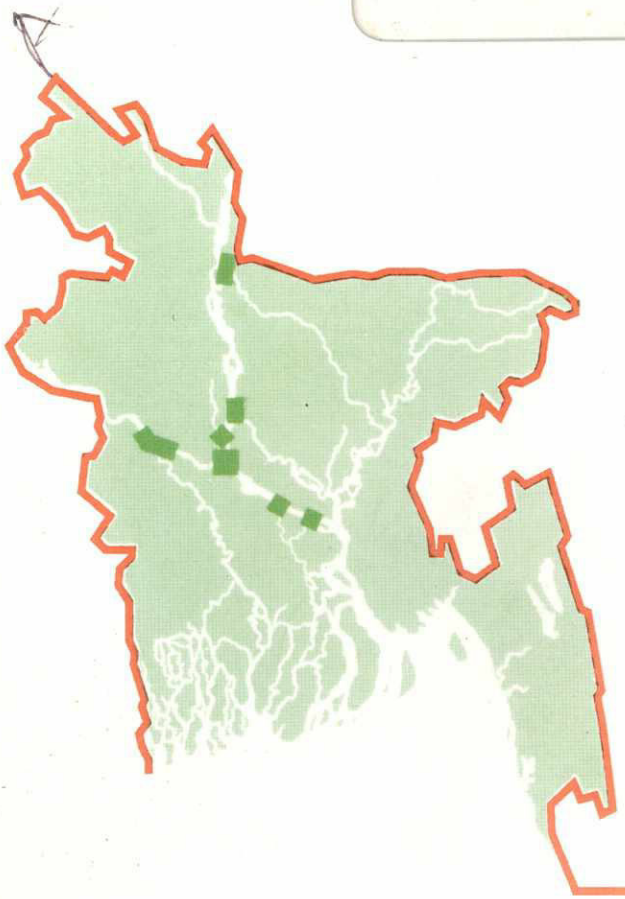
GOVERNMENT OF BANGLADESH
FLOOD PLAN COORDINATION ORGANIZATION

FAP 24 RIVER SURVEY PROJECT

Survey Report 5
Phase I
Dry Season 1992/1993



DELFT HYDRAULICS
DANISH HYDRAULIC INSTITUTE
OSIRIS
HYDROLAND
APPROTECH

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

Survey Report 5
Phase I
Dry Season 1992/1993

7 December 1993

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

January 10, 1994

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

Attention : Mr. Afzalur Rahman.
Superintending Engineer.

Subject : Report on surveys of the dry season 1992/93

Our ref : RSP/9.1/716

Dear Sir,

We are taking pleasure in submitting herewith our Survey Report 5, Phase 1, Dry season 1992/93.

The report serves as a documentation and presentation of all results of the dry season measurements, executed by the River Survey Project between October 1992 and May 1993. The report can be used for studies of the hydrology and morphology of the main river system of Bangladesh.

Thanking you.

Yours sincerely

Pieter van Groen
Team Leader

Contents

Main Report

Annexures

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	:	A sediment transport 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 5, Dry Season 1992/1993 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 dry season measurements apart from bathymetric surveys, obtained by the River Survey Project between October 1992 and May 1993. Most of the data have previously been presented in the following reports:

- River Survey Project, FAP 24
  1° Interim Report, Volume II
  Annexures on survey work
  February 1993

- River Survey Project, FAP 24
  2° Quarterly Progress Report
  December 1992 - February 1993

- River Survey Project, FAP 24
  3° Quarterly Progress Report
  March - May 1993

The present survey report comprises routine gaugings and special measurements. Several of the sediment transport calculations and the special measurements have not previously been published. Apart from the measurement results, only simple analyses and comparisons are presented.

The 1° Interim Report, covering the period October to December 1992, comprises the same type of analyses and comparisons, wherefore this period and these data are omitted from the present report.

Survey Report 5 serves as a basis for elaborate studies of the hydrology and morphology in the main river systems of Bangladesh. For this reason file names and sample numbers 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:

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

In the reporting period special measurements comprised comparative discharge measurements.

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

In the dry season from October 1992 to May 1993 the following sites have been surveyed by the routine gauging programme and the special measurement programme:

- o Routine gaugings:
  - Bahadurabad, 14 to 16 January 1993
  - Bahadurabad, 13 to 15 February 1993
  - Bahadurabad, 13 to 15 March 1993
- o Special measurements:
  - Comparative discharge measurement, Bahadurabad, 6 to 11 January 1993
  - Comparative tidal discharge measurements, Hospital Ghat, Khulna April 9, 1993
  - Comparative tidal discharge measurements, Bhairab Bazar, 26 to 28 April 1993

2.2 Summary of measurements

2.2.1 Routine gauging programme

Transect discharge and current measurements

The number of transects, the water-level and the average main channel discharge of all transects is listed in Table 2.1 for each routine gauging.

Location and date of transect survey	Number of transects	Water-level m PWD	Average discharge m^3/s
Bahadurabad, left main channel, January 14, 1993	3	14.03	4105
Bahadurabad, right main channel, 15 to 16 January 1993	5	14.30	1280
Bahadurabad, right main channel, February 13, 1993	4	13.99	926
Bahadurabad, left main channel, February 15, 1993	2	13.66	3348
Bahadurabad, right main channel, March 13, 1993	2	14.64	1106
Bahadurabad, left main channel, 15 to 16 March, 1993	5	13.88*	3609*

* Minor river stage variations.

Table 2.1 Current velocity range and discharge for all routine transect surveys performed from October 1992 to May 1993.

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

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 2.2 for each routine gauging.

Location and date of manual S4 current profiling	Number of verticals	Water-level m PWD	Average discharge m^3/s
Bahadurabad, left main channel, January 14, 1993	7	14.03	3733
Bahadurabad, right main channel, 15 to 16 January 1993	6	14.30	1197
Bahadurabad, right main channel, February 13, 1993	5	13.99	967
Bahadurabad, left main channel, February 15, 1993	8	13.66	3343
Bahadurabad, right main channel, March 13, 1993	5	14.64	1194
Bahadurabad, left main channel, March 15, 1993	9	13.88	3201

Table 2.2 Main channel discharges based on manual S4 current profilings performed from October 1992 to May 1993.

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

Suspended sediment measurement

The number of verticals applied to each cross-section, the suspended sediment concentration range and the total suspended sediment transport based on all point current and sediment measurements and an average bathymetry is listed in Table 2.3 for each routine gauging.

Location and date of manual current and sediment profiling	Number of verticals	Concentration range mg/l	Average suspended sediment transport kg/s
Bahadurabad, left main channel, January 14, 1993	7	60 - 227	438
Bahadurabad, right main channel, 15 to 16 January 1993	6	83 - 233	159
Bahadurabad, right main channel, February 13, 1993	5	49 - 237	108
Bahadurabad, left main channel, February 15, 1993	8	29 - 283	419
Bahadurabad, right main channel, March 13, 1993	5	52 - 115	79
Bahadurabad, left main channel, March 15, 1993	9	30 - 632	343

Table 2.3 Suspended sediment concentration range and transport for all routine manual current and suspended sediment profilings performed from October 1992 to May 1993.

A description of cross-sections, estimates of measurement uncertainty and plots of suspended sediment profiles are found in Chapter 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 2.4.

Location and date of manual current and sediment profiling	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, left main channel, January 14, 1993	-	-
Bahadurabad, right main channel, 15 to 16 January 1993	0.043	0.015
Bahadurabad, right main channel, February 13, 1993	0.046	0.023
Bahadurabad, left main channel, 15 to 16 February 1993	0.046	0.018
Bahadurabad, right main channel, March 13, 1993	0.038	0.019
Bahadurabad, left main channel, March 15, 1993	0.044	0.026

Table 2.4 Sectional average and standard deviation of D_{50} based on suspended sediment profilings performed from October 1992 to May 1993.

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

Bed load measurement

No propagating bed-forms were detected and therefore only Helley-Smith trap samplings were carried out in order to assess the bed load transport.

The number of Helley-Smith samples from each cross-section, the sectional average bed load transport range and the estimated total main channel bed load transport is listed in Table 2.5 for each routine gauging.

Location and date of Helley-Smith sampling	Number of Helley-Smith samples	Bed load transport range g/m/s	Bed load transport kg/s
Bahadurabad, left main channel, January 14, 1993	6	0.55 - 33	4.3
Bahadurabad, right main channel, 15 to 16 January 1993	3	0.66 - 41	2.8
Bahadurabad, right main channel, February 13, 1993	15	0.08 - 23	1.2
Bahadurabad, left main channel, February 15, 1993	20	0.01 - 41	5.0
Bahadurabad, right main channel, March 13, 1993	10	0.26 - 44	1.8
Bahadurabad, left main channel, March 15, 1993	5	0.02 - 0.9	0.4

Table 2.5 Range of bed load transport rates and bed load transport based on all Helley-Smith samples obtained by routine gaugings between October 1992 and May 1993.

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

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 2.6.

Location and date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, left main channel, January 14, 1993	0.316	0.047
Bahadurabad, right main channel, 15 to 16 January 1993	0.282	0.007
Bahadurabad, right main channel, February 13, 1993	0.228	0.041
Bahadurabad, left main channel, February 16, 1993	0.251	0.067
Bahadurabad, right main channel, March 13, 1993	0.237	0.05
Bahadurabad, left main channel, March 15, 1993	0.195	0.06

Table 2.6 Sectional average and standard deviation of D_{50} based on Helley-Smith samples obtained from October 1992 to May 1993.

Grain size distribution curves and summary tables of D_{35}, D_{50} and D_{65} are found in Annexure 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} in each routine gauging cross-section is listed in Table 2.7.

Location and date of Van Veen grab bed material samples	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, left main channel, January 14, 1993	-	-
Bahadurabad, right main channel, 15 to 16 January 1993	-	-
Bahadurabad, right main channel, February 13, 1993	0.166	0.0025
Bahadurabad, left main channel, 15 to 16 February 1993	0.156	0.095
Bahadurabad, right main channel, March 13, 1993	0.059	0.061
Bahadurabad, left main channel, March 15, 1993	0.168	0.102

Table 2.7 Sectional average and standard deviation of D_{50} based on bed material samples obtained by routine gaugings between October 1992 and May 1993.

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 Chapter 6 and Annexure 6. The bed material samples exhibit a large sectional scatter.

2.2.2 Special measurement programme

To assess the quality and compatibility of discharge data obtained by the Bangladesh Water Development Board (BWDB) and the River Survey Project, comparative discharge measurements have been performed at three locations:

- o Bahadurabad
- o Hospital Ghat, Khulna
- o Bhairab Bazar

The velocity range and the average main channel discharge based on manual current profilings obtained by BWDB are compared to transect current measurements obtained by the River Survey Project in Table 2.8.

Location and date of comparative discharge survey	Manual current profiling		Transect current measurement	
	Velocity range m/s	Discharge m^3/s	Velocity range m/s	Average discharge m^3/s
Zigabari channel in the standard BWDB cross-section, January 11, 1993	-	2150	0 - 1.2	2021
Zigabari, Assan-khari and Baha-durabad channels in the standard BWDB cross-section, January 11, 1993	0 - 1.08	4257	0 - 1.5*	3899*
Hospital Ghat, April 9, 1993	not yet available	not yet available	0 - 1.9	see tidal graph
Bhairab Bazar, 27 to 28 April 1993	not yet available	not yet available		see tidal graph

* Confluence 800 m downstream, exclusive discharge between the river banks and the end points of the survey line.

Table 2.8 Current velocity range and discharge based on manual profilings and transect measurements.

A more detailed description of cross-sections, individual transects, manual profilings and calculation procedures is found in Chapter 7. The tidal discharge variation measured by the River Survey Project at Hospital Ghat and Bhairab Bazar is plotted in Figures 2.1 and 2.2.

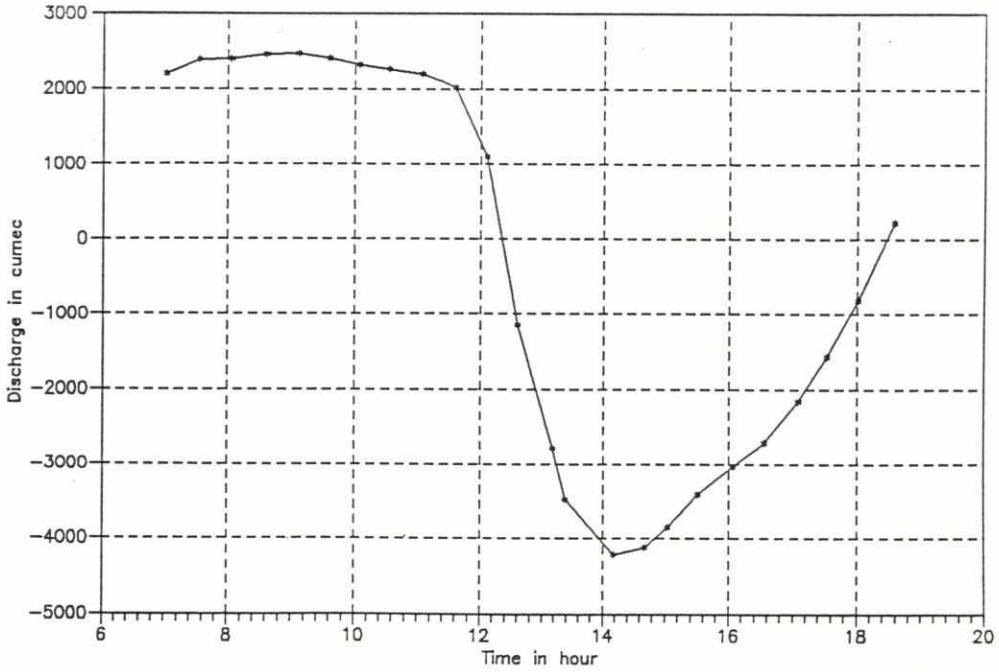


Figure 2.1 Tidal discharge variation at Hospital Ghat, Khulna, Gorai off-take, April 9, 1993.

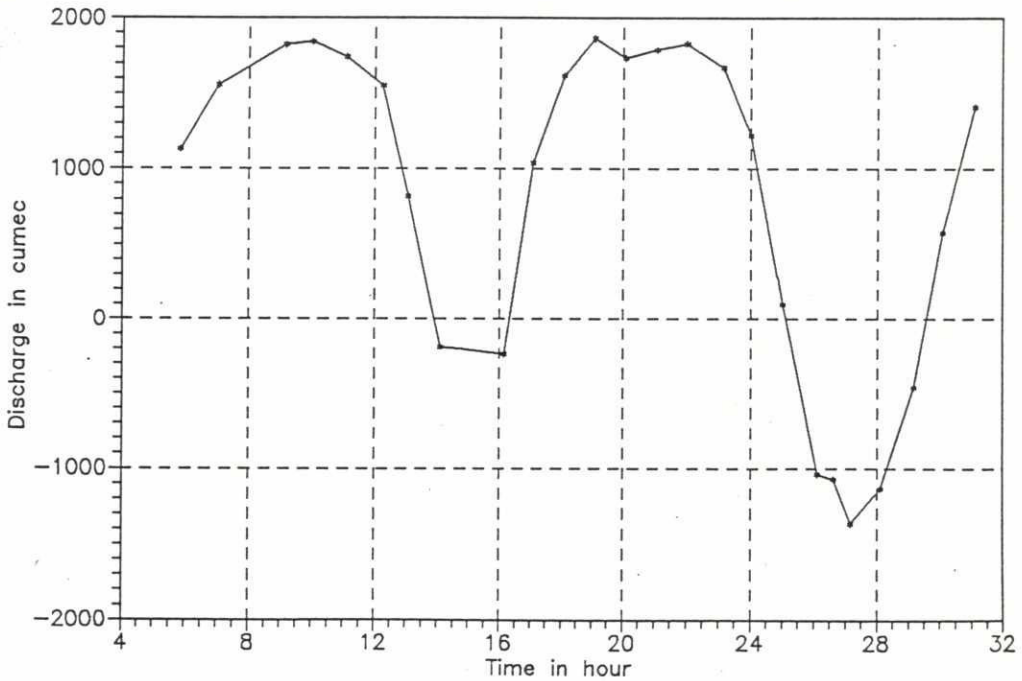


Figure 2.2 Tidal discharge variation at Bhairab Bazar, Upper Meghna river, 27 to 28 April 1993.

2.3 Conclusions and recommendations

Water-level gauging

Continuous water-level measurements provide a better basis for discharge uncertainty analyses than staff gauge observations. Staff gauge observations carry an uncertainty in the order of one cm irrespective of the datum. According to the low river stage Bahadurabad rating curve this uncertainty translates into a discharge uncertainty of 29 m^3/s.

The dynamic morphological environment renders it difficult to maintain continuous high quality water-level series. Consequently water-level data should always be looked upon with due skepticism.

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 manual S4 profilings is estimated within the range 1 to 12 percent of the average discharge.

Total discharges obtained by the moving boat method (ADCP/EMF current meters) and by manual profiling (S4 or Ott current meter) are compared in Table 2.10. The S4 current measurements were performed by the River Survey Project while the Ott current measurements were performed by BWDB. Generally a good agreement between the moving boat method and the manual profilings is observed, though unbiased discrepancies up to 11 per cent occur.

Location and date of survey	ADCP/EMF discharge m^3/s	S4 discharge m^3/s	Ott discharge m^3/s
Bahadurabad, left channel, January 14, 1993	4105	3733	-
Bahadurabad, right channel, 15 to 16 January 1993	1280	1197	-
Bahadurabad, right channel, February 13, 1993	926	967	-
Bahadurabad, left channel, February 15, 1993	3348	3343	-
Bahadurabad, right channel, March 13, 1993	1106	1194	-
Bahadurabad, left channel, 15 to 16 March 1993	3609	3201	-
Zigabari channel Bahadurabad, January 11, 1993	2021	-	2150
BWDB gauging cross-section Bahadurabad, January 11, 1993	3889*	-	4257

* Discharge in the navigable part of a downstream confluent cross-section.

Table 2.10 Comparison of dry season discharges.

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.

Tidal discharge variations

Based on the comparative tidal discharge measurements at Hospital Ghat south of Khulna and at Bhairab Bazar, Chapter 7, it is recommended that tidal discharge measurements must be concluded within a fraction of the tidal period to be of any value. A maximum discharge variation of 70 m^3/s/minute by an average tidal discharge amplitude of 3350 m^3/s has been observed at Hospital Ghat.

3. Description of survey areas

The River Survey Project performs routine gaugings and special measurements. The routine gaugings and surveys take place at eleven different sites in the Bangladeshi main rivers according to Figure 3.1. Almost all gauging areas are characterized by rapid planform changes in a braided river environment. Some of the routine gauging sites are tidally affected also.

Special measurements are located to facilitate the particular phenomena to be studied.

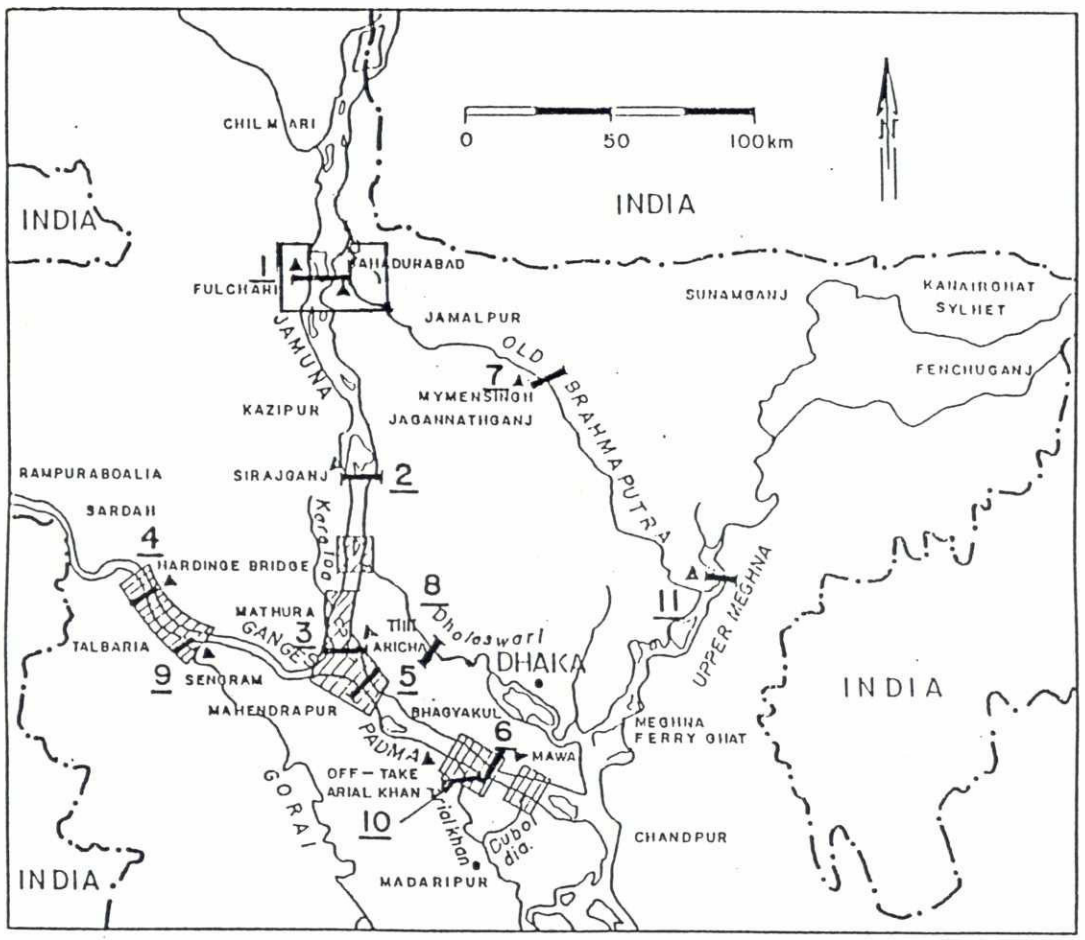


Figure 3.1 River Survey Project routine gauging sites in Bangladesh.

The present dry season report comprises gaugings and measurements from three different sites:

- Bahadurabad
- Hospital Ghat, Khulna
- Bhairab Bazar

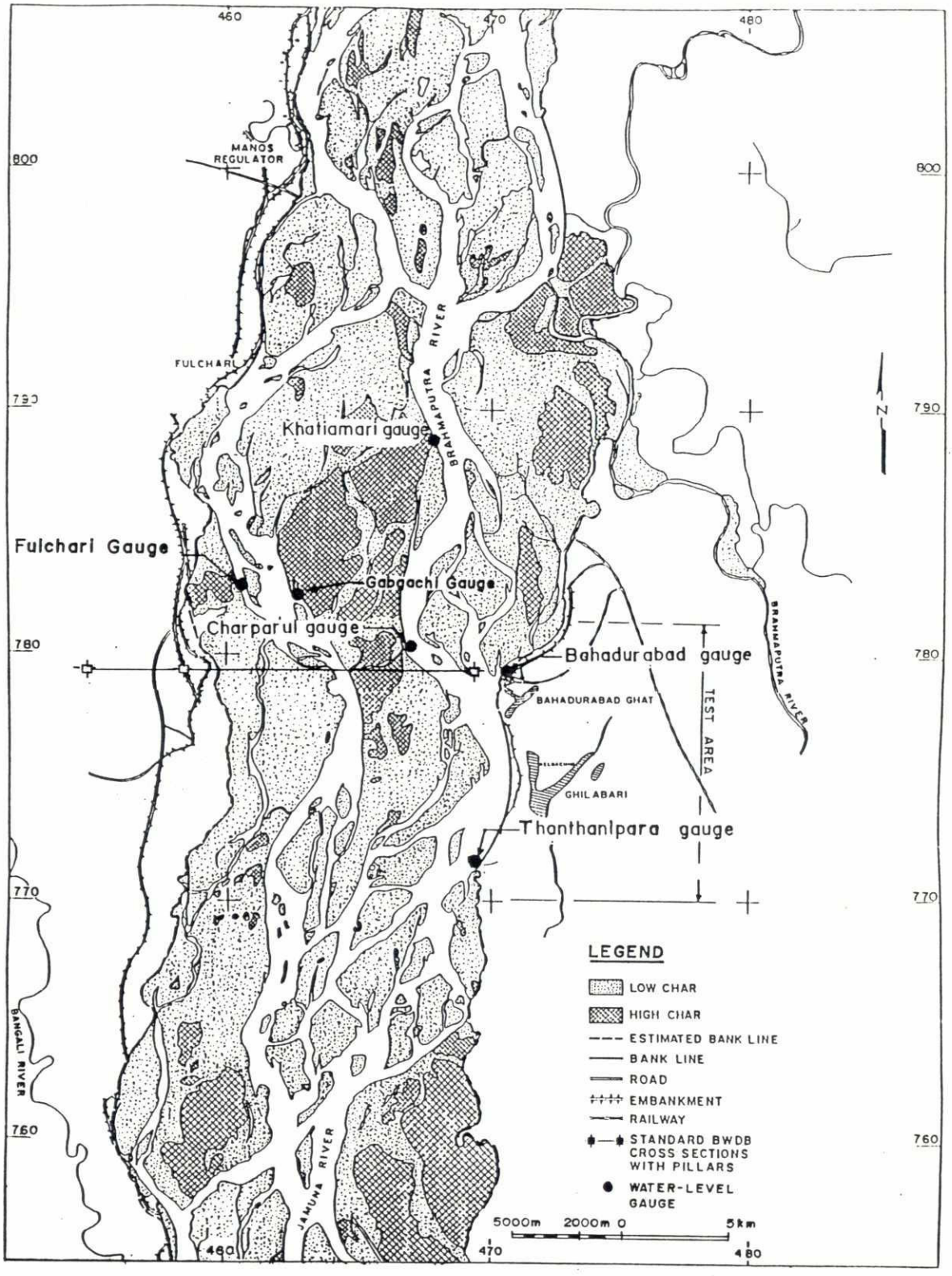


Figure 3.2 Planform of the Jamuna river in the vicinity of Bahadurabad, March 1992.

3.2 Hospital Ghat special measurement site

The Hospital Ghat cross-section is situated in the Rupsha river, a bifurcation of the Gorai off-take, at Khulna. The River Survey Project has no information on the stability of the cross-section and only a rough planform sketch is available, see Figure 3.3.

The BWDB operates a staff gauge in Khulna. The water-level is observed daily every 3 hour from 06:00 to 18:00. The water-level as well as the current is strongly influenced by tidal variations.

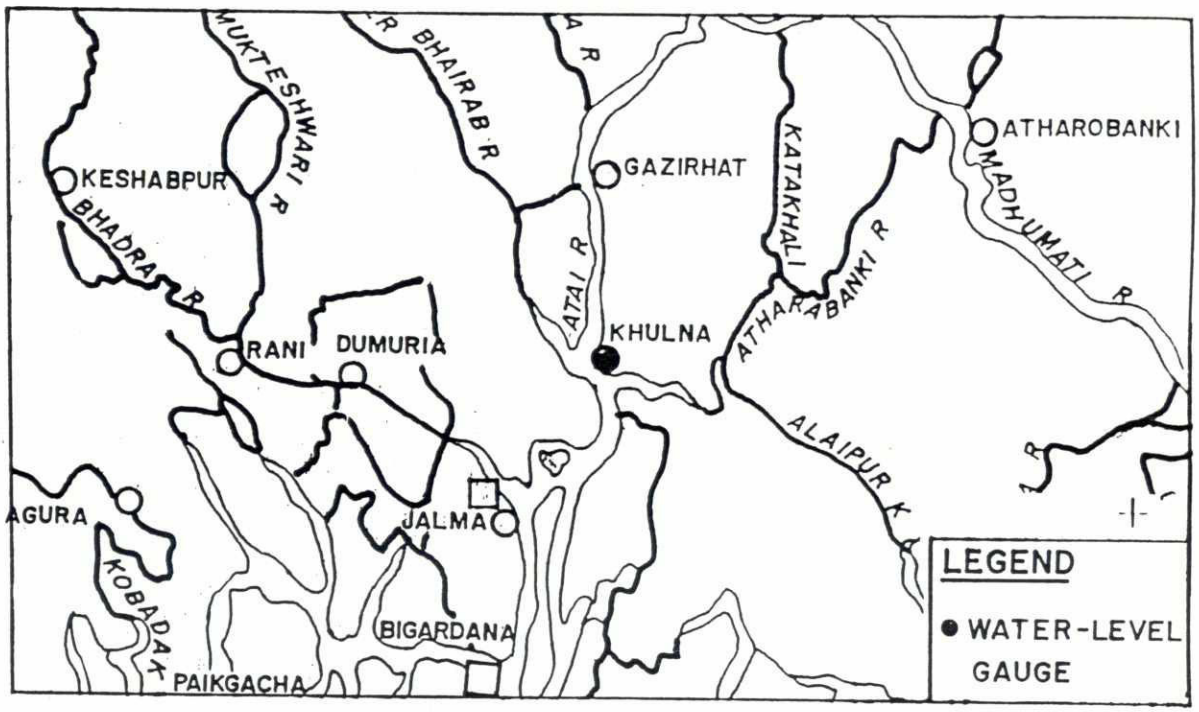


Figure 3.3 Sketch of the Rupsha river in the vicinity of Hospital Ghat at Khulna.

3.3 Bhairab Bazar special measurement site

The Bhairab Bazar cross-section in the Upper Meghna river is artificially fixed 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 BWDB performs routine gaugings in a cross-section approximately 50 m upstream of the railway bridge, see Figure 3.4.

The BWDB operates a staff gauges in Bhairab Bazar. The water-level is observed daily every 3 hour from 06:00 to 18:00. The water-level as well as the current is strongly influenced by tidal variations.

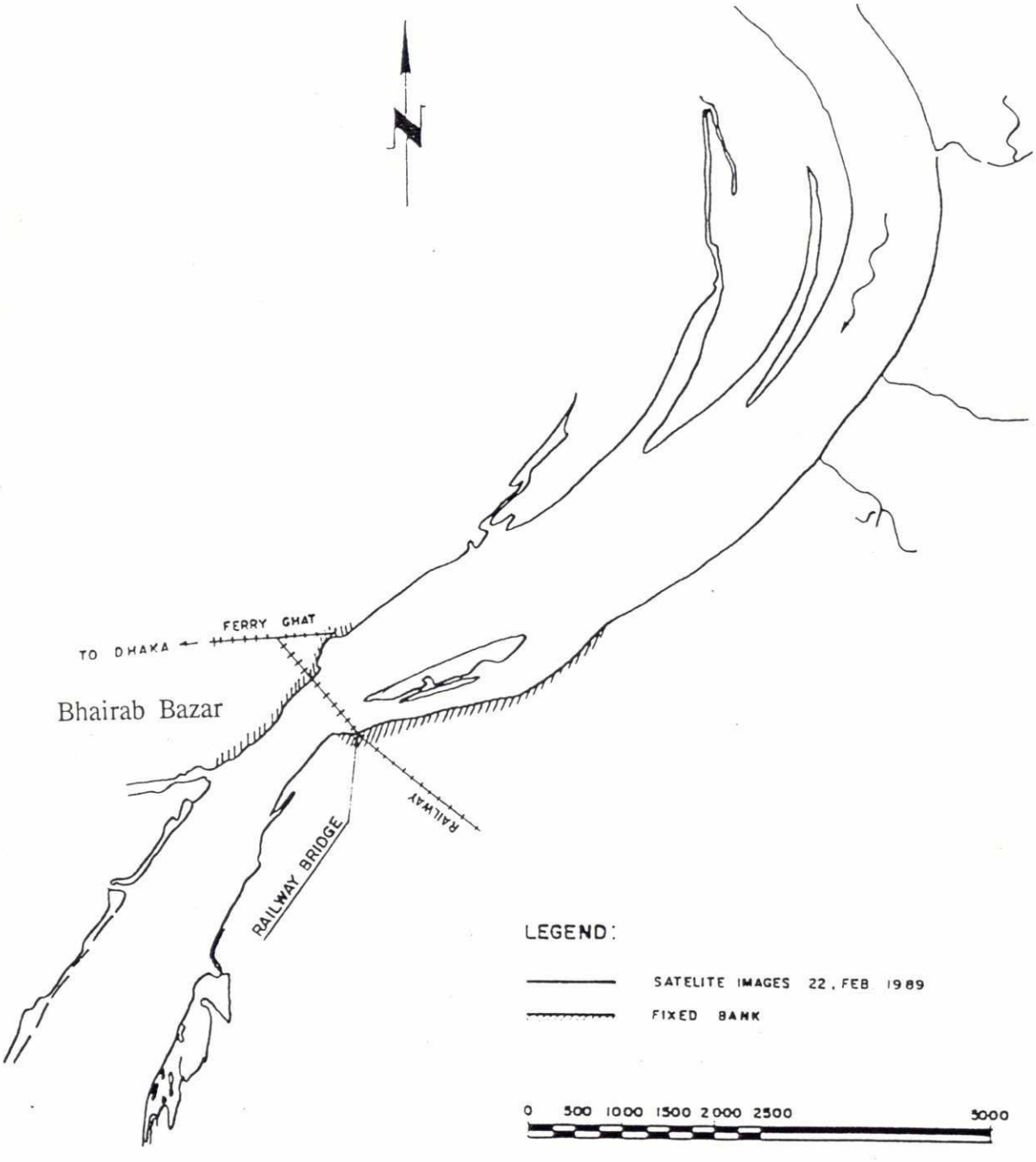


Figure 3.4 Planform of the Upper Meghna river in the vicinity of Bhairab Bazar, December 1988.

4. Summary of survey equipment and procedures

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

4.1 Survey vessels and equipment

The River Survey Project FAP 24 operates three survey vessels:

- 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 current measurement, integrated 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 (echo sounding)	X		
Simrad EA 300 P (echo-sounding)		X	X
Point current measurement:			
Ott meter (mechanical)	X		
S4 InterOcean (electromagnetic)	X	X	X
Integrated 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 electromagnetic S4 current meter.

ADCP and EMF measurements

The acoustic doppler current profiler (ADCP), listed under integrated 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 surface by normal lading conditions. Hereby the 300 kHz ADCP system is able to measure current profiles 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.

The electromagnetic EMF current meter, listed under integrated 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 supported by the DGPS positioning system.

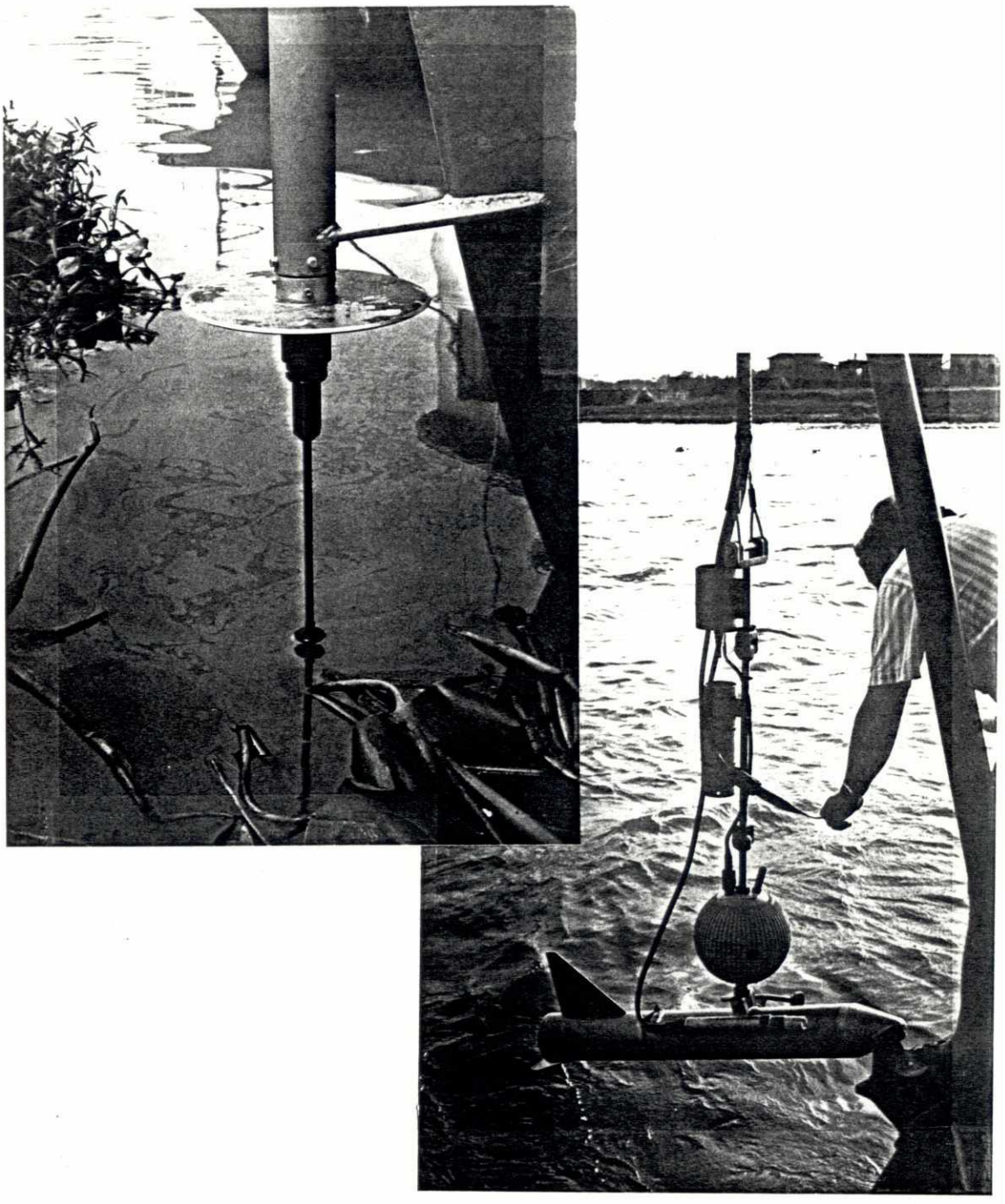


Figure 4.2 The EMF sensor mounted at the bow of Ms. DHA (upper left). The S4 current meter, the suspended sediment sampler and the MEX 3 turbidity meter mounted on a fish-type carrier (lower right). The turbidity meter is mounted on the right side of the carrier, while the suction hose of the suspended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

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.

