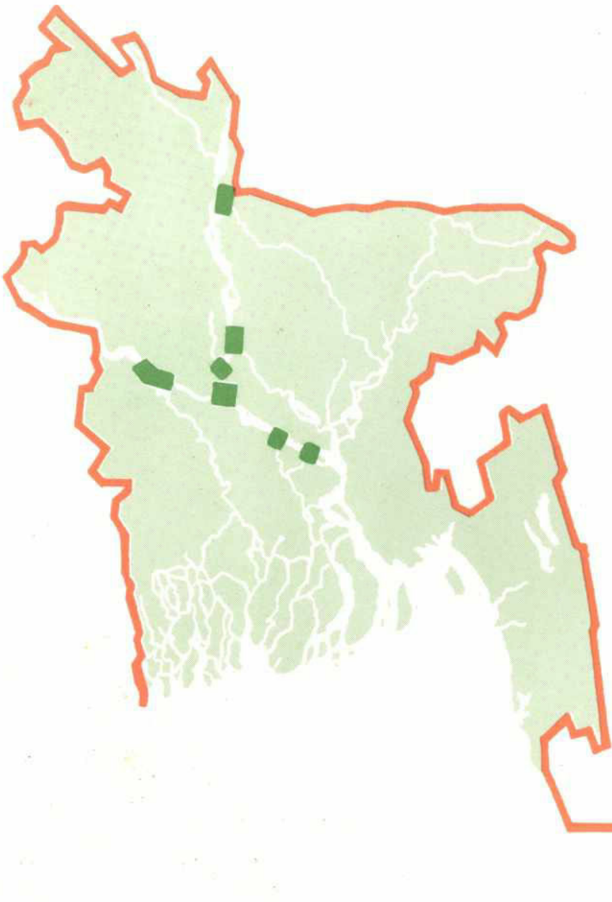
GOVERNMENT OF BANGLADESH
FLOOD PLAN COORDINATION ORGANIZATION

FAP 24 RIVER SURVEY PROJECT

Survey Report 8
Flood season 1993
Volume I : Main Report



DELFT HYDRAULICS
DANISH HYDRAULIC INSTITUTE
OSIRIS
HYDROLAND
APPROTECH

Project ALA/90/04 — Commission of the European Communities

Survey Report 8
Flood season 1993
Volume I : Main Report

July 12 1994

File: RPT-CI\SURV-REP.NO8

FAP 24 **RIVER SURVEY PROJECT**

Flood Plan Coordination Organization

DELFT-DHI **Commission of the European Communities**

House No. 96,
Road No. 23,
Banani, Dhaka
Tel : 600002, 603175
Fax: 88-02-883568

July 16, 1994

Chief Engineer
Flood Plan Coordination Organization (FPCO)
7 Green Road, Dhaka.

Attention	:	Mr. Afzalur Rahman. Superintending Engineer.
Subject	:	Report on surveys of the flood season 1993
Our ref	:	RSP/9.1/1014

Dear Sir,

We are taking pleasure in submitting herewith our Survey Report 8, Phase 2, Flood season 1993.

The report serves as a documentation and presentation of all the routine gaugings of the flood season measurements, executed by the River Survey Project during the period June-October, 1993. The report can be used for studies of the hydrology and morphology of the main river system of Bangladesh.

We have duly noted the recommendations made by the Project Management Unit and our Project Advisor on the format of our survey reports. These recommendations are currently being implemented, and our future survey reports will be prepared in a different format.

Thanking you.

Yours sincerely

for Pieter van Groen
Team Leader

Contents of Survey Report 8

Main Report
(Volume 1)

Contents of Main Report

Acronyms and abbreviations

ADCP	:	Acoustic Doppler Current Profiler
AWLR	:	Automatic Water-Level Recorder
BWDB	:	Bangladesh Water Development Board
BTM	:	Bangladesh Transverse Mercator
Contract	:	Consultancy contract of 22 May 1992 and amendments
DGPS	:	Differential Global Positioning System
DHA	:	Survey vessel A (mother ship)
DHC	:	Survey vessel C (catamaran type)
DISHPROF	:	Hydrographic software programme
DISHTRANS	:	Hydrographic software programme
EMF	:	ElectroMagnetic Flow meter
GPS	:	Global Positioning System
MEX 3	:	An optical turbidity meter
Ott	:	A mechanical current meter
PWD	:	Public Works Department (geodetic datum)
S4	:	An electromagnetic current meter
VHF	:	Very High Frequency

List of symbols

D	Depth	m
D_{nn}	Marginal diameter of finest nn % of a sediment sample	mm
$\sigma(p)$	Standard deviation of p	
$\mu(p)$	Average value of p	

1. Introduction

Survey Report 8, Flood Season 1993 has been prepared in response to the Consultancy Contract of May 22, 1992, River Survey Project FAP 24, ALA/90/04.

The Survey Report serves as final documentation and presentation of all flood season measurements obtained by the River Survey Project during the period June to October 1993, apart from bathymetric surveys, test gaugings, and part of the special measurements, which are being reported separately. Most of the data of this report have previously been presented in the following reports:

- River Survey Project, FAP 24
  4° Quarterly Progress Report
  June-August, 1993

- River Survey Project, FAP 24
  5° Quarterly Progress Report
  September-November, 1993

The present survey report comprises mainly the routine gaugings. Apart from a pure presentation of the measurement results, only simple analyses and comparisons are presented.

In order to present a complete separate document a summary of the survey equipment and applicable procedures is presented in Chapter 4.

Survey Report 8 may serve as a basis for further elaborate studies of the hydrology and morphology in the main river systems of Bangladesh. For this reason file names and sample numbers for the respective data are presented everywhere.

2. Summary and conclusion

2.1 General information

The River Survey Project performs routine gaugings, bathymetric surveys and special measurements in the main river systems of Bangladesh.

The routine gaugings comprise:

- water-level measurement
- transect discharge and current measurement
- point current measurement
- suspended sediment measurement
- bed load sediment transport measurement
- river bed material sampling.

Within the present reporting period part of the special measurements comprised a single comparative discharge measurement with BWDB at Bahadurabad.

In the future, special measurements are planned to support the study programme issued by the River Survey Project, i.e. Study Report 1, September 1993. The various special measurements may also lead to alterations of the routine gauging programme.

The sites surveyed by the routine gauging programme in the flood season from June to October 1993 are listed in Table 2.1 below.

Station	River	Location	Measurements periods in 1993	Data summary in Survey Bulletin No.
1	Jamuna	Bahadurabad	a) 03-09 June b) 09-17 July c) 23-24 August d) 06-11 September	06 07 10 11
2	Jamuna	Sirajganj	a) 21-30 July b) 17 September c) 24-27 October	08 12 23
3	Jamuna	Aricha	a) 19 September	13
4	Ganges	Hardinge Bridge	a) 26-28 September	15
5	Padma	Baruria	a) 03-08 August b) 19 September c) 01 October d) 19-22 October	09 14 17 22
6	Padma	Mawa	a) 03-07 October	18
7	Old Brahmaputra	Mymensingh	No measurements	-
8	Dhaleswari	Tilly	a) 16 October	21
9	Gorai	Kushtia	a) 29-30 September	16
10	Arial Khan	Off-take	a) 08 October	19
11	Meghna	Bhairab Bazar	a) 11-12 October	20

Table 2.1 : Routine gauging and special measurement programme as per the flood season, 1993

Part of the special measurements comprised comparative discharge measurements with BWDB at Bahadurabad on 23 to 24 August 1993.

2.2 Summary of measurements

2.2.1 Routine gauging programme

Water-level measurements
At the start of the monsoon 1993, two water-level stations were established in the Bahadurabad cross-section, the first one near Bahadurabad ferry ghat, and the second one near Gabgachi on the central island. In Gabgachi, two recorders were installed with different types of sensors for reasons of comparison. As the results of the two recorders appeared to be identical, only one recording is presented in the following figure.

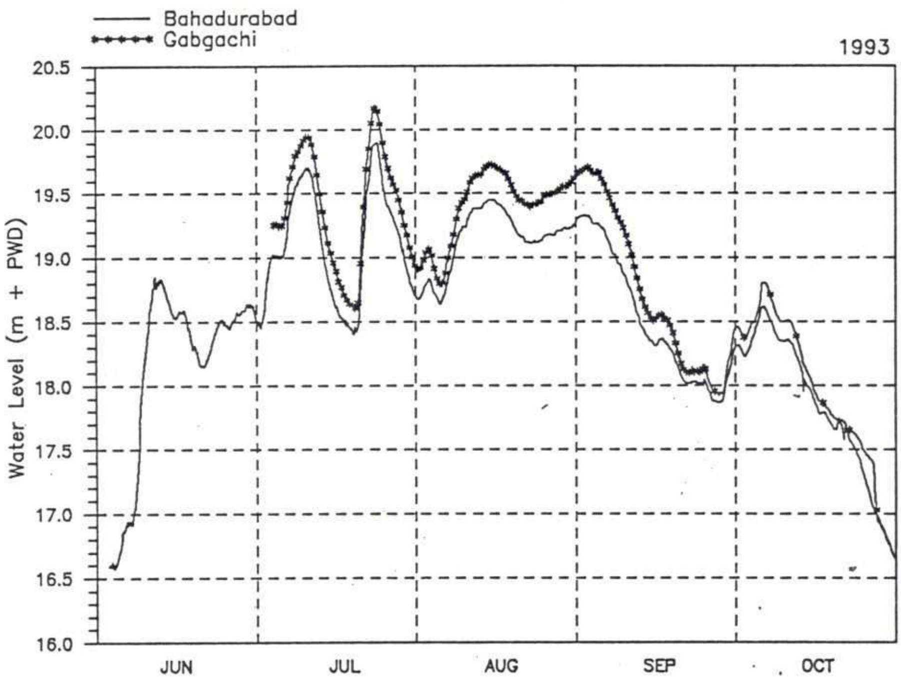


Figure 2.1: Water-levels near Bahadurabad. For details of location and data see Annexure 2

Transect discharge and current measurements
All the water-level and discharge gaugings carried out in the respective gauging stations in the flood season of 1993 are listed in Table 2.2 below.

A more detailed description of cross-sections, water-levels and individual transects as well as estimates of the measurement uncertainty is found in Chapters 3 and 6.

Location	Date of transect survey	Water-level m +PWD	Average discharge m^3/s
1. Bahadurabad	6/6/93	16.95	18,100
	13/7/93	19.67	43,400
	11/9/93	18.47	37,200
	2/11/93	16.23	13,900
2. Sirajganj	23/7/93	13.73	52,260
	26/7/93	13.50	44,420
	17/9/93	12.84	32,560
	26/10/93	11.34	19,995
3. Aricha	19/9/93	8.68	32,230
4. Hardinge Bridge	26/9/93	13.66	40,311
	28/9/93	13.72	42,019

Continued

Location	Date of transect survey	Water-level m +PWD	Average discharge m³/s
5. Baruria	4/8/93	7.35	52,654
	5/8/93	7.30	50,458
	6/8/93	7.29	52,816
	7/8/93	7.35	54,425
	8/8/93	7.44	56,875
	19/9/93	7.73	68,288
	1/10/93	7.72	71,240
	19/10/93	6.53	37,565
	20/10/93	6.42	35,100
	22/10/93	6.29	36,564
6. Mawa	3/10/93	5.53	62,538
	4/10/93	5.46	61,785
	6/10/93	5.40	60,778
	6/10/93	5.41	61,935
	7/10/93	5.27	59,298
8. Tilly	16/10/93	7.50	487
9. Gorai off-take	29-30/9/93	11.98	3,445
10. Arial Khan off-take	8/10/93	5.63	2,177
11. Bhairab Bazar	12/10/93	5.36	7,490

Table 2.2 Water-levels and discharge for all routine transect surveys performed during the flood season of 1993

Point current measurements
The number of verticals applied to each cross-section and the total main channel discharge based on all S4 point current measurements and the average bathymetric cross-section is listed in Table 2.3 for each routine gauging.

A more detailed description of average cross-sections and individual verticals as well as estimates of the measurement uncertainty is found in Chapters 3 and 6.

Location	Date of S4 current measurement	Water-level m +PWD (mean-values)	Average discharge m^3/s
1. Bahadurabad	3-9/6/93	17.30	21,000
	9-17/7/93	19.75	45,300
	6-11/9/93	18.78	43,500
	31/10 - 3/11/93	16.28	15,200
2. Sirajganj	21-30/7/93	13.50	50,159
	24-27/10/93	11.47	19,424
4. Hardinge Bridge	26-29/9/93	13.69	44,684
5. Baruria	3-8/8/93	7.35	59,305
	19-22/10/93	6.41	34,161
6. Mawa	3-7/10/93	5.41	64,471
8. Tilly	16/10/93	7.50	446
9. Gorai off-take	29-30/9/93	11.98	2,865
10. Arial Khan off-take	8/10/93	5.63	1,990

Table 2.3 : Water-levels and discharges based on manual S4 current measurements performed during the flood season of 1993

Suspended sediment measurement

The number of verticals applied to each cross-section, and the total suspended sediment transport based on all point current and sediment measurements is listed in Table 2.4 for each routine gauging.

A description of cross-sections, estimates of measurement uncertainty and plots of suspended sediment profiles are found in Chapters 3 and 6 and Annexure 3.

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} in each routine gauging cross-section is listed in Table 2.5.

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4.

Location	Date of suspended sediment measurement	Water-level m +PWD	Average suspended sediment transport kg/s
1. Bahadurabad	3-9/6/93	17.30	11,400
	9-17/7/93	19.75	49,900
	6-11/9/93	18.78	31,700
	31/10 - 3/11/93	16.28	5,300
2. Sirajganj	21-30/7/93	13.50	54,385
	24-27/10/93	11.47	11,748
4. Hardinge Bridge	26-29/9/93	13.69	83,323
5. Baruria	3-8/8/93	7.35	56,392
	19-22/10/93	6.41	18,738
6. Mawa	3-7/10/93	5.41	84,510
8. Tilly	16/10/93	7.50	222
9. Gorai off-take	29-30/9/93	11.98	6,008
10. Arial Khan off-take	8/10/93	5.63	1,910
11. Bhairab Bazar	12/10/93	5.36	160

Table 2.4 : Suspended sediment transport during the flood season of 1993

Location	Date of suspended sediment measurement	Suspended sediment grain size analysis	
		$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
1. Bahadurabad	3-9/6/93	0.021	0.007
	9-17/7/93	0.066	0.044
	6-11/9/93	0.057	0.040
	31/10 - 3/11/93	0.055	0.047
2. Sirajganj	21-30/7/93	0.061	0.03
	24-27/10/93	0.061	0.04
4. Hardinge Bridge	26-29/9/93	0.027	0.01
5. Baruria	3-8/8/93	0.027	0.01
	19-22/10/93	0.056	0.04
6. Mawa	3-7/10/93	0.058	0.03
8. Tilly	16/10/93	0.023	0.003
9. Gorai off-take	29-30/9/93	0.034	0.02
10. Arial Khan of-take	8/10/93	0.017	0.01
11. Bhairab Bazar	12/10/93	0.013	0.002

Table 2.5 Sectional average and standard deviation of D_{50} based on suspended sediment measurements performed during the flood season of 1993

Bed load measurement
The number of Helley-Smith samples from each cross-section, the sectional average bed load transport range and the estimated total bed load transport is listed in Table 2.6 for each routine gauging.

A description of cross-sections and individual samples is found in Chapter 6 and Annexure 5. The Helley-Smith samples exhibit a large scatter.

Location	Date of Helley-Smith sampling	Number of Helley-Smith samples	Bed load transport range g/ms	Bed load transport kg/s
1. Bahadurabd	3-9/6/93	25	0.4-736	322
	9-17/7/93	38	0.7-408	344
	6-11/9/93	19	0.1-421	395
2. Sirajganj	21-30/7/93	28	0.2-746	556
4. Hardinge Bridge	26-29/9/93	7	9-554	410
5. Baruria	3-8/8/93	20	0.9-454	277
	19-22/10/93	13	0.1-239	154
6. Mawa	3-7/10/93	13	0.1-421	255
9. Gorai off-take	29-30/9/93	2	2-385	7
10. Arial Khan off-take	8/10/93	2	0.6-5	1

Table 2.6 : Range of bed load transport rates and bed load transport based on all Helley-Smith samples obtained by routine gaugings during the flood season 1993

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the D_{50} mean grain diameter in each routine gauging cross-section is listed in Table 2.7.

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5.

Location	Date of Helley-Smith bed load sample	Suspended sediment grain size analysis	
		$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
1. Bahadurabad	3-9/6/93	0.233	0.068
	9-17/7/93	0.225	0.071
	6-11/9/93	0.260	0.072
2. Sirajganj	21-30/7/93	0.203	0.070
4. Hardinge Bridge	26-29/9/93	0.213	0.05
5. Baruria	3-8/8/93	0.159	0.06
	19-22/10/93	0.266	0.36
6. Mawa	3-7/10/93	0.139	0.06
9. Gorai off-take	29-30/9/93	0.203	0.08
10. Arial Khan off-take	8/10/93	0.212	0.019

Table 2.7 Sectional average and standard deviation of D_{50} based on Helley-Smith samples obtained during flood season of 1993

Bed material sampling
Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} in each routine gauging cross-section is listed in Table 2.8.

A description of cross-sections, individual samples, grain size distributions and summary tables of D_{16}, D_{35}, D_{50} and D_{90} is found in Chapters 3 and 6 and Annexure 6. The bed material samples exhibit a large sectional scatter.

Location	Date of material sampling	Suspended sediment grain size analysis	
		$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
1. Bahadurabad	3-9/6/93	0.189	0.077
	9-17/7/93	0.188	0.067
	6-11/9/93	0.172	0.061
	31/10 - 3/11/93	0.209	0.084
2. Sirajganj	21-30/7/93	0.163	0.070
4. Hardinge Bridge	26-29/9/93	0.177	0.004
5. Baruria	3-8/8/93	0.137	0.030
	19-22/10/93	0.140	0.040
6. Mawa	3-7/10/93	0.118	0.040
9. Gorai off-take	29-30/9/93	0.149	0.05
10. Arial Khan off-take	8/10/93	0.153	0.012

Table 2.8 Sectional average and standard deviation of D_{50} based on bed material samples obtained by routine gaugings during the flood season of 1993

2.2.2 Special measurement programme

The River Survey Project FAP 24 has a limited horizon compared to the time scale of the physical phenomena in the Bangladeshi rivers. The Bangladesh Water Development Board (BWDB) has a much longer horizon than the River Survey Project. Several of the analyses presented by the River Survey Project would be impossible without BWDB data. It is therefore of great importance to make comparative measurements in order to assess the compatibility of measurements obtained with different technologies.

During the flood season of 1993 only one comparative measurement between BWDB and the River Survey Project was planned to be carried out on 23 and 24 August 1994 at the Bahadurabad cross-section, following the completion of the test gauging.

Unfortunately the BWDB survey boats suffered from several mechanical break-downs during the two measurement days and therefore only the results obtained by the River Survey Project by using the recommended ADCP/EMF methodology is described in the following.

All together 5 transects covering the left channel and 3 transects covering the right channel were completed on August 23 and 24, 1993 respectively. The results have been reported previously in the 4° Quarterly Progress Report - Survey Bulletin No.10 and are summarized in Table 2.9 and 2.10 below.

Date and time	Water-level m +PWD	Discharge m^3/s
23/8/93 10:00 to 10:54	18.60	15,327
23/8/93 12:37 to 14:10	18.60	15,283
23/8/93 15:55 to 16:20	18.60	15,035

Table 2.9 : Discharge in the right channel at Fulchari, Jamuna River, August 1993

Date and time	Water-level m +PWD	Discharge m^3/s
24/8/93 09:10 to 09:55	19.12	27,535
24/8/93 11:00 to 11:42	19.12	28,509
24/8/93 12:14 to 12:54	19.12	27,626

Table 2.10 : Discharge in the confluent cross-section close to the standard BWDB gauging cross-section at Bahadurabad, Jamuna River, August 24, 1993

An average discharge of 15,215 m^3/s with a standard deviation of 1 per cent was observed in the right channel while the average discharge in the confluent cross-section amounted to 27,890 m^3/s, also with a standard deviation of 1 per cent.

2.3 Conclusions and recommendations

Water-level gauging

Continuous and accurate water-level measurements form the basis for establishing stage-discharge rating curves in the individual cross-sections.

Apart from the Bahadurabad cross-section, where automatic water-level recorders have been installed by the River Survy Project the other water-level data have been obtained from BWDB staff gauge readings.

From the coming flood season of 1994 all water-level data will be measured by automatic water-level recorders installed and operated by the River Survey Project at each of the 11 gauging sites.

Velocity and discharge measurement

Generally very little directional variation has been measured within the verticals by the S4 current meter. Some directional variation within the verticals has been measured by the ADCP current meter. This is probably due to the instantaneous nature of ADCP current measurements, whereby temporal variations are dutifully registered.

Standard deviations of the discharge in the range 1 to 4 of per cent of the average discharge, have been measured by the moving boat method using the ADCP/EMF current meter. These differences also reflect temporal variations in the flow due to eddies and flood waves. A continuous water-level recording with a relative precision in the order of mm may provide further insight into these variations.

The discharge uncertainty by the point integrating S4 measurements is estimated within the range 1 to 12 per cent of the average discharge.

Bed load sediment measurement

The bed load transport rates measured by Helley-Smith trap samples exhibit a large scatter. In most instances more samples are needed to obtain reliable estimates of average transport rates. Nevertheless the estimated bed load transport never exceeds 3 per cent of the total sediment transport.

Generally the D_{50} mean grain diameter of bed load material exceeds the D_{50} as measured in bed material samples. This is probably caused by loss of the finest bed load fraction in the Helley-Smith wire mesh bag.

3. Description of survey areas and selection of measurement cross-sections

3.1 General

The River Survey Project performs routine gaugings, bathymetric surveys, and some special measurements. The routine gaugings take place at eleven different sites (cross-sections) in the Bangladeshi main rivers according to Figure 3.1 and Table 3.1 below. Almost all gauging areas are characterized by rapid planform changes in a braided river environment. A few of the routine gauging sites are tidally affected also.

Detailed bathymetric surveys are made in 7 locations, which are also shown on Figure 3.1.

Special measurements are located where a particular phenomenon is to be studied.

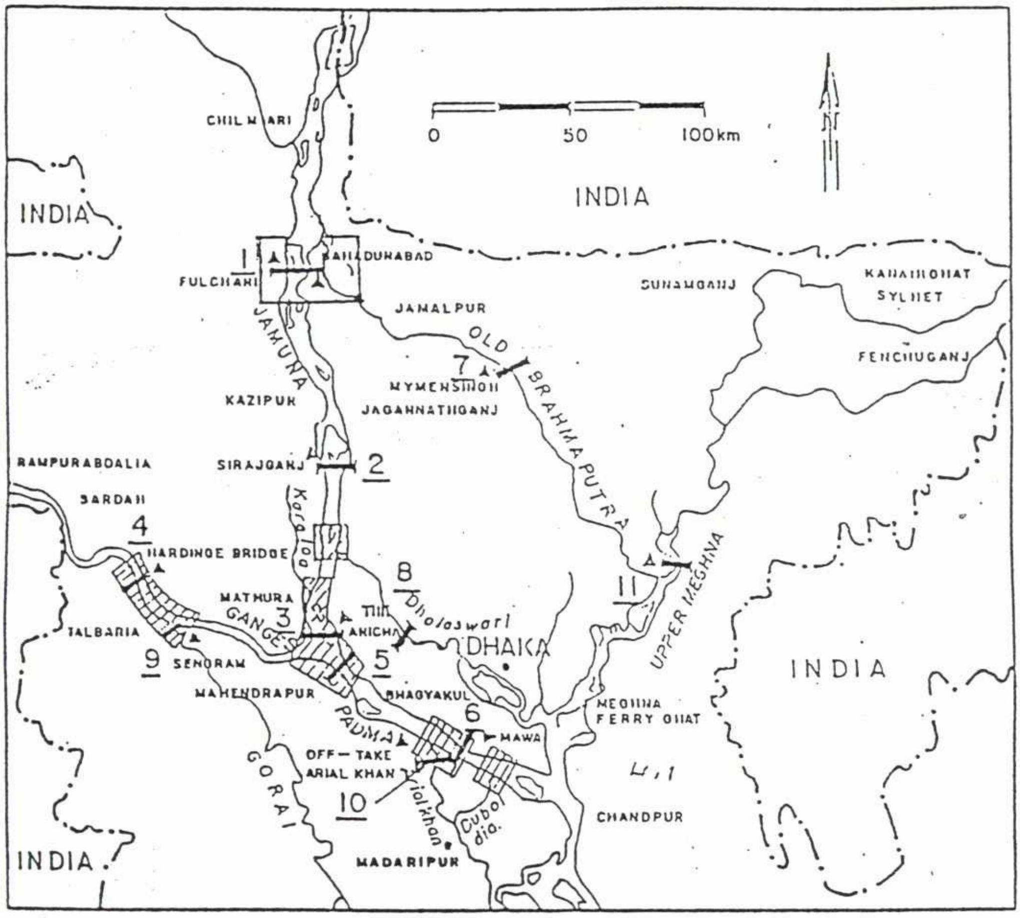


Figure 3.1 River Survey Project routine gauging sites

The present flood season report comprises routine gaugings at ten different sites and one special measurement in the form of a comparative discharge measurement with BWDB at Bahadurabad; ref. Table 2.1

Phase II	River	Location
Station 1	Brahmaputra	Bahadurabad
Station 2		Sirajganj
Station 3		Aricha
Station 4	Ganges	Hardinge Bridge
Station 5	Padma	Baruria
Station 6		Mawa
Station 7	Old Brahmaputra	Mymensingh
Station 8	Dhaleswari	Tilly
Station 9	Gorai	Kushtia (Railway Bridge)
Station 10	Arial Khan	Off-take
Station 11	Meghna	Bhairab Bazar

Table 3.1 Listing of routine gauging stations

The River Survey Project performs gauging in the cross-sections that most adequately support the gauging technology - the socalled recommended method using the ADCP/EMF instrumentation. This implies reconnaissance for cross-sections, where it is possible to navigate and pass with the A vessel. Due to the rapid planform changes of the rivers the location of these cross-sections may frequently change from time to time. Figure 3.2 shows an example on the shifts in the location of selected cross-sections between two measurement campaigns at Sirajganj. The precise positions of the individual survey lines are documented in the form of trackplots in the respective Survey Bulletins.

