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RIVER SURVEY PROJECT

Special Report No. 19

Joint measurements BWDB/RSP hydrology

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Joint discharge measurements, RSP and BWDB, Surface Water Hydrology

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Abbreviations

ADCP	: Acoustic Doppler Current Profiler
AWLR	: Automatic Water Level Recorder
BUET	: Bangladesh University of Engineering and Technology
BWDB	: Bangladesh Water Development Board
DHA, DHB, etc. ...	: Names of RSP survey vessels
DGPS	: Differential Global Positioning System
EMF	: Electromagnetic flow meter
FPCO	: Flood Plan Coordination Organization (presently merged with WARPO)
RSP	: The River Survey Project
SWMC	: Surface Water Modelling Centre
S4	: Brand name of an electromagnetic current meter
WARPO	: Water Resources Planning Organization

Symbols

A	: Cross-sectional area	(m^2)
C	: Chezy roughness coefficient	($m^{0.5}/s$)
D_{50}	: Median particle diameter	(m)
E(x)	: Expected value of x	
g	: Gravity acceleration	(m/s^2)
h	: Water depth *or* water level	(m)
i	: Water surface slope	(-)
n	: Number of propeller revolutions	(-)
q_s	: Suspended sediment transport per unit width	(kg/s/m)
Q	: Discharge	(m^3/s)
R_x	: Ratio of (x measured by BWDB) : (x measured by RSP)	(-)
s_u	: Standard deviation of u	(m/s)
u	: Flow velocity *or* depth-averaged flow velocity	(m/s)
$\bar{x}$	: The average of a parameter	
α	: Angle between cross-section orientation and flow direction	(degrees)
Δ	: Relative density	(-)
ψ	: Dimensionless sediment transport parameter	(-)
σ^2	: The variance of a variable	(-)
θ	: Dimensionless shear-stress parameter, or Shields parameter	(-)

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1 Introduction

The River Survey Project

The River Survey Project was initiated on 9 June 1992. The project was executed by Flood Plan Coordination Organization (FPCO), presently merged with Water Resources Planning Organization (WARPO) under the Ministry of Water Resources (formerly the Ministry of Irrigation, Water Development and Flood Control). It was funded by the European Commission. The Consultant is DELFT-DHI Consortium in association with Osiris, Hydroland, and Approtech. Project supervision is undertaken by a Project Management Unit with participation by WARPO, a Project Adviser, and a Resident Project Adviser.

The objectives of the project are (1) to establish the availability of detailed and accurate field data as part of the basis for the Flood Action Plan projects, and (2) to add to the basic data for any other planning, impact evaluation, and design activities within national water resources and river engineering activities.

The project consists of three categories of activities:

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

The programme of the Project was developed in a close dialogue with the Client and the Project Adviser. This report was prepared by Mr. Zahirul Hoque Khan and Mr. M. van der Wal.

Background for the BWDB/RSP joint measurements

During the first phase of the Project, an inconsistency was detected in the BWDB discharge time series at Bahadurabad, specifically from 1988 to 1992 *(RSP Study Report 2, 1993)*. The discharge measured during this period was higher than the discharge measured at the same stage in previous years. This pattern was especially visible in the shift of the annual stage-discharge rating curves of Bahadurabad.

The first results of RSP's discharge measurements in 1992 and 1993, (plotted on the last available BWDB rating curve for Bahadurabad), indicated that RSP measured lower discharges than BWDB during higher river stages at Bahadurabad. For details please refer to *RSP Survey and Study Report 6: 'Hydrological Study Phase I' (1993)*.

In the beginning of 1994, a *'Committee on Shift in the Rating Curve at Bahadurabad'* was established to examine the matter, with representatives from BWDB (Surface Water Hydrology I & II), FPCO, BUET, and RSP. Based primarily on elaborate analyses (by hydrodynamic modelling) by BWDB, RSP, and SWMC in 1993, the Committee confirmed the systematic increase of the discharge measured by BWDB after 1988. The Committee recommended that BWDB and RSP organise joint and simultaneous measurements to identify the causes of this inconsistency in the discharge data. It also requested an investigation of the sensitivity of the discharge for an inaccuracy in the data.

Tegada-Guibert (1993) recommended checking the possible sources of errors in the performance of discharge measurements after analysing the available data. For example, he recommended checking if there was inadequate correction of flow angles (oblique flow through the transects) during the 1988 floods while there were substantial changes in the flow direction.

In 1994, some of the RSP and BWDB routine measurements coincided; however, these measurements were in different transects. A comparison of the measurements was made. In 1995, RSP and BWDB made three simultaneous measurements at the same transect at Bahadurabad (July and November) and at Mawa (October). In addition, they made one simultaneous measurement on the same day at Hardinge Bridge at the BWDB transect (October) to ensure a good comparison. The main objectives of the joint exercise were to assess the quality of the prevailing survey procedure and to identify possible systematic instrumental or methodological explanations for the increase in the measured discharge at Bahadurabad. More specifically, the following aspects of the survey procedure and measuring methodology were studied:

- the positioning of the transect and the verticals,
- the measurement of the cross-sectional profile, especially the width at the water surface and the depths in the verticals,
- the flow velocity measurements, the instrument characteristics and the positioning of an instrument in a vertical,
- the measurement of flow angles, and
- sediment transport measurements, especially the measurement of the sediment concentration or the sediment transport.

These aspects will be discussed in the following chapters.

These joint surveys were discussed extensively with the Project Adviser, who is preparing a major refurbishing of two BWDB survey vessels. These vessels will be equipped with a DGPS positioning system and new instruments. It is expected that the results of these joint measurements will be used to select the new equipment for sustainable survey techniques.

2 Joint discharge measurements

2.1 Introduction

In 1994, several routine gaugings by RSP were made at almost the same time as the routine gaugings by BWDB, but along different transects. The main results of these gaugings are compared in Sections 2.2 and 2.3

In July and November 1995, joint measurements were taken in the Jamuna River at Bahadurabad. In October 1995, joint measurements were organized in the Padma River at Mawa and a limited joint survey was executed in the Ganges River at Hardinge Bridge. The main results of these measurements will be discussed in the following sections.

2.2 Routine gaugings at Bahadurabad in 1994

During the monsoon season BWDB made weekly discharge measurements at Bahadurabad, where also RSP made several routine gaugings and special discharge measurements. Figure 2.1 shows that many gaugings were taken on nearly the same dates, with only one or two days in between. Only those discharges of simultaneous gaugings were compared if the water level was almost constant during the gauging period at an almost constant water level during the gauging period.

BWDB and RSP independently executed two routine gaugings at Bahadurabad within 2 days; on 20 and 21 June by BWDB and 23 June by RSP, and on 17 and 23 October by both BWDB and RSP (see the hydrograph in Figure 2.2). Only the discharges and water levels measured in these routine gaugings were compared in Table 2.1 because the gauging transects were different. Most routine gaugings by RSP in the left channel were taken in a transect 4 to 5 km downstream of the BWDB transect (see Figure 2.3). Therefore, a detailed comparison would not be meaningful. The water level gauges of BWDB and RSP were placed close to each other on the left bank a short distance north of Bahadurabad Ghat. The three comparisons in Table 2.1 show that BWDB measured a discharge that was roughly 4 to 9 % above the one measured by RSP.

These gaugings were done in mid-flow conditions in the low 1994 peak of the hydrograph and the receding limb of the hydrograph. The hydrograph shows that the high water levels during the monsoon of 1994 were very moderate (see Figure 2.2). For a short period, the 18.5 m+PWD level was reached; this is 1.0 m below the danger level. In view of these circumstances, more extensive joint measurements were planned for the next flood season.

Date	Stage (m+PWD)		Discharge (m^3/s)		Q_{BWDB}/Q_{RSP}
	BWDB	RSP	BWDB	RSP	(%)
20, 21 June 94	18.36/18.52	18.37/18.52	36,400	-	
23 June 94	18.52	18.54	-	33,900	107.4
17 October 94	17.24	17.23	24,300	22,300	109.0
23 October 94	16.62	16.62	18,500	17,800	103.9

Table 2.1: Simultaneous and comparable routine gaugings at Bahadurabad in October 1994

2.3 Survey at Bahadurabad, July 1995

Main activities of the July 1995 joint survey

During an extensive joint survey at the Bahadurabad transect, the following activities took place:

16 July 95: RSP reconnaissance of the transect in the left and right channels;
17 July 95: joint measurements in the right channel, also called the Fulchari Channel;
18 July 95: joint measurements in the mid channel, also called the Old Bahadurabad Channel;
19 July 95: joint measurements in the left channel, also called the Bahadurabad Ghat Channel; and
20 July 95: special joint measurements in vertical 62.

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During the first days of the survey the weather was good, but windy. The water level just north of Bahadurabad Ghat was measured during the survey period by BWDB as 19.41 to 19.19 m+PWD, and by RSP as 19.42 to 19.19 m+PWD, see hydrograph in Figure 2.4. The difference in the water levels measured by both organizations is negligible for this period. The water level dropped at a maximum rate of 0.08 m/day on 16 July. This rate decreased gradually to 0.03 m/day over the next few days.

The transect

BWDB had preselected the transect and the verticals. The joint measurement was made at the BWDB transect, because it was much easier for RSP to adjust to the BWDB transect than for BWDB to adjust to the RSP transect due to the different positioning systems applied (sextants with land markers versus DGPS). BWDB started the measurement on the right bank of the Fulchari Right Channel, and took measurements in a total of eight channels crossing the transect; three of these eight channels were main channels (see Figures 2.5). In total, 64 verticals were measured in these eight channels by BWDB: 26 verticals on 17 July, 34 verticals on 18 July, 8 verticals on 19 July. A few verticals were measured twice. RSP took the easting and northing of most of the verticals, necessary for positioning the RSP survey vessel at the same location.

Measuring methods

While taking measurements in a vertical the BWDB survey catamaran was positioned dynamically (instead of anchoring the vessel).

The flow velocity measurements were taken at two points, 0.2 and 0.8 of the total depth, using a new Seba (propeller type) current meter suspended from the survey catamaran. The total water depth in a vertical was read from the Seba's winch counter. The vertical angle of the suspension cable above the water surface varied from 8 to 12° during most of the flow measurements.

RSP measured the discharge twice along the selected transects using the moving boat method. The velocities have been measured by an Acoustic Doppler Current Profiler and an electro-magnetic flow meter. The position of the survey vessel was determined by a differential Global Positioning System. In the shallow areas near the banks and chars, the flow velocity was measured by a Valeport current meter operated on a small survey vessel (DHE vessel). After completing a moving boat discharge measurement, RSP made flow velocity measurements by ADCP-EMF at an anchored position in the verticals. The RSP made a great effort in measuring 4 verticals from an anchored survey vessel, while, at the same time, BWDB measured 19 verticals in the right channel using dynamic positioning. Therefore RSP did not measure all the verticals in the different channels.

Figure 2.6 shows an example of the movement of the DHA vessel in an anchored position in vertical 62 in the left channel or in dynamic positioning. The anchored DHA drifts about 40 m in all directions; in dynamic positioning the movements are limited to 25 m in all directions. These results are highly dependent on the specific conditions (e.g., water depth, flow, wind, skill of the helmsman), and therefore no general conclusions can be drawn from this example.

Primary results

The results of the primary data, as analyzed by RSP and compared with BWDB's field sheets data are summarized in Table 2.2. A more detailed overview of the measurements is presented in Annexure 1.

	Width (m)	Difference in width (%)	Area (m²)	Difference in area (%)	Discharge (m³/s)	Difference in discharge (%)
Fulchari Right Channel						
RSP	3100	+5.3	15,500	+10.5	13,800	-5.8
BWDB	2935	-5.6	13,900	-11.7	14,600	+5.5
Old Bahadurabad Mid Channel						
RSP	1920	-10.4	15,600	+4.8	34,600	+3.5
BWDB	2121	+9.4	14,900	-5.0	33,400	-3.6
Bahadurabad Ghat Left Channel						
RSP	1700	+1.8	8,720	+10	6,700	-9.0
BWDB	1670	-1.8	7,850	-11	7,300	8.2
Total						
RSP	6720	-0.1	39,800	+7.8	55,100	-0.4
BWDB	6726	+0.1	36,700	-8.4	55,300	+0.4

Note : + higher, - lower

Table 2.2: Comparison of joint measurements at Bahadurabad, July 1995

In general, the discharge in a channel is calculated as

$$Q = A \cdot u \cdot \sin\alpha \qquad (2.1)$$

where,
Q = discharge (m³/s)
A = cross-sectional area (m²)
u = flow velocity (m/s)
α = angle between bearing of the cross-section transect and main surface flow direction (degrees)

The BWDB and RSP measurements of the main channel width at the water surface differed by 2 to 10%. The cross-sectional area measured by RSP was 5 to 10% larger than the area measured by BWDB. The discharge in the individual channels differed by 3 to 9%, but the total discharge was almost equal, differing by only 0.4%.

One of the reasons for these differences is that the position of the verticals in the left channel measured by BWDB and RSP was not always the same due to the high flow velocities in that channel. In addition, the survey vessel moved during the measurements as can be seen in the example in Figure 2.6. In the left channel, the bedforms, especially dunes, had heights of 2 to 2.5 m, so a deviating location of a vertical can cause a difference in the water depth up to the height of the bedform, depending on whether the verticals are taken on the crest or on the trough of the dunes.

In a number of verticals, above the water surface the suspension wire of the Seba current meter made an 8 to 12° angle with the vertical. Such an angle has almost no influence on the depth registration.

In approximately 14 verticals, the flow velocity measured by RSP was 5 to 20% lower than the one measured by BWDB (see Annexure 1, Table A1.1). The verticals in the Right Channel are presented in Figure 2.7, verticals in the Old Bahadurabad Channel in Figure 2.8, and verticals in the Bahadurabad Ghat Left Channel in Figure 2.9. The deviation between the flow velocities was slightly more than the estimated accuracy of the measurements, which is approximately 10%. The accuracy in the angle α measured by the BWDB is about 5 to 10°.

During the measurements at a given vertical, the BWDB catamaran moves about 20 to 30 m upstream and downstream, depending on the flow velocities and the distance to the marker of the transect. If these movements are slow they will have a small influence only on the calculated discharge.

On 20 July 1995, after completion of the joint discharge measurement, RSP and BWDB did some special measurements in the left channel at an anchored position (BWDB vertical number 62). The comparison of the flow velocities measured by ADCP, Ott, Seba, and S4 showed that BWDB's Ott and Seba tend to measure a slightly lower flow velocity.

2.4 Survey at Hardinge Bridge, October 1995

Schedule of activities

The joint survey upstream of Hardinge Bridge was done by BWDB and RSP, largely independently of each other, from 2 to 3 October 1995. The surveys were done at almost the same time and along the same transect, whereby the results become comparable. The schedule of the main activities was as follows:

2 October 95: RSP reconnaissance of the BWDB transect; some transect measurements by moving boat method, but these were repeated the next day;

3 October 95: RSP repeated the transect gauging and did one stationary velocity profile by ADCP;

The transect

The comparative measurement was made in the BWDB transect, which is about 700 m upstream of the Hardinge Bridge. This transect is almost perpendicular to the main flow direction. In this reach, the Ganges River has one single channel.

If the RSP survey vessel traversed along the transect the high flow velocities would reduce the quality of the ADCP measurements. Therefore, the transect measurements were taken with slow speed resulting in a gradually drifting downstream of the transect (see Figure 2.10).

Survey methods

Both BWDB and RSP applied their own routine gauging methods. RSP did a transect survey with one ADCP vertical measurement.

Results

After the water level in the Ganges River had reached a peak on 29 September 1995, the water level fell at a constant rate of 0.24 m per day during the survey period. There was no tidal influence on the flow. The main results of the BWDB and RSP surveys are presented in Table 2.3.

	Width (m)	Width difference (%)	Area (m^2)	Area difference (%)	Discharge (m^3/s)	Discharge difference (%)
RSP	1,638	+1.5	18,400	+5.4	32,600	-12.7
BWDB	1,613	-1.5	17,400	-5.7	36,800	+11.3

Note :+ higher, - lower

Table 2.3: Comparison of joint measurements at Hardinge Bridge, 2 and 3 October 1995

The results in Table 2.3 show that RSP registered a slightly larger width and cross-sectional area, but about 13 % less discharge than BWDB. The difference in cross-sectional area can probably be explained by the different sailing routes along the transect, but should not have any influence on the total discharge measured. RSP probably measured some lower flow velocities than BWDB had measured.

2.5 Survey at Mawa, October 1995

Schedule of activities

RSP and BWDB made another joint and simultaneous measurement in Padma River at Mawa from 20 to 22 October 1995. The schedule of activities was as follows:

- 19 October 95: RSP preparations for the joint survey, such as a reconnaissance of the BWDB transect;
- 20 October 95: RSP transect measurements and vertical measurements in the right and left channels;
- 21 October 95: RSP transect surveys, and joint BWDB/RSP vertical measurements;
- 22 October 95: Sediment transport by RSP in one vertical in the left channel and one in the right channel.

During these days, the wind was light and did not disturb the surveys.

The transect

The joint measurement near Mawa was made along the BWDB transect. During the determination of easting and northing of the BWDB verticals, as pre-defined by sextant angles to markers on the bank, it was observed that the markers of the transect on the left and right banks could not be connected by one transect line from the right to the left bank. In the middle of the transect, an off-set error of about 50 m was detected, see Figure 2.11. A transect for the left channel was defined based on the markers on the left bank, and a second transect line was defined for the right channel through the markers on the right bank. BWDB had probably always taken the measurements along these two transect lines

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because the surveyors used the markers on the left bank in the left channel and the markers on the right bank in the right channel. In the middle of the river, the markers are hardly visible, depending on the weather, because the width of the river is about 4 to 5 km in the transect area. With a DGPS system, this type of error can be prevented.

Survey methods

For discharge measurements, RSP used their standard ADCP-EMF moving boat method, and BWDB used their standard method with an Ott current meter (meter No. 51178 and propeller No. 2-77011). This current meter was calibrated on 9 October 1995. The number of revolutions was converted into flow velocities by the following formula:

$$u = 0.5048 \cdot n + 0.0003 \qquad (2.2)$$

where,

n = number of revolutions per second, $n > 1.77\ s^{-1}$, and
u = flow velocity (m/s).

During the measurements, BWDB used an echosounder to measure the depth in the velocity verticals. In total, BWDB measured flow velocity in 33 verticals over the whole width. RSP followed BWDB by measuring flow velocity in 21 verticals, using dynamic positioning.

Results

In October, the tidal effect on the flow conditions in Mawa was not negligible. The water levels, as recorded by AWLR, showed a variation of about 0.2 m between the daily maximum and minimum levels. Consequently, RSP, like BWDB, also measured the verticals in dynamic positioning, in order to reduce the time lapse between the BWDB measurement and the RSP measurement, and to minimize the effect of the tidal variation in the flow on the comparative measurements.

The results of the joint measurements are presented in Table 2.4.

	Total width (m)	Width difference (%)	Cross-sectional area (m^2)	Area difference (%)	Total discharge (m^3/s)	Discharge difference (%)
RSP	4,300	-21.6	32,000	+0.35	34,600	+3.0
BWDB	5,200	+17.8	31,900	-0.35	33,700	-2.8

Note :+ higher, - lower

Table 2.4: Comparison of joint measurements at Mawa, 20 to 22 October 1995

RSP measured a slightly higher discharge than BWDB did; however, the cross-sectional area was the same. It is remarkable that notwithstanding the significant difference in the cross-sectional width, the area of the cross-section was almost the same. The depths measured by BWDB at different verticals were plotted with the cross-sectional profiles measured by RSP.

For the right channel, the plot in Figure 2.12 can be compared with the iso-velocity lines and the iso-concentration lines based on the backscatter in Figure 2.13. The highest sediment concentration in that channel is near the right bank where the dunes are much higher than in the left part of the channel. The dunes disappear in the downstream direction as the depth of the channel increases (see the longitudinal profile with a length of 900 m, parallel to the main flow direction, in Figure 2.14). The flow velocity distribution over the cross-section is more regular, however, as in a prismatic channel.

For the left channel, similar information is presented in Figures 2.15 to 2.17. It is interesting to note the peak in the sediment concentration on the left side slope of the deepest part of the channel; the flow velocities have their peak values more in the center of the channel. The river bed is smooth, without dunes, but is maybe covered with ripples.

In the right channel, the differences between water depths measured by BWDB and RSP were small, 5 % on the average. But, at two verticals in the left channel (numbers 27 and 33), BWDB measured 1 to 2 m less depth than RSP. This is remarkable because in the left channel no dunes were found. This difference may have been caused by inaccuracies in the positioning of the survey vessels and their movements during the measurements. Figure 2.18 shows the movement of the survey vessel at three verticals, which was about 5 m in vertical 12, about 10 m in vertical 29, and more than 20 m in vertical 14. These movements, combined with the finite positioning accuracy, can explain the differences in vertical 27, which is on the edge of a rather steep slope. They are not, however, sufficient to explain the differences in the depth measured for vertical 33.

A comparison of flow velocity profiles at verticals 11, 12, 14, and 29 in Figures 2.19 and 2.20 shows that RSP measured 0.1 to 0.2 m/s higher velocities than BWDB. On the average, however, the difference in most verticals was only 1%.

The comparison of flow angle and flow velocity at 0.2 and 0.8 depths (see Annexure 1, Table A1.3) shows that the flow angles measured by BWDB and RSP differ by up to 15°. Since the transect itself makes an angle with the main flow direction, this difference in the flow angle causes a related variation in the flow components, and thus the flow velocity component perpendicular to the transect varies by 2 to 10%.

2.6 Survey at Bahadurabad, November 1995

Schedule of main activities

After presentation of the preliminary results of the joint measurement from July 1995, FPCO suggested to organize two additional comparative measurements, because one simultaneous measurement was hardly conclusive. One of these joint measurements was carried out at Bahadurabad. The schedule was as follows:

7 November 95: transect surveys and detailed measurements in 2 verticals;
8 November 95: transect surveys and measurements in 9 verticals.

The transect

The joint measurement was made in the left channel of Jamuna River, along the same BWDB transect as used in the July survey. The far left channel was divided into two channels by a mid channel bar along the BWDB transect.

Survey methods

RSP measured discharge twice in each channel along the transect using the ADCP-EMF moving boat method. After the completion of the transect survey, the RSP vessel followed the BWDB catamaran from which the velocity verticals were measured. BWDB used their routine method for this joint measurement.

Primary results

The water level in Bahadurabad fell gradually about 0.2 m during the survey period.

The primary results of the joint measurements are presented in Table 2.5. In the Bahadurabad Ghat channel, BWDB measured a greater width but a less cross-sectional area than RSP. The channel cross-section in Figure 2.20 shows that BWDB missed the deepest portion of the cross-sectional area, because velocity verticals were pre-selected without considering the cross-sectional profile. This is important because pre- and post-monsoon cross-sectional profiles are usually quite different in the Jamuna River. While the difference in discharge was not significant in Bahadurabad Ghat Channel, the discharge measured by RSP was about 12% less than BWDB measured in the Old Bahadurabad Channel. The difference in total discharge in the left channel was 570 m³/s; i.e., RSP measured 7.2% less discharge than BWDB.

	Width	Width	Area	Area	Discharge	Discharge
Bahadurabad Ghat Channel						
RSP	485	-21	2,980	+5.4	2,990	+2.0
BWDB	590	+17.3	2,820	-5.7	2,920	-2.1
Old Bahadurabad Channel						
RSP	720	-47.5	5350	-13.9	5,170	-12.5
BWDB	1060	+32.2	6090	+12.2	5,810	+11.1

Note : + higher, - lower

Table 2.5: Comparison of measurements in the left channel at Bahadurabad, November 1995

A few flow velocity profiles were compared, see the examples in Figure 2.22. These graphs illustrate that BWDB measured 3 to 37% higher flow velocities than RSP (see Annexure 1, Table A1.5 for details).