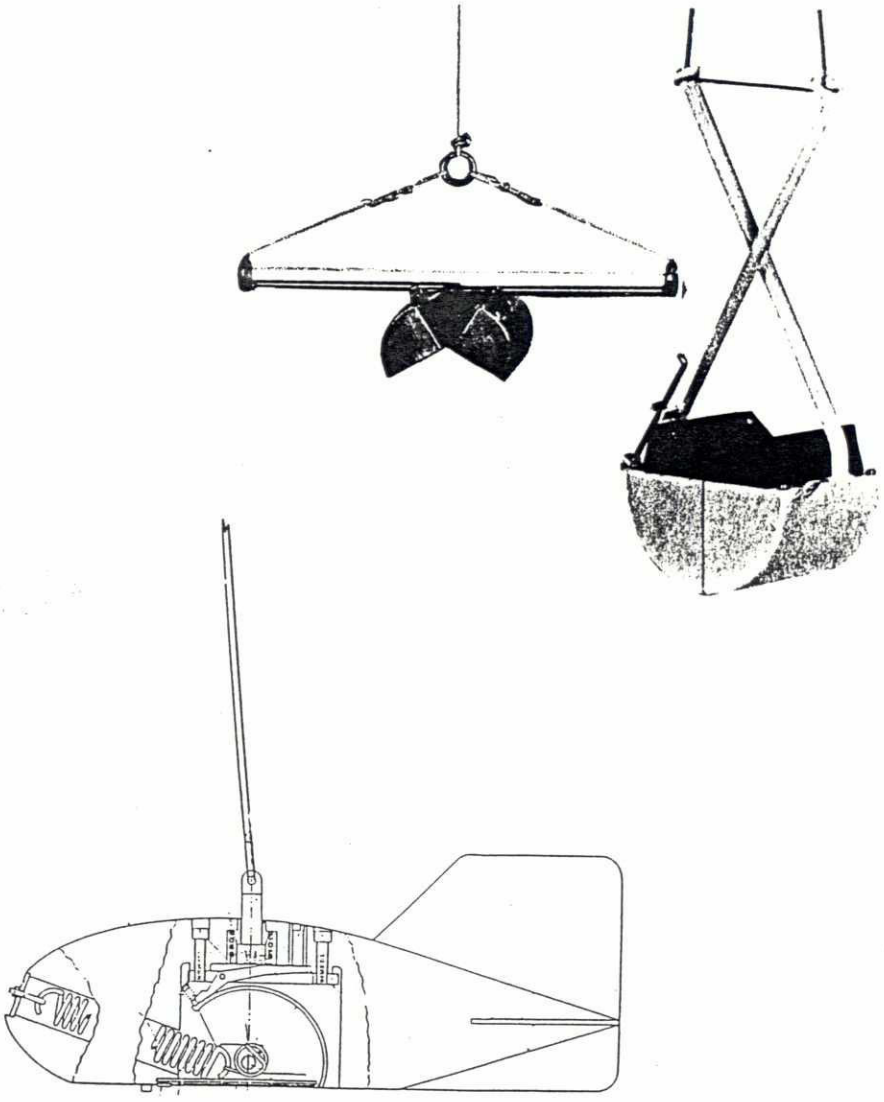


Figure 4.4 Principle sketch of the Van Veen grab and the US BM-54 bed material sampler.

S4 current meter

The S4 current meter is an integrated 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.

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.

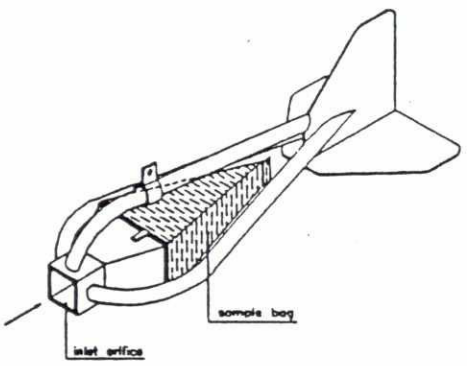


Figure 4.3 The Helley-Smith bed load trap sampler.

4.2 Survey procedures

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

- The special measurement programme
- The routine gauging 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, while the recommended method follows the moving boat concept.

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:

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

A river cross-section is classified into main channels, smaller channels and shallows. The practical definition of main channels, smaller channels and shallows reads:

- o 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.
- o Smaller channels are defined as having widths ranging from 100 m to 500 m and maximum depths ranging from 3 m to 10 m.
- o 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

As an illustration of these classifications, main channels, minor channels and shallows are indicated in Figure 4.5.

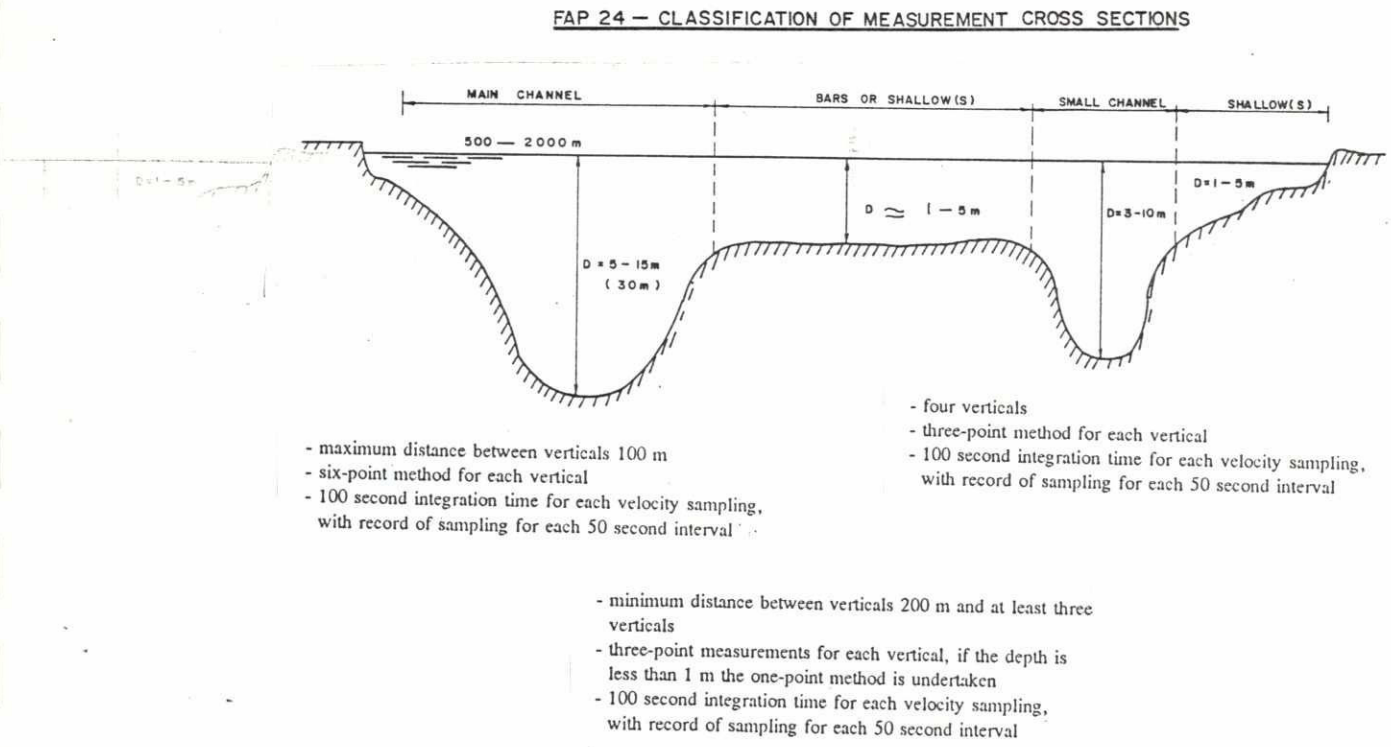


Figure 4.5 Principal classification of a cross-section with indications of main channels, smaller channels, shallows and the accompanying measurement requirements.

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 smaller deployment period is attempted.

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 judgment 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

During the present dry season Survey Report, covering the period from October 1992 to May 1993 the following routine gaugings were performed;

- Bahadurabad, 14 to 16 January 1993
- Bahadurabad, 13 to 15 February 1993
- Bahadurabad, 13 to 15 March 1993

and the following special measurements:

- Comparative discharge measurements, Bahadurabad, January 1993
- Comparative tidal discharge measurements, Hospital Ghat, Khulna, April 9, 1993
- Comparative tidal discharge measurements, Bhairab Bazar, 26 to 28 April 1993

The final quality assured River Survey Project data are reported in standardized tables found in Annexure 1 "Routine gauging inventory October 1992 to May 1993" and Annexure 2 "Special measurement inventory October 1992 to May 1993". 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 presented in Annexures 1 and 2; profile and transect survey files. A profile survey file contains measurements and information from a vertical situated at a specific position in the river. A transect survey file contains measurements from a cross-section characterized by a survey line.

The profile survey file comprises:

- Date, time and position
- S4 current measurements, north velocity, 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

Another type of data is found in the section termed sediment transport gauging in Annexures 1 and 2. With reference to the sample numbers, grain size distribution curves and tables of D_{16}, D_{35}, D_{50}, D_{65} and D_{90} for suspended sediment samples, bed load sediment samples and bed material samples are available on hard copy format.

6. Routine gauging results

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. Owing to the planform instability of the Bangladeshi rivers these informations are preceded by a description of the cross-sections from which they were obtained. Each gauging site visited during the period from January to May 1993 are described chronologically.

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

The Survey Data Report serves as a presentation of measurements and only simple analyses and standard data processings are performed. To facilitate more elaborate analyses a complete list of file names and sample identification numbers is found in Annexure 1.

6.1 Bahadurabad gauging site, 14 to 16 January 1993

6.1.1 Cross-sections and survey lines

The precise BTM position of survey profiles and a typical transect survey line in the left and the right main channel of the Jamuna River at Bahadurabad and Fulchari, are displayed in Figures 6.1 and 6.2. The precise position of all transects are found in the transect files.

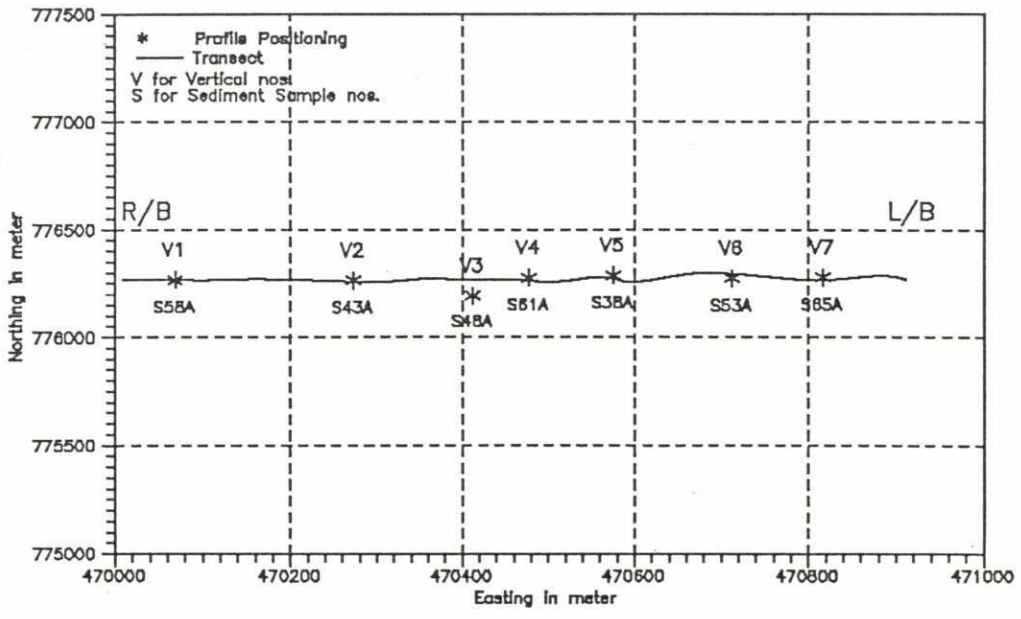


Figure 6.1 BTM positions of survey profiles and transect B31E1T02 in the left channel, Jamuna River, Bahadurabad, Jan 14, 1993.

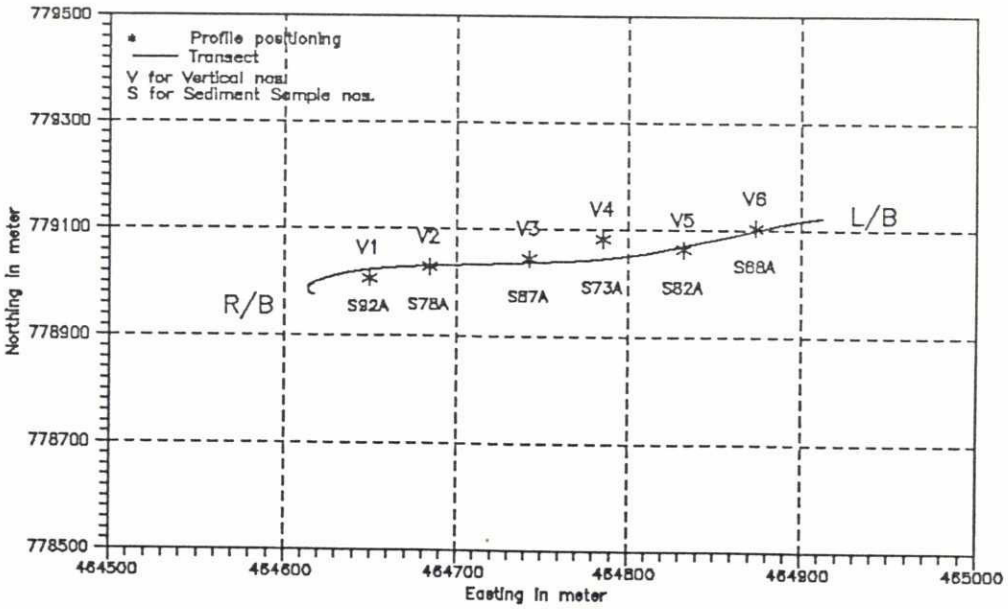


Figure 6.2 BTM positions of survey profiles and transect B31F1T02 in the right channel, Jamuna River, Bahadurabad, 15 to 16 Jan, 1993.

Though the end points of each main channel transect are identical it is not possible to retrieve the ideal survey line exactly during each transect measurement. Consequently the transect bathymetries exercise small variations with respect to length and area. The length and area of each transect is listed in Tables 6.1 and 6.2. From the tables a maximum variation of 3 and 2 per cent relative to the average area is observed. Based on Tables 6.1 and 6.2 average cross-sections for discharge calculations are established.

Date and time	Area m^2	Length m	Transect (filename)
14/01/93 08:56:03 to 09:05:11	5676	1401	B31E1T01
14/01/93 09:08:54 to 09:15:36	5516	1347	B31E1T02
14/01/93 17:45:30 to 17:53:06	5383	1357	B31E1T04

Table 6.1 Transect measurements in the left main channel at Bahadurabad Ghat, Jamuna River, 14 January 1993.

Date and time	Area m^2	Length m	Transect (filename)
15/01/93 13:22:47 to 13:26:11	1783	345	B31F1T02
15/01/93 13:30:30 to 13:34:27	1799	348	B31F1T03
15/01/93 13:42:40 to 13:46:29	1756	346	B31F1T04
16/01/93 14:22:59 to 14:26:52	1800	360	B31G1T04
16/01/93 14:30:05 to 14:33:20	1817	345	B31G1T05

Table 6.2 Transect measurements in the right main channel at Fulchari, Jamuna River, 15 to 16 January 1993.

The automatic water level recorders in Bahadurabad and Gabgachi were not yet in operation. Instead staff gauge observations from Bahadurabad and Fulchari, 14 to 16 January 1993, are presented in Figure 6.3. No variation of the water-level was observed throughout the routine gauging.

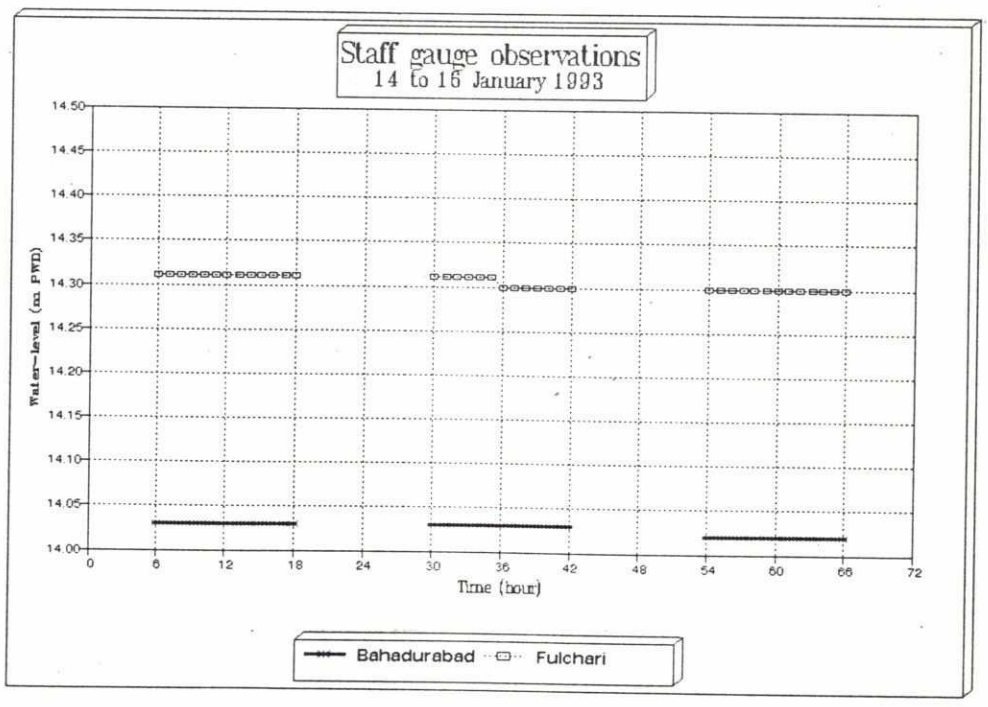


Figure 6.3 Water-level observations from the staff gauges in Bahadurabad and Fulchari, 14 to 16 January 1993.

6.1.2 Current velocities and discharge

ADCP and EMF measurements (recommended method)

All together 3 transects were surveyed in the left main channel at Bahadurabad and 5 transects in the right main channel at Fulchari on the 14 and 15 January 1993.

As an example a fraction of the velocity profiles from transect B31E1T02 in the left channel and from transect B31F1T02 in the right channel are displayed in Figures 6.4 and 6.5. The length of the current vectors represent 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.

Current velocities from 0 m/s to 1.2 m/s were measured in the left main channel on the 14 January 1993. Nearly no directional variation is observed within the verticals.

Current velocities from 0 m/s to 1.1 m/s were measured in the right main channel on the 15 and 16 January 1993. Some directional variation is observed within the verticals.

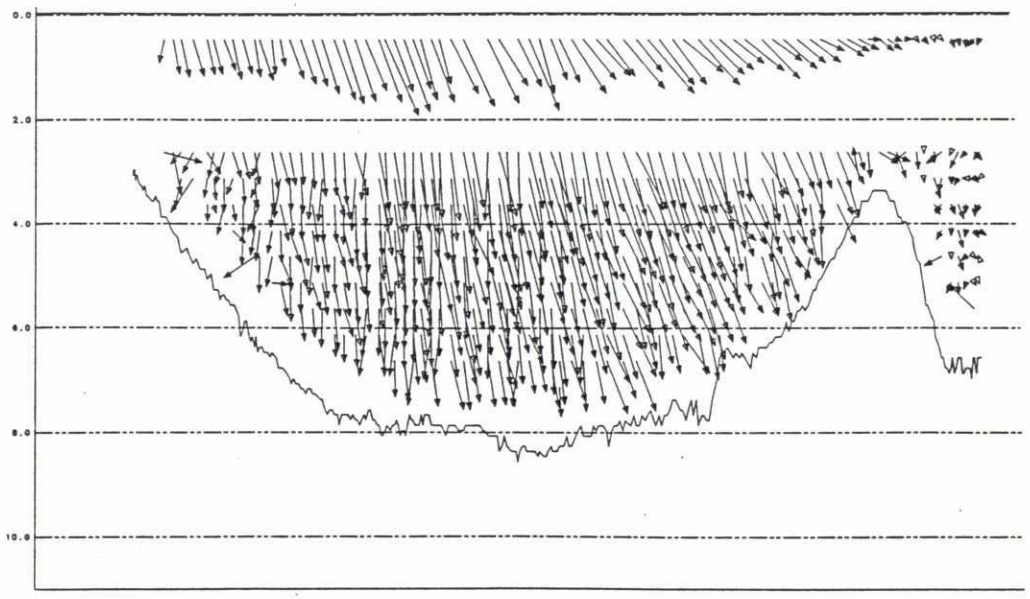


Figure 6.4 Current vectors from transect B31E1T02 in the left main channel of the Jamuna River, 14 January 1993.

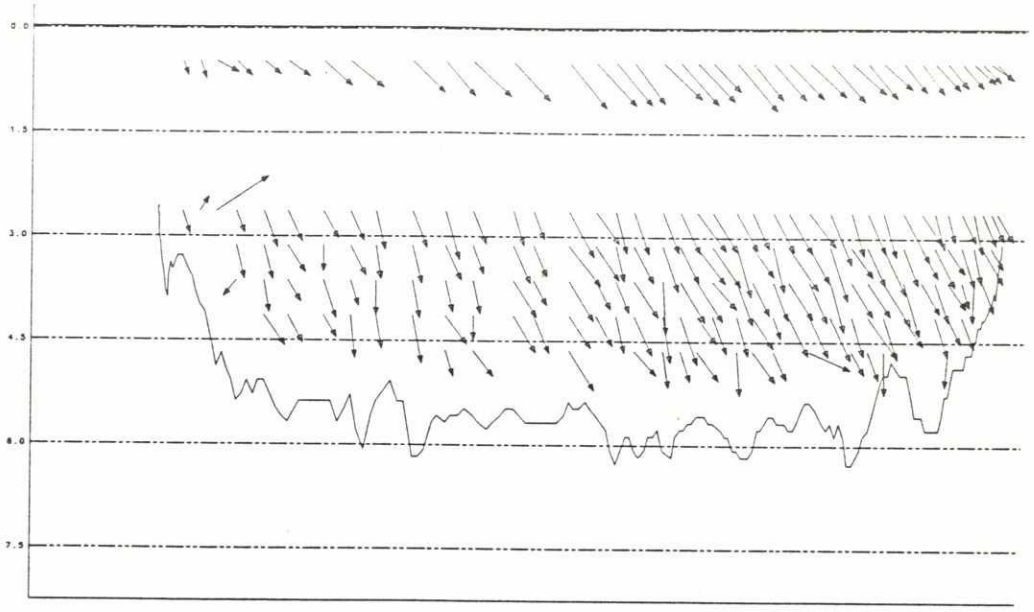


Figure 6.5 Current vectors from transect B31F1T02 in the right main channel of the Jamuna River, 15 January 1993.

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated. Tables 6.3 and 6.4 list the total discharge in the left and right main channel as well as the water-level according to the staff gauges at Bahadurabad and Fulchari.

Date and time	Discharge* m^3/s	Water-level m PWD**	Transect (filename)
14/01/93 08:56:03 to 09:05:11	4292	14.03	B31E1T01
14/01/93 09:08:54 to 09:15:36	3981	14.03	B31E1T02
14/01/93 17:45:30 to 17:53:06	4041	14.03	B31E1T04

* By the DISHTRANS programme

** Staff gauge zero 12.96 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993.

Table 6.3 Discharge and water-level in the left main channel at Bahadurabad Ghat, Jamuna River, 14 January 1993.

Date and time	Discharge* m^3/s	Water-Level m PWD**	Transect (filename)
15/01/1993 13:22:47 to 13:26:11	1264	14.30	B31F1T02
15/01/1993 13:30:30 to 13:34:27	1280	14.30	B31F1T03
15/01/1993 13:42:40 to 13:46:29	1273	14.30	B31F1T04
16/01/1993 14:22:59 to 14:26:52	1247	14.30	B31G1T04
16/01/1993 14:30:05 to 14:33:20	1336	14.30	B31G1T05

* By the DISHTRANS programme

** Staff gauge zero 13.19 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993 and displacement of gauge zero January 11, 1993, 11:00 hour.

Table 6.4 Discharge and water-level in the right main channel at Fulchari, Jamuna River, 15 to 16 January 1993.

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.

Despite the inflexibility of the water-level, discharge variations of 311 m^3/s and 89 m^3/s are observed in Table 6.3 and 6.4 respectively. These variations could be taken as a rough estimate of the measurement uncertainty. On the other hand the discharge is affected by flood waves and large scale eddies.

Based on the average discharge and the standard deviation, the discharge uncertainty is assessed to 4 and 3 per cent in the left and right channel respectively.

Manual S4-profilings (reference method)

All manual S4 current measurements in the left and right main channel at Bahadurabad Ghat obtained during 14 to 16 January 1993 are listed in Tables 6.5 and 6.6 respectively. All velocities should be increased by 6 per cent according to the Test Gauging Report, 31 October 1993. As an illustration of the figures the velocity profiles are plotted in Figures 6.6 and 6.7 in a similar way as the transects current vectors.

Vertical 1	
Total depth = 3.60 m	
Depth [m]	Velocity [m/s]
0.50	0.39
2.03	0.39
2.56	0.38
3.09	0.26

Vertical 2	
Total depth = 7.40 m	
Depth [m]	Velocity [m/s]
0.50	0.99
2.11	0.92
2.90	0.87
4.44	0.76
5.95	0.65
6.66	0.51

Vertical 3	
Total depth = 7.30 m	
Depth [m]	Velocity [m/s]
0.50	1.12
1.94	1.04
3.06	1.01
4.33	0.97
5.80	0.76
6.50	0.52

Vertical 4	
Total depth = 7.40 m	
Depth [m]	Velocity [m/s]
0.50	1.08
1.93	0.99
3.04	0.94
4.39	0.85
5.99	0.73
6.58	0.61

Vertical 5	
Total depth = 7.40 m	
Depth [m]	Velocity [m/s]
0.50	1.01
1.95	0.85
2.95	0.85
4.52	0.77
5.82	0.60
7.22	0.31

Vertical 6	
Total depth = 4.90 m	
Depth [m]	Velocity [m/s]
0.50	0.63
1.99	0.49
2.90	0.47
3.85	0.41

Vertical 7	
Total depth = 6.80 m	
Depth [m]	Velocity [m/s]
0.50	0.21
1.92	0.14
4.00	0.21
5.37	0.11
6.11	0.06

Table 6.5 S4 current measurements from verticals 1 to 7 in the left main channel of the Jamuna River, 14 January 1993.

Vertical 1	
Total depth = 5.00 m	
Depth [m]	Velocity [m/s]
0.50	0.58
2.07	0.52
2.95	0.50
4.55	0.38

Vertical 2	
Total depth = 5.50 m	
Depth [m]	Velocity [m/s]
0.50	0.64
2.00	0.64
3.25	0.59
4.45	0.47
5.30	0.40

Vertical 3	
Total depth = 6.30 m	
Depth [m]	Velocity [m/s]
0.50	0.86
2.00	0.74
2.53	0.73
3.72	0.65
5.04	0.52

Vertical 4	
Total depth = 5.80 m	
Depth [m]	Velocity [m/s]
0.50	0.83
2.04	0.69
2.46	0.71
3.76	0.63
4.86	0.54
5.47	0.46

Vertical 5	
Total depth = 5.70 m	
Depth [m]	Velocity [m/s]
0.50	0.93
1.99	0.79
2.83	0.75
3.47	0.69
4.54	0.60
5.31	0.45

Vertical 6	
Total depth = 5.30 m	
Depth [m]	Velocity [m/s]
0.50	0.38
2.05	0.69
2.49	0.69
3.20	0.64
4.31	0.58

Table 6.6 S4 current measurements from verticals 1 to 6 in the right main channel of the Jamuna River, 15 to 16 January 1993.

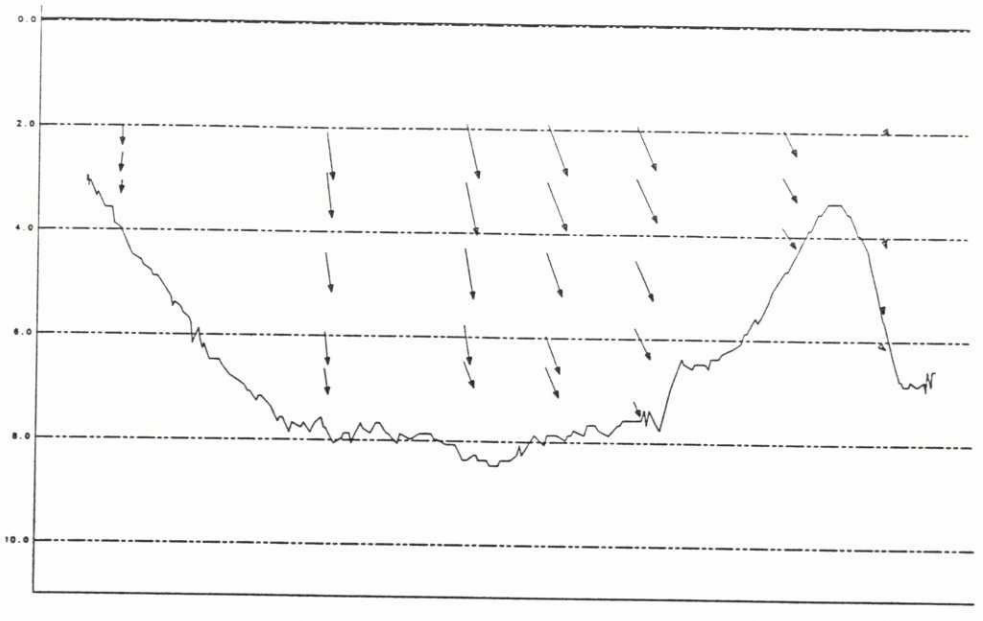


Figure 6.6 Plot of S4 current velocities from verticals 1 to 7 in the left channel at Bahadurabad, Jamuna River, January 14, 1993.

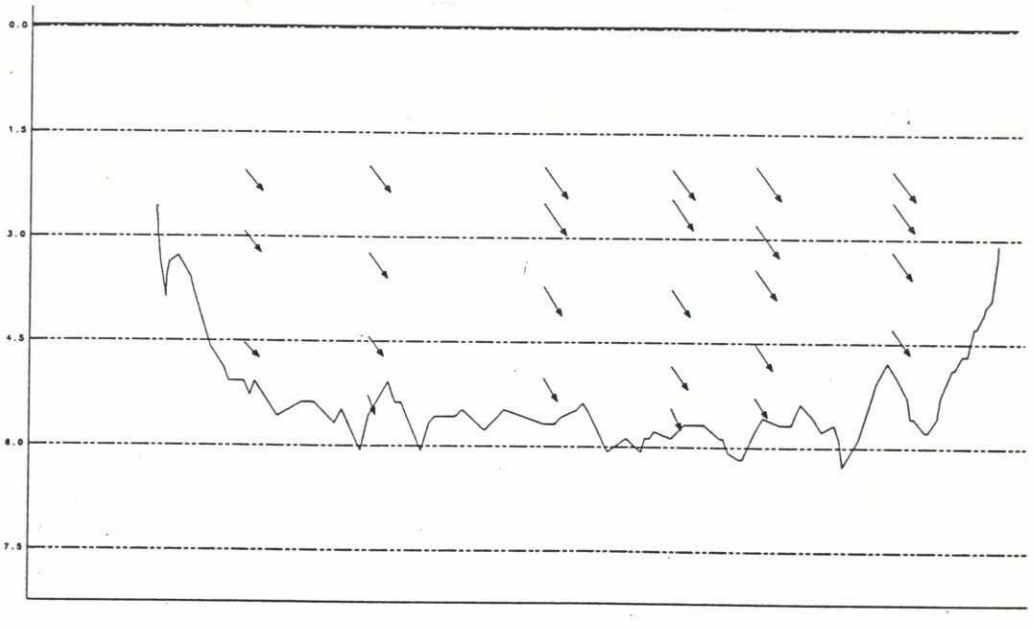


Figure 6.7 Plot of S4 current velocities from verticals 1 to 6 in the right channel at Fulchari, Jamuna River, 15 to 16 January 1993.

Current velocities from 0.06 m/s to 1.19 m/s were measured in the left main channel on the 14 January 1993. Nearly no directional variation is observed within the verticals.

Current velocities from 0.40 m/s to 0.99 m/s were measured in the right main channel on the 15 and 16 January 1993. Nearly no directional variation is observed within the verticals.

Based on the velocity-area method described in ISO 749-1979 the total discharge in the cross-section has been calculated. Table 6.7 lists the discharge in the left and right main channel based on the average bathymetric cross-section.

Location and date	S4 Discharge* m^3/s	Bathymetry (filenames)
Left main channel, Bahadurabad, January 14, 1993	3733	B31E1T01, 02 & 04
Right main channel, Fulchari, 15 to 16 January 1993	1197	B31F1T02, 03, 04, B31G1T02, 04 & 05.

* By the DISHPROF programme. The discharge has been corrected according to the Test Gauging Report, 31 October 1993 (+6 %).

Table 6.7 Discharges based on manual S4 current profilings.

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

The best estimate of the S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 9 per cent in the left main channel and 6 per cent in the right main channel is found by comparing average discharges. Assuming that the S4 and the transect discharge uncertainties are independent and normal distributed, the total S4 discharge uncertainty is assessed to 10 and 7 percent in the left and right main channel, respectively.

6.1.3 Suspended sediment transport

All suspended sediment concentration samples from the left and right main channel at Bahadurabad and Fulchari obtained during 14 to 16 January 1993 are listed in Table 6.8 and 6.9 respectively. The corresponding plots of suspended sediment profiles are found in Annexure 3.

Vertical 1	
Total depth = 3.60 m	
Depth [m]	Concentration [mg/l]
2.00	92.94
2.60	89.04
3.10	97.37

Vertical 2	
Total depth = 7.40 m	
Depth [m]	Concentration [mg/l]
2.10	98.53
2.90	110.53
4.45	175.00
5.92	165.43
6.56	227.38

Vertical 3	
Total depth = 7.30 m	
Depth [m]	Concentration [mg/l]
2.00	129.66
3.05	128.05
4.32	123.94
5.70	144.93
6.50	156.00

Vertical 4	
Total depth = 7.40 m	
Depth [m]	Concentration [mg/l]
1.90	112.41
3.00	118.06
4.40	122.48
5.90	140.00
6.70	157.82

Vertical 5	
Total depth = 7.40 m	
Depth [m]	Concentration [mg/l]
2.00	84.72
2.95	86.90
4.52	103.66
5.85	137.50
7.28	131.58

Vertical 6	
Total depth = 4.90 m	
Depth [m]	Concentration [mg/l]
1.99	80.56
2.91	88.72
3.87	110.28

Vertical 7	
Total depth = 6.80 m	
Depth [m]	Concentration [mg/l]
2.00	60.00
4.00	65.79
6.70	26336.00

Table 6.8 Suspended sediment concentrations from verticals 1 to 7 in the left main channel of the Jamuna River, 14 January 1993.

Vertical 1	
Total depth = 5.00 m	
Depth [m]	Concentration [mg/l]
2.06	83.44
2.95	90.12
4.55	99.36

Vertical 2	
Total depth = 5.50 m	
Depth [m]	Concentration [mg/l]
2.00	103.03
3.30	131.03
4.40	140.12
5.32	168.49

Vertical 3	
Total depth = 6.30 m	
Depth [m]	Concentration [mg/l]
2.00	111.56
2.55	116.90
3.72	122.67
4.99	152.56

Vertical 4	
Total depth = 5.80 m	
Depth [m]	Concentration [mg/l]
2.00	123.08
2.50	162.82
3.60	173.97
4.90	217.72

Vertical 5	
Total depth = 5.70 m	
Depth [m]	Concentration [mg/l]
2.00	194.37
2.83	172.66
3.47	211.69
4.53	118.25
5.31	232.68

Vertical 6	
Total depth = 5.30 m	
Depth [m]	Concentration [mg/l]
2.00	127.59
2.50	131.08
3.18	145.00
4.25	164.20
4.39	162.82

Table 6.9 Suspended sediment concentrations from verticals 1 to 6 in the right main channel of the Jamuna River, 15 to 16 January 1993.

Suspended sediment concentrations from 60 mg/l to 227 mg/l were measured in the left main channel on the on the 14 January 1993. The very large concentration measured by the river bed in vertical 7 should be considered erroneous by comparison to characteristic values given in River Engineering, November 1978. The value is probably a result of brief contact between the river bed and the suction hose.

Suspended sediment concentrations from 83 mg/l to 233 mg/l were measured in the right main channel on the 15 and 16 January 1993.

Using the velocity-area method multiplied by the local suspended sediment concentration, the suspended sediment transport across the gauging cross-sections has been calculated in Table 6.10.

Location and date	Suspended sediment transport* kg/s	Bathymetry (filenames)
Left main channel, Bahadurabad, January 14, 1993	438	B31E1T01, 02 & 04
Right main channel, Fulchari, 15 to 16 January 1993	159	B31F1T02, 03, 04, B31G1T04 & 05

* By the DISHPROF programme

Table 6.10 Suspended sediment transport at Bahadurabad Ghat, Jamuna River, 14 to 16 January 1993.

The uncertainty of the suspended sediment transport is estimated analogous to the uncertainty of the S4 discharge mentioned in Section 6.1.1 and not considering the uncertainty of the suspended sediment concentration; 10 and 7 per cent in the left and right channel respectively.

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 6.11.

A summary table of D_{16}, D_{35}, D_{50} and D_{90} in the right channel is found in Annexure 4. Judging by the sectional standard deviation the samples exhibit a 35 per cent scatter in the right channel. The grain size analysis procedure adopted during this period was later changed.

Location and date of manual current and sediment profiling	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, left main channel, January 14, 1993	-	-
Fulchari, right main channel, 15 to 16 January 1993	0.043	0.015

Table 6.11 Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment profilings.

6.1.4 Bed load sediment transport

No propagating bed-forms were detected and therefore only Helley-Smith trap samplings were carried out in order to assess the bed load transport. All measurement results from the left and right main channel at Bahadurabad and Fulchari are listed in Tables 6.12 and 6.13. Most of the samples are missing because the Helley-Smith trap sampler was only available on the DHA survey vessel. The samples show a large scatter though there is a certain similarity within the verticals in the left main channel.

Vertical & Samples	Bed load sediment transport g/m/s	
Vertical 2, sample 3 & 4	2.3	2.14
Vertical 3, sample 1 & 2	17.32	32.89
Vertical 5, sample 5 & 6	0.55	0.66

Table 6.12 Helley-Smith bed load sampling in the left main channel at Bahadurabad Ghat, Jamuna River, 14 January 1993.

Vertical and Samples (filename)	Bed load sediment transport g/m/s	
Vertical 3, sample 8 & 9	0.66	41.01
Vertical 5, sample 7	1.1	-

Table 6.13 Helley-Smith bed load sampling in the right main channel at Fulchari, Jamuna River, 15 to 16 January 1993.

The total bed load transport has been estimated by multiplying the average transport rates from Tables 6.12 and 6.13 by the distance between the samples, see Figures 6.1 and 6.2, and taking due consideration to the local current direction. Hereby a bed load transport of 4.3 and 2.8 kg/s is estimated in the left and the right main channel, respectively.

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 6.14.

Location and date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, left main channel, January 14, 1993	0.316	0.047
Bahadurabad, right main channel, 15 to 16 January 1993	0.282	0.007

Table 6.14 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 15 and 3 per cent scatter in the left and the right main channel, respectively.

6.2 Bahadurabad gauging site, 13 to 15 February 1993

6.2.1 Cross-sections and survey lines

The precise BTM position of survey profiles and a typical transect survey line in the right and the left main channel of the Jamuna River at Fulchari and Bahadurabad, are displayed in Figures 6.8 and 6.9. The precise position of all transects are found in the transect files.

Though the end points of each main channel transect are identical it is not possible to retrieve the ideal survey line exactly during each transect measurement. Consequently the transect bathymetries exercise small variations with respect to length and area. The length and area of each transect is listed in Tables 6.15 and 6.16. From the tables a maximum variation of 1 per cent relative to the average area is observed. Based on Tables 6.15 and 6.16 average cross-sections for discharge calculations are established.