The reconnaissance also aims at checking the cross-section on nearby bedforms by executing longitudinal soundings. The data from these soundings are stored in order to obtain an inventarisation of bedforms in the main river system. The longitudinal profiles will be published separately at the end of the project.

The BWDB also performs routine gaugings in fixed cross-sections located close to the areas to be covered by the River Survey Project.

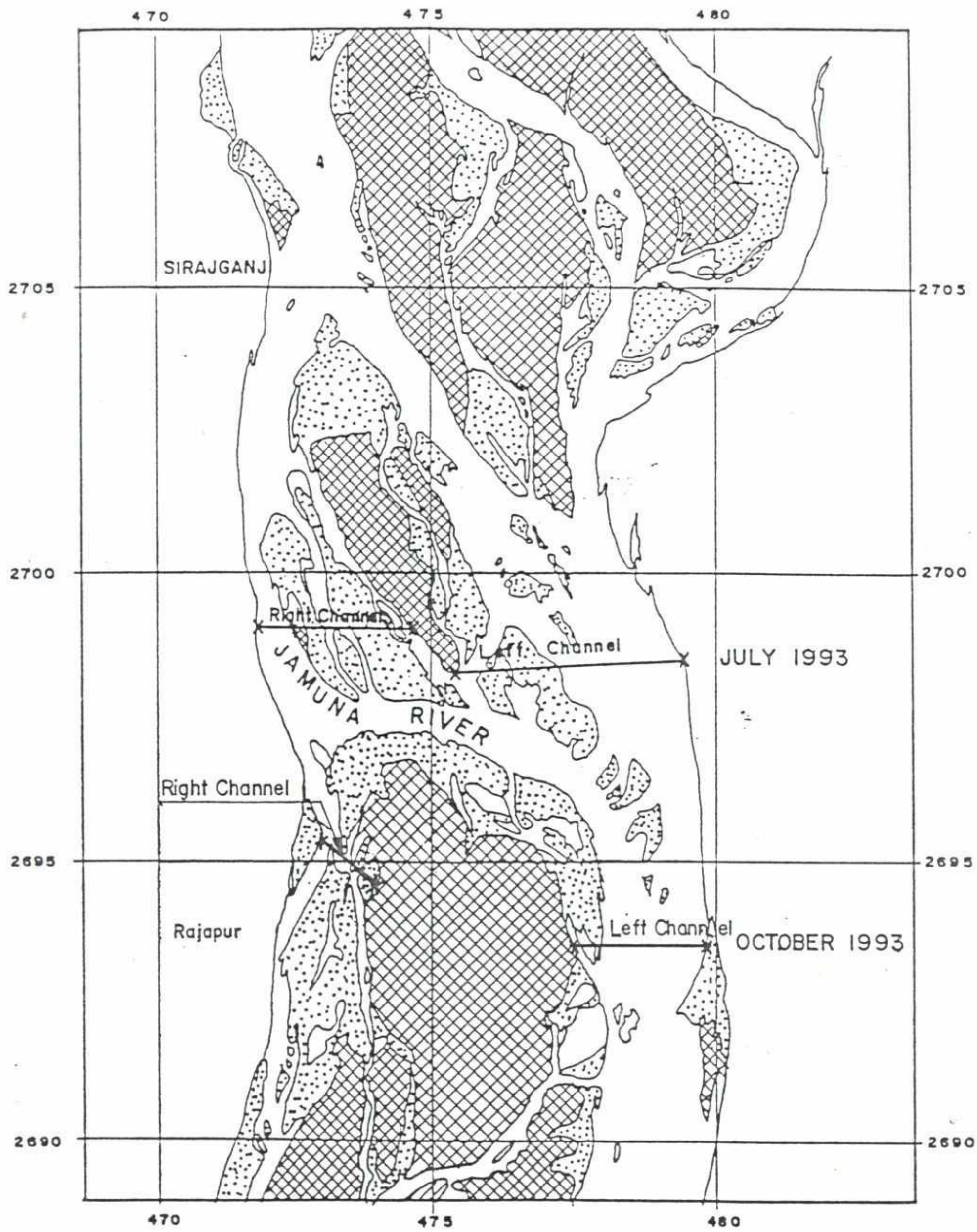


Figure 3.2 Alternative measurement cross-sections at Sirajganj

In order to obtain the reference water-level related to the respective discharge measurements the River Survey Project is going to install and operate Automatic Water-Level Recorders (AWLR's) in each of the 11 measurement sites. So far two stations have been installed at the Bahadurabad cross-section, one near Bahadurabad ferry ghat and one near Gabgachi on the central island. In Gabgachi, two different types of AWLR were installed, viz. a pressure type and an acoustic type, for reasons of comparison.

The AWLR's, performing ½-hourly registrations, will supplement the data from the existing staff gauges operated by BWDB with daily water-level observations for every 3 hours from 06:00 to 18:00.

3.2 Bahadurabad gauging area - station 1

Figure 3.3 shows an example on the locations of the river channels L1-L4 selected by the River Survey Project in September 1993 to cover the complete river cross-section at Bahadurabad in Jamuna River during the flood season. The Bahadurabad cross-section is located in a highly active braided river section of approximately 12 km width. Currently two distinct main channels, separated by an inhabited high char, cut through the area. Besides during the flood season two smaller channels L2 and L4 are crossing the char, see Figure 3.3. The bank-full discharge amounts to approximately 44,000 m^3/s.

The left river channel at Bahadurabad (L1) is approximately 3 km wide and comprises several main channels and a 200 m wide smaller channel following the right bank. Maximum cross-section depths are 13 m and 8 m respectively, see Figure 3.4.

The right river channel at Fulchari (L3) is approximately 2.2 km wide and comprises a 600 m wide main channel and a 450 m wide smaller channel. Maximum depth are 22 m and 10 m respectively, see Figure 3.5.

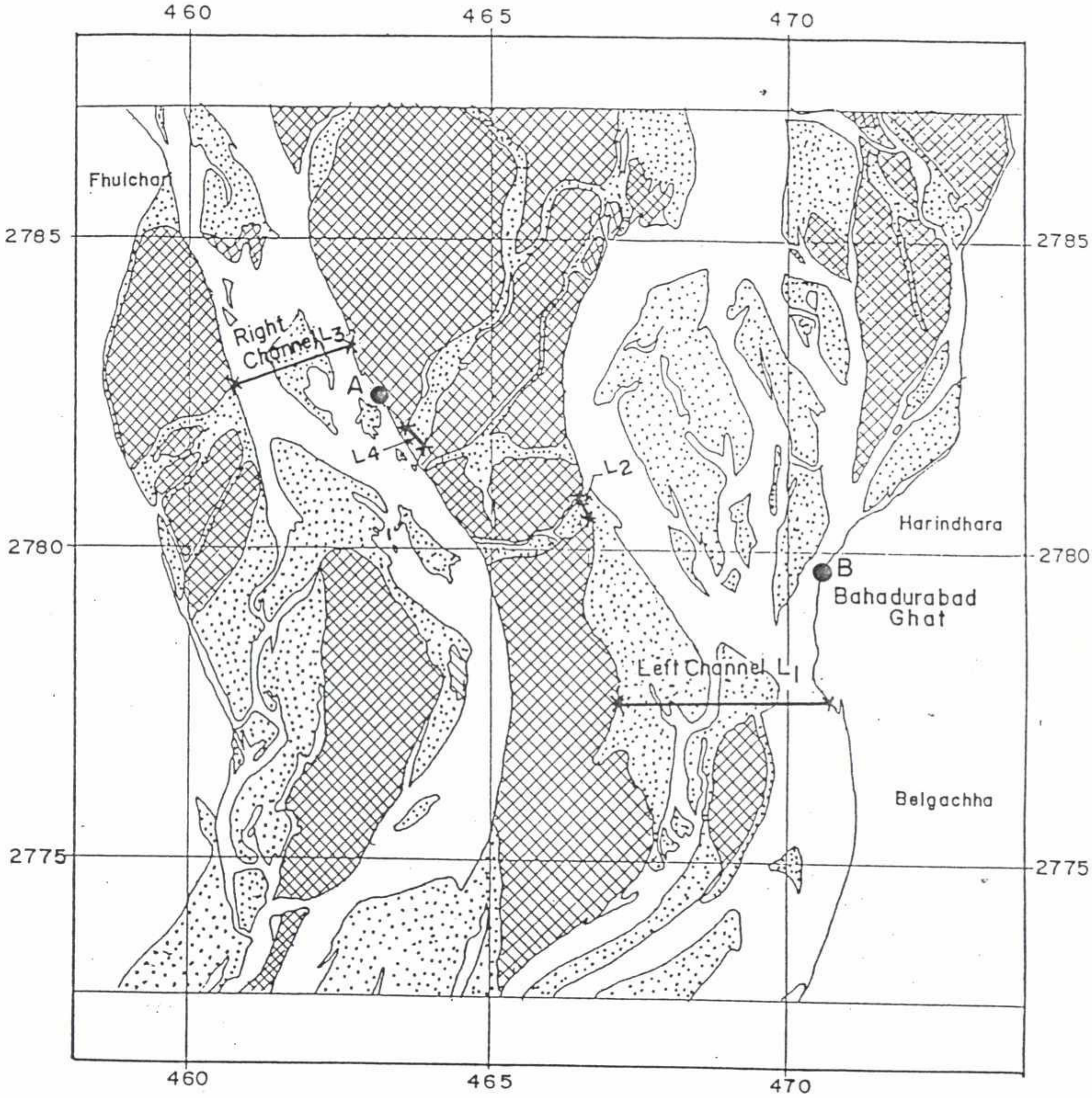
During the flood season the river channels L1-L3 could be covered by the A-vessel using the recommended method with combined ADCP/EMF measurements, while channel L4 was covered by point integrating measurements only.

The River Survey Project has established two automatic water-level stations (AWLR) in this cross-section, see Figure 3.3.

A pressure cell recorder was installed just upstream of the Bahadurabad Ghat and became operational on 6 June 1993. Unfortunately, the station went out of order already on 2 August 1993 due to siltation and catchment of floating debris. Water-level data collection continued by staff gauge reading.

For testing of two different measurement principles a combined acoustic and pressure cell type recorder was installed on the western side of the central island at Gabgachi covering the right river channel. This station became operational from 15 July 1993 and covered the whole monsoon period.

Besides, the River Survey Project installed and operated four staff gauges in selected locations in the left main channel at Bahadurabad; see Figure 3.3. The water-levels have been observed daily every hour from 6:00 to 18:00. The results are presented in a separate Working Paper 5 on water-level slope measurements in Jamuna River at Bahadurabad.



A : Gabgachi gauge
B : Bahadurabad gauge

Figure 3.3 Planform of Jamuna River in the vicinity of station 1 at Bahadurabad, March 1993.

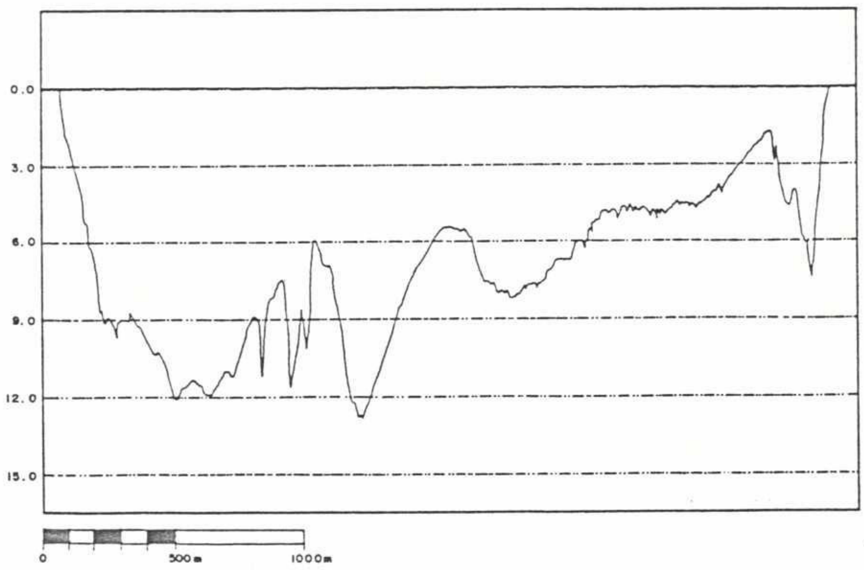


Figure 3.4 : Cross-section of left main channel at Bahadurabad, September 1993.

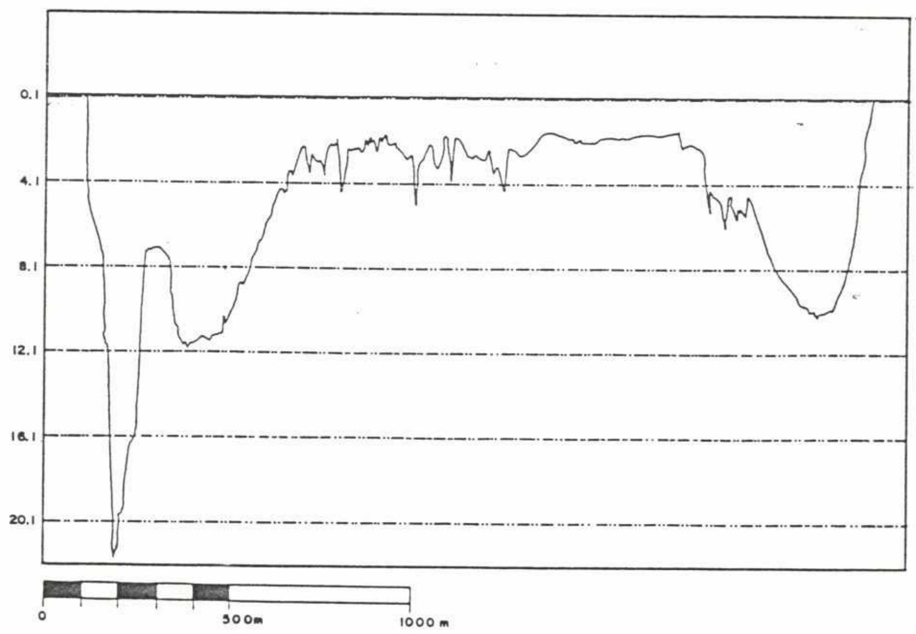


Figure 3.5 : Cross-section of right main channel at Bahadurabad, September 1993.

3.3 Sirajganj gauging area - station 2

The cross-section at Sirajganj in Jamuna River is also located in a highly active braided river section of approximately 8 km width. The area is dominated by two distinct main channels - left and right - separated by an inhabited high char; ref. Figure 3.6.

Figure 3.6 also shows the location of the cross-sections selected by the River Survey Project in July 1993.

The left river channel is approximately 3 km wide and comprises two main channels and a 500 m wide shallow area at the right bank - at the central island. Maximum depths are 13 m and 15 m respectively see Figure 3.7. The right river channel is approximately 2.8 km wide and comprises a 900 m wide main channel along the right bank and two smaller channels along the left bank at the central island.Maximum depths are 12 m and 5 m respectively. In between is a 700 m wide shallow area, ref. Figure 3.8.

During the flood season the entire river cross-section including the shallow areas could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB staff gauges are located at Sirajganj.

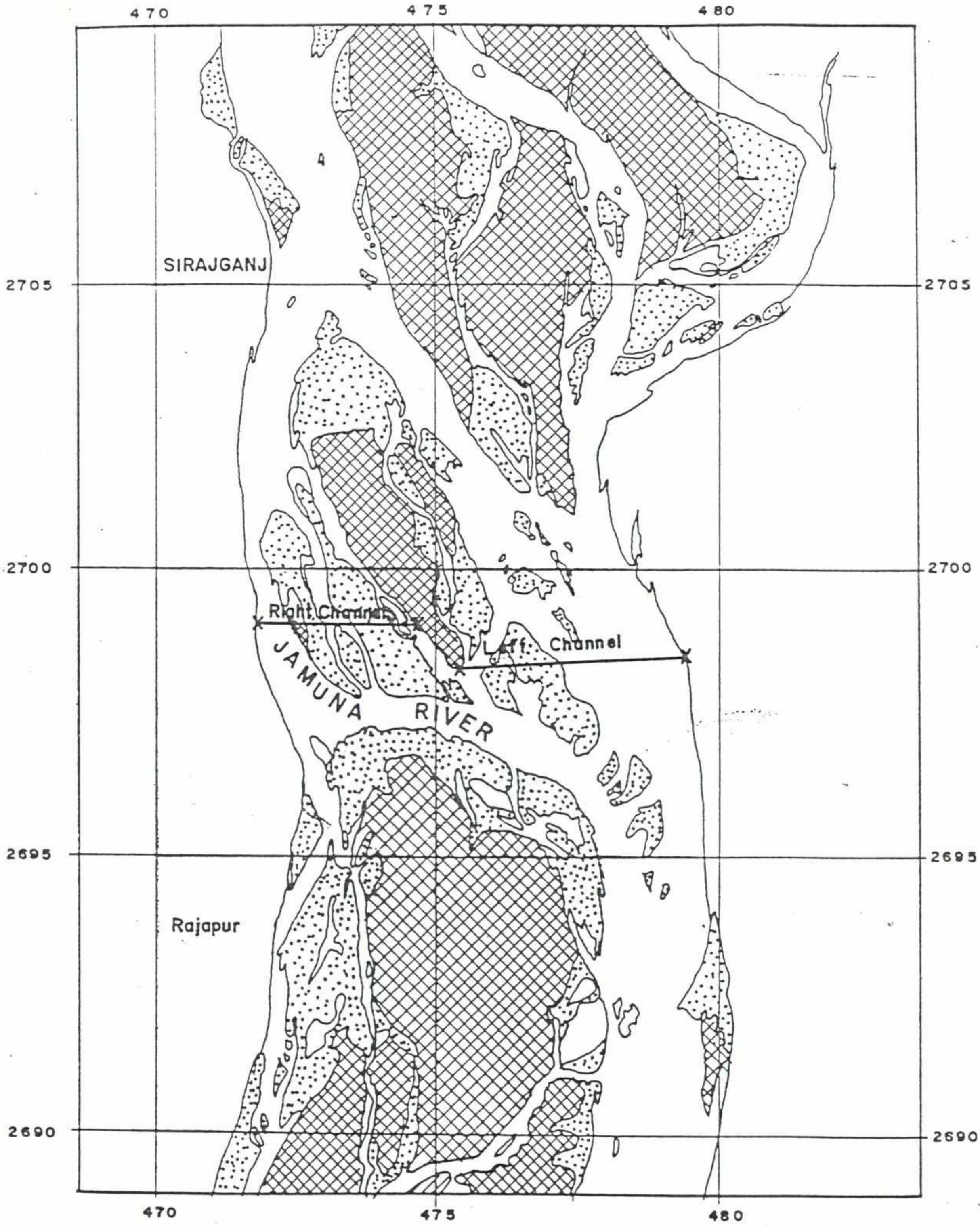


Figure 3.6 : Planform of Jamuna River in the vicinity of station 2 at Sirajganj, March 1993.

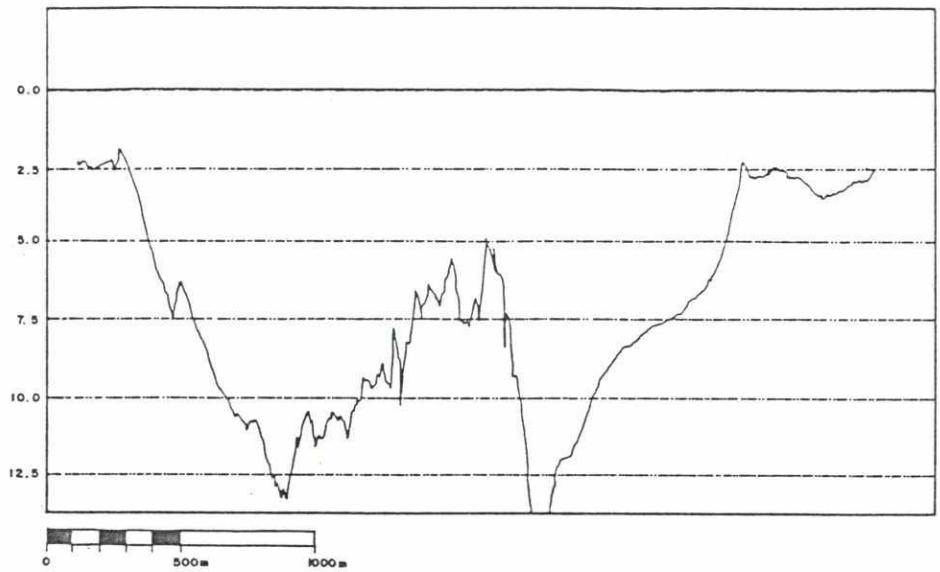


Figure 3.7 : Cross-section of the left main channel at Sirajganj, July 1993.

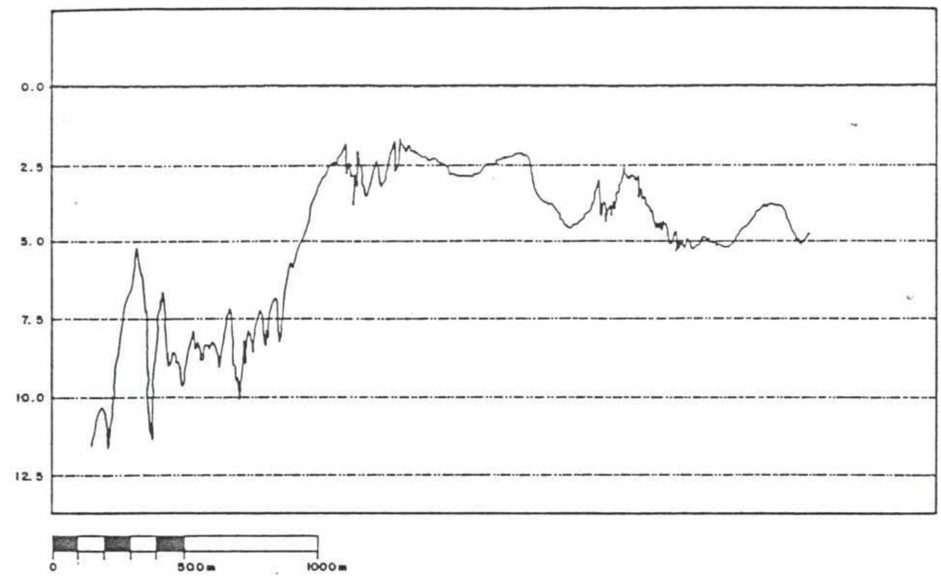


Figure 3.8 : Cross-section of the right main channel at Sirajganj, July 1993.

3.4 Aricha gauging area - station 3

The Aricha cross-section in Jamuna River just upstream of the confluence with the Ganges is also located in a highly active braided river cross-section of approximately 4 km width.

During the site reconnaissance carried out prior to selection of actual survey lines, it was found impossible to pass the river cross-section with the A vessel north of Aricha as planned.

Instead a series of transects was carried out in sub-sections as shown in Figure 3.9 below. The maximum depth in the respective channels is approximately 16 m.

The BWDB staff gauge is located in Aricha (Teota).

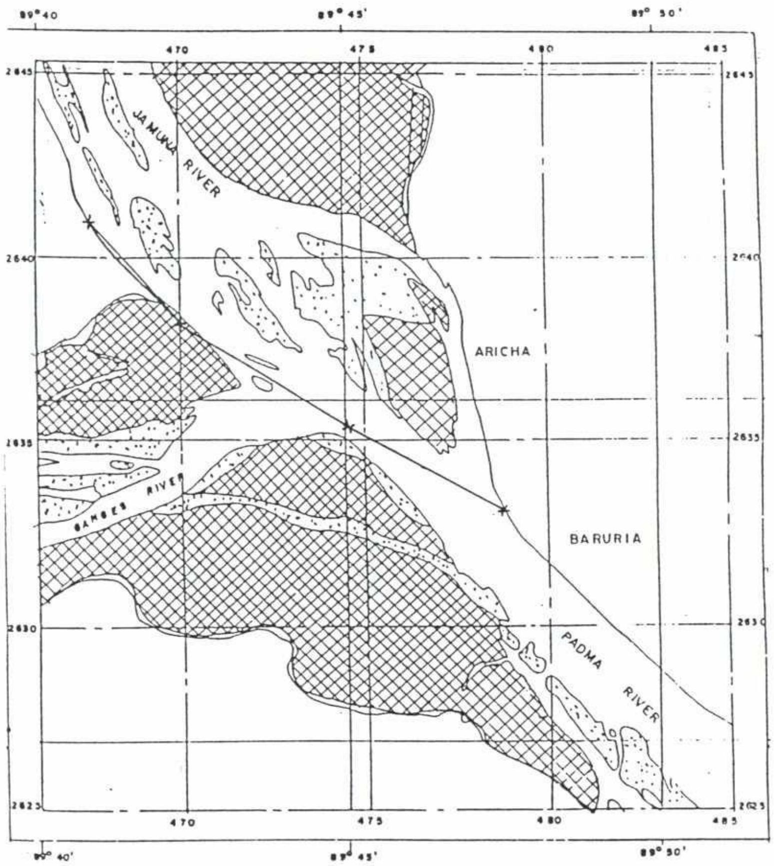


Figure 3.9 : Planform of Jamuna river in the vicinity of station 3 at Aricha, March 1993

3.5 Hardinge Bridge gauging area - station 4

The cross-section at Hardinge Bridge in Ganges River is controlled by the river training works up - and downstream of the bridge structure itself.

The river cross-section is dominated by a 1200 m wide main channel following the right bank; ref. Figure 3.10 and Figure 3.11. Maximum depth is 15 m. The remaining section is a more shallow area with a few narrow channels following the left bank.

During the flood season the entire river cross-section including the shallow area could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

Figure 3.10 also shows the location of the measurement cross-section selected by the River Survey Project in September 1993. The BWDB staff gauge is located at the left bank near the bridge.

It is expected that the guide bunds and the bridge pillars have a certain impact on the flow field and the river bed configuration near the bridge, which again influences the suspended sediment concentrations in this area, possibly with distinct seasonal effects. Therefore it is recommended to move the measurement cross-section upstream of the bridge to a distance of say 1 km.

