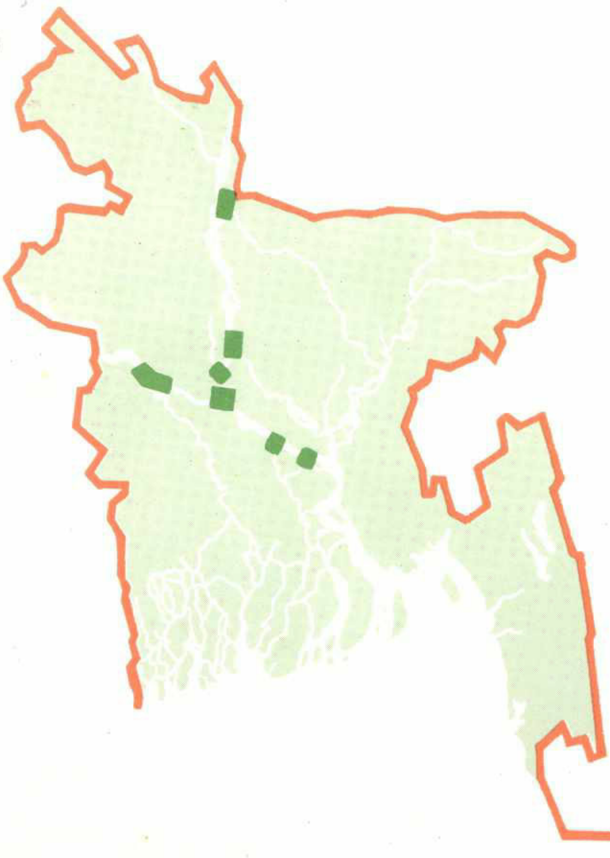
GOVERNMENT OF BANGLADESH
FLOOD PLAN COORDINATION ORGANIZATION

FAP 24 RIVER SURVEY PROJECT

Selection of Survey Techniques

November 1993



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

Selection of Survey Techniques

November 1993

FAP 24 RIVER SURVEY PROJECT
Flood Plan Coordination Organization
DELFT-DHI Commission of the European Communities
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May 10, 1994

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

Attention : Mr.Afzalur Rahman.
Superintending Engineer.

Subject : Report Selection of Survey Techniques

Our ref : RSP/9.1/926

Dear Sir,

During the monsoon of 1993 test measurements were executed on the Jamuna River near Bahadurabad. The results hereof were published in the draft survey report 'Test Gauging Report', distributed during the International Workshop of November 1993. The interpretation of the results of the test measurements, the discussions during the workshop and the experience gained while working on the rivers of Bangladesh, led to a selection of survey methods and instruments to be used in phase 2 of the River Survey Project.

With pleasure we submit herewith our report on the Selection of Survey Techniques.

Thanking you,

Yours sincerely

Pieter van Groen.
Team Leader.

Contents

Acronyms and abbreviations

ADCP	:	Acoustic Doppler Current Profiler
AWLR	:	Automatic Water Level Recorder
AZTM	:	Acoustic sediment transport meter
BoQ	:	Bill of Quantities outlined in the consultancy contract of 22 May 1992 and amendments
BTM	:	Bangladesh Transverse Mercator
BTMA	:	Bed load Transport MeterArnhem
Contract	:	The consultancy Contract of 22 May 1992, ALA/90/04 and amendments
DGPS	:	Differential Global Positioning System
DHA	:	Survey vessel A (mother ship)
DHC	:	Survey vessel C (catamaran type)
EMF	:	ElectroMagnetic Flow meter
FPCO	:	Flood Plan Coordination Organization
GPS	:	Global Positioning System
Hydro	:	A Hydrographic software package
MBM	:	Moving Boat Method
MEX 3	:	An optical turbidity meter
Ott	:	A mechanical current meter
PA	:	Project Adviser
PWD	:	Public Works Department (geodetic datum)
S4	:	An electromagnetic current meter
SOB	:	Survey Of Bangladesh
TS	:	Technical Specifications included in the Contract
UHF	:	Ultra High Frequency
WGS	:	World Geodetic System (1984)

