Jamuna River. It can be firmly concluded that it is not as high as in 60,000 m^3/s or more. One typical BWDB cross-section is shown in Figure 15, with marking of the high bank level and the mean bank line, as estimated for this analysis as a helping tool for approaching a conclusion. If the high bank is assumed to determine the bankfull discharge, almost all the floodplain and high 'chars' will be inundated during the bankfull discharge. On the other hand, if the mean bank is considered, only the low lying part of the floodplain is inundated during the bankfull discharge, and secondary channels can well be identified. Moreover, the mean bank level, which is just below the bank, is in line with the definition of Keith Richards (1980), mentioned in Chapter 2.

8.2 Ganges River

Unlike the Jamuna River, one mean bank level was estimated for each bank for each of the BWDB cross-sections of the Ganges River. In order to determine the bankfull discharge, the bank level profile was compared with discharge profiles of 40,000 m^3/s, 45,000 m^3/s and 50,000 m^3/s, for the years 1990 and 1991, see Figure 16. Two features are noted in this figure. From chainage -20 km to 40 km, the bank levels are relatively high, and the bank level downstream of chainage 40 km is inundated even at a discharge of 40,000 m^3/s, in both years. The backwater effect of the Ganges/Jamuna confluence at least partly accounts for this inundation. However, Figure 16 indicates that the average bankfull discharge of the Ganges is within the range from 40,000 m^3/s to 45,000 m^3/s. In between, any value could be selected, depending on individual judgement.

8.3 Padma River

For the Padma River, 70,000 m^3/s, 75,000 m^3/s and 80,000 m^3/s discharge profiles for the years 1990 and 1991 were compared with the bank level profile, see Figure 17. It was observed that the bank level at the mid portion of the river is relatively elevated. This feature, which may be due to the local geology or the plan-form of the river, was not investigated in the present study. However, the average bankfull discharge can be estimated at around 75,000 m^3/s, and in the range from 70,000 m^3/s to 80,000 m^3/s (Figure 17).

9 Results and discussion

9.1 Previous studies

Recent studies have produced different estimates of the bankfull discharge for the Jamuna River. For example, JBS determined the value for the bankfull discharge at 44,000 m^3/s, while FAP1, referring to BWDB, mentions a value of more than 60,000 m^3/s. Hossain (1989) has examined the bank level near Bahadurabad and discharge rating curves and has determined a value of 38,000 m^3/s. The present study confirms that the bankfull discharge of the Jamuna River cannot be as high as 60,000 m^3/s. The value determined by JBS is rather close to the value found by the present study.

For the Ganges and Padma Rivers, no other recent studies exist of the bankfull discharge. The Meghna River Bank Protection Study (1990) tentatively estimated the bankfull discharge at 72,500 m^3/s for the lower part of the Padma River, which is close to the results found for the Padma in the present study.

9.2 Bankfull discharge predictors

In literature, a number of predictors have been reported for estimating the bankfull discharge. Among those, a few have been compared with the results of the present analysis, the intention being to investigate whether any common expression exists that can describe the bankfull discharge of the main rivers.

Leopold et. al. (1964) observed a remarkable similarity in the recurrence frequency of bankfull discharges of various types of rivers, as the frequency varied in the interval from 1 to 2 years. They also noticed that for stations on well-defined floodplain and with an accurately known elevation, the recurrence interval is closer to 1 than to 2 years. The recurrence interval of bankfull discharge of the Jamuna and the Padma is nearly 1 year; and for the Ganges River, the recurrence interval is closer to 1 than 2 years, see Table 6. Hence, the findings of the present study are within the range suggested by Leopold et. al. (1964); but the range from a 1 year to a 2 years recurrence flood is large for each of the rivers, see Table 7.

Rivers	Return period
Jamuna	1 year
Ganges	1.40 year
Padma	1.05 year

Table 6: Return period of bankfull discharge

Chang (1979), using data published by Schumm (1968) and Charlton (1965), developed a relation between the annual mean discharge and the bankfull discharge, see Figure 18. In this figure, the bankfull discharge of the Jamuna, Ganges and Padma Rivers are plotted with respect to their mean annual discharge. The values are higher than predicted by Chang (1979), see also Table 7. The graphical relation presented by Chang is simple to use, but gives a value that is too low for the three rivers. The reason for this is that most of the data used to derive the relation were from small rivers. A slight change of the slope of the regression line presented by Chang can incur a significant difference with respect to bankfull discharge for the higher range of annual mean discharge, i.e. in the extrapolation range.

Williams (1978) derived a regression equation for the bankfull discharge, using 233 sets of data from active floodplains and valley flat sites, which reads as:

$$Q_b = 4\ A^{1.21}\ i^{0.28} \qquad (1)$$

where Q_b is the bankfull discharge (m^3/s), A is the cross-sectional area (m^2), and i is the water surface slope. Values computed by this equation are compared with values of the present study in Table 7. It is interesting to see that the bankfull discharges of the Ganges and the Padma are nearly the same as computed from this regression equation. However, for the Jamuna River, Equation 1 gives a much higher value than the results of the present study.

Author(s)	Predictor	Predicted bankfull discharge	Obtained bankfull discharge
Chang, 1979	Graphical relation: Q_m and Q_b	Jamuna: 33,000 m^3/s Ganges: 20,000 m^3/s Padma : 48,000 m^3/s	Jamuna: 45,000-50,000 m^3/s Ganges: 40,000-45,000 m^3/s Padma: 75,000 m^3/s
Williams, 1978a	$Q_b = 4\ A^{1.21} i^{0.28}$	Jamuna: 68,000 m^3/s Ganges: 42,000 m^3/s Padma : 74,000 m^3/s	
Inglis, 1968	50% of Q_{max}	Jamuna: 48,000 m^3/s Ganges: 38,000 m^3/s Padma : 66,000 m^3/s	
Wolman and Leopold, 1957	1 to 2 year return period	Jamuna: 48,000-67,000 m^3/s Ganges: 31,000-53,000 m^3/s Padma: 68,000-92,000 m^3/s	

Table 7: Comparison of different bankfull discharge predictors

Inglis suggested that the bankfull discharge would simply be 50% of the maximum discharge. If the discharge of 1988 is considered as the maximum discharge, then values predicted by Inglis come close to the findings of the present study, see Table 7.

The recurrence period of the bankfull discharge varies from 1 to 2 years, see Table 6. From the above comparison and discussion, it is clear that some of the predictors provide results that are close to the determined value.

10 Conclusions

- The floodplain level near the bank of the river is quite variable, the variation being typically 1 to 2 m within a short distance. Under natural conditions, this may be explained by the presence of crevasse splay, or by formation and decaying of flood spill channels. Also, because of the agricultural use of the floodplain, many manmade elevation variations are found (drainage, footpaths, levees, housing on small hills).

- A matured natural levee can only exist outside the active corridor of the river, or where the floodplain remains free from erosion or deposition for a long period of time. Along the main rivers in Bangladesh, bank erosion occurs frequently, so that a natural levee can develop only at a few locations. For estimating the size and the shape of a natural levee, two cases were analyzed, with a width between 1 to 1.5 km, and a height of 1.5 m to 2.5 m.

- For a study of the changes of the floodplain with time, a long and reliable series of data with a good coverage of the floodplain is required. In the present analysis, no major changes nor any trends have been observed of the level of the floodplain over the last three decades. The erosion of the floodplain near an outflanking or meandering river channel is often compensated by sedimentation within a few years.

- The bankfull discharge of the Jamuna River is about 48,000 m^3/s (between 45,000 m^3/s and 50,000 m^3/s), for the Ganges River it is about 43,000 m^3/s (between 40,000 m^3/s and 45,000 m^3/s), and for the Padma River it is about 75,000 m^3/s.

- The bankfull discharge as predicted according to Inglis, and also according to Wolman and Leopold, is accurate within about ± 5000 m^3/s for the main rivers of Bangladesh. The predictors of Williams and Chang are not suited for those rivers.

11 References

1 Bristow, C. S., 1987, 'Brahmaputra River: channel migration and deposition'.The society of Paleontologists and Mineralogists, pp.63-74

2 Chang, H. H., 1979, 'Fluvial Processes in River Engineering', John Wiley & Sons. USA

3 Coleman, J.M., 1969, 'Brahmaputra River: channel processes and sedimentation'. Sedimentary Geol., pp. 129-239

4 DELFT/DHI, 1993, River Survey Project, FAP24, 'Hydrological Study, Phase 1', Dhaka, Bangladesh

5 DELFT/DHI, 1994, River Survey Project, FAP24, 'Study Report 3, Morphological Studies Phase 1: Available Data and Characteristics', Dhaka, Bangladesh

6 Hossain, M. M., 'Dominant Discharge of the Ganges and Jamuna', Journal of the IEB, Vol. 20, No. 3, July, 1992

7 Inglis, C. 1968, Discussion on 'Systematic Evaluation of River Regime', Journal of Waterways and Harbour Division, ASCE, Vol. 94. No. WW1

8 ISPAN, 1993: Bangladesh Flood Action Plan, The Dynamic Physical and Socioeconomic Environment of Riverine Charlands: Padma. Environmental Study (FAP16), Geographic Information Study (FAP19). Prepared for the Flood Plan Coordination Organization of the Ministry of Irrigation, Water development and Flood Control. Irrigation Support Project for Asia and the Near East, October 1993

9 Klaassen, G. J. and Masselink, G., 1992, 'Planform changes of a braided river with fine sand as bed and bank material', 5th International Symposium on River Sedimentation, Karlsruhe, F. R. of Germany

10 Klaassen, G. J. and Vermeer, K., 1988, 'Channel Characteristics of the Braiding Jamuna River, Bangladesh', International Conf. on River Regime, Wallingford, England

11 Leopold, L. B., Wolman, M. G. and Miller, J. P., 1964, 'Fluvial Processes in Geomorphology', San Francisco, California, 522 pp

12 Rendel Palmer & Tritton, 1990, Jamuna Bridge Project, Phase II Study, River Training Works, Design Report-Vol. II

13 Richards, Keith 1982, 'Rivers, Form and Process in alluvial Channels' Methuen & Co., New York

14 Sir William Halcrow & Partners Ltd., 1993, 'River Training Studies of the Brahmaputra River (FAP1), Draft final Report, Technical Annexes, Annex 2, Morphology