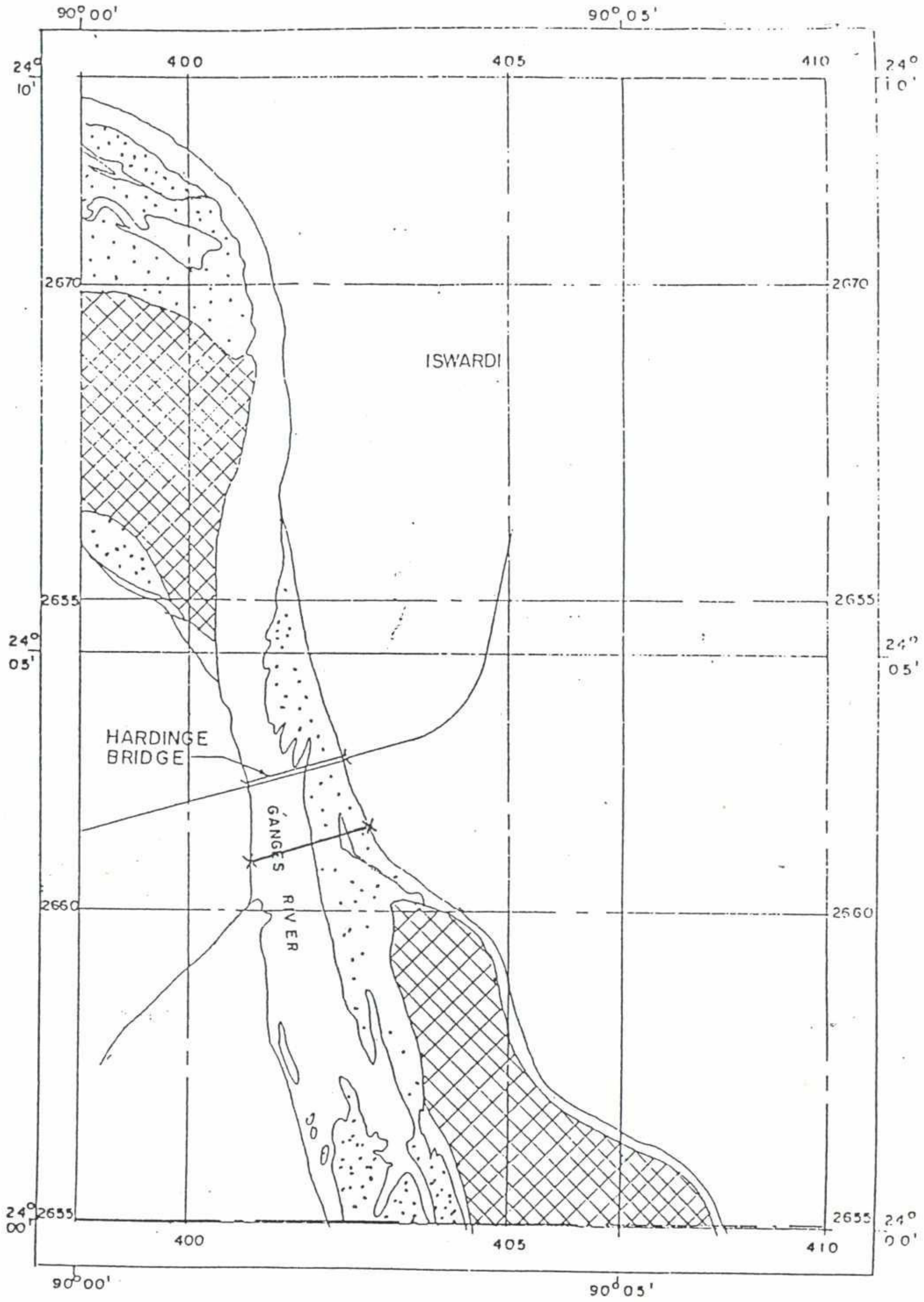


Figure 3.10 : Planform of Ganges River in the vicinity of station 4 at Hardinge Bridge, March 1993

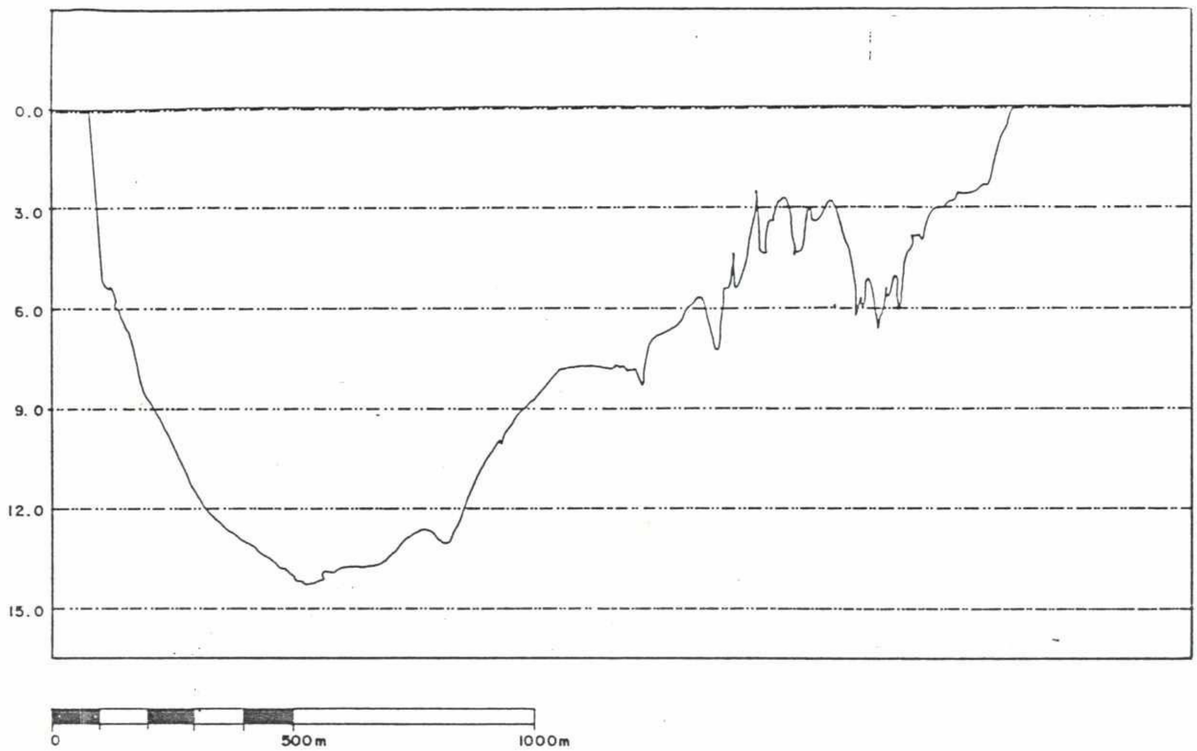


Figure 3.11 : Cross-section of Ganges River downstream of the Hardinge Bridge, September 1993

3.6 Baruria gauging area - station 5

The cross-section at Baruria in Padma River just downstream of the confluence between Jamuna and Ganges is shown in Figure 3.12 and Figure 3.13. It comprises a 1500 m wide main channel following the left bank and a 200 m wide smaller channel following the right bank. The maximum depths are 22 m and 11 m respectively. The channels are separated by a 1200 m wide shallow area, which becomes almost dry in the dry season.

During flood season conditions the entire river cross-section including the shallow area could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB operates a staff gauge on the left bank and performs routine gauging in a cross-section approximately 100 m downstream of the cross-section selected by the River Survey Project.

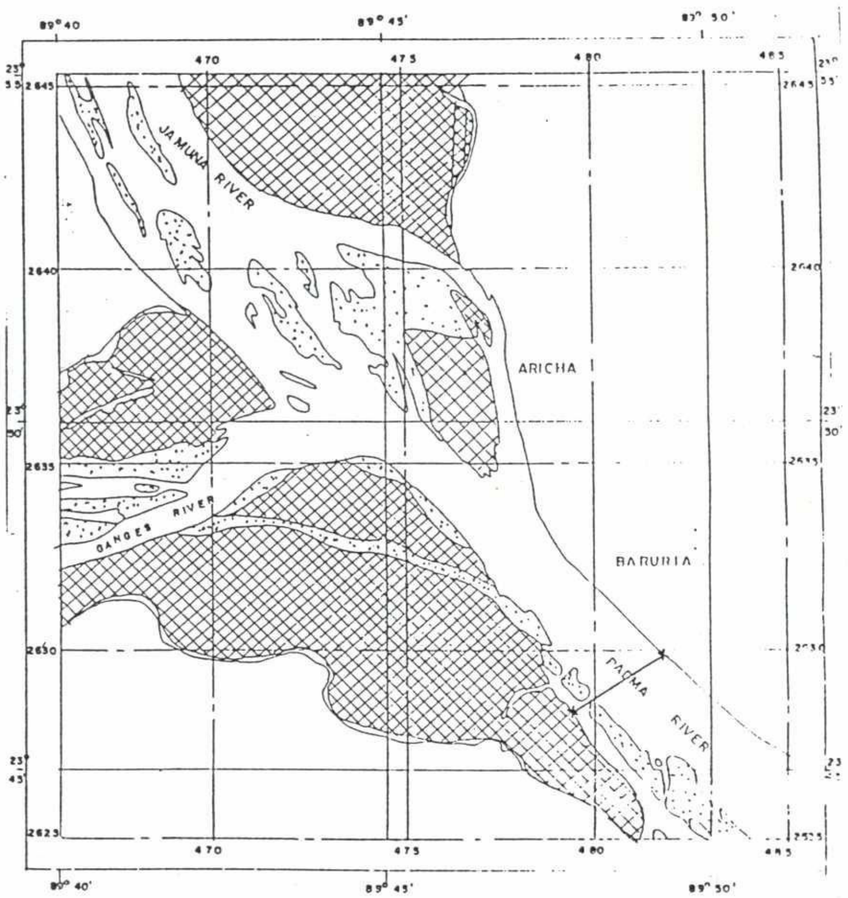


Figure. 3.12 : Planform of Padma River in the vicinity of station 5 at Baruria, March 1993

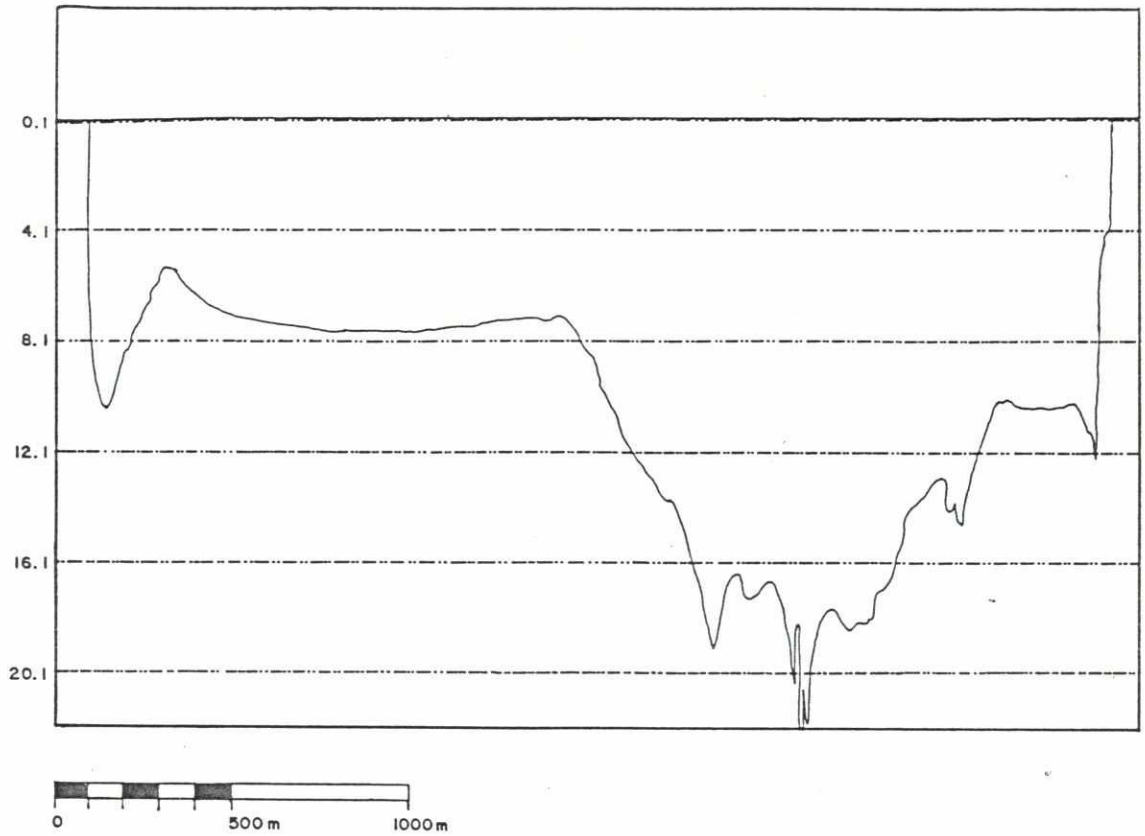


Figure 3.13 : Cross-section of Padma River at Baruria, August 1993.

3.7 Mawa gauging area - station 6

The cross-section at Mawa in Padma River is dominated by two main channels separated by a 500 m wide shallow area; see Figure 3.14 and Figure 3.15. One channel following the left bank is 700 m wide and 25 m deep and the other channel following the right bank is 2000 m wide and 15 m deep.

During flood season conditions the entire river cross-section including the shallow area could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB operates a staff gauge on the left bank and performs routine gaugings in a cross-section approximately 100 m downstream of the cross-section selected by the River Survey Project in October 1993.

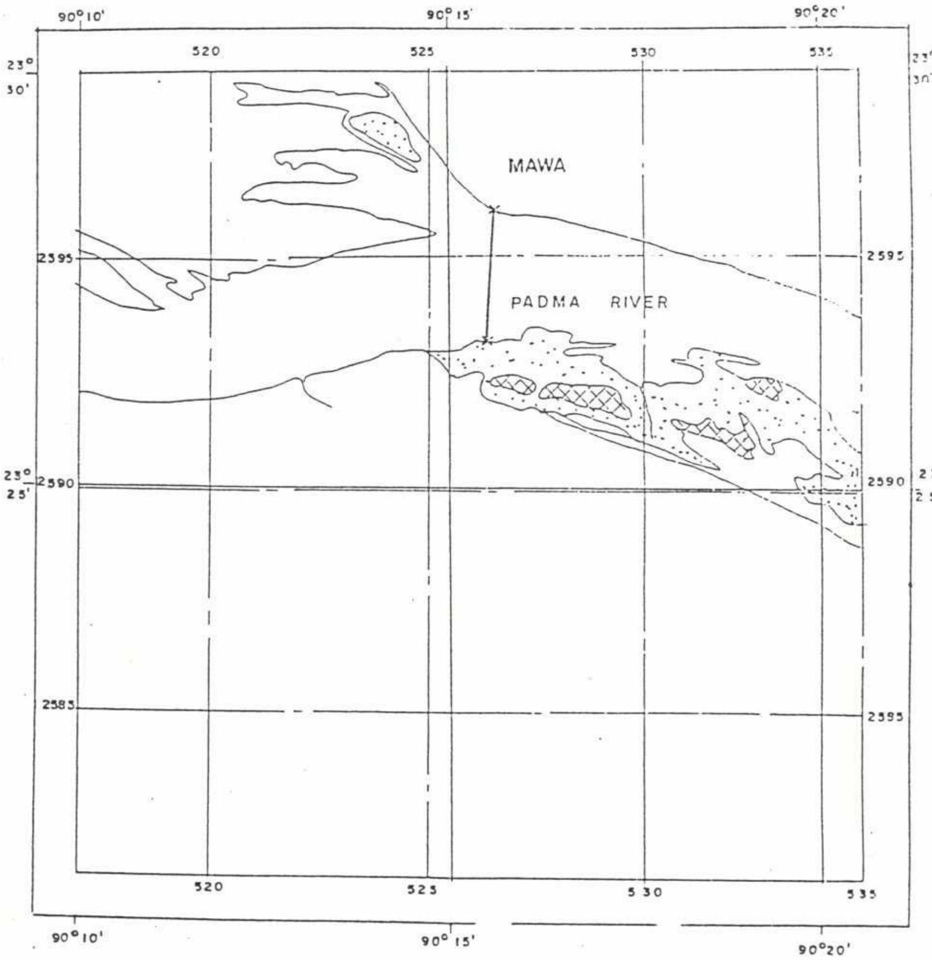


Figure 3.14 : Planform of Padma River in the vicinity of station 6 at Mawa, March 1993

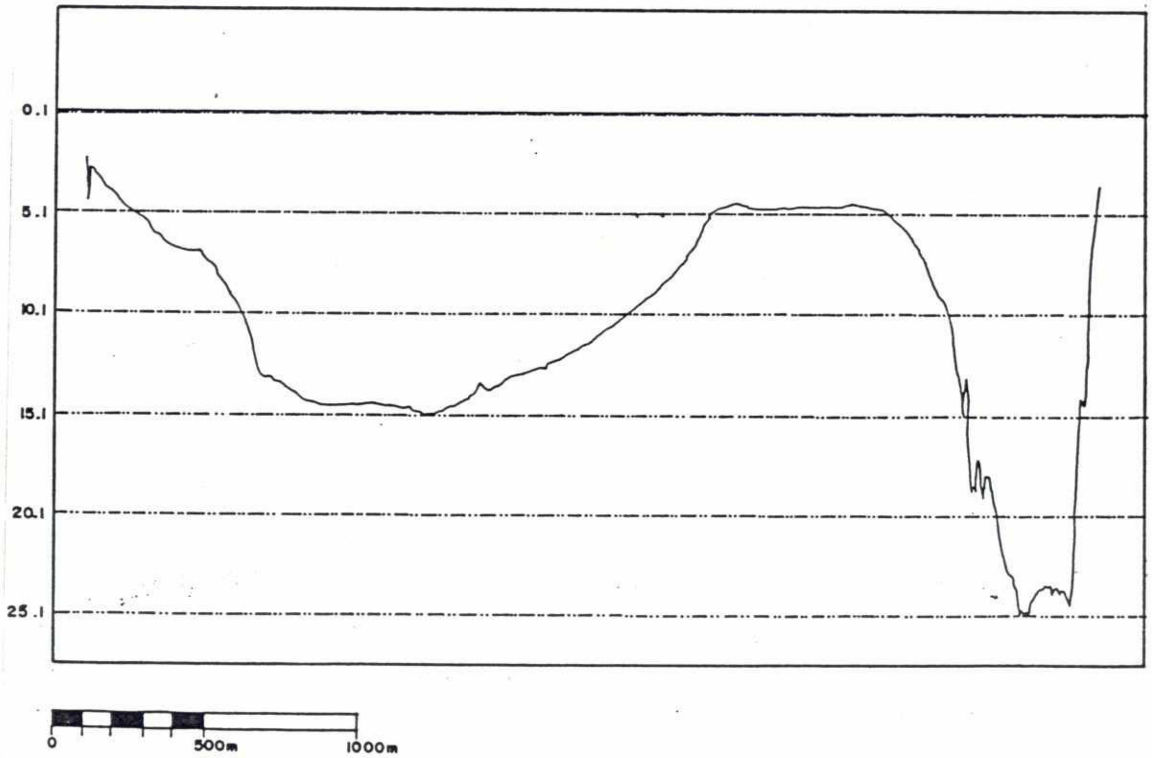


Figure 3.15 : Cross-section of Padma River at Mawa, August 1993.

3.8 Mymensingh gauging area - station 7

Station 7 is located in Old Brahmaputra at Mymensingh. No measurements have been carried out in this cross-section during the flood season 1993.

During a reconnaissance of the site it was found that the river section within the gauging area is controlled by river training structures along both banks.

Figure 3.16 shows the location of the permanent BWDB cross-section with the related water-level staff gauge on the right bank.

The BWDB operates a staff gauge on the right bank and performs routine gaugings in a cross-section approximate 500 m downstream of the railway bridge.

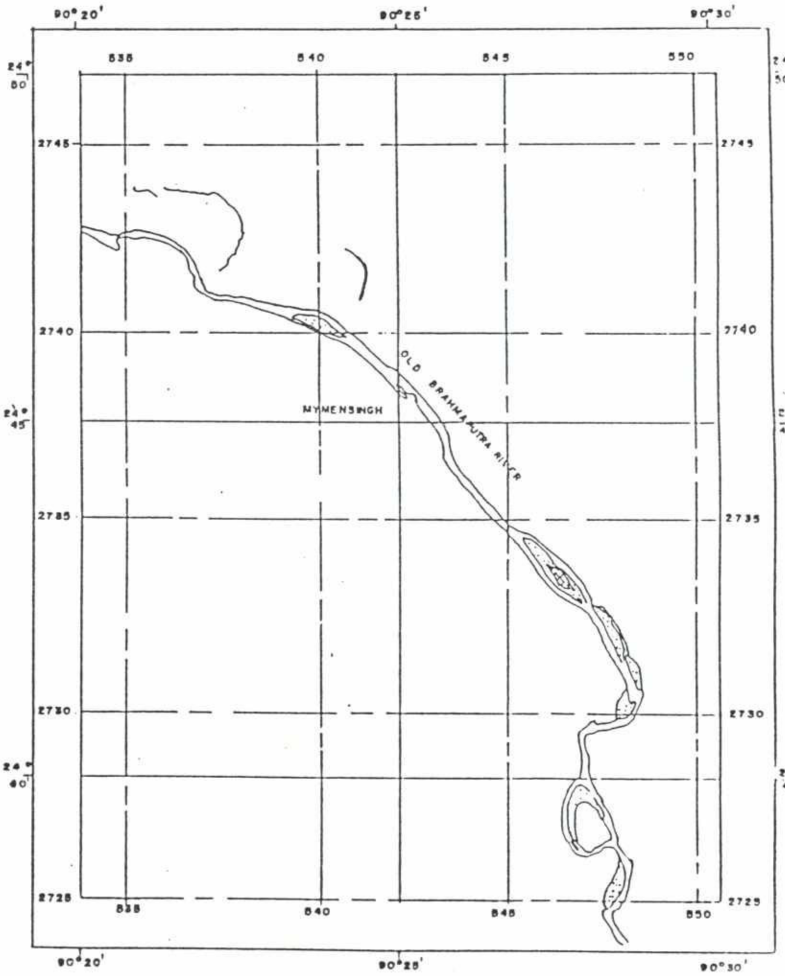


Figure 3.16 : Planform of Old Brahmaputra River in the vicinity of station 7 at Mymensingh, March 1993

3.9 Tilly gauging area - station 8

The cross-section at Tilly in Dhaleswari River is shown in Figure 3.17 and Figure 3.18. The cross-section constitutes a 100 m wide and 11 m deep smaller channel.

During flood season conditions the channel could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB operate a staff gauge on the right bank and performs routine gauging in a cross-section approximately 100 m downstream of the cross-section selected by the River Survey Project.

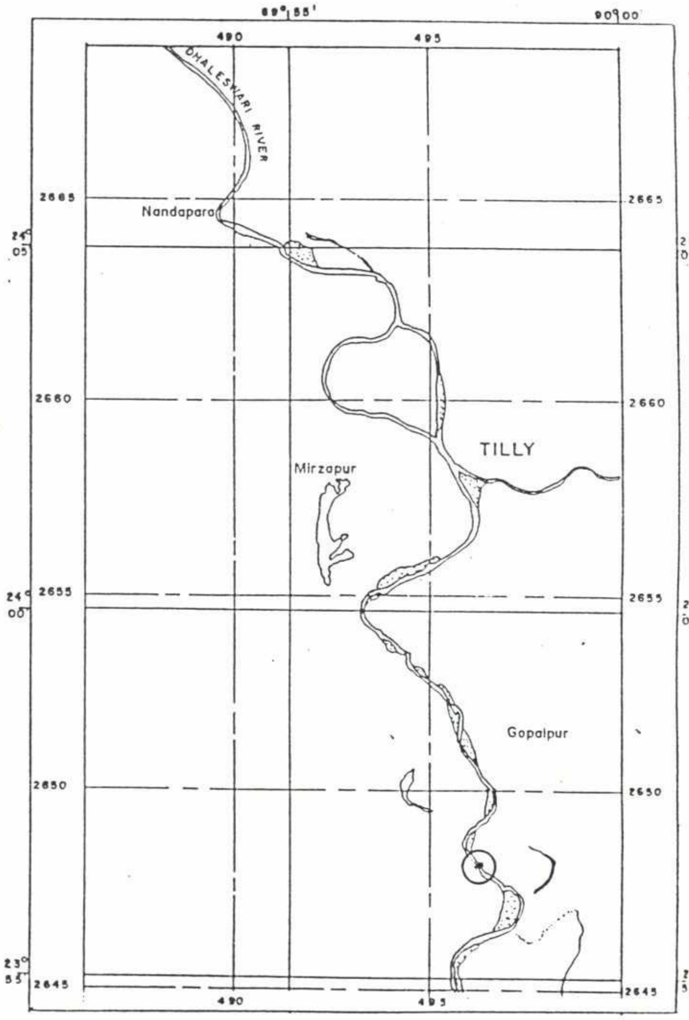


Figure 3.17 : Planform of Dhaleswari River in the vicinity of station 8 at Tilly, March 1993

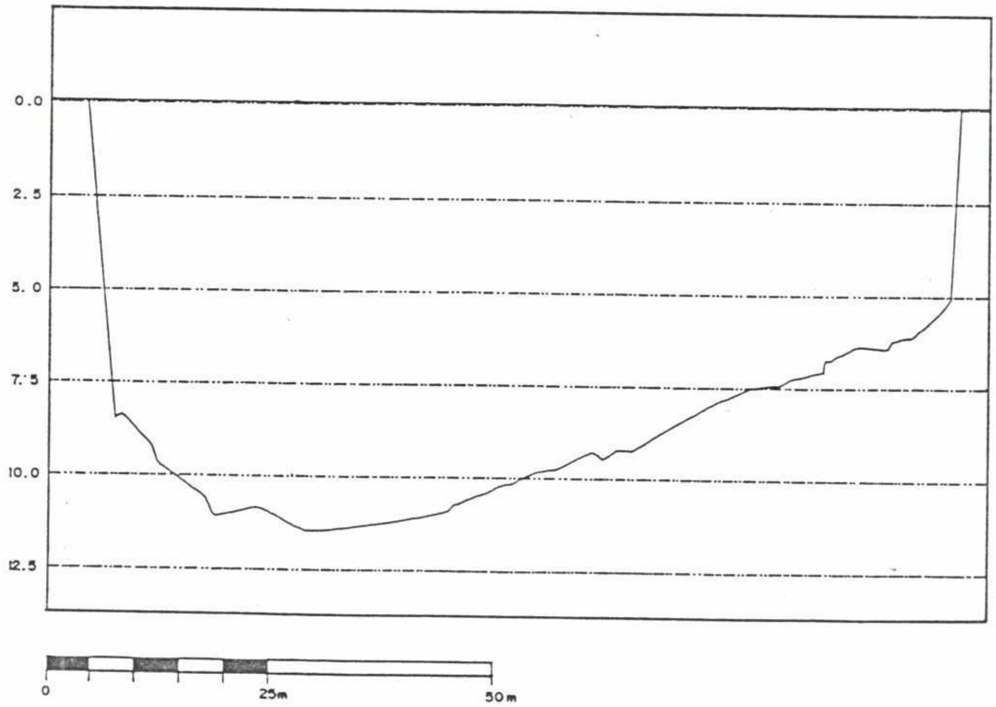


Figure 3.18 : Cross-section of Dhaleswari River at Tilly, October 1993

3.10 Gorai (off-take) gauging area - station 9

The cross-section at Kushtia in Gorai River is shown in Figure 3.19 and Figure 3.20. The cross-section constitutes a 300 m wide and 10 m deep smaller channel - square shaped.