More extensive measurements were taken in verticals 1 and 2 in order to compare the flow velocities measured at different depths and by different instruments: S4 (RSP) and the Ott propeller current meter which was calibrated on 5 October 1995. The measurement with the Ott current meter was taken 6 times 50 s at each depth of the vertical. The S4 also averaged the flow velocity over 50 s. The results are presented in Table 2.6, in which s_u is the standard deviation of the flow velocity measured by S4 during 2 times 50 s. The differences between the average flow velocity are within the range of +2 s_u and -2 s_u. Therefore, it is concluded that no systematic difference in the average flow velocity can be detected from these measurements by either instrument if the S4 measures 100 s and the Ott current meter 300 s. The flow velocities were in the range of the low and mid flow conditions in the Jamuna River.

profile 1				profile 2			
depth	u_{Ott}	u_{S4}	s_u	Depth	u_{Ott}	u_{S4}	s_u
(m)	(m/s)	(m/s)	(m/s)		(m/s)	(m/s)	(m/s)
2	0.683	0.70	0.075	1.7	1.372	1.46	0.20
4	0.653	0.725	0.075	3.4	1.34	1.40	0.105
6	0.678	0.755	0.05	5.1	1.275	1.29	0.095
8	0.672	0.795	0.06	6.8	1.113	1.15	0.095
bottom	0.653	0.665	0.065	bottom	0.923	0.92	0.125

Table 2.6: Comparison between Ott and S4 current meter registrations, Bahadurabad, November 1995

3 Analysis

In the analysis of the joint measurements, some statistical parameters were used to characterize the differences between the measured variables. For a general introduction on applied statistics in the field of hydrology see for example Ven Te Chow et al. (1988). The expected value of a variable x is the mean E(x) which is the first moment about the origin of the variable x. The sample estimate of the mean is the average $\bar{x}$ of the sample data. The variability of data, for example differences between two measurements, is measured by the variance σ^2, which is the second moment about the mean. The sample estimate of the variance is given as:

$$s^2 = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad (3.1)$$

The standard deviation is the square root of the variance. If the spread in the data increases then the standard deviation increases as well.

In this analysis the discharge is calculated as:

$$Q = B \,.\, h \,.\, \bar{v} \,.\, \sin\alpha \qquad (3.2)$$

The discharge measured by BWDB and by RSP are both calculated by this formula. The ratio of both reads as follows:

$$\frac{Q_{BWDB}}{Q_{RSP}} = \frac{B_{BWDB}}{B_{RSP}} \,.\, \frac{h_{BWDB}}{h_{RSP}} \,.\, \frac{\overline{v_{BWDB}}}{\overline{v_{RSP}}} \,.\, \frac{\sin\alpha_{BWDB}}{\sin\alpha_{RSP}} \qquad (3.3)$$

Formula (3.3) is rewritten as:

$$R_Q = R_B \, . \, R_h \, . \, R_{\bar{v}} \, . \, R_{\sin\alpha} \tag{3.4}$$

where,
R_x = ratio of parameter x measured by BWDB over parameter x measured by RSP.

The variance of the parameters in formula (3.4) can be calculated as:

$$s_{R_Q}^{\;2} = [\frac{\delta f}{\delta R_B}]^2 \, . \, s_{R_B}^{\;2} + [\frac{\delta f}{\delta R_h}]^2 \, . \, s_{R_h}^{\;2} + [\frac{\delta f}{\delta R_{\bar{v}}}]^2 \, . \, s_{R_{\bar{v}}}^{\;2} + [\frac{\delta f}{\delta R_{\sin\alpha}}]^2 \, . \, s_{R_{\sin\alpha}}^2 \tag{3.5}$$

This formula can be simplified by dividing it by formula (3.2):

$$\frac{s_{R_Q}^{\;2}}{R_Q^2} = \frac{s_{R_B}^2}{R_B^2} + \frac{s_{R_h}^{\;2}}{R_h^2} + \frac{s_{R_{\bar{v}}}^2}{R_{\bar{v}}^2} + \frac{s_{R_{\sin\alpha}}^2}{R_{\sin\alpha}^{\;2}} \tag{3.6}$$

The parameters on the right hand side of this formula were estimated from the measurements to calculate their contribution to the variance in the discharge. This simplified approach does not distinguish between systematic and random errors, operational and instrument errors, or the individual conditions in each joint measurement. The approach is only meant to give a preliminary idea about the relation between the measurement inaccuracies of different parameters. The results of the analysis of the accuracies of the different parameters in the joint surveys are presented in Table 3.1. The accuracy of the discharge was calculated from the parameters by applying formula (3.6) (see the results in Table 3.2).

R_Q	$S_{R_Q}^{\;2}$	R_h	$S_{R_h}^{\;2}$	R_v	$S_{R_V}^{\;2}$	$R_{\sin\alpha}$	$S_{R_{\sin\alpha}}^2$
July, Bahadurabad, Jamuna River							
Ghat 1.03	0.02	0.969	0.0086	1.046	0.0049	0.947	0.0040
Ful 1.15	0.07	0.993	0.035	1.075	0.014	1.077	0.0071
October, Mawa, Padma River							
1.08	0.012	0.947	0.003	0.996	0.0048	1.023	0.0023
November, Bahadurabad, Jamuna River							
1.10	0.02	0.971	0.013	1.121	0.007	1.011	0.0035
1.03 to 1.15	0.01 to 0.07	0.95 to 0.99	0.003 to 0.035	1.00 to 1.12	0.005 to 0.014	0.95 to 1.08	0.002 to 0.007

Table 3.1: Statistical parameters in various joint surveys

The measured and calculated ratio of the discharges measured by BWDB and RSP, including an estimation for the variance or standard variation, shows that the calculated ratio is about 3 to 9% higher than the observed ratio. This falls within the range of the average value + or - 3 σ.

Survey	$R_{Q,\ observed}$	$R_{Q,\ calculated}$	Standard deviation
Bahadurabad, July, (*** Fulchari Channel	1.06	1.15	0.07
Bahadurabad, July (** Bahadurabad Ghat Channel	0.96	1.03	0.02
Mawa, October (*	0.97	1.08	0.03
Bahadurabad, November Bahadurabad Ghat Channel	1.07	1.10	0.03

(* tidal influence, (** time lapse and positioning, (*** few verticals

Table 3.2: Observed and calculated accuracies of the discharge

The influence of the measurement of the width is not included in the above table.

In general, the following conclusions can be drawn on the comparison between the BWDB and the RSP measurements:

- BWDB measured on the average a higher discharge than RSP, varying from -3 to + 13 %;
- the BWDB measurements relative to the RSP measurements showed the following tendencies:
  the depth in a vertical was measured 1 to 5% less,
  the flow velocities were measured 0 to 12% higher,
  the flow direction was measured 5% lower or higher;
- the differences in the measured channel width were often small, but in some cases significant differences were found.

The differences in these parameters can explain the differences in the measured discharges. The results are further discussed in the next chapter.

4 Discussion of survey methods to measure the discharge

4.1 Introduction

BWDB and RSP used different methods and equipment for their discharge measurements. Several aspects of survey methods, i.e., anchoring, positioning of the survey vessel, depth measurement, positioning of the flow meter, and measurement of the flow velocity and direction, will be discussed in this chapter to explain the differences found in the main hydrodynamic parameters.

Differences can result from the instruments (especially the measuring method, and the operation and maintenance of the instruments), the measuring procedures, and the data processing. The standard method applied by BWDB for the data processing is a sound method. The measuring procedures and the instruments are discussed in the following sections.

4.2 Anchoring or dynamic positioning

The BWDB used the velocity-area method for the discharge measurements by taking point-integrated velocity measurements at 2 points per vertical. During these measurements, the catamaran-type survey boat did not anchor, but tried to remain on the same spot by using the outboard-engines. During the joint measurements, the catamaran anchored for a special measurement at RSP's request; however, it lost the anchor when it tried to weigh it. This showed that the existing equipment of the catamaran is not sufficient for anchoring longer than about 0.5 hour in the main rivers during mid and high flow conditions when the bedforms migrate actively on the river bed.

RSP's discharge measurements were taken in the main channels using the moving boat method with a combination of ADCP and EMF. In the smaller channels, RSP used a Valeport current meter for the velocity-area method. For the near bed measurements, an instrument needed to be placed on the river bed which required anchoring. The accuracy of anchoring a survey vessel using DGPS is about 20 m given favourable conditions. A disadvantage of anchoring, however, is the swaying of the vessel in mid and high flow conditions; the vessel can easily move 40 m in all directions (see an example in Figure 2.6). The movements of the anchored vessel can be reduced by a second anchor at the stern of the vessel; however, this increases the time needed for the measurements considerably. Anchoring is recommended for detailed measurements near the river bed which take more than 0.5 hour. Beyond 0.5 hour, it becomes increasingly difficult for the helmsman to be highly attentive, and the risk that the engines will stop suddenly increases.

During the joint measurements in Mawa on 21 October 1995, the DHA vessel made 21 vertical measurements in dynamic mode in 4.5 hours (this means about 13 minutes per vertical). The procedure worked quite well in the mid flow conditions.

4.3 Positioning of the survey vessel in a transect

The position of the BWDB catamaran along a pre-selected transect with pre-selected verticals was determined in the field by using a sailing line along the transect (indicated by poles 2 and 3) and one sextant taking the angle between vessel and poles 1 and 2 (see Figure I). If serious bank erosion occurs in the transect line during the period between selecting the verticals and the survey, then the position of the verticals near the eroding bank can be less than optimal. If the channel is deep in front of the eroding bank, the cross-sectional area will become underestimated.

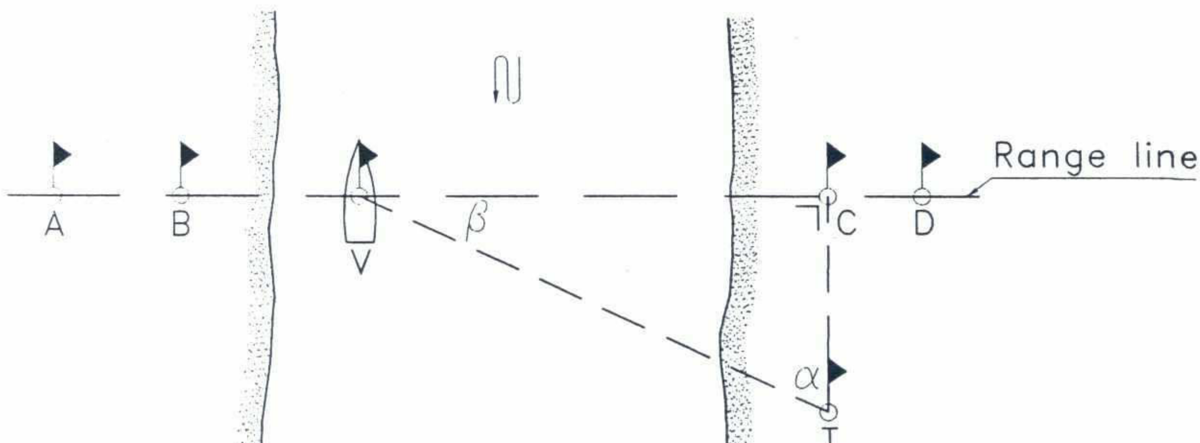

Figure I: Positioning by sextant

The distance between the vessel and pole 2 can be calculated by knowing the distance between poles 1 and 2 and measuring the angle α. In the sextant method, the distance between poles 2 and 3 should be sufficiently large, and the angle should not be too small. Moreover, the visibility of the poles from the survey vessel becomes critical in wide rivers (e.g., in the Padma River near Mawa where the channel is 4 to 5 km wide). Rain can reduce the visibility of the markers considerably and thus increase the inaccuracy of the survey. The skill of the engine driver should be sufficient to maintain the same position in a highly variable flow. The time needed for a reading of the sextant should be as short as possible to maintain sufficient accuracy. This seems to be difficult in high flow conditions, even though the catamaran is a very stable, easy to handle survey vessel.

The positions of the verticals along the fixed transect line were pre-selected before the monsoon started. These positions were determined by the rule that the discharge between two adjacent verticals should be within 10% of the total channel discharge. During the monsoon, cross-sectional profiles can change considerably in a few weeks time; the pre-selected verticals can form an improper distribution of cross-sectional profiles in the actual channel cross-section. This can induce errors in the measured cross-sectional area due to the interpolation of the depth between the verticals (see for example the cross-section in Figure 2.15).

RSP determined the position of the vessel by using DGPS. On the DHA vessel, every few seconds the helmsman get information on the position of the vessel relative to the predetermined survey line. (For details, see RSP 1° Interim Report, 1993). The accuracy of this system is usually better than 5 m. The number of readable satellites, the quality of the signal from the reference station, and the atmospheric conditions are important for the DGPS positioning accuracy.

4.4 Depth measurement

BWDB measured the depth using a winch counter for the wire length of the current meter. The wire angles above the water surface were usually not measured; however, the standard measuring form had a column for these angles.

In many verticals the accuracy of this method seemed sufficient for measuring the depth. But sometimes (e.g., in vertical 33 in the left channel in Mawa), the measured depth was about 2 m less than what was measured by RSP. No explanation was found for this irregular difference. In the joint survey in Bahadurabad in July, the differences in the measured water depth in the verticals were probably due to the presence of bedforms, such as dunes, in combination with a major inaccuracy in the positioning of the verticals (because RSP had not defined the transect line with sufficient accuracy).

Figure II illustrates how the drag forces on the instrument and the suspension cable in the main channels with greater depths can increase the relative error in the measurement of the water depth in high flow conditions.

A comparison of RSP's depth measurements using ADCP and echosounder showed that they were identical and reliable (see Test Gauging Report, RSP, 1993). The echosounder and the ADCP at DHA vessel measured slightly different depths (less than the bedform heights) because the transducers were placed several meters apart from each other.

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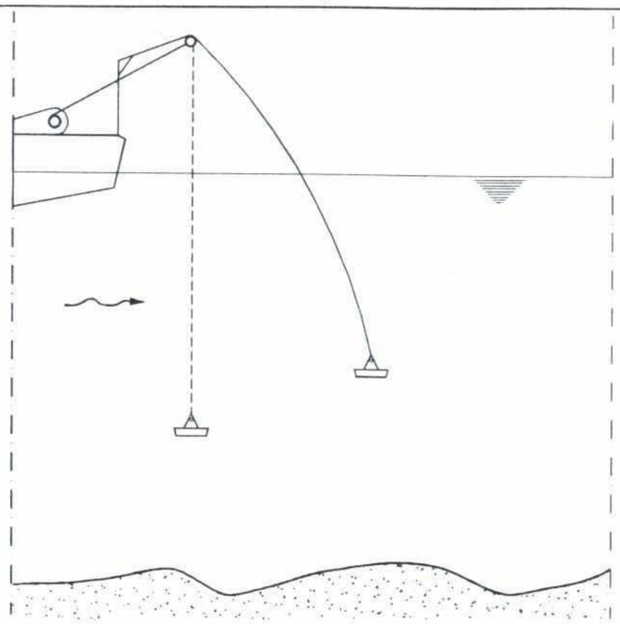

Figure II : Wire length versus depth

4.5 Vertical control of the current meter

After measuring the water depth aboard the BWDB catamaran, the required instrument level was calculated (0.8 h and 0.2 h) and the wire length was adjusted accordingly, using the winch counter.

RSP's ADCP transducers were installed flush with the underside of the survey vessels; i.e., they were installed at an almost fixed level relative to the water level. The draught of the survey vessel varied only slightly, mainly depending on the level in the fuel tank. The EMF was installed in front of the bow of the DHA at a depth of 0.5 m. This means that the EMF followed all the motions of the bow (e.g., due to waves). The S4 current meter was lowered from a suspension cable on a winch. The accuracy of the winch was estimated at 0.1 to 0.2 m. The depth of that instrument was measured accurately with a pressure cell.

The accuracy of the position of the BWDB current meter in a vertical was similar to the accuracy of the water depth measurements (see Section 4.4). This means that the accuracy was sufficient in most verticals.

4.6 Flow velocity

In principle, the flow velocities (when measured at a fixed point during a sufficiently long period) can deviate slightly between different instruments using different measuring principles: Ott or SEBA propeller current meters; ADCP; or EMF or S4 electromagnetic current meters. The main differences may be due to the type of current meter, the natural temporal variability of the flow (which is measured differently by these types of instruments), the different sampling periods, and the calibration of the current meter. For details see RSP Special Report 11, Optimization of hydraulic measurements, 1996.

Inter-calibration tests of ADCP, S4, and Ott during the RSP test gauging programme showed that the Ott current meter measured higher flow velocities than the other instruments (see the RSP Test gauging report). In the joint measurements, the flow velocities were measured 0 to 12% higher by the Ott or SEBA propeller current meters as compared with RSP measurements. For further discussion on the issue, please consult *RSP Special Report 11*. The relatively wide variation in the difference within one joint survey indicates the importance of proper maintenance of the instruments, including regular calibrations of the propeller meters.

Type of current meter	BWDB	RSP
SEBA, Ott propeller current meters	100 s	50 or 100 s
ADCP acoustic /EMF electromagnetic current meter	-	5 to 6 s
S4 electromagnetic current meter	-	100 s

Table 4.1: Standard sampling periods of different types of current meters

A comparison of Ott, ADCP, and Seba reveals that Seba and Ott measured a higher velocity than the ADCP. In 1991, Lee Gorden took some comparison measurements of discharge by ADCP and Ott in the Rhine River in Germany and Holland. He found that the ADCP moving boat method gave 10% less discharge than the Ott velocity-area method; he found no difference in the area. Jepson (1965) showed that Ott current meters, which are calibrated in steady flow conditions, over-registered the flow when the velocities fluctuate (e.g., in a river). BWDB's use of an old Ott current meter at Mawa may account for a relatively lower flow velocity because it is common for an old Ott to register a slightly lower flow velocity.

4.7 Flow direction

In general, BWDB used a non-directional current meter for flow velocity measurements. The flow angle was measured with a sextant between the surface float and the markers of the transect line. A surface float was used to indicate the flow direction, which was applied at 0.2 and 0.8 depths, and to calculate the flow component perpendicular to the transect line.

The vector plots based on ADCP measurements show that in general, the vertical variation of the flow angle is small. For example see the vector plot of the left channel near Bahadurabad in Figure III. Flow angle variations in a vertical can be found only at some very local places in the cross-section; i.e., mainly at the boundaries between the sub-channels of the cross-section. Since the variations of the flow direction along the vertical are only local phenomena, the effect on the total discharge can be assumed to be negligibly small.

Another important consideration is the influence of the accuracy of the flow angle measurement. An individual measurement of the flow direction is probably not accurate, but the average flow direction shows less variation than the individual values. An error in the measurement of this angle has a significant influence on the flow component perpendicular to the transect line, especially when the transect line is oblique to the main flow direction. This error increases in case of increasing oblique flow.

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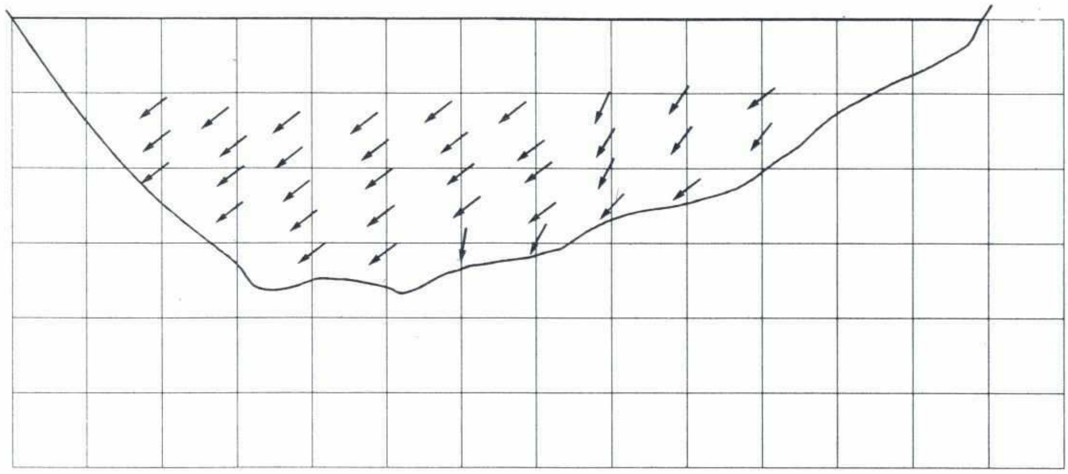

Figure III: Vector plot of flow distribution, Bahadurabad, Left Channel (example)

A surface float is sensitive to wave action and wind, especially if the wind direction is oblique to the flow direction. Therefore, it is recommended to use a submerged float in the shape of a cross, made of aluminum or cotton, with a small flag above the water surface.

4.8 Spatial variability of the flow velocity in a transect

The horizontal variation of the flow in magnitude and direction can be considerable depending on the bathymetry of the channel and the flow conditions (see Annexure 1). In the joint measurements, for example, the flow velocities ranged from 0.5 to 2.0 m/s and the flow angles ranged from 20 to 120°. Therefore, an adequate horizontal distribution of measuring verticals was required to cover the variations appropriately (see Table 4.2). The relatively high number of verticals, as measured by BWDB, seemed appropriate for covering the horizontal variations.

Channel	Number of verticals	Width (m)	Average distance (m)
Fulchari channel	37	2871	78
Bahadurabad Ghat channel	25	2153	86

Table 4.2: Example of the distance of BWDB verticals in the Bahadurabad transect

RSP measured the discharge by the ADCP moving boat method. The ADCP measured a high number of flow velocity profiles, recording a vertical every second. Depending on the sailing speed this corresponds to a distance of 1-2 m between the verticals. The verticals were subsequently averaged over 25 to 50 m in order to eliminate the influence of the turbulence in the flow.

In a vertical, the measurements started at a certain distance below the draught of the survey vessel, depending on the transducer depth and the instrument frequency. The ADCP took no measurements in a top layer of the cross-section with a thickness of 1.0 or 1.5 m + the draught of the vessel. Below the top layer, the vertical was divided into increments, called bins. The bin height depended on the frequency of the ADCP. The average velocity was measured over each bin height. No measurements were taken in the lowest 5% of the water column; this was a function of the transducer angles. The characteristics of the two types of ADCP used by RSP are summarized in Table 4.3. The 300 kHz ADCP on the DHA vessel was used in most of the joint surveys; only the Hardinge Bridge survey was done with the DHB vessel.

	Type of ADCP	
	300 KHz	600 KHz
Vessel	DHA	DHB
Transducer depth	1.2 m	0.8 m
Unmeasured top layer	2.7 m	1.8 m
Bin height	0.5 m	0.25 m
Transducer angle	20 deg	20 deg
Unmeasured bottom layer	5 %	5 %

Table 4.3: Characteristics of the ADCPs used by RSP

In the top layer, where the ADCP did not take measurements, the flow velocity was measured by an electro-magnetic flow meter (EMF) mounted at a fixed depth (0.5 m below the water surface if all the tanks of the DHA vessel were full) in front of the bow of the DHA vessel.

Near a shallow bank, the DHA vessel could not sail close to the bankline because of the draught of the vessel. Usually the transects were not measured until the very point of grounding; the safe minimum water depth was taken as about two times the minimal navigational depth, depending on the flow and the weather conditions. At each end of each line, the distance to the water line was estimated, in order to assess the discharge through the unmeasured zone. In these shallow areas of the cross-sections, RSP applied the DHE survey vessel with the traditional velocity-area method with a Valeport propeller current meter. In each vertical, the flow velocity was measured at two depths, at the water surface and about 1 m below the water surface.

The draught of the BWDB catamaran was considered so shallow that the unmeasured zone was neglected.

Recommendations

- The water depth should be measured more accurately, for example by repeated measurements;
- The instruments for measuring flow velocities should be well maintained, and regular calibration curves should be prepared;
- The measurement of the flow direction should be improved, for example by a submerged drogue.

5 Comparison of sediment transport measurements

5.1 Introduction

During the joint measurements, sediment transport measurements were made at the BWDB transects at Bahadurabad and Mawa in July and October 1995, respectively. Bahadurabad is BWDB's only discharge and sediment gauging station in Jamuna River. The data are used for different planning and design purposes, and it is important to optimize the gauging technique as well as the reliability of the data.

The sediment concentration and suspended sediment transport measured by BWDB and RSP in individual verticals were compared for both locations (Sections 5.2 and 5.3). The analysis of these measurements was extended with an analysis of the routine gaugings to generalize the conclusions of the joint surveys (Section 5.4). Possible reasons for discrepancies between BWDB and RSP results are given.

5.2 Survey at Bahadurabad, July 95

In the joint measurement near Bahadurabad, BWDB used their routine methods to take the suspended sediment measurements. BWDB measured in a total of 64 predefined verticals in all the channels intersected by the BWDB transect. Sediment samples and flow velocity measurements were made simultaneously in a vertical at 0.2 and 0.8 of the water depth in the vertical by a Binckley silt sampler and a SEBA propeller current meter, respectively. The sediment samples were taken in the alternate verticals; the flow velocities were measured in every vertical.