List of symbols

h	Depth	m
q	Discharge per unit width	m^2/s
q_s	Sediment discharge per unit width	kg/s/m
U	Depth average velocity	m/s

1. Introduction

According to the consultancy contract of May 22, 1992, River Survey Project FAP 24, ALA/90/04, a test gauging has to be performed in the Jamuna/Brahmaputra River at the Bahadurabad cross-section.

The test gauging has to be performed as early as possible during phase 1. The river flow stage during the test gauging should correspond to a discharge higher than the mean discharge, which is 20,000 m^3/s and as close as possible to bank-full discharge, which is approximately 40,000 m^3/s.

The test gauging was originally planned to take place during the 1992 flood season. Owing to a delayed project start in combination with a relatively low river stage during the 1992 flood season it was decided that execution of a test gauging at that moment would not have fulfilled the objectives. Consequently it was decided to postpone the test gauging programme until August 1993.

From 16 till 22 August 1993 the test measurements have been executed in the Jamuna River near Bahadurabad to achieve a final acceptance of the measuring techniques introduced by the consultant (see Test Gauging Report, October 31, 1993).

The results of these tests and other previous survey results are analyzed in order to assess the applicability of the various techniques in the main river systems of Bangladesh. The analyses (Chapter 2) are directed towards

- optimization of methods
- selection of techniques

Optimization of methods means that reductions are sought, in terms of measurement intensity and time, reducing survey work without loosing accuracy. Selection of techniques means that results obtained with different instruments and methods are compared in order to find the most suitable methods for different conditions (location and stage).

The results from the analysis are used to propose the techniques to be applied in phase 2 of the River Survey Project, see Chapter 3. The techniques must fulfil two objectives:

- Collection of reliable and accurate data
- Providing useful observations and data necessary for a better understanding of hydraulic and morphological processes.

Operational aspects of the proposed techniques, to realize a desired survey programme (location, parameters and frequencies) are elaborated in Chapter 4.

2. Main conclusion from analysis of test gauging data

2.1 General information

The measurement results presented in Chapter 8 of the Test Gauging Report, October 31, 1993 have been subject to a more detailed analysis in order to select and optimize the future survey techniques.

Optimization of survey techniques means that methods are sought aiming at reducing the survey work without loosing the required accuracy. Both spatial and temporal reductions are considered. For instance

- o spatially
  - number of measurement points in the vertical profile
  - number of verticals in the cross-section
  - horizontal distribution in view of bed-forms
  - network lay-out (place of gauging stations in the river systems)
- o temporally
  - sampling time per point measurement
  - duration of one measurement (per station)
  - seasonal frequencies

Selection of survey techniques means that instruments and methods are compared on basis of survey results. This has been done for the following kind of measurements

- o water-levels (pressure cell versus acoustic sensor)
- o discharge (recommended versus reference method)
- o suspended sediment transport (MEX 3, pump bottle, depth integrating and ADCP)
- o bed load (Helley-Smith and dune-tracking)
- o bed material sampling (Van Veen and US BM-54)

The conclusions of the data analysis are summarized in the next sections.

2.2 Positioning

The performance of the Differential Global Positioning System (DGPS) using a mobile reference station to be installed in the individual survey areas have been very reliable. The reference station continuously transmits correction signals to the respective survey vessels.

The positioning system has been verified by comparing known BTM coordinates of bench-mark no. GPS 764 at Bahadurabad with the coordinates as measured by DGPS in stationary mode. The results are presented below:

GPS 764 coordinates	Measured coordinates	Discrepancy
BTM E 471086.158	BTM E 471084.4	E 1.8m
BTM N 778478.880	BTM E 778477.4	N 1.4m

The deviation was within the 2 m horizontal accuracy as claimed by the manufacturer for the DGPS system operating in stationary mode.