15 Volker, A., 1981, Lecture notes on reclamation and polders. International Institute for Hydraulic and Environmental Engineering

16 William, G. P., 1978, 'Bankfull Discharge of Rivers', Water Resource, Res. 14(6), pp. 1141-1154

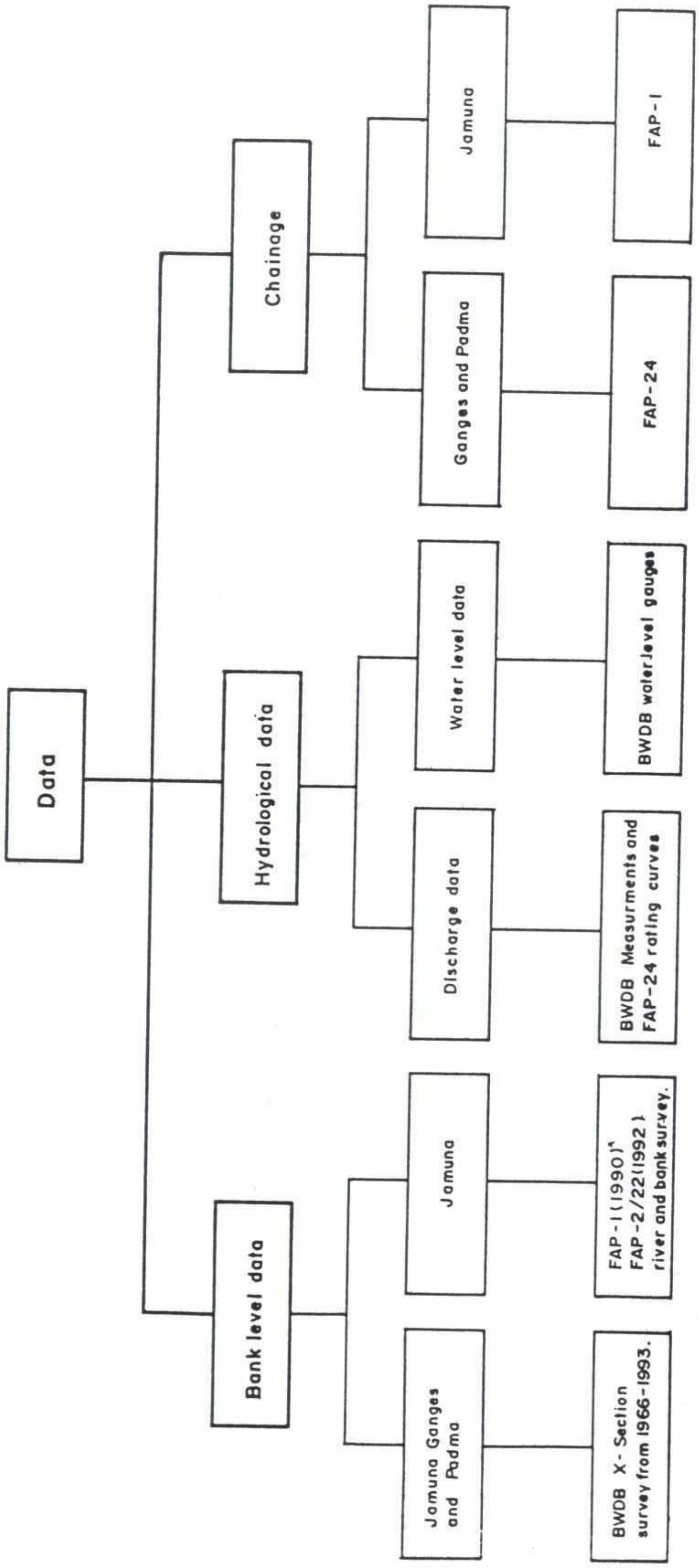


Figure 1: Type and source of data used

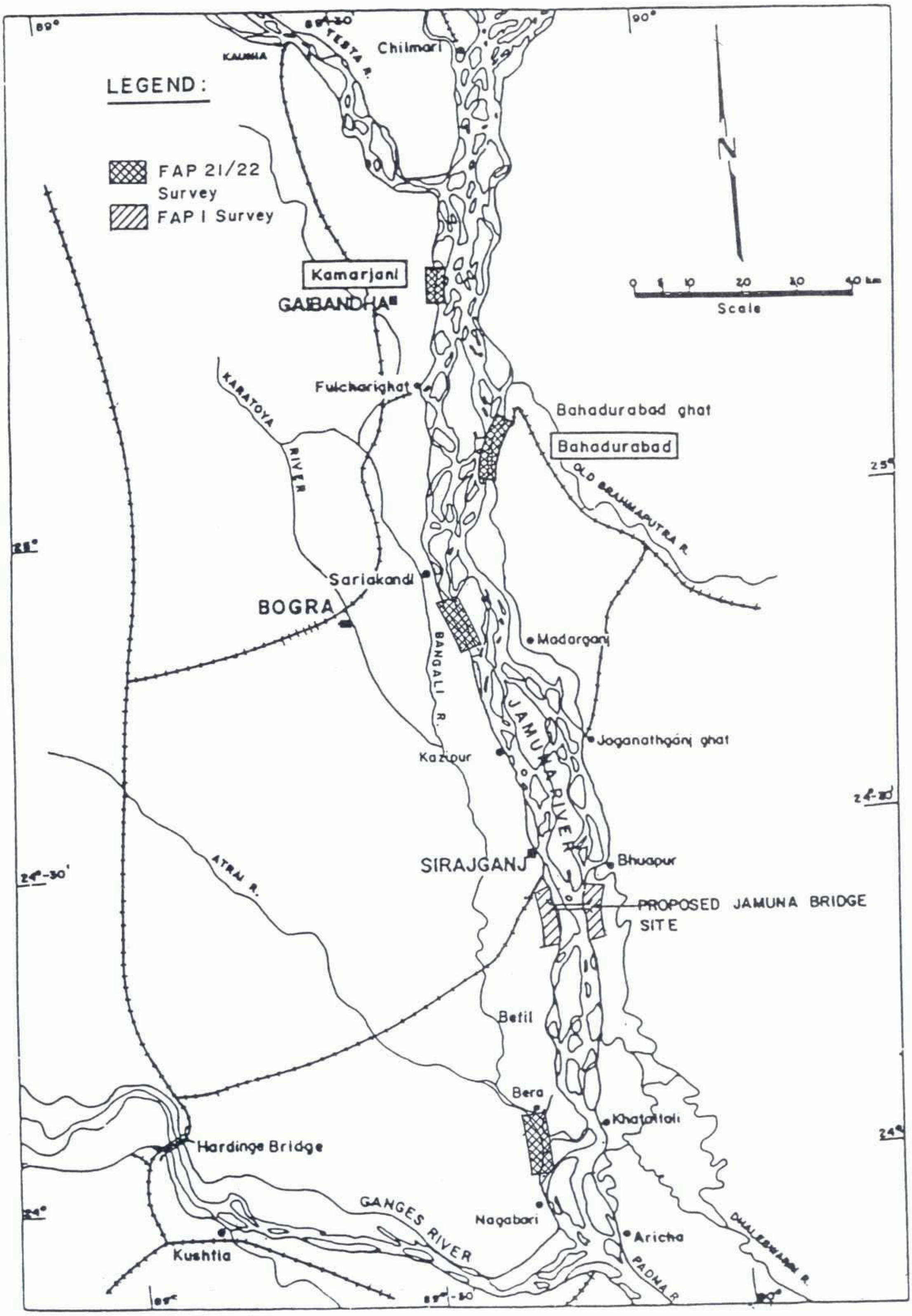


Figure 2: Locations of FAP21/22 and FAP1 flood plain and river surveys in the Jamuna River