During the survey, the DHA vessel started to follow the BWDB catamaran from which the verticals were measured. RSP measured suspended sediment concentration and flow velocity simultaneously by ADCP and by pump-bottle sampling at depths of 0.2 and 0.8 on BWDB verticals. RSP needed more time to measure a vertical than BWDB because RSP took the measurements from an anchored vessel, while the BWDB catamaran was kept in position by dynamic control.

The flow velocity ranged from 0.9 to 2.76 m/s in the verticals of the transect. The comparison of the sediment measurements in a few selected verticals (Annexure 1, Table A1.2) shows that BWDB measured remarkably less concentration of the sand fraction than RSP at both 0.2 and 0.8 depths. This difference between pump-bottle samples and Binckley silt sampler increased with higher flow velocities (see Figure 5.1 for measurements at 0.8 depth and Figure 5.2 for measurements at 0.2 depth). At 0.8 depth, this difference increases strongly if $u >$ about 2 m/s, while at 0.2 depth, this difference increases gradually with increasing flow velocities.

The suspended sand transport in those selected verticals, as a function of the flow velocity, shows the same tendency (see Figure 5.3). There was a good agreement amongst the six verticals in the Fulchari and the Old Bahadurabad Channels where flow velocity was relatively low. In the other five verticals in the Bahadurabad Ghat Channel, where flow velocities were high (exceeding 2 m/s), the difference was significant (see Annexure 1, Table A1.2).

The measured sediment concentrations of silt and clay (fine fraction) at 0.2 and 0.8 depths did not show significant differences between the different instruments. The concentrations at 0.8 depth were much higher than at 0.2 depth.

The deflection angle of the Binckley sampler supporting cable was measured a few times. The angle in the high flow verticals ranged from 30 to 45° at 0.2 depth, and from 40 to 60° at 0.8 depth.

5.3 Survey at Mawa, October 95

In the joint measurement in Padma River near Mawa in October 1995, RSP measured sediment concentration using the depth-integrating bottle sampler (taking 2 liter samples), and the flow velocity by ADCP, in the predefined BWDB verticals. In this way the measuring time per vertical was reduced. The DHA vessel followed the BWDB catamaran rather closely, keeping the time between the BWDB measurement and the RSP measurement of a vertical short; this helped to avoid a tidal influence on the comparison of measurements.

BWDB used a Binckley silt sampler and an Ott current meter for these measurements.

The average flow velocity measured by the Ott current meter and by ADCP in some selected verticals (8 verticals in the right channel and 4 verticals in the left channel) did not differ significantly (only 3 %).

The comparison of the sediment concentration in these selected verticals (shown in Table A1.4) shows that in most of these verticals, the depth integrating bottle measured a lower sand concentration than the Binckley silt sampler (see Figure 5.4). This difference could be due to the different measurement principles of the applied instruments. In RSP Special Report 12: 'Optimization of sediment measurements' it is described that the depth integrating sampler measured the silt and clay fraction with a sufficient accuracy, but underestimated the sand fraction. It is important to note that the flow velocities in those verticals were less than 2 m/s, and that no tendency of increasing differences between the measurements was seen in the graph in Figure 5.4.

The vertical angle of the suspension cable of the Binckley silt sampler ranged from 8 to 12° in those measurements. This small angle will not induce a significant deviation in the measured sediment concentration. This is in line with the absence of a tendency of increasing differences in the graph in Figure 5.4.

The comparison of the sand transport by the Binckley silt sampler and the depth integrating sampler in some selected verticals shows that the depth integrating sampler measured less sediment transport than the Binckley silt sampler, with the exception of verticals 1 and 27 (Figure 5.5).

5.4 Routine gaugings at Bahadurabad, 1994-1995

5.4.1 Introduction

BWDB carries out regular sediment transport measurements in the main rivers of Bangladesh. The weekly sediment transport measurements by BWDB at Bahadurabad were compared with the sediment transport measurements in the reference vertical in the routine gaugings by RSP in the same area.

The analysis of the joint BWDB/RSP surveys showed that the Binckley silt sampler measured suspended sand concentrations which were too low if the flow velocity exceeded 2 m/s. This comparison of routine gaugings was made to confirm the result of the joint sediment transport measurements.

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5.4.2 Data used

BWDB measured in a standard transect north of Bahadurabad Ghat. By their standard procedure, the sediment concentration was measured at 0.2 and 0.8 depth in each vertical. First, the water depth was measured. The concentration of fine and coarse sediment was measured with a Binckley silt sampler. In the analysis, only the concentration of coarse sediment (with $D_{50} > 0.063$ mm) was determined. These measurements were done without anchoring (dynamic positioning).

RSP performed routine gauging in different transects a few kilometers downstream and upstream of the standard BWDB transect. The sediment concentration was measured by pump-bottle system (point integrated). The flow velocity was measured with an electro-magnetic flow meter (S4 type). In general, 3 to 6 points were selected in a vertical depending on the local water depth of that vertical. These measurements were taken while the survey vessel was anchored.

The following two comparisons were made:

- BWDB and RSP measurements at Bahadurabad in 1994 and 1995 were compared;
- to observe any trends in the BWDB data at Bahadurabad, measurements from 1994 and 1995 were compared with those from 1984 to 1987.

5.4.3 Data analysis

The measured suspended sediment transport per unit width (q_s) is calculated from the measured sediment concentration, the depth averaged flow velocity, and the water depth of the vertical. This was done for both the BWDB and the RSP data. The comparison was based on the relationship between the dimensionless shear-stress parameter, or Shields parameter (θ) and the dimensionless sediment transport parameter (ψ). The Shields parameter (θ) and the sediment transport parameter (ψ) are defined as follows:

$$\theta = \frac{h \cdot i}{\Delta \cdot D_{50}} = \frac{u^2}{C^2 \cdot \Delta \cdot D_{50}} \qquad (5.1)$$

and

$$\psi = \frac{q_s}{\sqrt{g \cdot \Delta \cdot D_{50}^3}} \qquad (5.2)$$

where,

h = the water depth (m),
i = the water surface slope (-),
Δ = the relative density (-),
D_{50} = the median particle diameter (m),
u = the depth averaged flow velocity (m/s),
C = the Chezy roughness coefficient ($m^{0.5}/s$),
g = the gravity acceleration (m/s^2).

The water surface slope should be the local water level slope at the considered vertical, but this parameter was not measured. Only a rough estimate for the overall water level slope over a large distance was available. Also, the Chezy coefficient could not be measured directly, but was estimated from the empirical White-Colebrook formula or the Chezy equation.

To assess the sensitivity of the comparison, different combinations of the Chezy coefficient were selected (see Table 5.1). The computation of the Shields parameter (θ) was based on the assumed Chezy roughness values presented in Table 5.1.

Assumption	June to September C ($m^{0.5}/s$)	October to May C ($m^{0.5}/s$)
1	85	50
2	70	50
3	65	65

Table 5.1: Selected combinations of Chezy values

All sediment samples from RSP and BWDB for the period of 1994-1995 were plotted in a graph relating the Shields parameter and sediment transport; Chezy roughness values of 70 and 50 were selected for June to September, and for October to May, respectively (see Figure 5.6). The similar comparisons for the other two selected combinations of Chezy values are presented in Figures 5.7 and 5.8. These graphs show that in the monsoon period, the sediment transport measured by BWDB was up to 10 times less than the sediment transport measured by RSP. In the lean period, BWDB measured the same sediment transport of the sand fraction as RSP. This confirmed the results of the joint sediment transport measurements. This confirmation is not sensitive to the selected Chezy coefficients.

To complete the analysis, the regression lines were also fitted to the data points (see Table 5.2):

$$\psi = A \cdot \Theta^{B} \tag{5.3}$$

in which A and B are coefficients (-).

Chezy coefficient combination	BWDB		RSP	
	A	B	A	B
85 / 50	28	1.09	123	1.63
70 / 50	20	1.14	79	1.82
65 / 65	19	1.15	86	1.76

Table 5.2 Regression coefficients in sediment transport formula

A comparison with the Engelund-Hansen sediment transport formula has been included in Figures 5.5 to 5.7. The comparison shows that the observed transport of sediment with grain size D_{50} > 0.063 mm in Jamuna River is higher than calculated with this formula. The Engelund-Hansen sediment transport formula was calibrated for sediments with D_{50} > 0.190 mm. In the Jamuna River, an important part of the particles have diameters > 0.063 mm and < 0.190 mm. Further, the overall water level slope was used while the local water level slope can be much higher than the overall water level slope. These aspects explain why higher sediment transports were measured in the Jamuna River.

To investigate if this underestimation of the sediment transport in the BWDB data was limited to the 1994-1995 period, the sediment transport data measured in the period 1984-1987 were compared with the 1994-1995 sediment transport data in a separate graph in Figure 5.9. This figure shows that the 1984-1987 data were slightly higher (about 2 times higher) than the 1994-95 sediment transport data. This is still less, however, than the factor 10 as compared with the RSP sediment data. This means that this underestimation of the sediment transport during the monsoon probably existed over a much longer period than 1994-1995.

The most probable explanation of the underestimation of the sediment transport by BWDB during the monsoon period is the large deflection angle of the Binckley silt sampler supporting cable in high flow velocities. This means that the sample was taken in a higher position in the vertical than 0.8 h. Some improvement in estimating the sediment transport can be obtained by further lowering the suspension cable, so that the sample can be taken from the right position in the vertical. Also, the positioning of the sampler itself in the flow may be less optimal in high flow conditions; however, the joint measurements did not provide information about this.

The Binckley silt sampler was selected and introduced by the Food and Agriculture Organization of the United Nations (1969). In their report, the following field technique for collection of sediment samples was recommended:

> *'When velocities are relatively low, sediment samples should be taken from a launch or catamaran while at anchor, or while holding position on the transit line, by lowering the sampler to the depth required. After closing the sampler and entrapping a quantity of water and suspended sediment, the instrument should be raised to the surface, opened, and emptied into an elutriator, thus separating the coarse sand fraction.*
>
> *Since the instrument is neither heavy nor stream-lined, at relatively high velocities it was necessary to develop a special sampling technique to avoid the occurrence of excessively large drag angles. To reduce these large drag angles, the drifting technique was employed, whereby the gauging craft was taken to a point a short way upstream of the transit line. Here the speed was reduced with the craft heading upstream, and the instrument was lowered to the required depth. The craft was then allowed to drift slowly backwards across the transit line when the sampler was closed. In this way the drag angle on the sample suspension cable was reduced to nearly zero. This method made it possible to obtain samples without loading the sampler with heavy weights which damage the instrument.'*

The report also mentioned that the main advantage of this instrument is that it can be used under the most extreme conditions if the right technique is adopted. Unfortunately, this drifting-technique was probably not applied in the joint measurements; instead, the dynamic positioning technique was used. This technique is right for the flow velocity measurements, but less suitable for the sediment transport measurements in high flow. It is recommended to organize a joint measurement which uses the right technique for the Binckley silt sampler.

The survey team may have been confused about when 'relatively high velocities' start to change the field technique from anchoring or dynamic positioning to drifting. Based on the results of the survey in Bahadurabad in July 1995, it is proposed that "relatively high velocities" be defined as $u > 2$ m/s; this definition can be used as a clear criteria to change the field technique.

5.4.4 Conclusions

1 The weekly sediment transport data measured by the BWDB in Bahadurabad underestimated the sediment transport in the monsoon compared with the RSP sediment transport data. The difference between the transects used by BWDB and RSP can not explain this difference in sediment transport measurements.

2 In the lean season, the sediment transport data measured by BWDB were very close to the sediment transport data measured by RSP.

3 The tendency to underestimate the sediment transport during the monsoon probably existed for a longer period, at least up to 10 years.

6 Conclusions and recommendations

The following conclusions can be drawn on the discharge measurements:

- On average, BWDB measured a higher discharge than RSP, varying from -3 to +13 %, because of differences in the measurement of the channel width, cross-sectional area, flow velocities, and flow direction.

- The comparison of BWDB measurements with RSP measurements showed the following tendencies:

  - the depth at the vertical was measured 1 to 5% lower,
  - the flow velocities were measured 0 to 12% higher,
  - the angle of the flow direction was measured 5% lower or higher.

- The measuring method for the width of a cross-section resulted in some significant differences (up to 25%) as compared with the RSP measurements.

- The maximum distance over which markers on the bank were visible seemed to be about 2 km under normal weather conditions.

- The basic principles of the measurement and the data processing applied by BWDB were based on ISO standards.

The following conclusions can be drawn on the sediment transport measurements:

- If the flow velocities were less than 2 m/s, the Binckley silt sampler measured the concentration of the sand fraction with a sufficient accuracy.

- If the flow velocities were above 2 m/s, the Binckley silt sampler did not measure the concentration of the sand fraction with sufficient accuracy, most probably because of the applied field technique.

- It is proposed that "relatively high velocities" be defined as $u > 2$ m/s. This definition can be used as a clear criteria to change the field technique from dynamic positioning of the survey vessel to a drifting survey vessel while taking samples with the Binckley silt sampler.

Recommendations

- The positioning system can be improved by using DGPS positioning. This will improve the accuracy of the width measurement, and help select the transect in each survey perpendicular to the main flow direction. This will in turn reduce the influence of errors in the measured flow direction on the total discharge in the channel.
- An echosounder can improve the accuracy of the measurement of the channel cross-sectional area.
- The Ott current meter should be regularly maintained, checked and calibrated.
- The registration of the flow direction should be improved, for example by using submerged floats.
- Near an eroding bank, it should be checked whether one or more extra verticals need to be measured in addition to the predefined verticals in the transect line.
- The mouth of the Binckley silt sampler should face the current. For measurements in high flow velocities, it is recommended that the orientation of the mouth and the stability of the sampler relative to the approach flow be checked.
- A small sinker should be attached to the Binckley silt sampler to improve its stability and its orientation. In turn, the winch and cable for the suspension of the sampler should be improved.
- The BWDB catamaran should be upgraded with stronger anchoring equipment.

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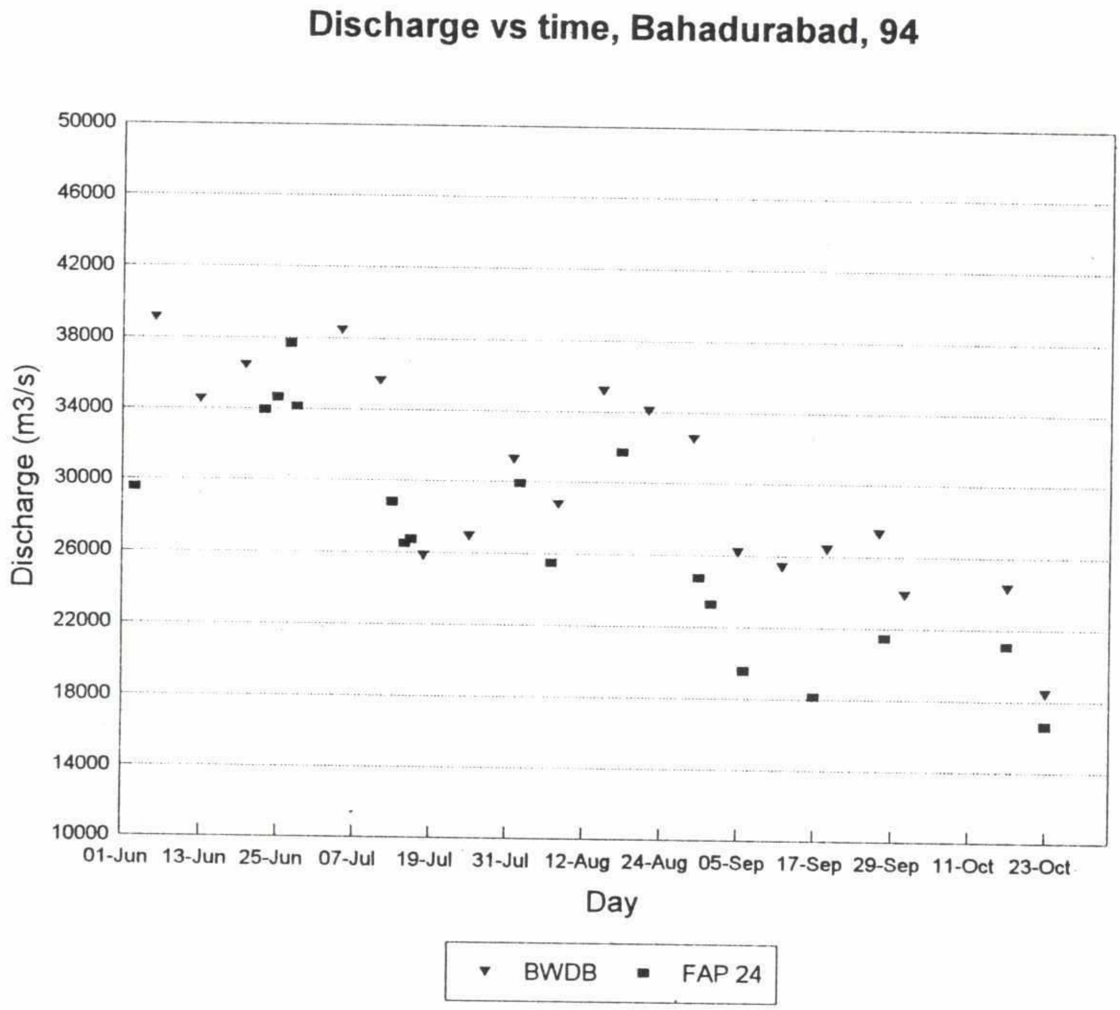