According to field experience the DGPS system is operating with a horizontal accuracy of 4 m in dynamic mode. This pertains in particular to the moving boat method (MBM).

2.3 Water-level

Simultaneous measurements with an acoustic sensor and pressure cell recorder during the flood season of 1993 have shown that the two types of recorders measure with the same accuracy and reliability, see Annexure 1 and Figure 2.1.

The measuring principles are obviously quite different. For the pressure cell aspects related to the weight of the water column (salinity, sediments) and the atmospheric pressure are of importance. For the acoustic type the speed of sound through the air and consequently the air properties like temperature and humidity (rain) should be considered carefully.

It was investigated whether heavy rain would disrupt the acoustic signals, but the records have clearly shown a continuous and reliable functioning, see Figure 3.3 of Annexure 1.

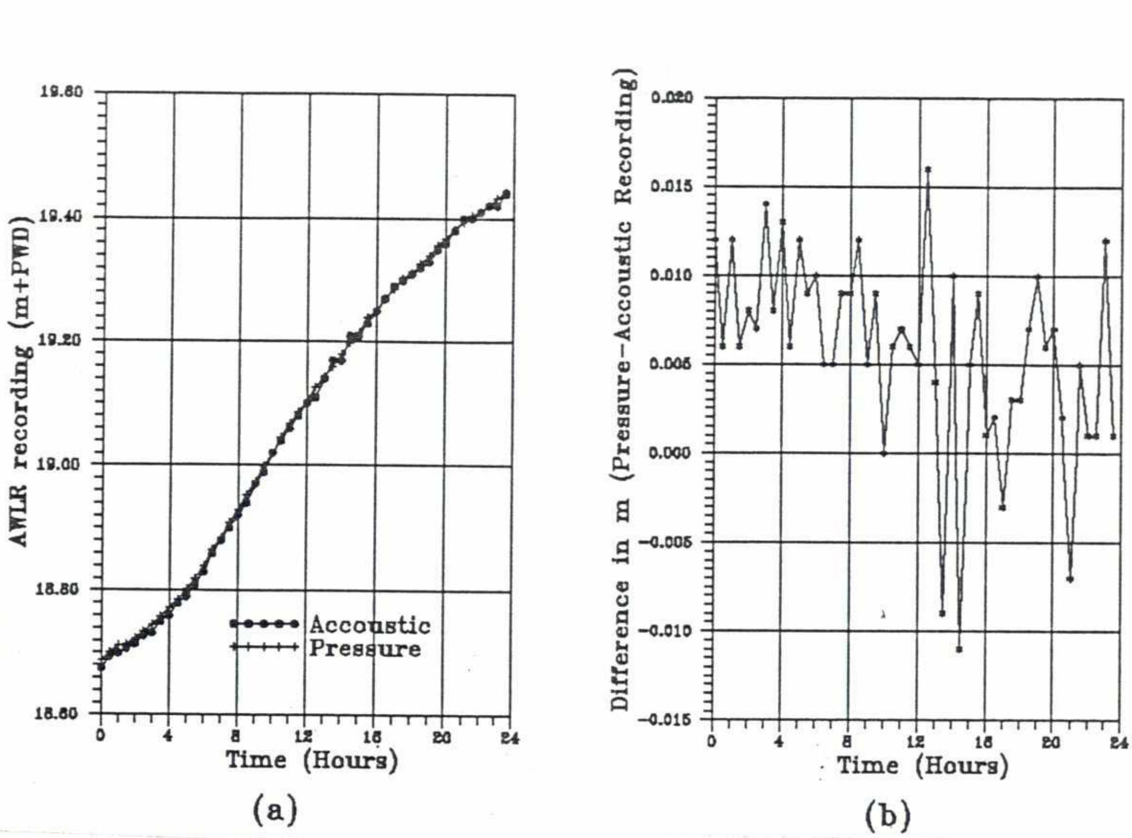


Figure 2.1 Comparison of half hourly recordings by the pressure cell type and the acoustic type water-level recorder at Gabgachi, 20 July 1993.