During flood season conditions the channel could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB operate a staff gauge on the right bank near the railway bridge and performs routine gauging in a cross-section approximately 500 m downstream of this gauging station. The cross-section selected by the River Survey Project is approximately 2 km upstream of the railway bridge.

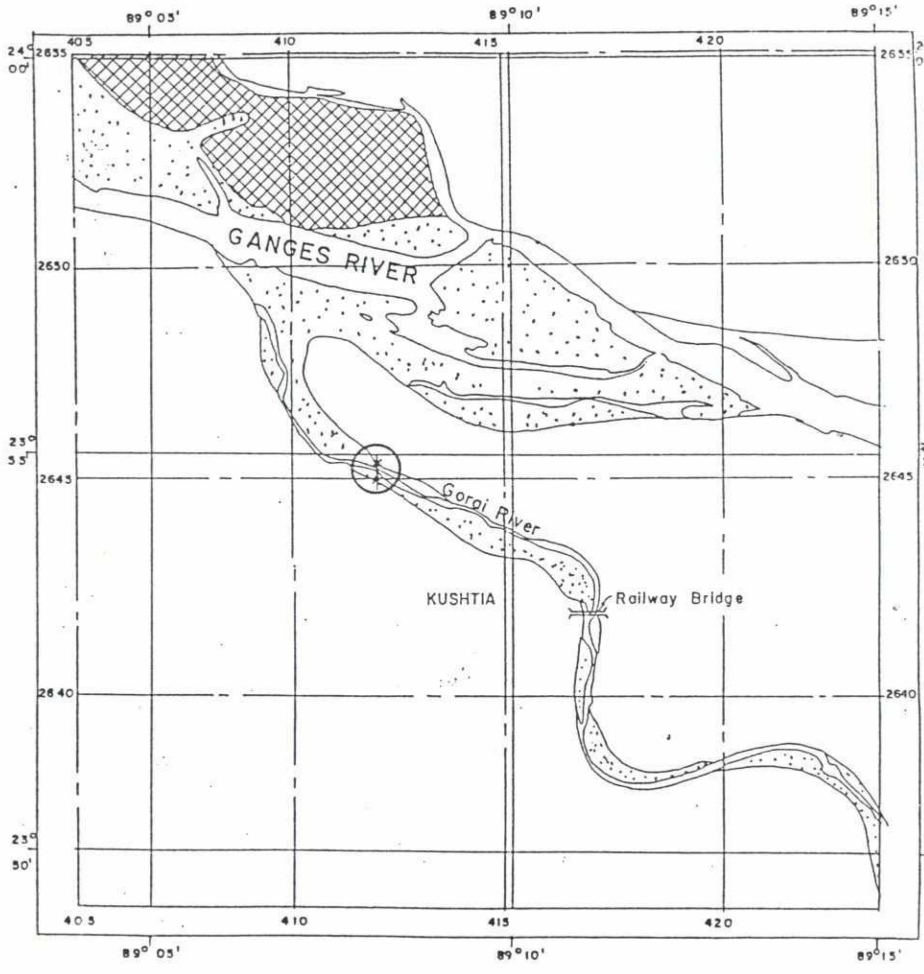


Figure 3.19 : Planform of Gorai River in the vicinity of station 9 at Kushtia, March 1993

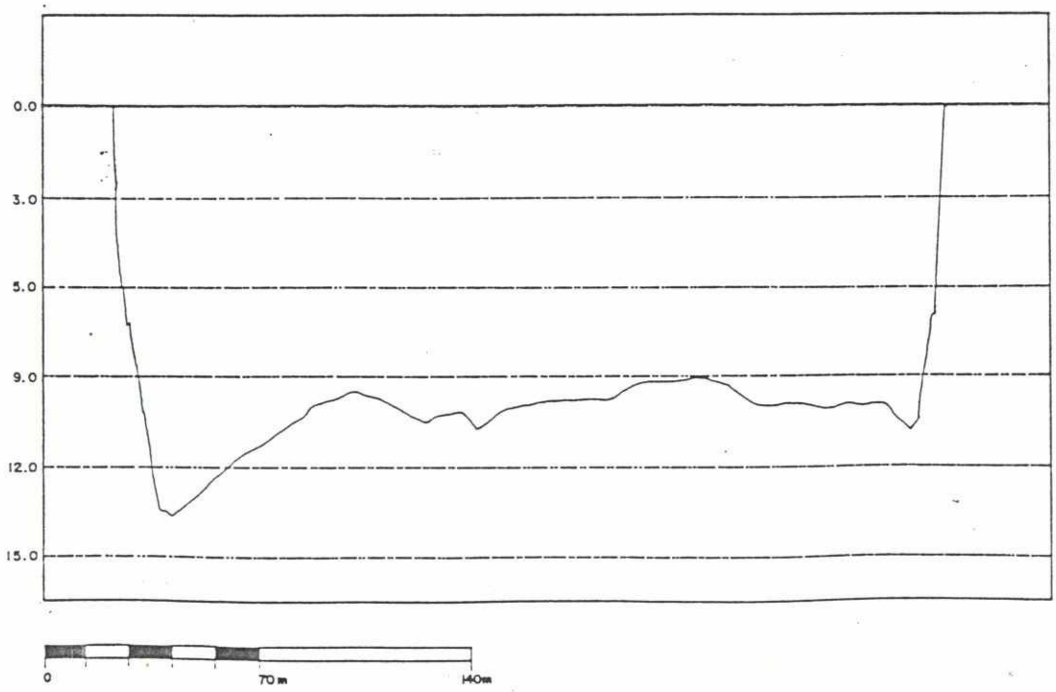


Figure 3.20 : Cross-section of Gorai River at Kushtia, September 1993

3.11 Arial Khan gauging area - station 10

The cross-section selected by the River Survey Project at the Arial Khan off-take is shown in Figure 3.21 and Figure 3.22. The off-take comprises a 100 m wide and 12.5 m deep minor channel following the left bank. The area between this channel and the right bank is 300 m wide and more shallow. During the dry season this area becomes completely dry.

During flood season conditions the channel could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

The BWDB operates a staff gauge on the right bank and performs routine gauging in a cross-section approximately 3 km downstream of the cross-section selected by the River Survey Project near the inlet.

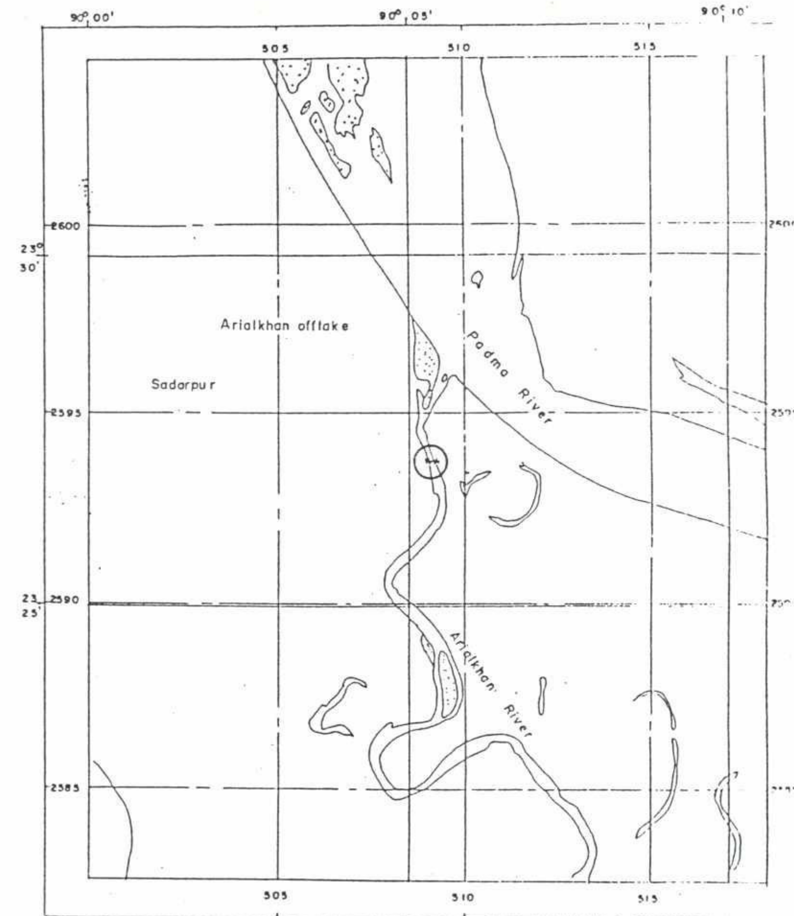


Figure 3.21 : Planform of Arial Khan off-take in the vicinity of station 10, March 1993

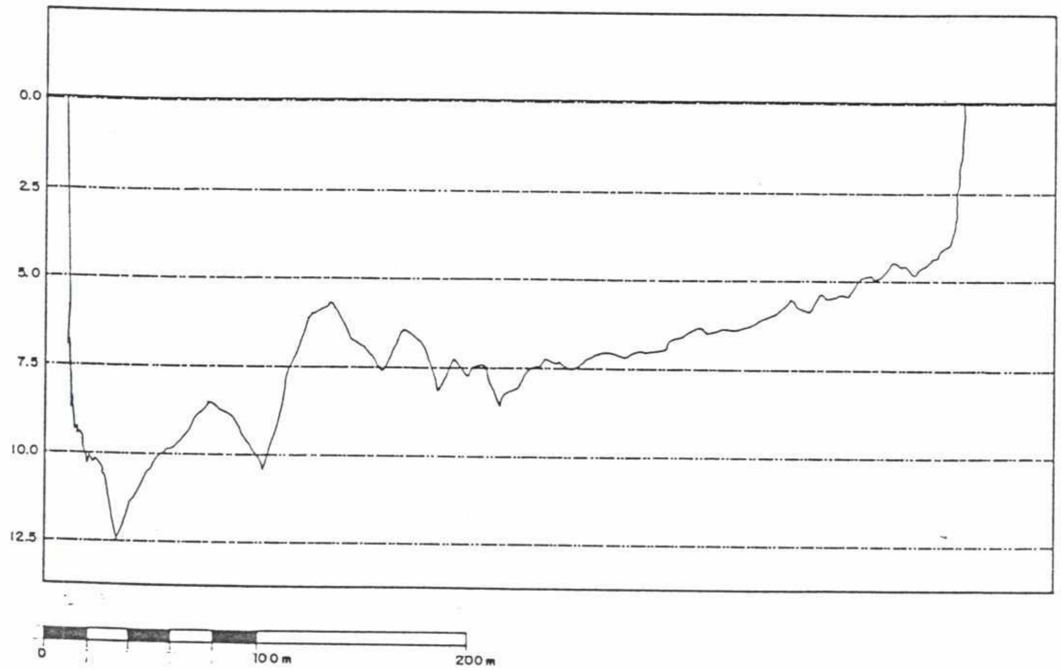


Figure 3.22 : Cross-section of Arial Khan River at the off-take from Padma River, October 1993

3.12 Bhairab Bazar gauging area - station 11

The Bhairab Bazar cross-section in the Upper Meghna River is controlled by substantial river training works, both up- and downstream of the Bhairab Bazar railway bridge. Currently a low char is extending to a point 200 m upstream of the railway bridge.

The cross-section selected by the River Survey Project is shown in Figure 3.23 and Figure 3.24.

The BWDB operates a staff gauge on the left bank and performs routine gaugings in a cross-section approximately 50 m upstream of the railway bridge.

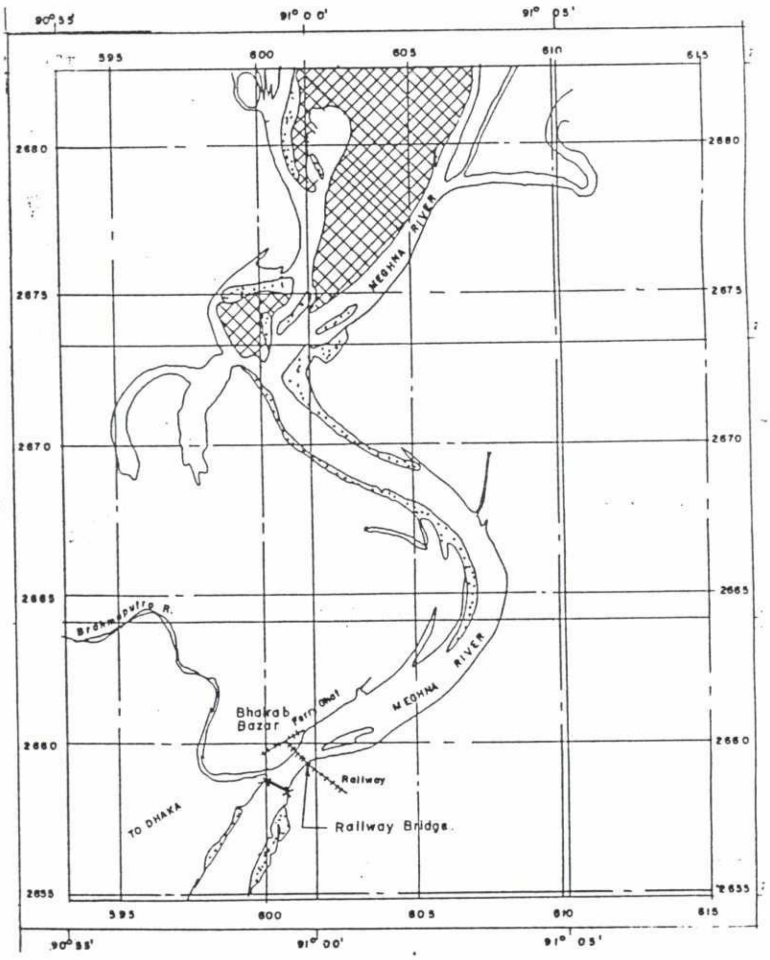


Figure 3.23 : Planform of the Upper Meghna River in the vicinity of station 11 at Bhairab Bazar, December 1988

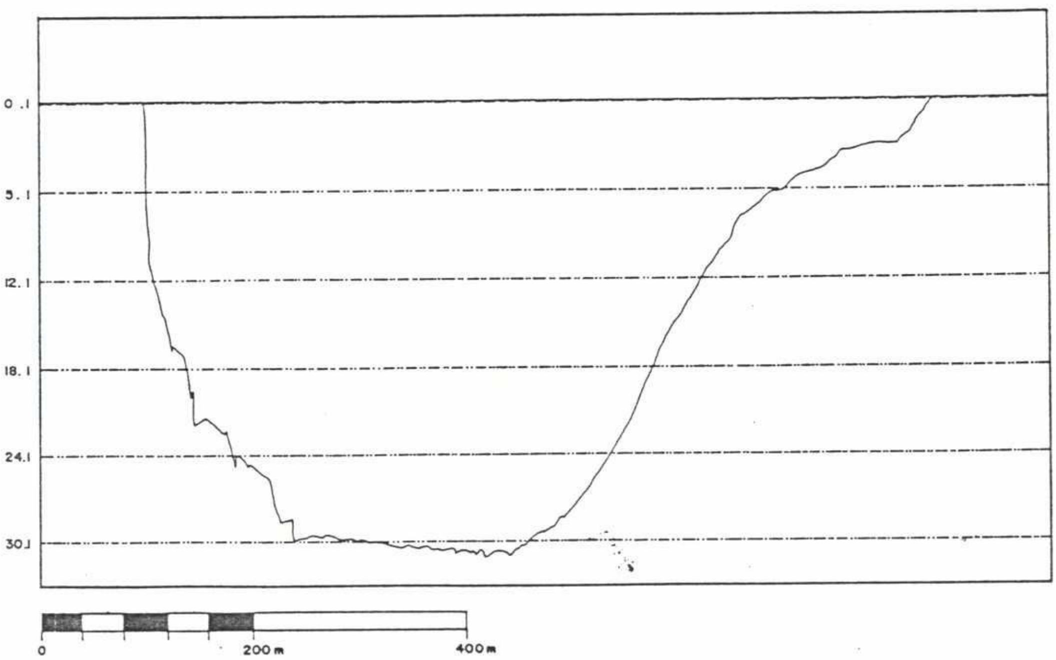


Figure 3.24 : Cross-section of the Upper Meghna River at Bhairab Bazar, October 1993

4. Summary of survey equipment and procedures

The survey equipment, the survey procedures and the quality assurance constitute the framework for all data produced by the River Survey Project. Each of these subjects are addressed in the succeeding sections.

4.1 Survey vessels and equipment

During the flood season in 1993 the River Survey Project operated three survey vessels as follows:

- Ms. DHA, a former police patrol boat, built for shallow waters, see Figure 4.1. The boat has been modified for advanced survey work in Bangladesh. Ms. DHA has the following main dimensions:
  - Length over all 20.25 m
  - Breadth over all 4.70 m
  - Draft 1.15 m

- Ms. DHC, a newly built catamaran survey vessel, see Figure 4.1. The vessel has the following main dimensions:
  - Length over all 8.70 m
  - Breadth over all 6.30 m
  - Draft 0.45 m

- A 12 feet aluminium craft with two 25 hp outboard engines, see Figure 4.1.

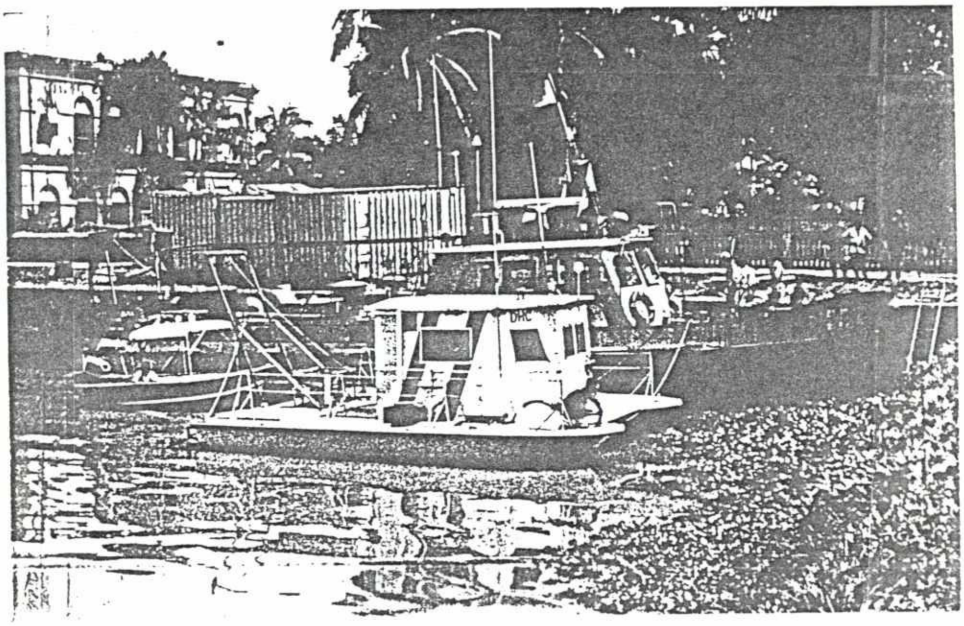


Figure 4.1 The fleet of survey vessels on River Survey Project FAP 24 moored at Narayanganj. Ms. DHA is lying behind Ms. DHC and the alu. craft

Each of the survey vessels are able to perform specialized survey operations comprising bathymetric survey, point integrating current measurement, integrating current measurement, suspended sediment measurement, bed load sediment transport measurement and river bed sediment sampling. Table 4.1 below states the capability and instrumentation aboard each of the survey vessels.

Equipment	DHA	DHC	Alu.cr.
DGPS Positioning system:			
Trimble 4000, 9 channel	X		
Trimble Navtrac, 6 channel		X	X
Bathymetric survey:			
Elac Laz 4420 (dual frequency echo sounding)	X		
Simrad EA 300 P (single frequency echo sounding)	X	X	X
Point integrating current measurement:			
Ott meter (mechanical)	X		
S4 InterOcean (electromagnetic)	X	X	X
Integrating current measurement:			
300 Khz ADCP (vertical)	X		
EMF (horizontal)	X		
Float tracking (horizontal)	X	X	X
Suspended sediment measurement:			
Pump bottle sampling	X	X	X
Depth integ. susp. sediment sampler	X		
MEX 3 Turbidity recorder	X		
Bed load sediment transport measurement:			
Helley-Smith trap sampler	X	X	X
Sand-dune tracking by echo-sounding	X	X	X
River bed sediment sampling:			
Van Veen grab	X	X	X
US BM-54	X	X	
Side scan sonar:			
EG & G Model 260	X		
Communication:			
VHF radios	X	X	X
Walkie talkies	X	X	X

Table 4.1 Capabilities and instrumentation aboard the three river survey project vessels; DHA, DHC and the alu boat, August 1993

The equipment in Table 4.1 cannot be seen independently of one another. Very often one type of equipment is supported by another. In particular this is the case for the positioning system, which is the corner stone of all measurements in the dynamic braided rivers of Bangladesh.

A few remarks need to be attached to the equipment listed in Table 4.1 to have a background for understanding measurement results and problems encountered during operation. The equipment for discharge measurements, suspended sediment measurements, bed load measurements and river bed material sampling is briefly presented in the following sections.

4.1.1 Current measurement

Current measurements are performed as moving boat measurements with the 300 Khz ADCP current meter and/or the EMF current meter or as stationary point current measurements with the electromagmxtic S4 current meter.

ADCP and EMF measurements
The acoustic doppler current profiler (ADCP), listed under integrating current measurement in Table 4.1, is able to provide a two dimensional vertical current profile. The measuring principle is based on the doppler shift of acoustic waves reflected from particles in the water column.

The ADCP transducers are mounted in a well midships of the DHA vessel, 0.85 m below the water surface by normal lading conditions. Hereby the 300 kHz ADCP system is able to measure current verticals in the depth range from 2.7 m below the surface to approximately 1.5 m above the river bed (the 300 kHz ADCP does not cover the last 6 per cent plus 1 bin size (0.5 m) of the water column). For this reason ADCP measurements have to be preceded by a survey for a suitable cross-section.

Under fixed river bed conditions the ADCP operates independently of the positioning system and uses its own bottom track as reference for determination of the absolute current velocities and discharge calculations.

When measuring across a moving river bed all the measured current velocities are related to the positioning data recorded during navigation.

The electromagnetic EMF current meter, listed under integrating current measurements, provides discrete current measurements from a preset deployment level, while the survey vessel is progressing. The EMF sensor is mounted 0.5 m below the surface in the bow of the DHA vessel, see Figure 4.2. The EMF current meter is interfaced to the DGPS positioning system.

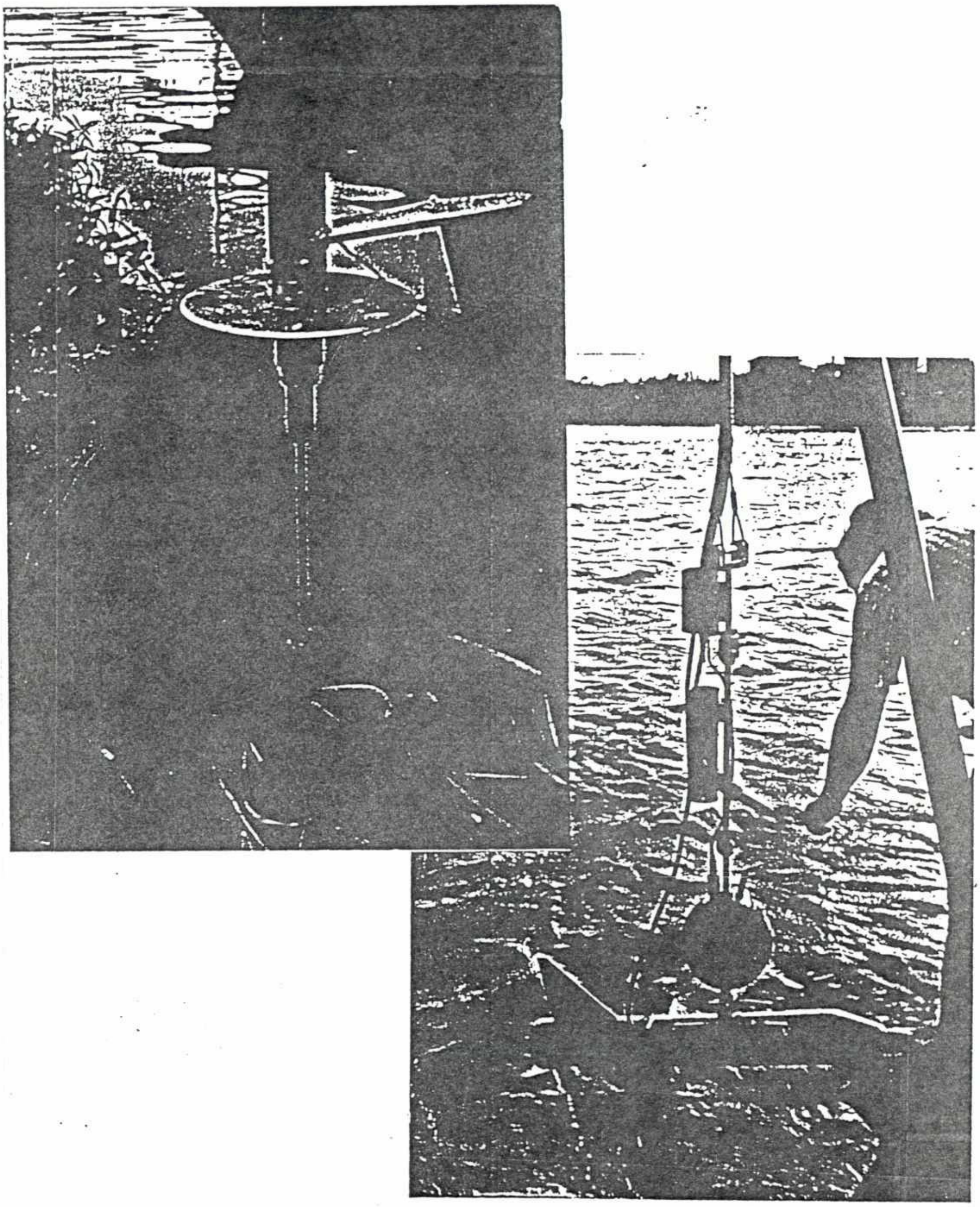


Figure 4.2 The EMF sensor mounted at the bow of Ms. DHA (upper left). The S4 current meter, the suspended sediment sampler and the MEX 3 turbidity meter mounted on a fish-type carrier (lower right). The turbidity meter is mounted on the right side of the carrier, while the suction hose of the suspended sediment pump is mounted at the same level but to the left. The spherical S4 current meter and the suspended sediment pump are seen above the carrier

S4 current meter

The S4 current meter is an integrating instrument which provides point current and direction measurements as well as pressure, temperature and conductivity data. The precise depth is obtained from the pressure cell. The S4 current meter, the suction nozzle for the suspended sediment sampler and the MEX 3 turbidity sensor have all been installed on and above a winch operated carrier, see Figure 4.2.