Figure 2.1: Flow gauging by BWDB and RSP at Bahadurabad, flood season 1994

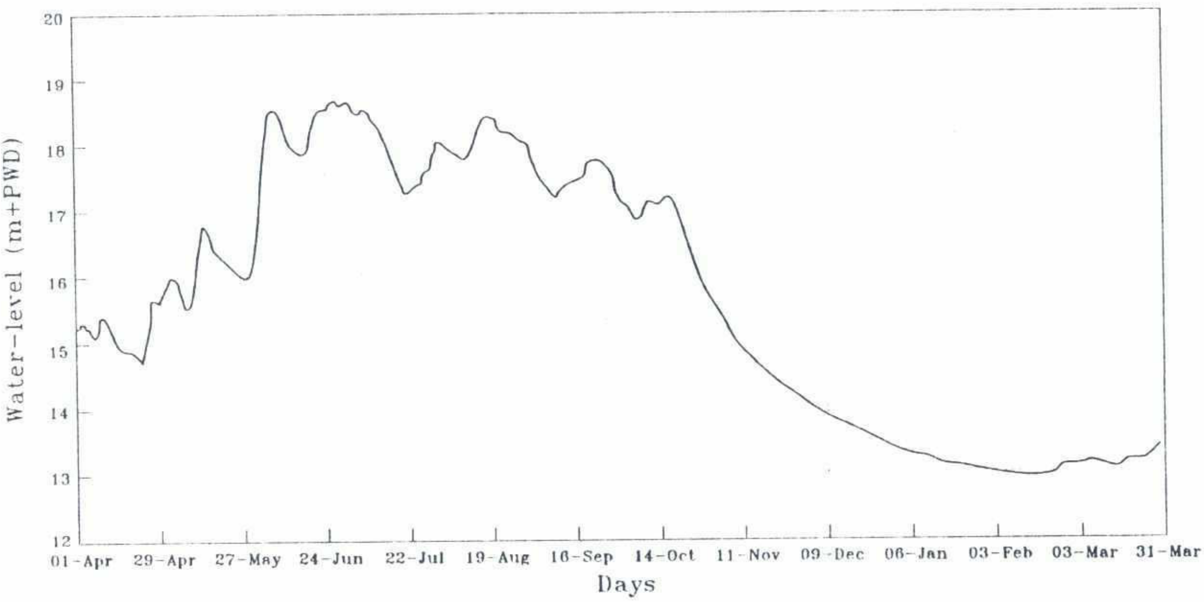

Figure 2.2: Hydrograph, Bahadurabad, hydrological year 1994/95

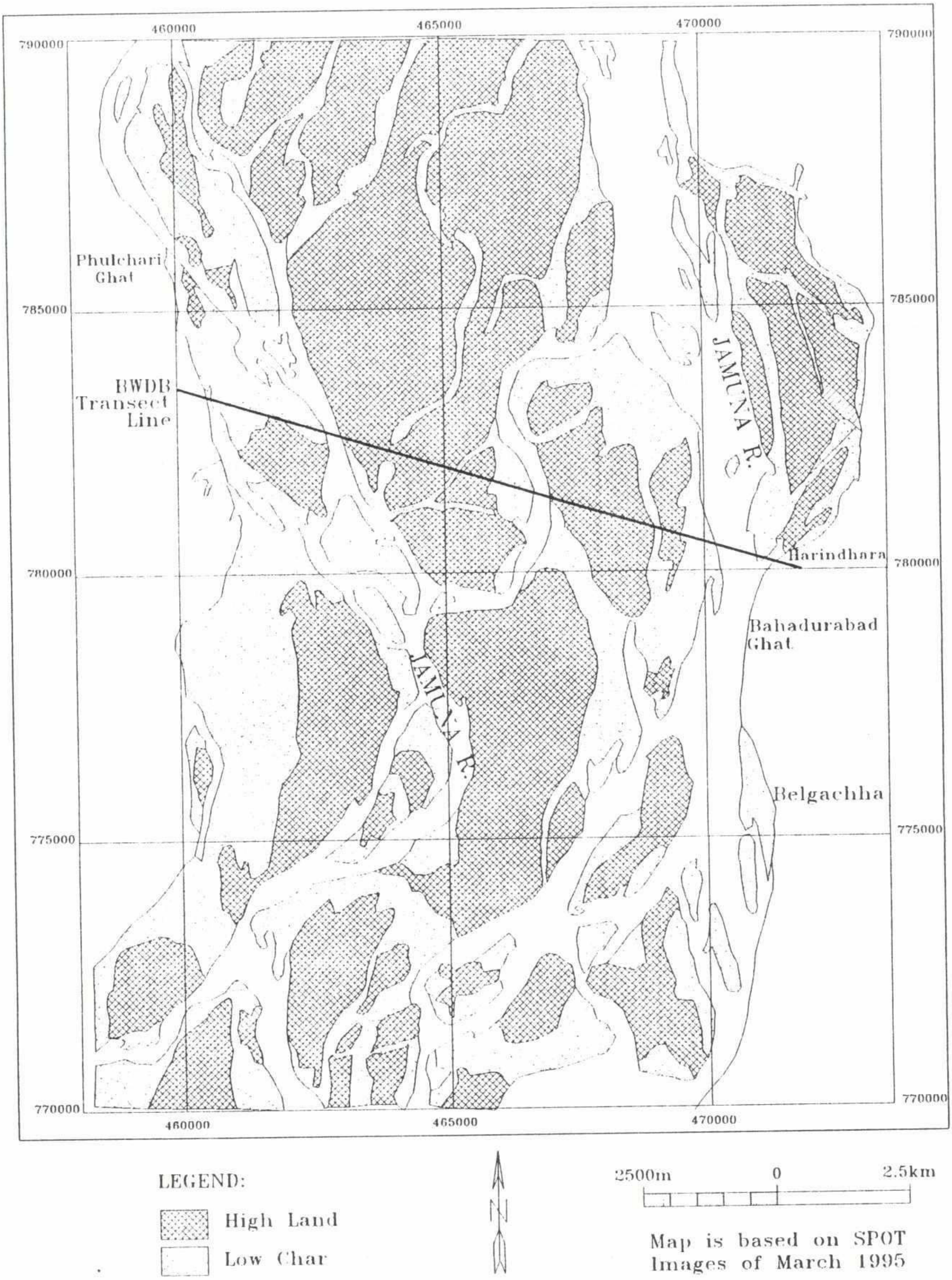

Figure 2.3: Location of the BWDB flow gauging transect at Bahadurabad

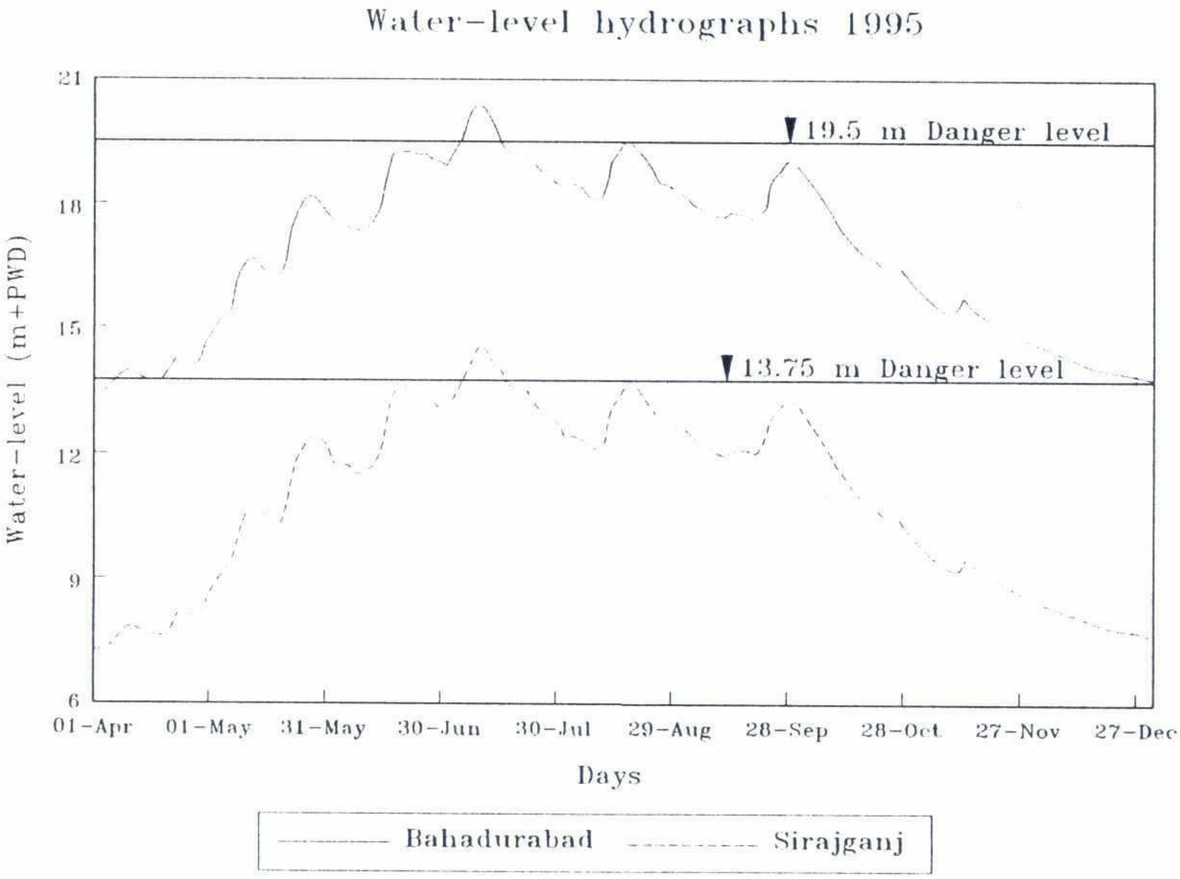

Figure 2.4: Hydrograph, Bahadurabad, hydrological year 1995/96

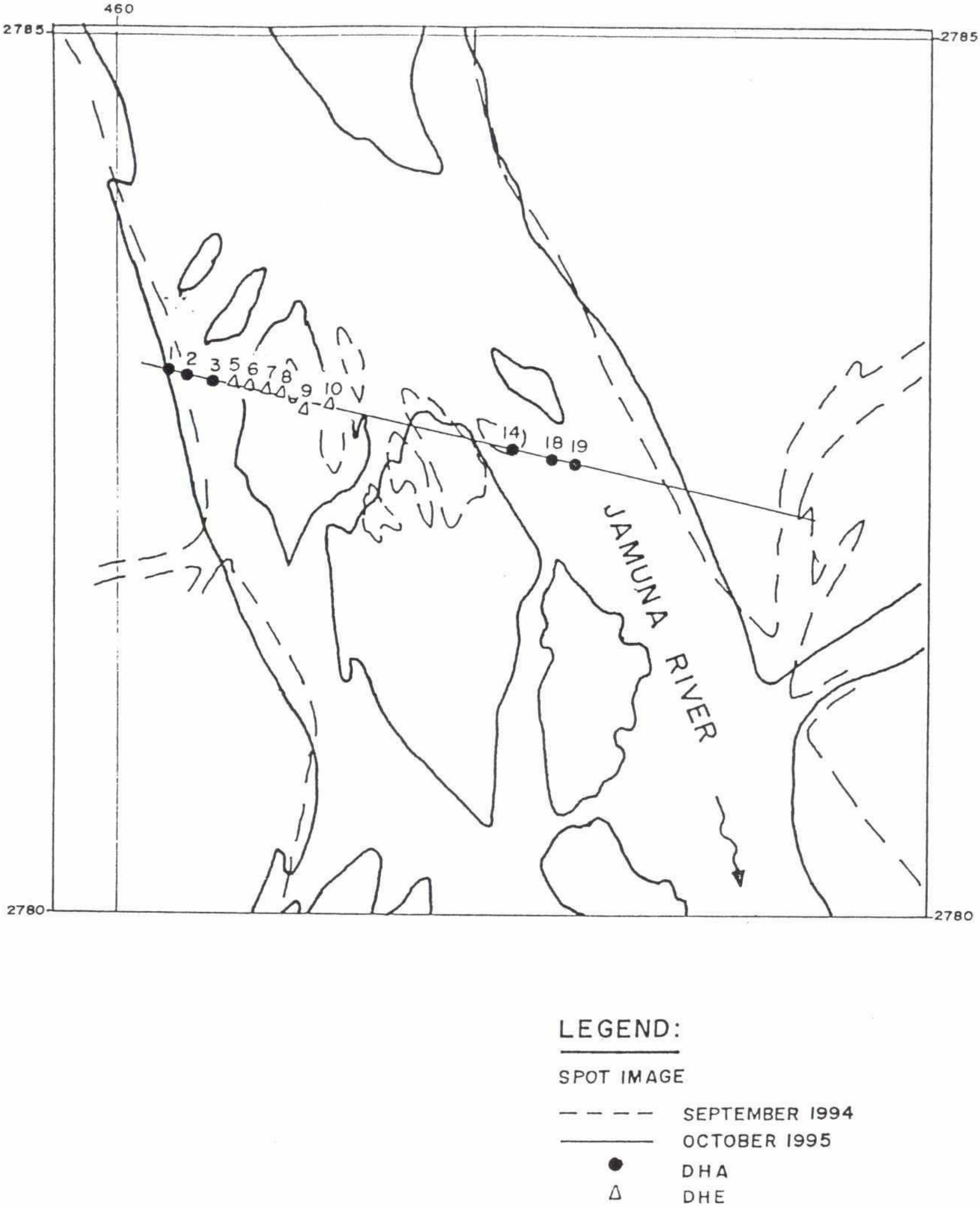

Figure 2.5.a: Location of verticals in Fulchari channel for joint measurements at Bahadurabad, July, 1995

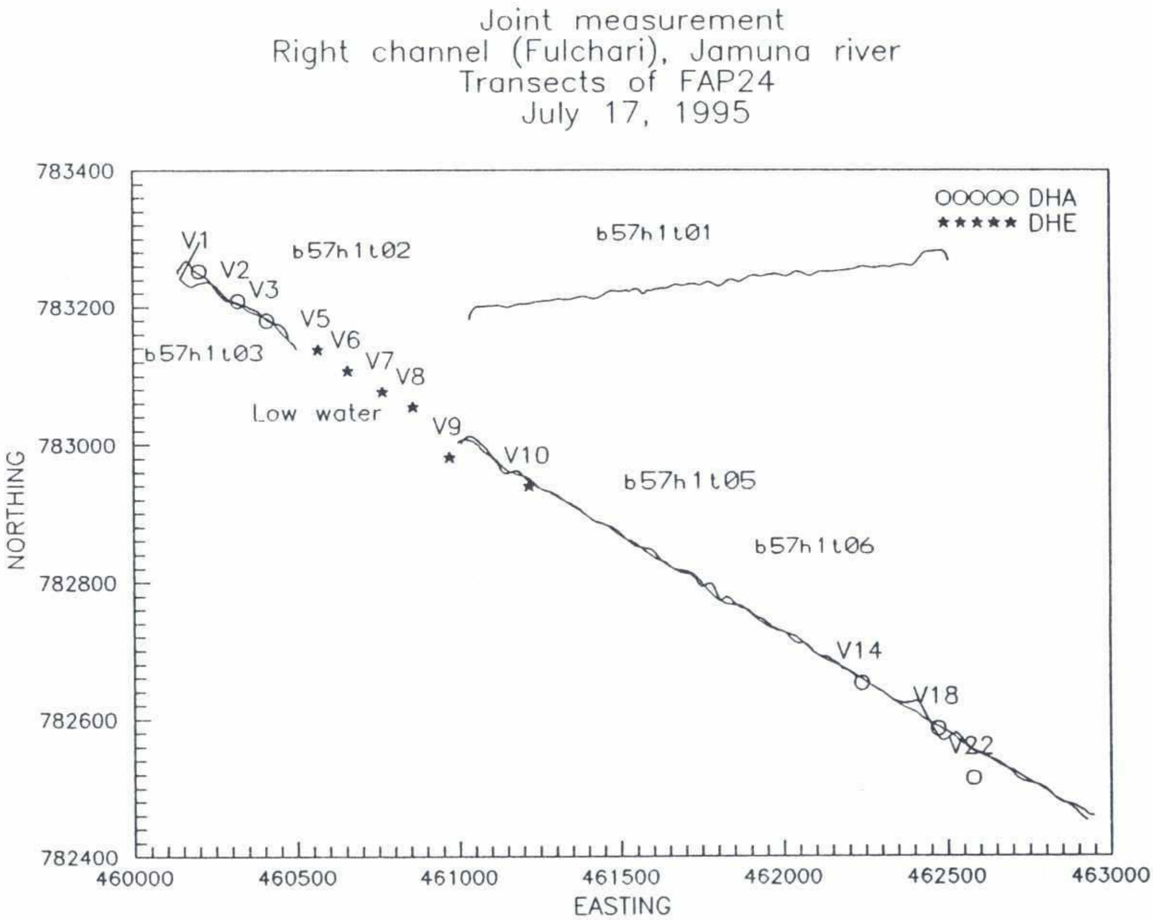

Figure 2.5.b: Location of verticals in Fulchari channel for joint measurements at Bahadurabad, July, 1995

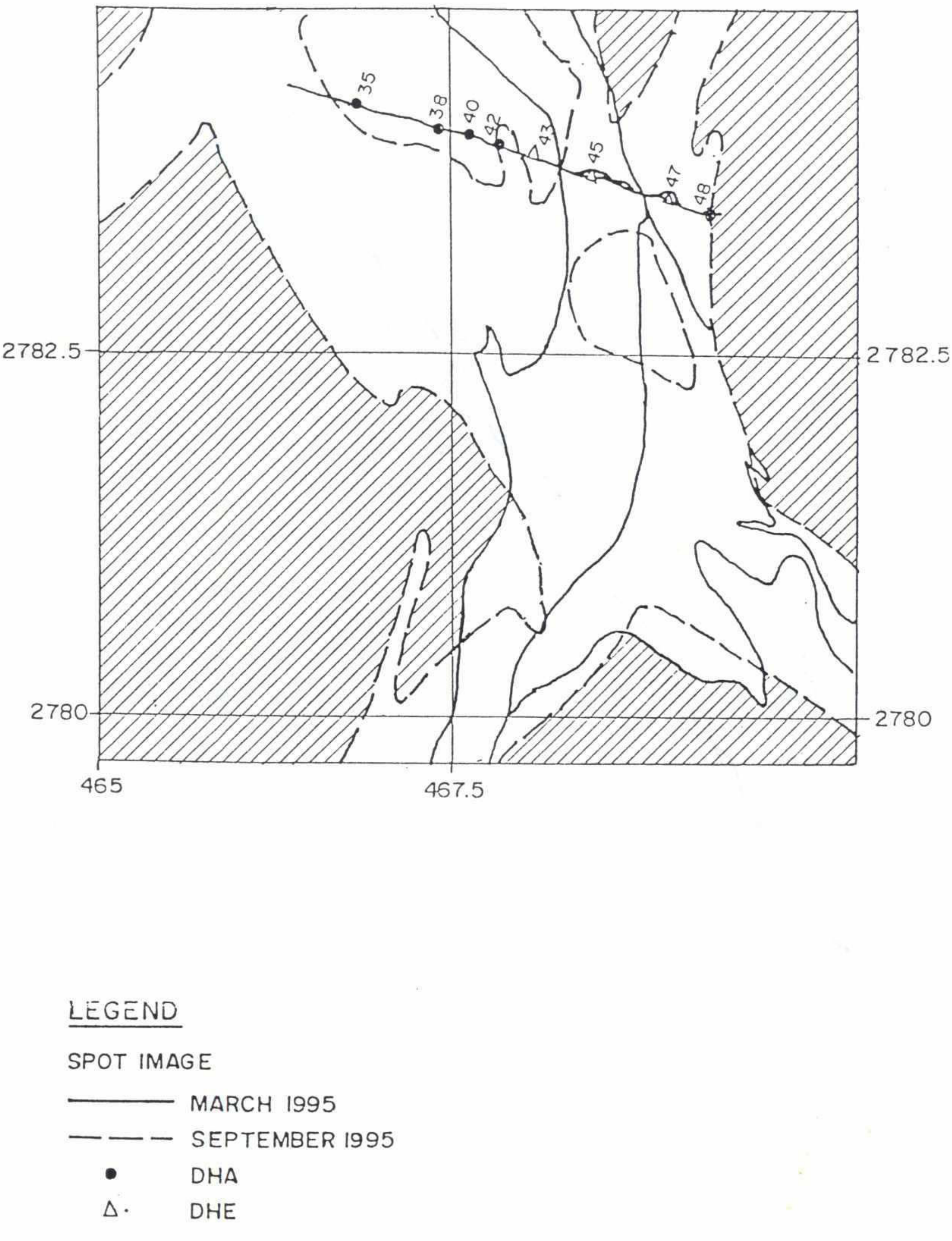

Figure 2.5.c: Location of verticals in Old Bahadurabad channel for joint measurements at Bahadurabad, July, 1995

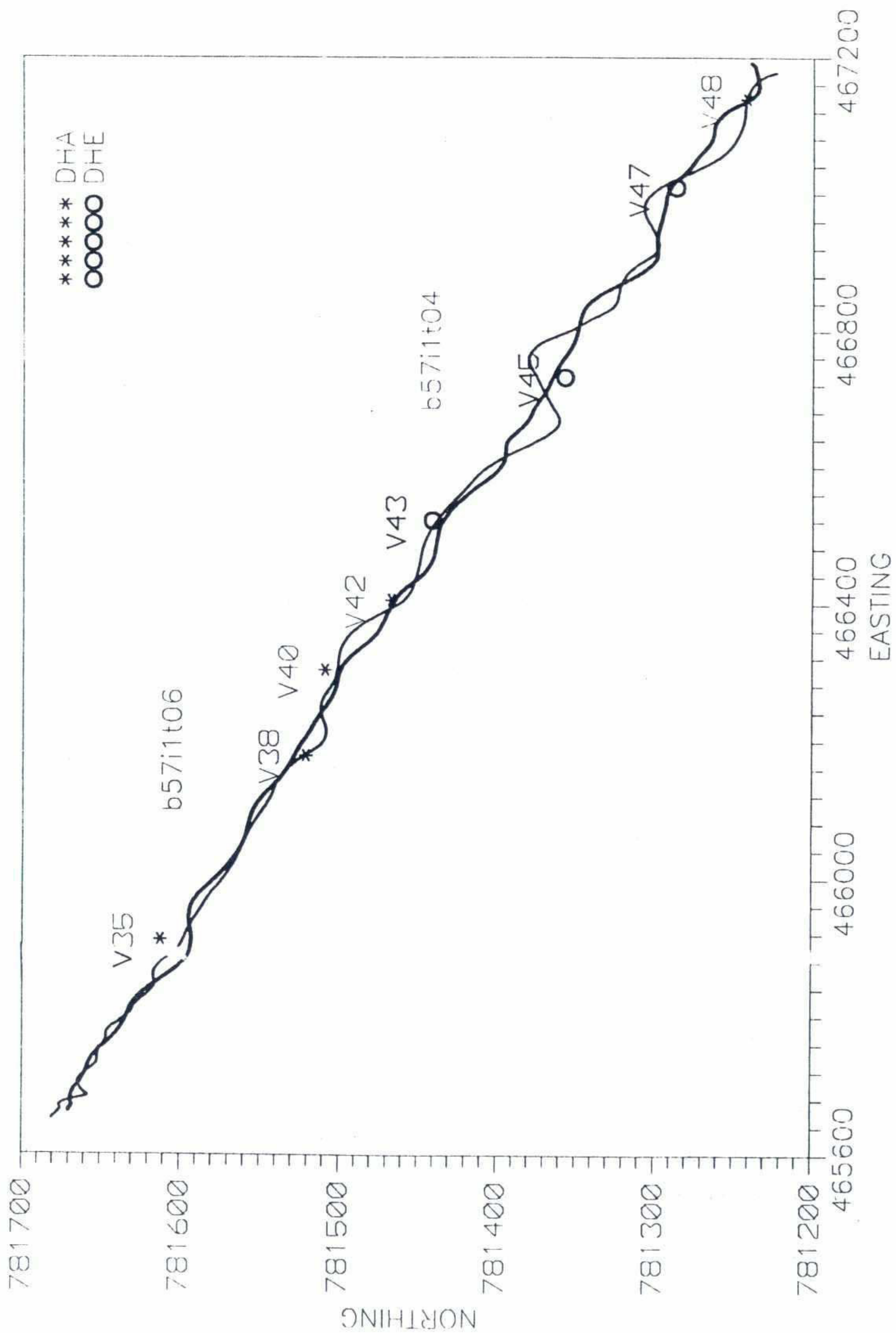

Figure 2.5.d: Location of verticals in Old Bahadurabad channel for joint measurements at Bahadurabad, July, 1995

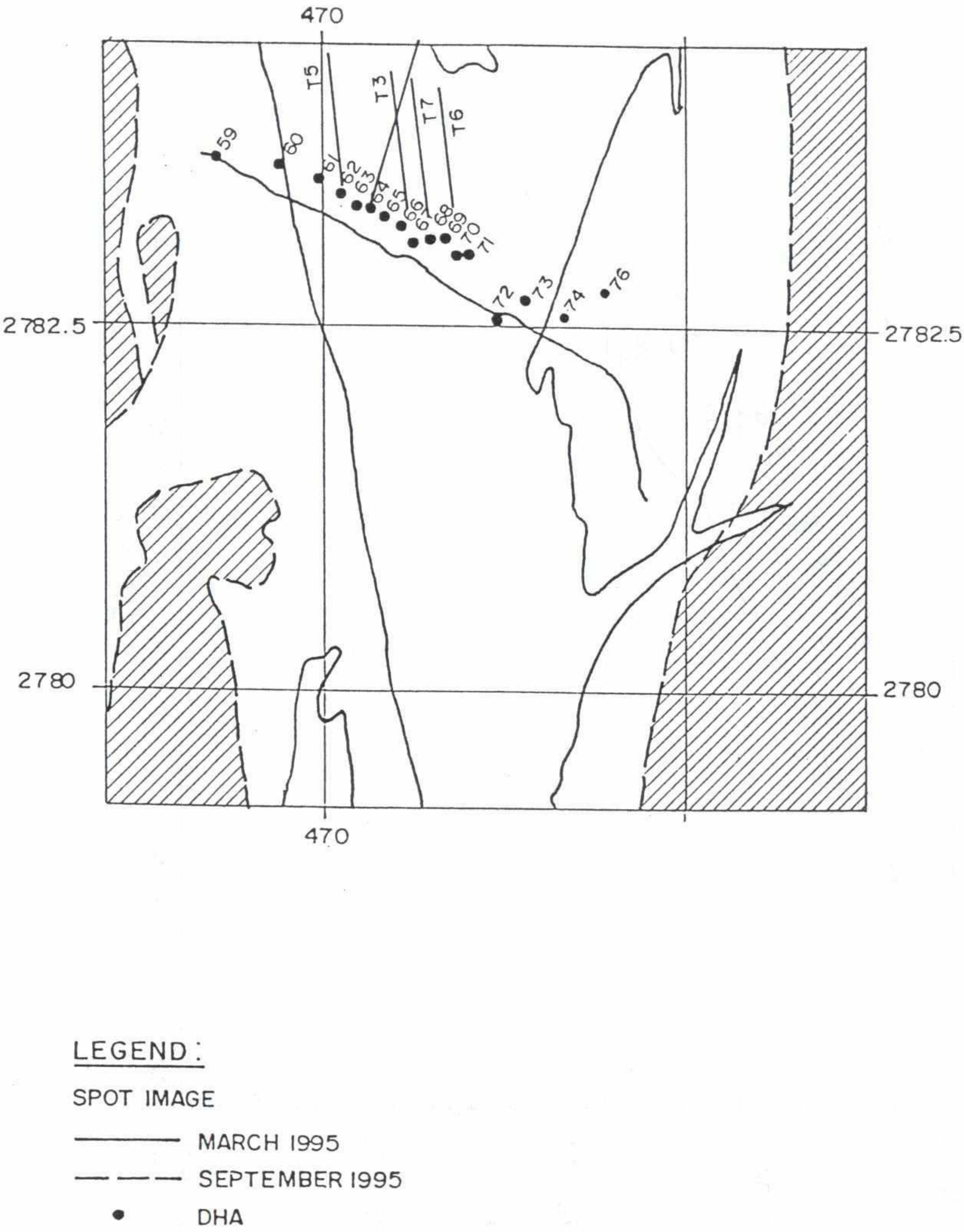

Figure 2.5.e: Location of verticals in Bahadurabad Ghat channel for joint measurements at Bahadurabad, July, 1995

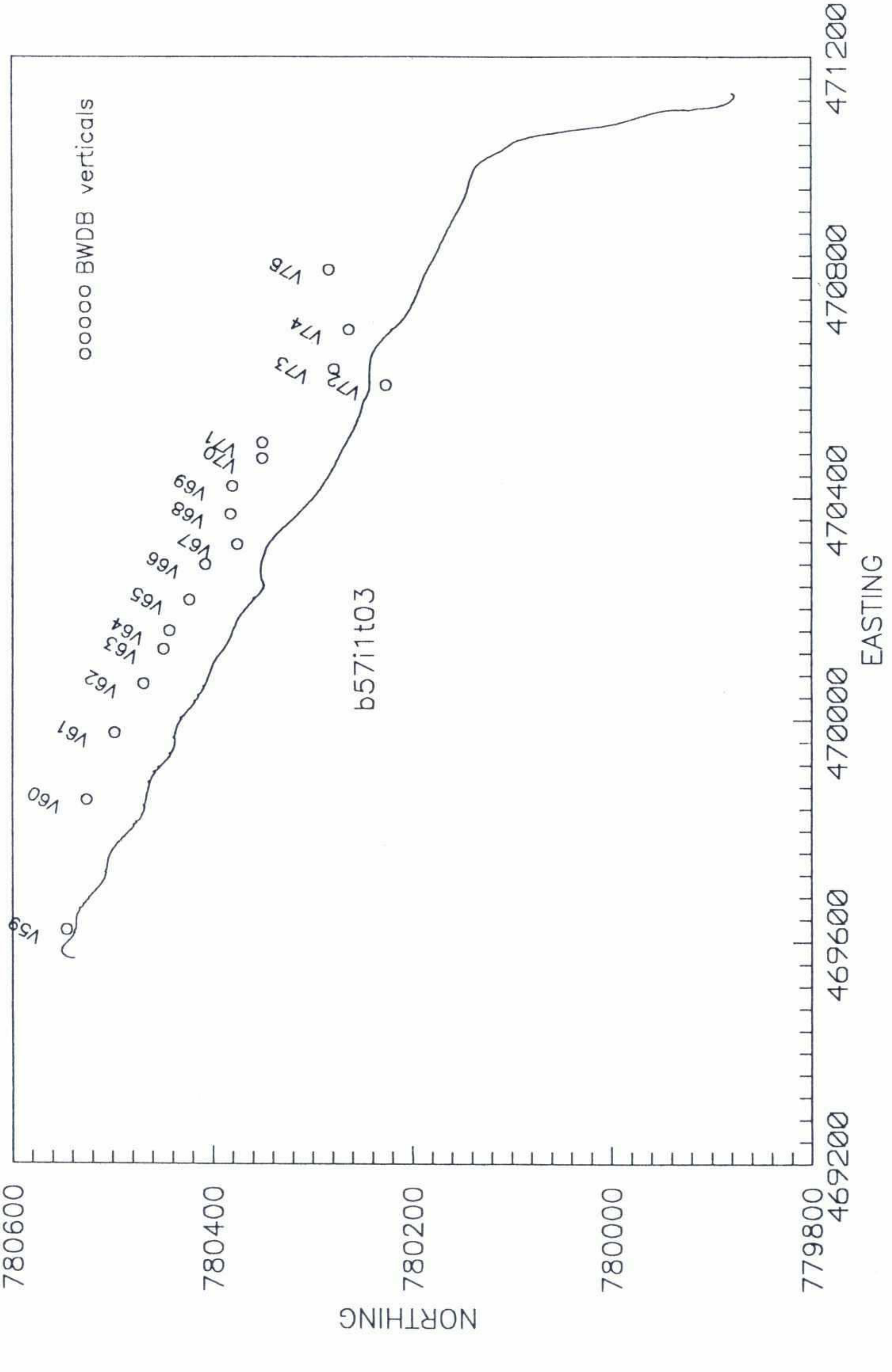

Figure 2.5.f: Location of verticals in Bahadurabad Ghat channel for joint measurements at Bahadurabad, July, 1995