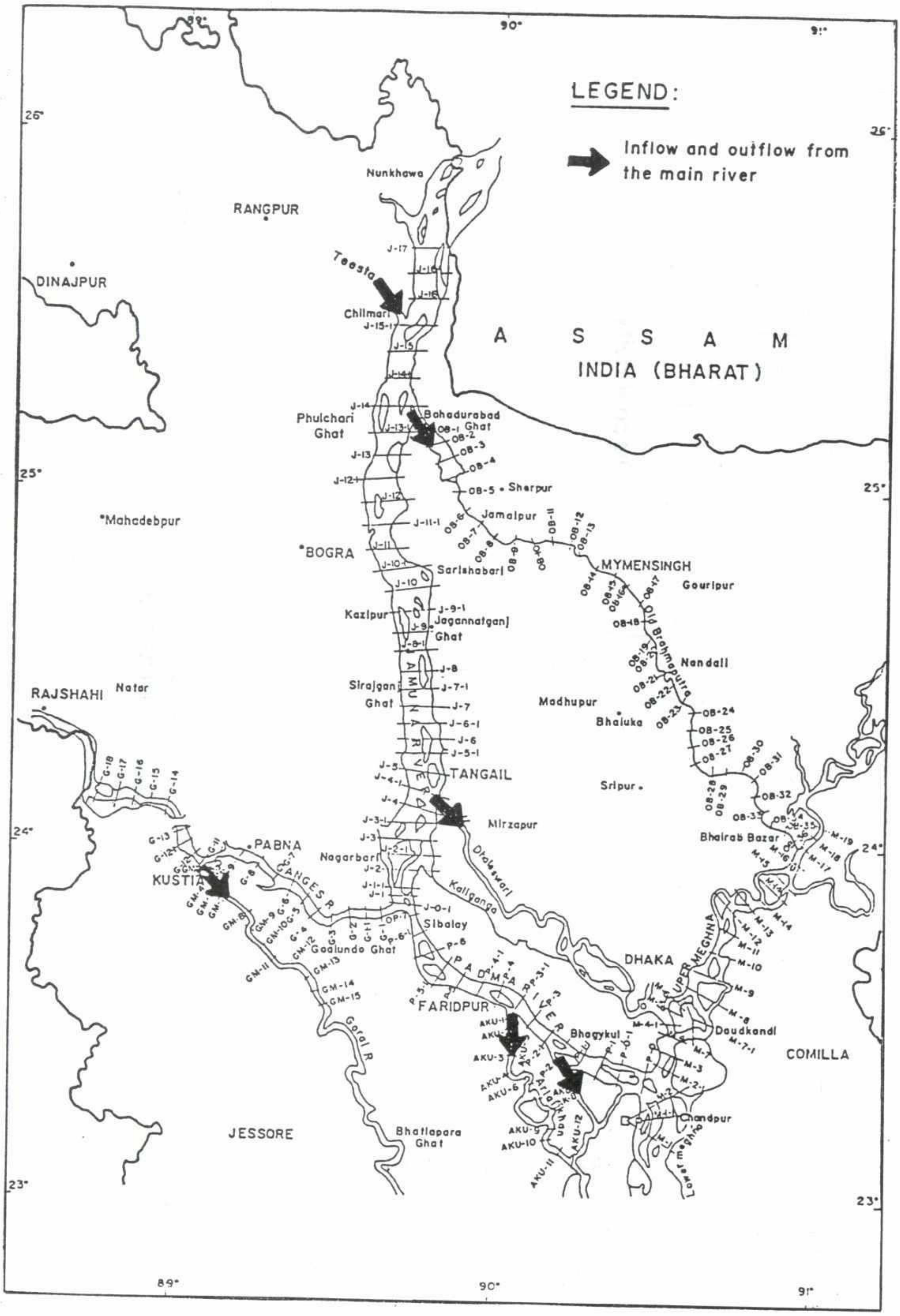


Figure 3: Standard BWDB cross-sections in the main river system

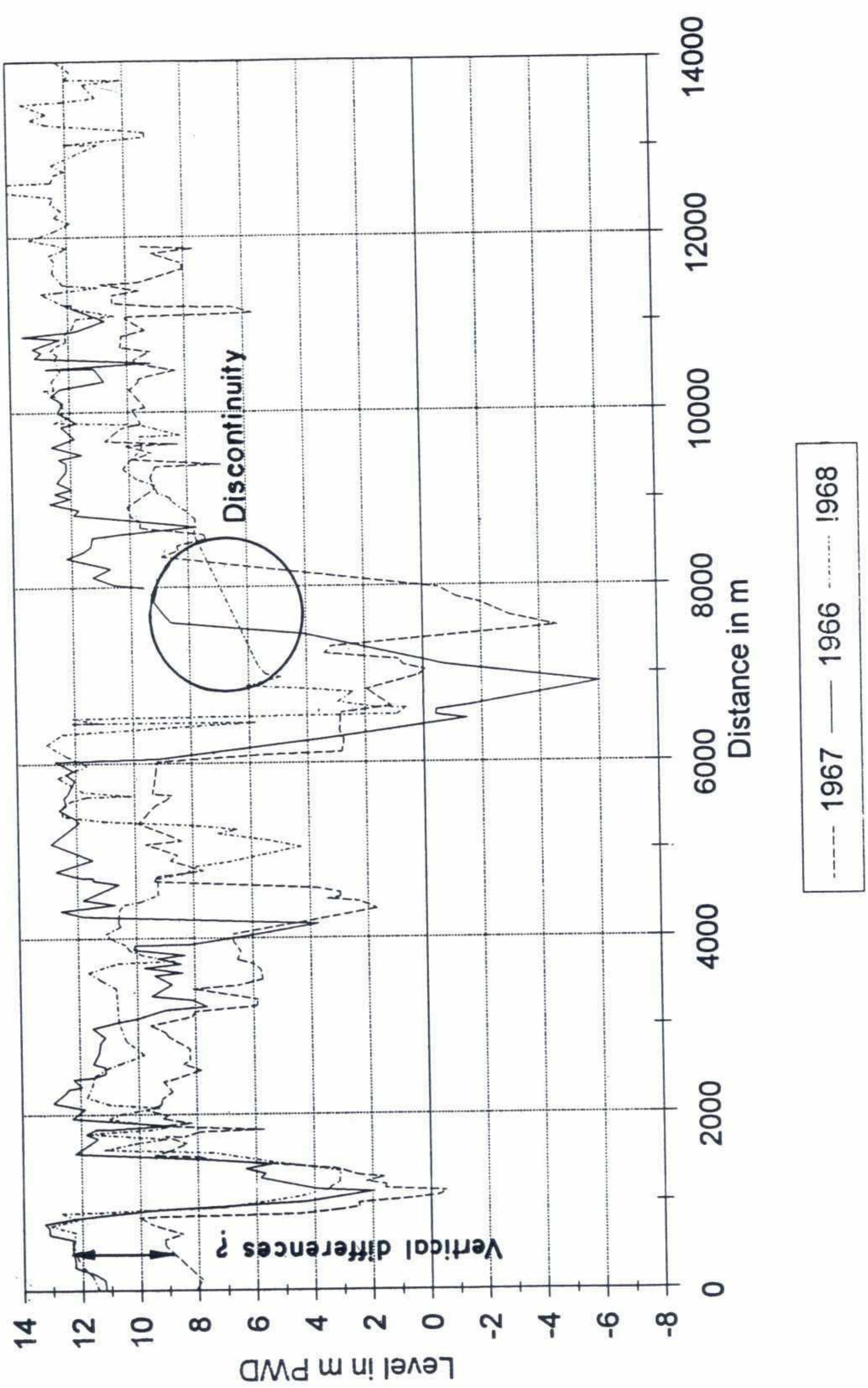


Figure 4: Checking vertical control of BWDB cross-section J#6-1

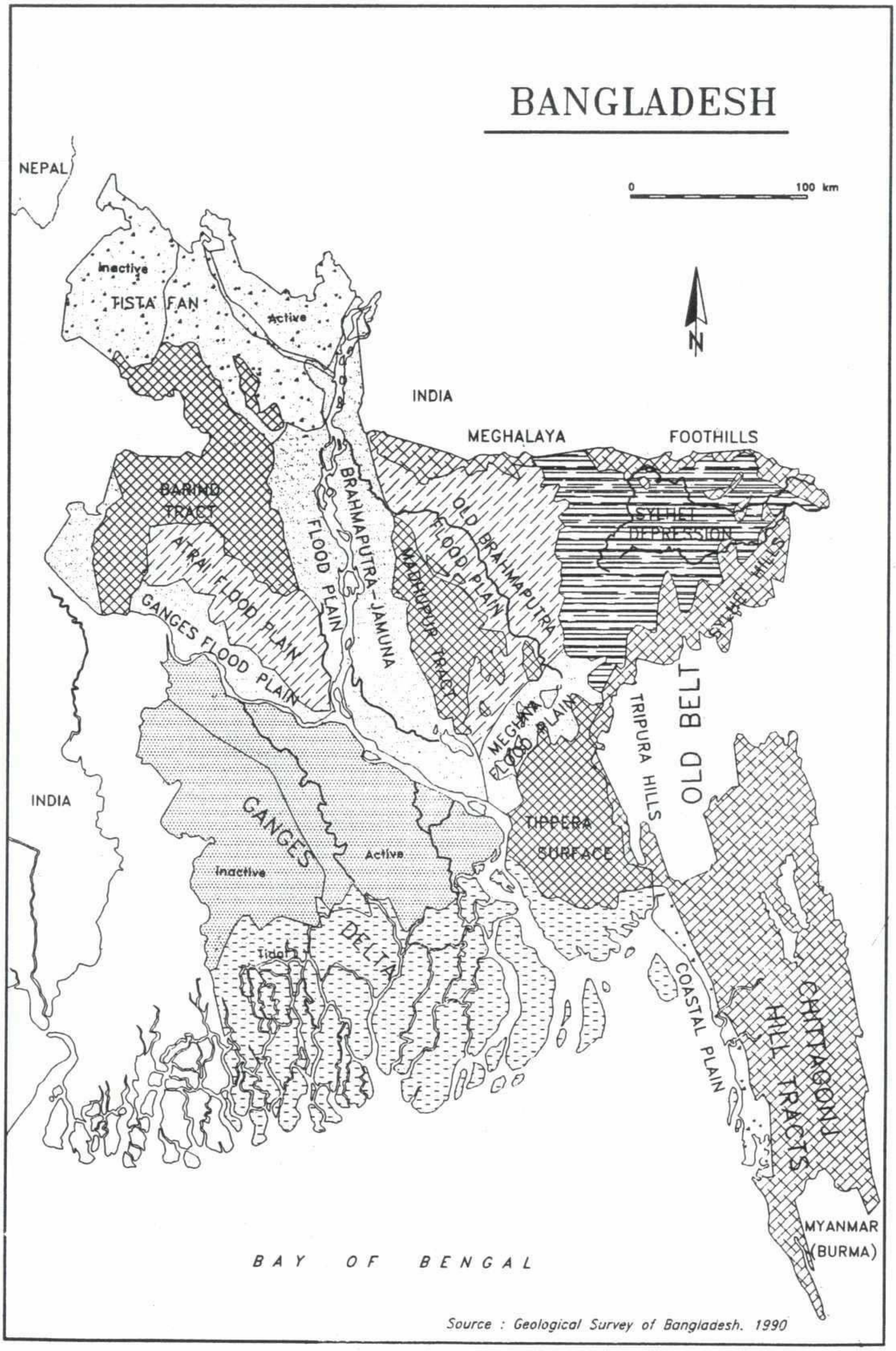
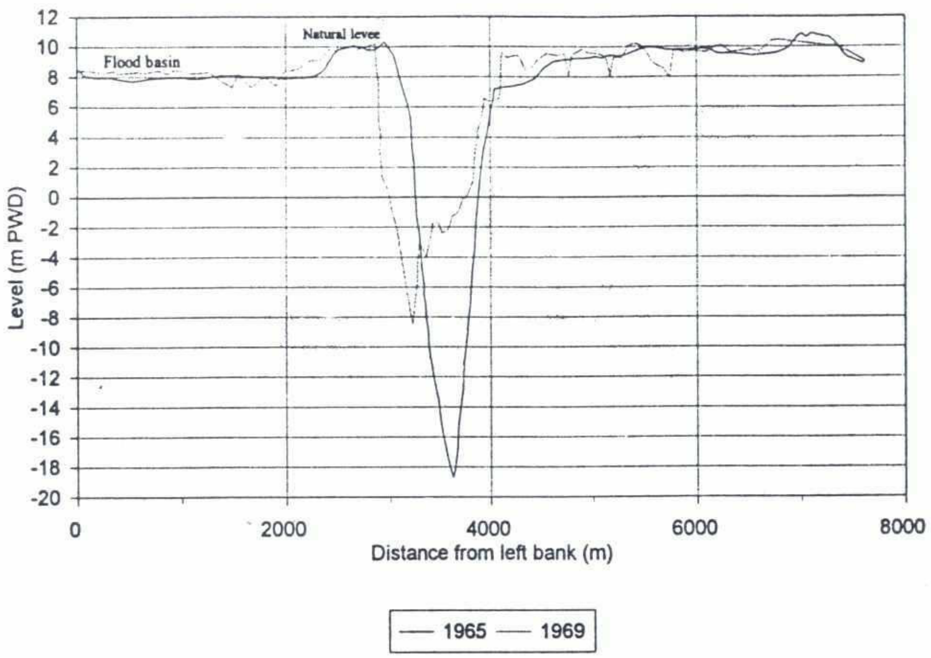
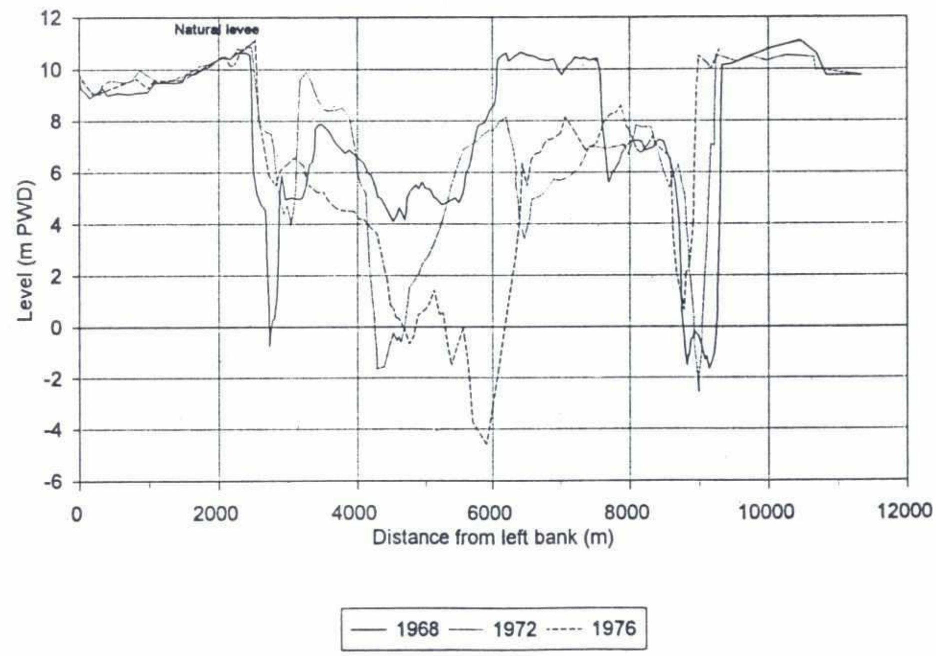