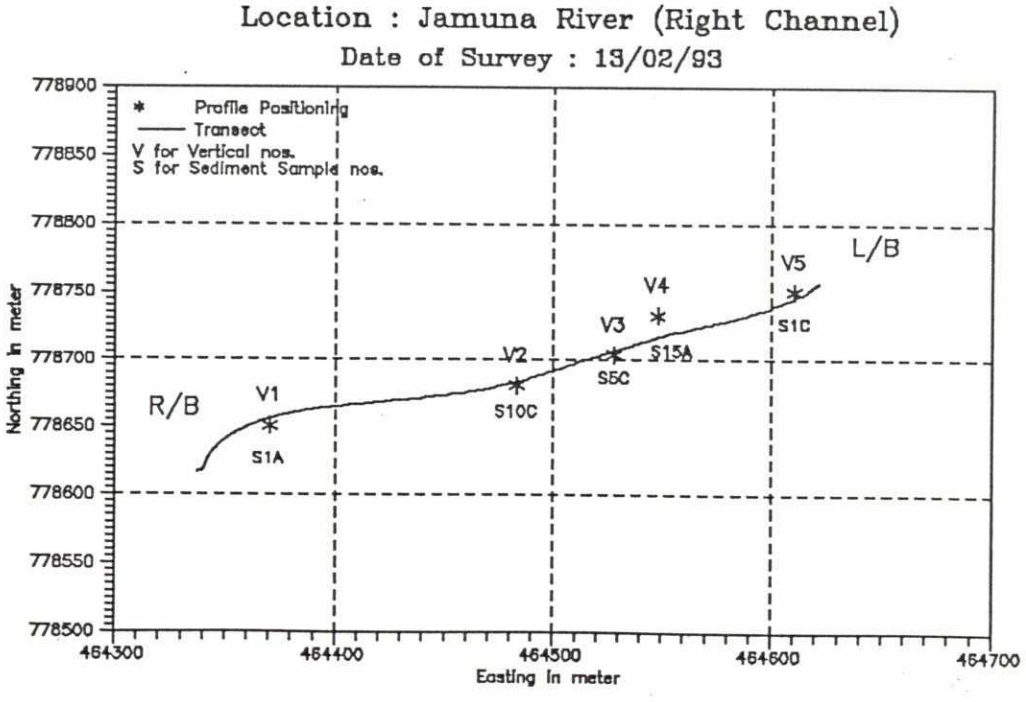


Figure 6.8 BTM positions of survey profiles and transect B32D1T02 in the right main channel, Jamuna River, Fulchari, February 13, 1993.

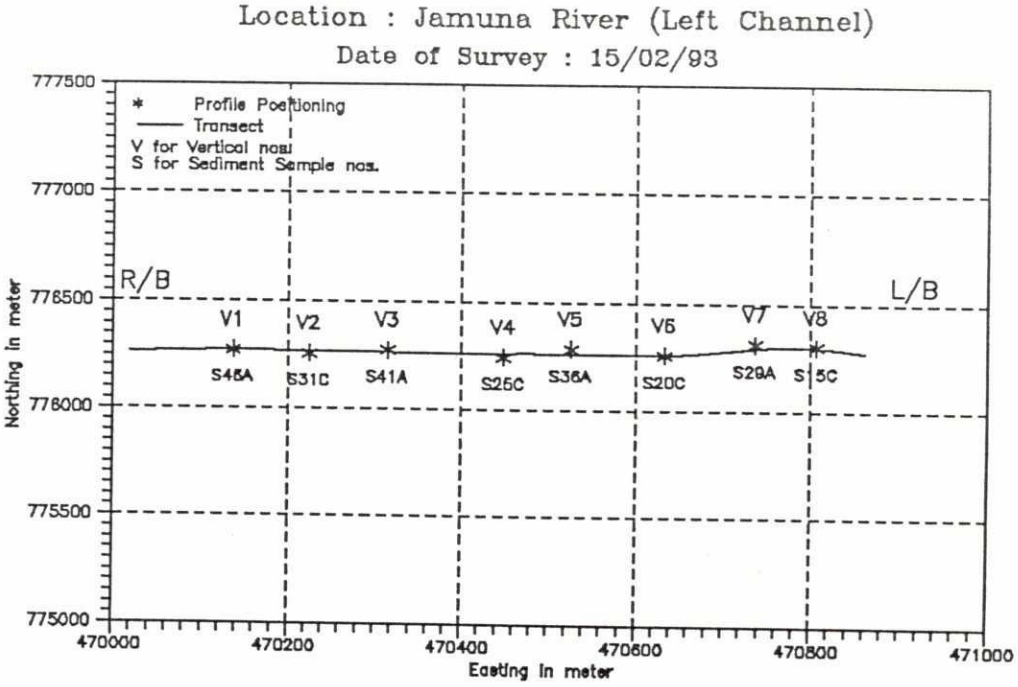


Figure 6.9 BTM positions of survey profiles and transect B32F1T02 in the left main channel, Jamuna River, Bahadurabad Ghat, 15 February, 1993.

Date and time	Area m^2	Length m	Transect (filename)
13/02/93 09:29:48 to 09:33:24	1509	335	B32D1T02
13/02/93 09:35:57 to 09:40:20	1524	335	B32D1T03
13/02/93 18:00:56 to 18:05:09	1525	337	B32D1T04
13/02/93 18:07:38 to 18:11:47	1519	337	B32D1T05

Table 6.15 Transect measurements in the right main channel at Fulchari, Jamuna River, 13 February 1993.

Date and time	Area m^2	Length m	Transect (filename)
15/02/93 10:01:34 to 10:09:47	4752	1150	B32F1T01
15/02/93 10:13:58 to 10:23:25	4793	1170	B32F1T02

Table 6.16 Transect measurements in the left main channel at Bahadurabad, Jamuna River, 15 February 1993.

The automatic water level recorders in Bahadurabad and Gabgachi were not yet in operation. Instead staff gauge observations from Bahadurabad and Fulchari, 13 to 15 February 1993, are presented in Figure 6.10. The variation of the water-level throughout the routine gauging was within 5 cm.

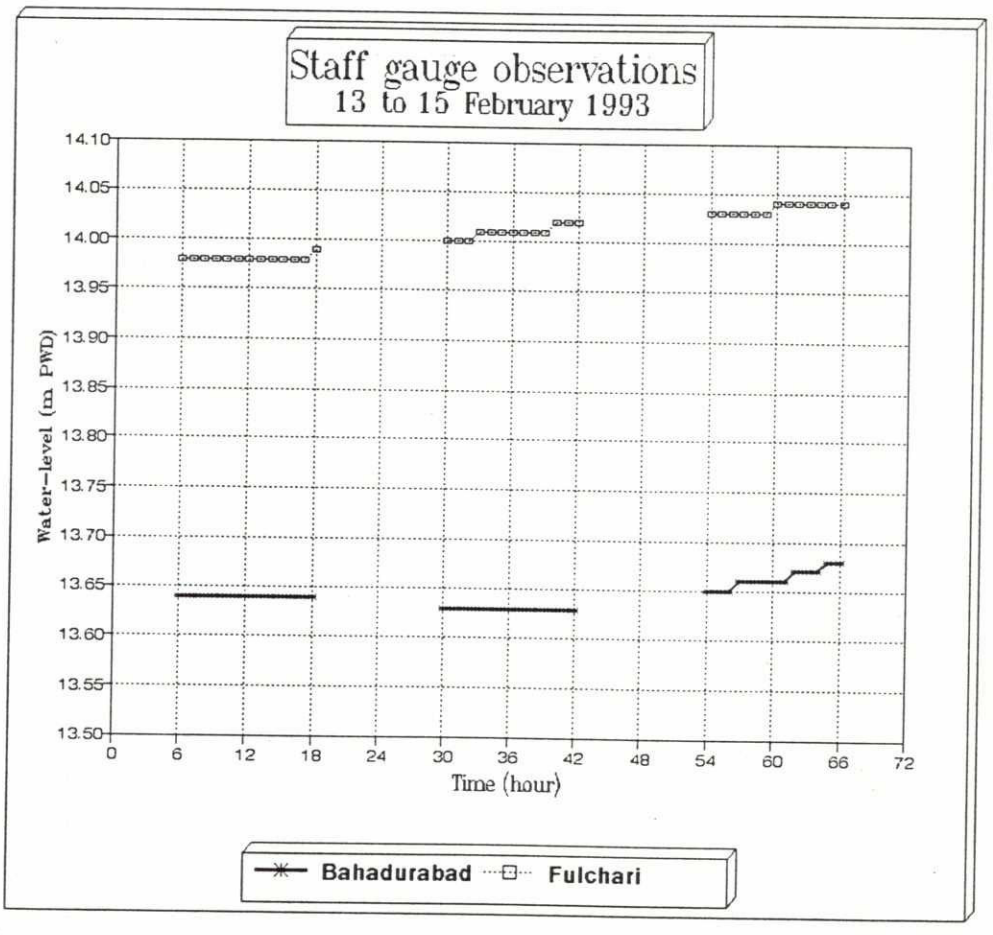


Figure 6.10 Water-level observations from the staff gauges in Fulchari and Bahadurabad, 13 to 15 February 1993.

6.2.2 Current velocities and discharge

ADCP and EMF measurements (recommended method)

All together 4 transects were surveyed in the right main channel at Fulchari and 2 transects in the left main channel at Bahadurabad on the 13 and 15 February 1993.

As an example a fraction of the velocity profiles from transect B32D1T02 in the right channel and from transect B32F1T02 in the left channel are displayed in Figures 6.11 and 6.12. The length of the current vectors represent 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.

Current velocities from 0 m/s to 0.9 m/s were measured in the right main channel on the 13 February 1993. Nearly no directional variation is observed within the verticals.

Current velocities from 0 m/s to 0.9 m/s were measured in the left main channel on the 15 February 1993. Some directional variation is observed within the verticals.

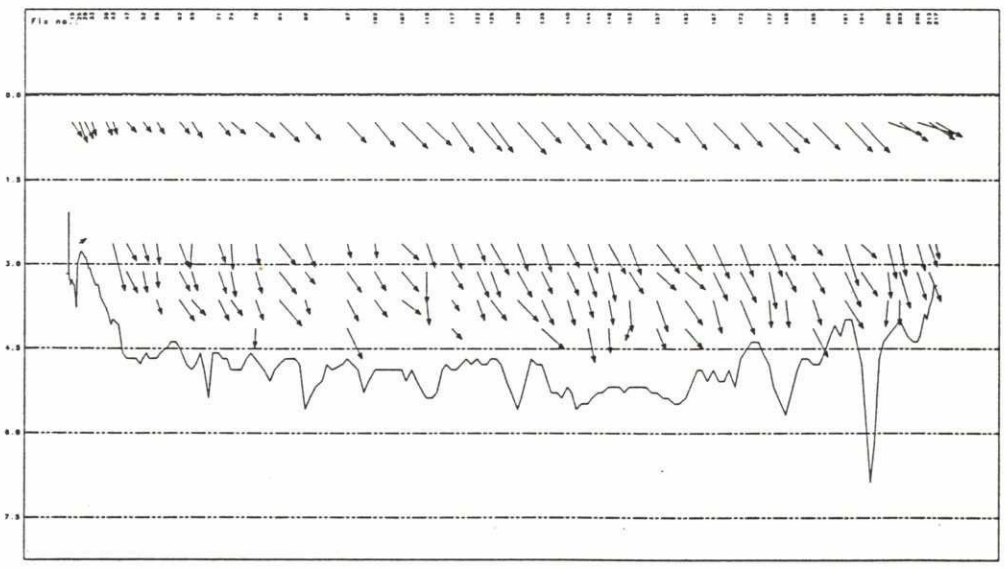


Figure 6.11 Current vectors from transect B32D1T02 in the right main channel of the Jamuna River, 13 February 1993.

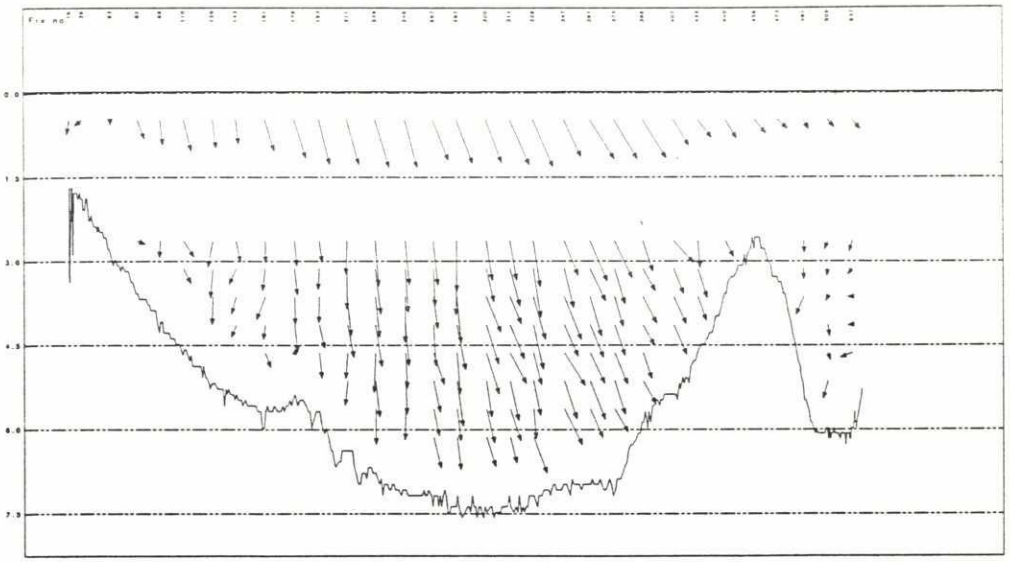


Figure 6.12 Current vectors from transect B32F1T02 in the left main channel of the Jamuna River, 15 February 1993.

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated. Tables 6.17 and 6.18 list the total discharge in the right and the left main channel as well as the water-level according to the River Survey Project staff gauges at Fulchari and Bahadurabad.

Date and time	Discharge* m^3/s	Water-level m PWD**	Transect (filename)
13/02/93 09:29:48 to 09:33:24	956	13.98	B32D1T02
13/02/93 09:35:57 to 09:40:20	898	13.98	B32D1T03
13/02/93 18:00:56 to 18:05:09	915	13.99	B32D1T04
13/02/93 18:07:38 to 18:11:47	935	13.99	B32D1T05

* By the DISHTRANS programme

** Staff gauge zero 13.19 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993 and displacement of gauge zero January 11, 1993, 11:00 hour.

Table 6.17 Discharge and water-level in the right main channel at Fulchari, Jamuna River, 13 February 1993.

Date and time	Discharge* m^3/s	Water-level m PWD**	Transect (filename)
15/02/93 10:01:34 to 10:09:47	3331	13.66	B32F1T01
15/02/93 10:13:58 to 10:23:25	3364	13.66	B32F1T02

* By the DISHTRANS programme

** Staff gauge zero 12.96 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993.

Table 6.18 Discharge and water-level in the left main channel at Bahadurabad, Jamuna River, 15 February 1993.

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.

Discharge variations of 58 m^3/s and 33 m^3/s are observed in Table 6.3 and 6.4 respectively. The discharge is affected by flood waves and large scale eddies. Based on the average discharge and the standard deviation, the discharge uncertainty is assessed to 3 and 1 per cent in the right and left channel respectively.

Manual S4-profilings (reference method)

All manual S4 current measurements in the left and right main channel at Bahadurabad and Fulchari obtained on 13 and 15 February 1993 are listed in Tables 6.19 and 6.20 respectively. All velocities should be increased by 6 per cent according to the Test Gauging Report, 31 October 1993. As an illustration the velocity profiles are depicted in Figures 6.13 and 6.14 in a similar way as the transect current vectors.

Vertical 1	
Total depth = 4.80 m	
Depth [m]	Velocity [m/s]
1.45	0.49
1.96	0.53
3.02	0.55
4.14	0.44

Vertical 2	
Total depth = 5.00 m	
Depth [m]	Velocity [m/s]
1.00	0.76
2.00	0.79
3.08	0.68
4.05	0.58
4.50	0.52

Vertical 3	
Total depth = 5.00 m	
Depth [m]	Velocity [m/s]
1.06	0.75
1.50	0.81
2.21	0.76
3.29	0.66
4.14	0.54
4.77	0.52

Vertical 4	
Total depth = 5.50 m	
Depth [m]	Velocity [m/s]
1.24	0.57
1.80	0.58
2.76	0.57
3.59	0.43

Vertical 5	
Total depth = 4.60 m	
Depth [m]	Velocity [m/s]
1,00	0.70
2.00	0.64
3.00	0.59
4.00	0.49
4.50	0.46

Table 6.19 S4 current measurements from verticals 1 to 5 in the right main channel of the Jamuna River, 13 February 1993.

Vertical 1	
Total depth = 5.00 m	
Depth [m]	Velocity [m/s]
0.50	0.57
2.00	0.51
3.00	0.48
4.00	0.42
4.30	0.40

Vertical 2	
Total depth = 5.50 m	
Depth [m]	Velocity [m/s]
0.99	0.83
1.12	0.80
2.20	0.76
3.29	0.71
4.41	0.57
4.99	0.50

Vertical 3	
Total depth = 7.10 m	
Depth [m]	Velocity [m/s]
0.50	1.05
1.40	1.00
2.80	0.91
4.20	0.77
5.66	0.70
6.60	0.56

Vertical 4	
Total depth = 7.10 m	
Depth [m]	Velocity [m/s]
1.00	1.07
1.43	1.05
2.83	1.06
4.28	1.02
5.70	0.95
6.45	0.86

Vertical 5	
Total depth = 7.40 m	
Depth [m]	Velocity [m/s]
1.25	0.89
2.78	0.94
4.28	0.82
5.61	0.67
6.53	0.54

Vertical 6	
Total depth = 5.50 m	
Depth [m]	Velocity [m/s]
1.00	0.79
2.20	0.82
3.30	0.78
4.40	0.68
4.96	0.60

Vertical 7	
Total depth = 2.60 m	
Depth [m]	Velocity [m/s]
0.50	0.40
1.50	0.43
2.25	0.24

Vertical 8	
Total depth = 5.90 m	
Depth [m]	Velocity [m/s]
1.02	0.20
2.32	0.22
3.54	0.18
4.74	0.17
5.03	0.14

Table 6.20 S4 current measurements from verticals 1 to 8 in the left main channel of the Jamuna River, 15 February 1993.

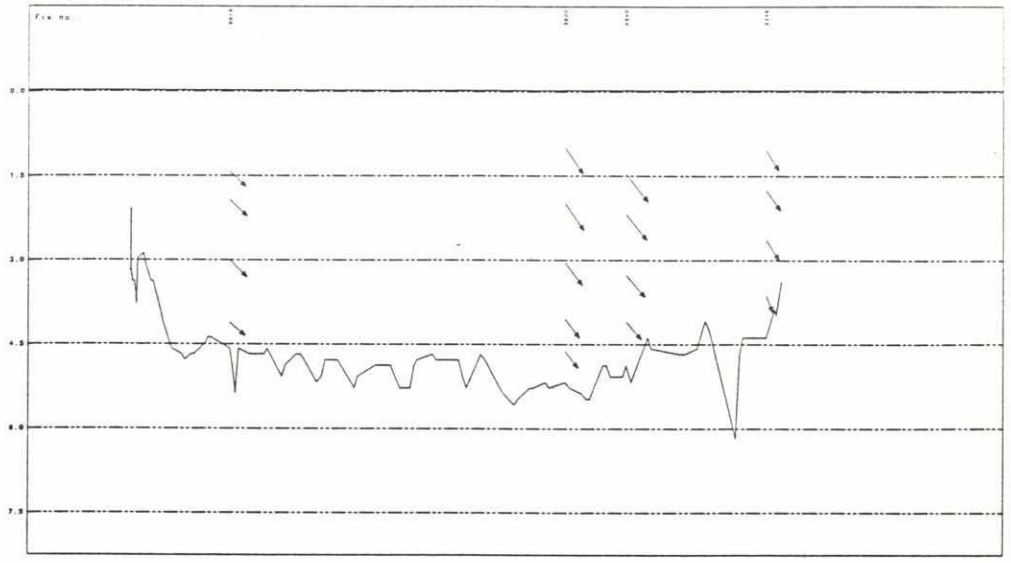


Figure 6.13 Plot of S4 current velocities from verticals 1 to 5 in the right main channel at Fulchari, Jamuna River, February 13, 1993.

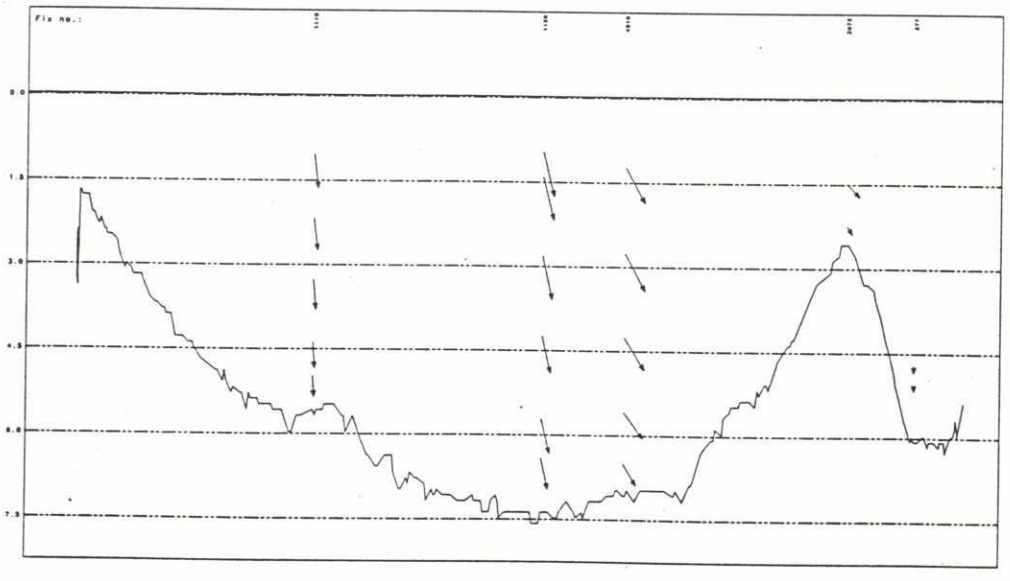


Figure 6.14 Plot of S4 current velocities from verticals 1 to 8 in the left main channel at Bahadurabad, Jamuna River, February 15, 1993.

Current velocities from 0.46 m/s to 0.86 m/s were measured in the right main channel on the 13 February 1993. Nearly no directional variation is observed within the verticals.

Current velocities from 0.15 m/s to 1.13 m/s were measured in the left main channel on the 15 February 1993. Nearly no directional variation is observed within the verticals.

Based on the velocity-area method described in ISO 749-1979 the total discharge in the cross-section has been calculated. Table 6.21 lists the discharge in the left and right main channel based on the average bathymetric cross-section.

Location and date	S4 Discharge* m^3/s	Bathymetry (filename)
Right main channel, Fulchari, February 13, 1993	967	B32D1T02, 03 ,04 & 05
Left main channel, Bahadurabad, February 15, 1993	3343	B31F1T02 & 03

* By the DISHPROF programme. The discharge has been corrected according to the Test Gauging Report, 31 October 1993 (+6 %).

Table 6.21 Discharges based on manual S4 current profilings.

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

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 in the right main channel and 0 per cent in the left main channel is found by comparing average discharges. Assuming that the S4 and the transect discharge uncertainties are independent and normal distributed, the total S4 discharge uncertainty is assessed to 5 and 1 per cent in the right and left main channel, respectively.

6.2.3 Suspended sediment transport

All suspended sediment concentration samples from the left and right main channel at Bahadurabad Ghat obtained during 13 and 15 February 1993 are listed in Tables 6.22 and 6.23 respectively. The corresponding plots of suspended sediment profiles are found in Annexure 3.

Vertical 1	
Total depth = 4.80 m	
Depth	Concentration
[m]	[mg/l]
1.45	48.61
1.95	55.68
3.02	62.34
4.01	63.41
4.28	75.95

Vertical 2	
Total depth = 5.00 m	
Depth	Concentration
[m]	[mg/l]
1.00	71.14
2.00	87.34
3.00	93.88
4.00	106.58
4.50	121.21

Vertical 3	
Total depth = 5.00 m	
Depth	Concentration
[m]	[mg/l]
1.00	135.40
2.00	158.23
3.00	201.50
4.00	228.79
4.50	236.62

Vertical 4	
Total depth = 5.50 m	
Depth	Concentration
[m]	[mg/l]
1.52	97.33
2.21	98.16
3.30	116.56
4.10	118.12

Vertical 5	
Total depth = 4.60 m	
Depth	Concentration
[m]	[mg/l]
1.00	71.23
1.80	75.00
2.76	81.69
3.68	84.00

Table 6.22 Suspended sediment concentrations from verticals 1 to 5 in the right main channel of the Jamuna River, Fulchari February 13, 1993.

Vertical 1	
Total depth = 5.00 m	
Depth	Concentration
[m]	[mg/l]
0.50	83.33
3.00	82.14
4.00	107.25
4.30	120.83

Vertical 2	
Total depth = 5.50 m	
Depth	Concentration
[m]	[mg/l]
0.99	123.08
1.12	133.77
2.20	180.61
3.29	186.90
4.41	220.73
4.99	282.67

Vertical 3	
Total depth = 7.10 m	
Depth	Concentration
[m]	[mg/l]
1.40	65.79
2.77	136.23
4.23	152.15
5.60	156.30
6.30	170.74

Vertical 4	
Total depth = 7.10 m	
Depth	Concentration
[m]	[mg/l]
1.00	137.50
1.43	115.86
2.83	115.92
4.28	150.00
5.70	158.06
6.45	189.87

Vertical 5	
Total depth = 7.40 m	
Depth	Concentration
[m]	[mg/l]
1.40	59.52
2.80	69.68
4.20	106.59
5.64	106.29
6.50	139.24

Vertical 6	
Total depth = 5.30 m	
Depth	Concentration
[m]	[mg/l]
1.00	47.68
2.20	80.85
3.30	89.47
4.40	109.20
4.96	137.97

Vertical 7	
Total depth = 2.60 m	
Depth	Concentration
[m]	[mg/l]
0.50	59.54
1.50	78.48
2.25	103.36

Vertical 8	
Total depth = 5.9	
Depth	concentration
(m)	(mg/l)
1.00	29.11
2.36	42.11
3.54	45.00
4.74	60.53
5.03	81.21

Table 6.23 Suspended sediment measurements from verticals 1 to 8 in the left main channel of the Jamuna River, Bahadurabad February 15, 1993.

Suspended sediment concentrations from 49 mg/l to 237 mg/l were measured in the right main channel on the on the 13 February 1993.

Suspended sediment concentrations from 29 mg/l to 283 mg/l were measured in the left main channel on the 15 February 1993.

Using the velocity-area method multiplied by the local suspended sediment concentration, the suspended sediment transport across the average bathymetric cross-sections has been calculated in Table 6.24.

Location and date	Suspended sediment transport* kg/s	Bathymetry (filename)
Right main channel, Fulchari, February 13, 1993	108	B32D1T02, 03, 04 & 05
Left main channel, Bahadurabad, February 15, 1993	419	B32F1T01 & 02

* By the DISHPROF programme.

Table 6.24 Suspended sediment transport in the Jamuna river.

The uncertainty of the suspended sediment transport is estimated analogous to the uncertainty of the S4 discharge mentioned in Section 6.2.1 and not considering the uncertainty of the suspended sediment concentration; 5 and 1 per cent in the left and right channel respectively.

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 6.25.

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 50 and 39 per cent scatter in the right and left channel, respectively.

Location and date of manual current and sediment profiling	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, February 13, 1993	0.046	0.023
Bahadurabad, left main channel, 15 to 16 February 1993	0.046	0.018

Table 6.25 Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment profilings.

6.2.4 Bed load sediment transport

No propagating bed-forms were detected and therefore only Helley-Smith trap samplings were carried out in order to assess the bed load transport. All measurement results from the right and the left main channel at Fulchari and Bahadurabad are listed in Tables 6.26 and 6.27.

Vertical & Samples	Bed load sediment transport g/m/s			
Vertical 1, sample 6, 7 & 8	0.08	0.55	0.27	
Vertical 2, sample 26, 27, 28	2.81	3.63	9.24	
Vertical 3, sample 23, 24 & 25	5.19	0.49	1.48	
Vertical 4, sample 21, 22	7.35	23.32		
Vertical 5, sample 10, 11, 12 & 13	0.24	0.98	0.07	11.1

Table 6.26 Helley-Smith bed load sampling in the right main channel at Fulchari, Jamuna River, 13 February 1993.

The samples show a large scatter and exceptionally transport rates within the same vertical vary with a factor of 10 to 50. More samples or longer deployment intervals are probably the only way to obtain reliable average transport rates.

The total bed load transport has been estimated by multiplying the average transport rates from Tables 6.26 and 6.27 by the distance between the samples, see Figures 6.8 and 6.9, and taking due consideration to the local current direction. Hereby a bed load transport of 1.2 and 5.0 kg/s is estimated in the right and the left main channel, respectively.

Vertical and Samples (filename)	Bed load sediment transport g/m/s		
Vertical 1, samples 70, 71 & 72	0.01	0.03	0.02
Vertical 2, samples 66, 67,68	1.45	3.44	2.47
Vertical 3, samples 62, 63 & 64	3.86	21.01	50.0
Vertical 4, samples 58, 59 & 60	5.03	4.18	4.99
Vertical 5, samples 54, 55 & 56	1.87	1.57	41.3
Vertical 6, samples 50, 51 & 52	0.24	1.54	0.88
Vertical 7, samples 33 & 34	0.06	0.24	-

Table 6.27 Helley-Smith bed load sampling in the left main channel at Bahadurabad Ghat, Jamuna River, 15 February 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 6.28.

Location and date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, February 13, 1993	0.228	0.041
Bahadurabad, left main channel, February 16, 1993	0.251	0.067

Table 6.28 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 50 and 39 per cent scatter in the right and left channel, respectively.

Bed material sampling

River bed sediment samples were obtained by the Van Veen grab sampler. 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 6.29.

Location and date of Van Veen grab sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, February 13, 1993	0.166	0.0025
Bahadurabad, left main channel, 15 to 16 February 1993	0.156	0.095

Table 6.29 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 2 and 61 per cent scatter in the right and left main channel.

6.3 Bahadurabad gauging site, 13 to 16 March 1993

6.3.1 Cross-sections and survey lines

The precise BTM position of survey profiles and a typical transect survey line in the right and the left main channel of the Jamuna River at Fulchari and Bahadurabad are displayed in Figures 6.15 and 6.16. The precise position of all transects are found in the transect files.

Though the end points of each main channel transect are identical it is not possible to retrieve the ideal survey line exactly during each transect measurement. Consequently the transect bathymetry exercises small variations with respect to length and area. The length and area of each transect is listed in Tables 6.30 and 6.31. From the tables a maximum variation of 6 and 10 per cent relative to the average area is observed. Based on Tables 6.30 and 6.31 average cross-sections for discharge calculations are established.

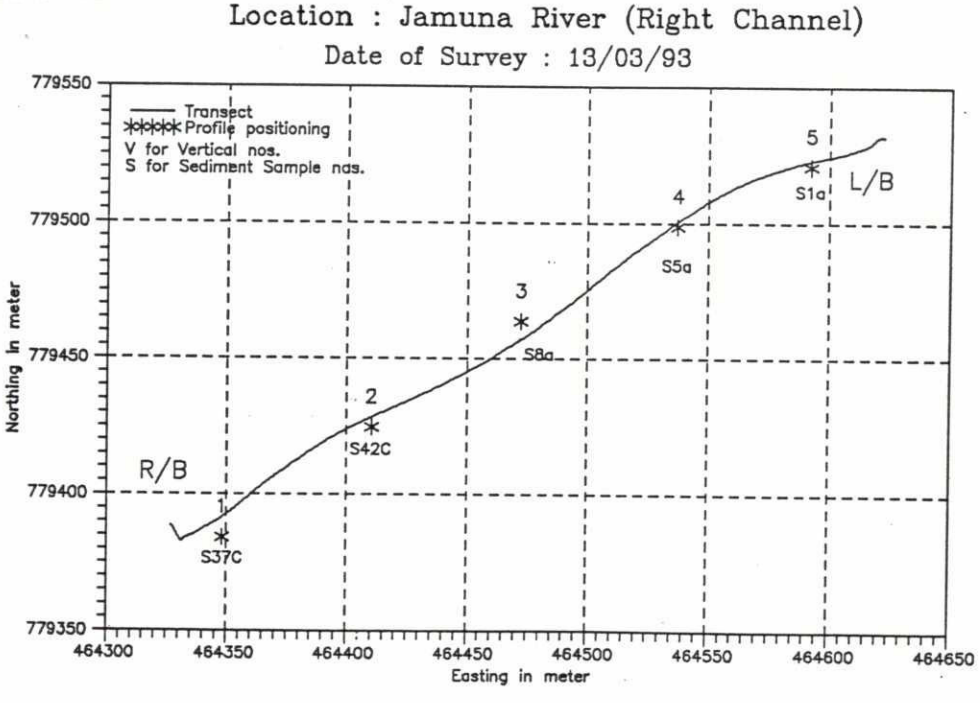


Figure 6.15 BTM positions of survey profiles and transect B33D1T01 in the right main channel, Jamuna River, Fulchari, March 13, 1993.

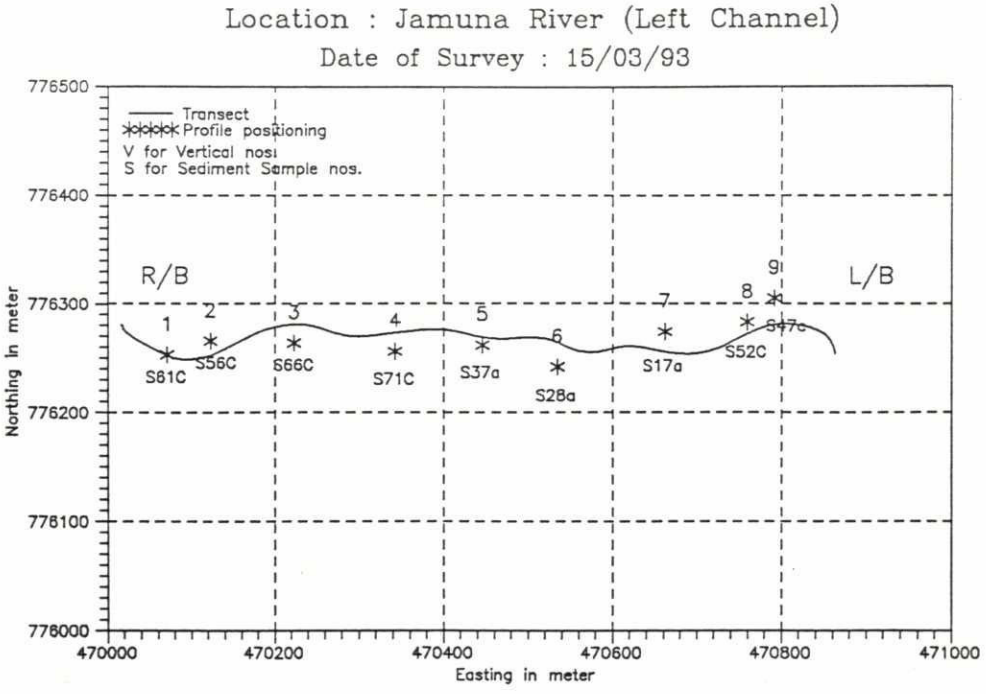


Figure 6.16 BTM positions of survey profiles and transect B33F1T01 in the left main channel, Jamuna River, Bahadurabad, March 15, 1993.

Date and time	Area m^2	Length m	Transect (filename)
15/03/93 08:15:17 to -	4272	1219	B33F1T01
15/03/93 - - 08:40:15	4711	1362	B33F1T02
16/03/93 11:13:28 to 11:21:50	4485	1290	B33G1T04
16/03/93 - - 11:34:48	4650	1332	B33G1T05
16/03/93 14:38:47 TO 14:47:19	4538	1319	B33G1T06

Table 6.30 Transect measurements in the left main channel at Bahadurabad, Jamuna River, 15 and 16 March 1993.

Date and time	Area m^2	Length m	Transect (filename)
13/03/93 10:53:08 to 10:57:09	1273	342	B33D1T01
13/02/93 17:57:25 to 18:03:20	1553	340	B33D1T03

Table 6.31 Transect measurements in the right main channel at Fulchari, Jamuna River, March 13, 1993.

The Gabgachi automatic water level recorder (AWLR) was not yet in operation. Instead staff gauge observations from Bahadurabad and Fulchari, 13 to 16 March 1993, are presented in Figure 6.17. The variation of the water-level throughout the routine gauging was within 4 cm.

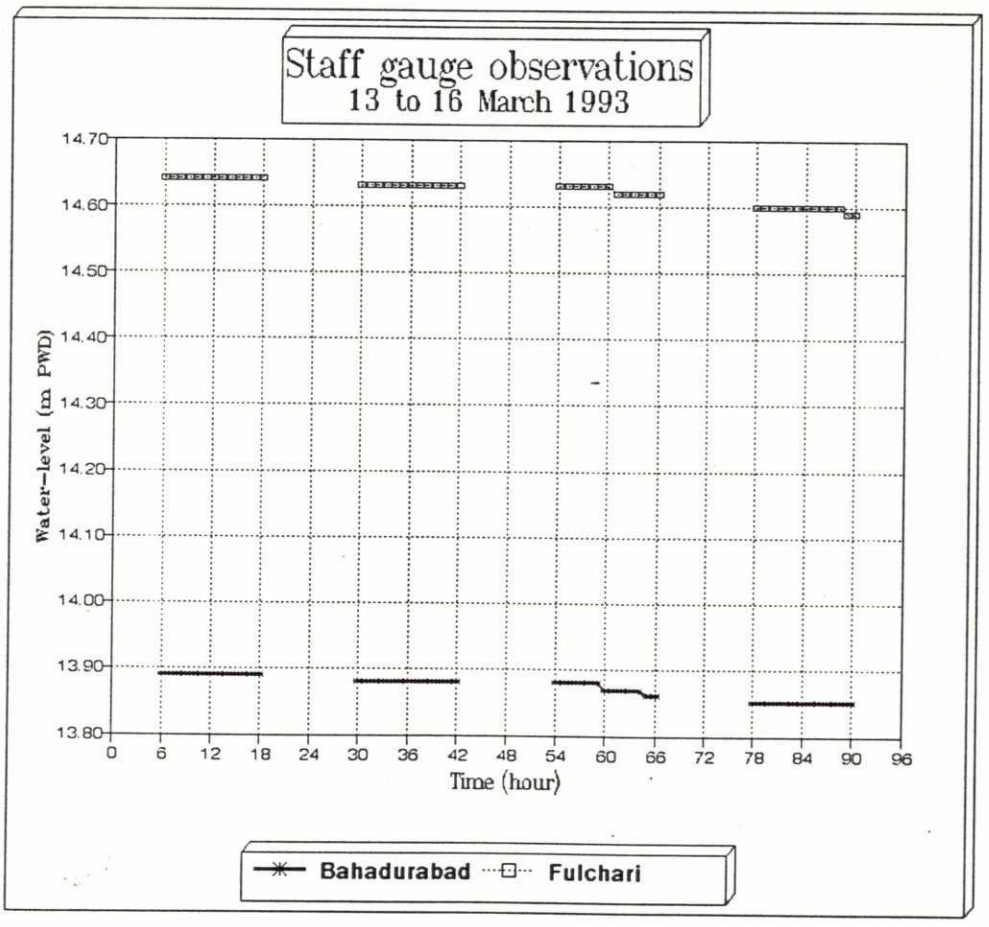


Figure 6.17 Water-level observations from the staff gauges in Fulchari and Bahadurabad, 13 to 16 March 1993.