The deployment wire, the suction hose and the various electrical interfaces have been integrated into a so-called umbilical. To avoid vibrations, which would disturb measurements, a faring has been mounted on the umbilical.

Accurate point current measurements presupposes stationary anchoring of the survey vessel.

4.1.2 Suspended sediment measurement

Suspended sediment samples "pump bottle samples" are obtained through the suction nozzle mounted on the left side of the fish-type carrier displayed in Figure 4.2. The mixture of suspended sediment and water is pumped aboard the survey vessel for sampling. Precise depth measurement is provided by the pressure cell in the S4 current meter.

4.1.3 Bed load sediment transport measurement

Bed load sediment transport is measured directly by the Helley-Smith trap sampler depicted in Figure 4.3. The bed load transport is collected in a 250 μm wire mesh bag mounted just behind the sampler mouth.

Bed load sediment transport measurements presupposes stationary anchoring of the survey vessel.

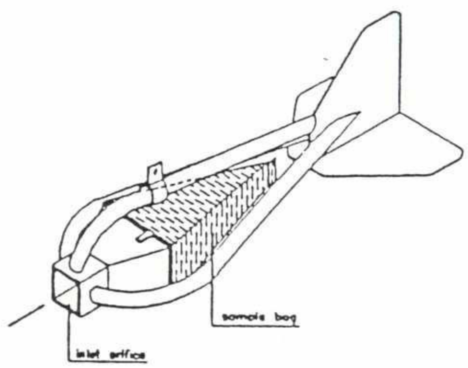


Figure 4.3 The Helley-Smith bed load trap sampler

4.1.4 River bed material sampling

River bed material samples are obtained either by the Van Veen grab or the US BM-54 sediment sampler. The Van Veen grab sampler, Figure 4.4, is only applicable in relatively low flow conditions while the US BM-54 sampler is generally applicable.

The US BM-54 sampler, Figure 4.4, consists of a tow fish with a coil spring powered bucket mounted inside. Upon contact with the river bed the bucket snap-shots a bed material sample.

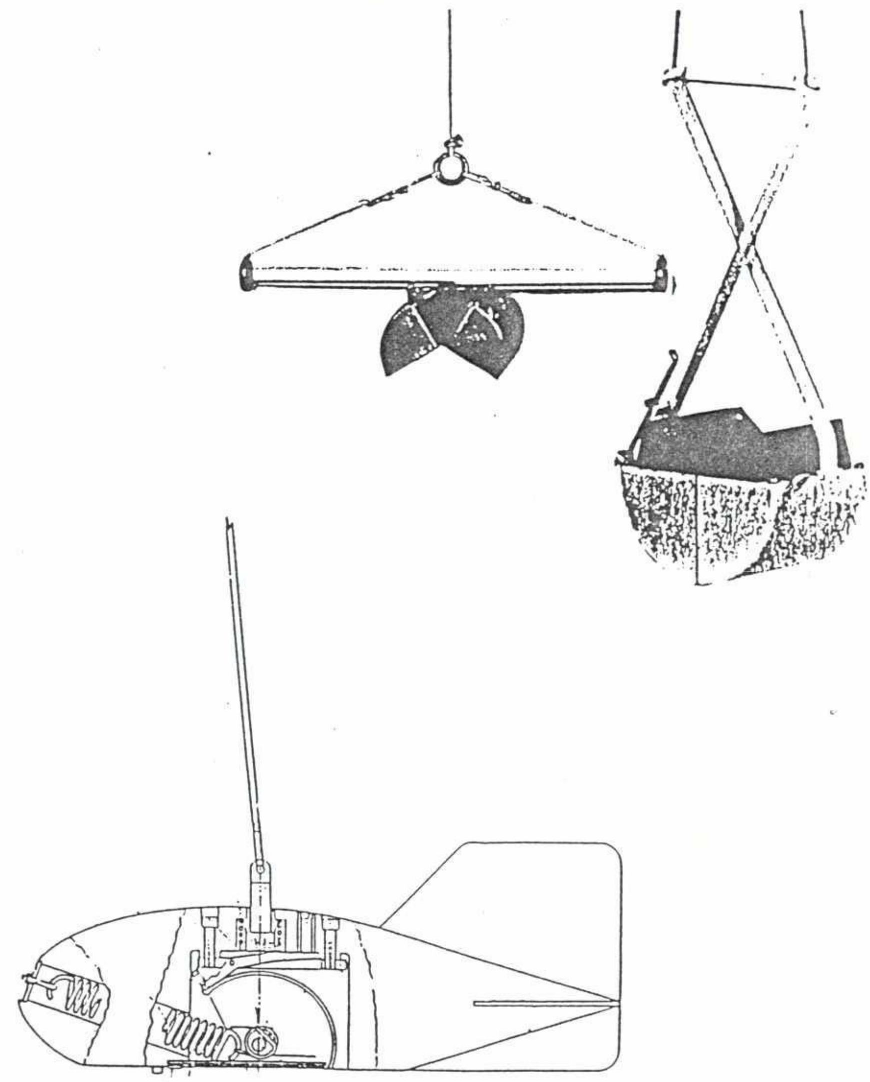


Figure 4.4 Principle sketch of the Van Veen grab and the US BM-54 bed material sampler

4.2 Survey procedures

Two types of gauging programmes have been performed by the River Survey Project:

- o The routine gauging programme
- o The special measurement programme

Survey procedures for the special measurement programme are specifically outlined prior to each special survey.

Survey procedures for the routine gauging programme are defined by the reference method and the recommended method as described in the Test Gauging Report, 31 October 1993. The basic difference between the two methods is the procedure for discharge measurements. The reference method follows the area-velocity concept deploying manual current and suspended sediment sampling , while the recommended method follows the moving boat concept using the ADCP/EMF instrumentation.

Application of the survey equipment described in the preceding sections in the routine gauging programme is governed by the survey procedures. The survey procedures guide the surveyors with respect to the following items:

- o Determination of transect lines
- o Positioning of verticals for current and sediment measurements
- o Number of measurements in a vertical
- o Sampling time
- o Number and amount of sediment samples

4.2.1 Determination of transect lines

Depending on the connection of the braided river channels, transects are distributed to ensure a complete coverage of all channels carrying discharge. To minimize the number of cross-sections, confluent river channels are preferred.

The measurement limitations of the ADCP equipment described in Section 4.1.1 is the primary criterion for the localization of transects and survey lines.

In general a transect is determined as a straight line at right angle to the main current direction in the deepest and most homogeneous cross-section available.

4.2.2 Positioning of verticals, number of measurements and sampling time

When measuring according to the reference method a river cross-section is classified into main channels, smaller channels and shallows. The practical definition of main channels, smaller channels and shallows reads:

- Main channels are defined to be 500 m to 2 km wide (geometric width), maximum depths ranging from 5 m to 25 m, exceptionally amounting to 30 m or even more in intensive scouring holes.
- Smaller channels are defined as having widths ranging from 100 m to 500 m and maximum depths ranging from 3 m to 10 m.
- Shallows are those zones without well defined channels as described above, but where depths are less than 3 m at the moment of the gauging

This classification into main channels, small channels and shallows are illustrated in Figure 4.5 below

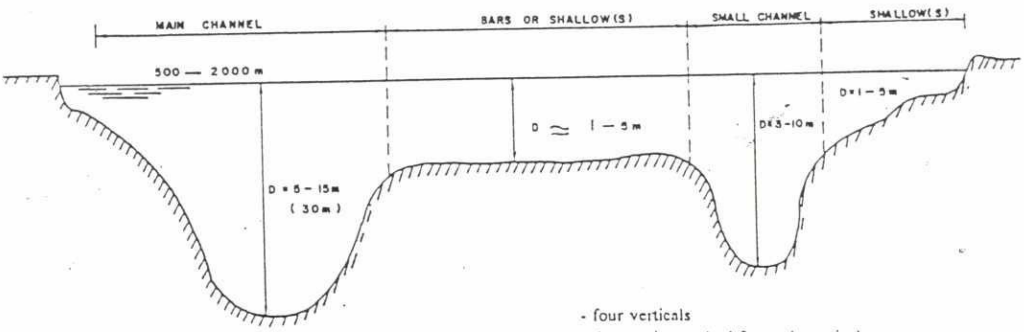


Figure 4.5 Principal classification of a cross-section with indications of main channels, smaller channels, shallows and the accompanying measurement requirements

The spacing of verticals, the number of point current measurements, the number of point sediment samples and the sampling time within main channels, smaller channels and shallows shall comply with the following requirements:

- o Measurement in main channels
  - maximum distance between verticals 100 m
  - six-point method for each vertical
  - 100 second integration time for each velocity sampling, with record of sampling for each 50 second interval

- o Measurement in smaller channels
  - four verticals
  - three-point method for each vertical
  - 100 second integration time for each velocity sampling, with record of sampling for each 50 second interval

- o Measurement in shallows
  - minimum distance between verticals 200 m and at least three verticals
  - three-point measurements for each vertical, if the depth is less than 1 m the one-point method is undertaken
  - 100 second integration time for each velocity sampling, with record of sampling for each 50 second interval

With D denoting total depth the six-point measurements are obtained in the following depths:

- as close to the surface as possible
- 0.2 D
- 0.4 D
- 0.6 D
- 0.8 D
- as close to the river bed as possible

The three-point measurements are obtained in the following depths:

- 0.2 D
- 0.6 D
- 0.8 D

One-point measurements are obtained 0.6 D below the surface.

4.2.3 Number and amount of sediment samples

The suspended sediment samples are obtained during 100 second of continuous pumping from the above mentioned depths. Small fractions of the suspension are collected in a 0.5 l bottle. For this reason the samples are termed pump bottle samples.

The grain size distribution of the suspended sediment is based on a 25 l sample obtained by the suction hose from the lowest sampling level and regardless of the sampling time.

Two Helley-Smith trap samples are obtained from each vertical. In general the trap sampler is deployed for two minutes. In case the trap sampler is completely full of sediment by recovery, a shorter deployment period is attempted.

One river bed material sample is collected in every second vertical using the US-BM 54 sediment sampler.

4.3 Quality assurance

The primary quality assurance is performed aboard the survey vessels according to the current version of the Vessel Survey Quality Plan, 31 May 1993. This plan describes:

- Final calibration
- Checklist for each type of survey
- Standardized file format and naming conventions
- Data logging
- Basic statistic quality check
- Back-up procedures
- Survey log
- Instrument log
- Instrument service

During measurements it relies on the judgement of the surveyor in charge whether a measurement, a transect or a bathymetric survey line is accepted or not. Nevertheless measurements are always accompanied by the surveyors log book describing circumstances and peculiarities.

Owing to the amount and intensity of ADCP data and bathymetric measurements, part of the quality assurance has to be performed by the post processing at the main office. This pertains in particular to visual removal of spikes.

5. Outline of survey data

The final quality assured River Survey Project data are registered in standardized tables. The tables contain file names and sample numbers, and serve as a catalog for more elaborate analyses than the ones presented in the present Survey Report.

Two main types of survey files are produced during the routine gauging programme: Profile and transect survey files. A profile survey file contains measurements of:

- current velocities and direction
- suspended sediment concentrations
- Andreasen settling tube samples
- turbidity
- integrating suspended sediment concentrations
- bottom samples

in a vertical situated in a specific position in the river.

A transect survey file contains measurements in terms of cross-sections by echo sounding and discharge and current profiles by the combined ADCP/EMF moving boat set-up in a pre-determined survey line.

The current profile survey file comprises :

- Date, time and position
- S4 current measurements, north and east velocity, direction and position
- S4 depth, pressure, temperature, conductivity and turbidity

The transect survey file comprises:

- Date, time and survey line
- ADCP and EMF current measurements, north velocity, east velocity, direction and position
- ADCP backscatter record
- Echo-sounding depth, time and position

The other type of data dealing with sediments also contain grain size distribution curves and tables of D_{16}, D_{35}, D_{50}, D_{65} and D_{90} for suspended sediment samples as well as bed load sediment samples and bed material samples. Hard copy formats are available with reference to the respective sample nos.

6. Routine gauging results

6.1 General

The River Survey Project has conducted routine gauging surveys in the areas described in Chapter 3 according to the procedures outlined in Chapter 4. The routine gaugings comprise discharge, suspended sediment transport, bed load sediment transport measurements and sediment sampling. Each gauging site visited during the period from June to October 1993 are described chronologically according to their respective station nos; ref. Table 2.1.

All information presented have been subjected to standard data processing and visual quality assurance. On this basis measurements have either been accepted or discarded.

Part of the original data have been presented previously - mostly in tabular form - in the Survey Bulletin Nos 6 - 23.

The present Survey Data Report serves as a presentation of measurements and only simple analyses and standard data processing are performed. To facilitate more elaborate analyses complete lists of file names and sample identification numbers are included in the respective Survey Bulletins.

The results of an intensive water-level slope gauging campaign carried out at the Bahadurabad cross-section during the second half of 1993 have been presented in a separate Working Paper 5: Water-level slope measurements in Jamuna River at Bahadurabad.

6.2 Cross-sections and survey lines

A typical example on data coverage of a river channel is shown in Fig 6.1 below. The measurements are a combination of individual measurements and complete crossings of channels by typical transect survey lines with the A vessel using the recommended method with combined ADCP/EMF measurements.

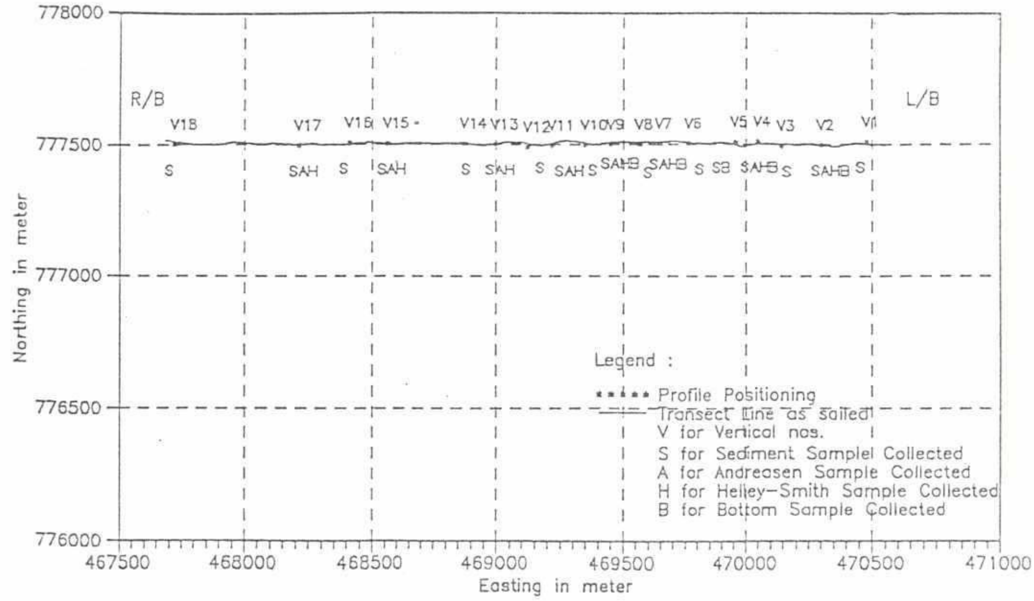


Figure 6.1: Example on BTM positions of survey profiles and transect in the left channel of Jamuna River at Bahadurabad

Though the theoretical end points of each main channel transect are identical it is not possible to follow the same survey line exactly during each transect measurement. Consequently the transect bathymetries exercise small variations with respect to depth, length and area.

The respective track-plots of the transects including their length and area as well as the corresponding cross-sections are displayed and listed in the respective Survey B[illegible]tins ref. Table 2.1.

6.3 Definitions and measurement accuracies

6.3.1 ADCP and EMF measurements (recommended method)

A typical example on current velocity measurements covering a complete cross-section by the recommended method is shown in Figure 6.2 below.

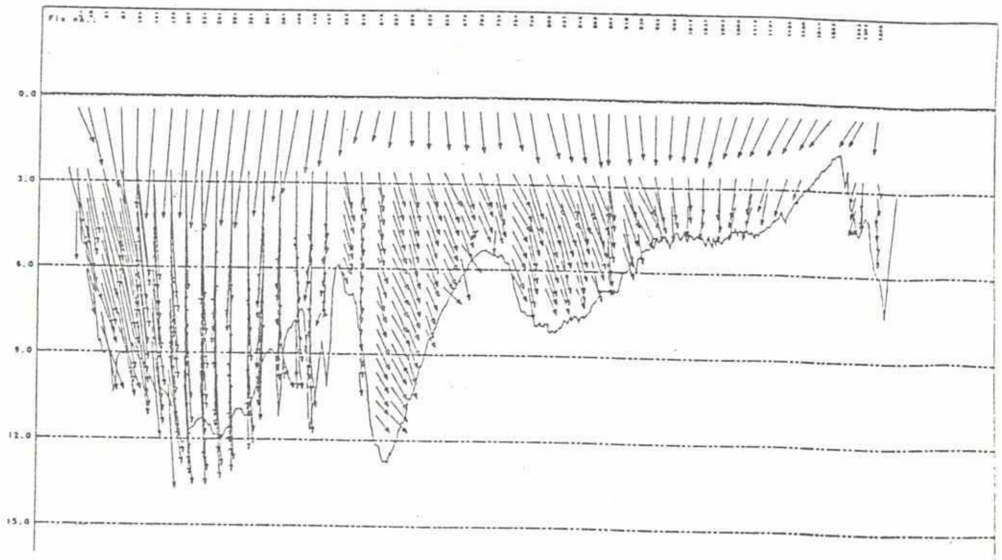


Figure 6.2 Current vector distribution from a typical transect measurement in the left main channel of Jamuna river at Bahadurabad

The length of the current vectors represents the magnitude of the local horizontal current. The current direction is indicated relative to North. The individual current vector is plotted at its vertical position in the cross-section, which is bound by the indicated river bed contour. As long as it is kept in mind that all velocity vectors represent horizontal velocities this mixed projection should cause no confusion.

The uncertainty of individual ADCP current measurements consists of a long-term bias error and a short term random error. The dominant random error depends on acoustic frequency, depth cell length, acoustic pulse rate, acoustic beam angle and measurement interval. With the specific settings of the 300 kHz ADCP operated by the River Survey Project, a velocity measurement uncertainty of approximately 10 cm/s must be expected according to manufacturer information; ref. RD Instruments, product information.

The uncertainty on individual EMF (E-type 40 mm diam.) current measurements is 10 cm/s.

The accuracy of discharge measurements is also influenced by flood waves and large scale eddies in the river.

6.3.2 S4 measurements (reference method)

The electronic measurement uncertainty of the S4 electromagnetic current meter is normally within 1 cm/s.

The related discharge calculation is based on the velocity area method described in ISO 749 -1979.

6.3.3 Suspended sediment transport

The uncertainty in determination of the suspended sediment transport is estimated to be analogous to the uncertainty of the discharge measurements mentioned above and thereby not considering the uncertainty of the suspended sediment concentration.

6.4 Bahadurabad gauging site - station 1

6.4.1 Measurement periods

During the flood season of 1993 the gauging site - station 1 - in Jamuna River at Bahadurabad has been covered with measurements as follows :

Station	Recommended method	Reference method	Measurements periods in 1993	Data summary in Survey Bulletin No.
1	Q	$Q+S_S+S_B$ $Q+S_S+S_B$ $Q+S_S+S_B$	a) 03-09 June b) 09-17 July c) 23-24 August d) 06-11 September	06 07 10 11

Q : Discharge; S_S : Suspended sediment transport
S_B : Bed load transport

Table 6.1 Gauging programme as made in Jamuna River at Bahadurabad during the flood season of 1993

a) - b) and d) were routine measurements while c) was a special campaign with comparative measurements with BWDB; ref. Chapter 7.

6.4.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration a fraction of the velocity profiles from transect B3961T02 in the left channel and from transect B3991To1 in the right channel are displayed in Figures 6.3 and 6.4.

Current velocities from 0.4 m/s to 2.5 m/s were measured in the left main channel on the 6 September 1993. Some directional variation is observed within the individual verticals as well as within the entire cross-section.

Current velocities from 0.2 m/s to 2.0 m/s were measured in the right main channel on the 9 September 1993. A significant directional variation is observed within the individual verticals as well as within the entire cross-section.

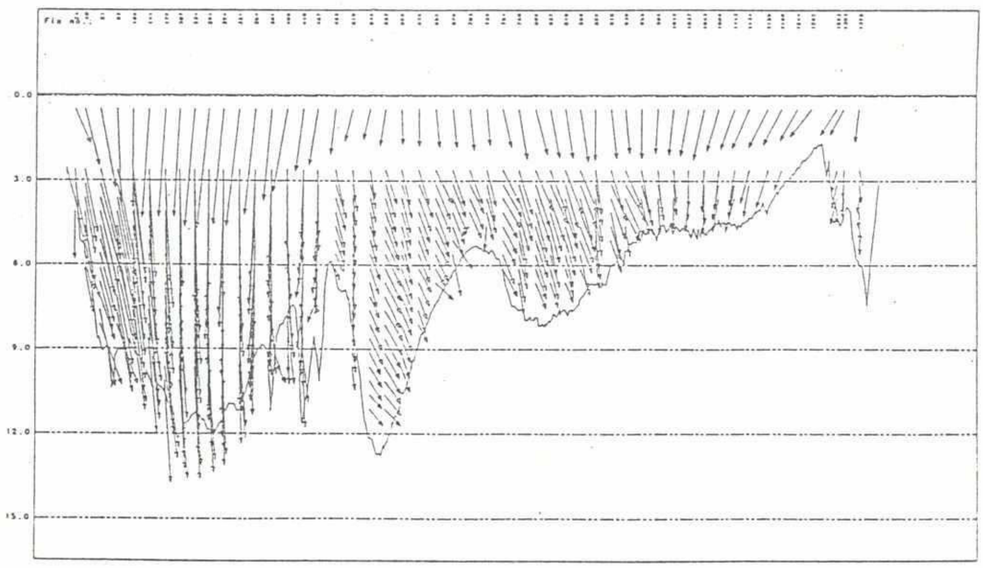


Figure 6.3 Current vectors from transect B3961T02 in the left main channel of Jamuna River, 6 September 1993

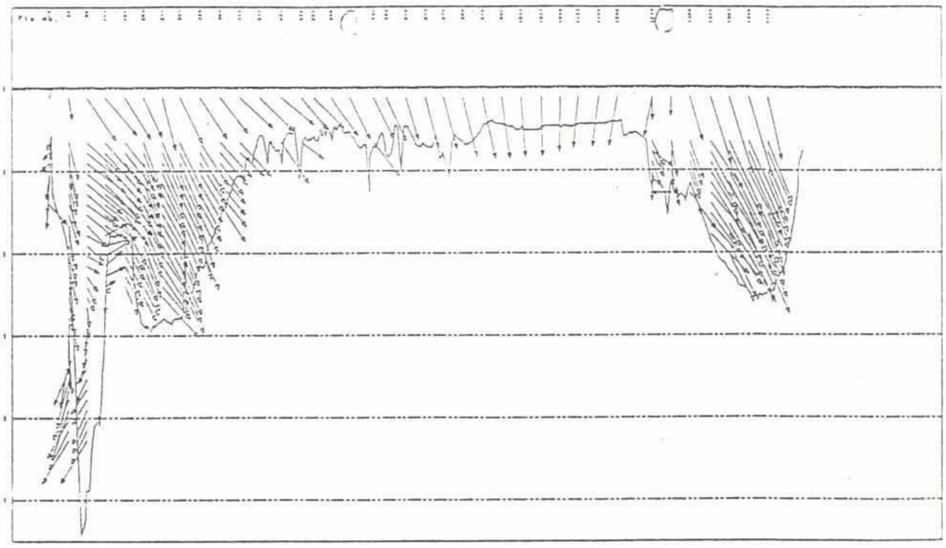


Figure 6.4 Current vectors from transect B3991T01in the right main channel of Jamuna River, 9 September 1993

All the discharge gaugings carried out at Bahadurabad involving measurements in up to 4 channels have been listed in table 6.2 below.