2.4 River charting

The integrated bathymetric survey system consisting of the Differential Global Positioning System interfaced to a single (210 kHz) or a dual (30 kHz and 210 kHz) frequency echo-sounder have functioned well during the first year of measurements. Even during peak flow conditions with high concentrations of suspended sediments the acoustic contact with the river bed has been very stable.

Bathymetric surveys have been carried out for:

- o Charting of the river bed
- o Cross-section surveys for discharge measurements
- o Sand-dune tracking

A separate mobile DGPS unit mounted in a backpack has also been used for mapping of river banks and shorelines on the various shoals and islands in the river.

Experience from the field, during execution of the bathymetric pilot survey has shown that the number and extent of shallow areas is larger than expected. This means that optimization of the bathymetric survey operation requires deployment of shallow draft survey boats.

So far the distance between survey lines has been kept at 100 m. This aspect of line inter distance will be further investigated in a prospective report on the bathymetric pilot survey in a 10 km x 20 km area in the Jamuna River at Bahadurabad Ghat.

The locations for dune-tracking are determined with the aid of an echosounder. The pattern of the dunes are 'mapped' with the side scan sonar. The side scan sonar image is used to plan the survey lines of the dune-tracking. Although not really required, usually the lines are drawn as perpendicular as possible to the dune crests.

2.5 Discharge and current velocities

2.5.1 Recommended method

This section comes in three parts. Firstly results of the recommended method are summarized. Then the results of the reference method is presented and finally the differences between the methods is discussed.

The recommended method is also known as the moving boat method (MBM) where current velocities are measured by either ADCP or EMF or ADCP and EMF in combination. The discharge is calculated by interpolation of numerous vertical velocity profile measurements, see 1° Interim Report Volume II, Appendix 1, February 1993.

Discharge measurements by the recommended method using the combined instrument configuration of EMF and ADCP have shown consistent results. During the test gauging 9 discharge measurements, covering a main river channel of 2,900 m width, were carried out. Each crossing of the test gauging cross-section lasted approximately half an hour. The standard deviation of the discharge amounted to 3.2 per cent only. The maximum and minimum values deviate about 5% from the average. This indicates that no averaging over several transects is needed. It is concluded that the reproductivity is very good and the stochastic part of the errors is small. For possible systematic errors see Subsection 2.5.3.

As an example of the reproductivity, two (out of the nine) discharge measurements (the maximum and the minimum) are compared in the following figure.

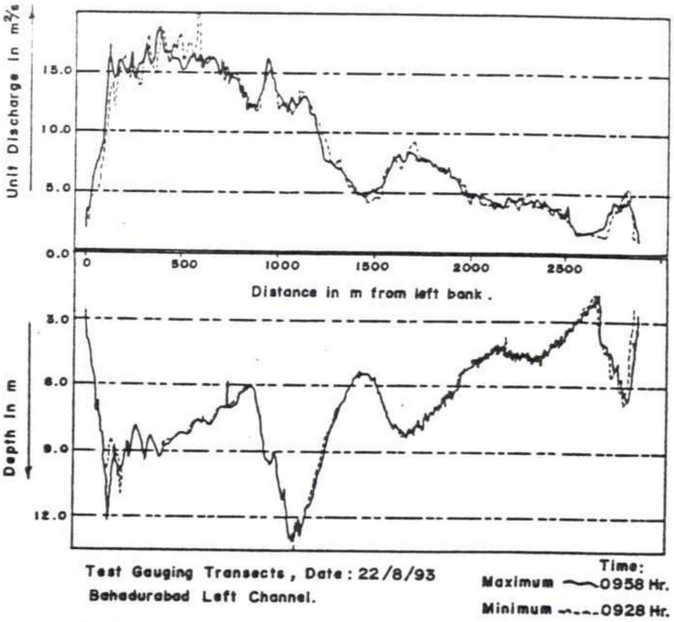


Figure 2.2 : Comparison of EMF/ADCP gaugings

A typical record from the Bahadurabad cross-section (left channel) is shown in Figure 2.3. A large horizontal variation in flow directions requires current direction measurements for the related discharge calculations. Judging by Figure 2.3 this is obviously the case in the Bahadurabad cross-section.