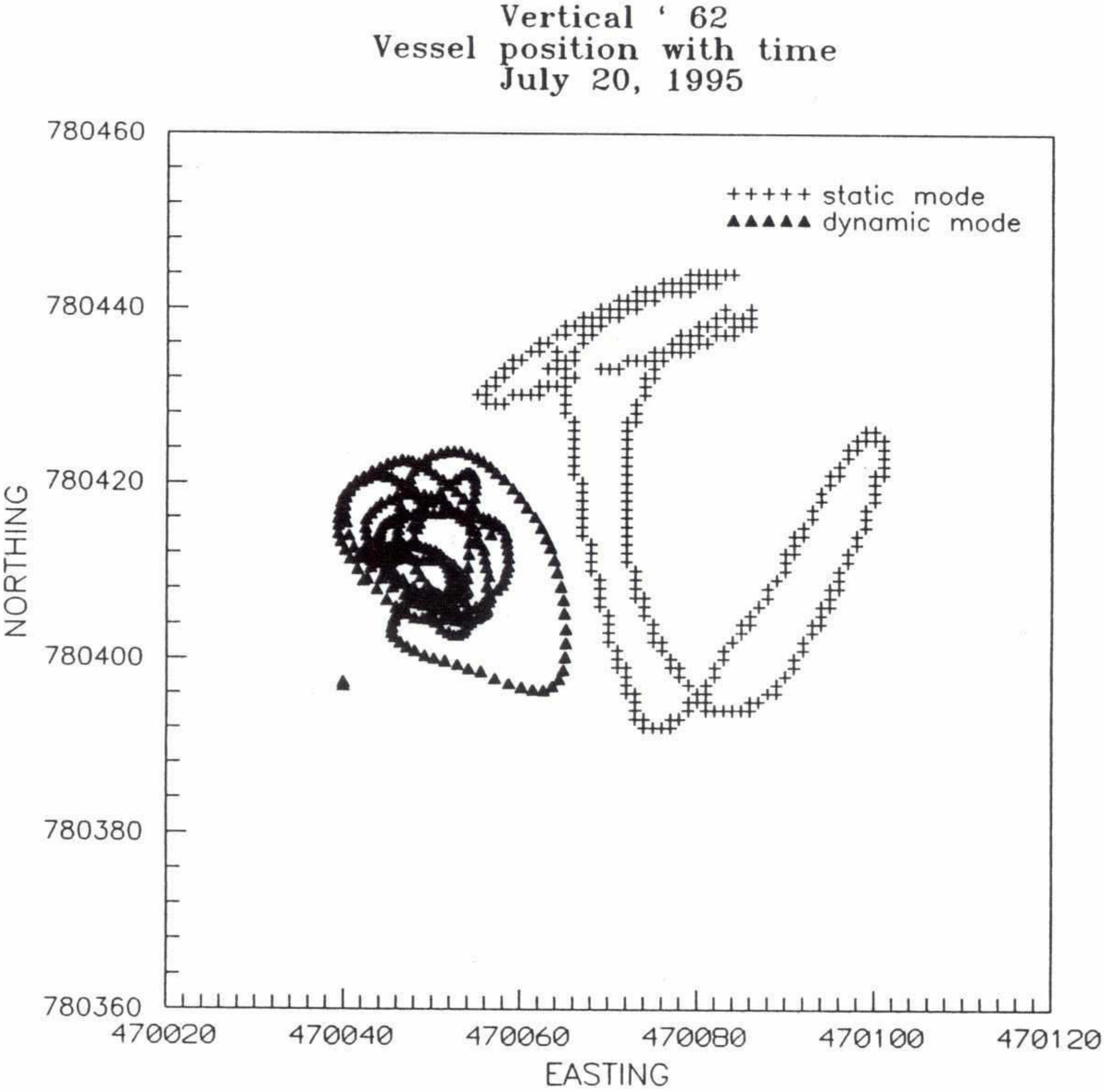

Figure 2.6: Drift of vessel during vertical profiling, with and without anchoring

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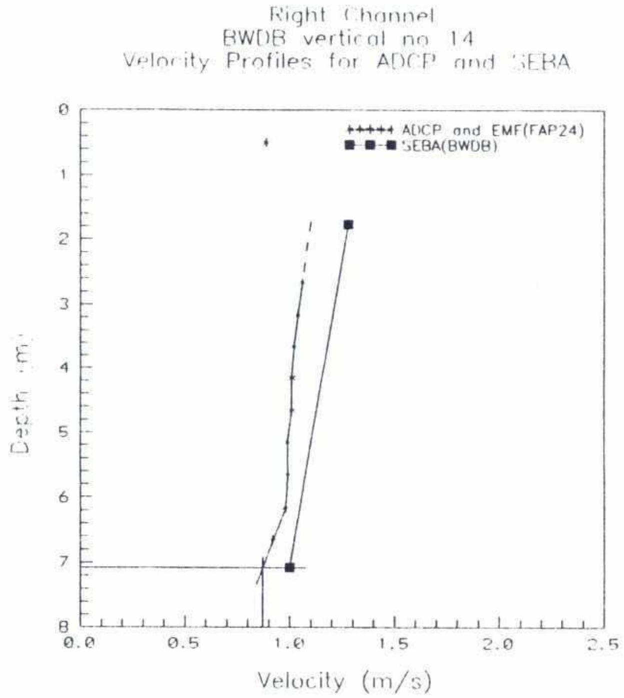


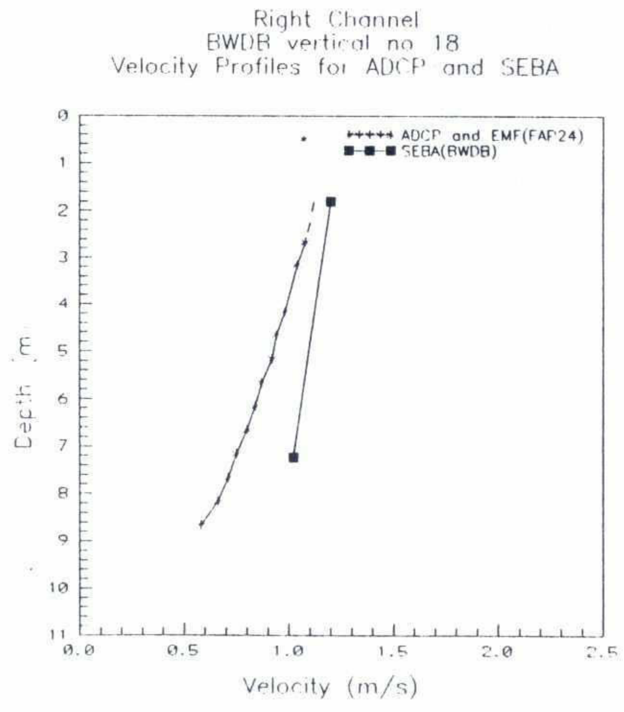
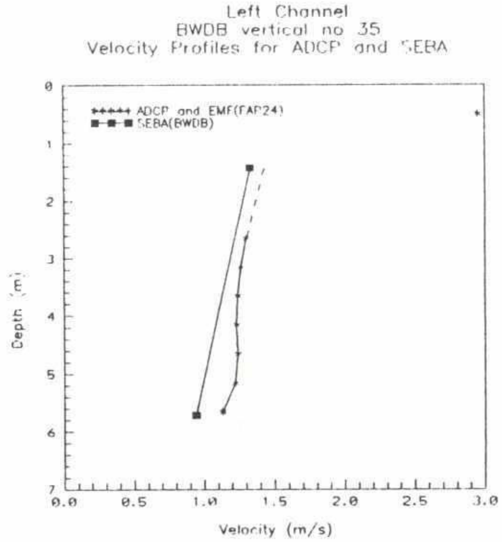
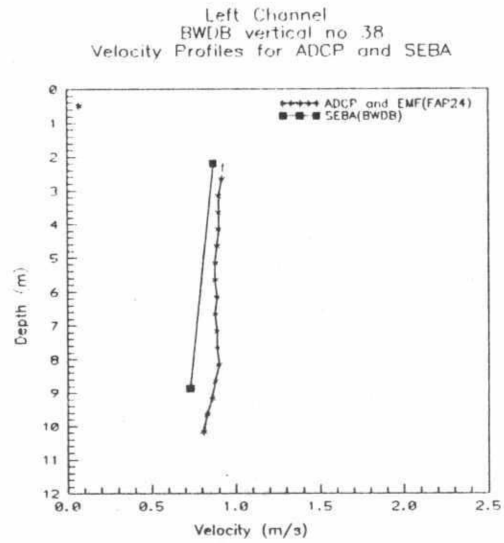


Figure 2.7: Vertical profiles by BWDB and RSP, July 17, 1995, Fulchari Channel





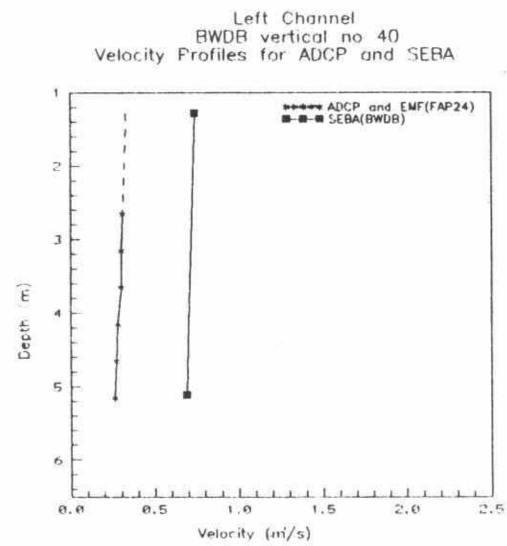


Figure 2.8.a: Vertical profiles by BWDB and RSP, July 18, 1995, Old Bahadurabad Channel

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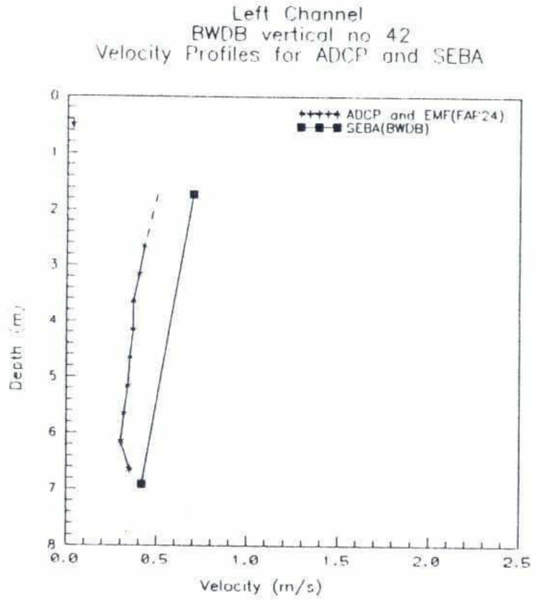


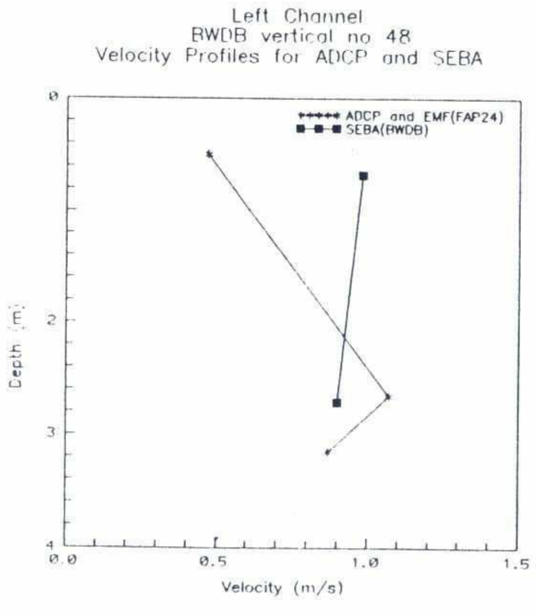


Figure 2.8.b: Vertical profiles by BWDB and RSP, July 18, 1995, Old Bahadurabad Channel

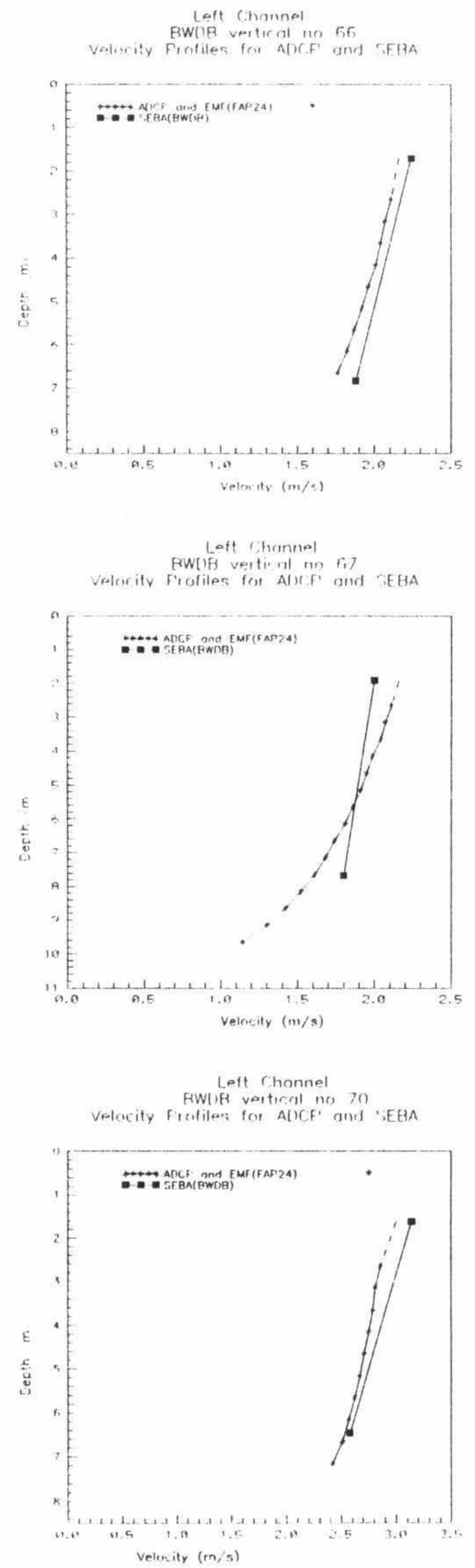


Figure 2.9: Vertical profiles by BWDB and RSP, July 19, 1995, Bahadurabad Ghat Channel

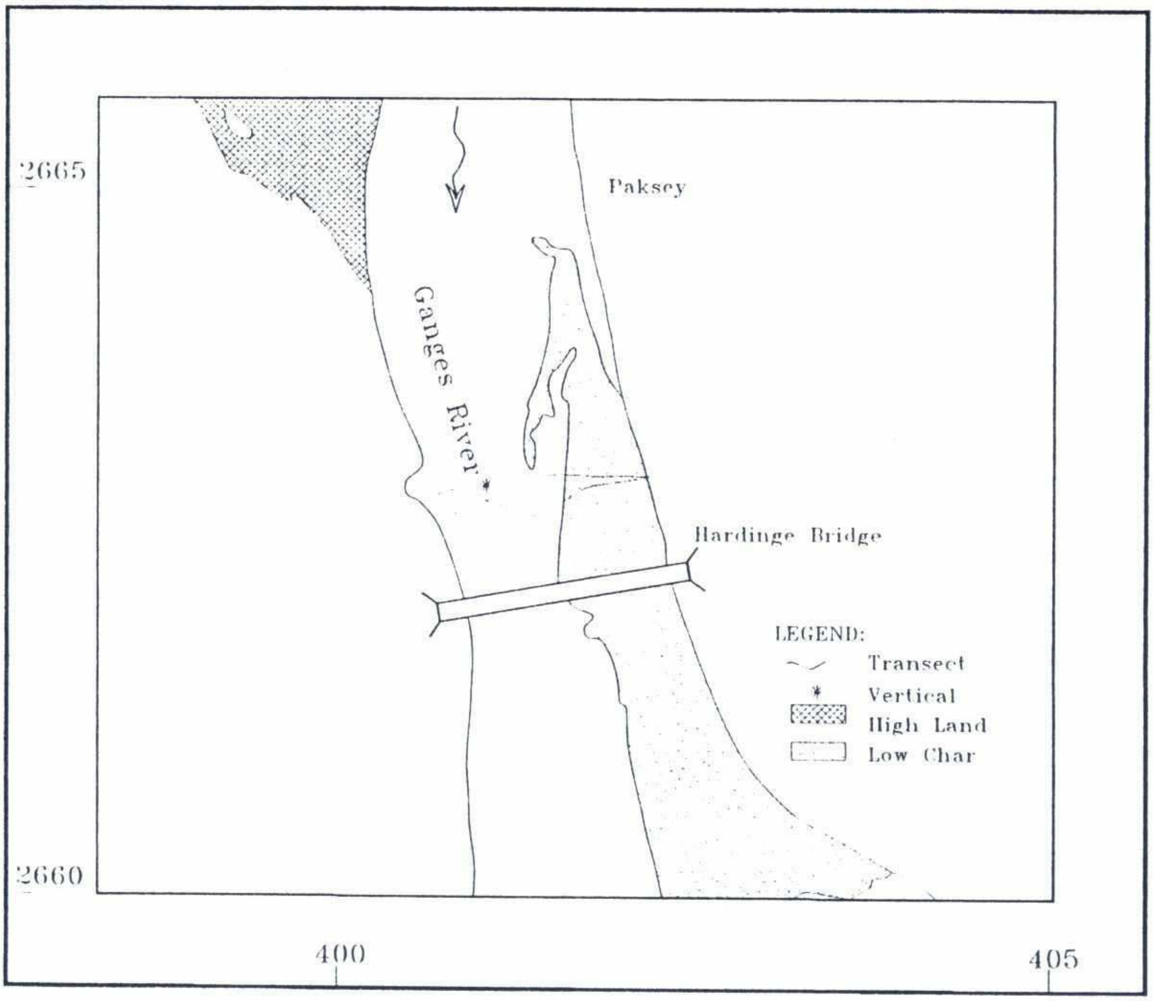


Figure 2.10: Flow gauging transect at Hardinge Bridge

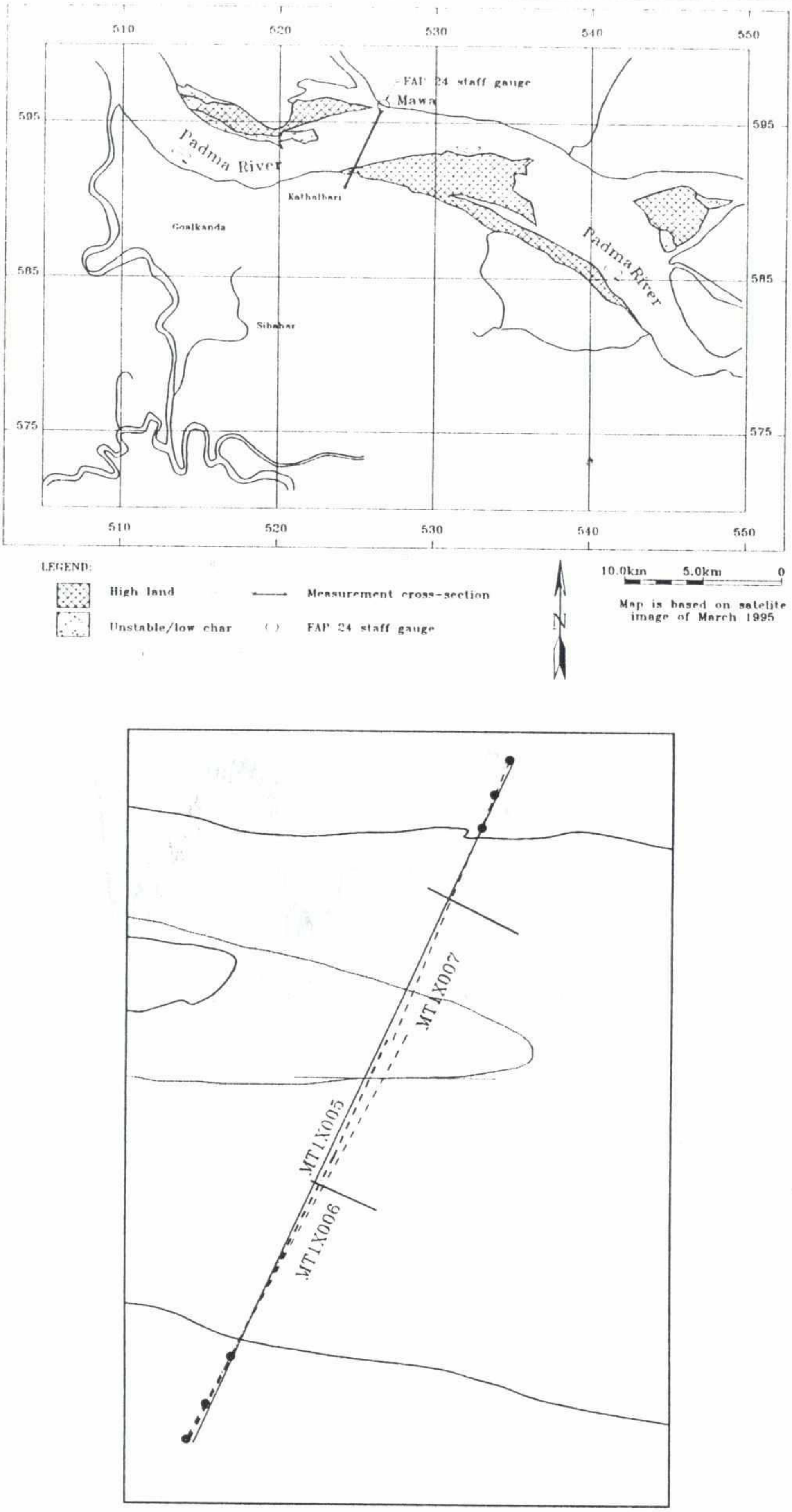


Figure 2.11: Transects, Mawa, October 1995

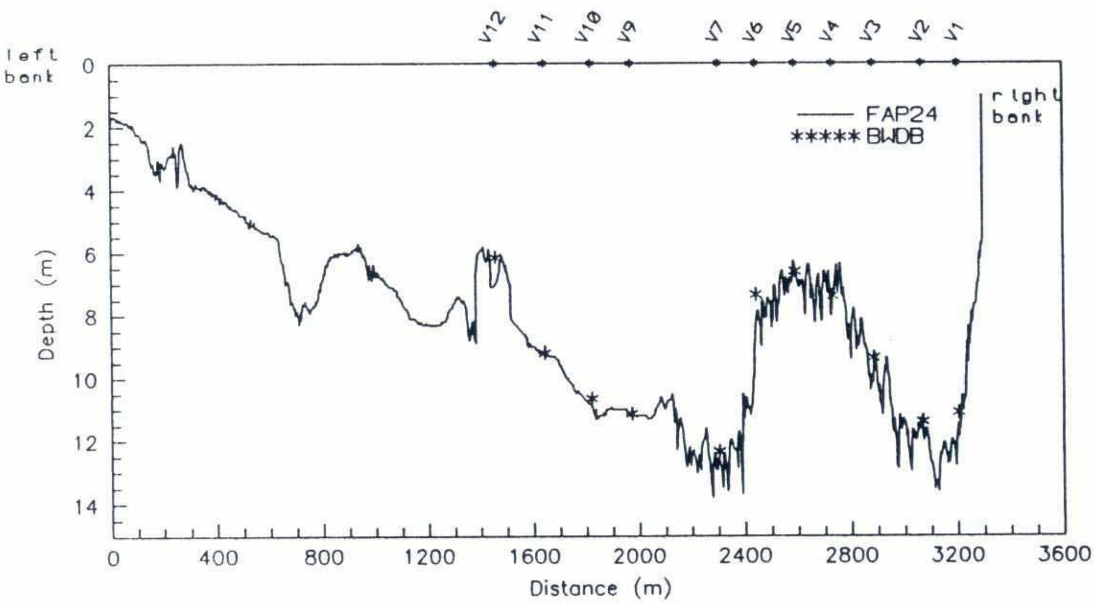
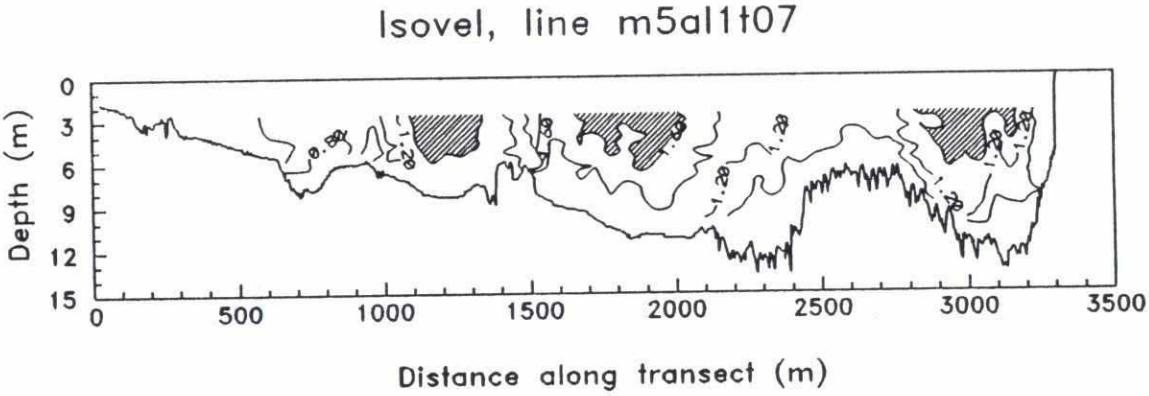