6.3.2 Current velocities and discharge

ADCP and EMF measurements (recommended method)

As an example a fraction of the velocity profiles from transect B33D1T01 in the right channel and from transect B33F1T01 in the left channel are displayed in Figures 6.18 and 6.19. The length of the current vectors represent 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.

Current velocities from 0 m/s to 0.8 m/s were measured in the right main channel on the 13 March 1993. Substantial directional variation is observed within the verticals.

Current velocities from 0 m/s to 1.2 m/s were measured in the left main channel on the 15 and 16 March 1993. Some directional variation is observed within the verticals.

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated. Tables 6.32 and 6.33 list the total discharge in the right and the left main channel as well as the water-level according to the BWDB staff gauges at Fulchari and Bahadurabad.

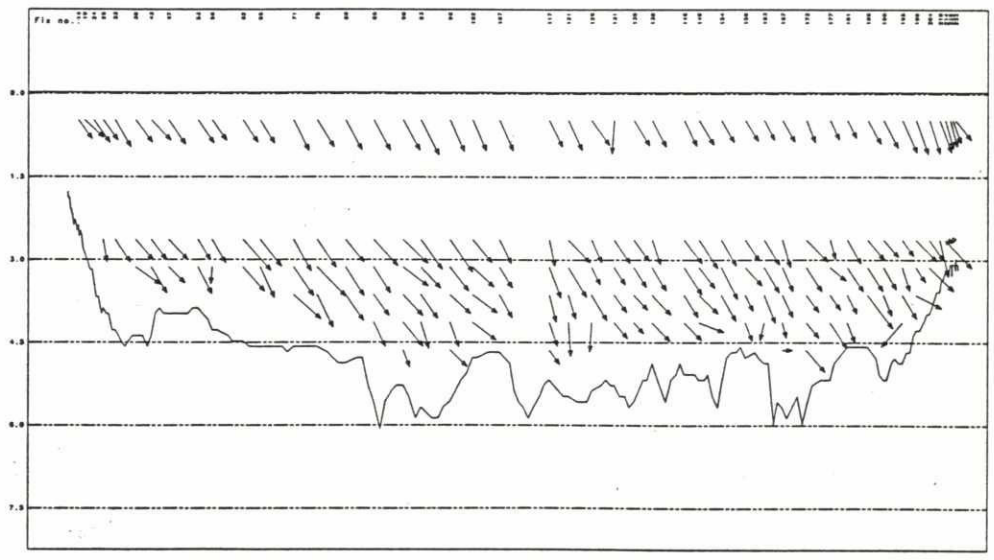


Figure 6.18 Current vectors from transect B33D1T01 in the right main channel of the Jamuna River, Fulchari March 13, 1993.

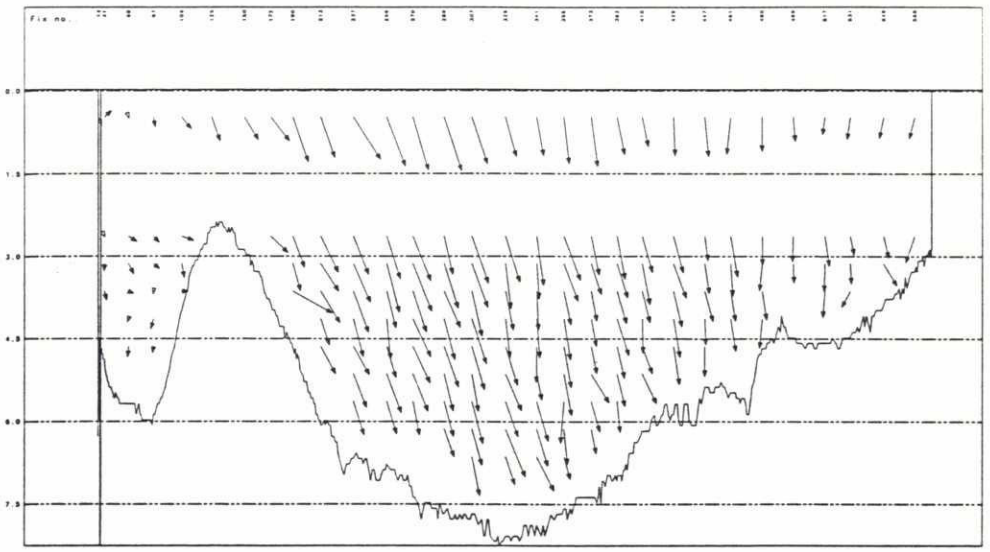


Figure 6.19 Current vectors from transect B33G1T05 in the left main channel of the Jamuna River, Bahadurabad February 15, 1993.

Date and time	Discharge* m^3/s	Water-level m PWD**	Transect (filename)
13/03/93 10:53:08 to 10:57:09	1101	14.64	B33D1T01
13/02/93 17:57:25 to 18:03:20	1111	14.64	B33D1T03

* By the DISHTRANS programme

** Staff gauge zero 14.19 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993 and subsequent displacements of the gauge zero level; 11.01.1993 11:00 and 22.02.1993 10:00

Table 6.32 Discharge and water-level in the right main channel at Fulchari, Jamuna River, 13 March 1993.

Date and time	Discharge* m^3/s	Water-level m PWD**	Transect (filename)
15/03/93 08:15:17 to -	3445	13.88	B33F1T01
15/03/93 - - 08:40:15	3565	13.88	B33F1T02
16/03/93 11:13:28 to 11:21:50	3660	13.85	B33G1T04
16/03/93 - - 11:34:48	3591	13.85	B33G1T05
16/03/93 14:38:47 TO 14:47:19	3525	13.85	B33G1T06

* By the DISHTRANS programme.

** Staff gauge zero 12.96 m PWD, according to Report on Transfer of Bench-mark Levels across Jamuna River at Bahadurabad, October 1993.

Table 6.33 Discharge and water-level in the left main channel at Bahadurabad, Jamuna River, 15 and 16 March 1993.

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.

Despite the inflexibility of the water-level, discharge variations of 10 m^3/s 215 m^3/s are observed in Tables 6.32 and 6.33. The discharge is affected by river stage variation, flood waves and large scale eddies. Based on the latest Bahadurabad rating curve (ref. Hydrological Study, June 1993) the discharge/river stage gradient amounts to 29 $m^3/s/cm$. Based on this gradient and the water-level recordings, Figure 6.17, the corrected discharge variations become 10 m^3/s and 302 m^3/s respectively. Based on the average discharge and the standard deviation, the discharge uncertainty is assessed to 1 and 3 per cent in the right and left main channel respectively.

Manual S4-profilings (reference method)

All manual S4 current measurements in the left and right main channel at Bahadurabad and Fulchari obtained on 13 and 15 March 1993 are listed in Tables 6.34 and 6.35 respectively. All velocities should be increased by 6 per cent according to the Test Gauging Report, 31 October 1993. As an illustration the velocity profiles are depicted in Figures 6.20 and 6.21 in a similar way as the transect current vectors.

Vertical 1	
Total depth = 4.60 m	
Depth	Velocity
[m]	[m/s]
0.91	0.61
1.85	0.61
2.75	0.55
3.65	0.49
4.34	0.43

Vertical 2	
Total depth = 5.70 m	
Depth	Velocity
[m]	[m/s]
0.58	0.72
1.10	0.71
2.25	0.66
3.41	0.63
4.61	0.547

Vertical 3	
Total depth = 4.90 m	
Depth	Velocity
[m]	[m/s]
0.50	0.75
1.97	0.71
2.98	0.64
4.04	0.57
4.64	0.50

Vertical 4	
Total depth = 4.80 m	
Depth	Velocity
[m]	[m/s]
0.50	0.88
2.02	0.80
2.77	0.75
3.79	0.66
4.54	0.56

Vertical 5	
Total depth = 4.40 m	
Depth	Velocity
[m]	[m/s]
0.50	0.69
2.00	0.63
2.60	0.56
3.60	0.44
4.20	0.442

Table 6.34 S4 current measurements from verticals 1 to 5 in the right main channel of the Jamuna River, March 13, 1993.

Vertical 1	
Total depth = 3.60 m	
Depth	Velocity
[m]	[m/s]
0.98	0.49
1.55	0.41
2.16	0.35
2.88	0.28

Vertical 2	
Total depth = 4.50 m	
Depth	Velocity
[m]	[m/s]
0.99	0.65
1.81	0.53
2.67	0.49
3.57	0.39

Vertical 3	
Total depth = 5.80 m	
Depth	Velocity
[m]	[m/s]
1.14	0.79
2.29	0.80
3.47	0.74
4.70	0.59

Vertical 4	
Total depth = 7.20 m	
Depth	Velocity
[m]	[m/s]
0.94	1.07
1.42	1.04
2.89	0.93
4.30	0.84
5.72	0.69
6.21	0.63

Vertical 5	
Total depth = 7.80 m	
Depth	Velocity
[m]	[m/s]
0.50	1.45
1.56	1.01
3.02	0.88
4.68	0.83
6.15	0.74
7.16	0.58

Vertical 6	
Total depth = 7.40 m	
Depth	Velocity
[m]	[m/s]
0.50	1.15
2.00	1.04
3.00	0.96
4.40	0.89
6.60	0.89
6.00	0.71
7.00	0.625

Vertical 7	
Total depth = 5.10 m	
Depth	Velocity
[m]	[m/s]
0.50	1.05
1.03	0.65
2.02	0.63
2.97	0.55
3.95	0.51
4.80	0.43

Vertical 8	
Total depth = 3.10 m	
Depth	Velocity
[m]	[m/s]
0.95	0.35
1.78	0.34
2.41	0.26

Vertical 9	
Total depth = 5.50 m	
Depth	Velocity
[m]	[m/s]
1.08	0.21
2.18	0.18
3.30	0.16
4.37	0.16

Table 6.35 S4 current measurements from verticals 1 to 9 in the left main channel of the Jamuna River, March 15 1993.

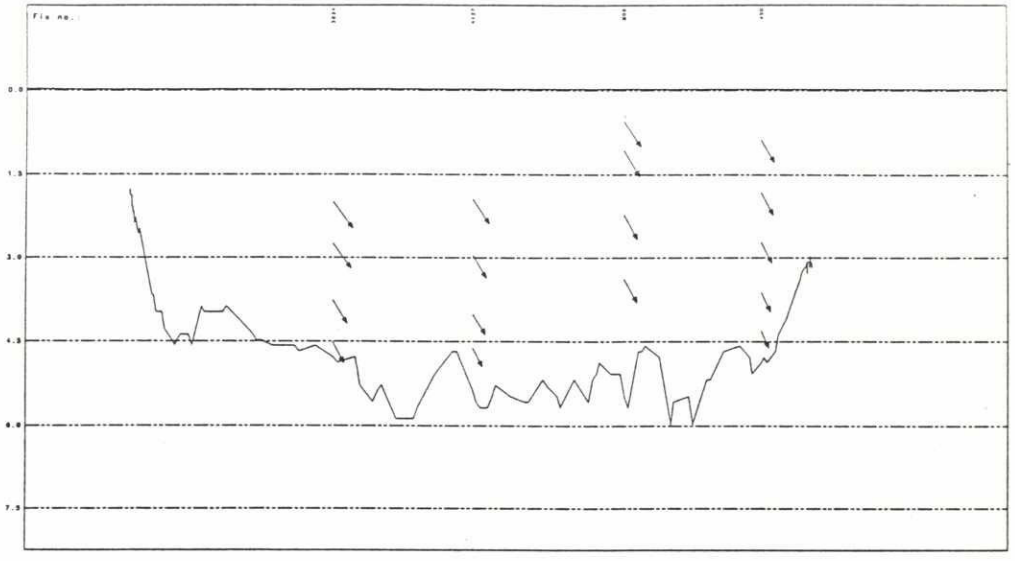


Figure 6.20 Plot of S4 current velocities from verticals 1 to 5 in the right main channel at Fulchari, Jamuna River, March 13, 1993.

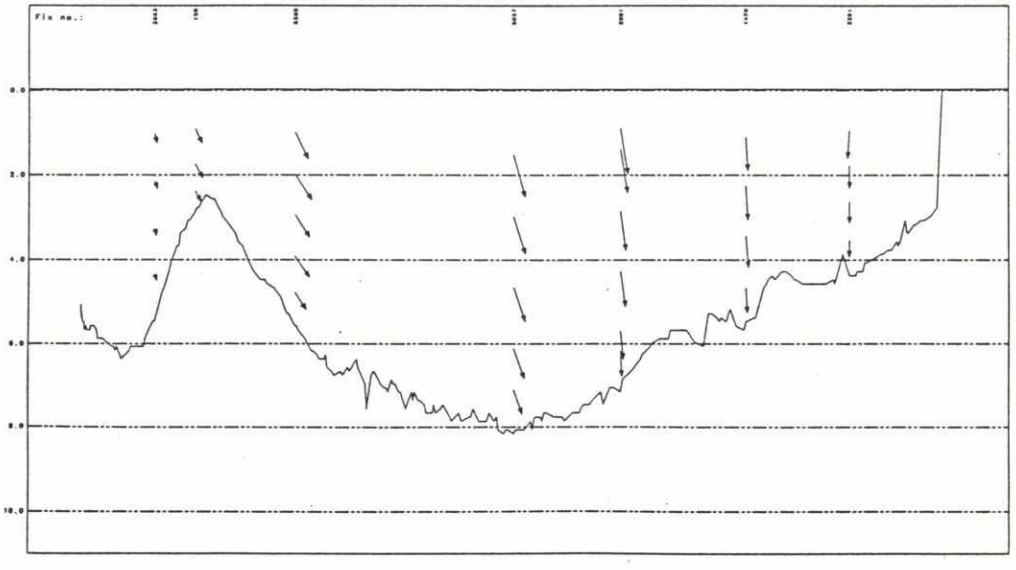


Figure 6.21 Plot of S4 current velocities from verticals 1 to 9 in the left main channel at Bahadurabad, Jamuna River, March 15, 1993.

Current velocities from 0.46 m/s to 0.93 m/s were measured in the right main channel on the 13 March 1993. Nearly no directional variation is observed within the verticals.

Current velocities from 0.17 m/s to 1.54 m/s were measured in the left main channel on the 15 March 1993. Nearly no directional variation is observed within the verticals.

Based on the velocity-area method described in ISO 749-1979 the total l discharge in the cross-section has been calculated. Table 6.36 lists the discharge in the left and right main channel based on the average bathymetric cross-section.

Location and date	S4 Discharge* m^3/s	Bathymetry (filename)
Right main channel, Fulchari, March 13, 1993	1194	B33D1T01 & 03
Left main channel, Bahadurabad, March 15, 1993	3201	B33F1T01 & 02

* By the DISHPROF programme. The discharge has been corrected according to the Test Gauging Report, 31 October 1993 (+6 %).

Table 6.36 Discharges based on manual S4 current profilings.

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

The best estimate of the S4 discharge uncertainty is probably provided by a comparison with the ADCP/EMF transects described above. A discrepancy of 8 per cent in the right main channel and 11 per cent in the left main channel is found by comparing average discharges. Assuming that the S4 and the transect discharge uncertainties are independent and normal distributed, the total S4 discharge uncertainty is assessed to 8 and 12 percent in the right and left main channel, respectively.

6.3.3 Suspended sediment transport

All suspended sediment concentration samples from the left and right main channel at Bahadurabad and Fulchari obtained during 13 and 15 March 1993 are listed in Tables 6.37 and 6.38 respectively. The corresponding plots of suspended sediment profiles are found in Annexure 3.

Date of Survey: 13 March 1993
Location : Right Channel at Fulchari

Vertical 1		Vertical 2		Vertical 3		Vertical 4		Vertical 5	
Total depth = 4.60 m		Total depth = 5.70 m		Total depth = 4.90 m		Total depth = 4.60 m		Total depth = 4.40 m	
Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]
0.91	74.83	0.59	77.63	2.00	66.67	2.00	58.54	2.00	52.24
1.85	71.90	1.10	81.48	2.90	67.67	2.80	77.03	2.60	57.14
2.75	73.97	2.24	90.79	4.00	69.86	3.80	90.07	3.60	60.65
3.67	84.62	3.41	91.61	4.60	115.44			4.20	66.67
4.35	91.79	4.53	99.36						

Table 6.37 Suspended sediment concentrations from verticals 1 to 5 in the right main channel of the Jamuna River, Fulchari March 13, 1993.

Date of survey : 15 March 1993
Location : Left Channel at Bahadurabad

Vertical 1		Vertical 2		Vertical 3		Vertical 4		Vertical 5	
Total depth = 3.60 m		Total depth = 4.50 m		Total depth = 5.80 m		Total depth = 7.20 m		Total depth = 7.80 m	
Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]
0.98	146.15	0.95	187.33	1.16	87.84	0.96	73.13	1.50	63.38
1.55	173.81	1.78	217.11	2.29	96.97	1.42	93.79	3.10	86.76
2.16	181.58	2.68	394.59	3.47	132.87	2.90	102.59	4.70	93.33
2.88	181.90	3.56	631.82	4.73	131.21	4.32	104.18	6.20	92.99
						5.76	119.18	7.13	102.21
						6.20	162.76		

Vertical 6		Vertical 7		Vertical 8		Vertical 9	
Total depth = 7.40 m		Total depth = 5.10 m		Total depth = 3.1		Total depth = 5.5	
Depth [m]	Concentration [mg/l]	Depth [m]	Concentration [mg/l]	Depth (m)	Concentration (mg/l)	Depth (m)	Concentration (mg/l)
2.00	45.39	1.00	34.90	1.00	69.33	1.10	30.49
3.00	68.00	2.00	57.69	1.80	87.14	2.18	43.24
4.40	78.91	3.00	49.30	2.44	143.48	3.30	51.19
6.00	98.67	4.00	72.60			4.38	111.25
7.00	105.06	4.80	88.72				

Table 6.38 Suspended sediment concentrations from verticals 1 to 9 in the left main channel of the Jamuna River, Bahadurabad March 15, 1993.

Suspended sediment concentrations from 52 mg/l to 115 mg/l were measured in the right main channel on the on the 13 March 1993.

Suspended sediment concentrations from 30 mg/l to 632 mg/l were measured in the left main channel on the 15 March 1993.

Using the velocity-area method multiplied by the local suspended sediment concentration, the suspended sediment transport across the average bathymetric cross-sections has been calculated in Table 6.39.

Location and data	Suspended sediment transport* kg/s	Bathymetry (filename)
Right main channel, Fulchari, March 13, 1993	79	B33D1T01 & 02
Left main channel, Bahadurabad, March 15, 1993	343	B33F1T01 & 02

* By the DISHPROF programme.

Table 6.39 Suspended sediment transport in the Jamuna river.

The uncertainty of the suspended sediment transport is estimated analogous to the uncertainty of the S4 discharge mentioned in Section 6.3.1 and not considering the uncertainty of the suspended sediment concentration; 8 and 12 per cent in the left and right channel respectively.

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 6.40.

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 deviations the samples exhibit a 50 and 59 per cent scatter in the right and left channel, respectively.

Location and date of manual current and sediment profiling	Suspended sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, March 13, 1993	0.038	0.019
Bahadurabad, left main channel, March 15, 1993	0.044	0.026

Table 6.40 Sectional average and standard deviation of D_{50} mean grain diameter based on suspended sediment samples.

6.3.4 Bed load sediment transport

No propagating bed-forms were detected and therefore only Helley-Smith trap samplings were carried out in order to assess the bed load transport. All measurement results from the right and the left main channel at the Bahadurabad gauging site are listed in Tables 6.41 and 6.42. Most of the samples from the left channel are missing because the Helley-Smith trap sampler was only available on the DHA survey vessel. The samples show a large scatter and more samples are needed to obtain reliable average bed load transport rates.

Vertical & Samples	Bed load sediment transport g/m/s	
Vertical 1, sample 9 & 10	44.17	0.27
Vertical 2, sample 7 & 8	6.21	6.84
Vertical 3, sample 5 & 6	9.61	2.51
Vertical 4, sample 3 & 4	5.53	1.14
Vertical 5, sample 1 & 2	0.26	2.08

Table 6.41 Helley-Smith bed load sampling in the right main channel at Fulchari, Jamuna River, March 13, 1993.

Vertical and Samples (filename)	Bed load sediment transport g/m/s	
Vertical 3, samples	0.59	0.42
Vertical 7, samples	0.9	-
Vertical 8, samples	0.02	0.03

Table 6.42 Helley-Smith bed load sampling in the left main channel at Bahadurabad Ghat, Jamuna River, March 15, 1993.

The total bed load transport has been estimated by multiplying the average transport rates from Tables 6.41 and 6.42 by the distance between the samples, see Figures 6.15 and 6.16, and taking due consideration to the local current direction. Hereby a bed load transport of 1.8 and 0.4 kg/s is estimated in the right and left main channel, respectively.

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 6.43.

Location and date of Helley-Smith bed load sample	Bed load sediment grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, March 13, 1993	0.237	0.05
Bahadurabad, left main channel, March 15, 1993	0.195	0.06

Table 6.43 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 21 and 31 per cent scatter in the right and left main channel, respectively.

Bed material sampling

River bed sediment samples were obtained by the Van Veen grab sampler. Grain size distribution analysis have been performed for each bed material sample. The sectional average values $\mu(D_{50})$ and the standard deviations $\sigma(D_{50})$ are listed in Table 6.44.

Location and date of Van Veen grab sample	Bed material grain size analysis	
	$\mu(D_{50})$ mm	$\sigma(D_{50})$ mm
Bahadurabad, right main channel, March 13, 1993	0.059	0.061
Bahadurabad, left main channel, March 15, 1993	0.168	0.102

Table 6.44 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 103 and 61 per cent scatter in the right and left channel, respectively.

7. Special measurement results

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.

To facilitate more elaborate analyses a complete list of file names and sample identification numbers is found in Annexure 2.

In the following sections discharge measurements obtained by BWDB are compared to discharge measurements obtained by the River Survey Project. The BWDB is using Ott current meters, positioning by sextant, while the River Survey Project is using the EMF/ADCP methodology described in the 1° Interim Report.

7.1 Comparative discharge measurements Bahadurabad, 6 to 11 January 1993

Gauging cross-section

The position of the gauging sites in the Jamuna river is indicated in Figure 7.1. The standard BWDB cross-section comprised three channels; Zigabari, Assankhari and Bahadurabad, see Figure 7.1. The Zigabari channel by the right bank is 1100 m wide with a maximum depth of 7 m while the Assankhari and Bahadurabad channels are shallow channels with maximum depths of 2.5 m. Only the Zigabari channel by the right bank in the standard BWDB cross-section was suitable for the moving boat methodology. Consequently a limited comparison was made in the Zigabari channel.

At a confluent river section 800 m downstream of the standard BWDB cross-section, the river provided a suitable cross-section for a complete coverage by the moving boat methodology. Based on this downstream confluent cross-section a total discharge comparison to the standard BWDB cross-section was made.

The navigable part of the Zigabari cross-section is 720 m wide and up to 7 m deep, while the confluent cross-section is 440 m wide and up to 19 m deep, see Figures 7.2 and 7.3.

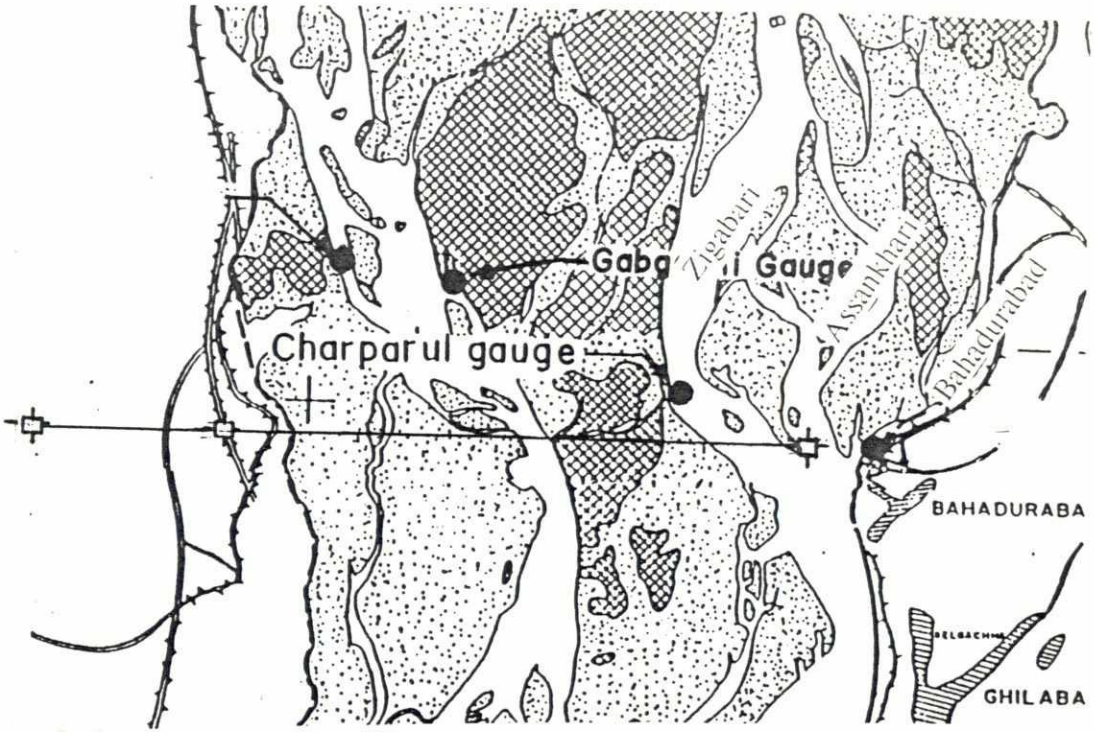


Figure 7.1 Location map for the Bahadurabad comparative discharge gauging cross-sections.

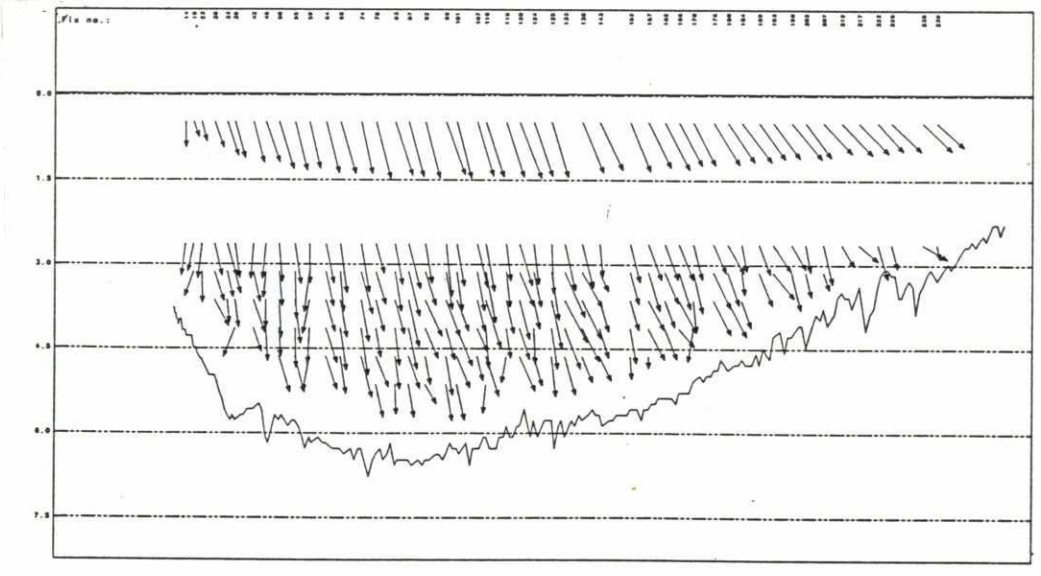


Figure 7.2 The navigable part of the Zigabari channel in the standard BWDB gauging cross-section in the Jamuna river at Bahadurabad (File: B31B1T01).

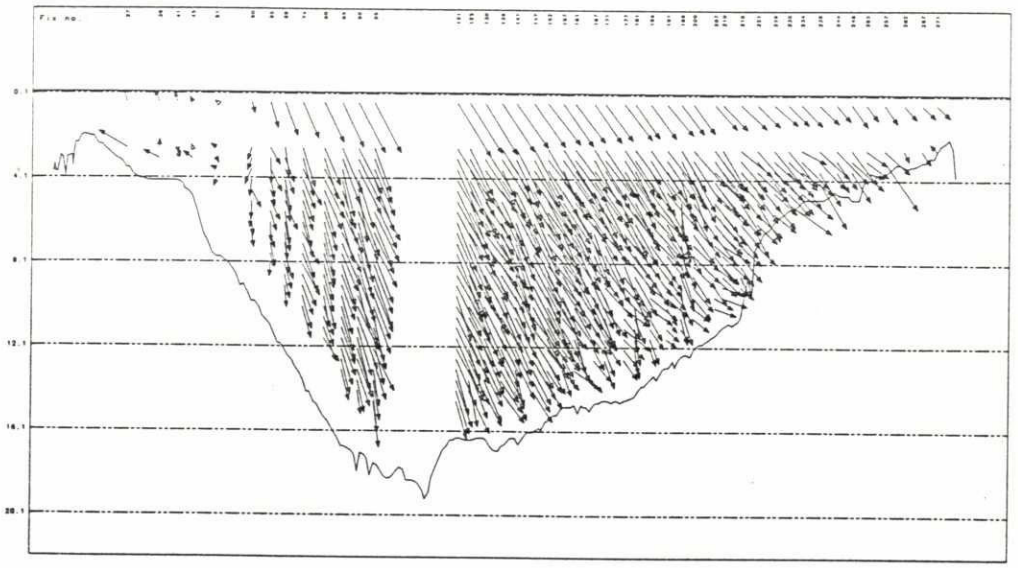


Figure 7.3 The confluent River Survey Project gauging cross-section (B31B1T08) downstream of the standard BWDB cross-section in the left main channel of the Jamuna river at Bahadurabad.

ADCP and EMF measurements executed by the River Survey Project

All together 5 transects covering the Zigabari channel and 3 transects covering the confluent cross-section were completed on January 11, 1993.

As an example a fraction of the velocity profiles measured in the Zigabari cross-section as transect B31B1T01 and in the confluent cross-section as transect B31B1T08 are displayed in Figures 7.4 and 7.5. The length of the current vectors represent 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.

Current velocities ranging from 0 m/s to 1.2 m/s were measured in the Zigabari cross-section on January 11, 1993. Some directional variation is observed within the verticals.

Current velocities ranging from 0 m/s to 1.5 m/s were measured in the downstream confluent cross-section on January 11, 1993. Nearly no directional variation is observed within the verticals.

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	Discharge m^3/s	Transect (filename)	Remarks
11/01/93 11:50:25 to 11:54:41	2024*	B31B1T01	GPS positioning
11/01/93 12:20:12 to 12:28:10	1998*	B31B1T03	GPS positioning
11/01/93 12:47:36 to 12:57:05	2040*	B31B1T05	GPS positioning

* Discharge according to on-line information on the survey vessel, exclusive discharge between the river banks and the end points of the survey line.

Table 7.1 Discharge in the Zigabari channel, part of the standard BWDB gauging cross-section, Jamuna River, January 11, 1993.

Date and time	Discharge m^3/s	Transect (filename)	Remarks
11/01/93 14:21:45 to 14:26:19	3835*	B31B1T08	GPS positioning
11/01/93 14:40:24 to 14:44:33	3883*	B31B1T09	GPS positioning
11/01/93 - to -	3948*	B31B1T10	GPS positioning

* Discharge according to on-line information on the survey vessel, exclusive discharge between the river banks and the end points of the survey line.

Table 7.2 Discharge in the confluent cross-section downstream of the standard BWDB gauging cross-section, Jamuna River, January 11, 1993.

An average discharge of 2021 m^3/s with a standard deviation of 1 per cent was observed in the Zigabari channel while the average discharge in the confluent cross-section amounted to 3889 m^3/s, with a standard deviation of 1 per cent also.

Ott current measurements executed by BWDB

Current velocities from 0 m/s to 1.08 m/s were measured on January 11, 1993 according to information supplied by BWDB.

A special calculation by the BWDB for a 641 m part of the Zigabari cross-section, allegedly identical to the navigable part, revealed a discharge of 2150 m^3/s, ref. Report on joint measurement programme.., 9 February 1993.

The total discharge in the Zigabari, Assankhari and Bahadurabad channels, see Figure 7.1, on January 11, 1993, has been calculated to 4257 m^3/s; ref. Report on joint measurement programme.., 9 February 1993.

The total discharge in the entire standard BWDB cross-section at Bahadurabad on January 11, 1993 has been calculated to 5480 m^3/s according to information supplied by BWDB.

7.2 Comparative tidal discharge measurements

Special problems are encountered in the lower river regions where the tidal cycle affects the discharge. In particular rating curves are obscured if the tidal cycle is not taken into account. The comparative tidal discharge measurement serves as a quantification of the temporal discharge variation at Hospital Ghat and Bhairab Bazar.

7.2.1 Hospital Ghat, Khulna, 9 April 1993

Gauging cross-section

The position of the Hospital Ghat gauging site in the Gorai off-take at Khulna is indicated in Figure 7.4. The River Survey Project was using a cross-section situated 100 m downstream of the standard BWDB cross-section. The cross-section is 370 m wide and up to 12 m deep, see Figure 7.5. The water-level and the discharge are strongly affected by tidal variations.

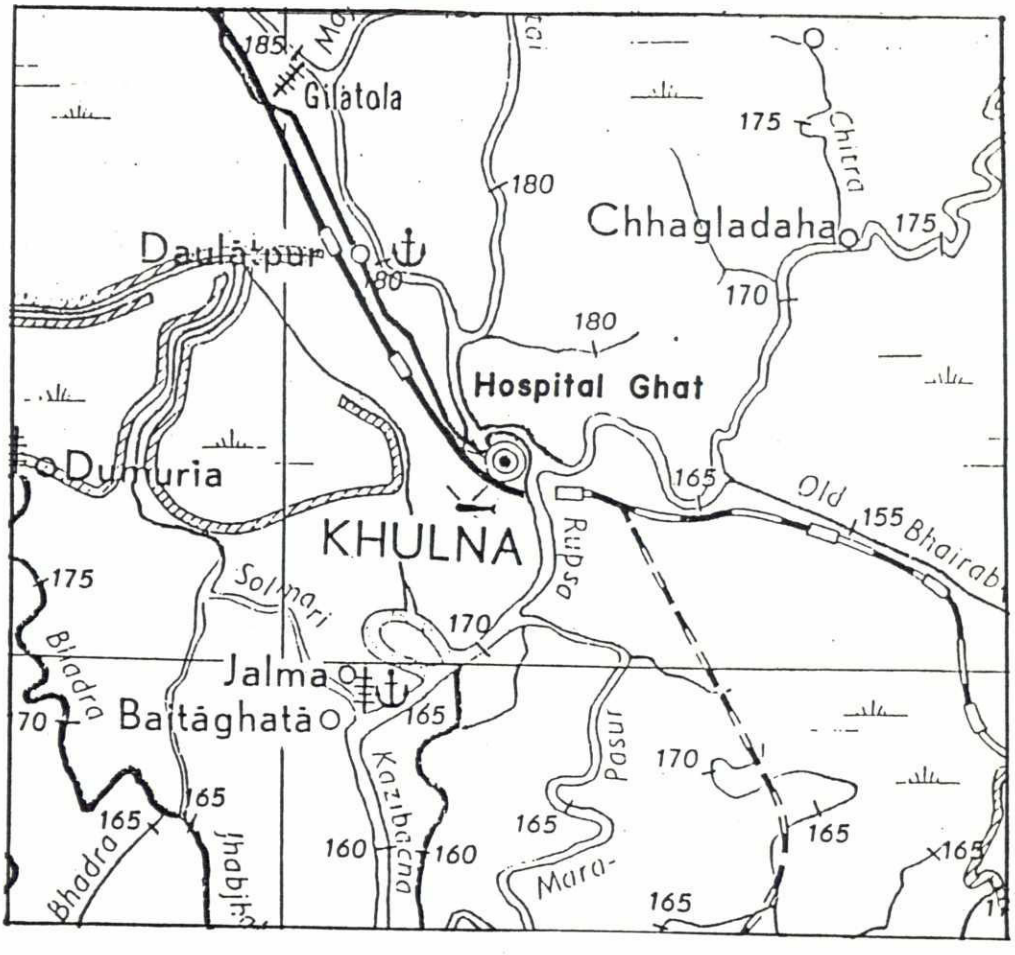


Figure 7.4 Location map for the Hospital Ghat gauging cross-section.

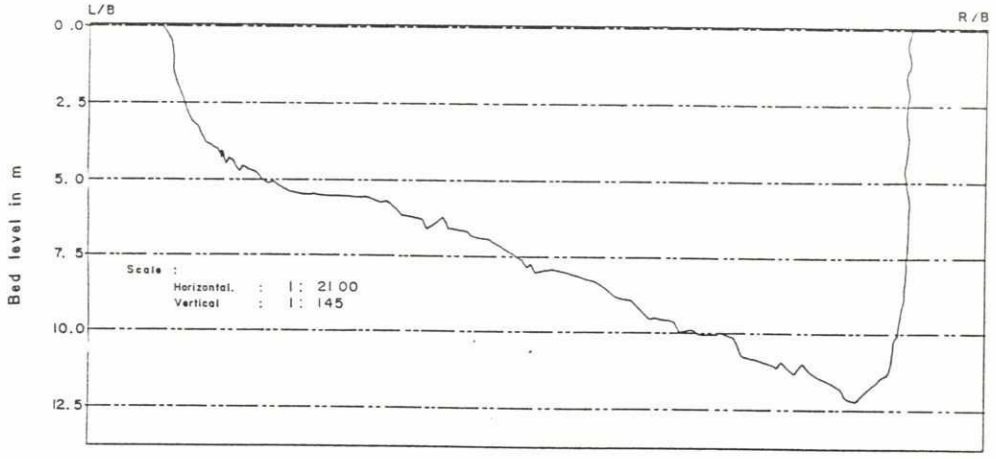


Figure 7.5 The Hospital Ghat gauging cross-section at Khulna.

ADCP and EMF measurements executed by the River Survey Project

All together 49 transects were surveyed between 07:00 am and 18:30 pm on April 9, 1993, in the Hospital Ghat cross-section.

As an example a fraction of the velocity profiles measured in transect G3491T07-o (outflow) and G3491t31-o (inflow) are displayed in Figures 7.6 and 7.7. The length of the current vectors represent 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.

Current velocities ranging from 0 m/s to 1.9 m/s were measured on April 9, 1993. Both the current velocities and directions appear scattered, indicating that the ADCP/EMF equipment has been operated in the vicinity of its particular operational limit. The operational limit of the 300 kHz broad band ADCP is defined by the depth cell length, the ping rate, the acoustic beam angle and the measurement interval. With the particular operational ADCP settings employed during the Hospital Ghat measurements a standard deviation of the random error on the velocity of 10 cm/s would be expected; ref. RD Instruments. By horizontal spatial averaging the influence of the random error is completely recovered.

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated and plotted in Figure 7.8. A pronounced tidal variation is observed. The low

tide outflow amounted to 2500 m^3/s while the high tide inflow amounted to 4200 m^3/s. The maximum temporal change of the discharge was approximately 70 m^3/s/minute.