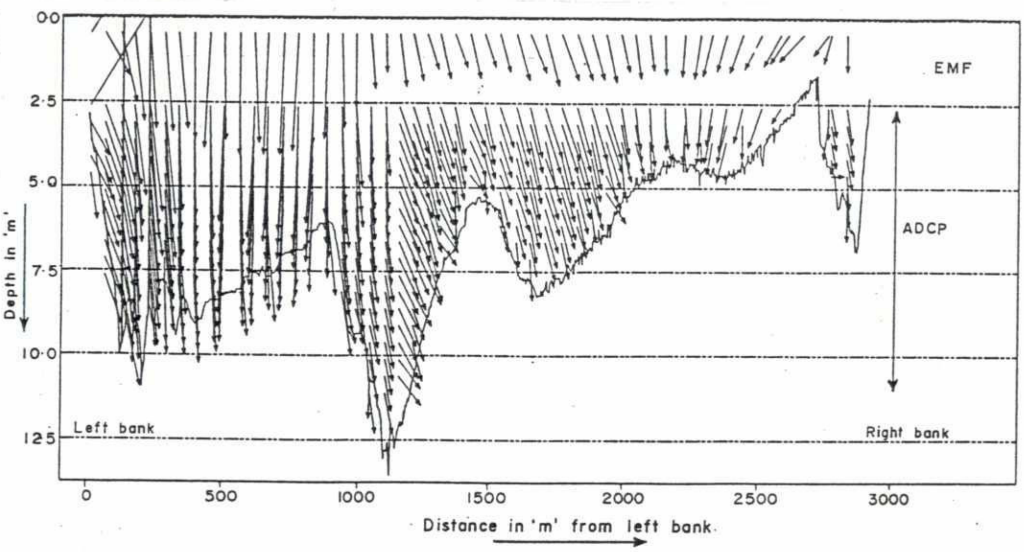


Figure 2.3 Current velocity distribution in the Bahadurabad left channal cross-section.

From Figure 2.3 it can also be seen that the vertical variation in the flow direction is generally small. Only around strong horizontal gradients the flow direction varies along the vertical. It is concluded that the surface flow direction seems to be reasonably representative for the flow direction in the whole cross-section.

The moving boat method using EMF measurements alone in a layer 0.5 m - 1.0 m below the surface is relevant in some cross-section, see Figure 2.4, depending on the flow field. In some cases the EMF method is not applicable viz.

- o two phase flow (density currents)
- o strong variations in the flow direction over the vertical