Figure 5: Generalised physiographic map of Bangladesh (Geological survey of Bangladesh 1990)



a. BWDB standard cross-section: G#2



b. BWDB standard cross-section: G#3

Figure 6: Flood plain features and their changes with time, Ganges River

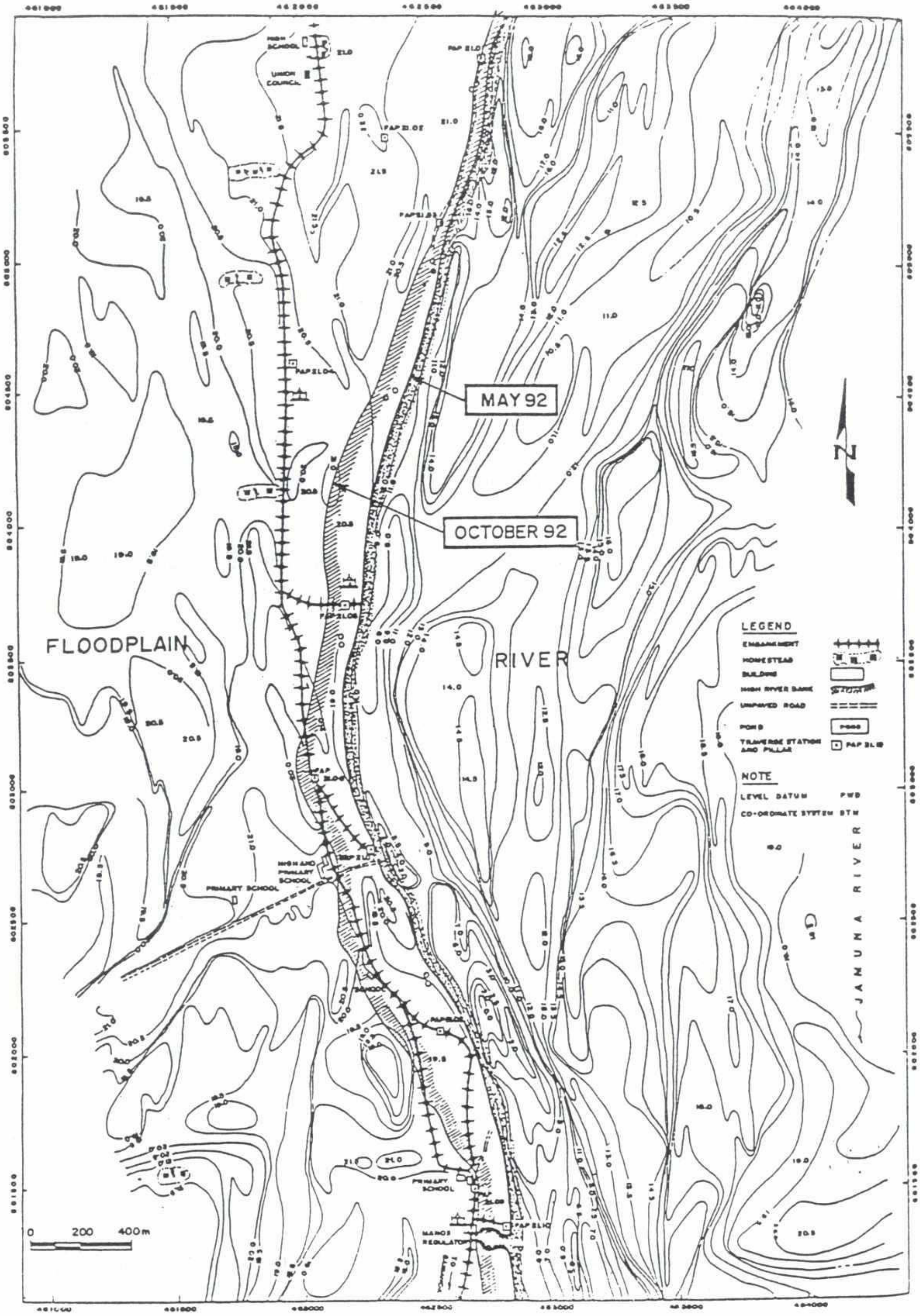
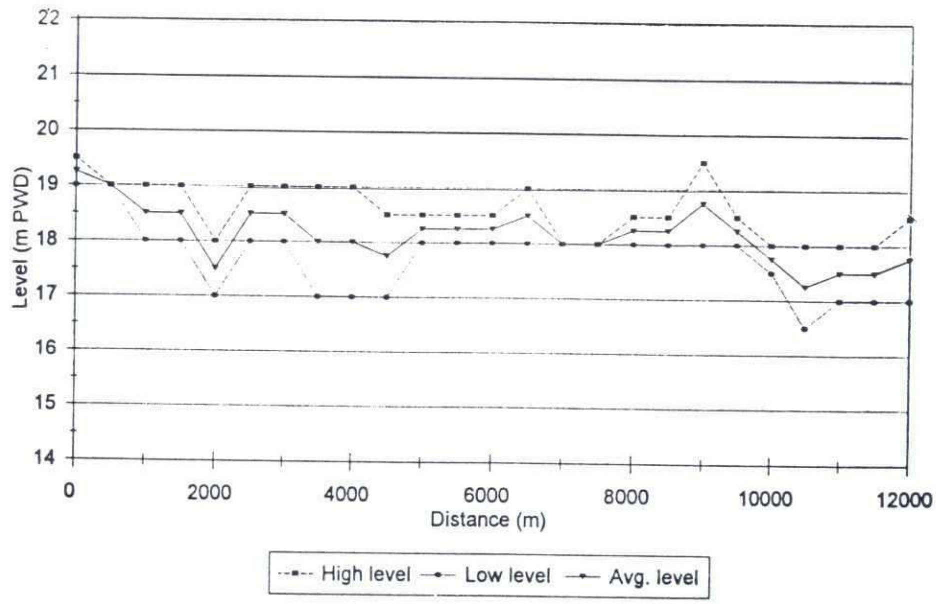
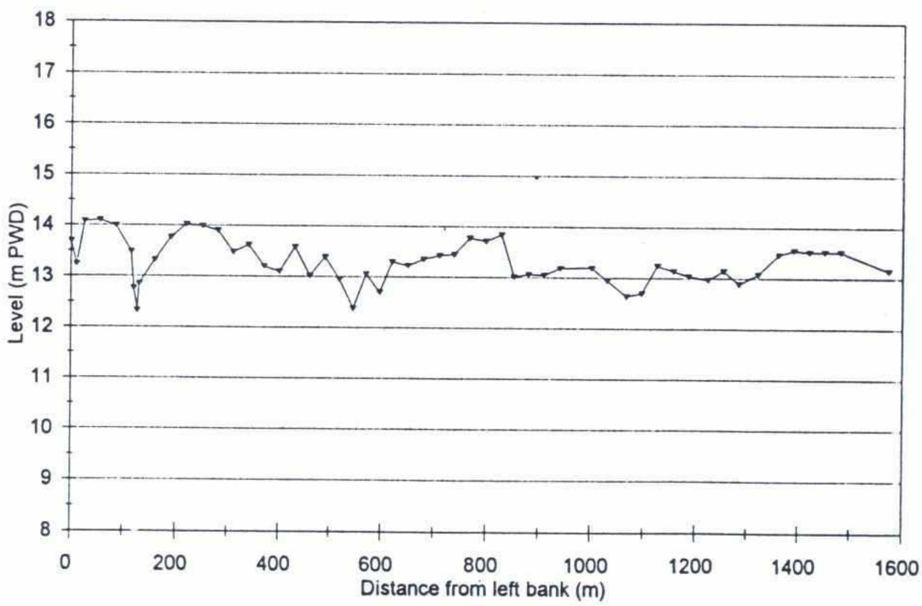


Figure 7: A typical topographic contour map of floodplain and river at Kamarjani, surveyed and presented by FAP21/22

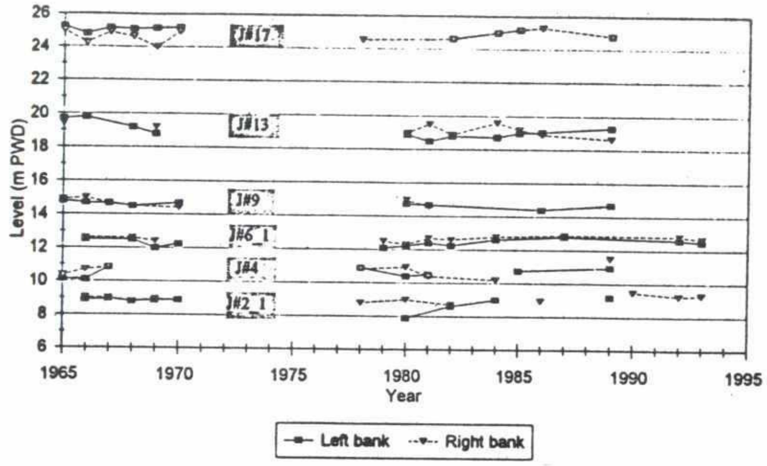


a. Floodplain level along the river bank at Bahadurabad, width of the strip is 500 m.