Date	Water-level m +PWD		Discharge m³/s	Transect filenames are listed in
	L	R		
06/06/1993	16.95	15.73	18,100	Survey Bulletin No. 6
13/07/1993	19.67	18.41	43,400	Survey Bulletin No. 7
11/09/1993	18.47	16.02	37,200	Survey Bulletin No. 11

L : Left channel at Bahadurabad Ghat
R : Right channel at Fulchari Ghat

Table 6.2 Water-level and discharge at Bahadurabad, Jamuna River

Further details including the flow distribution between the individual channels are presented in the respective Survey Bulletin Nos. 6, 7, and 11.

S4-current measurement (reference method)
All the current measurements by S4 instrument in the Bahadurabad cross-section are listed in the respective Survey Bulletins Nos 6, 7, and 11, ref. Table 2.1.

The velocity profiles are shown in Annexure 3.

During peak flow condition in July 1993 current velocities were measured from 0.6 m/s to 3.6 m/s in the left channel and from 0.5 m/s to 2.0 m/s in the right channel.

The total discharge in the cross-section has been calculated using the velocity - area method. Table 6.3 shows the discharge and lists the Survey Bulletins containing the filemanes used to determine the average bathymetric sectional area.

Date	Water-level m +PWD (mean values)		S4 discharge m^3/s	Bathymetry filenames are listed in
	L	R		
3-9 June	17.30	16.10	21,000	Survey Bulletin No. 6
9-17 July	19.75	18.50	45,300	Survey Bulletin No. 7
6-11 September	18.78	16.26	43,500	Survey Bulletin No. 11

L : Left channel at Bahadurabad Ghat
R : Right channel at Fulchari Ghat

Table 6.3 Discharge based on point integrating S4 current measurements

Due to the long measurement periods involved in covering the wide river channels at Bahadurabad by the point integrating S4 measurements it should be noted that a direct comparison between the calculated discharges in Table 6.2 and Table 6.3 is irrelevant.

The values measured by the recommended method represents a daily mean value, while the velocity - area method provided a mean value of some days, during which even the water-levels have been changing significantly.

6.4.3 Suspended sediment transport measurements

All the suspended sediment concentration samples collected in the Bahadurabad cross-section have been listed in the respective Survey Bulletins Nos. 6, 7, and 11; ref Table 2.1. The corresponding plots of suspended sediment concentrations profiles are presented in Annexure 3.

During peak flow condition in July 1993 suspended sediment concentrations were measured from 372 mg/l to 6185 mg/l in the left channel and from 277 mg/l to 1927 mg/l in the right channel.

Using the velocity area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.4 below.

Date	Suspended sediment transport kg/s	Bathymetry filenames are listed in
3-9 June, 1993	11,400	Survey Bulletin No. 6
9-17 July, 1993	49,900	Survey Bulletin No. 7
6-11 Sept., 1993	31,700	Survey Bulletin No. 11

Table 6.4 Suspended sediment transport in Jamuna River at Bahadurabad

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} in each routine gauging cross-section is listed in Table 6.5.

Date of manual suspended sediment measurement	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-9 June, 1993	0.021	0.007
9-17 July, 1993	0.066	0.044
6-11 September, 1993	0.057	0.040

Table 6.5 Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

A summary table of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 33, 67, 70 and 85 per cent scatter respectively.

6.4.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. All the measurement results have been listed in the respective Survey Bulletin Nos. 6, 7, and 11; ref. Table 2.1.

The total bed load transport has been estimated by multiplying the average transport rates by the distance between the samples and the respective bank lines. The estimated bed load transport is listed in Table 6.6 below.

Date of Helley-Smith bed load sample	Bed load sediment transport kg/s
3-9 June, 1993	322
9-17 July, 1993	344
6-11 September, 1993	395

Table 6.6 Helley-Smith bed load transport measurements at Bahadurabad cross-section

As expected the samples and results show a large scatter.

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average values $\mu(D_{50})$ and the sectional standard deviations $\sigma(D_{50})$ of the D_{50} mean grain diameter are listed in Table 6.7 below.

Date of Helley-Smith bed load sampling	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-9 June, 1993	0,233	0.068
9-17 July, 1993	0,225	0.071
6-11 September, 1993	0,260	0.072

Table 6.7 Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith bed load samples

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviations the samples exhibit a 29, 32 and 28 per cent scatter respectively.

6.4.5 Bed material sampling

River bed material samples have been collected by using the US BM 54 snap-shot sampler. Grain size distribution analysis has been performed for each sample and the sectional average values μ (D_{50}) and the standard deviation σ (D_{50}) are listed in Table 6.8 below.

Date of bed material sampling	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-9 June, 1993	0.189	0.077
9-17 July, 1993	0.188	0.067
6-11 September, 1993	0.172	0.061

Table 6.8 Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviation the samples exhibit a 41, 36, 35 and 40 per cent scatter respectively.

6.5 Sirajganj gauging site - station 2

6.5.1 Measurement periods

During the flood season of 1993 the gauging site - station 2 - in Jamuna River at Sirajganj has been covered with measurements as follows:

Station	Recommended method	Reference method	Measurements periods in 1993	Data summary in Survey Bulletin No.
2	Q Q+S_S	Q+S_S+S_B	a) 21-30 July b) 17 September c) 24-27 October	08 12 23

Q : Discharge; S_S : Suspended sediment transport
S_B : Bed load transport

Table 6.9 Gauging programme as made in Jamuna River at Sirajganj during the flood season of 1993

6.5.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration an example of the distribution of the velocity profiles from transect S37T1T02 covering the left channel of Jamuna River at Sirajganj is shown in Figure 6.5 below.

During peak flow conditions in July current velocities were measured from 0.5 m/s to 1.6 m/s in the left channel and from 0.5 m/s to 2.0 m/s in the right channel. Some directional variation has been observed within the cross-sections.

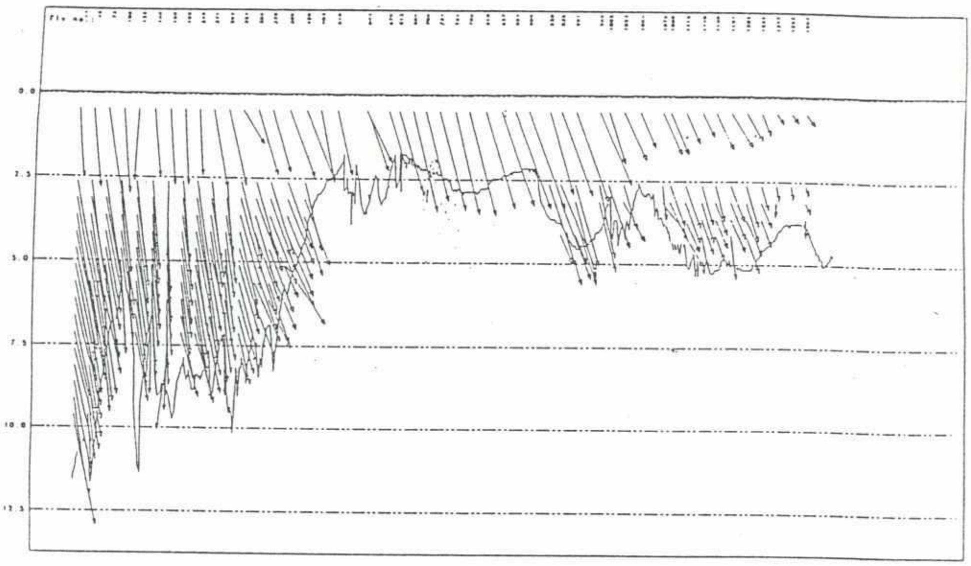


Figure 6.5 : Current vectors from transect S37T1T02 in the left channel of Jamuna River at Sirajganj, 29 July 1993

The corresponding discharge calculations are listed in the Table 6.10 below.

Date and Time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
23/7/93 15:52 to 16:59	13.73	52,260	S37N1TO1 & 02
26/7/93	13.50	44,420	S37Q1TO3 & 04
17/9/93 14:43 to 16:15	12.84	32,560	S39H1TO1 & 02 S39H1TO3 & 04
26/10/93	11.34	19,995	S3AQ1T03 & 04 S3AR1T01 & 02

Table 6.10 : Water-levels and discharges in Jamuna River at Sirajganj

S4 current measurement (reference method)
All the current measurements by S4 instrument in the Sirajganj cross-section are listed in the respective Survey Bulletins Nos 8 and 23 ; ref Table 2.1.

The velocity profiles are shown in Annexure 3 and an example on plotting in a similar way as the transect current vectors in Figures 6.6 below.

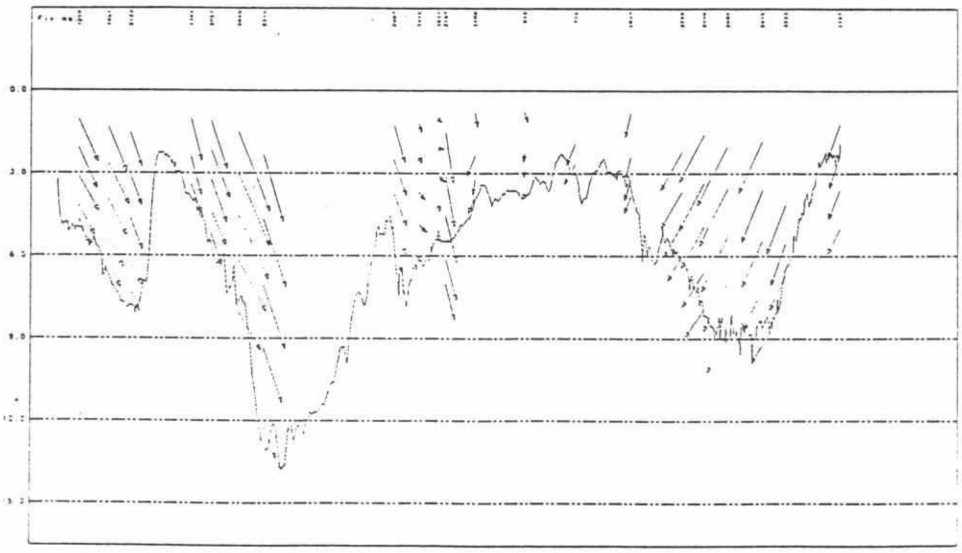


Figure 6.6 : Plot of S4 current profiles from verticals in the left channel of Jamuna River at Sirajganj

The total discharge on the entire river cross-section has been calculated using the velocity - area method. Table 6.11 shows the discharge and lists the filenames used to establish the average bathymetric sectional area.

Date	Water-level m +PWD	S4 discharge m^3/s	Bathymetry (filenames)
21 - 30 July 1993	13.50	50,159	S37N1T01 & 02 S37Q1T03 & 04
24 - 27 October 1993	11.47	19,424	S3AQ1T03 & 04 S3AR1T01 & 02

Table 6.11 : Discharge based on point integrating S4 current measurements

The best estimate of the S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 4 per cent and 3 per cent is found by comparing average discharges.

6.5.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in the Sirajganj cross-section have been listed in the respective survey Bulletins Nos 8 and 23; ref. Table 2.1. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

During the first measurement campaign in July suspended sediment concentration from 500 mg/l to 2700 mg/l were measured and in October 200 mg/l to 3300 mg/l were measured.

Using the velocity - area method and the related flow field distribution multiplied by the suspended sediment concentrations, the suspended sediment transport has been calculated in Table 6.12 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
21 - 30 July 1993	54,385	S37N1T01 & 02 S37Q1T03 & 04
24 - 27 October 1993	11,748	SAQ1T03 & 04 S3AR1T01 & 02

Table 6.12 Suspended sediment transport in Jamuna River at Sirajganj

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value μ (D_{50}) and the standard deviation σ (D_{50}) of the mean grain diameter D_{50} is listed in Table 6.13 below.

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 49 and 66 per cent scatter.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
21 - 30 July 1993	0.061	0.03
24 - 27 October 1993	0.061	0.04

Table 6.13 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

6.5.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. All the results have been listed in Survey Bulletin No. 8; ref. Table 2.1.

The total bed load transport has been estimated by multiplying the average transport rates by the distance between the samples and the respective bank lines. The estimated bed load transport is estimated in Table 6.14 below.

Date of Helley-Smith bed load sampling	Bed load sediment transport kg/s
21-30 July 1993	556

Table 6.14 : Helley-Smith bed load transport measurements in Jamuna River at Sirajganj

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the D_{50} mean grain diameter are listed in Table 6.15 below.

Date of Helley-Smith bed load sampling	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
21-30 July 1993	0.203	0.07

Table 6.15 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith samples.

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 34 per cent scatter.

6.5.5 Bed material sampling

Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ is listed in Table 6.16.

Date of bed material sampling	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
21-30 July 1993	0.163	0.07

Table 6.16 Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviation the samples exhibit a 43 per cent scatter.

6.6 Aricha gauging site - station 3

6.6.1 Measurement period

During the flood season of 1993 the gauging site - station 3 - in Jamuna river at Aricha just up-stream of the confluence with Ganges River has been covered only once with a discharge measurement (Q) following the recommended method.

The measurements were carried out on the 19th September 1993 and the results have been summarized in Survey Bulletin No.13.

6.6.2 Current velocities and discharge measurements

As also mentioned in Chapter 3.4 it turned out to be impossible to find a suitable cross-section for the recommended method north of Aricha as planned and instead a series of transects were carried out in sub-sections as shown in Figure 3.9.

For illustration the sectional distribution of the velocity profiles from transect A39J1T09 covering the left channel of Jamuna River downstream of Aricha is shown in Figure 6.7 below.

Current velocities were measured from 0.5 m/s to 1.8 m/s. Nearly no directional variation has been observed in the individual verticals while some variation is observed between the channels.

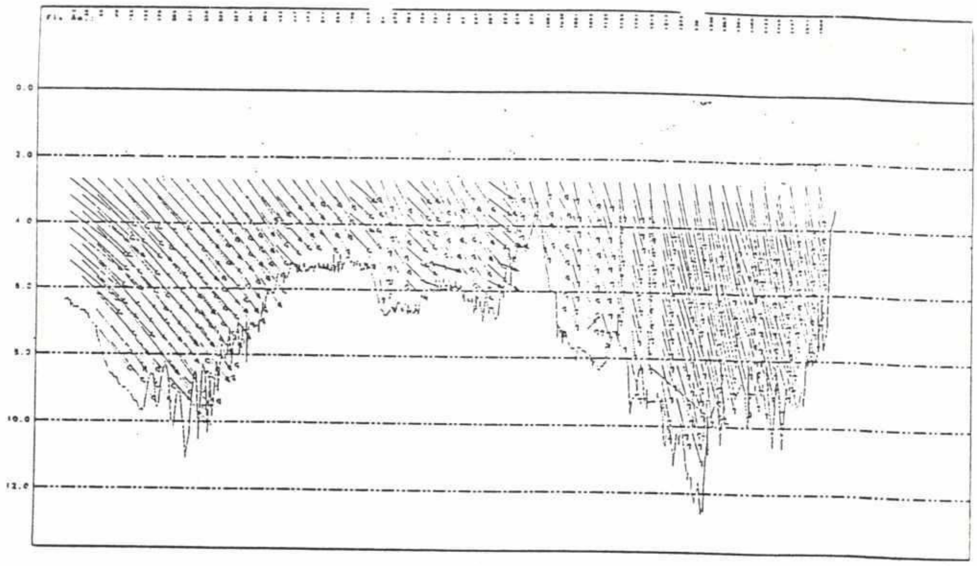


Figure 6.7 : Current vectors from transect A39J1T09 in the left channel of Jamuna River downstream of Aricha 19 September 1993

The calculated discharge is listed in Table 6.17 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filenames)
19/9/93 11:20 to 13:42	8.68	32,232	A39J1T02 A39J1T06 A39J1T07 A39J1T08

Table 6.17 : Water-level and discharge in Jamuna River at Aricha

6.7 Hardinge Bridge gauging site - station 4

6.7.1 Measurement period

During the flood season of 1993 the gauging site - station 4 - in Ganges River just down-stream of Hardinge Bridge has been covered only once with measurements of discharge (Q), suspended sediment (S_S), and bed load transport (S_B) following the reference method.

The measurements were carried out on 26-28 September, 1993 and the results have been summarized in Survey Bulletin No.15.

6.7.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration the sectional distribution of the velocity profiles from transect H39T1T01 covering the entire cross-section of Ganges River at approximately 1000 m downstream of Hardinge Bridge, is shown in Figure 6.8 below.

Current velocities were measured from 0.4 m/s at the left bank to 4.3 m/s in the main channel. Nearly no directional variation has been observed in the individual verticals. A minor variation is observed in the main channel.

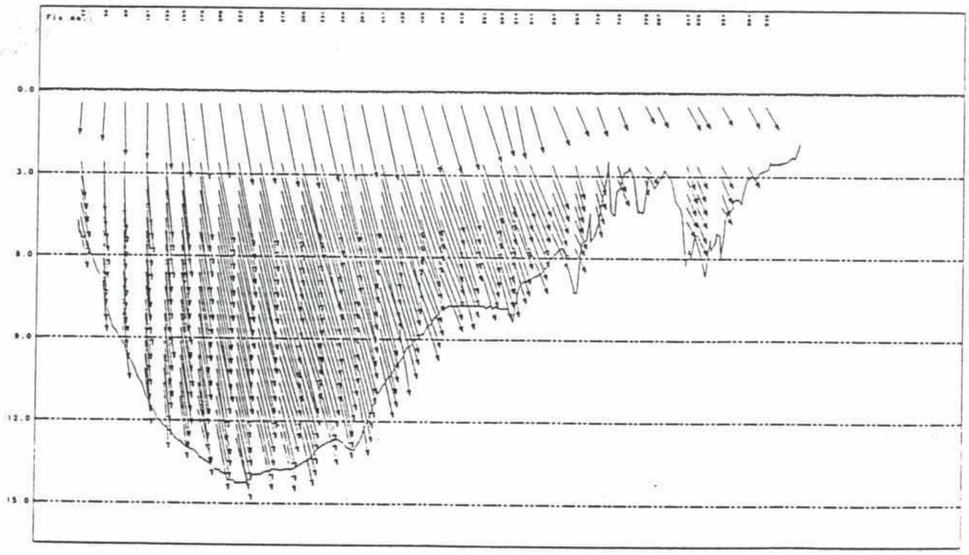


Figure 6.8 : Current vectors from transect H39T1T01 in Ganges River downstream of Hardinge Bridge, 28 September 1993

All together 12 transects (6 double crossings) were surveyed on 26-29 September 1993 and the corresponding discharge calculations are listed in Table 6.18 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
26/9/93 11:50 to 13:03	13.66	38,695	H39Q1T02 &05
26/9/93 17:41 to 18:17	13.66	41,271	H39Q1T07 &08
27/9/93 08:59 to 09:39	13.65	40,968	H39R1T01 &02
28/9/93 08:13 to 08:56	13.71	42,232	H39S1T01 &02
28/9/93 16:54 to 17:11	13.71	40,832	H39S1T03 &04
28/9/93 08:10 to 08:49	13.74	42,993	H39T1T01 &02

Table 6.18 : Water-levels and discharges in Ganges River down-stream of Hardinge Bridge

S4 current measurement (reference method)
The current measurements by S4 instrument at Hardinge Bridge are listed in Survey Bulletin No. 15.

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transect current vectors in Figure 6.9 below.

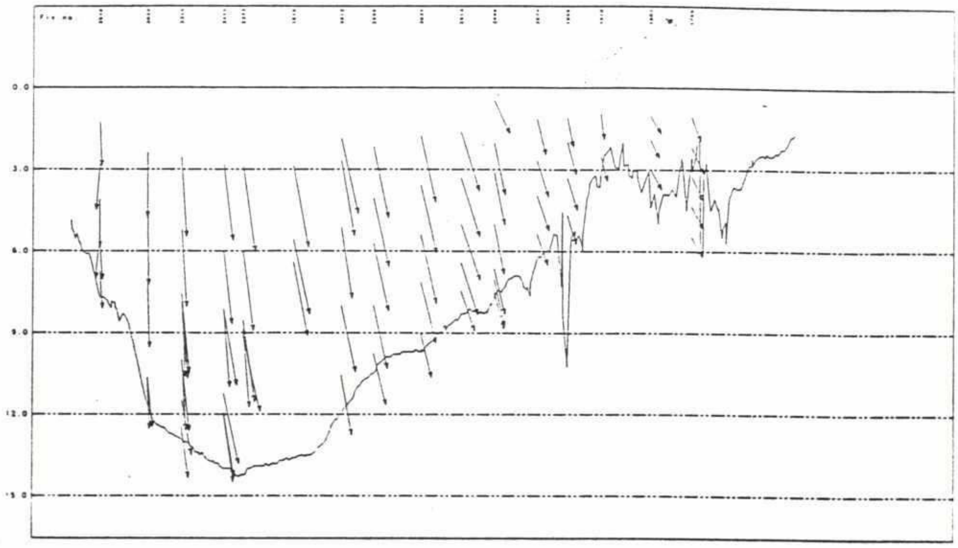


Figure 6.9 : Plot of S4 current velocities from verticals 1 to 16 in Ganges River downstream of Hardinge Bridge, 26-29 September 1993

Current velocities were measured in the range of 0.91 m/s at the left bank to 3.95 m/s in the main channel.

The total discharge in the cross-section has been calculated using the velocity-area method. Table 6.19 shows the discharge and lists the filenames used to determine the average bathymetric sectional area

Date	S4 discharge m^3/s	Bathymetry (filenames)
26-29 September, 1993	44,684	H39Q1T02,05,07 & 08 H39R1T01 & 02 H39S1T01,02,03 & 04 H39T1T01 &02

Table 6.19 : Discharges based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transect described above. A discrepancy of 9 per cent is found by comparing average discharges.

6.7.3 Suspended sediment transport measurement

The suspended sediment concentration samples collected in Ganges River have been listed in the Survey Bulletin No. 15; ref. Table 2.1. The corresponding plots of the suspended sediment concentration profiles are presented in Annexure 5.

Suspended sediment concentrations from 1120 mg/l to 6520 mg/l were measured. Maximum concentrations occur in the main channel following the right bank.

Using the velocity - area method and the related flow field distribution multiplied by the suspended sediment concentration distribution, the suspended sediment transport has been calculated in Table 6.20 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
26-29 September, 1993	83,323	H39Q1T02,05,07 & 08 H39R1T01 & 02 H39S1T01,02,03 & 04 H39T1T01 &02

Table 6.20 : Suspended sediment transport in Ganges River, 26-29 September 1993

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.21.

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional deviation the samples exhibit a 37 per cent scatter.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
26-29 September, 1993	0.027	0.01

Table 6.21 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

6.7.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. All the measurement results have been listed in Survey Bulletin No. 15; ref. Table 2.1 and a summary is presented in Table 6.22 below.

Vertical and Samples No.	Bed load sediment transport kg/ms	
1 , sample 1 & 2	0.281469	0.174452
9 , sample 1 & 2	0.457456	0.318640
11 , sample 1 & 2	0.173574	0.554230
12 , sample 1 & 2	0.058179	0.068640
14 , sample 1 & 2	0.013377	0.187060
16 , sample 1 & 2	0.014945	0.047971
18 , sample 1 & 2	0.008662	0.004989

Table 6.22 : Helley-Smith bed load sampling in Ganges River downstream of Hardinge Bridge, 26-29 September 1993

As expected the samples show a large scatter.

The total bed load transport has been estimated by multiplying the average transport rates from Table 6.22 by the distance between the samples and to the respective bank lines.

The total bed load is estimated to 410 kg/s.

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the D_{50} mean grain diameter in the cross-section is listed in Table 6.23.

Date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
26-29 September 1993	0.213	0.05

Table 6.23 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith samples in Ganges River at Hardinge Bridge

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 23 per cent scatter.

6.7.5 Bed material sampling

Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.24 below.

Date of bed material sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
26-29 September 1993	0,177	0.004

Table 6.24 : Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples in Ganges River at Hardinge Bridge

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviation the samples exhibit a 2 per cent scatter.

6.8 Baruria gauging site - station 5

6.8.1 Measurement periods

During the flood season of 1993 the gauging site - station 5 - in Padma River at Baruria has been covered with measurements as follows.

Station	Recomme n- ded method	Reference method	Measurements periods in 1993	Data summary in Survey Bulletin No.
5		$Q+S_S+S_B$	a) 03-09 August	09
	Q		b) 19 September	14
	Q		c) 01 October	17
		$Q+S_S+S_B$	d) 19-22 October	22

Q : Discharge; S_S : Suspended sediment transport
S_B : Bed load transport

Table 6.25 : Gauging programme as made in Padma River at Baruria during the flood season of 1993

6.8.2 Current velocities and discharge measurement

ADCP and EMF measurements (recommended method)
For illustration an example of the sectional destribution of the velocity profiles from transect U3A11T05 covering the entire cross-section of Padma River at Baruria is displayed in Figure 6.10 below.

During the peak flow conditions current velocities were measured from 0.3 m/s in the small channel following the right bank to 3.0 m/s in the main channel.

Nearly no directional variation is observed within the vertical nor within the entire cross-section.