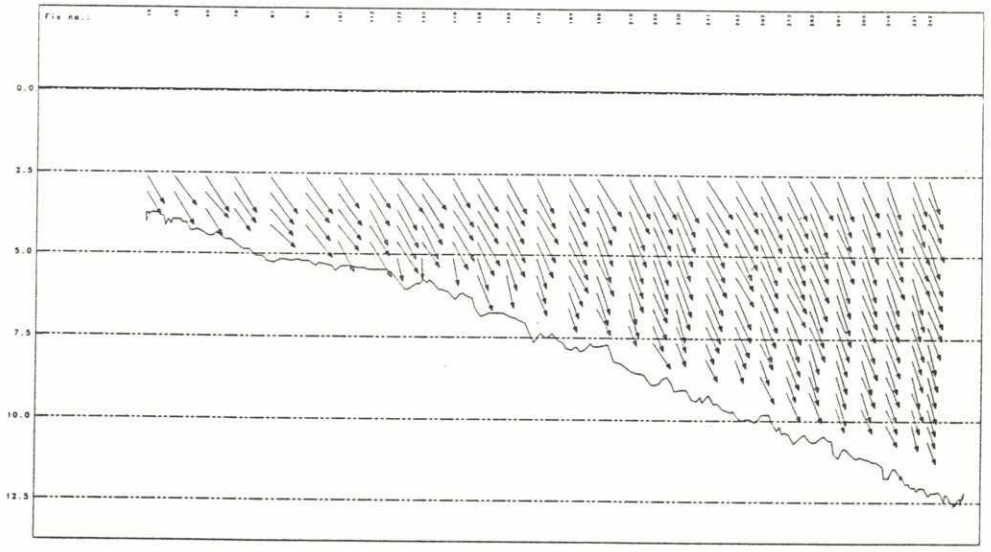


Figure 7.6 Current vectors (spatial average) from transect G3491T07-o during outflow from the Gorai off-take, Hospital Ghat, April 9, 1993.

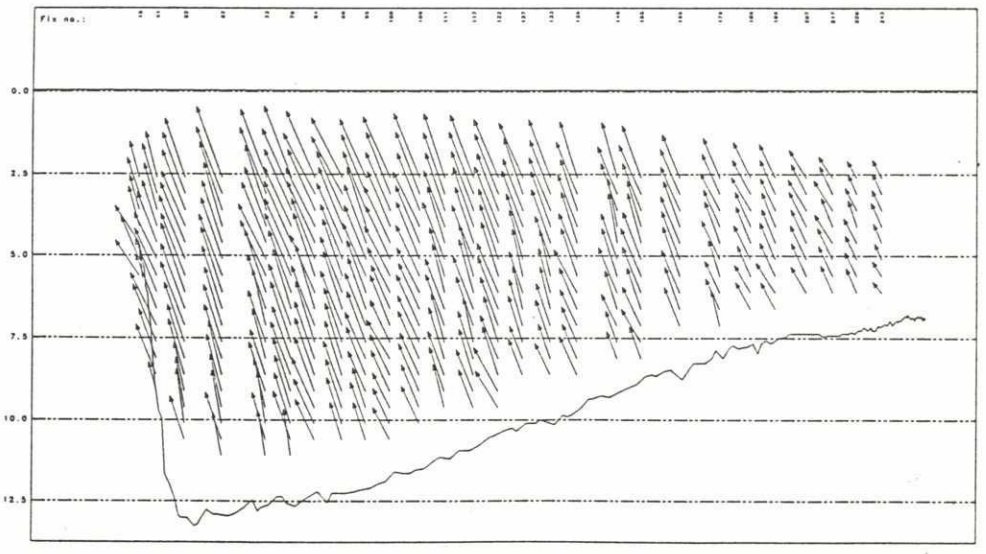


Figure 7.7 Current vectors (spatial average) from transect G3491t31-o during inflow to the Gorai off-take, Hospital Ghat, April 9, 1993.

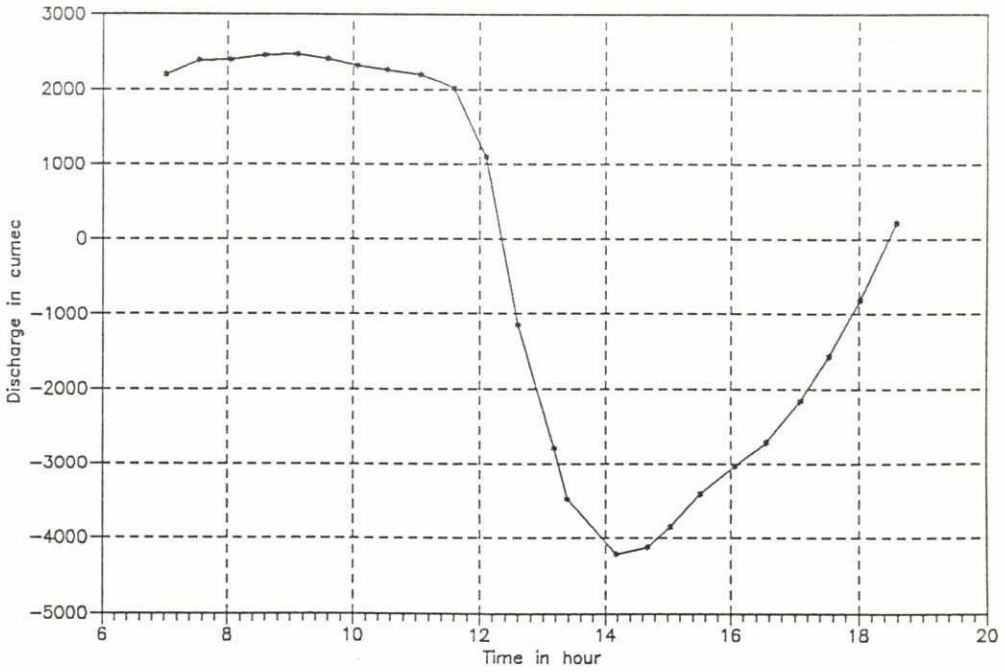


Figure 7.8 Tidal discharge variation at Hospital Ghat, Gorai off-take, April 9, 1993.

Ott current measurements executed by BWDB

Not available for the December 9, 1993 edition.

7.2.1 Bhairab Bazar, 26 to 28 April 1993

Gauging cross-section

The position of the Bhairab Bazar gauging site in the Upper Meghna river is indicated in Figure 7.9. The River Survey Project was using a gauging cross-section identical to the standard BWDB cross-section. The cross-section is approximately 600 m wide and up to 24 m deep, see Figure 7.10. The water-level from 25 to 27 April 1993 at Bhairab Bazar is depicted in Figure 7.11. From the figure at least two tidal components are visible.

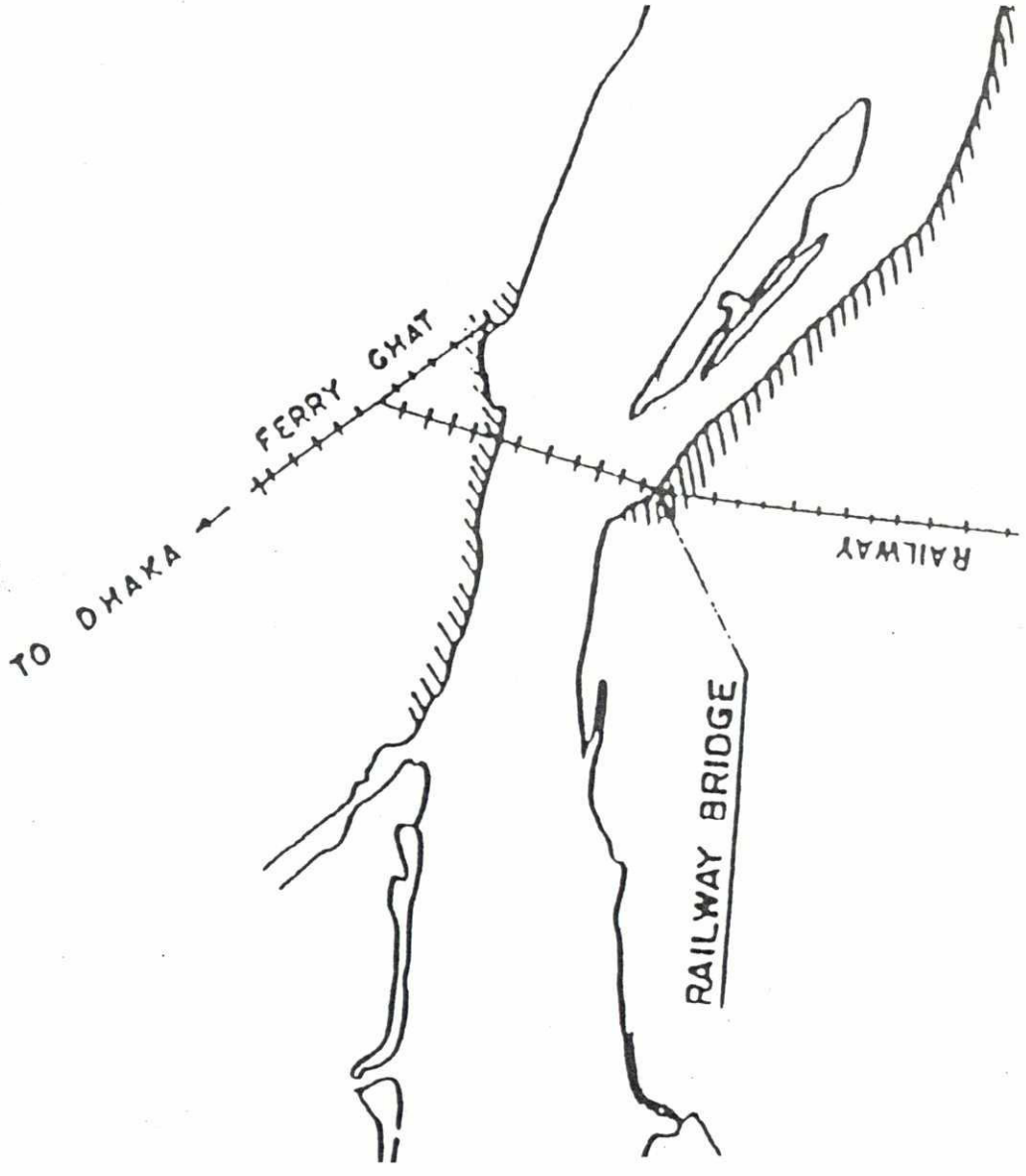


Figure 7.9 Location map for the Bhairab Bazar gauging cross-section.

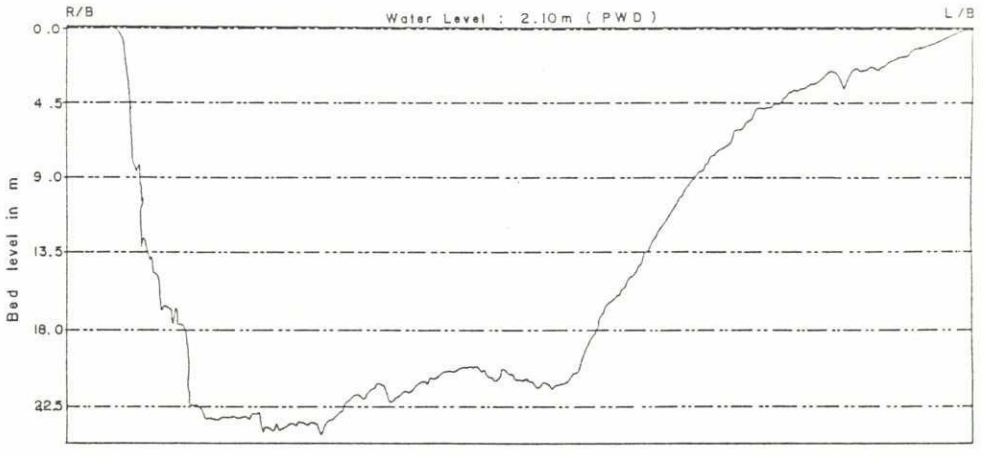


Figure 7.10 The Bhairab Bazar gauging cross-section in the Upper Meghna river.

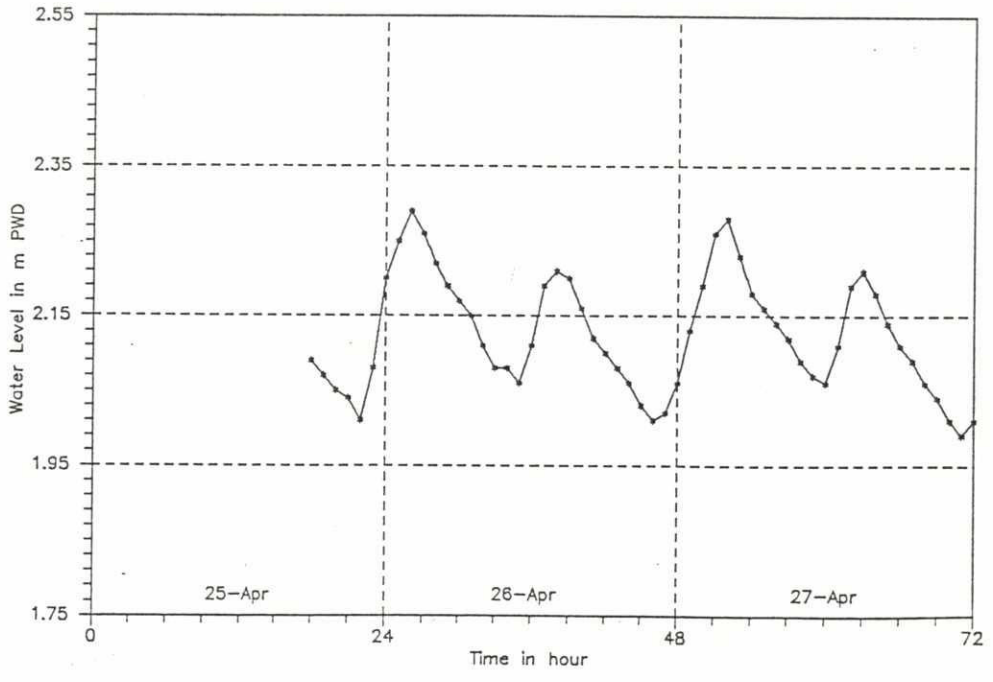


Figure 7.11 Water-level recording from the BWDB staff gauge at Bhairab Bazar, 25 to 27 April 1993.

ADCP and EMF measurements executed by the River Survey Project

All together 26 transects were surveyed between 06:00 am April 27 and 07:00 am April 28, 1993, in the Bhairab Bazar cross-section.

As an example a fraction of the velocity profiles measured in transect Z34R1T06-o (outflow) and Z34S1T10-o (inflow) are displayed in Figures 7.12 and 7.13. The length of the current vectors represent 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.

Current velocities ranging from 0 m/s to 0.5 m/s were measured on 27 and 28 April 1993. Both the current velocities and directions appear scattered, indicating that the ADCP/EMF equipment has been operated in the vicinity of its particular operational limit under the physical conditions at Bhairab Bazar. The operational limit of the 300 kHz broad band ADCP is defined by the depth cell length, the ping rate, the acoustic beam angle and the measurement interval. With the particular operational ADCP settings employed during the Bhairab Bazar measurements, a standard deviation of the random error on the velocity of 10 cm/s would be expected; ref. RD Instruments. By horizontal spatial averaging the influence of the random error is reduced, though not completely.

Based on the calculation method described in 1° Interim Report, Volume II, Annexure 1, the total transect discharges have been calculated and plotted in Figure 7.14. A pronounced tidal variation in concordance with the water-level curve, Figure 7.11, is observed. The low tide outflow amounted to 1400 m^3/s while the high tide inflow amounted to 1900 m^3/s.

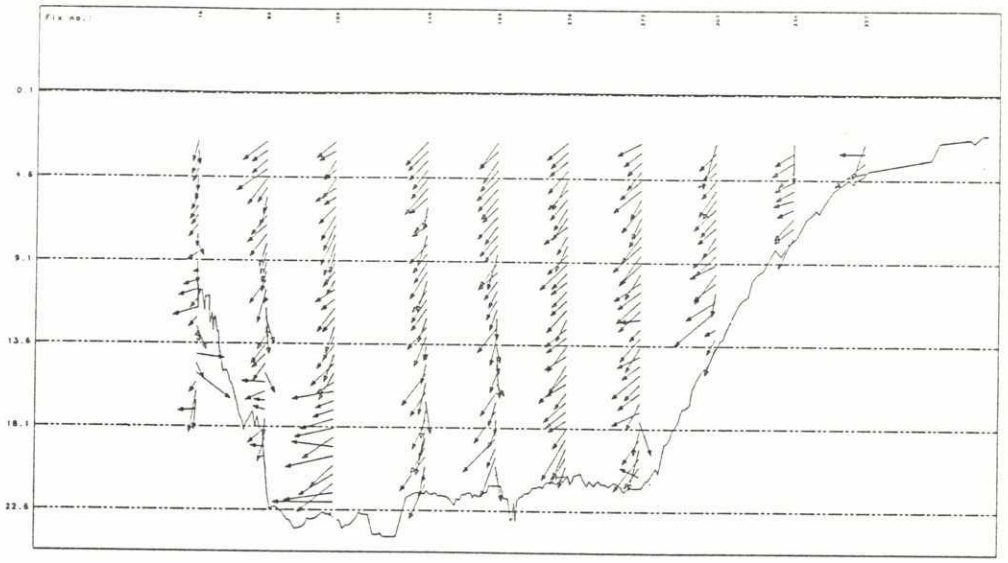


Figure 7.12 Current vectors (spatial average) from transect Z34R1T06-o during outflow from the Upper Meghna river at Bhairab Bazar, April 27, 1993.

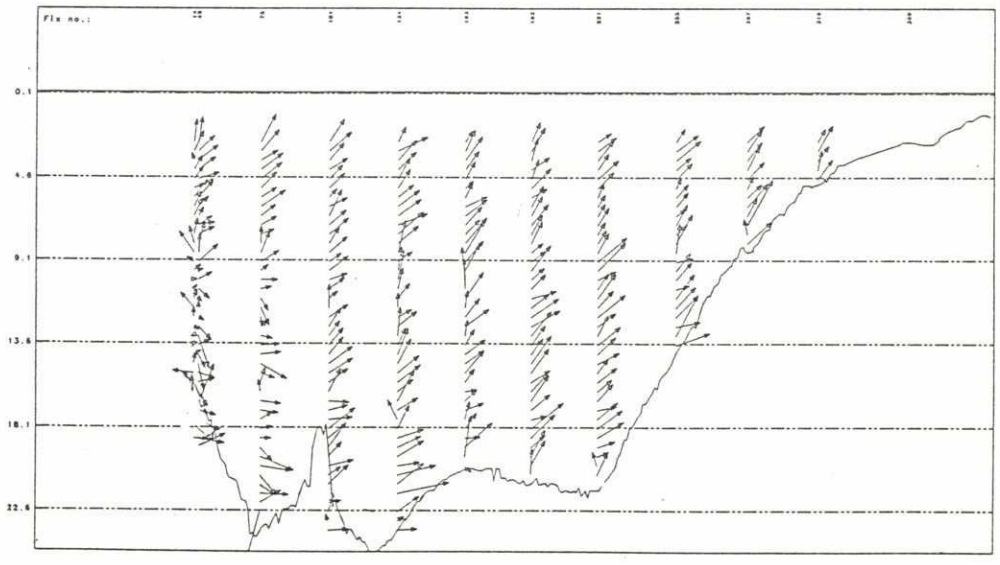


Figure 7.13 Current vectors (spatial average) from transect Z34S1T10-o during inflow to the Upper Meghna river at Bhairab Bazar, April 28, 1993.

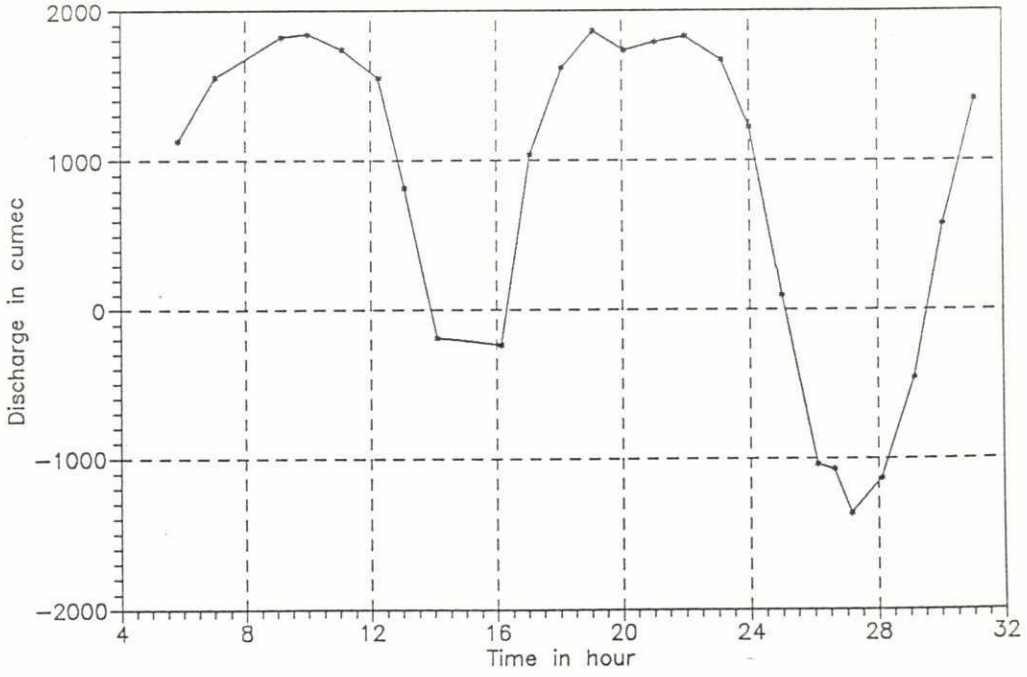


Figure 7.14 Tidal discharge variation at Bhairab Bazar, 27 to 28 April 1993.

Ott current measurements executed by BWDB

Not available for the December 9, 1993 edition.

List of references

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

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

- 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.

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

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

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

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

- 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
Test Gauging Report, Survey Procedures and Data Presentation
DELFT HYDRAULICS & Danish Hydraulic Institute
October 31, 1993.

o ISO 748
Liquid flow measurement in open channels - Velocity-area methods
International Standard Organization.
1979.

o RD Instruments
Acoustic Doppler Current Profilers, RD-SC/DR Series
9855 Businesspark Ave., San Diego, CA92131, USA.

Annexures

Annexure 1

Routine gauging inventory, October 1992 to May 1993

No page No. 7.

Location : Left Channel at Bahaduradad

Date of Survey : 14/01/93

Type	Time		File Name	Ver. No.	Easting	Northing	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
Transect	08:56:03	09:05:11	B31E1T01		470910.5	776268.9	T	T	T							
Transect	09:08:54	09:15:37	B31E1T02		470041.1	776223.4	T	T	T							
Profile	09:34:15	10:43:51	B31E1P01	4	470477.4	776277.1	P	P	P	P		38-42A	42A			
Profile	11:05:09	12:15:57	B31E1P02	3	470412.3	776192.6	P	P	P	P		43-47A		01-02		
Profile	12:35:34	13:45:13	B31E1P03	2	470272.5	776264.1	P	P	P	P		48-52A	52A	03-04		
Profile	14:05:55	15:18:23	B31E1P04	5	470575.2	776285.8	P	P	P	P		53-57A	57A	05-06		
Profile	15:38:19	16:08:55	B31E1P05	6	470712.3	776273.6	P	P	P	P		58-60A				
Profile	16:27:12	16:50:29	B31E1P06	1	470068.6	776266.3	P	P	P	P		61-63A				
Profile	17:04:25	17:38:29	B31E1P07	7	470816.3	776279.1	P	P	P	P		64-67A				
Transect	15:38:19	16:08:55	B31E1T04		470880.6	776270.4	T	T	T	T						

1.1 SURVEY PROGRAMME

Location : Right Channel at Fulchari

Date of Survey : 15/01/93, 16/01/93

Type	Time		File Name	Ver. No.	Easting	Northing	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Heiley Smith Samples	Integrated Sediment Samples	Bottom Samples
Profile	14:13:50	14:14:42	B31F1P01	6	464873.8	779104.2	P	P	P	P		68-72A				
Profile	13:22:47	13:26:12	B31F1P02	4	464785.8	779082.5	P	P	P	P		73-77A	77A			
Profile	17:23:37	18:16:53	B31F1P03	2	464684.0	779029.0	P	P	P	P		78-81A				
Transect	13:22:47	13:26:12	B31F1T02		464616.9	778975.9	T	T	T							
Transect	13:30:30	13:34:30	B31F1T03		466922.9	779102.9	T	T	T							
Transect	13:42:40	13:46:32	B31F1T04		464620.8	778973.0	T	T	T							
Transect	09:35:27	09:28:57	B31G1T02		464623.8	778969.9	T	T	T							
Profile	10:27:46	11:32:49	B31G1P01	5	464832.4	779063.7	P	P	P	P		82-86A		07		
Profile	11:50:44	12:55:25	B31G1P02	3	464742.3	779045.6	P	P	P	P		87-91A		08-09		
Profile	13:33:16	13:54:59	B31G1P03	1	464649.3	779007.6	P	P	P	P		92-94A				
Transect	14:22:59	14:26:54	B31G1T04		464915.0	779110.5	T	T	T							
Transect	14:30:05	14:33:21	B31G1T05		464617.8	778969.9	T	T	T							

1.2 SURVEY PROGRAMME

Location : Right Channel at Fulchari

Date of Survey : 13/02/93

Type	Time		File Name	Ver. No.	Easting (meter)	Northing (meter)	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
Transect	09:29:48	09:33:25	B32D1T02				T	T	T							
Transect	09:35:57	09:40:20	B32D1T03				T	T	T							
Transect	18:00:54	18:05:10	B32D1T04				T	T	T							
Transect	18:07:37	18:11:47	B32D1T05				T	T	T							
Profile	10:28:55	12:08:15	B32D1P01	1	464370.5	778650.8	P	P	P	P		1A-5A	5A	6-8	9	1
Profile	14:20:37	15:49:59	B32D1P02	4	464548.1	778733.1	P	P	P	P		15A-18A	18A	21-22	19	2-3
Profile	10:32:30	11:30:27	B32D2P02	5	464610.5	778750.5		P		P		1C-4C		10-13	14	
Profile	11:43:17	12:48:16	B32D2P03	3	464528.0	778704.0		P		P		5C-9C	9C	23-25		4
Profile			B32D2P05	2	464483.0	778681.0		P		P		10C-14C	10,14	26-28		5-7

1.1 SURVEY PROGRAMME

Location : Left Channel at Bahaduradad

Date of Survey : 15/02/93

Type	Time		File Name	Ver. No.	Easting (meter)	Northing (meter)	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
Transect			B32F1T01				T	T	T							
Transect	10:13:58	10:23:26	B32F1T02				T	T	T							
Profile	11:56:03	12:04:23	B32F2P01	8	470806.6	776306.8		P		P		15C-19C	19C			12-14
Profile	14:01:13	14:08:08	B32F2P02	6	470633.4	776263.1		P		P		20C-24C	24C	50-52	53	15
Profile	15:19:53	15:38:38	B32F2P03	4	470448.6	776248.4		P		P		25C-30C	30C	58-60	61	17
Profile	16:49:08	17:08:36	B32F2P04	2	470225.1	776258.4		P		P		31C-34C	36C	66-68		19
Profile	11:02:08	11:47:33	B32F1P01	7	470737.4	776317.3	P	P	P	P		29A-31A	31A	33-34	35	8
Profile	12:49:19	14:11:12	B32F1P02	5	470526.0	776289.0	P	P	P	P		36A-40A	40A	54-56	57	9,16
Profile	15:07:00	15:53:16	B32F1P03	3	470316.0	776276.0	P	P	P	P		41A-45A	45A,44A	62-64	65	10,18
Profile			B32F1P05	1	470137.0	776273.0	P	P	P	P		46A-49A	49A	70-72	73	11,20

1.2 SURVEY PROGRAMME

Type	Time		File Name	Ver. No.	Easting (meter)	Northing (meter)	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
Transect	10:53:08	10:57:09	B33D1T01				T	T	T							
Transect	17:57:25	18:07:04	B33D1T03				T	T	T							
Profile	11:56:53	13:20:05	B33D1P01	5	464592.3	779520.9						4	1	2	2	
Profile	13:37:09	14:38:03	B33D1P02	4	464537.5	779498.8	P	P	P	P		3	1	2	2	
Profile	15:02:07	16:20:04	B33D1P03	3	464472.4	779463.9	P	P	P	P		4	1	2	2	
Profile	13:37:29	13:44:48	B33D2P05	1	464368.5	779367.6		P		P		5	1	2	2	
Profile	15:14:55	15:28:32	B33D2P08	2	464410.3	779424.7		P		P		5	1	2	2	

Table 2.1 SURVEY PROGRAMME AS MADE

Location No. 1 : Jamuna River at Fulchari (Right Channel)
Station No.1 - R
Date of Survey : 13 March 93

Type	Time		File Name	Ver. No.	Easting (meter)	Northing (meter)	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
	From	To					ADCP	HYDRO	EMF	S4	MEX	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
Transect	08:15:17	00:00:00	B33F1T01				T	T	T							
Transect	08:31:11	08:40:15	B33F1T02				T	T	T							
Profile	09:04:51	10:49:46	B33F1P01	7	470661.8	776274.4	P	P	P	P		5	1	1	2	1
Profile	11:08:45	12:33:58	B33F1P02	6	470534.7	776241.9	P	P				5	1		2	1
Profile	13:06:30	14:32:45	B33F1P03	5	470445.9	776262.2	P	P	P	P		5	1		1	1
Profile	09:05:25	10:21:06	B33F2P01	9	470791.5	776305.5		P		P		4	1		2	1
Profile	11:12:03	11:14:32	B33F2P02	8	470759.5	776283.1		P		P		3	1	2	2	1
Profile	11:15:57	12:09:56	B33F2P03	2	470122.6	776266.0		P		P		4	1		2	1
Profile	12:57:58	14:08:31	B33F2P04	1	470070.5	776253.2		P				4	1		2	1
Profile	14:21:11	15:13:02	B33F2P05	3	470223.3	776264.0		P		P		4	1	2	2	1
Profile	15:26:02	16:57:48	B33F2P06	4	470342.7	776256.3		P		P		6	1		2	1

Table 2.2 SURVEY PROGRAMME AS MADE

Location No. 1 : Jamuna River at Bahadurabad (Left Channel)
Station No.1 - L
Date of Survey : 15 March 93

Annexure 2

Special measurement inventory, October 1992 to May 1993

Location : Left Channel at Bahaduradad
Date of Survey : 11/01/93

Place of survey / Date/Channel	Type	Time		File	Ver.	Easting	Northing	Q(ADCP)	Q	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
		From	To	Name	No.			(on-line)	(off-line)	ADCP +++30	HYDRO +++50	EMF +++60	S4 +++70	MEX +++80	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Samples	Integrated Sediment Samples	Bottom Samples
								(m3/s)	(m3/s)										
Bahaduradad	Transect	11:50:25	11:54:40	B31B1T01						T	T	T							
Left Channel	Transect	12:20:12	12:28:10	B31B1T03						T	T	T							
11/01/1993	Transect	12:47:36	12:57:06	B31B1T05						T	T	T							
	Transect	13:01:06	13:09:51	B31B1T06						T	T	T							
✓	Transect	14:21:45	14:26:21	B31B1T05B	✓	/	/	/	/	/ T	/ T	/ T	/	/	/	/	/	/	/
✓	Transect	15:13:00	15:17:26	B31B1T06	/	/	/	/	/	/ T	/ T	/ T	/	/	/	/	/	/	/

12

Location : Khulna
Date of Survey : April 09, 1993

Place of survey /	Type	Time		File	Ver	Easting	Northing	Q(ADCP)	Q	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
		From	To	Name	No.			(on-line)	(off-line)	ADCP +++30	HYDRO +++50	EMF +++60	S4 +++70	MEX +++80	Suspended Sediment Samples	Andreasen Tube Samples	Helley Smith Semples	Integrated Sediment Somples	Bottom Samples
								(m3/s)	(m3/s)										
	Transect	06:57:00	07:02:00	G3491T01				2183											
	Transect	07:03:00	07:04:00	G3491T02				2142											
	Transect	07:25:00	07:32:00	G3491T03				2342											
	Transect	07:34:00	07:39:00	G3491T04				2358											
	Transect	07:56:00	08:03:00	G3491T05				2354											
	Transect	08:04:00	08:11:00	G3491T06				2342											
	Transect	08:31:00	08:36:00	G3491T07				2416											
	Transect	08:40:00	08:44:00	G3491T08				2403											
	Transect	08:56:00	09:05:00	G3491T09				2438											
	Transect	09:05:00	09:09:00	G3491T10				2445											
	Transect	09:29:00	09:35:00	G3491T11				2379											
	Transect	09:36:00	09:41:00	G3491T12				2381											
	Transect	09:58:00	10:04:00	G3491T13				2295											
	Transect	10:04:00	10:09:00	G3491T14				2301											
	Transect	10:27:00	10:33:00	G3491T15				2270											
	Transect	10:33:00	10:38:00	G3491T16				2207											
	Transect	10:58:00	11:03:00	G3491T17				2197											
	Transect	11:04:00	11:07:00	G3491T18				2181											
	Transect	11:30:00	11:35:00	G3491T19				2012											
	Transect	11:37:00	11:41:00	G3491T20				1935											
	Transect	12:00:00	12:06:00	G3491T21				1219											
	Transect	12:08:00	12:10:00	G3491T22				898											
	Transect	12:30:00	12:35:00	G3491T23				891											
	Transect	12:36:00	12:41:00	G3491T24				1285											
	Transect	13:01:00	13:06:00	G3491T25				2614											
	Transect	13:11:00	13:16:00	G3491T26				2942											
	Transect	13:20:00	13:25:00	G3491T27				3469											
	Transect	14:04:00	14:09:00	G3491T28				4188											
	Transect	14:10:00	14:15:00	G3491T29				4240											
	Transect	14:30:00	14:35:00	G3491T30				4075											
	Transect	14:43:00	14:48:00	G3491T31				4210											
	Transect	14:56:00	15:01:00	G3491T32				3876											
	Transect	15:02:00	15:06:00	G3491T33				3840											
	Transect	15:26:00	15:30:00	G3491T34				3506											
	Transect	15:31:00	15:37:00	G3491T35				3511											
	Transect	16:00:00	16:03:00	G3491T36				3054											
	Transect	16:04:00	16:09:00	G3491T38				3065											
	Transect	16:28:00	16:32:00	G3491T39				2841											
	Transect	16:33:00	16:37:00	G3491T40				2729											
	Transect	16:57:00	17:01:00	G3491T41				2272											
	Transect	17:09:00	17:13:00	G3491T42				2041											
	Transect	17:27:00	17:31:00	G3491T43				1603											
	Transect	17:32:00	17:37:00	G3491T44				1494											
	Transect	17:57:00	18:00:00	G3491T45				378											
	Transect	18:01:00	18:06:00	G3491T46				748											
	Transect	18:27:00	18:31:00	G3491T47															
	Transect	18:33:00	18:37:00	G3491T48				194											

Location : Bhairab Bazar
Date of Survey : April 27, 1993

	Type	Time		File	Ver.	Easting	Northing	Q(ADCP)	Q	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
		From	To	Name	No.			(on-line)	(off-line)	ADCP	HYDRO	EMF	S4	MEX	Suspended	Andreasen	Helley	Integrated	Bottom
										+++30	+++50	+++60	+++70	+++80	Sediment	Tube	Smith	Sediment	Samples
								(m3/s)	(m3/s)						Samples	Samples	Samples	Samples	
	Transect	05:43:13	05:51:41	Z34R1T01				1172											
	Transect	05:52:03	05:56:41	Z34R1T04				1229											
	Transect		07:01:25	Z34R1T05				1510											
	Transect	07:03:00	07:09:02	Z34R1T06				1652											
	Transect	09:07:00	09:12:23	Z34R1T15				1840											
	Transect	09:58:47	10:04:21	Z34R1T16				1840											
	Transect	10:58:29	11:03:49	Z34R1T18				1732											
	Transect	11:04:36	11:11:01	Z34R1T19				1633											
	Transect	12:12:46	12:18:15	Z34R1T23				1527											
	Transect	12:57:00	13:03:09	Z34R1T24				874											
	Transect	13:06:32	13:12:12	Z34R1T25				756											
	Transect	13:59:14	14:04:53	Z34R1T26				81											
	Transect	14:05:32	14:10:28	Z34R1T27				280											
	Transect	16:02:00	16:07:52	Z34R1T29				227											
	Transect	16:09:36	16:15:39	Z34R1T30				312											
	Transect	16:58:00	17:04:06	Z34R1T31				934											
	Transect	17:05:05	17:10:18	Z34R1T32				1160											
	Transect	17:57:00		Z34R1T33				1455											
	Transect	18:06:33	18:09:12	Z34R1T34				1682											
	Transect	18:57:00	19:02:55	Z34R1T35				1899											
	Transect	19:04:02	19:09:34	Z34R1T36				1895											
	Transect	19:59:32	20:04:42	Z34R1T37				1777											
	Transect	20:05:48		Z34R1T38				1750											
	Transect	20:59:58	21:05:02	Z34R1T39				1804											
	Transect	21:06:17		Z34R1T40				1765											
	Transect	21:59:01	22:03:57	Z34R1T41				1828											
	Transect	23:06:47	23:12:12	Z34R1T45				1704											
	Transect	23:58:15	00:02:58	Z34R1T46				1211											