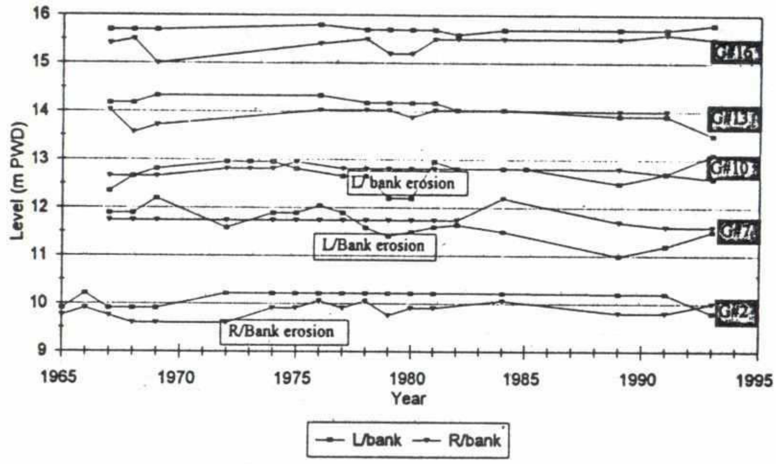


b. Perpendicular section of floodplain at the left bank near Jamuna Bridge.

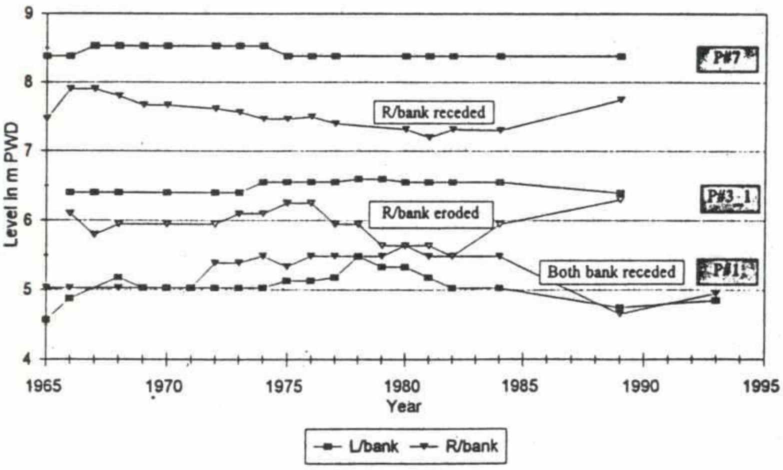
Figure 8: Floodplain level variability along with and in the transverse direction of the river, based on FAP21/22 and FAP1 surveys



a. Jamuna river

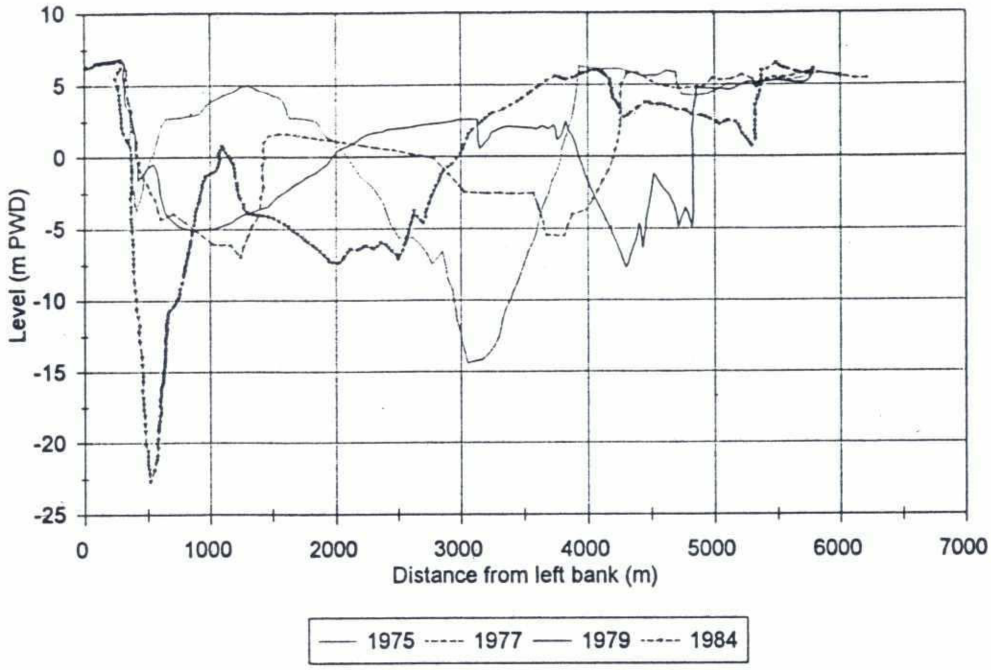


b. Ganges river

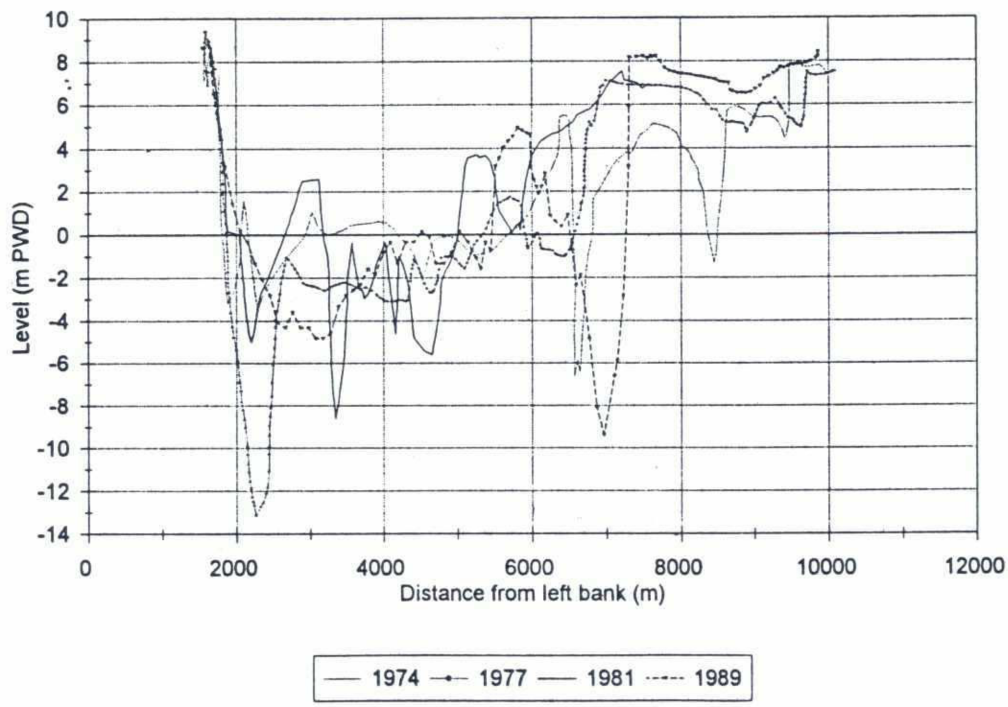


c. Padma river

Figure 9: Changes of floodplain level with time



a. **BWDB standard cross-section: P#3_1, Padma river.**



b. BWDB standard cross-section: P#7, Padma river.