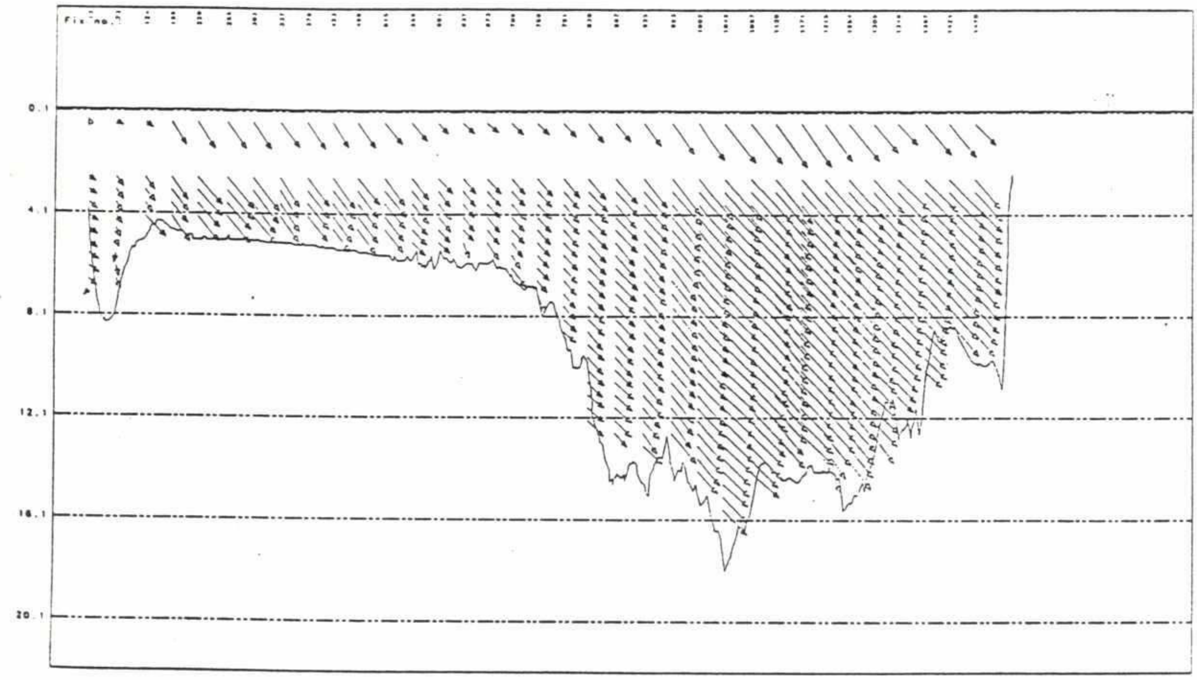


Figure 6.10 : Current vectors from transect U3AM1T02 covering the entire cross-section in Padma River at Baruria, 1st October 1993

The discharge calculations for the individual measurements are listed in Table 6.26 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
04/08/93 9:30 to 9:52	7.35	52,654	U3841T01
05/08/93 8:29 to 17:24	7.30	50,458	U3851T01 & 02
06/08/93 8:03 to 17:47	7.29	52,816	U3861T01 & 02
07/08/93 7:42 to 17:36	7.35	54,425	U3871T01 & 02
08/08/93 8:57 to 9:22	7.44	56,875	U3881T06
19/09/93 14:08 to 14:37	7.73	68,288	U39J1T01
01/10/93 14:14 to 15:16	7.72	71,240	U3A11T04 & 05
19/10/93 8:29 to 17:52	6.53	37,565	U3AJT01,02, 03,& 04
20/10/93 8:02 to 17:21	6.42	35,100	U3AK1T01, 02,03 & 04
22/10/93 9:32 to 16:32	6.29	36,564	U3AM1T01 &02

Table 6.26 : Water-levels and discharges in Padma River at Baruria

S4 current measurement (reference method)

The current measurements by S4 instrument in Padma Rivers at Baruria are listed in the respective survey Bulletins Nos. 9 and 22; ref. Table 2.1.

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transect current vectors in Figure 6.11 below.

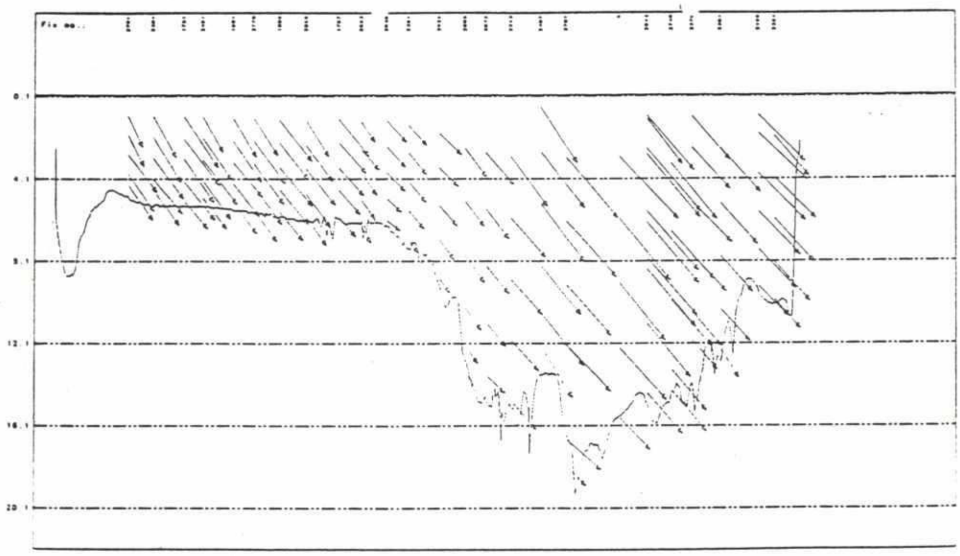


Figure 6.11 : Plot of S4 current velocities from verticals 1 to 26 in Padma River at Baruria, 19-22 October 1993

During the first measurement campaign in August current velocities were measured in the range of 0.26 m/s to 3.52 m/s. During the measurements in October the velocities were measured in the range of 0.43 m/s to 2.35 m/s.

The total discharge in the cross-section has been calculated using the velocity area method. Table 6.27 shows the discharge and lists the filenames used to determine the average bathymetric sectional area.

Date	Water-level m +PWD	S4 discharge m^3/s	Bathymetry (filenames)
3-8 August 1993	7.35	59,305	U3841T01 U3851T01 & 02 U3861T01 & 02 U3871T01 & 02 U3881T06
19-22 October 1993	6.41	34,161	U3AJ1T01,02,03 & 04 U3AK1T01,02, 03 & 04 U4AL1T01,02 & 03 U3AM1T01,02 & 03

Table 6.27 : Discharge based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of between 11 per cent and 2 per cent is found by comparing average discharges.

6.8.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in the Baruria cross-section have been listed in the respective survey Bulletins Nos.9 and 22. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

During the first measurement campaign in August suspended sediment concentrations from 265 mg/l to 5,115 mg/l were measured.

During the measurements in October the concentrations varied between 177 mg/l and 3400 mg/l.

Using the velocity area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.28 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
3-8 August, 1993	56,392	U3841T01 U3851T01 & 02 U3861T01 & 02 U3871T01 & 02 U3881T06
19-22 October, 1993	18,738	U3AJ1T01,02,03 & 04 U3AK1T01,02,03 & 04 U4AL1T01,02 & 03 U3AM1T01,02 & 03

Table 6.28 : Suspended sediment transport in Padma River at Baruria

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.29 below.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-8 August, 1993	0.027	0.01
19-22 October, 1993	0.056	0.04

Table 6.29 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 37 and 71 per cent scatter.

6.8.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. All the measurement results have been listed in the respective Survey Bulletins Nos. 9 and 22; ref. Table 2.1

The total bed load transport has been estimated by multiplying the average transport rates by the distance between the samples and to the respective bank lines. Table 6.30 lists the estimated bed load transport.

Date	Bed load sediment transport kg/s
3-8 August 1993	277
19-22 October 1993	154

Table 6.30 : Helley-Smith bed load sampling in Padma River at Baruria

As expected the samples show a large scatter.

Grain size distribution analysis has been performed for each Helley-Smith sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the D_{50} mean grain diameter in the cross-section is listed in Table 6.31.

Date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-8 August 1993	0.159	0.06
19-22 October 1993	0.266	0.36

Table 6.31 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith samples in Padma River at Baruria

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 38 and 135 per cent scatter.

6.8.5 Bed material sampling

Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.32.

Date of bed material sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-8 August, 1993	0.137	0.03
19-22 October, 1993	0.140	0.04

Table 6.32 : Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples in the Padma River at Baruria

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviations the samples exhibit a 22 and 29 per cent scatter.

6.9 Mawa gauging site - station 6

6.9.1 Measurement period

During the flood season of 1993 the gauging site - station 6 - in Padma River has been covered only once with measurements of discharge (Q), suspended sediment (S_S), and bed load transport (S_B) following the reference method.

The measurements were carried out on 3-7 October 1993 and the results have been summarized in Survey Bulletin No.18.

6.9.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration the sectional distribution of the velocity profiles from transect M3A61T01 covering the entire cross-section at Mawa is displayed in Figure 6.12 below.

Current velocities were measured from 0 m/s to 0.7 m/s in the left main channel and from 0 m/s to 2.0 m/s in the right main channel respectively.

Nearly no directional variation is observed within the individual verticals but a shift in direction in the order of 45° between the left and right channel is observed.

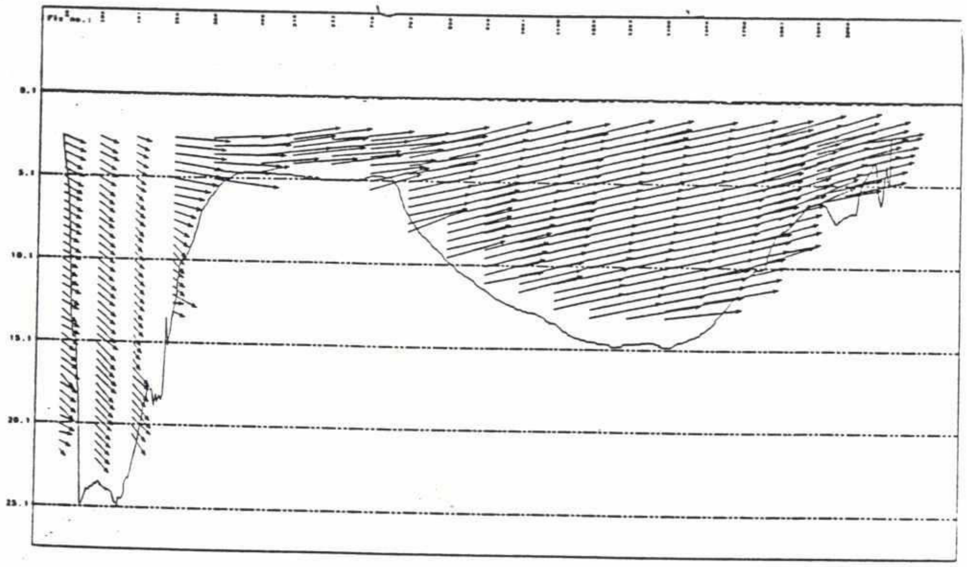


Figure 6.12 : Current vector from transect M3A61T01 in Padma River at Mawa, 6 October 1993

The corresponding discharge calculations are listed in table 6.33 below

Date and time	Water-level m +PWD	Discharge m³/s	Transect (filename)
3/10/93 07:48 to 09:00	5.53	62,538	M3A31T01 & 02
4/10/93 17:17 to 18:17	5.46	61,785	M3A41T01 02 & 03
6/10/93 11.02 to 12:08	5.40	60,778	M3A61T01 & 02
6/10/93 16:20 to 17:44	5.41	61,935	M3A61T03 & 04
7/10/93 80:30 to 09:38	5.27	59,298	M3A71T01 & 02

Table 6.33 Water-levels and discharges in Padma River at Mawa, 3-10 October 1993

S4-current measurement (reference method)
All the current measurements by S4 instrument in the Mawa cross-section are listed in the Survey Bulletin No 18, ref. Table 2.1.

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transects current vectors in Figure 6.13 below

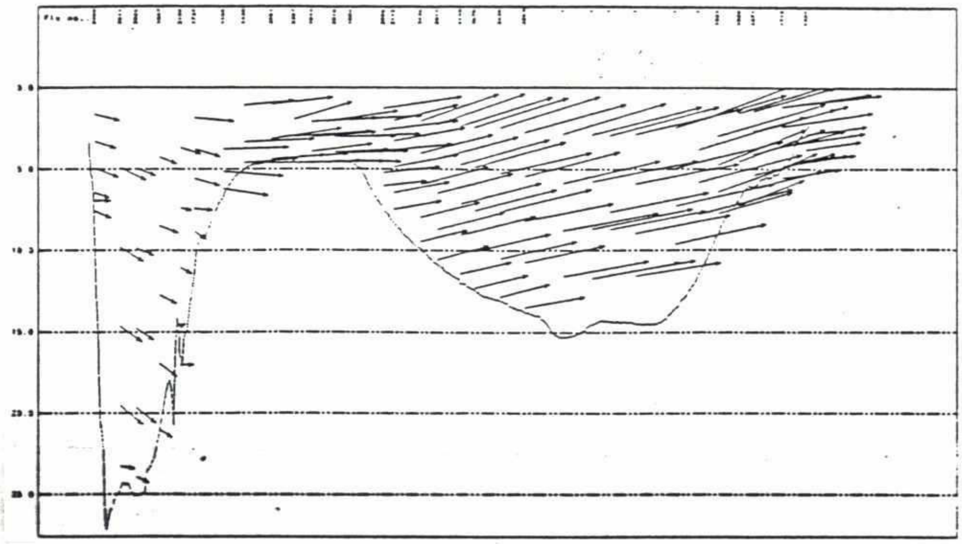


Figure 6.13 : Plot of S4 current velocities from verticals 1 to 34 in Padma River at Mawa, 3-7 October 1993

Current velocities were measured from 0.13 m/s to 0.7 m/s in the left main channel and from 1.4, m/s to 3.0 m/s in the right main channel respectively.

The shift in current direction between the left and right channel is observed.

The total discharge in the cross-section has been calculated using the velocity area method. Table 6.34 shows the discharge and lists the filenames included to establish the average bathymetric sectional area.

Date	S4 discharge m^3/s	Bathymetry (filenames)
3-7 October 1993	64,471	M3A31T01 & 02 M3A41T01, 02 & 03 M3A61T01 & 02 M3A61T03 & 04 M3A71T01 & 02

Table 6.34 : Discharge based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 5 per cent is found by comparing average discharges.

6.9.3 Suspended sediment transport measurements

All the suspended sediment concentration samples collected in the Mawa cross-section have been listed in Survey Bulletin No. 18; ref Table 2.1. The corresponding plots of suspended sediment concentrations profiles are presented in Annexure 3.

Suspended sediment concentrations from 17 mg/l to 8000 mg/l were measured.

Using the velocity-area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.35 below.

Date	S4 discharge m^3/s	Bathymetry (filenames)
3-7 October 1993	84,510	M3A31T01 & 02 M3A41T01, 02, & 03 M3A61T01 & 02 M3A61T03 & 04 M3A71T01 & 02

Table 6.35 : Suspended sediment transport in Padma River at Mawa, 3-7 October 1993

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} in each routine gauging cross-section is listed in Table 6.36.

200

Date of suspended sediment measurement	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-7 October, 1993	0.058	0.03

Table 6.36 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 52 per cent scatter.

6.9.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. All the measurement results have been listed in the Survey Bulletin No.18 and ref. Table 2.1.

The total bed load transport has been estimated by multiplying the measured average transport rates by the distance between the samples and the respective bank lines.

The total bed load is presented in Table 6.37 below.

Date	Bed load sediment transport kg/s
3-7 October 1993	255

Table 6.37 : Helley-Smith bed load sampling in Padma River at Mawa 3-7 October 1993

As expected the samples show a large scatter.

Grain size distribution analysis has been performed for each Helley-Smith sample. The sectional average values $\mu(D_{50})$ and the sectional standard deviations $\sigma(D_{50})$ of the D_{50} mean grain diameter are listed in Table 6.38.

Date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-7 October, 1993	0.139	0.06

Table 6.38 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith bed load samples in Padma River at Mawa

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviations the samples exhibit a 43 per cent scatter.

6.9.5 Bed material sampling

Grain size distribution analysis has been performed for each bed material sample and the sectional average values μ (D_{50}) and the standard deviation σ (D_{50}) are listed in Table 6.39.

Date of bed material sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
3-7 October 1993	0.118	0.04

Table 6.39: Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples in Padma River at Mawa

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviation the samples exhibit a 34 per cent scatter.

6.10 Tilly gauging site - station 8

6.10.1 Measurement period

During the flood season of 1993 the gauging site - station 8 - in Dhaleswari River at Tilly has been covered only once with measurements of discharge (Q) and suspended sediment transport (S_S) following the recommended method.

The measurements were carried out on 16 October, 1993 and the results have been summarized in Survey Bulletin No. 21.

6.10.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration the sectional distribution of the velocity profiles from the transect T3AG1T05 covering the entire cross-section at Tilly is displayed in Figure 6.14 below.

Current velocities were measured from 0 m/s to 0.8 m/s. Nearly no directional variation is observed within the cross-section.

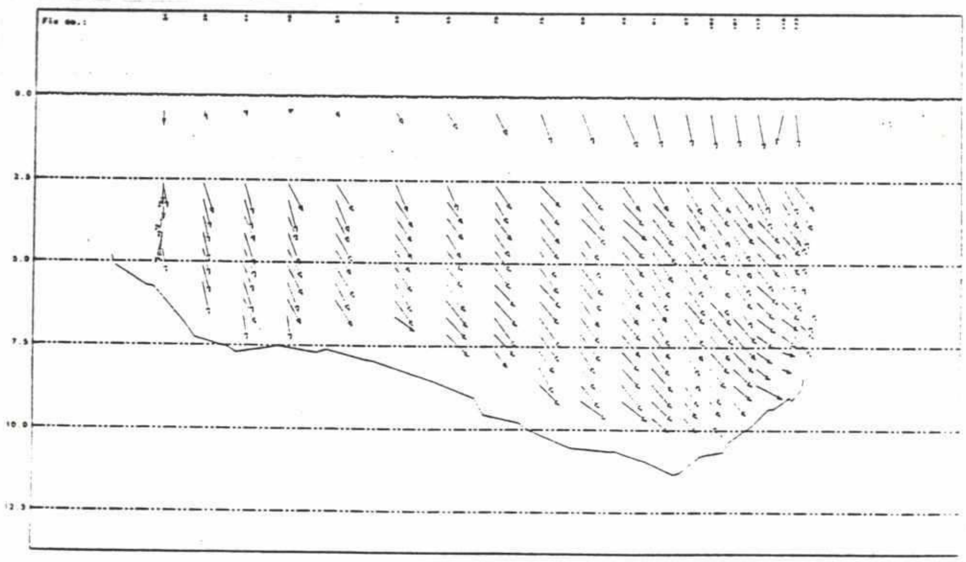


Figure 6.14 : Current vectors from transect T3AG1T05 in Dhaleswari river at Tilly, 16 October 1993

All together 6 transects (3 double crossings) were surveyed on 16 October 1993 and the corresponding discharge calculations are listed in Table 6.40 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
16/10/93 08:04 to 08:12	7.50	475	T3AG1T03 & 04
16/10/93 08:29 to 08:35	7.50	490	T3AG1T05& 06
16/10/93 14:07 to 14:16	7.49	495	T3AG1T08& 09
Mean	7.50	487	

Table 6.40 : Water-level and discharges in Dhaleswari River at Tilly, October 16, 1993

S4-current measurement (reference method)
The current measurements by S4 instrument in the Tilly cross-section are listed in survey Bulletin No. 21.

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transect current vectors in Figure 6.15 below.

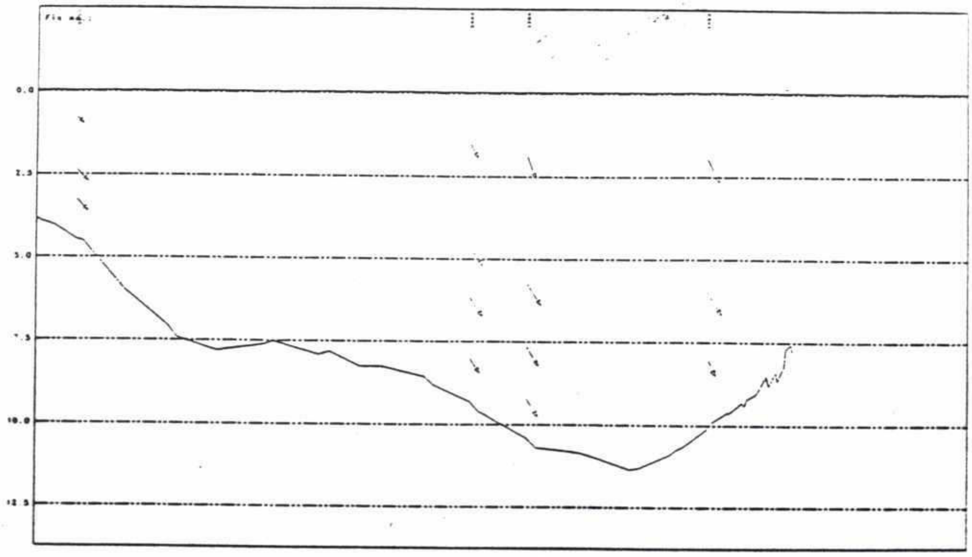


Figure 6.15 : Plot of S4 current velocities from verticals 1 to 4 in Dhaleswari River at Tilly, 16 October 1993

Current velocities were measured from O, 21 m/s to 0.64 m/s. Nearly no directional variation was observed within the cross-section.

The total discharge in the cross-section has been calculated using the velocity area method. Table 6.41 shows the discharge and lists the filenames used to determine the average bathymetric sectional area.

Date	S4 discharge m^3/s	Bathymetry (filenames)
16 October 1993	446	T3AG1T03, 04, 05, 06, 08 & 09

Table 6.41 : Discharge based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 8 per cent is found by comparing average discharges.

6.10.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in the Tilly cross-section have been listed in Survey Bulletin No. 21, ref. Table 2.1. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

Suspended sediment concentrations from 413 mg/l to 600 mg/l were measured. The concentration distribution is very uniform within the cross-section. Using the velocity - area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.42 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
16 October 1993	222	T3AG1T03, 04, 05, 06, 08 & 09

Table 6.42 : Suspended sediment transport in Dhaleswari River at Tilly, 16 October 1993

Andreasen settling tube determination of grain size distribution form the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviations $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.43.

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 13 per cent scatter.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
16 October 1993	0.023	0.003

Table 6.43 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

6.11 Gorai (off-take) gauging site - station 9

6.11.1 Measurement period

During the flood season of 1993 the gauging site - station 9 - in Gorai River at Kushtia has been covered only once with measurements of discharge (Q), suspended sediment (S_S) and bed load transport (S_B) following the reference method.

The measurements were carried out on 29-30 September 1993 and the results have been summarized in Survey Bulletin No. 16.

6.11.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration the sectional distribution of the velocity profiles from the transect K39UT05 covering the entire cross-section at Kushtia is displayed in Figure 6.16 below.

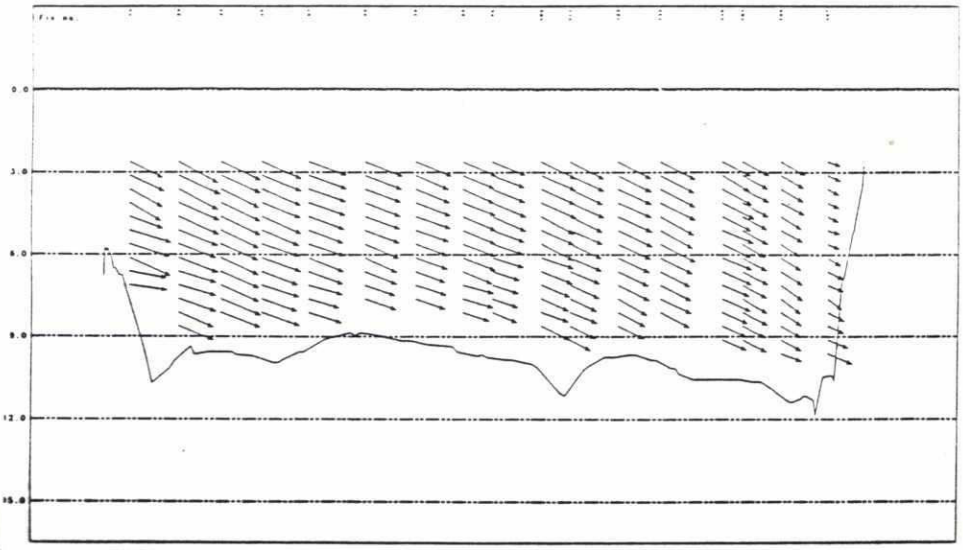


Figure 6.16 : Current vectors from transect K39UT05 in Gorai River at Kushtia, 30 September 1993

All together 4 transects (2 double crossings) were surveyed on 29 and 30 September 1993 and the corresponding discharge calculations are listed in Table 6.44 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
29/9/93 17:00 to 17:09	11.98	3,380	K39T1T03 &4
30/9/93 08:15 to 08:33	11.98	3,507	K39U1T02 05 & 06
Mean	11.98	3,445	-

Table 6.44 : Water-level and discharges in Gorai River at Kushtia, 29 and 30 September 1993

S4 current measurement (reference method)
The current measurements by S4 instrument in Gorai River cross-section at Kushtia are listed in Survey Bulletin No.16

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transect current vectors in Figure 6.17 below.

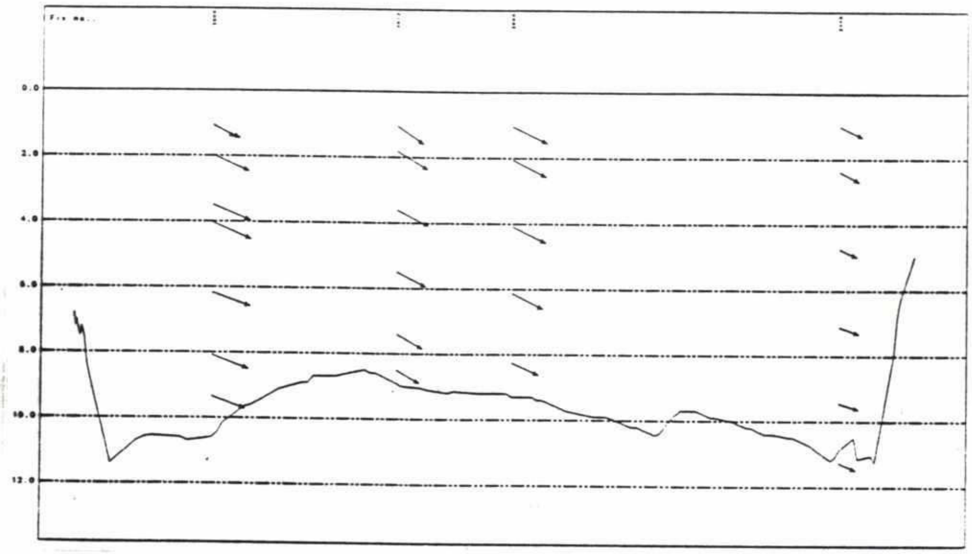


Figure 6.17 : Plot of S4 current velocities from verticals 1 to 4 in Gorai River at Kushtia, 29 to 30 September 1993

Current velocities were measured from 0.9 m/s to 1.9 m/s. Nearly no directional variation was observed within the cross-section.

The total discharge in the cross-section has been calculated using the velocity area method. Table 6.45 shows the discharge and lists the filenames used to determine the average bathymetric sectional area.