Figure 2.12: Cross-section profile, Mawa, Right Channel, October 21, 1995



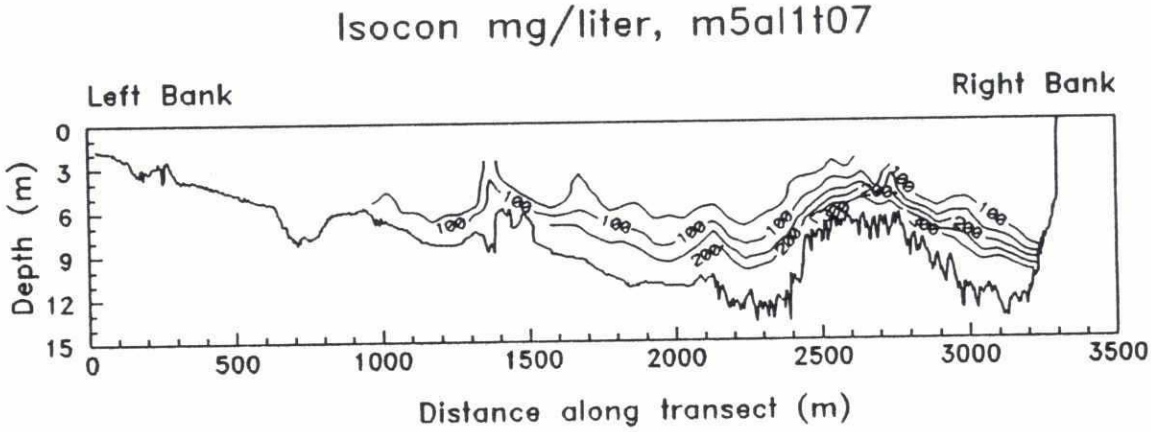


Figure 2.13: Velocity and backscatter distribution, Mawa, Right Channel, October 21, 1995

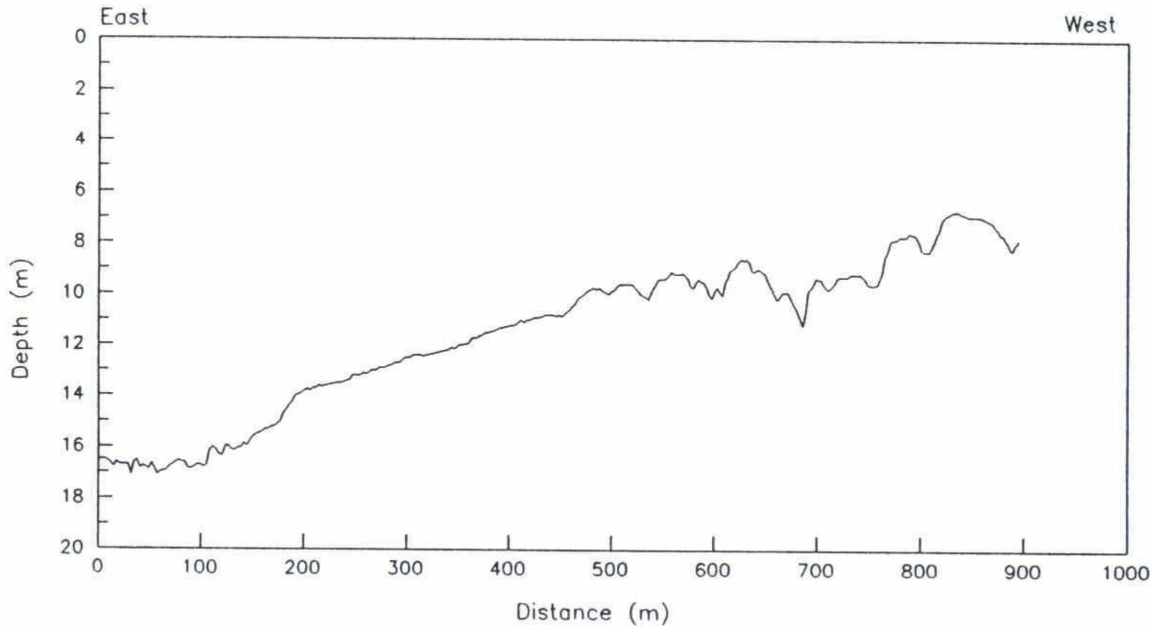


Figure 2.14: Longitudinal depth transect, Mawa, Right Channel, October 21, 1995

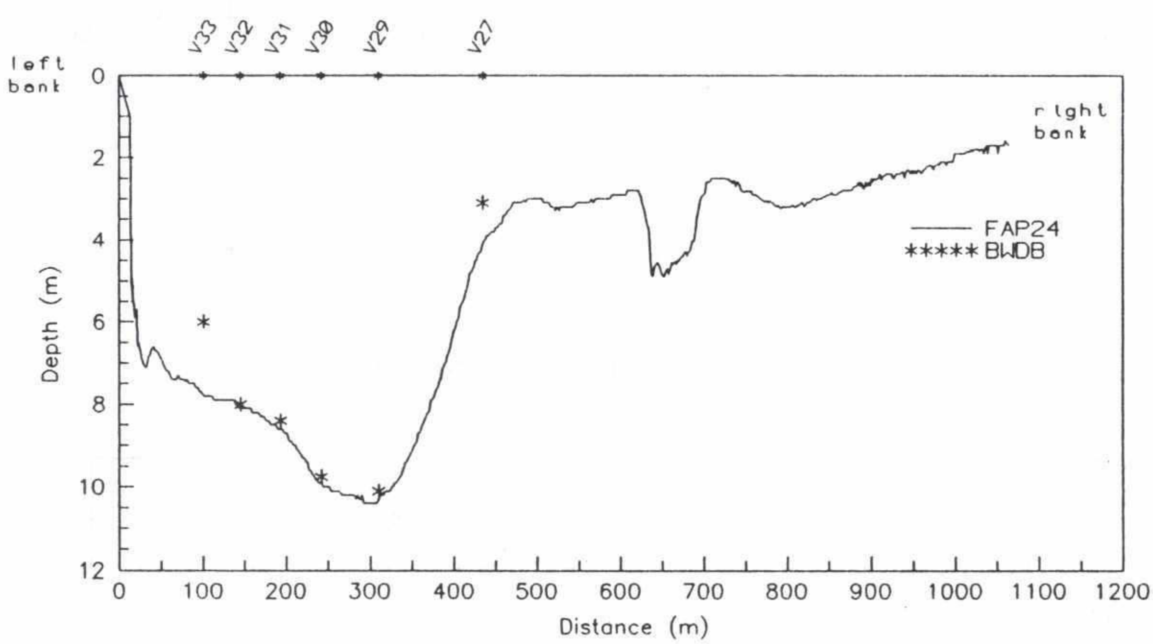


Figure 2.15: Cross-section profile, Mawa, Left Channel, October 21, 1995

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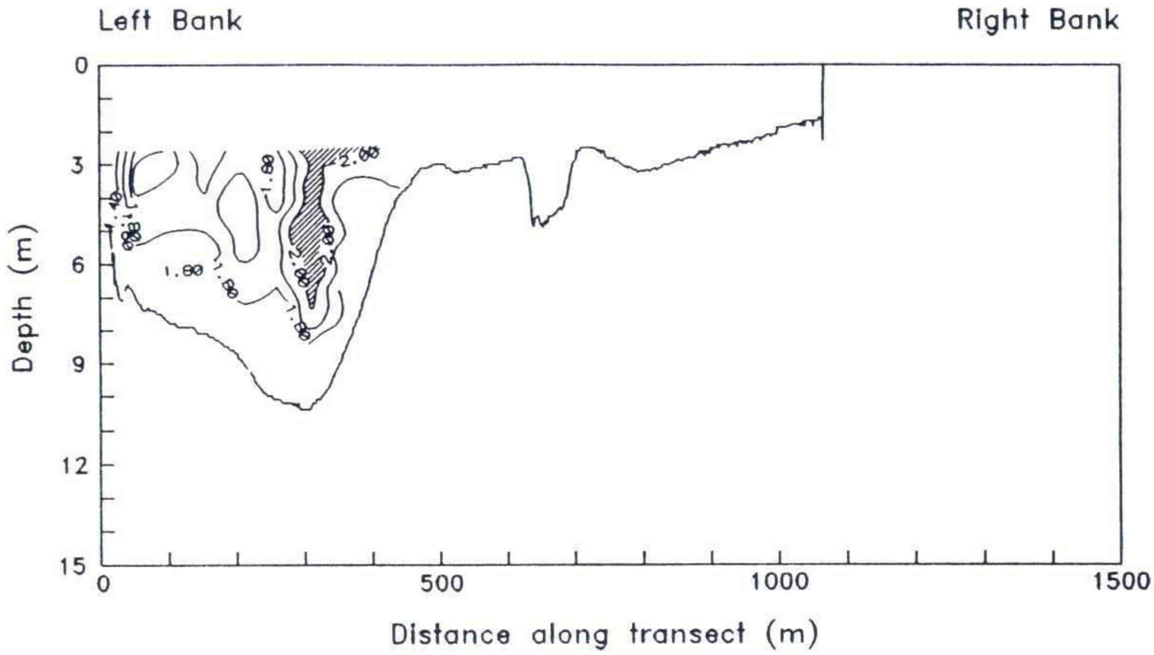

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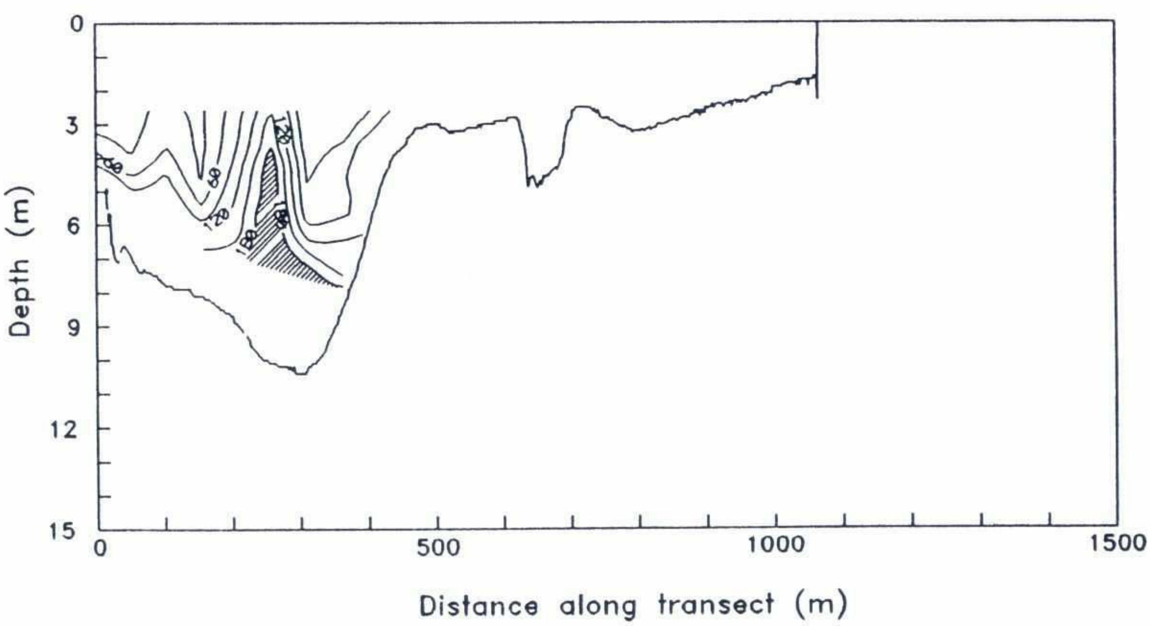


Figure 2.16: Velocity and backscatter distribution, Mawa, Left Channel, October 21, 1995

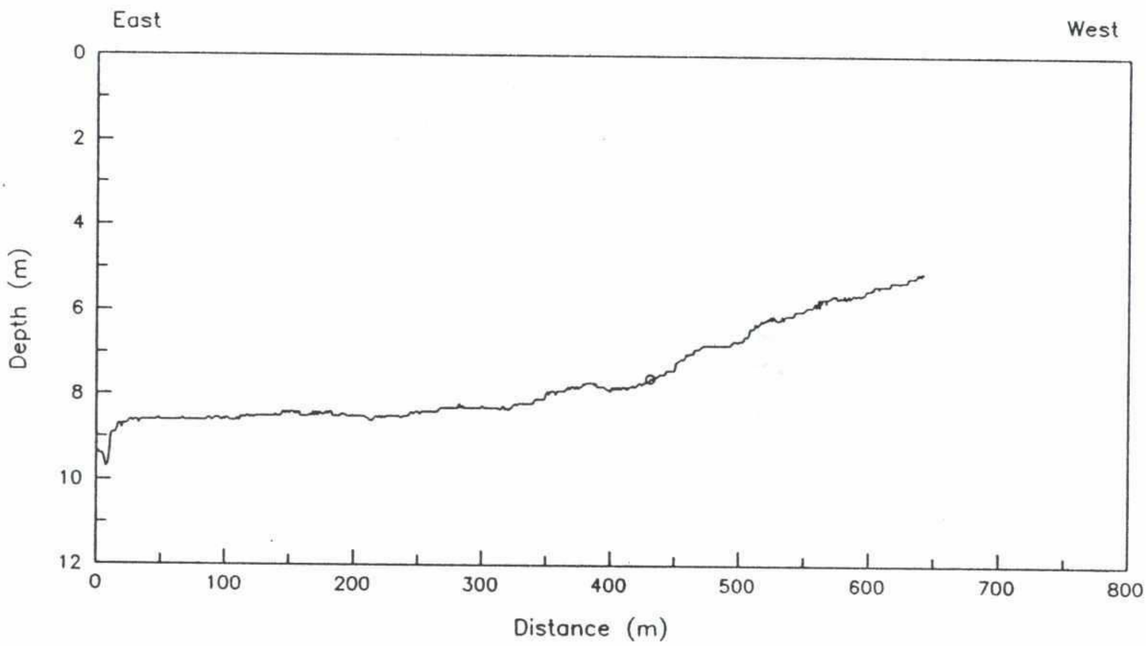


Figure 2.17: Longitudinal depth transect, Mawa, Left Channel, October 21, 1995

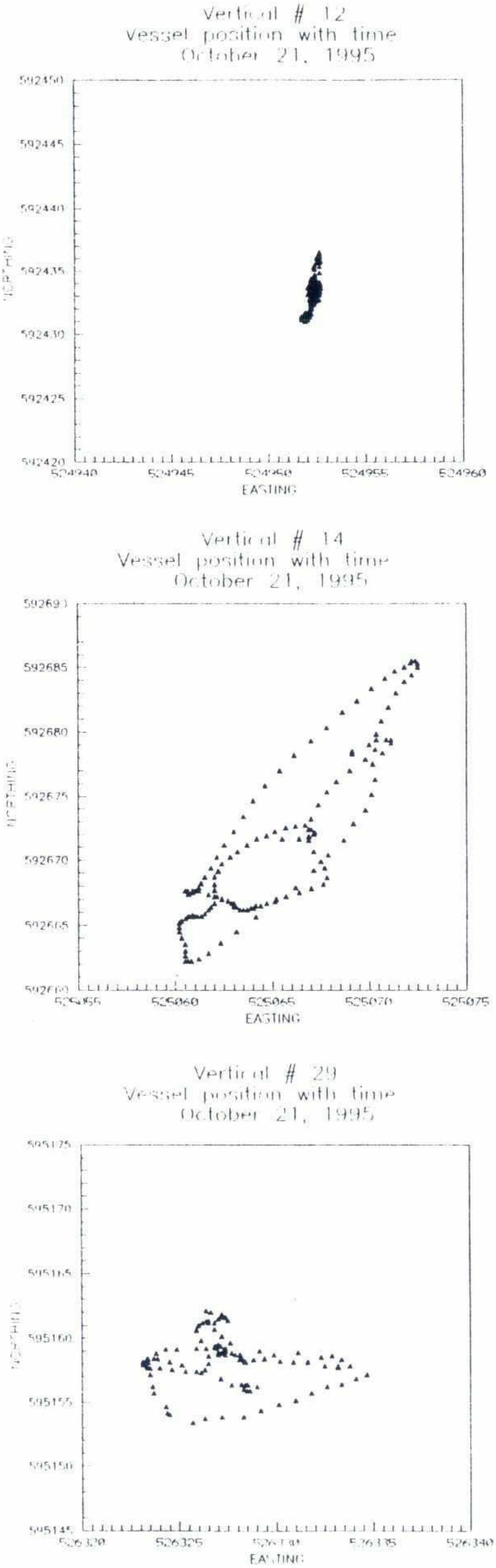
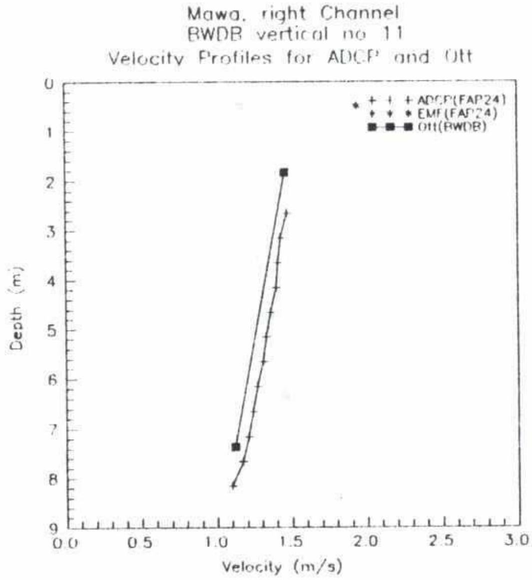


Figure 2.18: Drift of vessel during vertical profiling, Mawa, October 21, 1995



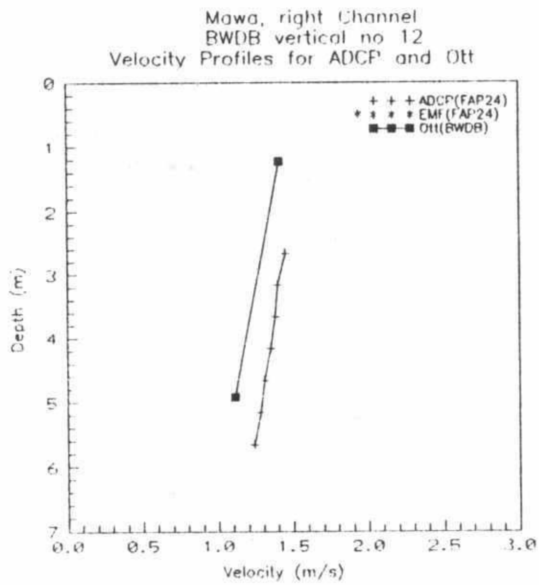
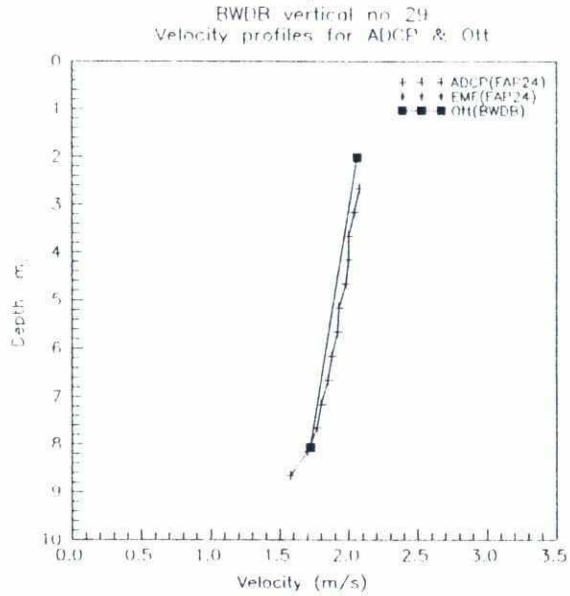


Figure 2.19: Vertical profiles by BWDB and RSP, Mawa, Right Channel, October 21, 1995



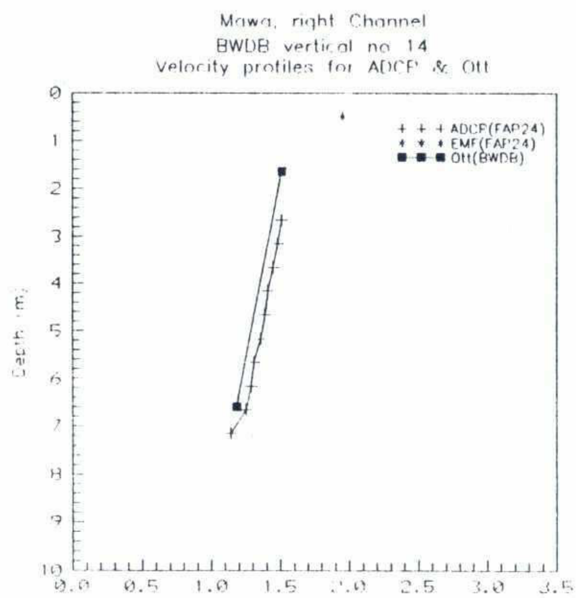


Figure 2.20: Vertical profiles by BWDB and RSP, Mawa, Left Channel, October 21, 1995