Figure 10: Bank level change due to bank erosion and bank recedence

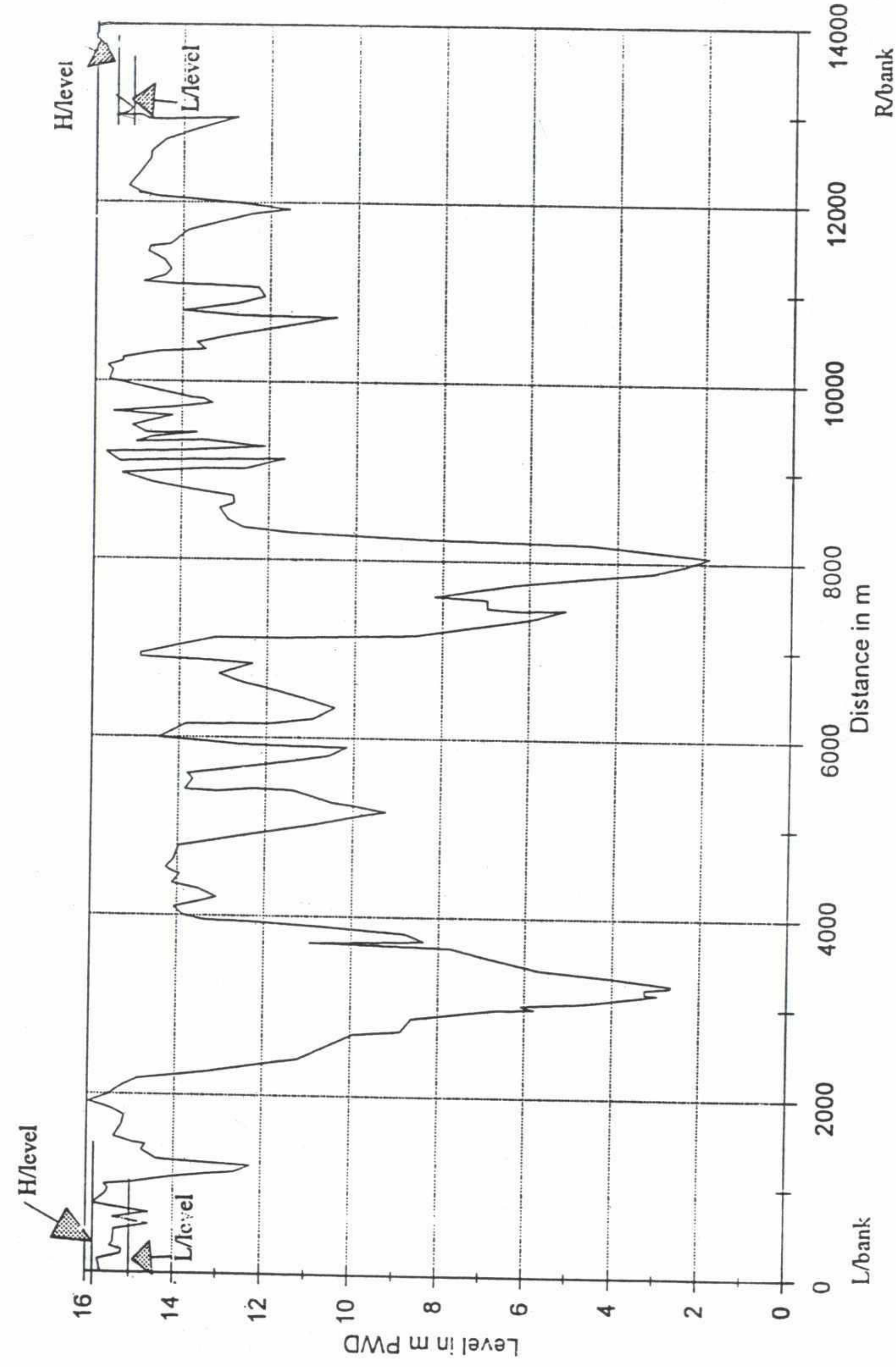
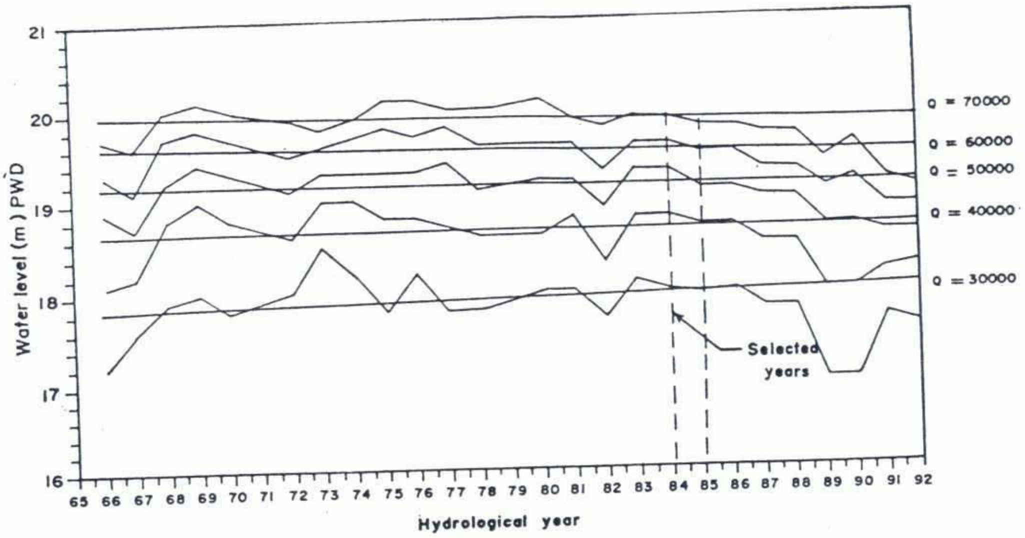
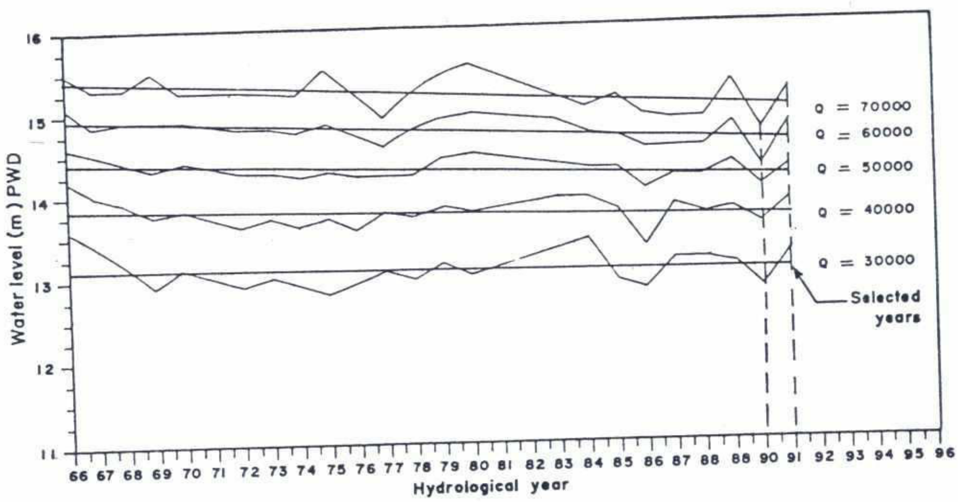


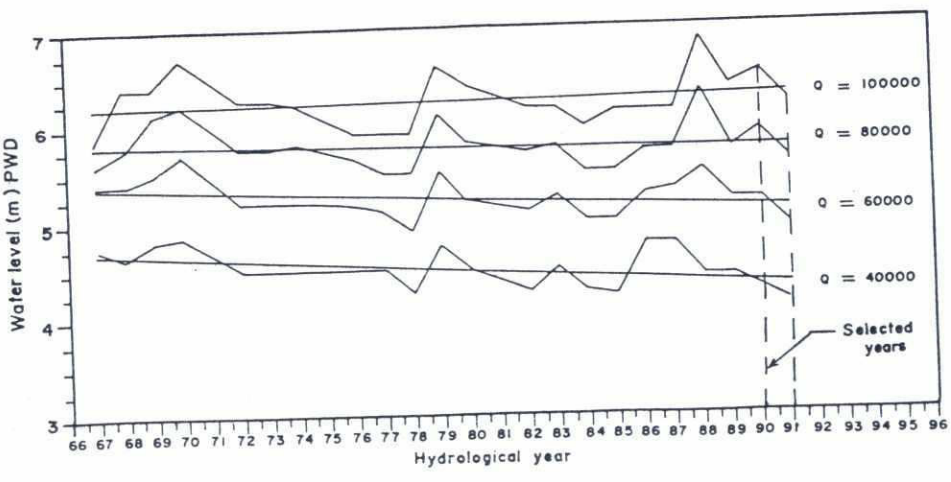
Figure 11: A typical cross-section survey in the Jamuna River and the definition of high and low bank level