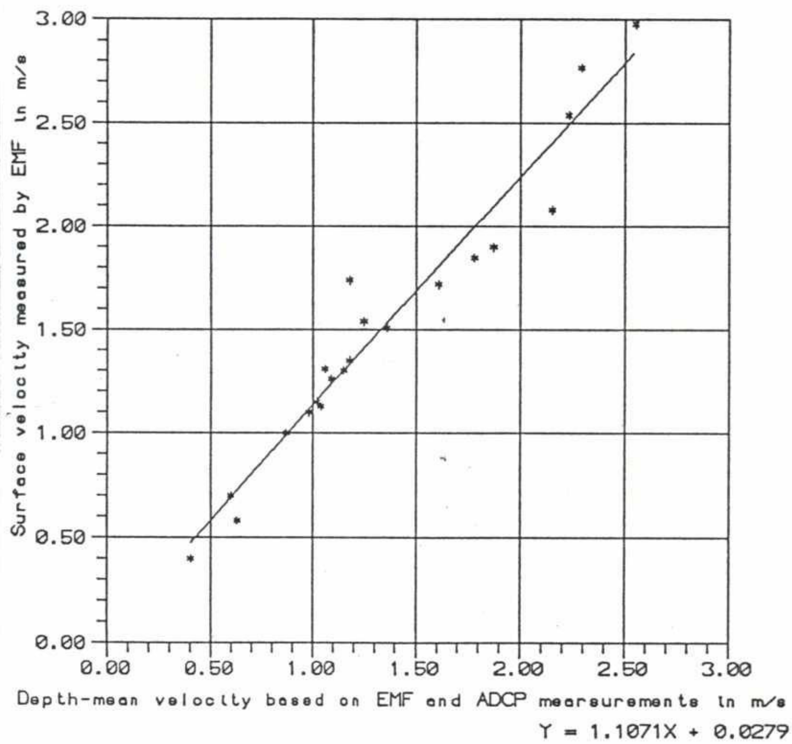


Figure 2.4 Surface velocity as measured by EMF versus depth mean velocity as measured by EMF and ADCP

So this means that the surface velocity equals 1.107 times the mean velocity or the other way around : the mean velocity is 0.90 times the surface velocity. The latter figure is rather consistant as ratio's of about 0.9 are usual in big sand-bed rivers.

2.5.2 Reference method

The reference method is also known as the velocity area method. The discharge is calculated by interpolation of point velocity measurements in the test gauging cross-section. The velocity averaged over the vertical is computed assuming zero velocity by the river bed and no variation in the uppermost part of the velocity vertical. For the horizontal interpolation the mean section method was used.

The velocity area methods was applied by using two type of current meters

- o in general the S4, an electromagnetic type
- o and sometimes an Ott, a propellor type

Although the results (comparison of velocity verticals) were reasonably close, quite some differences were observed which needs further investigation.

The velocity area method appeared very time consuming (17 verticals and 6 points per vertical for one channel), so some study was done on possibilities to reduce the nos of measuring points in the cross-section. Obviously, the possible reductions depend on the (ir)regularity of the flow field.

Analysis and comparison of the current distribution in the test gauging cross-section as measured by the reference method by manual profiling have revealed the following findings.

- o In most areas the vertical current profile is rather regular. This means that the number of point measurements by manual profiling may be reduced from 6 to 2 or 3 points, see Annexure 2

- o The U^2/h distribution has been analyzed in Annexure 3. Obviously this approach does not take into account the varying cross-sections and the plan-form geometry. A constant U^2/h distribution indicates a regular flow distribution in balance with the erodible cross-section. Apparently there is an imbalance in the deeper part of the test gauging cross-section whereas the shallow majority of the cross-section seems to be in balance, see Figure 2.5. This indicates a regular horizontal flow distribution in the shallow majority of the cross-section. Consequently only a few measurement verticals are needed in the shallow majority of the cross-section compared to the present specification of one vertical per 100 m.