22

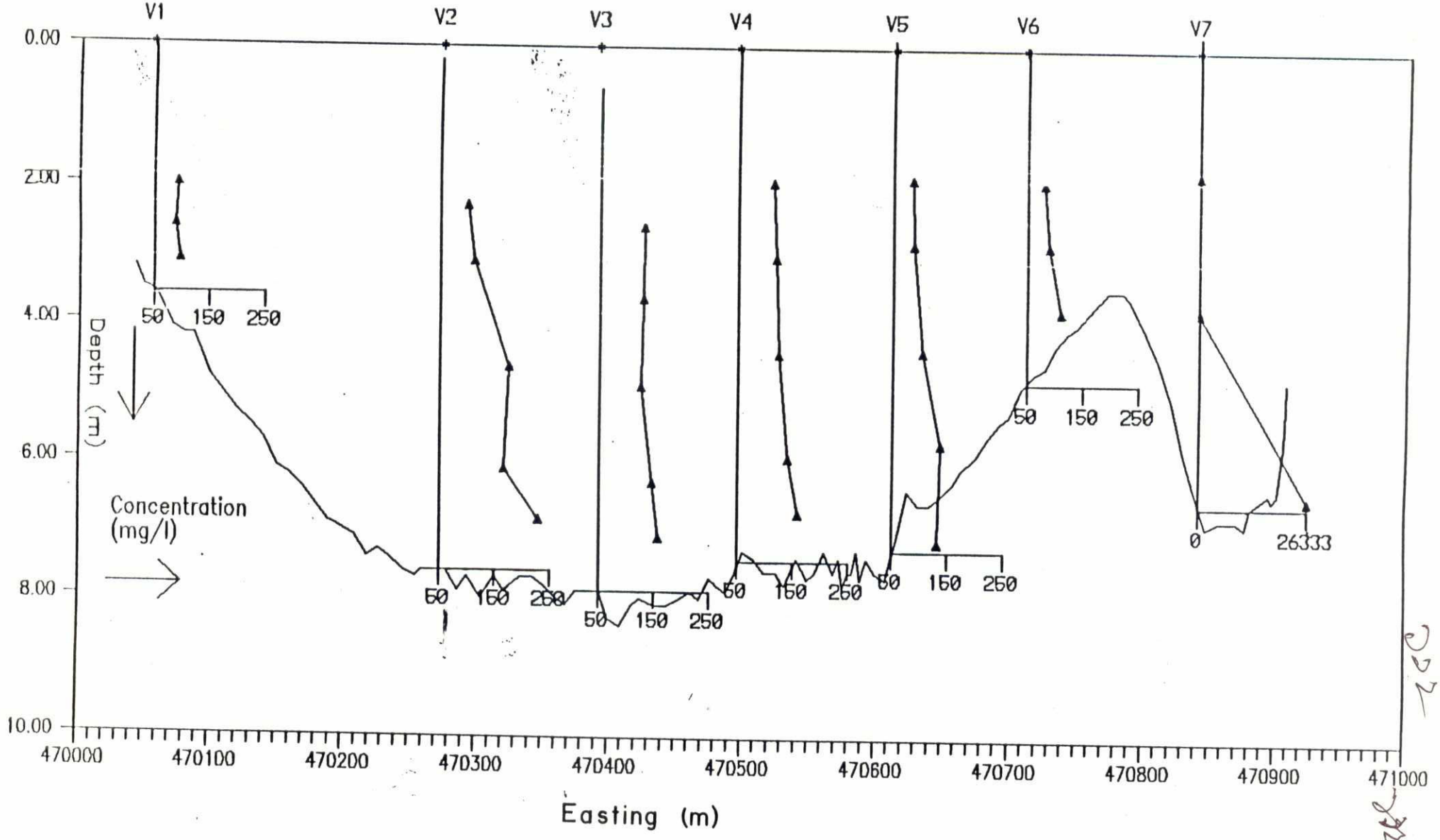
Location : Bhairab Bazar
Date of Survey : April 28, 1993

	Type	Time		File	Ver.	Easting	Northing	Q(ADCP)	Q	DISCHARGE GAUGING					SEDIMENT TRANSPORT GAUGING				
		From	To	Name	No.			(on-line)	(off-line)	ADCP	HYDRO	EMF	S4	MEX	Suspended	Andreasen	Helley	Integrated	Bottom
										+++30	+++50	+++60	+++70	+++80	Sediment	Tube	Smith	Sediment	Samples
								(m3/s)	(m3/s)						Samples	Samples	Samples	Samples	
	Transect	00:59:12	01:03:57	Z234S1T02				91											
	Transect	02:00:05	02:05:43	Z234S1T05				998											
	Transect	02:08:00	02:13:21	Z234S1T06				1029											
	Transect	02:30:16	02:36:06	Z234S1T07				1121											
	Transect	02:37:49	02:43:46	Z234S1T08				1276											
	Transect	03:01:34	03:08:01	Z234S1T09				1422											
	Transect	03:09:01	03:16:36	Z234S1T10				1299											
	Transect	04:00:08	04:05:01	Z234S1T11				1078											
	Transect	04:06:17	04:11:57	Z234S1T12				1123											
	Transect	05:06:20	05:11:12	Z234S1T14				413											
	Transect	05:58:45	06:04:19	Z234S1T15				606											
	Transect	06:05:00	06:10:34	Z234S1T16				521											
	Transect	07:01:27	07:06:03	Z234S1T17				1446											
	Transect	07:07:02	07:12:58	Z234S1T18				1483											

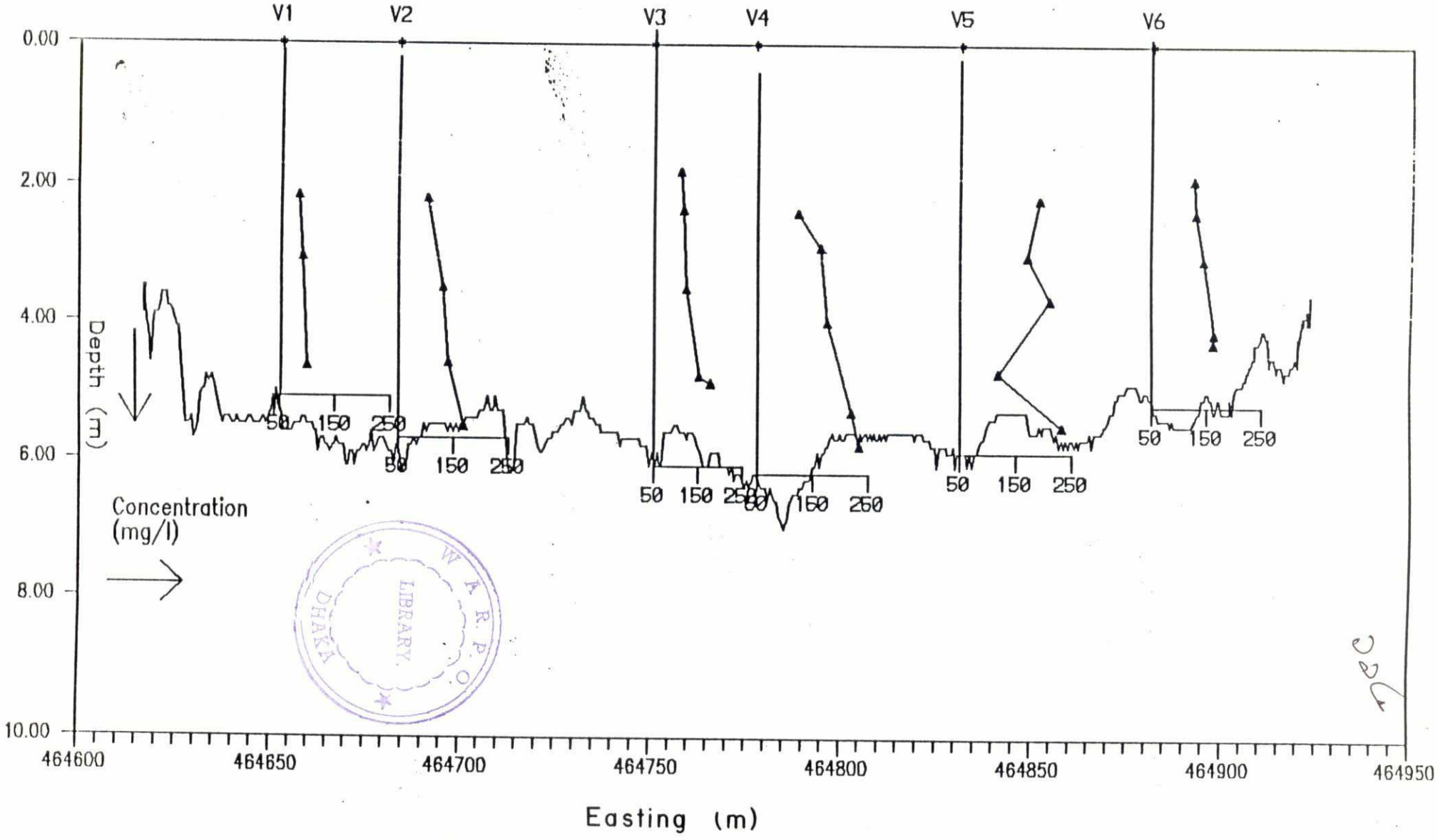
Annexure 3

Plots of suspended sediment profiles, Jamuna river, January to March 1993

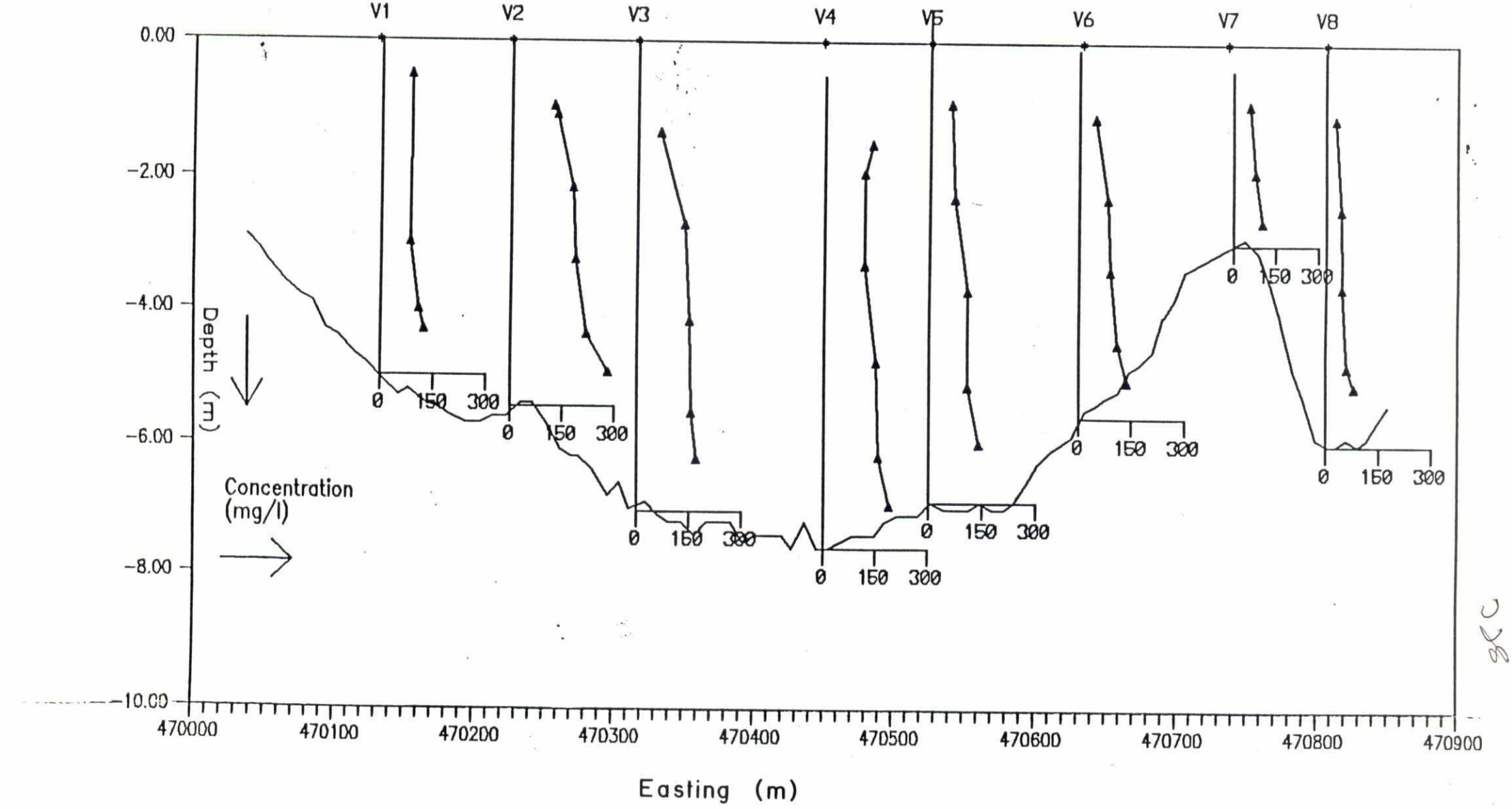
FAP 24 River Survey Project
Suspended Sediment Concentration Profile
Surveyed in January 1993 – River : Jamuna – Left Channel



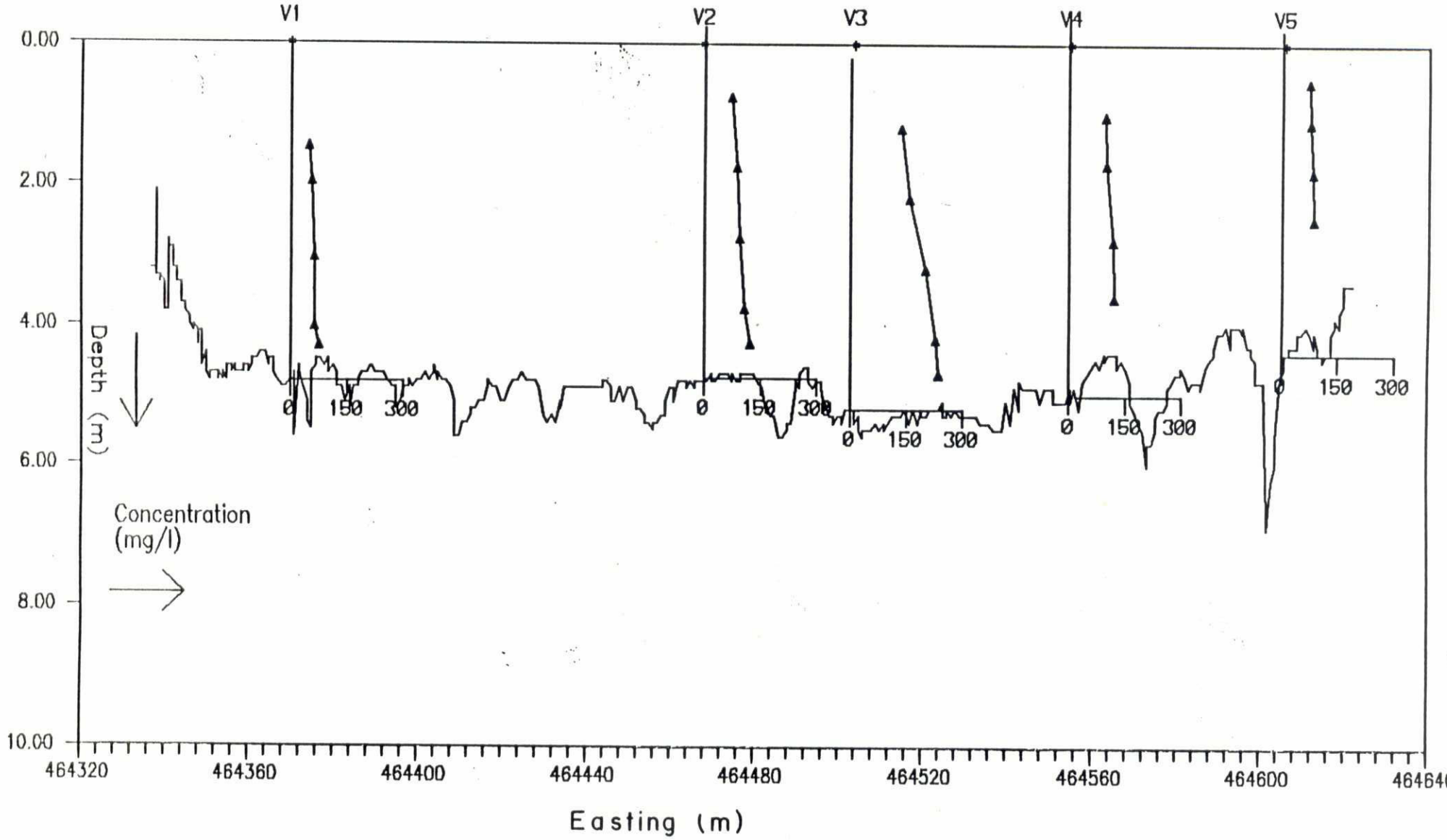
FAP 24 River Survey Project
Suspended Sediment Concentration Profile
Surveyed in January 1993 – River : Jamuna – Right Channel



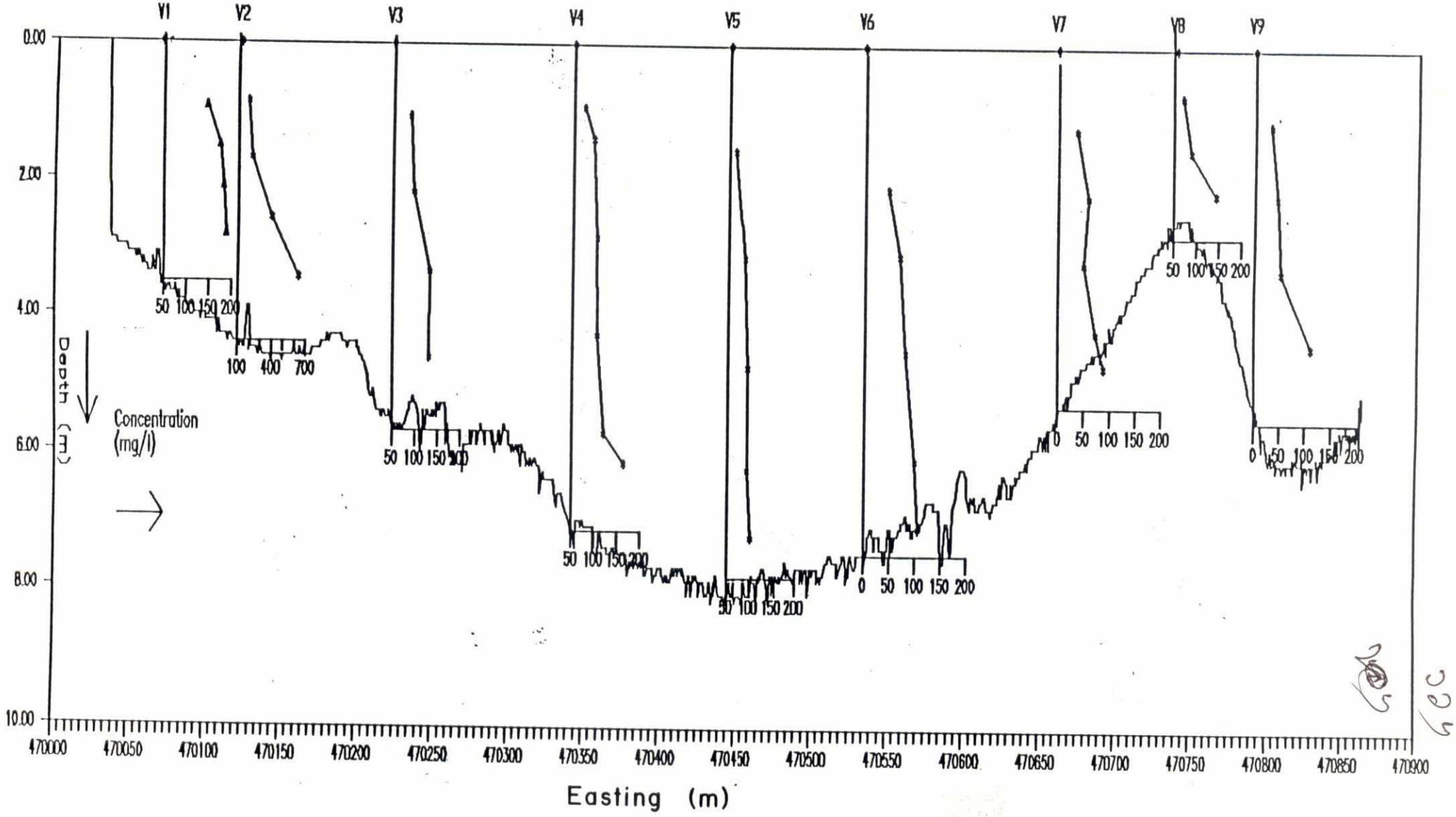
FAP 24 River Survey Project
Suspended Sediment Concentration Profile
Surveyed in February 1993 – River : Jamuna – Left Channel



FAP 24 River Survey Project
Suspended Sediment Concentration Profile
Surveyed in February 1993 – River : Jamuna – Right Channel



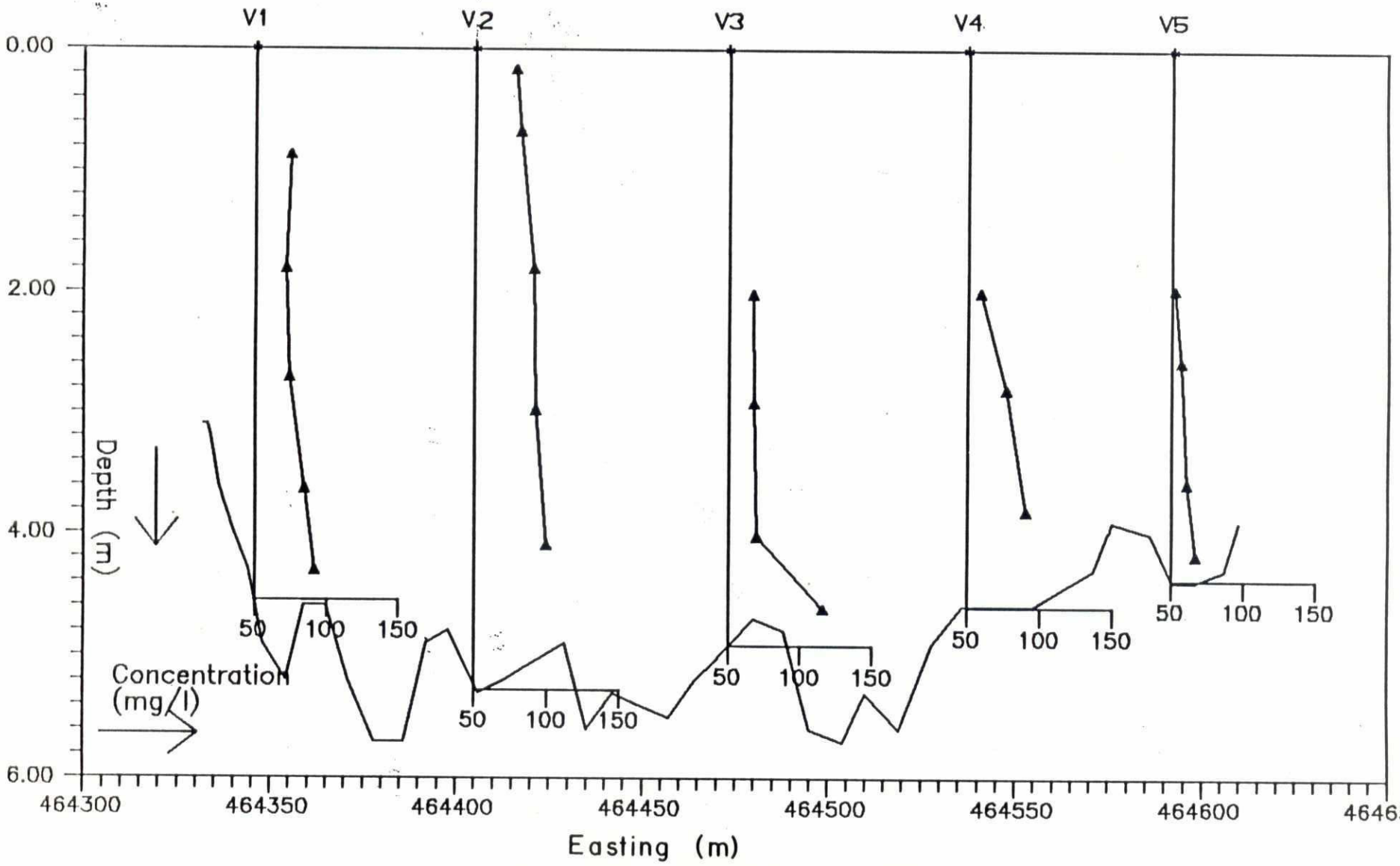
FAP 24 River Survey Project
Suspended Sediment Concentration Profile
Surveyed in March 1993 – River : Jamuna – Left Channel



FAP 24 River Survey Project

Suspended Sediment Concentration Profile

Surveyed in March 1993 – River : Jamuna – Right Channel



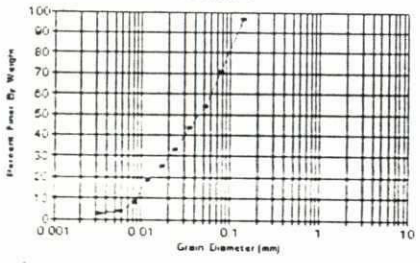
Annexure 4

Grain size distribution of suspended sediment samples, Jamuna river, January to March 1993

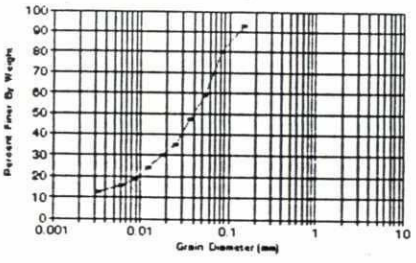
Location ?.

Grain Size Distributiion of Suspended Sediment Sample (Andreasens' Tube Samples)

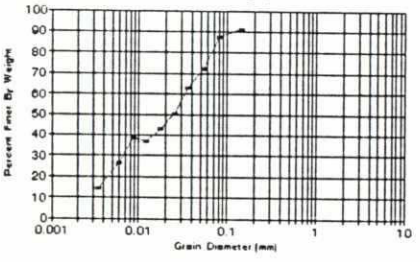
Sample No : 42A
Vertical: 4



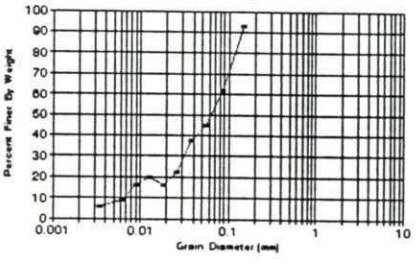
Sample No : 52A
Vertical : 2



Sample No : 57A
Vertical: 5 (Right)

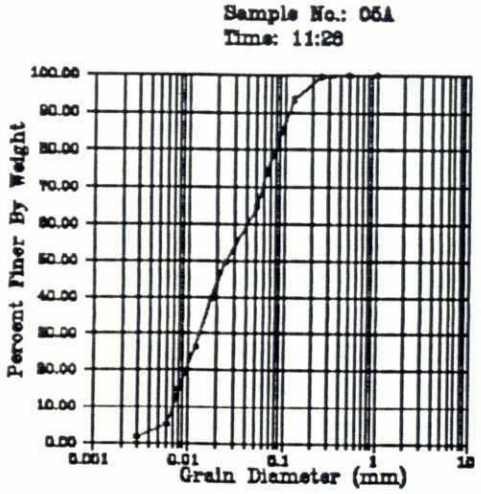


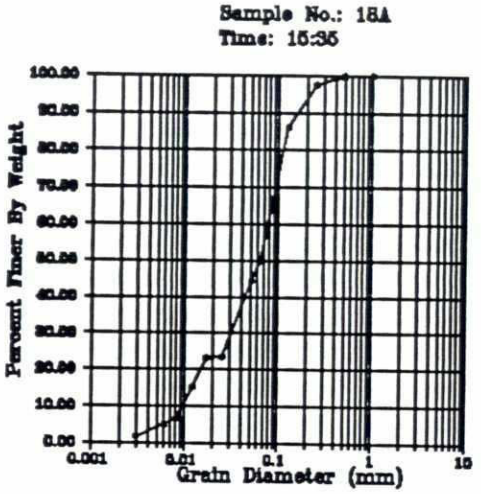
Sample No : 77A
Vertical : 4(Right)

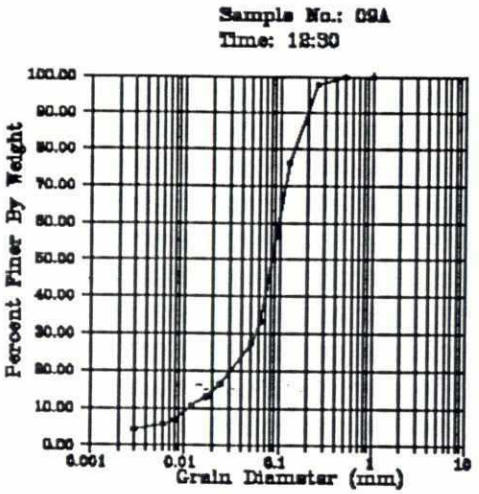


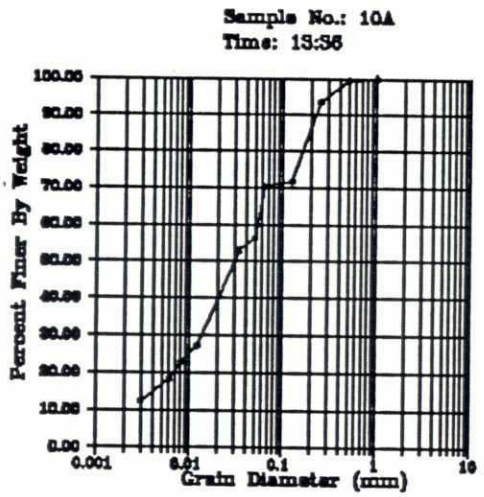
Collection Time	Collection Date	D16 (mm)	D35 (mm)	D50 (mm)	D90 (mm)	Standard Deviation
10:15	14/01/93	0.013	0.026	0.045	0.134	2.986
13:20	14/01/93	0.006	0.025	0.04	0.132	4.558
14:55	14/01/93	0.004	0.008	0.025	0.127	5.116
16:35	15/01/93	0.009	0.035	0.062	0.146	4.501

Grain Size Distribution Of Suspended Sediment



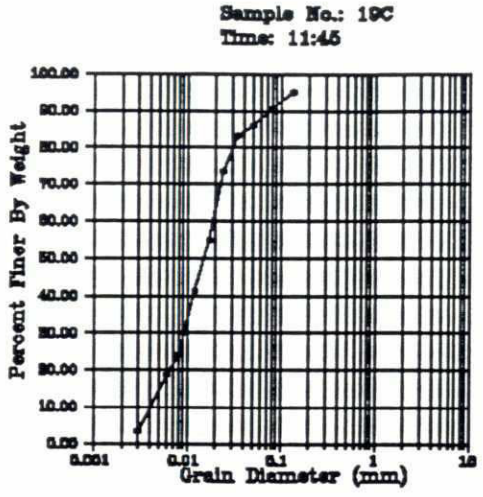


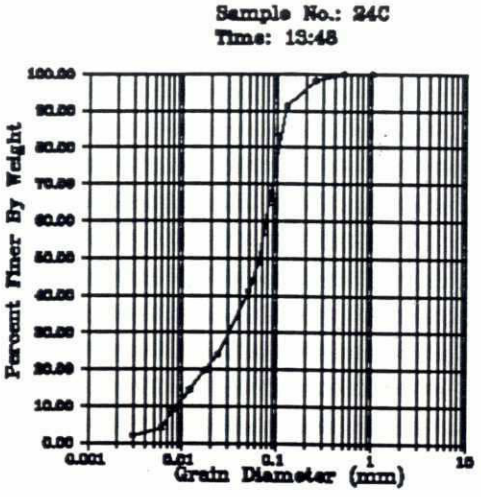


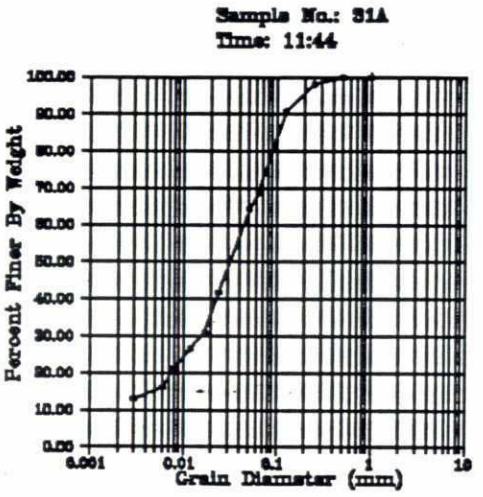


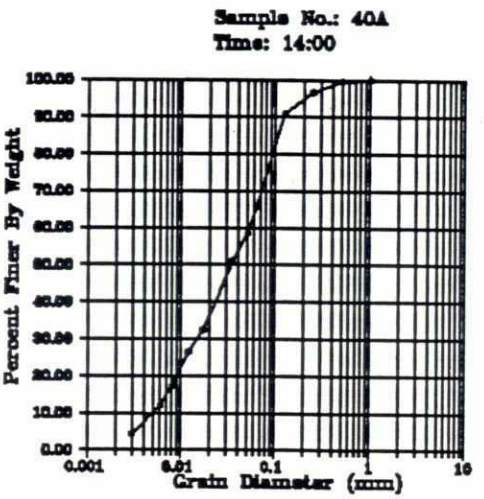
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/02/93	11:28	0.008	0.015	0.025	0.110	3.363
13/02/93	15:35	0.015	0.040	0.060	0.175	3.042
13/02/93	12:30	0.025	0.065	0.080	0.200	2.693
13/02/93	13:36	0.005	0.017	0.030	0.225	6.333

Grain Size Distribution Of Suspended Sediment





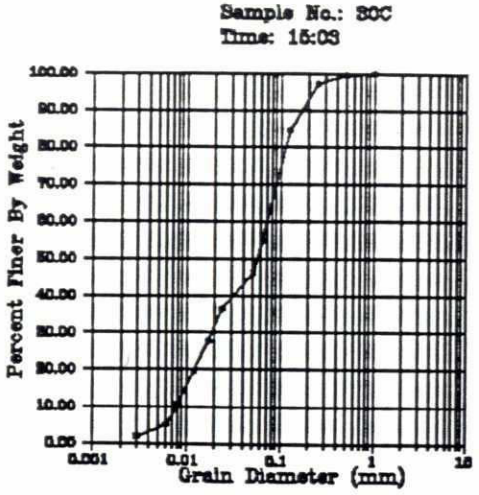


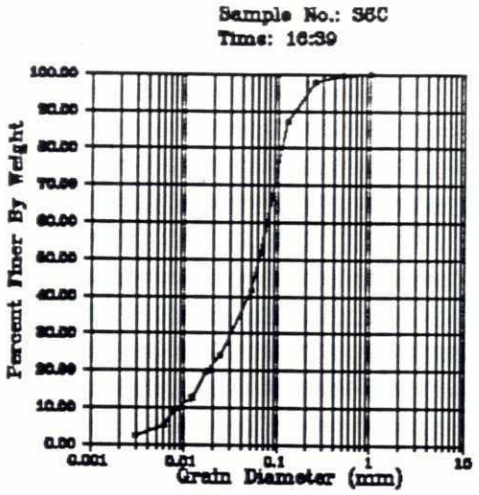


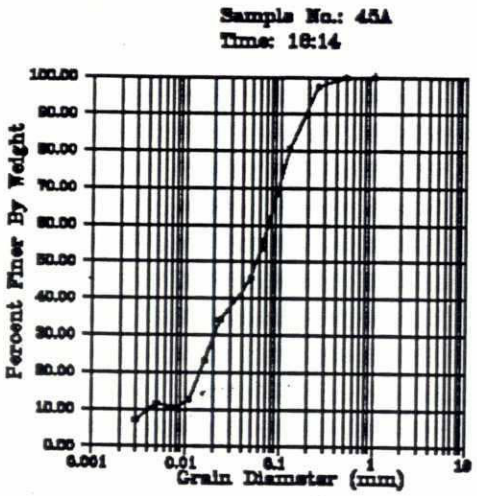
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
15/02/93	14:05	0.015	0.040	0.055	0.180	3.197
15/02/93	13:48	0.015	0.040	0.065	0.128	3.089
15/02/93	11:44	0.006	0.020	0.031	0.130	4.196
15/02/93	15:25	0.008	0.015	0.021	0.110	3.455

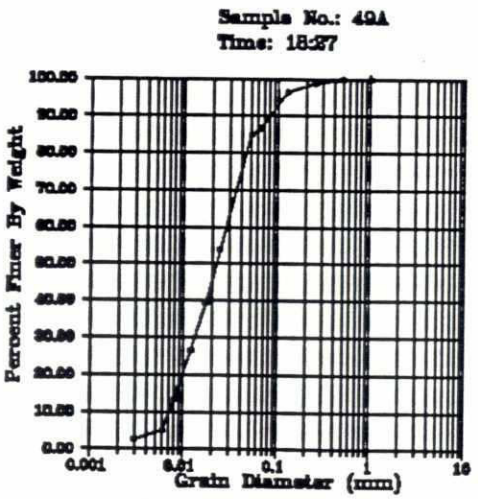
D22

Grain Size Distribution Of Suspended Sediment



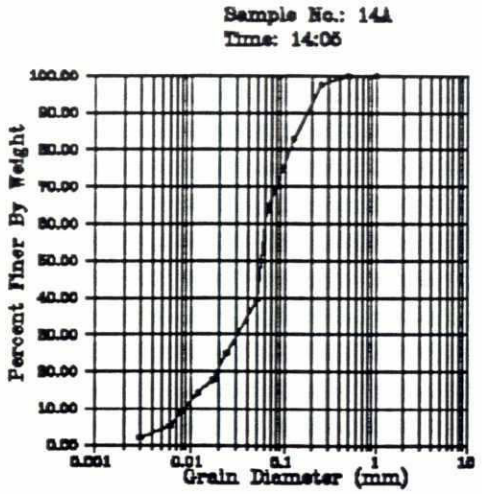






Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
15/02/93	15:03	0.010	0.024	0.058	0.180	4.106
15/02/93	16:39	0.015	0.040	0.060	0.160	3.042
15/02/93	16:14	0.014	0.025	0.058	0.190	3.407
15/02/93	18:27	0.009	0.015	0.023	0.100	2.365

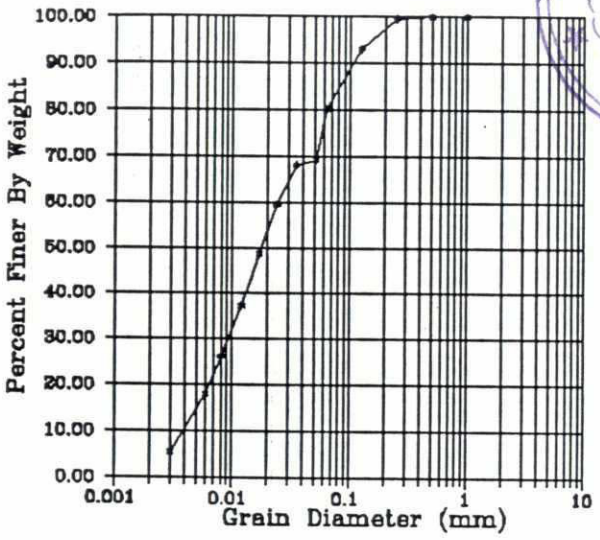
Grain Size Distribution Of Suspended Sediment



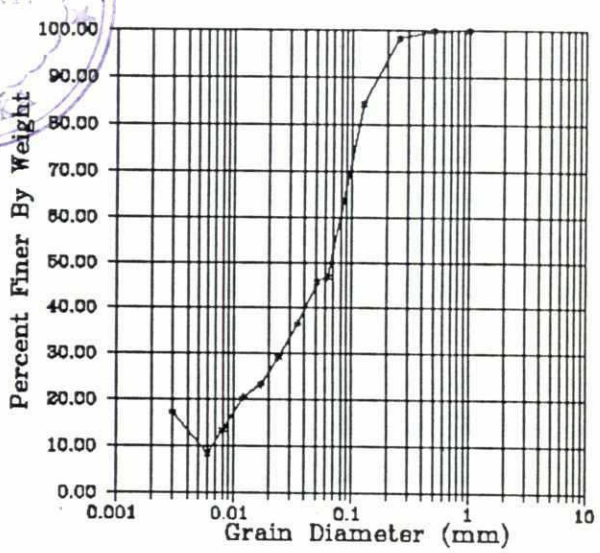
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/02/93	14:05	0.009	0.025	0.039	0.100	3.321