Date	S4 discharge m^3/s	Bathymetry (filenames)
29-30 September 1993	2,865	K39T1T03&4 K39U1T02, 05&06

Table 6.45 : Discharge based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy 17 of per cent is found by comparing average discharges.

6.11.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in the Kushtia cross-section have been listed in Survey Bulletin No. 16, ref. Table 2.1. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

Suspended sediment concentrations from 1524 mg/l to 3798 mg/l were measured. The concentration distribution is quite uniform within the cross-section with maximum concentrations in vertical no.3 approximately in the middle of the river. Using the velocity - area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.46 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
29-30 September, 1993	6,008	K39T1T03 & 04 K39U1T02, 05 & 06

Table 6.46 : Suspended sediment transport in Gorai River at Kushtia 29-30 September, 1993

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviations $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.47.

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 58 per cent scatter.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
29-30 September, 1993	0.034	0.02

Table 6.47 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

6.11.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley - Smith trap sampling. All the results have been listed in Survey Bulletin No. 16; ref. Table 2.1 and a summary is presented in Table 6.48 below.

Vertical and Samples (filename)	Bed load sediment transport kg/ms	
Vertical 2, sample 1 & 2	0.385	0.270
Vertical 4, sample 1 & 2	0.002	0.014

Table 6.48 : Helley-Smith bed load sampling in Gorai River at Kushtia 29 to 30 September 1993

The total bed load transport has been estimated by multiplying the average transport rates from Table 6.48 by the distance between the samples. Hereby a bed load transport of 7.2 kg/s is estimated.

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average values $\mu(D_{50})$ and the sectional standard deviations $\sigma(D_{50})$ of the D_{50} mean grain diameter is listed in Table 6.49.

Date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
29-30 Septeber 1993	0.203	0.08

Table 6.49 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith bed load samples

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 39 per cent scatter.

6.11.5 Bed material sampling

Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.50 below.

Date of bed material sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
29-30 September, 1993	0.149	0.05

Table 6.50 : Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviations the samples exhibit a 34 per cent scatter.

6.12 Arial Khan (off-take) gauging site - station 10

6.12.1 Measurement period

During the flood season of 1993 the gauging site - station 10 - in Arial Khan River at the off-take has been covered only once with measurements of discharge (Q), suspended sediment (S_S) and bed load transport (S_B) following the reference method.

The measurements were carried out on 8 October 1993 and the results have been summarized in Survey Bulletin No. 19.

6.12.2 Current velocities and discharge measurements

ADCP and EMF measurements (recommended method)
For illustration the sectional distribution of the velocity profiles from transect 03A81T02 covering the entire cross-section of Arial Khan River close to its off-take from Padma River is displayed in Figure 6.18 below.

Current velocities were measured from 0.2 m/s to 1 m/s. Some directional variation is observed within the individual verticals as well as within the cross-section as such.

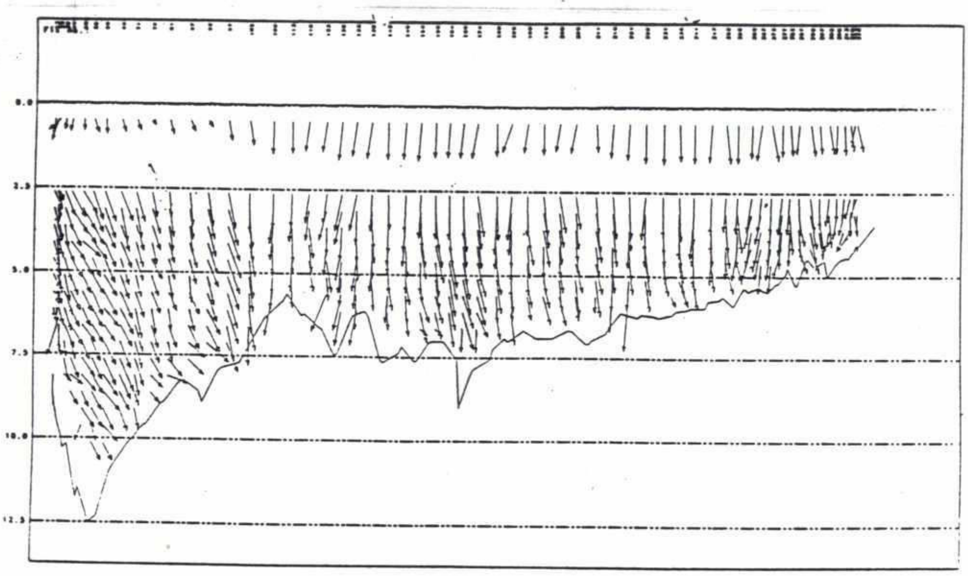


Figure 6.18 : Current vectors from transect 03A81T02 in Arial Khan River at the off-take from Padma River, 8 October 1993

All together 4 transects (2 double crossings) were surveyed on 8 October 1993 and the corresponding discharge calculations are listed in Table 6.51 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
8/10/93 09:30 to 09:45	5.65	2,157	03A81T02 & 03
8/10/93 14:22 to 14:35	5.61	2,197	03A81T06 & 07
Mean	5.63	2,177	

Table 6.51 : Water-level and discharge in Arial Khan River at the off-take from Padma River, 8 October 1993

S4 - current measurement (reference method)
The current measurements by S4 instrument in Arial Khan off- take are listed in Survey Bulletin No. 19.

The velocity profiles are shown in Annexure 3 and are plotted in a similar way as the transect current vectors in Figure 6.19 below.

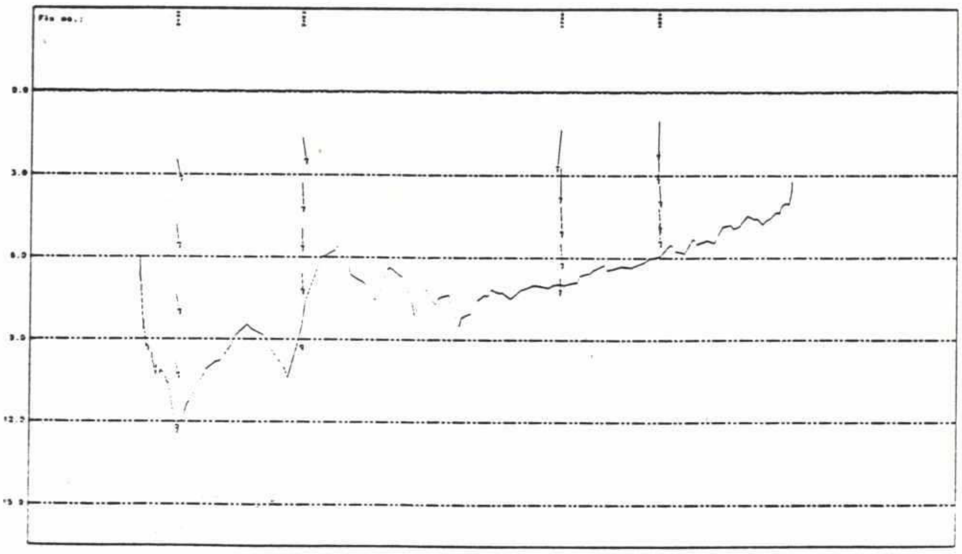


Figure 6.19 : Plot of S4 current velocities from verticals 1 to 4 in Arial Khan off-take, 8 October 1993

Current velocities were measured from 0.92 m/s to 1.91 m/s. Some directional variation is observed within the individual verticals as well as within the cross-section as such.

The total discharge in the cross-section has been calculated using the velocity area method. Table 6.52 shows the discharge and lists the filenames used to determine the average bathymetric cross-section area.

Date	S4 discharge m^3/s	Bathymetry (filenames)
8 October 1993	1,990	03A81T02 & 03 03A81T06 & 07

Table 6.52 : Discharge based on point integrating S4 current measurements

The best estimate of the point integrating S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 9 per cent is found by comparing average discharges.

6.12.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in Arial Khan off-take have been listed in Survey Bulletin No. 19, ref. Table 2.1. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

Suspended sediment concentrations from 490 mg/l to 1730 mg/l were measured. Maximum concentrations occur in the deepest section close to the left bank. Using the velocity - area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.53 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
8 October 1993	1,910	03A81T02&03 03A81T06&07

Table 6.53 : Suspended sediment transport in Arial Khan off-take 8, October 1993

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviations $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.54.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
8 October 1993	0.0173	0.010

Table 6.54 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 58 per cent scatter.

6.12.4 Bed load sediment transport measurements

During the flood season of 1993 the bed load transport has been assumed on the basis of Helley-Smith trap sampling. The measurement results have been listed in Survey Bulletin No. 19; ref. Table 2.1 and a summary is presented in Table 6.55 below.

Vertical and Samples (filename)	Bed load sediment transport g/ms	
Vertical 3, sample 1 & 2	4.825	0.992
Vertical 5, sample 1 & 2	0.594	-

Table 6.55 : Helley-Smith bed load sampling in Arial Khan off-take, 8 October 1993

As expected the samples show large scatter.

The total bed load transport has been estimated by multiplying the average transport rates from Table 6.56 by the distance between the samples and to the respective bank lines. Hereby a bed load transport of 1 kg/s is estimated.

Grain size distribution analysis have been performed for each Helley-Smith sample. The sectional average values $\mu(D_{50})$ and the sectional standard deviations $\sigma(D_{50})$ of the D_{50} mean grain diameter in each routine gauging cross-section is listed in Table 6.56 below.

Date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
8 October, 1993	0.212	0.019

Table 6.56 : Sectional average and standard deviation of D_{50} mean grain diameter based on Helley-Smith bed load samples

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 5. Judging by the sectional standard deviation the samples exhibit a 9 per cent scatter.

6.12.5 Bed material sampling

Grain size distribution analysis have been performed for each bed material sample. The sectional average value $\mu(D_{50})$ and the standard deviation $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.57. below.

Date of bed material sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
8 October, 1993	0.153	0.012

Table 6.57 : Sectional average and standard deviation of D_{50} mean grain diameter based on bed material samples

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 6. Judging by the sectional standard deviations the samples exhibit a 8 per cent scatter.

6.13. Bhairab Bazar gauging site - station 11

6.13.1 Measurement period

During the flood season of 1993 the gauging site - station 11 - in the upper Meghna River has been covered only once with measurements of discharge (Q) and suspended sediment transport (S_S) following the recommended method.

The measurements were carried out on 11-12 October 1993 and the results have been summarized in Survey Bulletin No. 20.

6.13.2 Current velocities and discharge measurements

ADCP and EMF measuremets (recommended method)
For illustration the sectional distribution of the velocity profiles from the transect Z3AC1T01 covering the entire cross-section at Bhairab Bazar is displayed in Figure 6.20 below.

Current velocities were measured from 0 m/s to 0.7 m/s. Nearly no directional variation is observed within the cross-section.

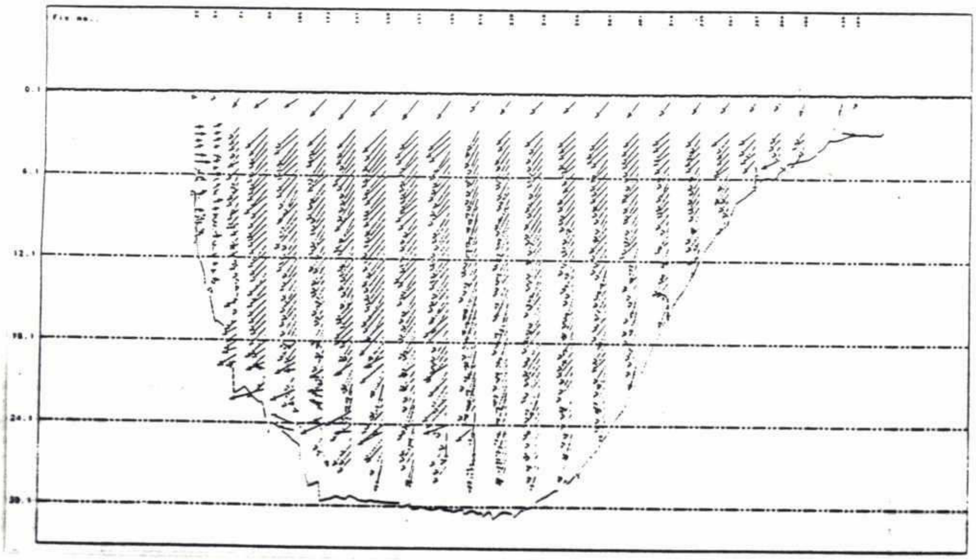


Figure 6.20 : Current vectors from transect Z3AC1T01 in the upper Meghna River at Bhairab Bazar, 11 October 1993

All together 2 transects (1 double crossing) were surveyed on 12 October 1993 and the corresponding discharge calculations are listed in Table 6.58 below.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
12/10/93 10:28 to 10:48	5.36	7,490	Z3AC1T01 & 02

Table 6.58 : Water-level and discharge in the upper Meghna River at Bhairab Bazar, 12 October 1993

6.13.3 Suspended sediment transport measurements

The suspended sediment concentration samples collected in the upper Meghna at Bhairab Bazar have been listed in Survey Bulletin No. 20; ref. Table 2.1. The corresponding plots of suspended sediment concentration profiles are presented in Annexure 3.

Suspended sediment concentrations from 8 mg/l to 880 mg/l were measured. Maximum concentrations occur in vertical no 7 at the left bank. For the remaining cross-section the distribution was rather uniform with concentration levels below 50 mg/l.

Using the velocity area method and the related flow field distribution multiplied by the suspended sediment concentration, the suspended sediment transport has been calculated in Table 6.59 below.

Date	Suspended sediment transport kg/s	Bathymetry (filenames)
12 October 1993	160	Z3AC1T01, 02 & 03

Table 6.59 : Suspended sediment transport in the upper Meghna at Bhairab Bazar, 12 October 1993

Andreasen settling tube determination of grain size distribution from the lowest sampling level in each vertical have been performed. The sectional average value $\mu(D_{50})$ and the standard deviations $\sigma(D_{50})$ of the mean grain diameter D_{50} is listed in Table 6.60 below.

Date	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
12 October 1993	0.013	0.002

Table 6.60 : Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment measurements

Grain size distribution curves and summary tables of D_{16}, D_{35}, D_{50} and D_{90} are found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 15 per cent scatter.

7. Special measurement results

7.1 General

The River Survey Project FAP 24 has a limited horizon compared to the time scale of the physical phenomena in the Bangladeshi rivers. The local Bangladesh Water Development Board (BWDB) has a much longer horizon than the River Survey Project. Several of the analyses presented by the River Survey Project would be impossible without BWDB data. It is therefore of great importance to make comparative measurements in order to assess the compatibility of measurements obtained with different technologies.

All information presented have been subjected to standard data processing and visual quality assurance. On this basis measurements have either been accepted or discarded.

During the flood season of 1993 a comparative measurement between BWDB and the River Survey Project was planned to be carried out on 23 and 24 August 1994 at the Bahadurabad cross-section, following the completion of the test gauging.

Unfortunately the BWDB survey boats suffered from several mechanical break-downs during the two measurement days and therefore only the results obtained by the River Survey Project by using the recommended ADCP/EMF methodology is described in the following.

7.2 Comparative discharge measurements Bahadurabad, 23 to 24 August 1993

7.2.1 Gauging cross-section

The position of the gauging cross-sections in Jamuna river used for comparison are indicated in Figure 7.1. The standard BWDB cross-section of the left river channel comprised three channels as follows:

Zigabari
Assankhari and
Bahadurabad

During the flood season the Zigabari channel by the right bank was 1500 m wide with a maximum depth of 10 m while the Assankhari and Bahadurabad channels were 900 m and 400 m wide and 14 m and 11 m deep respectively; see Figure 7.2.

The right river channel comprises two main channels; one following the right bank was 700 m wide and 12 m deep and the other following the left bank was 900 m wide and 10 m deep. In between is a 1100 m wide more shallow area, which becomes almost dry in the dry season; see Figure 7.3.

During the flood season conditions both river channels including the shallow areas could be covered by the A vessel using the recommended method with combined ADCP/EMF measurements.

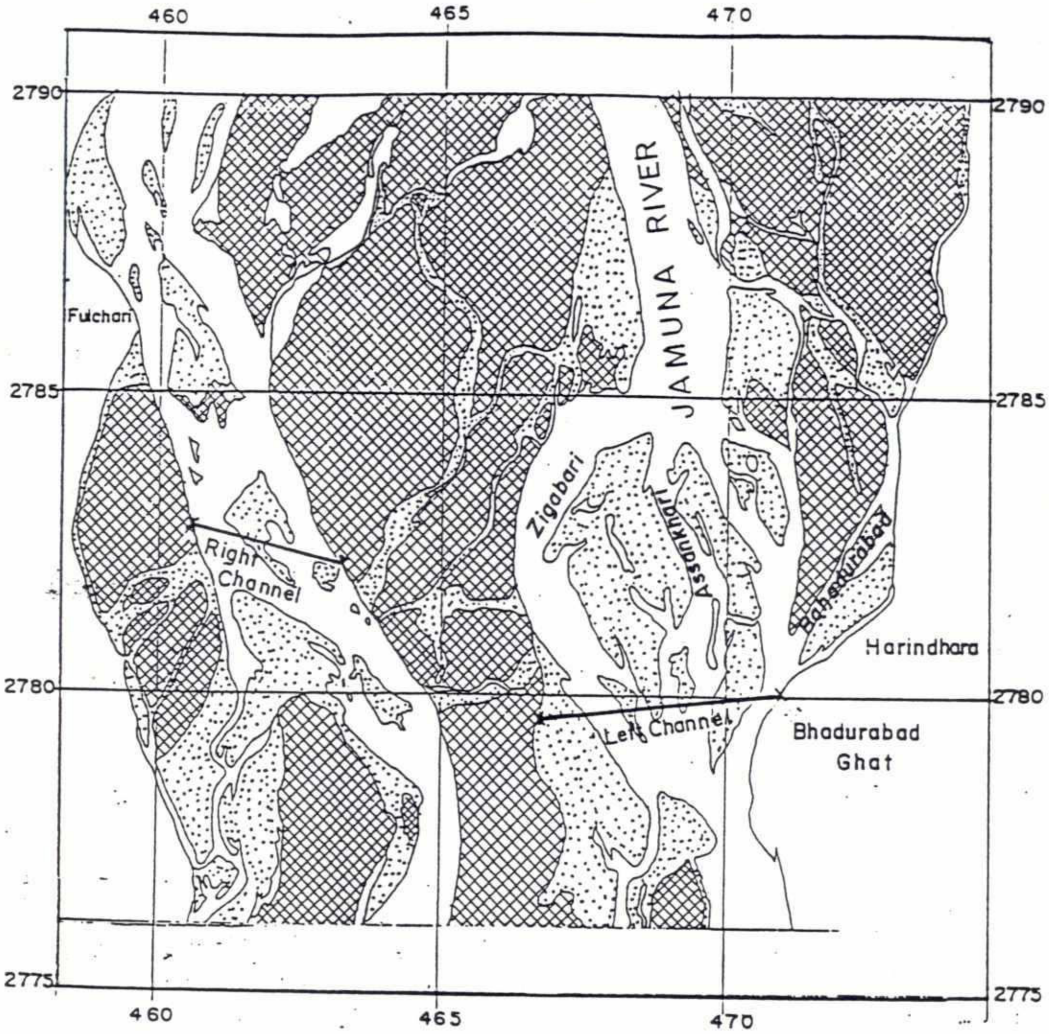


Figure 7.1 Location map for the Bahadurabad comparative discharge gauging cross-sections

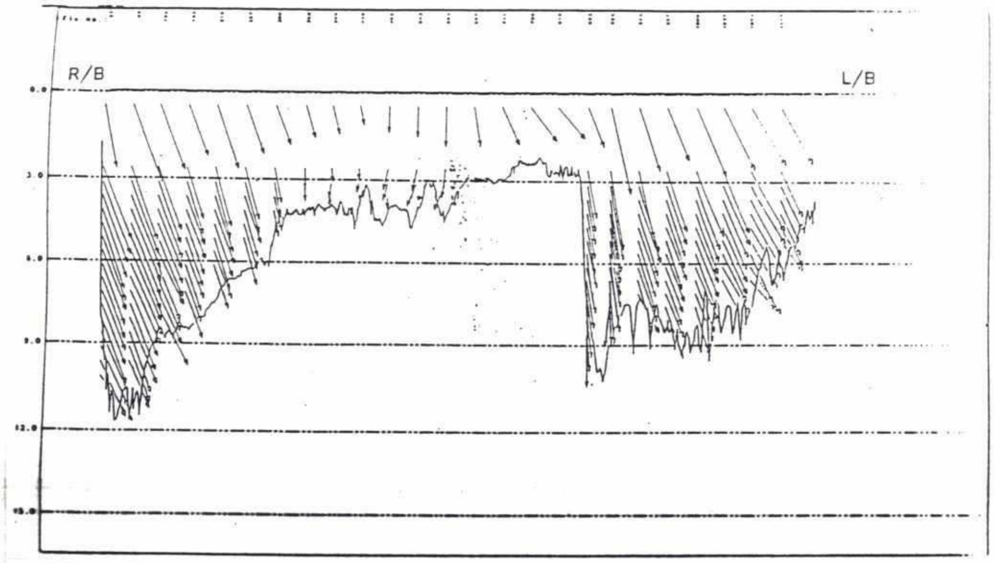


Figure 7.2 Cross-section of left main channel close to BWDB survey line at Bahadurabad, August 1993

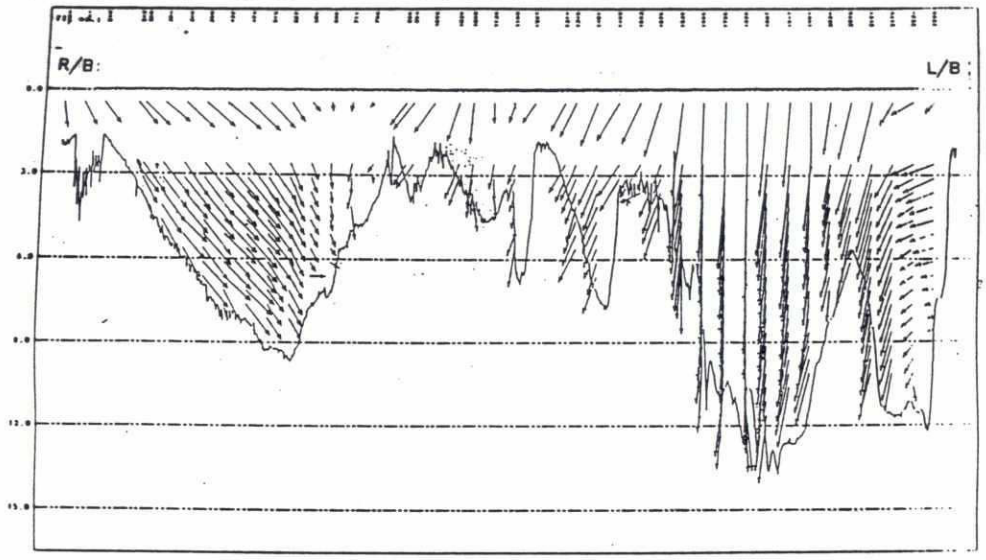


Figure 7.3 Cross-section of the left main channel close to the BWDB survey line at Bahadurabad, August 1993

7.2.2 Measurement results obtained by the River Survey Project

All together 5 transects covering the left channel and 3 transects covering the right channel were completed on August 23 and 24, 1993 respectively. The results have been reported previously in the 4° Quarterly Progress Report - Survey Bulletin No.10.

Examples of the measurement results are displayed in Figure 7.1 and 7.2 Current velocities ranging from 0 m/s to 2.5 m/s were measured in the left main channel on August 24, 1993. Some directional variation is observed within the verticals while a substantial higher veriation has been registered over the cross-section as such. This shows the importance of also measuring the direction of the current to be used for discharge calculations.

Current velocities ranging from 0 m/s to 2.0 m/s were measured in the right main channel on August 23, 1993. Some directional variation is observed within the verticals as well as between the verticals covering the cross-section

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated in Tables 7.1 and 7.2.

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
23/8/93 10:00 to 10:54	18.60	15,327	B38N1T03 & 04
23/8/93 12:37 to 14:10	18.60	15,283	B38N1T06 & 07
23/8/93 15:55 to 16:20	18.60	15,035	B38N1T11

Table 7.1 Discharge in the right channel at Fulchari, Jamuna River, August 1993

Date and time	Water-level m +PWD	Discharge m^3/s	Transect (filename)
24/8/93 09:10 to 09:55	19.12	27,535	B3801T01
24/8/93 11:00 to 11:42	19.12	28,509	B3801T02
24/8/93 12:14 to 12:54	19.12	27,626	B3801T04

Table 7.2 Discharge in the confluent cross-section close to the standard BWDB gauging cross-section at Bahadurabad, Jamuna River, August 24, 1993

An average discharge of 15,215 m^3/s with a standard deviation of 1 per cent was observed in the right channel while the average discharge in the confluent cross-section amounted to 27,890 m^3/s, also with a standard deviation of 1 per cent also.

RA

List of references

o P. Ph. Jansen, L. van Bendegom et al.
Principles of River Engineering, The non tidal alluvial river
π Pitman
The Hague, November 1978

o River Survey Project FAP 24
1° Interim Report, Volume II
DELFT HYDRAULICS & Danish Hydraulic Institute
February 1993.

o BWDB
Report on Joint measurement programme with FAP 24 on Brahmaputra at Bahadurabad, Memo no- FAP-24/177
North Eastern Measurement Division, SWH-1, BWDB.
Dhaka February 9, 1993.

o Danish Hydraulic Institute
Vessel Survey Quality Plan, River Survey Project
Danish Hydraulic Institute
31 May 1993.

o River Survey Project FAP 24
2° Quarterly Progress Report (December 1992 - February 1993)
DELFT HYDRAULICS & Danish Hydraulic Institute
7 July 1993.

o River Survey Project FAP 24
Hydrological Study, Phase 1
DELFT HYDRAULICS & Danish Hydraulic Institute
June 1993.

o River Survey Project FAP 24
Study Report 1, Selection of study topics for phase 2
DELFT HYDRAULICS & Danish Hydraulic Institute
September 1993.

o River Survey Project FAP 24
Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad
DELFT HYDRAULICS & Danish Hydraulic Institute
October 1993

o River Survey Project FAP 24
Working Paper 5
Water-level slope measurements in the Jamuna River at Bahadurabad.