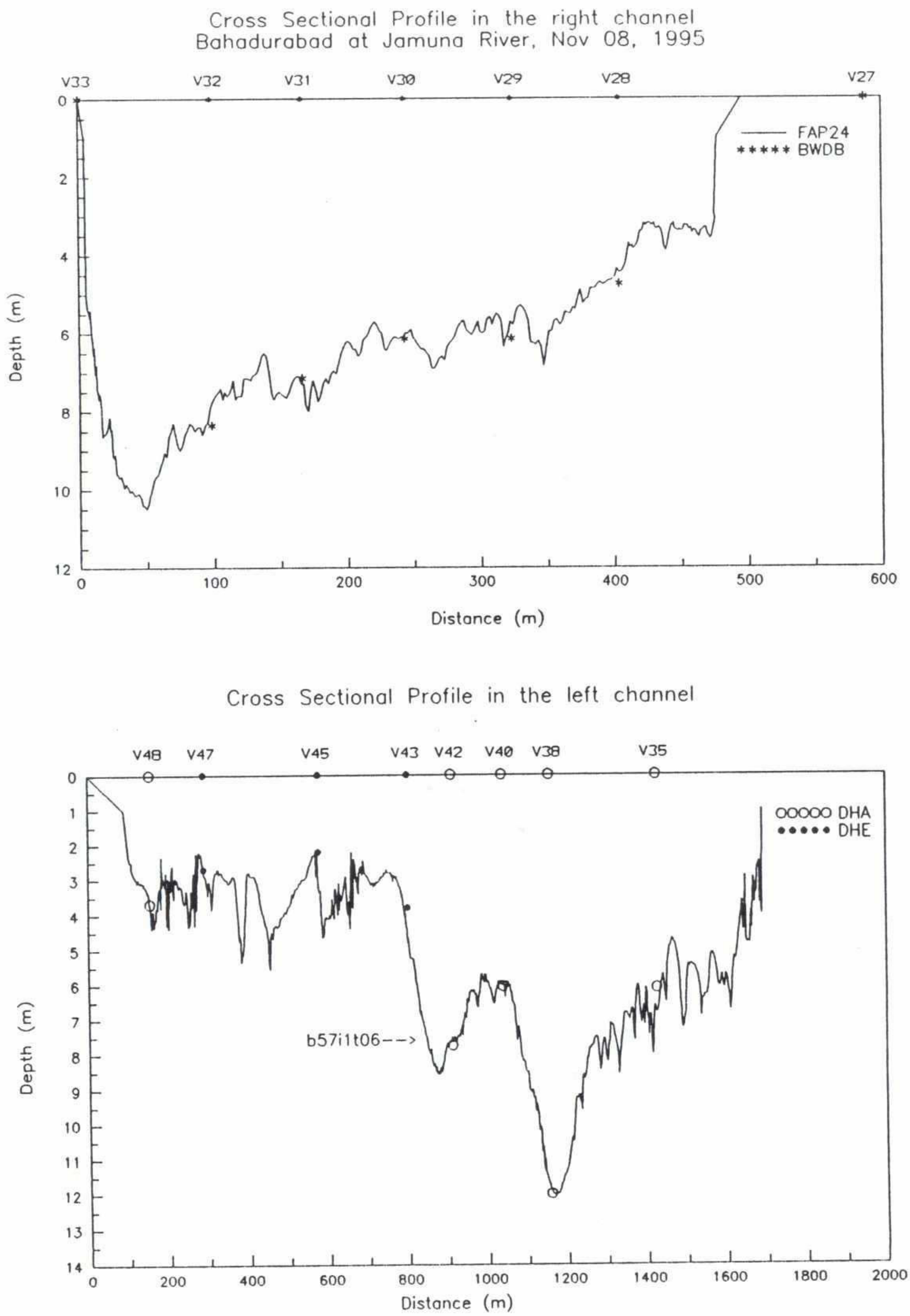


Figure 2.21: Gauging transect, Bahadurabad, November 1995

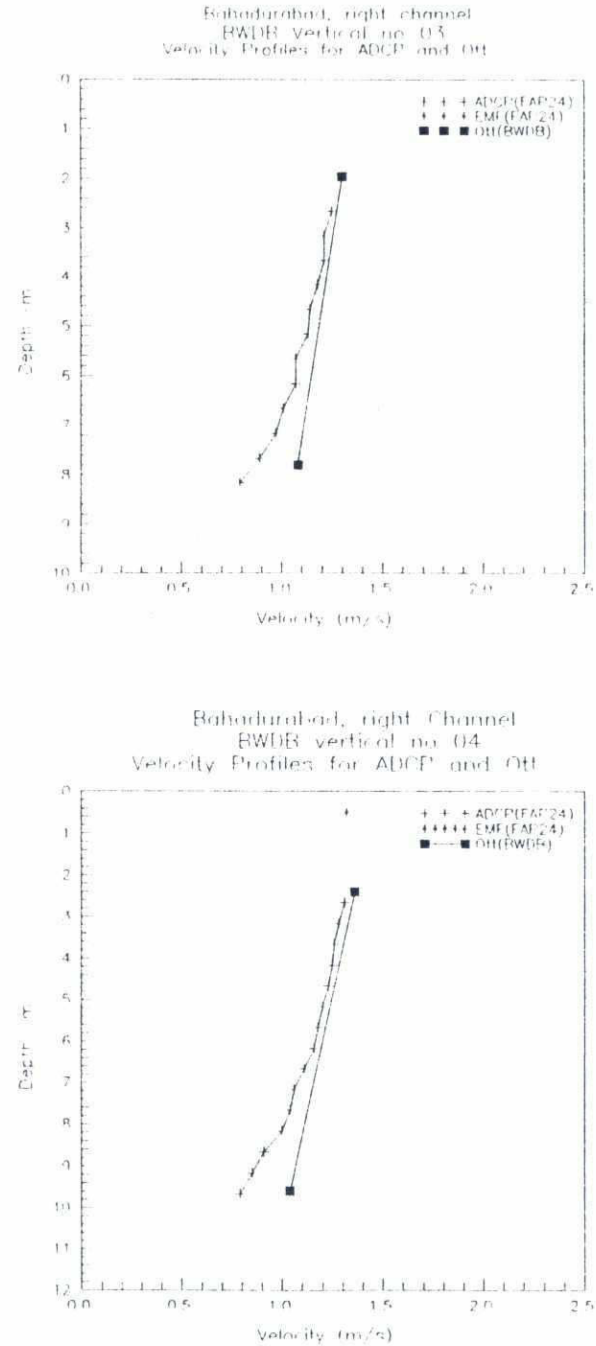
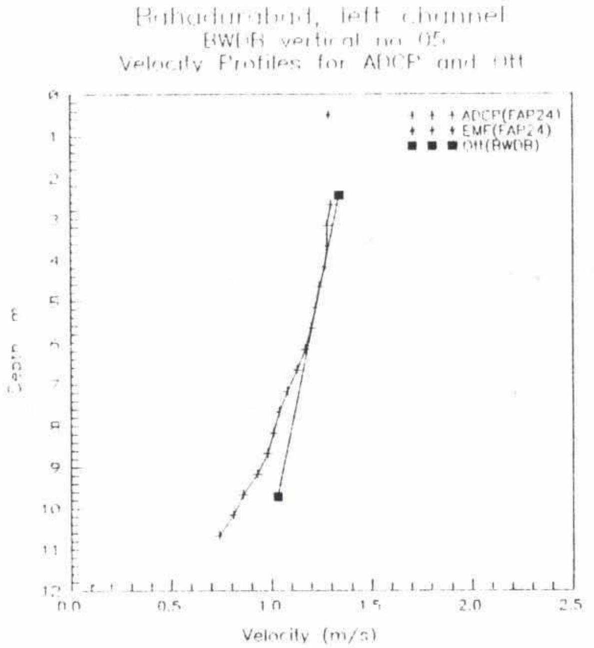


Figure 2.22.a: Vertical profiles by BWDB and RSP, Bahadurabad, Left Channel, November 7-8, 1995



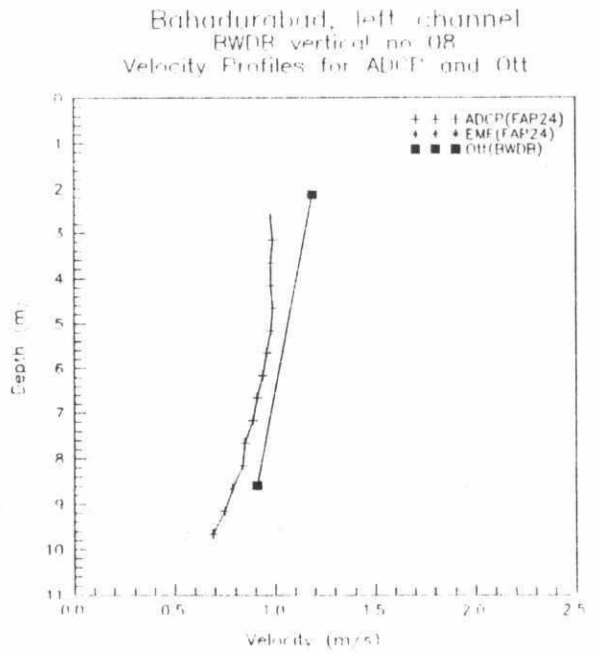
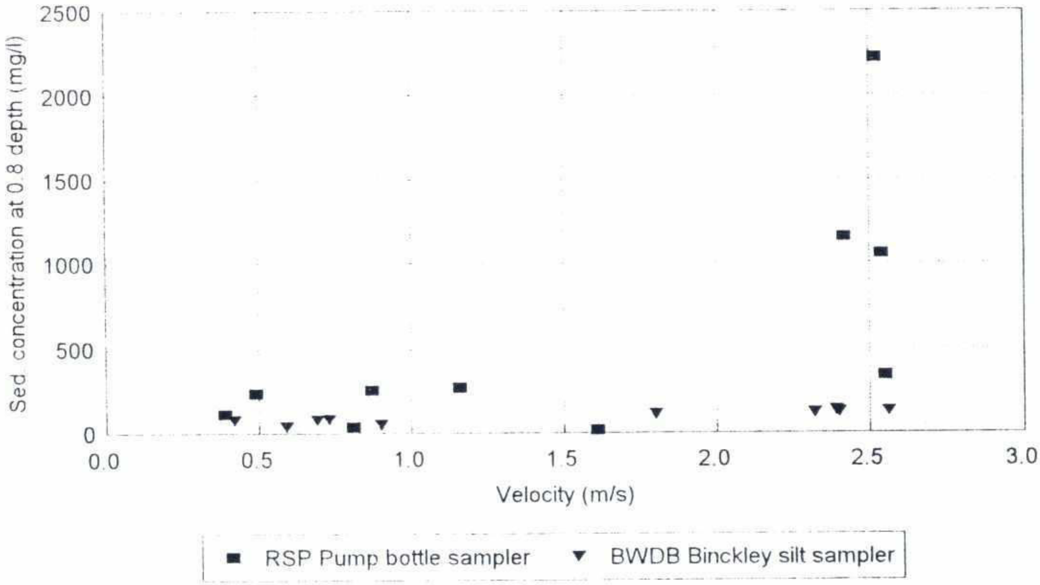


Figure 2.22.b: Vertical profiles by BWDB and RSP, Bahadurabad, Left Channel, November 7-8, 1995



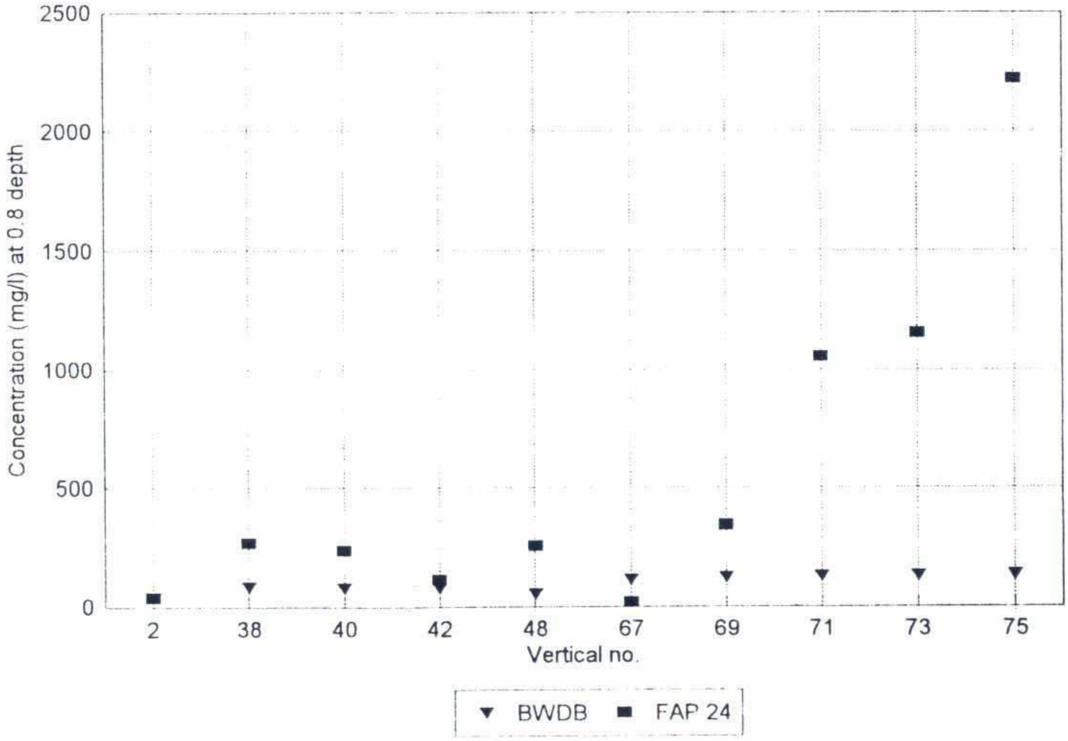
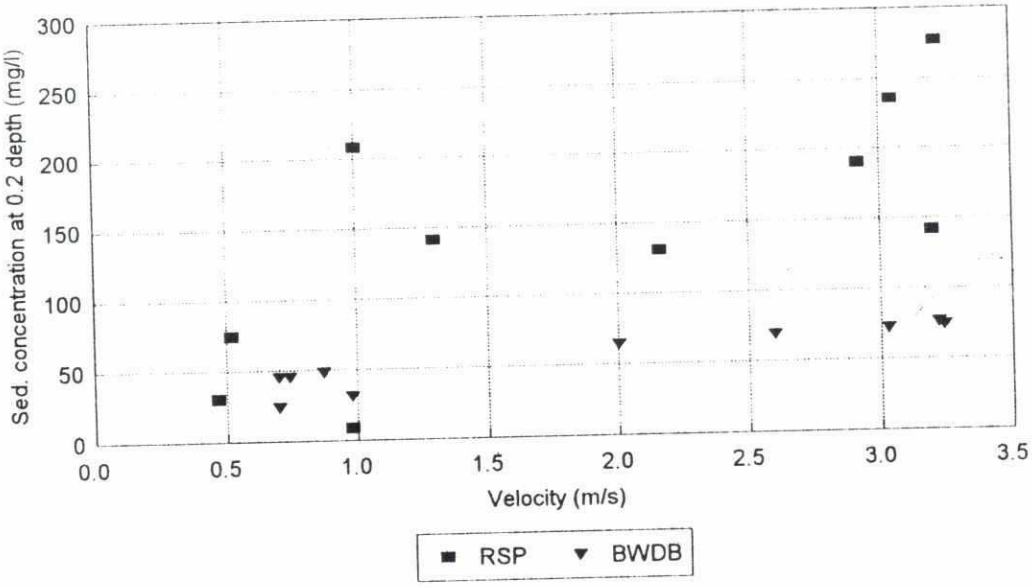


Figure 5.1: Suspended sand concentrations by BWDB and RSP, Bahadurabad, 17-18 July 1995, 0.8 h



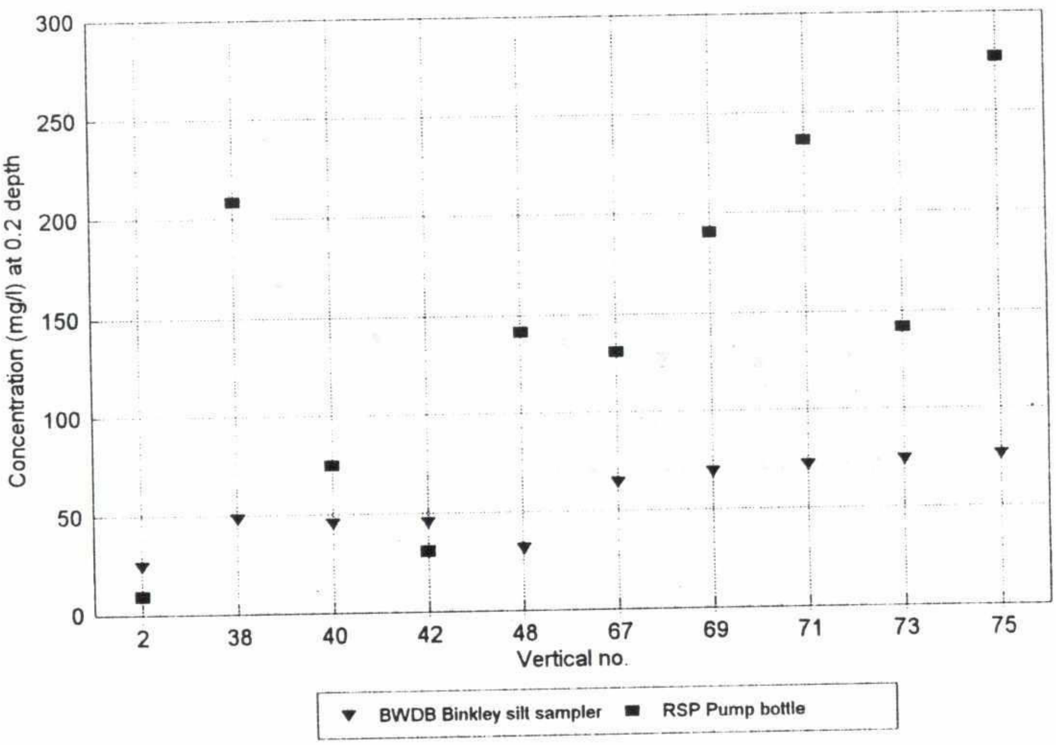


Figure 5.2: Suspended sand concentrations by BWDB and RSP, Bahadurabad, 17-18 July 1995, 0.2 h

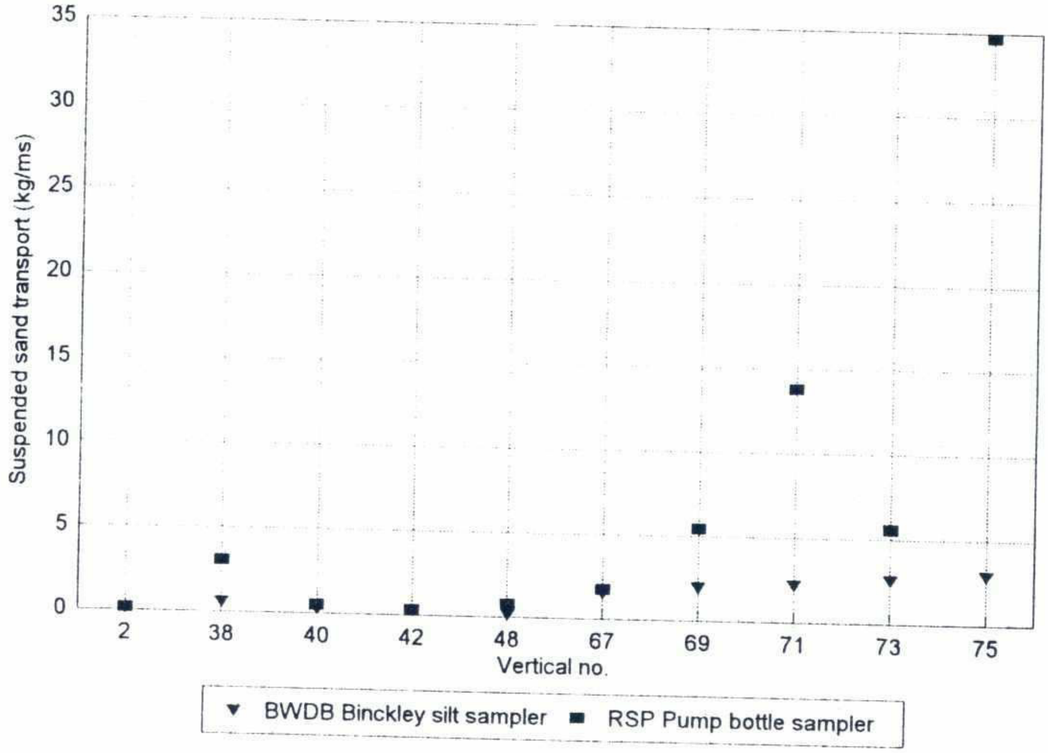
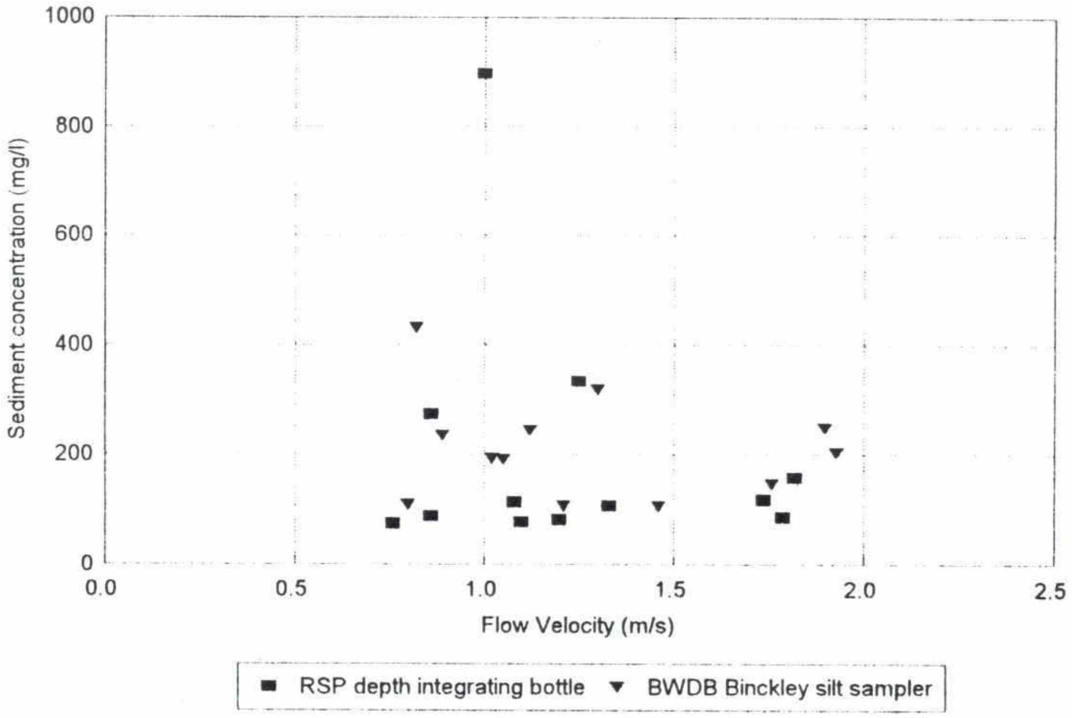


Figure 5.3: Suspended sand transport by BWDB and RSP, Bahadurabad, 17-18 July 1995



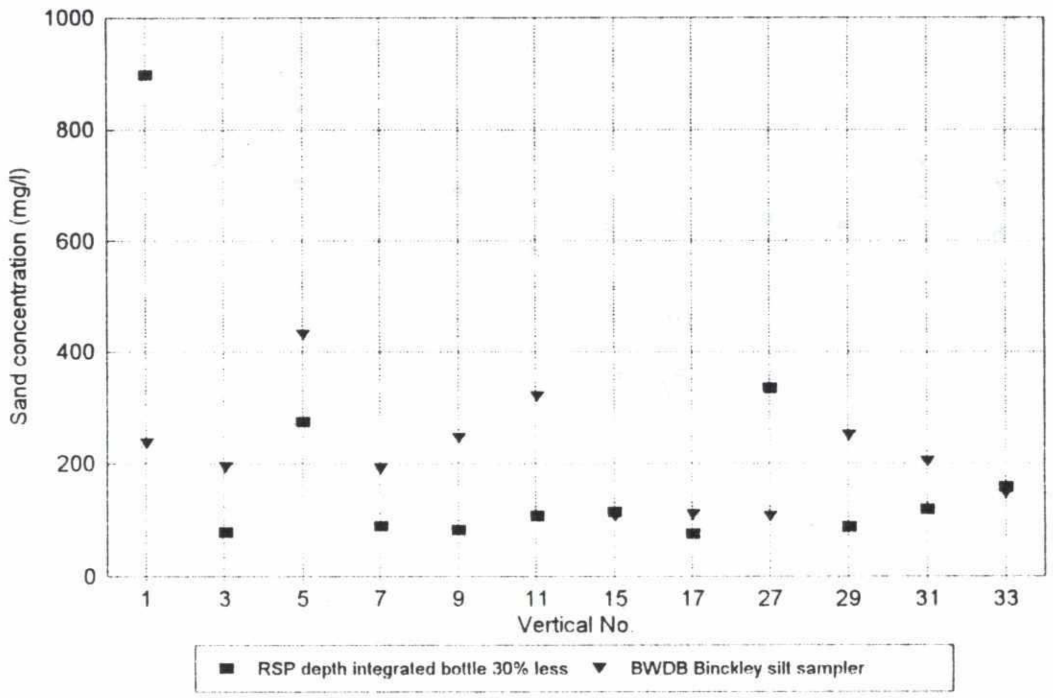


Figure 5.4: Suspended sand concentrations by BWDB and RSP, Mawa, 21-22 October 1995