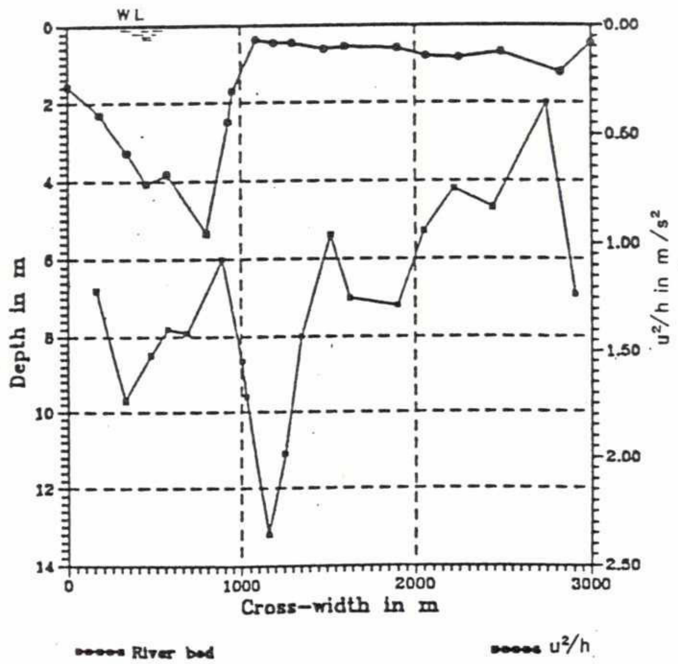


Figure 2.5 Transverse distribution of U^2/h in the test gauging cross-section.

2.5.3 Comparison between methods

Comparison of the recommended method and the reference method is obviously a little bit difficult because of the complete different nature of the methods. What is done however is comparison of verticals and of total discharges. From the verticals it is concluded that there is a fairly good agreement between the two methods, see Figure 2.6

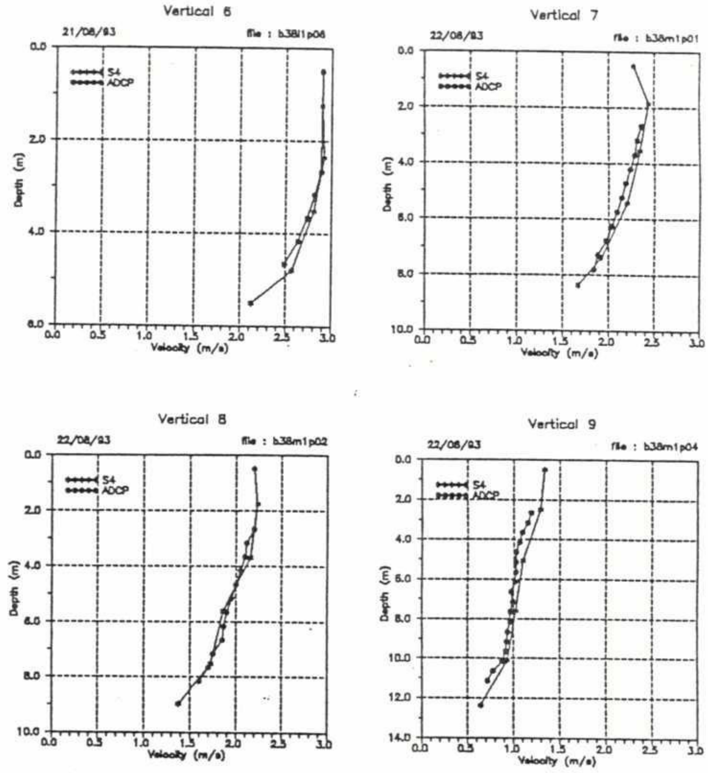


Figure 2.6 Comparison of ADCP and S4 velocity verticals

Comparison of a series of discharges gave as a result that the ADCP/EMF gives on average 7% higher discharges than the S4.

The overall conclusion is that the recommended method is certainly a good alternative and is the more attractive the bigger the cross-sections are. However, further comparison between various techniques is certainly required.

2.6 Suspended sediment transport measurements

Suspended sediment transport has been measured in various ways :

- o Point integrating pump bottle sampling
- o Depth integrating bottle sampling
- o Optical turbidity measurements (MEX 3)
- o Acoustic backscatter measurements (ADCP)

All these techniques are aiming at determination of suspended sediment concentration. Hence the methods are indirect, which means that they should be combined with velocity measurements in order to determine the transport.

As point integrating sampling comes closest to the method of sampling applied in Bangladesh (using a Brinkly sampler) this methods is discussed first, whereafter the other three methods are compared with the results of the first one. The comparisons focus on concentration rather than transport.