Grain Size Distribution Of Suspended Sediment

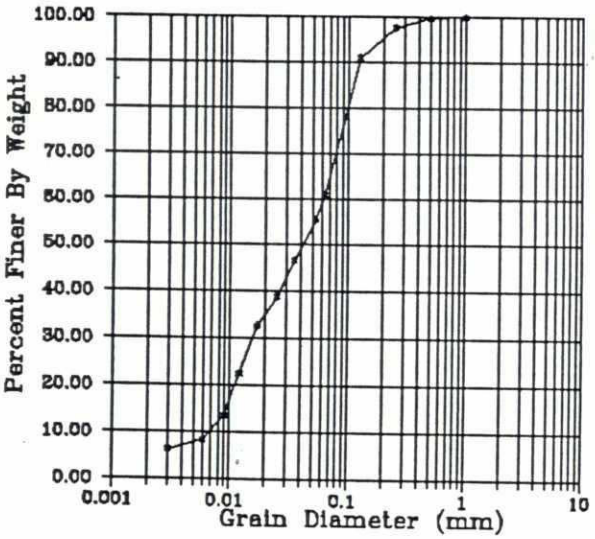
Sample No.: 41A
Time: 13:30



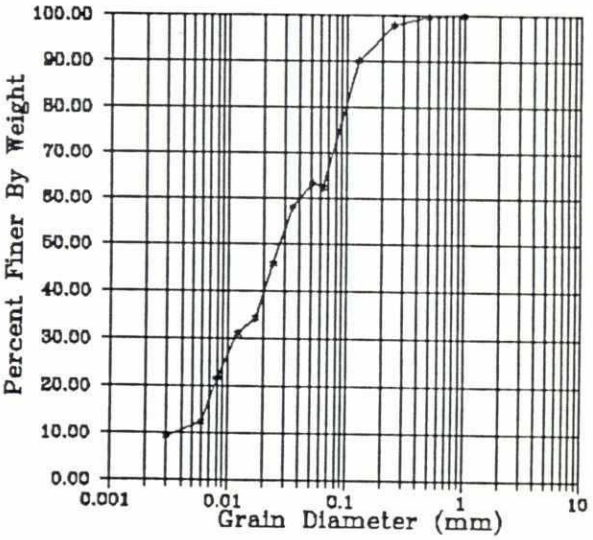
Sample No.: 46A
Time: 15:00



Sample No.: MAS3
Time: 16:00



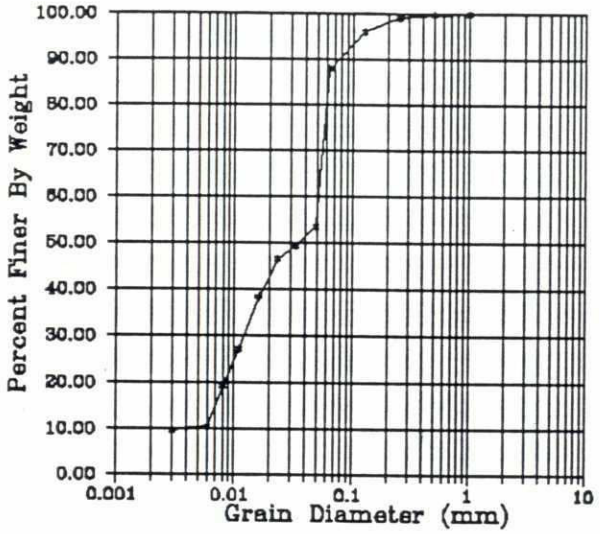
Sample No.: MAS2
Time: 14:00



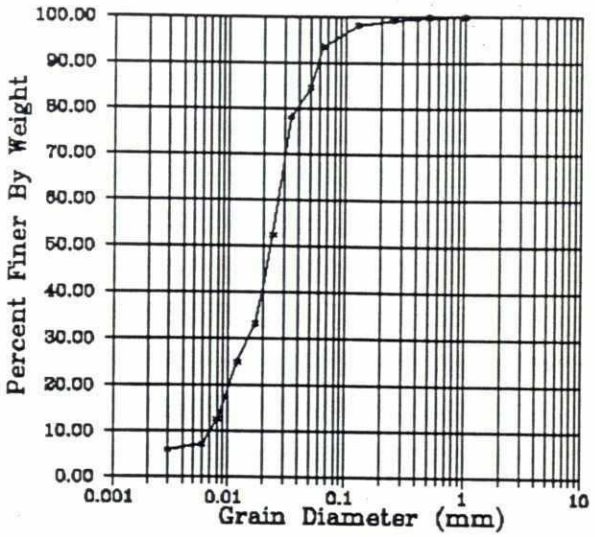
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/03/93	13:30	0.005	0.012	0.018	0.100	4.022
13/03/93	15:00	0.009	0.031	0.069	0.170	4.818
13/03/93	16:00	0.009	0.020	0.040	0.140	3.597
13/03/93	14:00	0.006	0.019	0.029	0.135	4.162

Grain Size Distribution Of Suspended Sediment

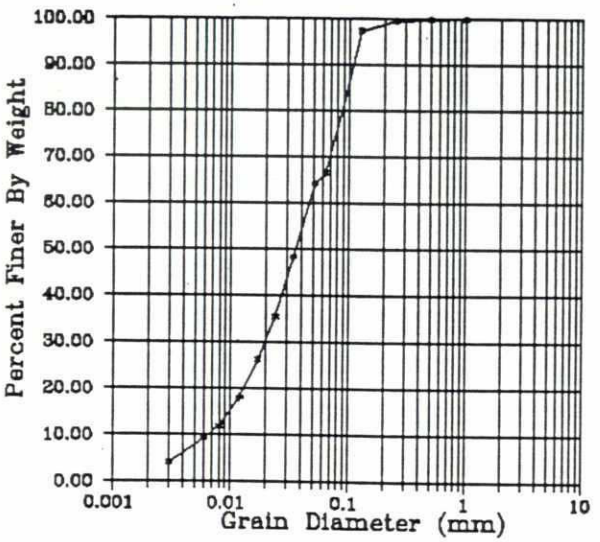
Sample No.: MAS1
Time: 12:30



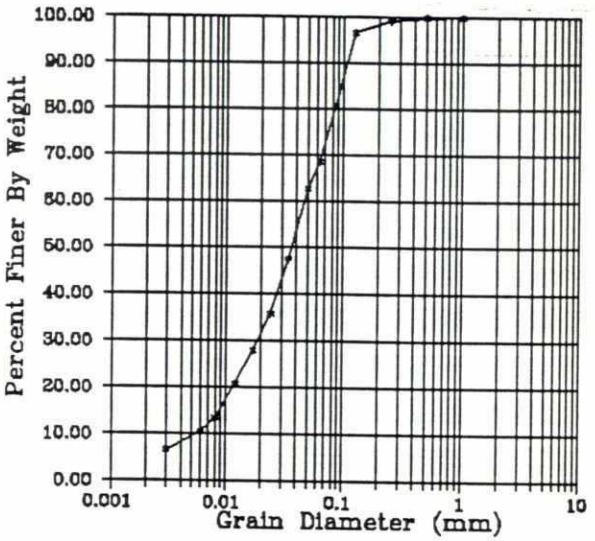
Sample No.: 65C
Time: 13:30



Sample No.: 60C
Time: 11:30



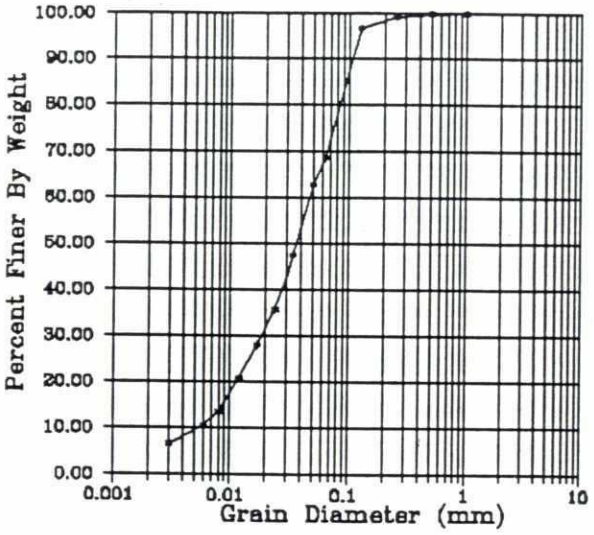
Sample No.: 70C
Time: 15:00



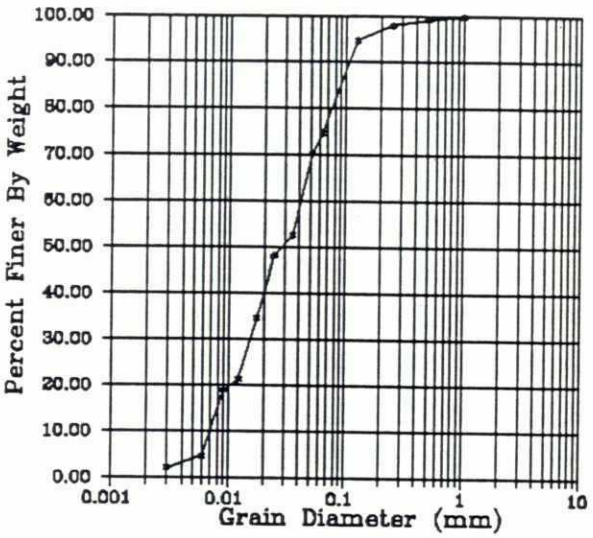
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/03/93	12:30	0.007	0.015	0.035	0.075	3.357
15/03/93	13:30	0.009	0.019	0.024	0.060	2.354
15/03/93	11:30	0.010	0.025	0.036	0.100	3.050
15/03/93	15:00	0.010	0.025	0.038	0.100	3.150

Grain Size Distribution Of Suspended Sediment

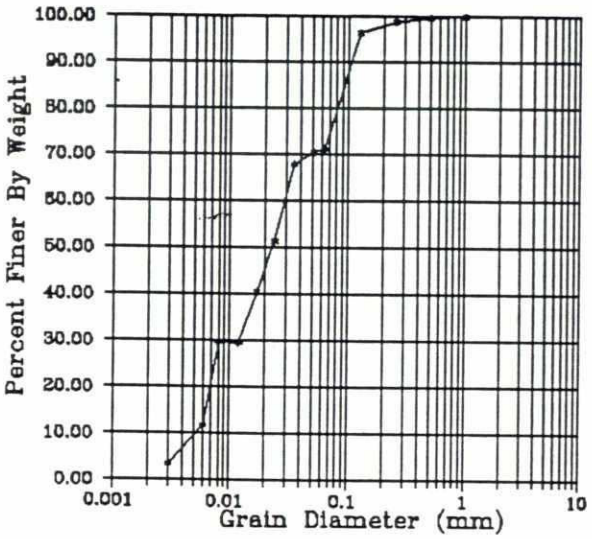
Sample No.: 77C
Time: 16:00



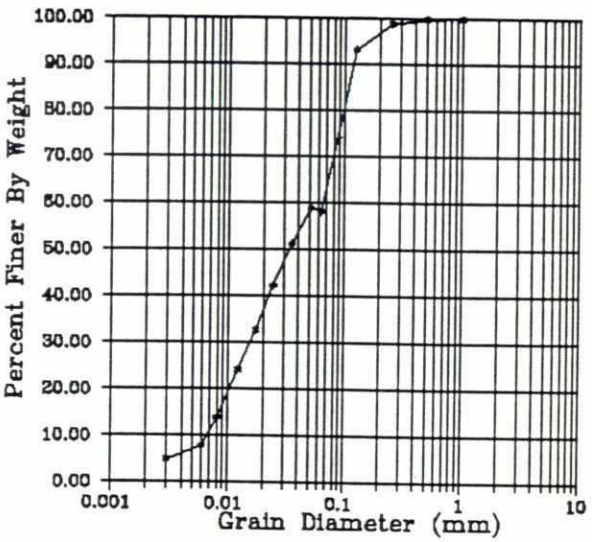
Sample No.: 45A
Time: 14:15



Sample No.: 35A
Time: 12:15



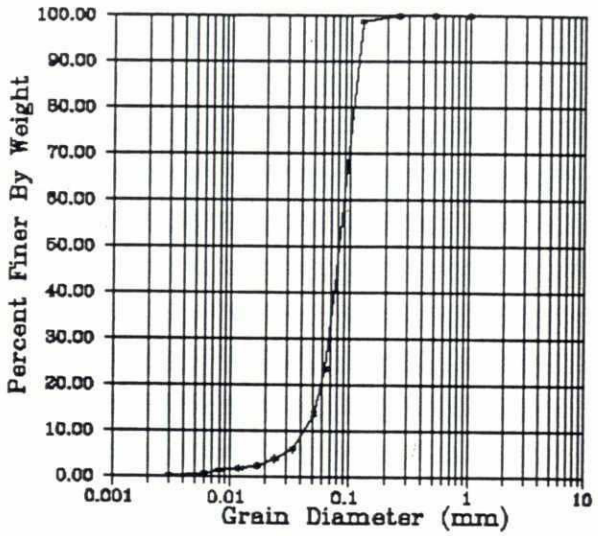
Sample No.: 27A
Time: 10:00



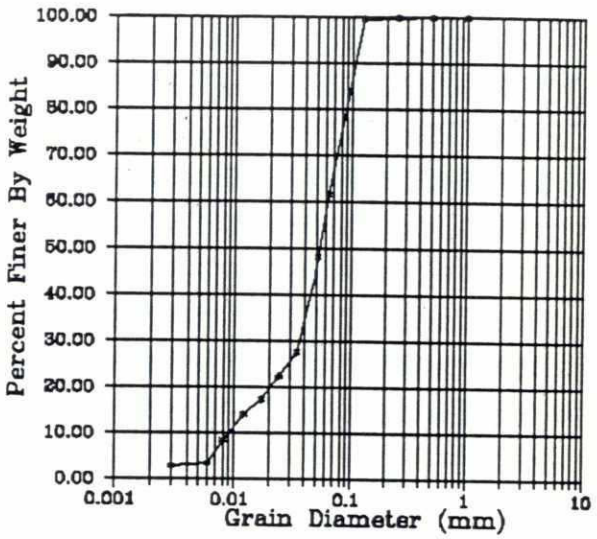
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
15/03/93	16:00	0.007	0.021	0.041	0.130	4.251
15/03/93	14:15	0.008	0.019	0.020	0.100	3.429
15/03/93	12:15	0.006	0.015	0.024	0.100	3.811
15/03/93	10:00	0.009	0.019	0.035	0.120	3.487

Grain Size Distribution Of Suspended Sediment

Sample No.: 55C
Time: 11:00



Sample No.: 51C
Time: 10:15

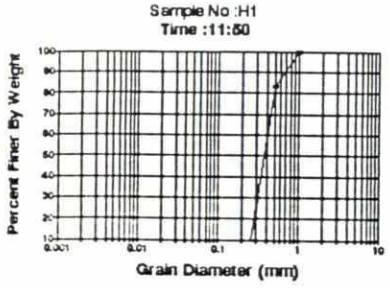


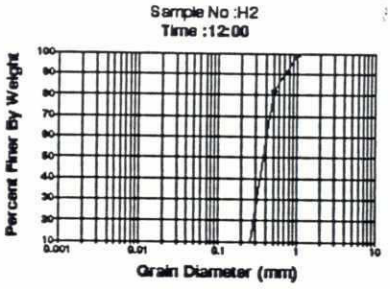
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/02/93	14:05	0.009	0.025	0.039	0.100	3.321
15/03/93	10:15	0.014	0.040	0.096	0.100	1.550

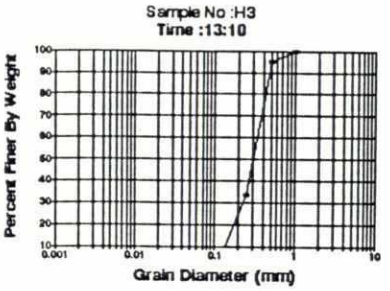
Annexure 5

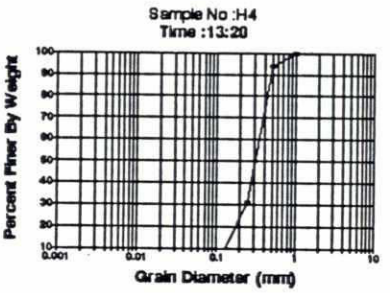
Grain size distribution of bed load samples, Jamuna river, January to March 1993

Grain Size Distribution Of Bed Load By Sieve Analysis (Helley-Smith Sampling)



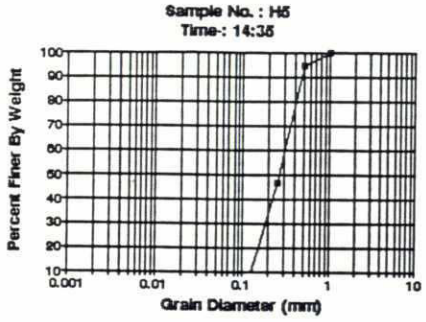


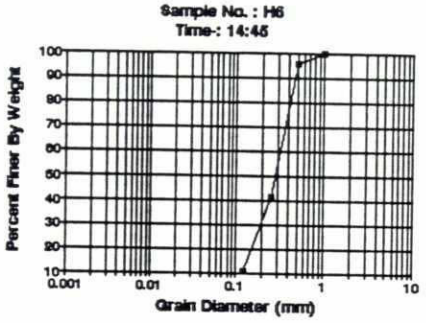


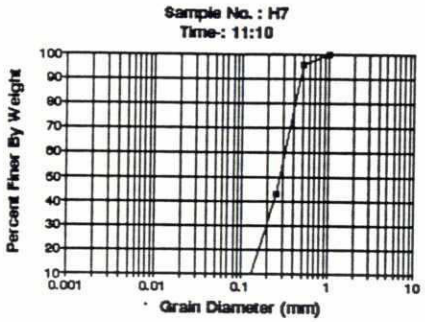


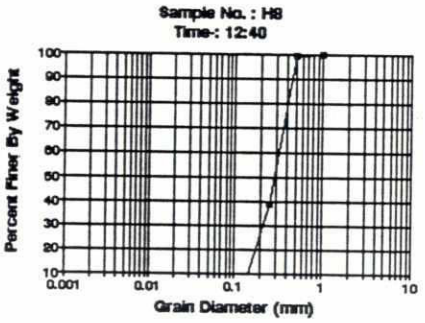
Collection Time	Collection Date	Total Welght(kg)	Transport Rate(Kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Devlation
11:50	14/01/93	158.000	0.0173245614	0.325	0.372	0.426	1.379
12:00	14/01/93	300.000	0.03289473684	0.325	0.373	0.428	1.416
13:10	14/01/93	21.000	0.00230263158	0.254	0.301	0.356	1.679
13:20	14/01/93	19.500	0.00213815789	0.261	0.308	0.364	1.710

Grain Size Distribution Of Bed Load By Sieve Analysis (Helley-Smith Sampling)





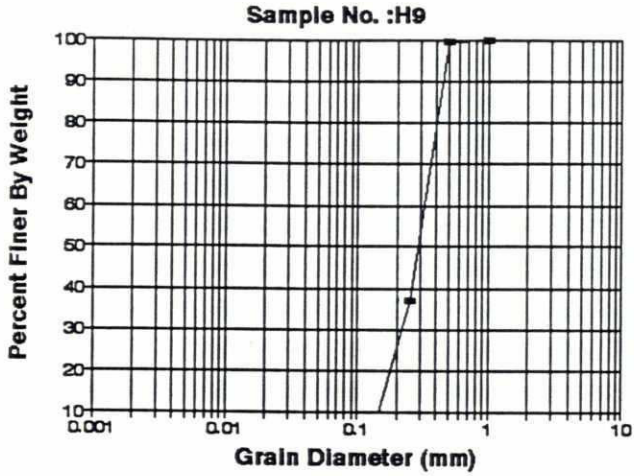




Collection Time	Collection Date	Total Weight(kg)	Transport Rate(Kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
14:35	14/01/93	5.000	0.00055	0.201	0.261	0.325	1.741
14:45	14/01/93	6.000	0.00066	0.216	0.279	0.338	1.774
11:10	16/01/93	10.000	0.00110	0.214	0.274	0.334	1.702
12:40	16/01/93	253.000	0.00066	0.232	0.283	0.337	1.601

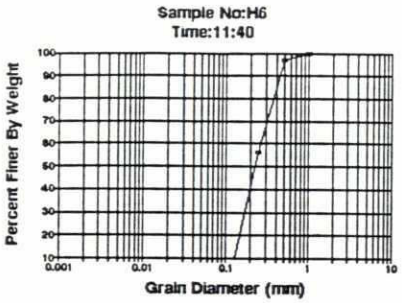
200

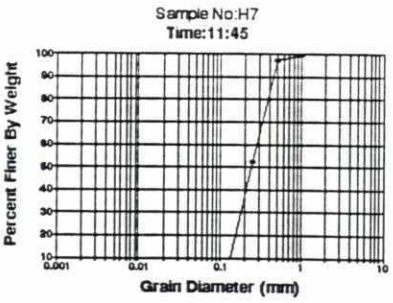
Grain Size Distribution Of Bed Load By Sieve Analysis (Helley-Smith Sampling)

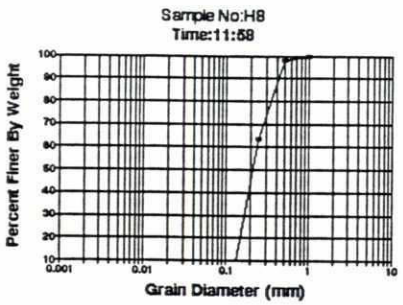


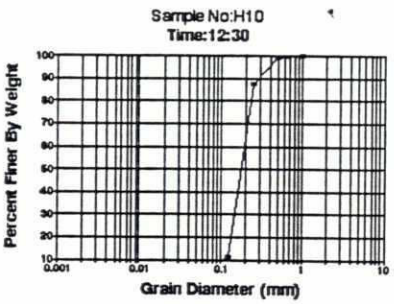
Collection Time	Collection Date	Total Weight(kg)	Transport Rate(Kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
12:50	16/01/93	374.000	0.04101	0.239	0.288	0.341	1.598

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



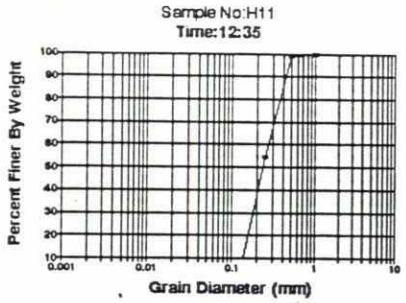


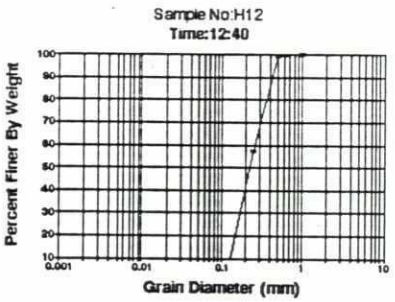


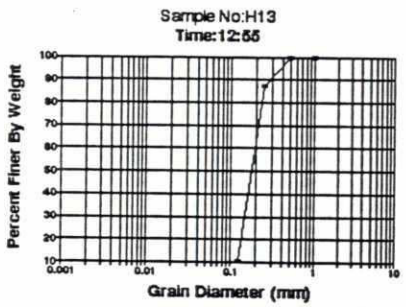


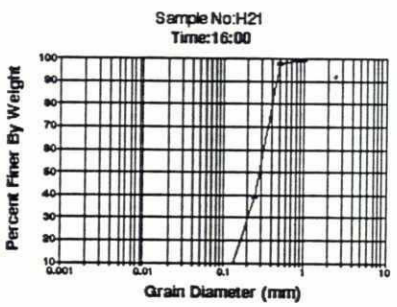
Collection Time	Collection Date	Total Weight(gm)	Transport Rate(kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
11:40	13/02/93	0.719	0.00008	0.184	0.229	0.291	1.701
11:45	13/02/93	5.000	0.00055	0.196	0.243	0.304	1.647
11:58	13/02/93	2.424	0.00027	0.18	0.214	0.258	1.626
12:30	13/02/93	2.158	0.00024	0.155	0.177	0.203	1.364

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



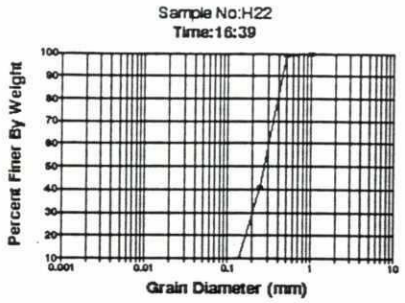


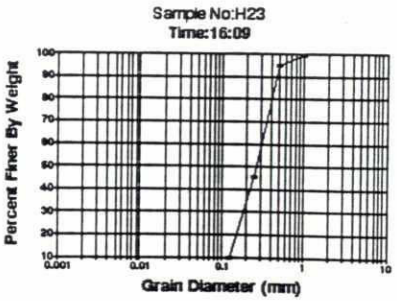


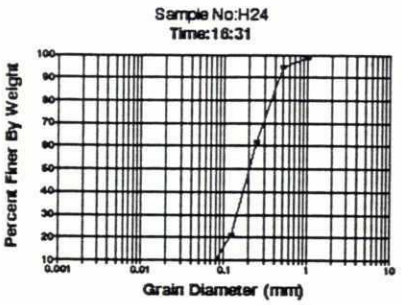


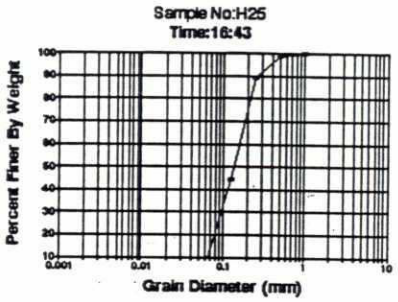
Collection Time	Colection Date	Total Weight(gm)	Transport Rate(Kg/M-s	D35 (mm)	D50 (mm)	D65 (mm)	Satndard Deviation
12:35	13/02/93	26.825	0.00098	0.194	0.236	0.294	1.613
12:40	13/02/93	2.000	0.00007	0.183	0.225	0.283	1.666
12:55	13/02/93	303.600	0.01110	0.156	0.178	0.204	1.359
16:00	13/02/93	201.000	0.00735	0.228	0.284	0.339	1.681

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



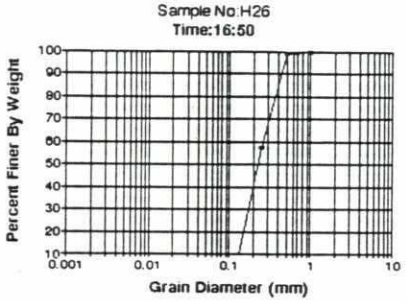


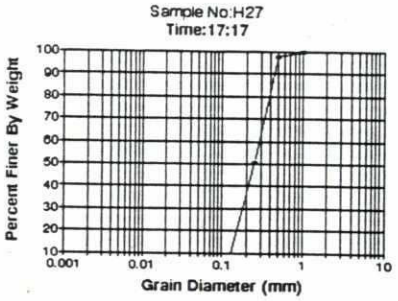


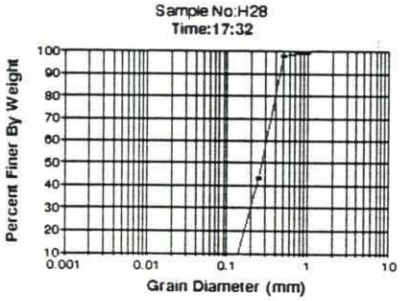


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/M-s	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
16:39	13/02/93	638.000	0.02332	0.224	0.279	0.333	1.643
16:09	13/02/93	142.000	0.00519	0.212	0.269	0.325	1.658
16:31	13/02/93	4.490	0.00049	0.203	0.265	0.328	1.749
16:43	13/02/93	40.425	0.00148	0.158	0.204	0.267	1.978

Grain Size Distribution of Bed load By Sieve Analysis (Helley-Smith Sampling)

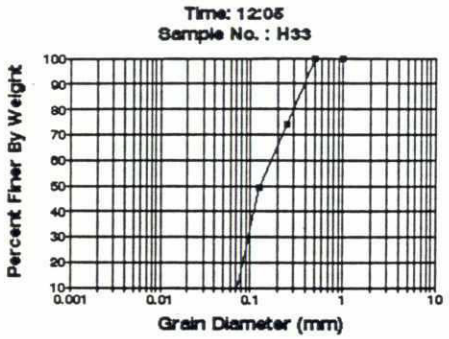


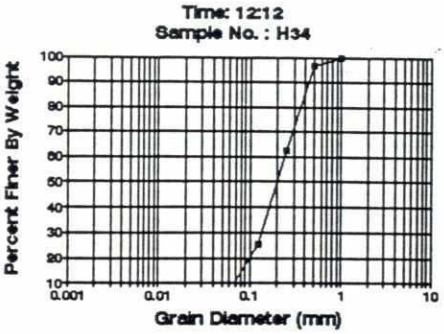


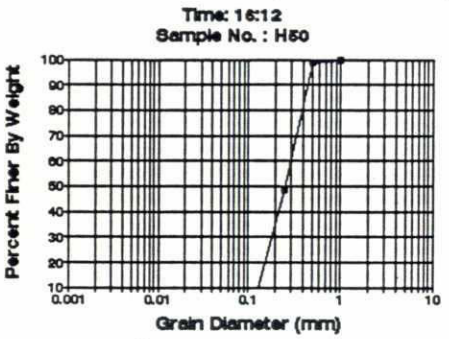


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/	D35 (mm)	D50 (mm)	D65 (mm)	Satandard Devlation
16:50	13/02/93	77.022	0.002815	0.105	0.136	0.171	1.752
17:17	13/02/93	33.180	0.003638	0.186	0.227	0.283	1.640
17:32	13/02/93	25.295	0.009245	0.192	0.247	0.308	1.708

Grain Size Distribution Of Bed Load By Sieve Analysis (Helley-Smith Sampling)

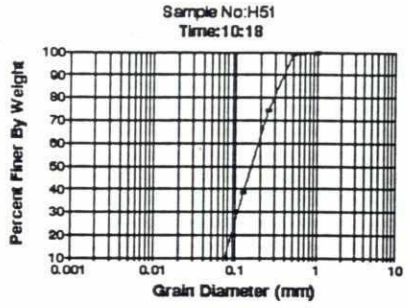


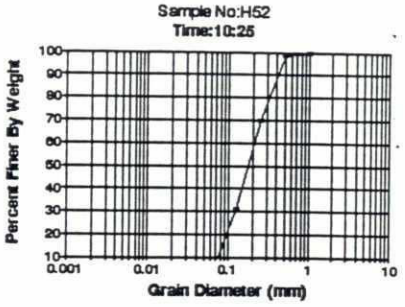


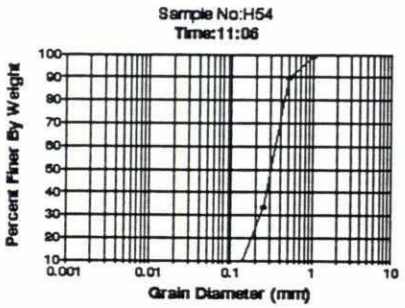


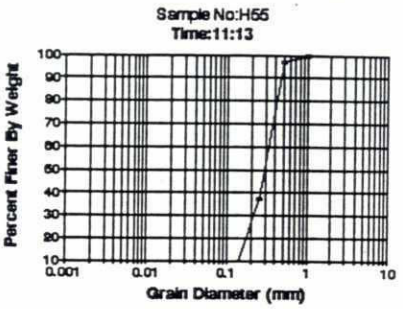
Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
12:05	16/02/93	218.000	0.00797	0.102	0.128	0.194	2.094
12:12	16/02/93	1.611	0.00006	0.150	0.198	0.262	2.113
16:12	16/02/93	6.500	0.00024	0.198	0.254	0.313	1.689

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



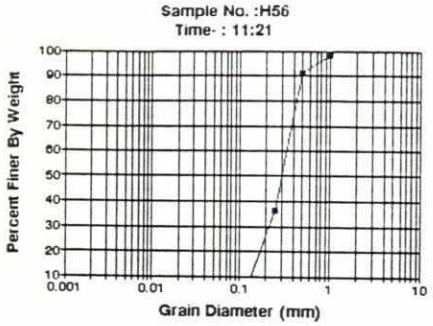


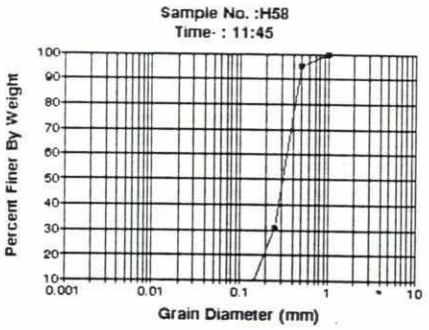


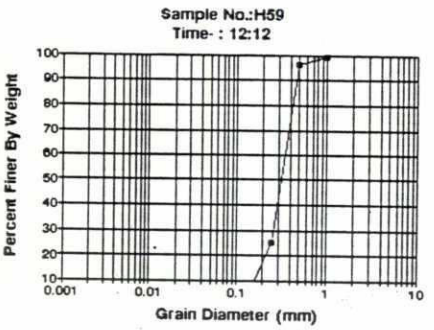


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
10:18	16/02/93	42.200	0.001542398	0.117	0.156	0.208	2.011
10:25	16/02/93	24.139	0.000882273	0.134	0.174	0.227	2.000
11:06	16/02/93	51.251	0.001873209	0.254	0.306	0.368	1.704
11:13	16/02/93	43.000	0.001571637	0.238	0.289	0.344	1.657

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)

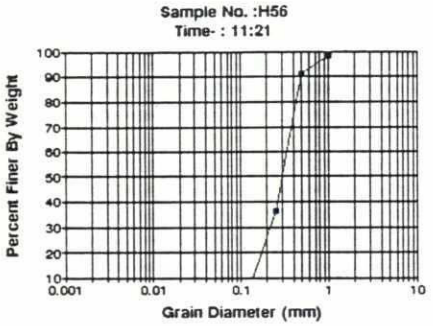


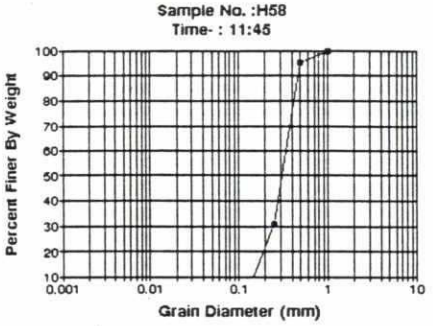


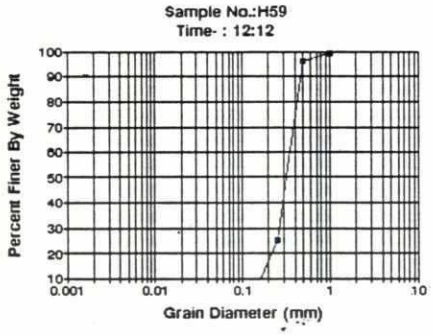


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
11:21	16/02/93	1131.000	0.04134	0.241	0.297	0.359	1.714
12:12	16/02/93	137.500	0.00503	0.262	0.307	0.361	1.623
12:20	16/02/93	114.500	0.00418	0.275	0.318	0.368	1.538

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)

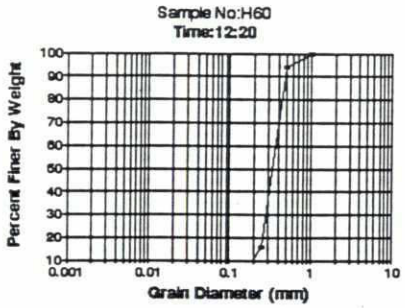


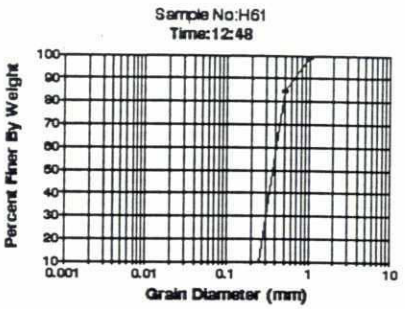


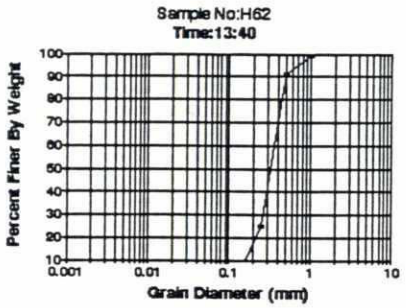


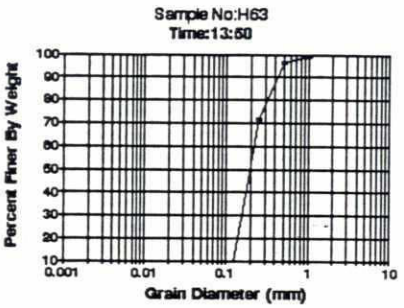
Collection Time	Collection Date	Total Weight(gm)	Transport Rate(kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
11:21	16/02/93	1131.000	0.04134	0.241	0.297	0.359	1.714
12:12	16/02/93	137.500	0.00503	0.262	0.307	0.361	1.623
12:20	16/02/93	114.500	0.00418	0.275	0.318	0.368	1.538

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



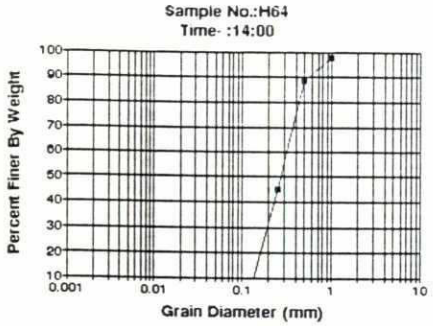


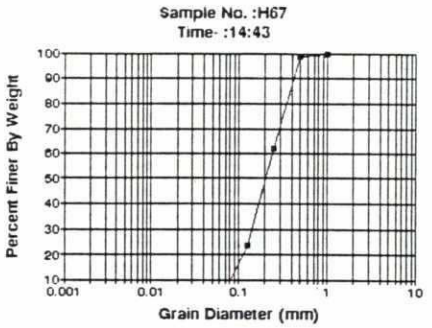


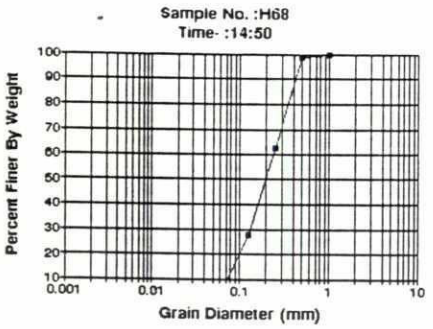


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
12:20	16/02/93	136.500	0.00499	0.296	0.338	0.386	1.348
12:48	19/02/93	81.000	0.00296	0.318	0.365	0.418	1.366
13:40	16/02/93	105.600	0.00386	0.278	0.325	0.380	1.563
13:50	16/02/93	574.900	0.02101	0.168	0.197	0.232	1.623

Grain Size Distribution of Bed Load By sieve Analysis (Helley-Smith Sampling)