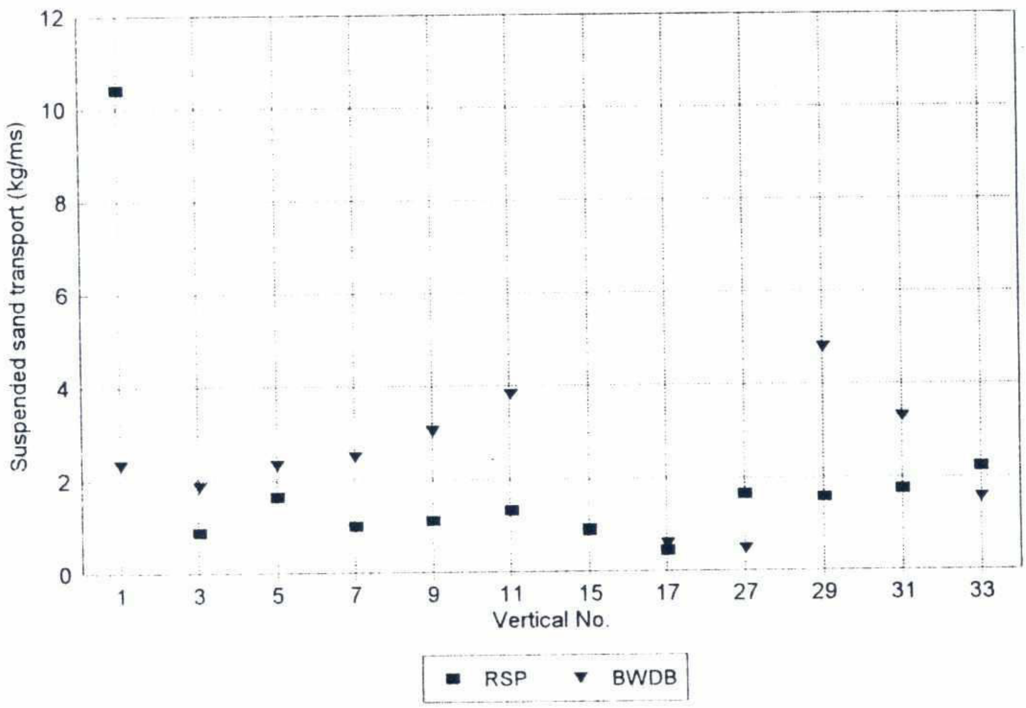


Figure 5.5: Suspended sand transport by BWDB and RSP, Mawa, 21-22 October 1995

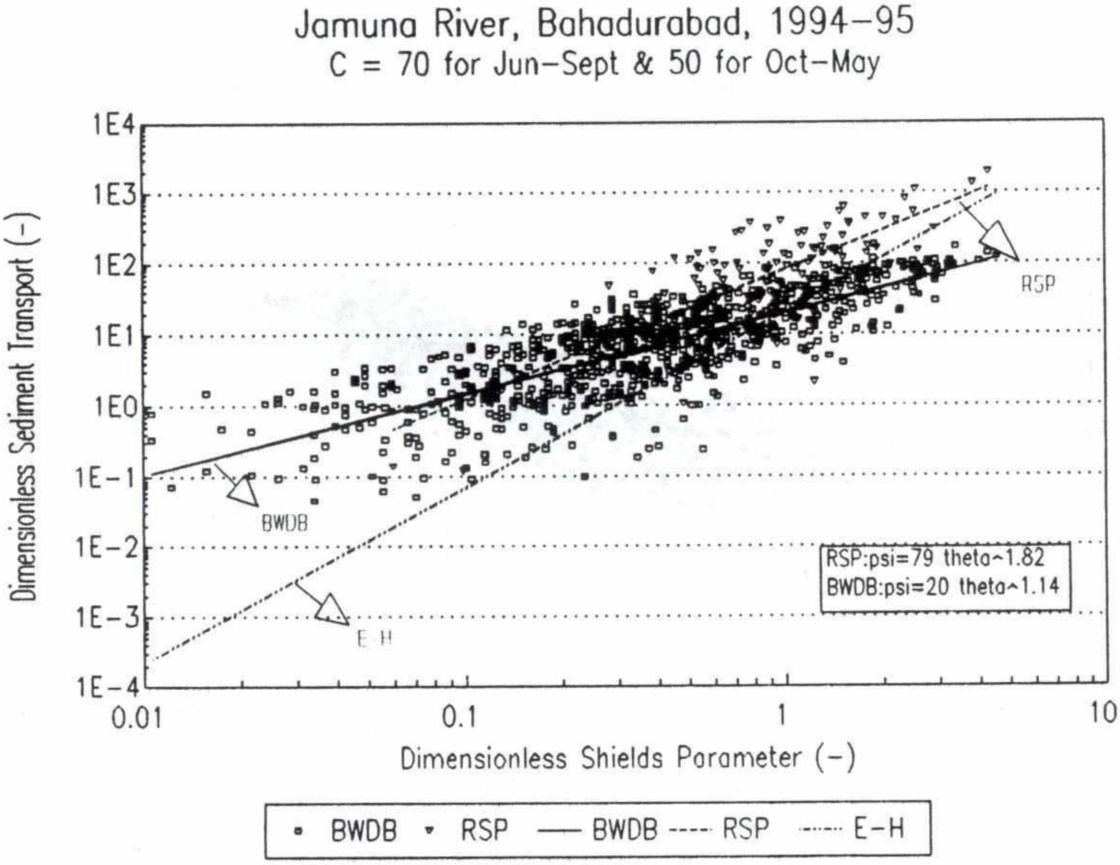


Figure 5.6: Sediment transport versus Shields parameter, case 1

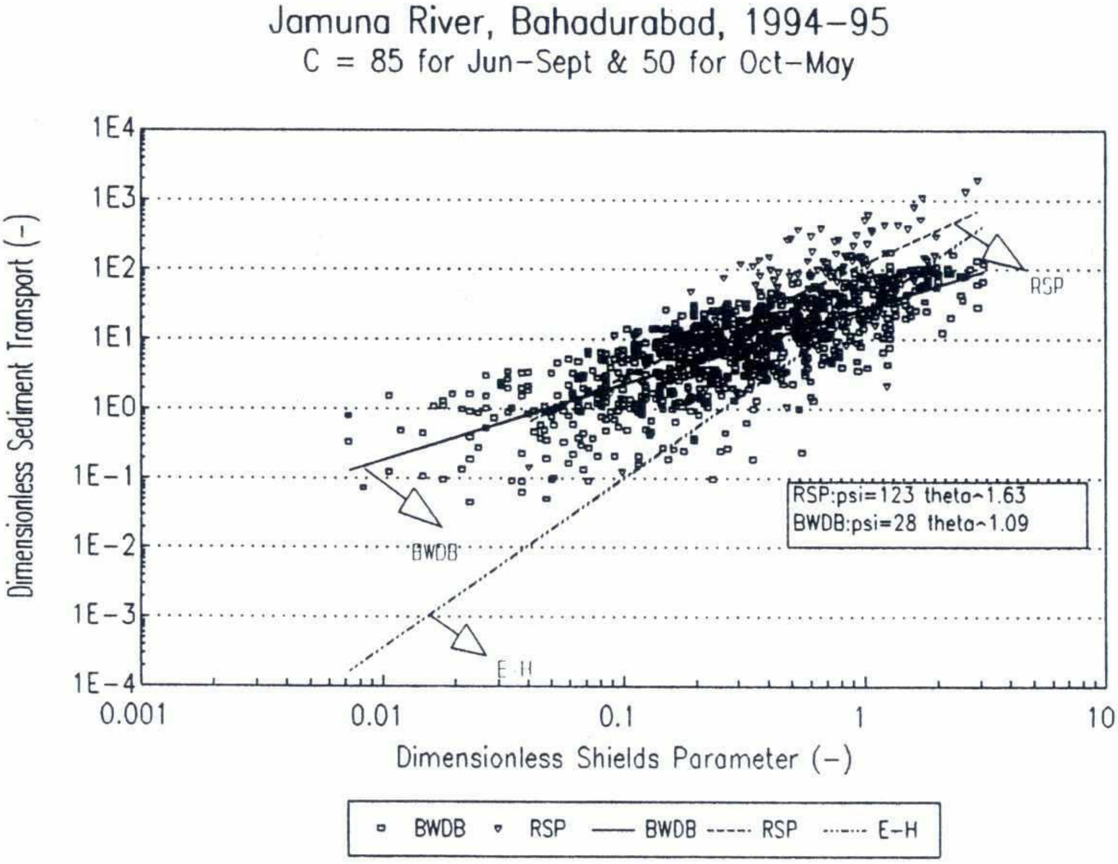


Figure 5.7: Sediment transport versus Shields parameter, case 2

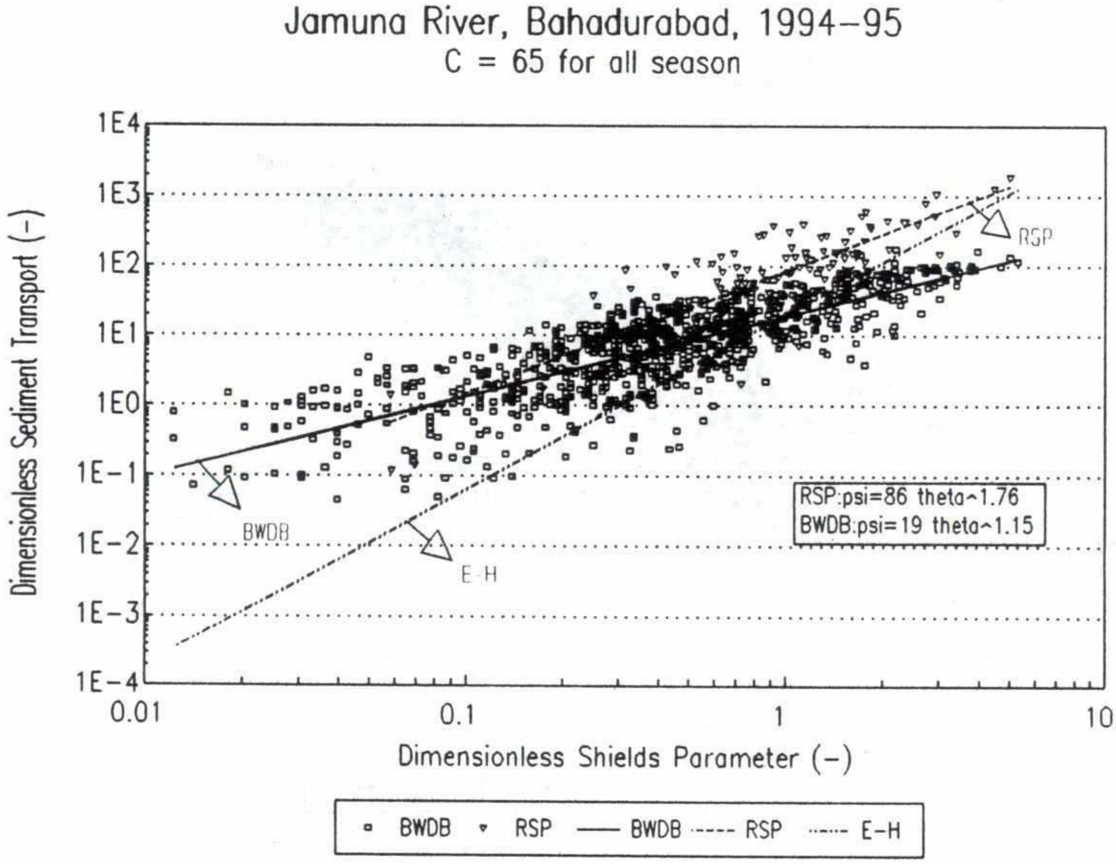


Figure 5.8: Sediment transport versus Shields parameter, case 3

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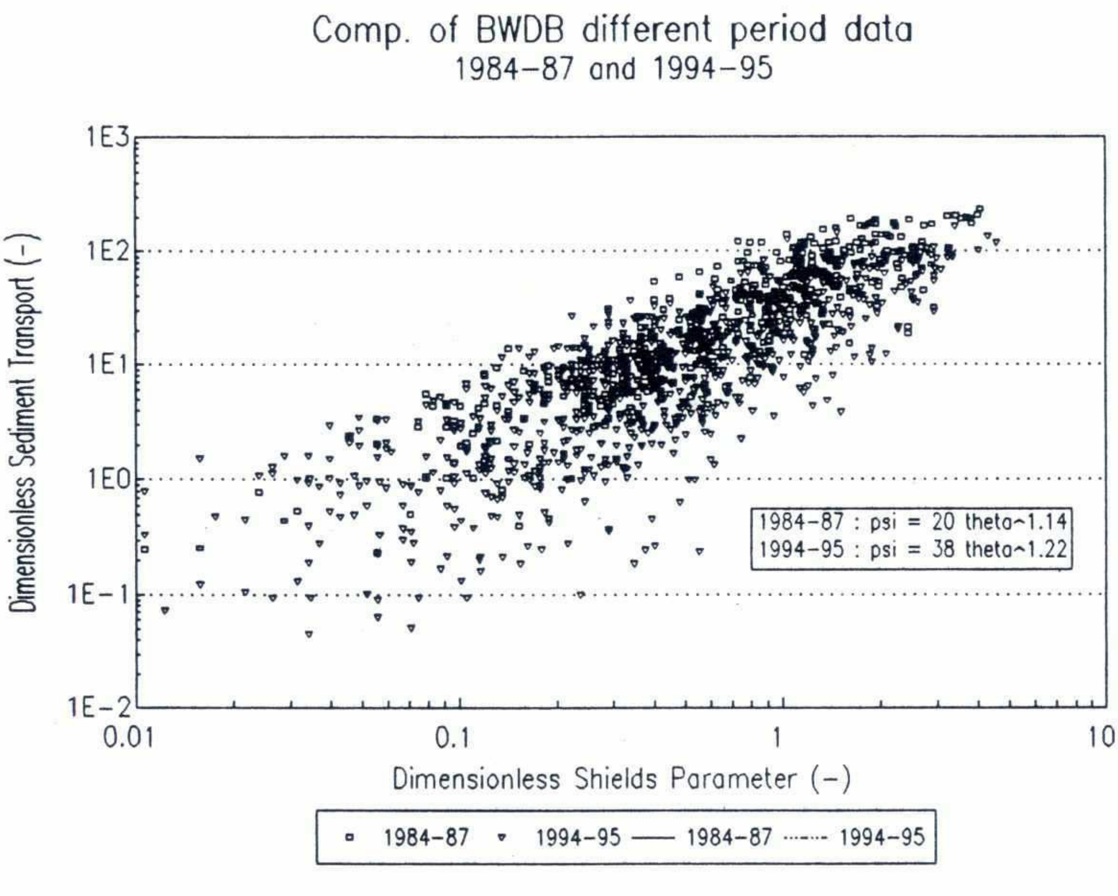

Figure 5.9: Sediment transport versus Shields parameter, BWDB data 1984-87 and 1994-95

Annexure 1: Detailed data of the joint surveys

1 Survey in Jamuna River near Bahadurabad, 16 - 20 July 1995

Joint measurements were taken from 17 to 20 July 1995 along the BWDB transect in Jamuna River, just north of Bahadurabad Ghat on the left bank, and just downstream of Fulchari on the right bank. Some results from the measurements are presented in Table A1.1.

Vertical No.	Depth		Velocity (u)		Ratio BWDB/RSP (-)	Flow angle	
	(h)	(m)	RSP (m/s)	BWDB (m/s)		RSP (degrees)	BWDB (degrees)
Right Channel							
V14	0.2	1.72	1.1	1.28	1.16	42.11	49
	0.8	7.08	0.77	1	1.30	47.92	49
V18	0.2	1.81	1.12	1.2	1.07	43.57	45.5
	0.8	7.24	0.74	1.02	1.38	39.03	45.5
V22	0.2	1.57	1.19	1.13	0.95	43.57	48.17
	0.8	6.28	0.93	1.05	1.12	44.22	48.17
Left Channel							
V35	0.2	1.43	1.43	1.33	0.93	50.64	56.17
	0.8	5.72	0.81	0.94	1.16	64.19	56.17
V62	0.2	1.04	1.83	1.93	1.05	54.39	57.5
	0.8	4.16	1.55	1.71	1.10	54.43	57.5
V66	0.2	1.71	2.16	2.24	1.04	63.07	55
	0.8	6.84	1.23	1.88	1.52	62.92	55
V67	0.2	1.92	2.16	2.00	0.93	65.48	52.33
	0.8	7.68	1.61	1.80	1.11	68.1	52.33
V69	0.2	1.78	2.65	2.60	0.98	68.35	58
	0.8	7.12	2.28	2.32	1.02	69.9	58
V70	0.2	1.62	3.00	3.14	1.05	68.17	64
	0.8	6.48	2.53	2.58	1.02	69.61	64
V73	0.2	1.86	3.20	3.24	1.01	67.75	69.33
	0.8	7.44	2.42	2.56	1.06	70.69	69.33
V75	0.2	2.1	3.22	3.22	1.00	74.29	66
	0.8	8.4	2.52	2.39	0.95	79.37	66

Table A1.1: Comparison of velocity measurements at Bahadurabad in the BWDB verticals, July 1995

Vertical	concentration at 0.2 h			concentration at 0.8 h			sediment transport		
	BWDB	RSP	Ratio	BWDB	RSP	Ratio	BWDB	RSP	ratio
	mg/l	mg/l	-	mg/l	mg/l	-	kg/(m.s)	kg/(m.s)	-
2	24	9	2.7	40	38	1.0	0.039	0.12	0.3
38	48	208	0.2	82	270	0.3	0.54	3.02	0.2
40	45	75	0.6	77	234	0.3	0.26	0.44	0.6
42	45	30	1.5	77	113	0.7	0.28	0.22	1.3
48	31	141	0.2	52	254	0.2	0.12	0.72	0.2
67	64	131	0.5	111	18	6.2	1.50	1.70	0.9
69	69	190	0.4	119	342	0.3	1.93	5.44	0.4
71	72	236	0.3	124	1050	0.1	2.17	13.8	0.2
73	74	142	0.5	127	1150	0.1	2.54	5.58	0.4
75	76	277	0.3	132	2220	0.1	2.89	34.7	0.1
average:	55	144	0.7	94	570	0.94	1.2	6.6	0.45

Table A1.2: Concentration and sediment transport of the sand fraction in selected verticals in the joint survey near Bahadurabad, July 1995

2 Survey in Padma River near Mawa, October 1995

Vertical No.	Depth (m)		Velocity (u) (m/s)		Ratio BWDB/RSP	Flow angle relative to transect (degrees)	
			RSP	BWDB		RSP	BWDB
V01	0.2	2.22	1.2	1.03	0.86	53.58	46.13
	0.8	8.88	0.87	0.75	0.86	52.30	46.13
V02	0.2	2.28	1.25	1.27	1.02	47.31	48.00
	0.8	9.12	0.75	0.89	1.19	42.24	48.00
V03	0.2	1.87	1.2	1.22	1.02	46.99	48.82
	0.8	7.48	0.93	0.82	0.88	48.15	48.82
V04	0.2	1.48	0.95	1.01	1.06	39.83	46.00
	0.8	5.92	0.72	0.75	1.04	42.10	46.00
V05	0.2	1.32	1	0.96	0.96	40.61	48.33
	0.8	5.28	0.76	0.67	0.88	40.94	48.33
V07	0.2	2.47	1.05	1.16	1.10	49.40	53.00
	0.8	9.88	0.67	0.94	1.40	48.28	53.00
V09	0.2	2.23	1.35	1.23	0.91	48.16	52.53
	0.8	8.92	1.06	1.01	0.95	47.03	52.53
V10	0.2	2.13	1.43	1.47	1.03	52.28	56.00
	0.8	8.52	1.17	1.13	0.97	50.53	56.00
V11	0.2	1.84	1.52	1.46	0.96	56.85	56.17
	0.8	7.36	1.19	1.13	0.95	56.91	56.17
V12	0.2	1.23	1.55	1.41	0.91	57.16	56.00
	0.8	4.92	1.29	1.11	0.86	58.50	56.00
V14	0.2	1.65	1.55	1.51	0.97	58.15	60.78
	0.8	6.60	1.25	1.18	0.94	59.85	60.78
V15	0.2	1.41	1.14	1.34	1.18	52.59	54.88
	0.8	5.64	1	1.07	1.07	51.73	54.88
V17	0.2	1.36	1.1	0.95	0.86	56.75	49.00
	0.8	5.44	0.69	0.65	0.94	53.67	49.00
V29	0.2	1.5	2.1	2.06	0.98	98.21	99.38
	0.8	6	1.73	1.73	1.00	98.97	99.38
V30	0.2	2.02	1.93	2.14	1.11	98.95	85.30
	0.8	8.08	1.66	1.77	1.07	95.15	85.30
V31	0.2	1.68	1.88	2.12	1.13	102.60	85.65
	0.8	6.72	1.67	1.73	1.04	98.90	85.65
V32	0.2	1.6	2	2.01	1.01	104.34	99.67
	0.8	6.4	1.68	1.67	0.99	100.18	99.67
V33	0.2	1.2	2.05	1.95	0.95	102.29	97.00
	0.8	4.8	1.93	1.58	0.82	99.95	97.0

Table A1.3: Comparison of flow velocity at BWDB verticals at Mawa, October 1995 x Q

Vertical	concentration			concentration		sediment transport		
	BWDB	RSP	Ratio	BWDB	RSP	BWDB	RSP	ratio
	mg/l	mg/l	-	mg/l	mg/l	kg/(m.s)	kg/(m.s)	-
1	235	897	0.3	-	409	2.3	10.4	0.2
3	193	78	2.5	-	393	1.8	0.9	2.1
5	431	274	1.6	-	409	2.3	1.6	1.4
7	191	89	2.2	-	462	2.5	1.0	2.5
9	245	82	3.0	-	474	3.0	1.1	2.7
11	320	106	3.0	-	359	3.8	1.3	2.9
15	107	114	0.9	-	362	0.9	0.9	1.0
17	109	75	1.4	-	441	0.6	0.4	1.4
27	106	334	0.3	-	726	0.5	1.6	0.3
29	250	87	2.9	-	432	4.8	1.6	3.0
31	203	118	1.7	-	481	3.3	1.7	1.9
33	147	158	0.9	-	505	1.6	2.2	0.7
average	211	201	1.7	-		2.3	2.1	1.7

Table A1.4 The concentration and the sediment transport in selected verticals in the joint survey in Padma River near Mawa, October 1995

3 Survey in Jamuna River near Bahadurabad, November 1995

Joint measurements were made by BWDB and RSP on 7 to 8 November 1995 in the left channel of the Jamuna River near Bahadurabad Ghat.

Vertical No.	Depth by BWDB (m)		Velocity (u) (m/s)		Ratio BWDB	Velocity vector (m/s)		Ratio BWDB	Flow angle relative to transect	
			RSP	BWDB	RSP	RSP	BWDB	RSP	RSP	BWDB
Left Channel										
V03	0.2	1.95	1.25	1.3	1.04	1.47	1.60	1.09	58	55
	0.8	7.8	0.86	1.08	1.26	1.05	1.33	1.26	55	55
V04	0.2	2.4	1.3	1.36	1.05	1.49	1.57	1.05	61	60
	0.8	9.6	0.8	1.04	1.30	0.96	1.20	1.25	56	60
V05	0.2	2.43	1.3	1.34	1.03	1.39	1.56	1.12	69	59
	0.8	9.72	0.85	1.03	1.21	1.04	1.20	1.15	55	59
V06	0.2	2.35	1.32	1.24	0.94	1.49	1.49	1.00	62	56
	0.8	9.4	0.83	0.98	1.18	1.06	1.18	1.11	51	56
V07	0.2	2.4	1.18	1.21	1.03	1.31	1.47	1.12	64	56
	0.8	9.6	0.87	0.96	1.10	1.03	1.16	1.12	57	56
V08	0.2	2.15	0.92	1.19	1.29	1.04	1.30	1.25	63	67
	0.8	8.6	0.8	0.91	1.14	0.97	0.99	1.02	55	67
V09	0.2	2.06	0.62	0.85	1.37	0.66	0.90	1.37	71	71
	0.8	8.24	0.61	0.61	1.00	0.70	0.64	0.93	61	71
V10	0.2	1.03	0.96	1.02	1.06	0.99	1.05	1.06	77	76
	0.8	4.12	0.71	0.77	1.08	0.77	0.79	1.03	67	76

Table A1.5: Comparison of flow velocity at BWDB verticals at Bahadurabad, 7-8 November 1995