a. Bahadurabad



b. Hardinge Bridge



c. Mawa

Figure 12: Specific gauge analysis by RSP

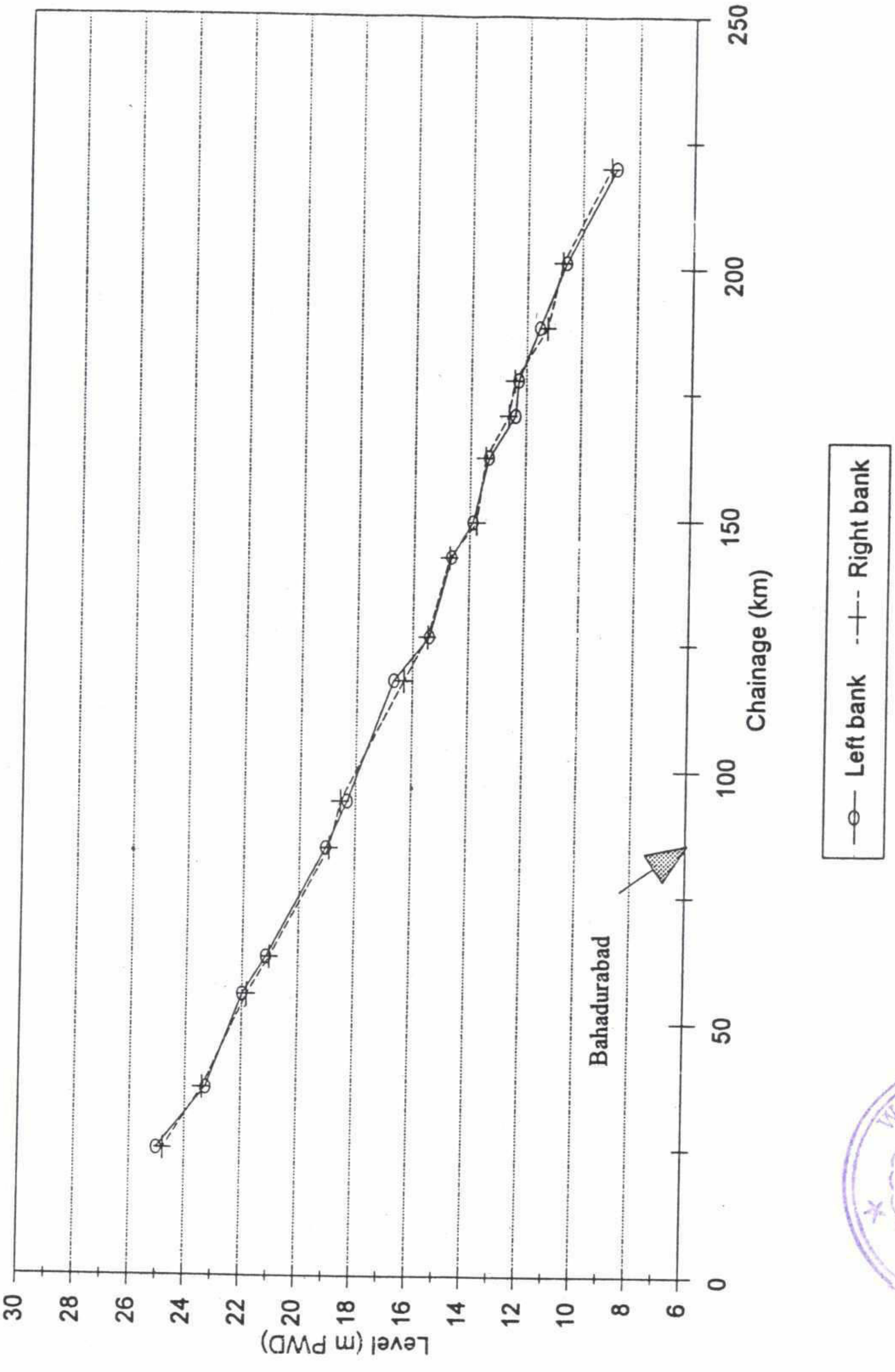


Figure 13: Mean bank level profiles of the Jamuna River

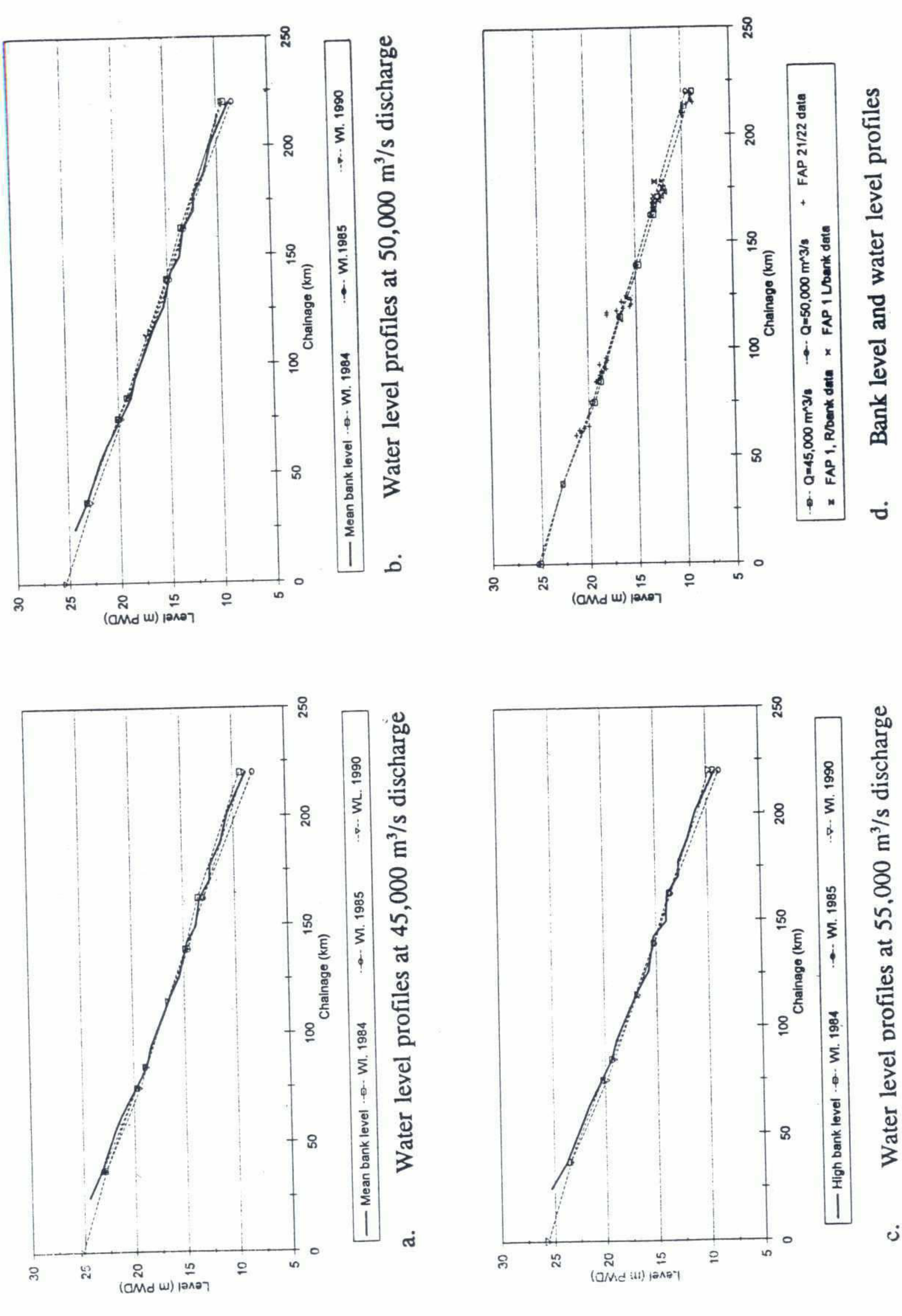


Figure 14: Comparison of bank level and water level profiles at different discharges, Jamuna River

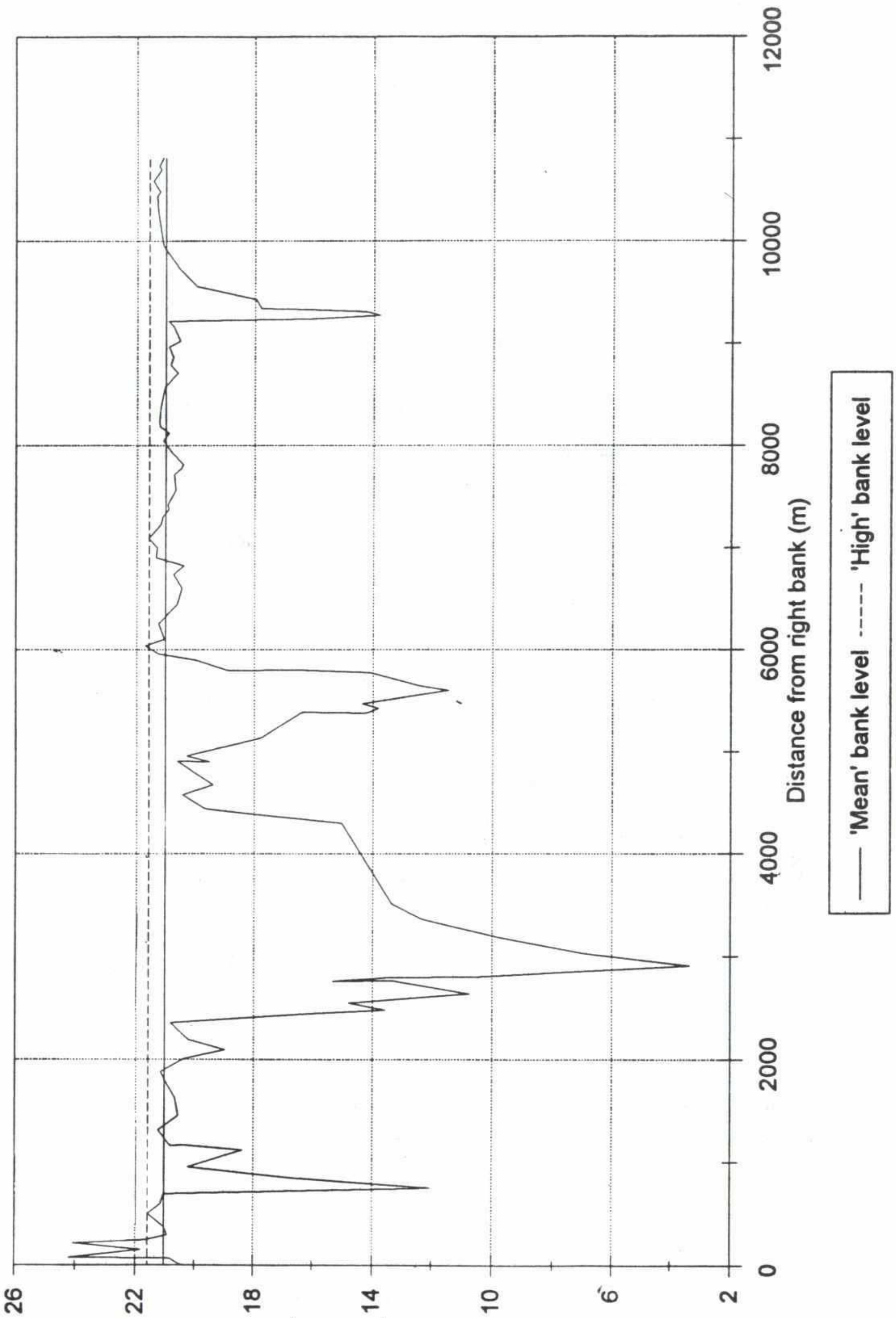
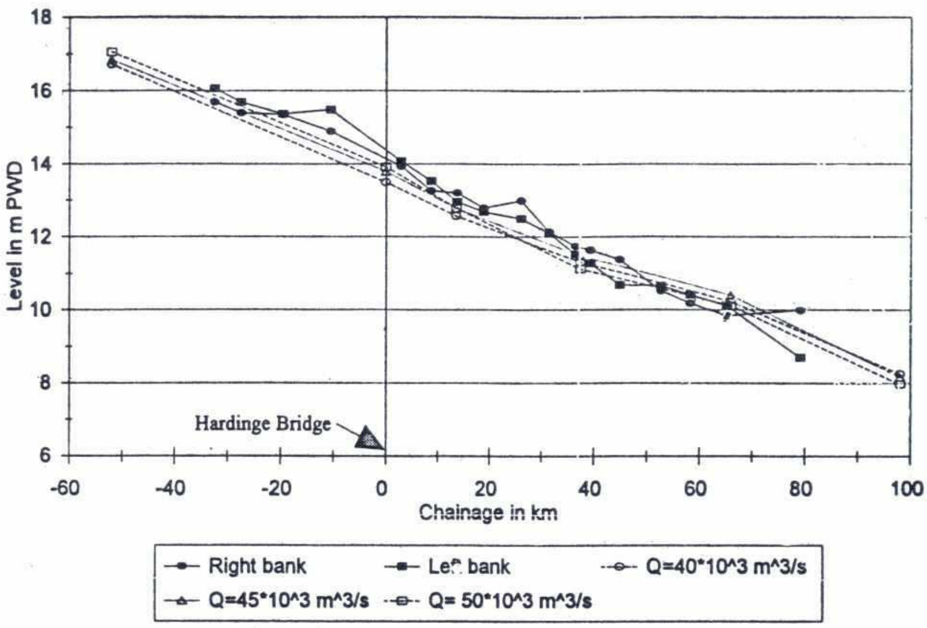
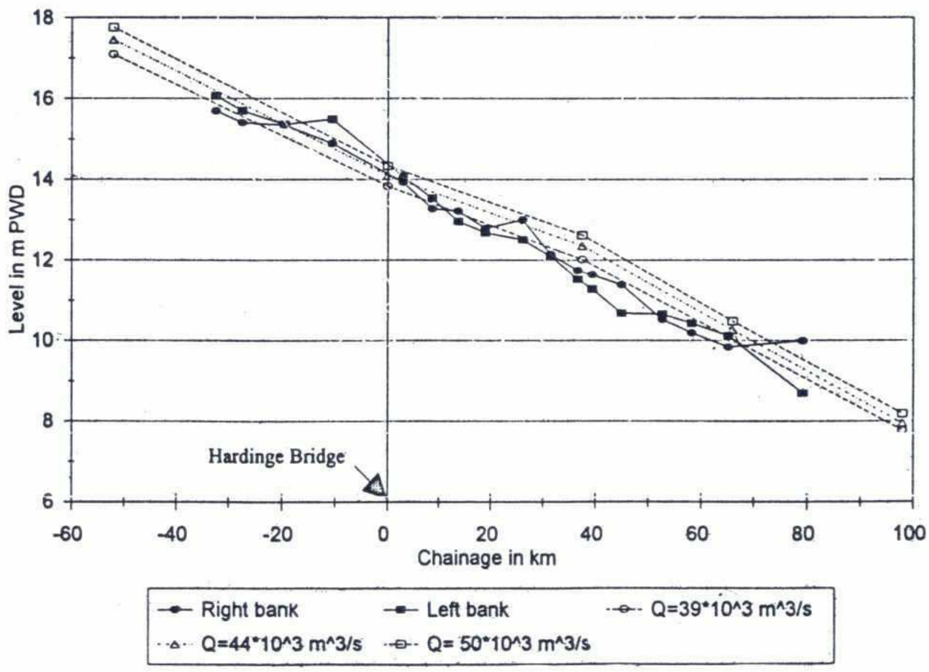