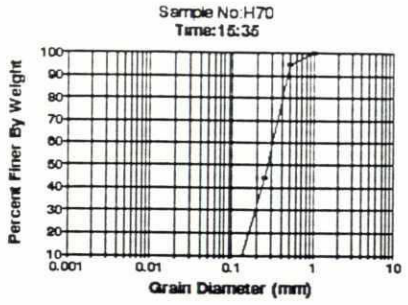


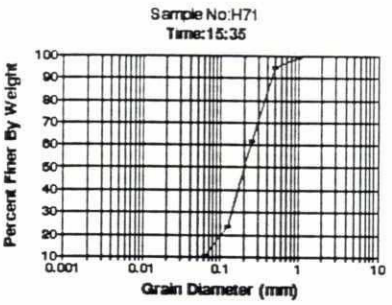


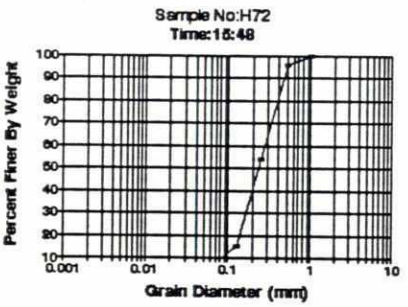


Collection Time	Collection Date	Total Weight(gm)	Transport Rate(kg/M-S)	D35 (mm)	D50 (mm)	D65 (mm)	Satndard Deviation
14:00	16/02/93	456.000	0.05000	0.210	0.270	0.343	1.751
14:43	16/02/93	31.400	0.00344	0.153	0.201	0.264	1.966
14:50	16/02/93	22.500	0.00247	0.144	0.194	0.260	2.071

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)

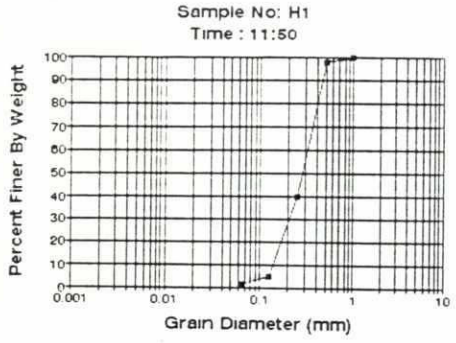


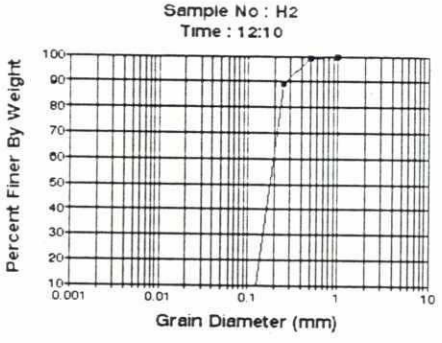


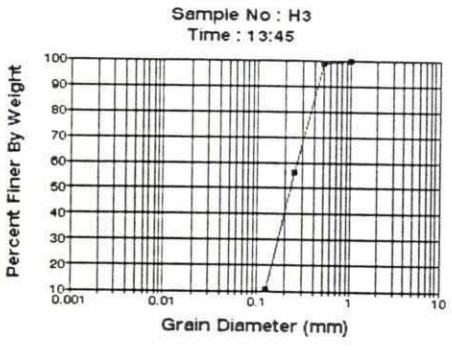


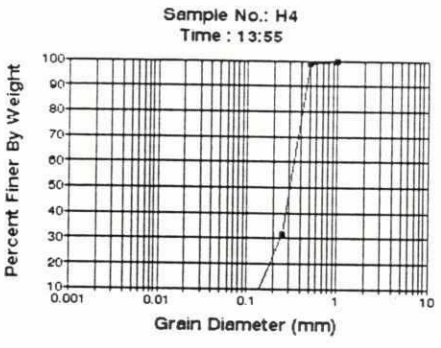
Collection Time	Collection Date	Total Weight(gm)	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
15:35	16/02/93	0.201	0.00001	0.211	0.27	0.331	1.694
15:40	16/02/93	0.712	0.00003	0.154	0.202	0.269	2.204
15:48	16/02/93	0.625	0.00002	0.177	0.232	0.299	1.806

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



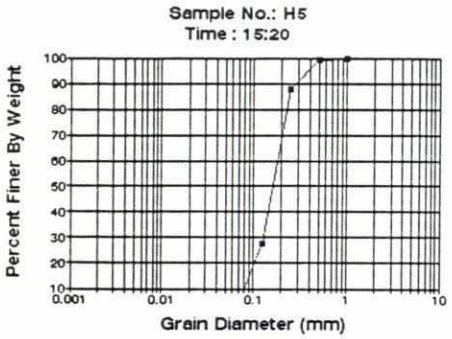


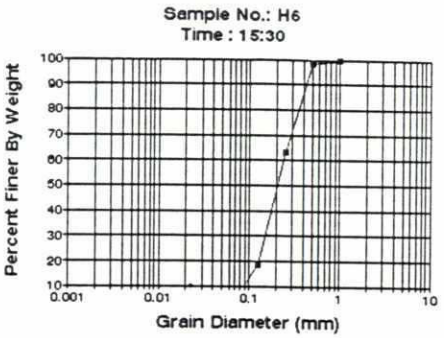


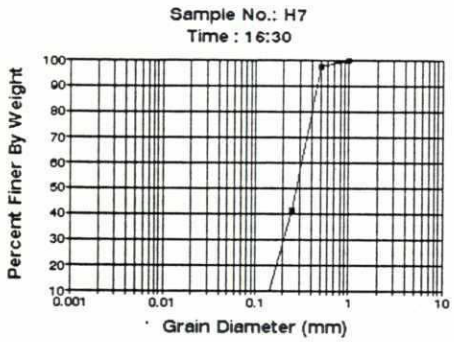


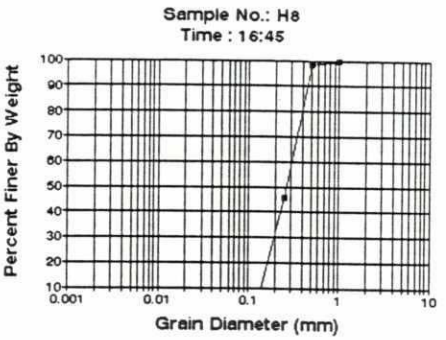
Collection Time	Collection Date	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
11:50	13/03/93	0.00026	0.226	0.281	0.337	1.659
12:10	13/03/93	0.00208	0.157	0.178	0.203	1.338
13:45	13/03/93	0.00553	0.18	0.227	0.288	1.704
13:55	13/03/93	0.00114	0.258	0.302	0.353	1.627

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



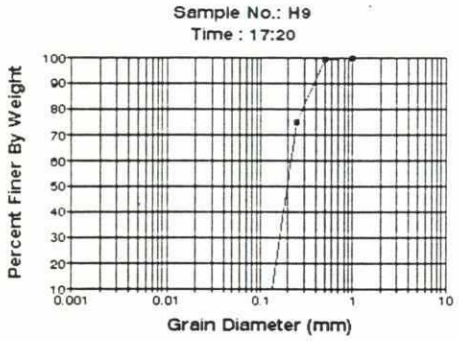


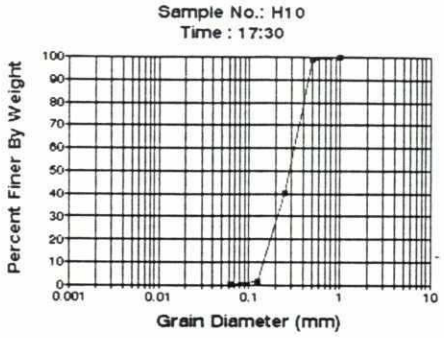


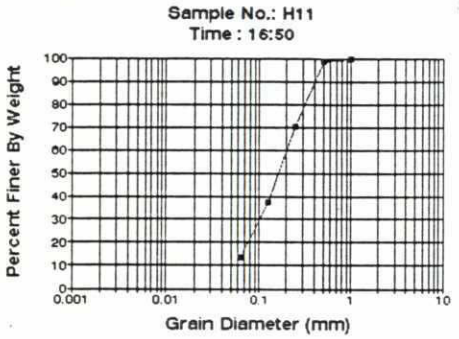


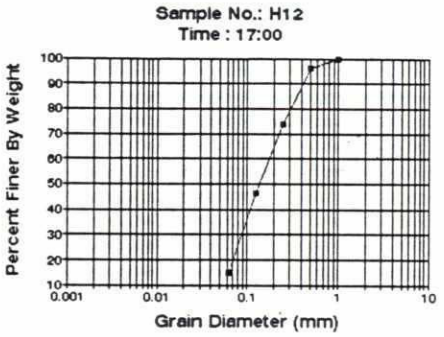
Collection Time	Collection Date	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
15:20	13/03/93	0.00961	0.136	0.161	0.192	1.608
15:30	13/03/93	0.00251	0.161	0.203	0.259	1.835
16:30	13/03/93	0.00621	0.222	0.277	0.333	1.627
16:45	13/03/93	0.00684	0.21	0.264	0.322	1.641

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)



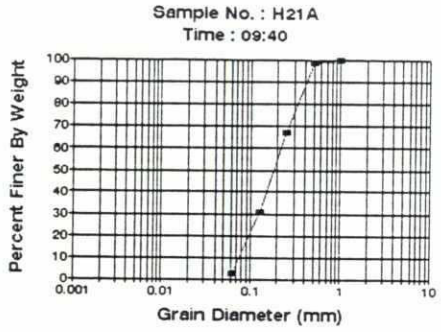


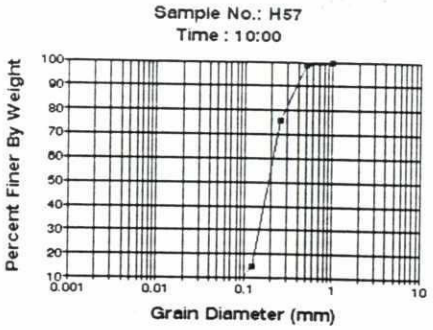


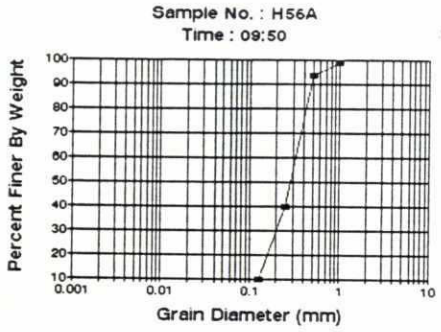


Collection Time	Collection Date	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
17:20	13/03/93	0.04417	0.171	0.197	0.227	1.504
17:30	13/03/93	0.00027	0.227	0.28	0.335	1.614
16:50	14/03/93	0.00002	0.105	0.157	0.218	2.685
17:00	14/03/93	0.00003	0.09	0.133	0.197	2.645

Grain Size Distribution of Bed Load By Sieve Analysis (Helley-Smith Sampling)





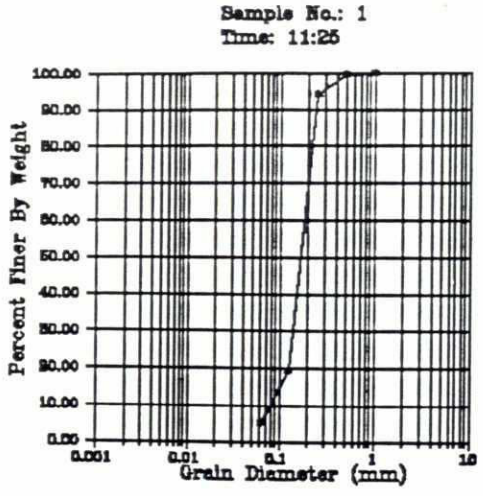


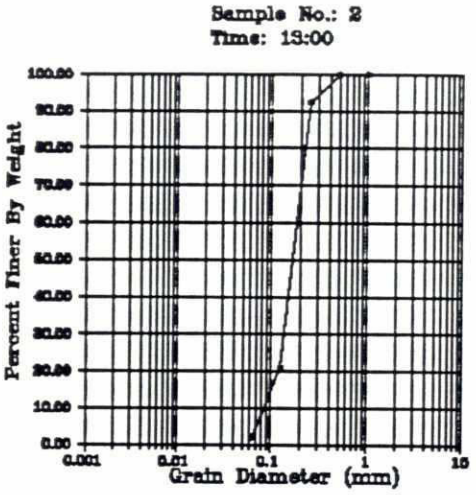
Collection Time	Collection Date	Transport Rate(Kg/M-s)	D35 (mm)	D50 (mm)	D65 (mm)	Standard Deviation
09:40	15/03/93	0.0009	0.136	0.181	0.241	2.046
09:50	15/03/93	0.00059	0.224	0.285	0.345	1.762
10:00	15/03/93	0.00042	0.157	0.186	0.221	1.592

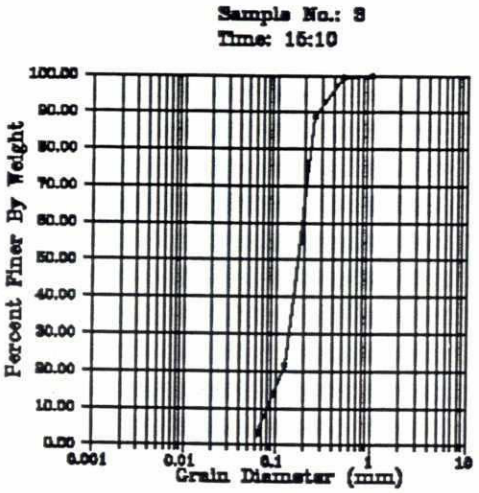
Annexure 6

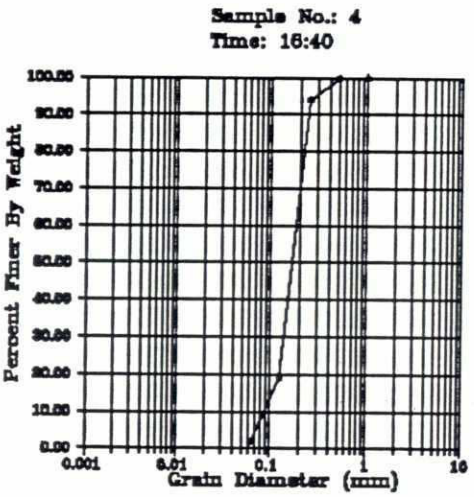
Grain size distribution of bed material samples, Jamuna river, February to March 1993

Grain Size Distribution Of Bed Material



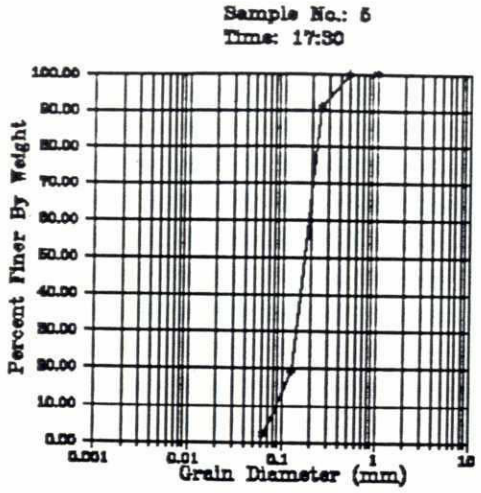


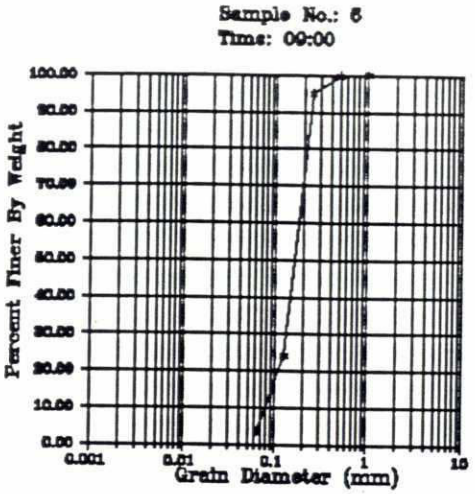


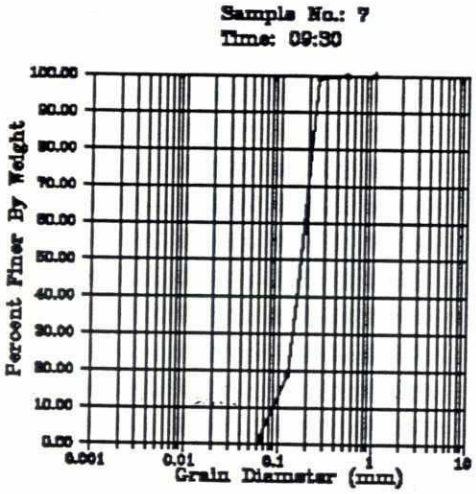


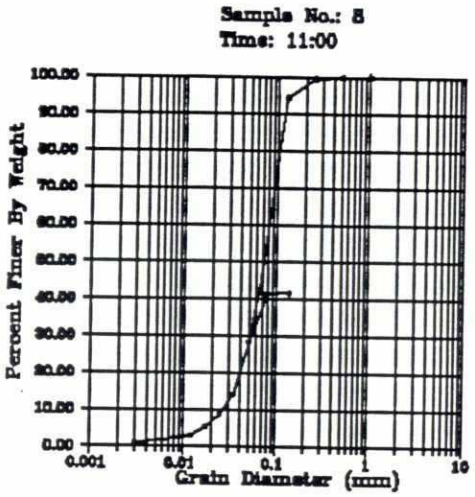
No	Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
01	13/02/93	11:00	0.100	0.144	0.166	0.250	1.467
02	13/02/93	13:00	0.100	0.143	0.166	0.250	1.486
03	13/02/93	15:10	0.100	0.144	0.168	0.260	1.532
04	13/02/93	16:40	0.121	0.145	0.167	0.250	1.435

Grain Size Distribution Of Bed Material



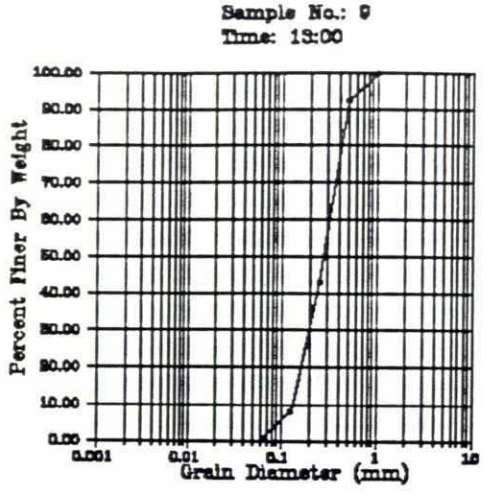


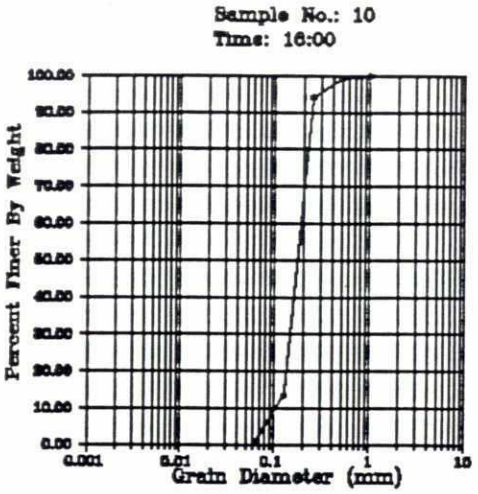


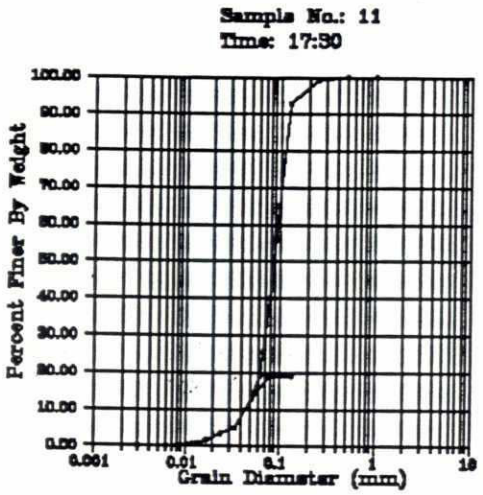


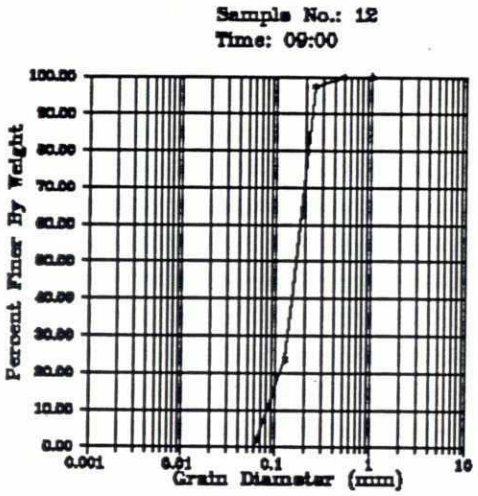
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
13/02/93	17:30	0.109	0.145	0.168	0.250	1.467
14/02/93	09:00	0.095	0.139	0.161	0.240	1.543
14/02/93	09:30	0.120	0.144	0.164	0.220	1.409
15/02/93	11:00	0.036	0.063	0.070	0.125	1.714

Grain Size Distribution Of Bed Material



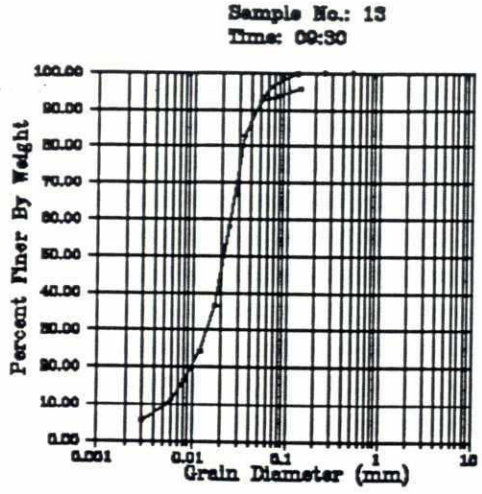


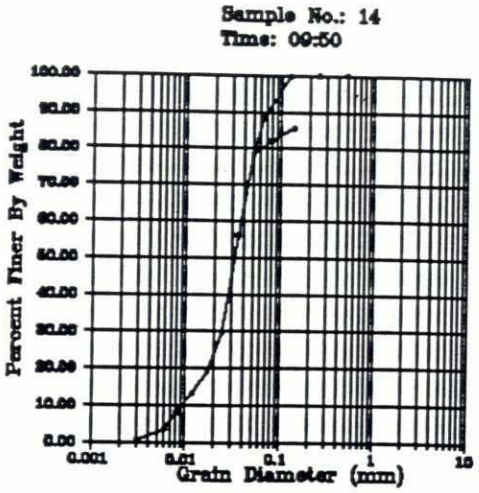


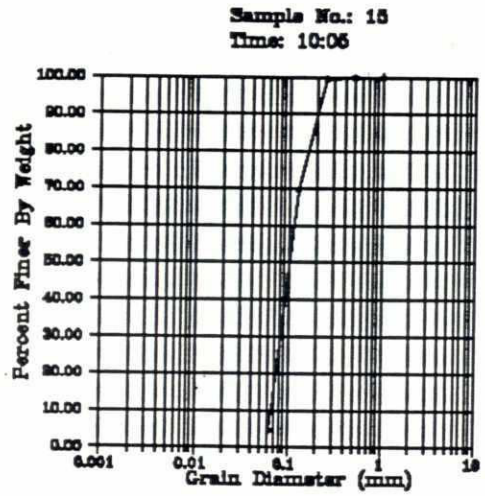


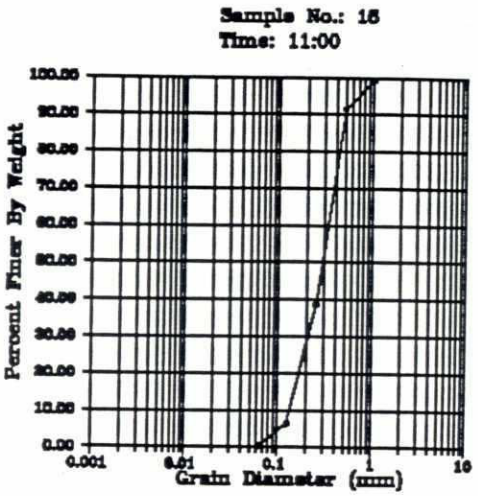
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
15/02/93	13:00	0.150	0.213	0.276	0.490	1.751
15/02/93	16:00	0.140	0.150	0.171	0.250	1.338
15/02/93	17:30	0.061	0.075	0.085	0.130	1.432
16/02/93	09:00	0.100	0.139	0.160	0.240	1.507

Grain Size Distribution Of Bed Material





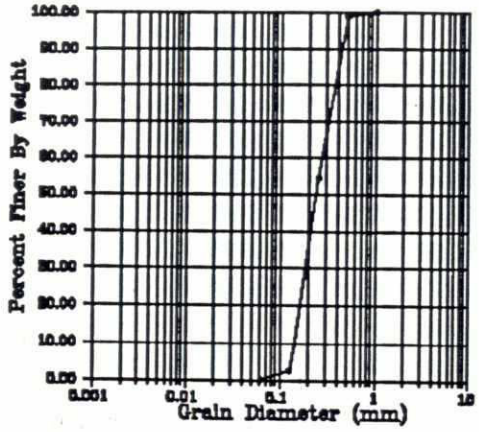




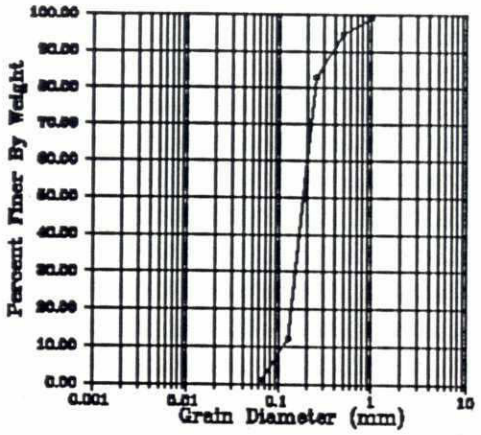
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
16/02/93	09:30	0.008	0.016	0.022	0.046	2.284
16/02/93	09:50	0.015	0.026	0.033	0.070	1.933
16/02/93	10:05	0.070	0.087	0.102	0.200	1.576
16/02/93	11:00	0.150	0.231	0.290	0.500	1.729

Grain Size Distribution Of Bed Material

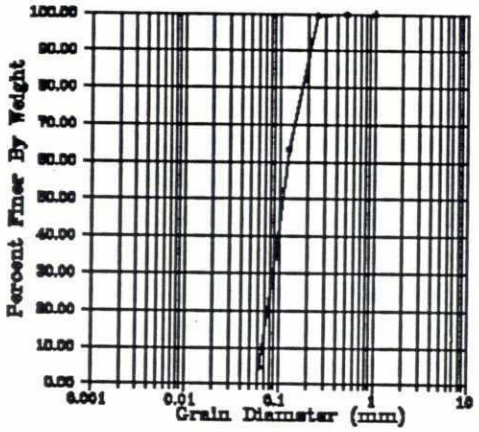
Sample No.: 17
Time: 12:10



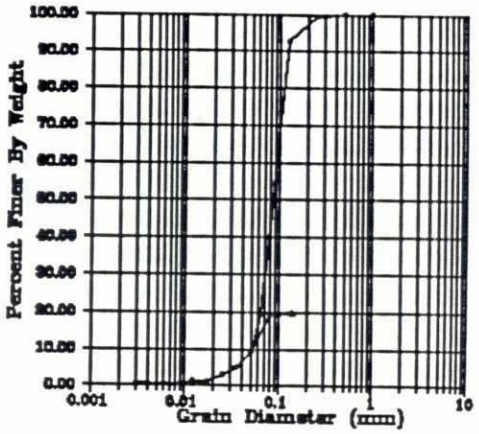
Sample No.: 18
Time: 13:30



Sample No.: 19
Time: 14:30



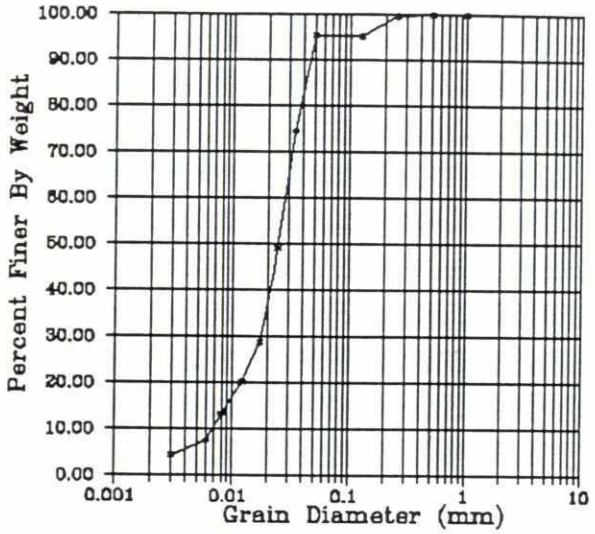
Sample No.: 20
Time: 15:30



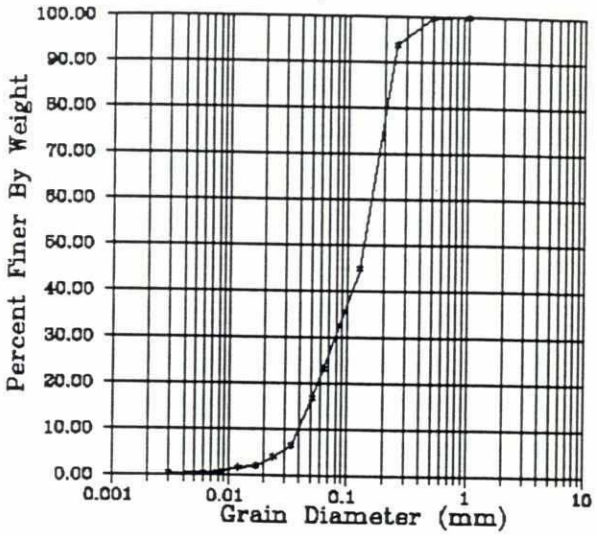
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
16/02/93	12:10	0.150	0.193	0.235	0.440	1.631
16/02/93	13:30	0.140	0.156	0.181	0.390	1.431
16/02/93	14:30	0.070	0.090	0.107	0.210	1.612
16/02/93	11:00	0.150	0.231	0.290	0.500	1.729

Grain Size Distribution of Bed Material

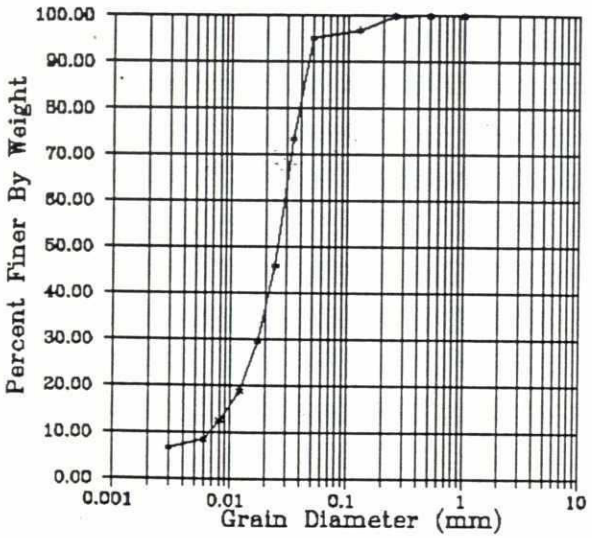
Sample No.: 1
Time: 11:00



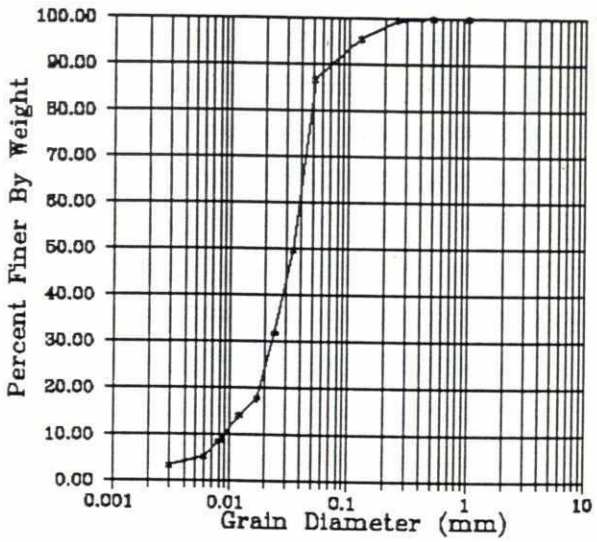
Sample No.: 2
Time: 13:00



Sample No.: 3
Time: 09:30



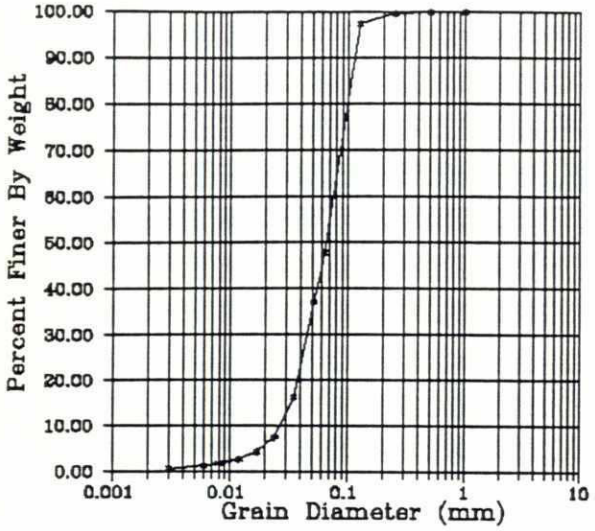
Sample No.: 4
Time: 16:40



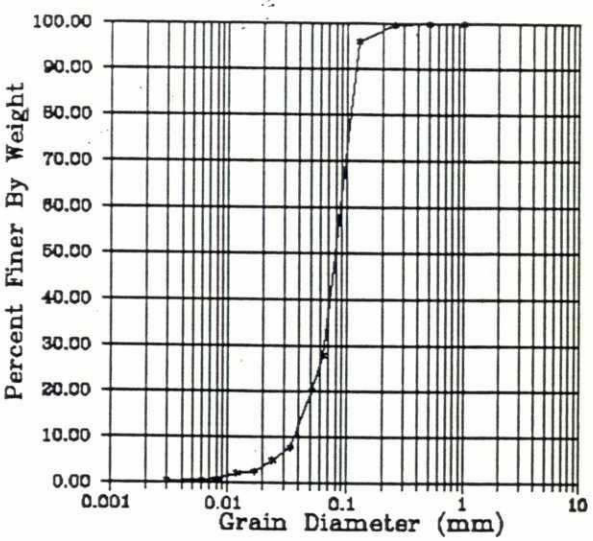
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
14/03/93	11:00	0.009	0.020	0.025	0.045	2.883
14/03/93	13:00	0.050	0.095	0.150	0.250	2.250
14/03/93	09:30	0.010	0.020	0.025	0.045	2.050
14/03/93	16:40	0.015	0.025	0.035	0.070	1.273

Grain Size Distribution of Bed Material

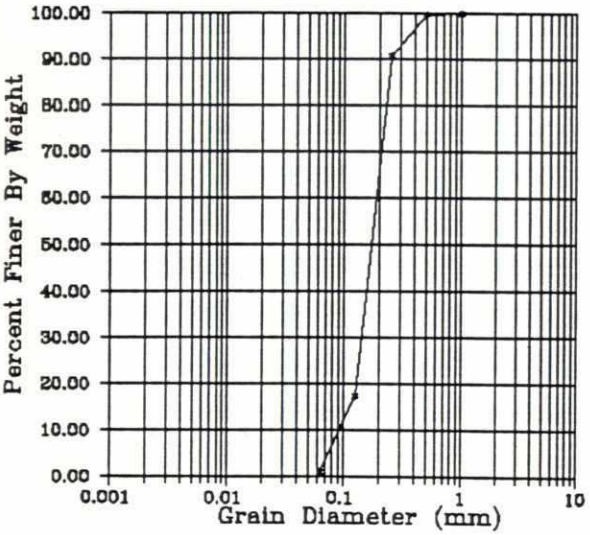
Sample No.: 50A
Time: 14:00



Sample No.: 55A
Time: 12:00

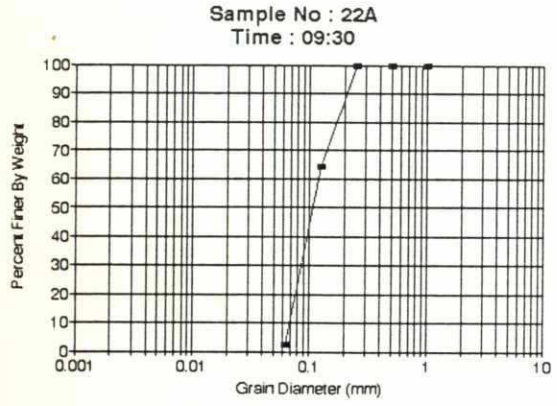


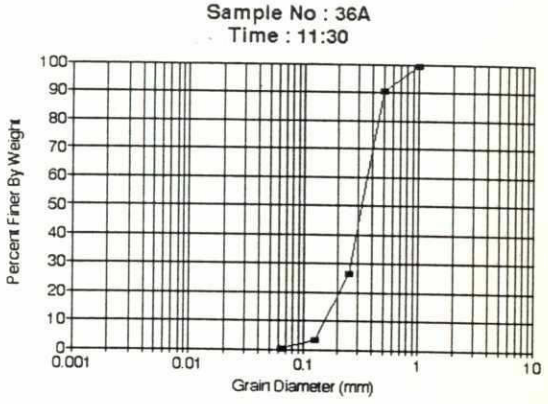
Sample No.: 65A
Time: 16:30

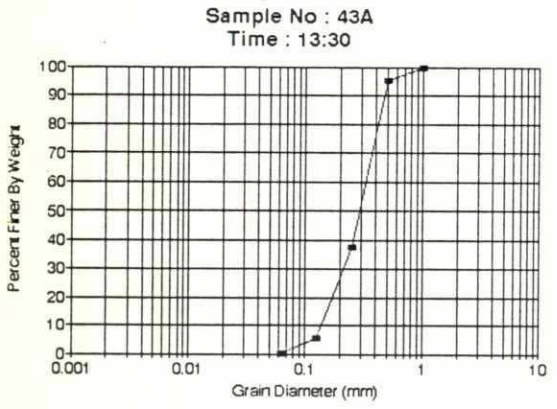


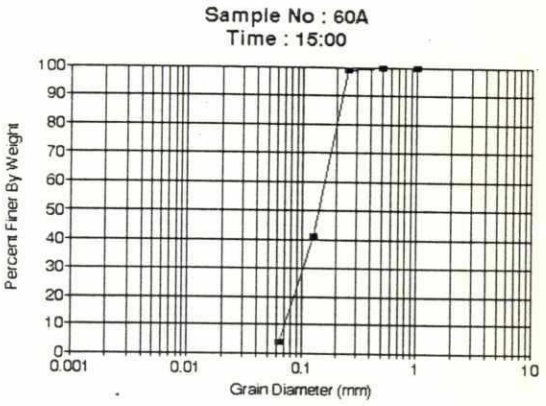
Date	Time	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)	Standard Deviation
15/03/93	14:00	0.035	0.050	0.065	0.110	1.698
15/03/93	12:00	0.045	0.070	0.080	0.135	1.670
15/03/93	16:30	0.148	0.150	0.170	0.250	1.415

Grain Size Distribution of Bed Material









Date	Time	D16 (mm)	D35 (mm)	D50 (mm)	D90 (mm)	Standard Deviation
15/03/93	09:30	0.075	0.090	0.106	0.200	1.589
15/03/93	11:30	0.200	0.275	0.323	0.500	1.605
15/03/93	13:30	0.175	0.237	0.291	0.490	1.676
15/03/93	15:00	0.080	0.112	0.139	0.230	1.632