Figure 15: High and mean bank line on a cross-section, Jamuna River

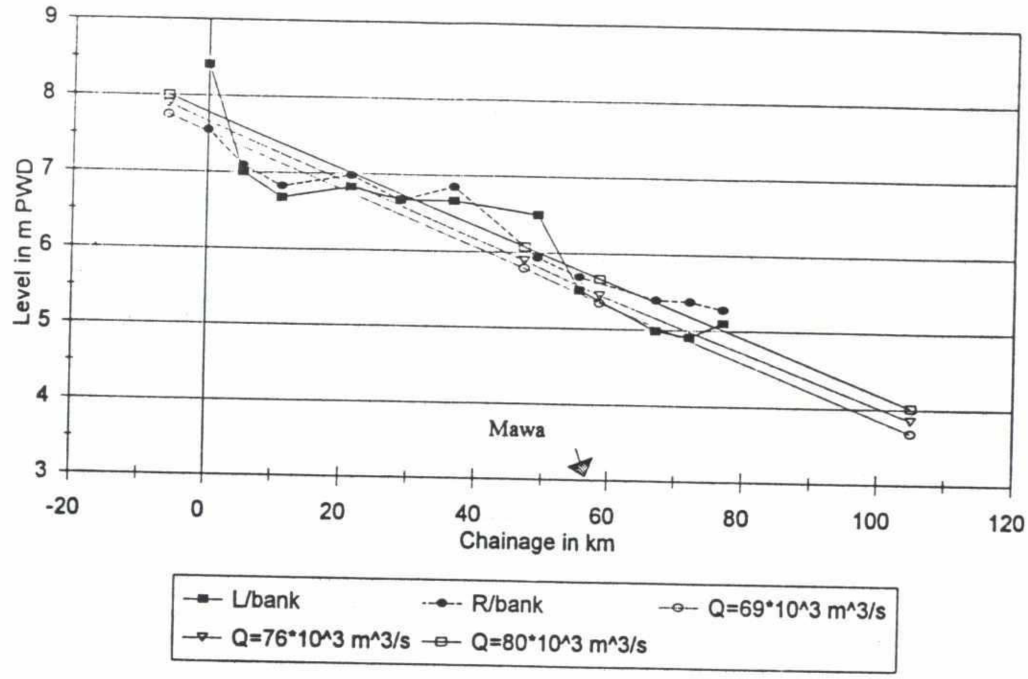


a. Water level profiles, 1990

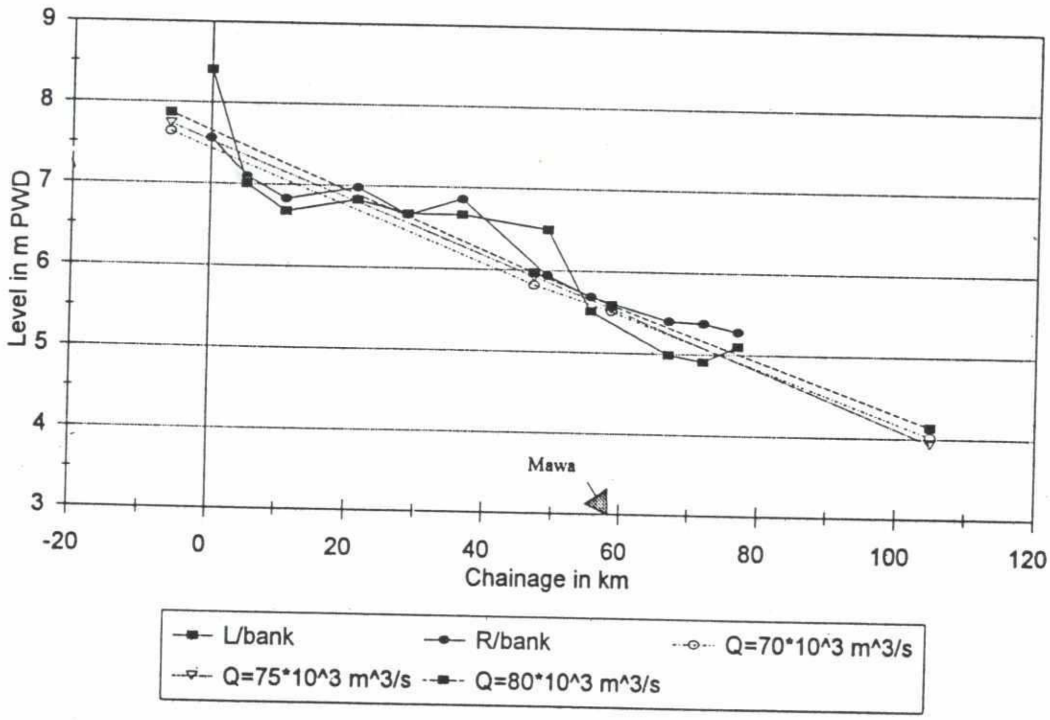


b. Water level profiles, 1991

Figure 16: Bank level and water level profiles at different discharges, Ganges River



a. Water level profiles, 1990



b. Water level profiles, 1991

Figure 17: Bank level and water level profiles at different discharges, Padma River

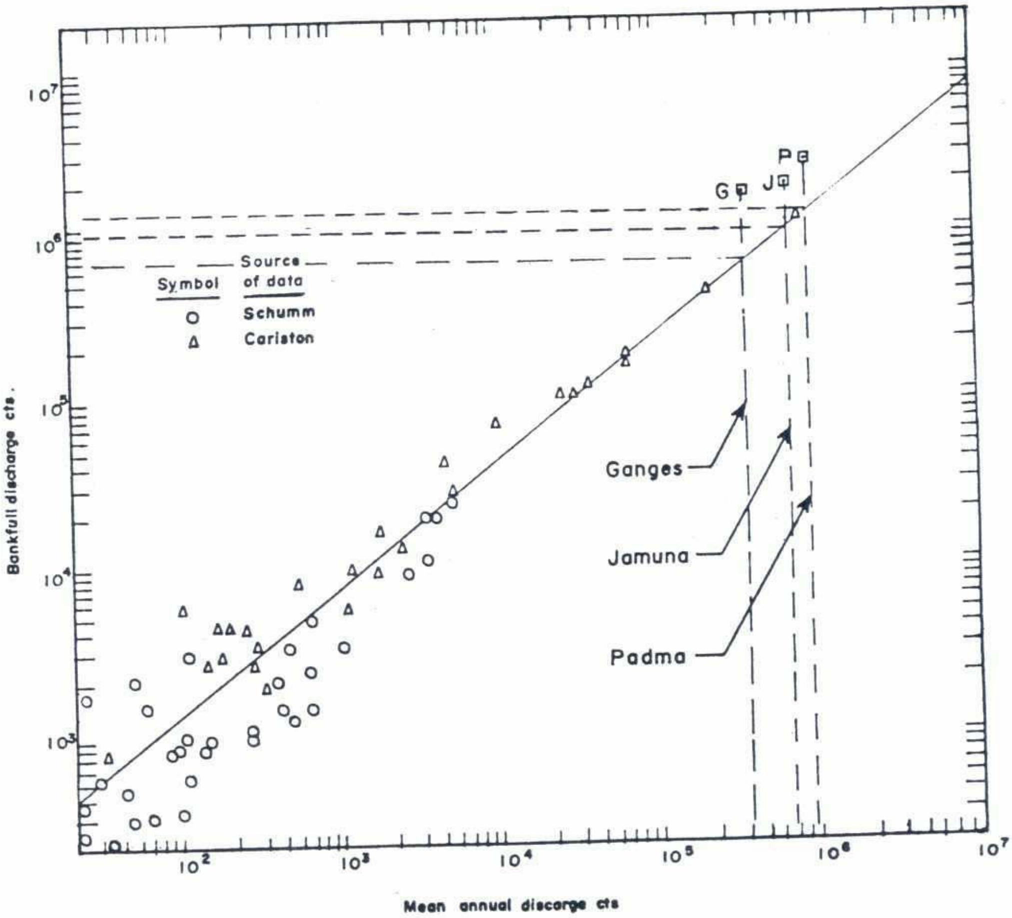


Figure 18: Relation between mean annual discharge and bankfull discharge, after Chang (1979)