2.6.1 Point integrating sampling

Point integrating pump bottle sampling of suspended sediment means that a carrier is lowered to a certain point in a measuring vertical. On the carrier an intake nozzle is mounted and via a tube and pump system a water/sediment sample is pumped into a bottle or container aboard the survey vessel. The samples are taken to the laboratory where (amongst others) the sediment concentration is determined. Usually 6 points per vertical are taken to establish a fair concentration vertical.

The method is rather solid in case a number of conditions (regarding intake velocity, tube velocity, sampling duration, analyses method) are met appropriately. However, the method is time consuming both in the field and in the laboratory. As a first step a reduction of the number of point samples is considered (both less points in the vertical and less verticals). Thereafter, in the next sub-sections, other methods are considered.

Vertical concentration profiles
A comparison of concentration profiles determined by a six point pump bottle method and concentration profiles determined from less than six points indicates that the number of points per vertical may be reduced, see Annexure 3. However, comparisons done so far are based on the total suspended sediment concentration of which the wash load accounts for a substantial portion. Further analyses discerning between wash load and bed material load are required prior to more firm conclusions. These analyses are included in the study programme, topic 9.3; ref. Study Report 1, September 1993.

Horizontal concentration distribution
In order to investigate how the sediment transport through the cross-section is related to the flow field, the sediment index, $q_s/q^{1.42}$, is plotted over the width, see Figure 2.7. The index is taken from the sediment rating curve of Bahadurabad, which reads

$$q_s = 0.30\,(q)^{1.42}$$

Where

q_s = suspended sediment discharge per unit width
q = water discharge per unit width

See further Annexure 3.

From the example, see also Figure 2.5, it can be seen that in spite of the irregular cross-section and flow field the sediment index is surprisingly regular, indicating possibilities for reducing the number of sediment measurement verticals in the cross-section. Obviously this is not a general conclusion and further analysis is required for other stages and other stations. This is further addressed in the study programme, topic 9.3; ref. Study Report 1, September 1993.

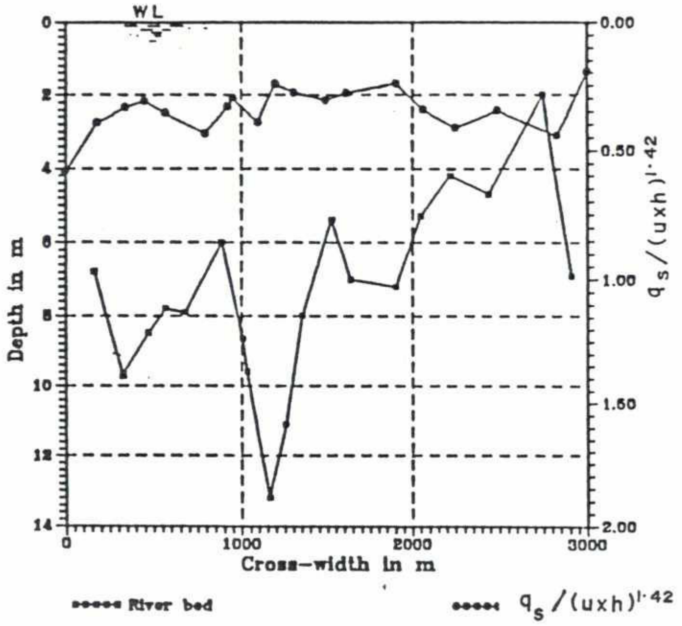


Figure 2.7 The $q_s/q^{1.42}$ index plotted as a function of the width.

2.6.2 Point versus depth-integrated suspended sediment sampling

Obviously, considerable time can be gained when (at least a part of) the six point verticals can be replaced by depth integrating sampling. If transport is the main objective, the vertical concentration profile is less important and direct measurement of the depth average concentration may be considered. In the following the suspended sediment concentrations measured by point sampling and depth integrated sampling have been compared, see Figures 2.8 and 2.9.

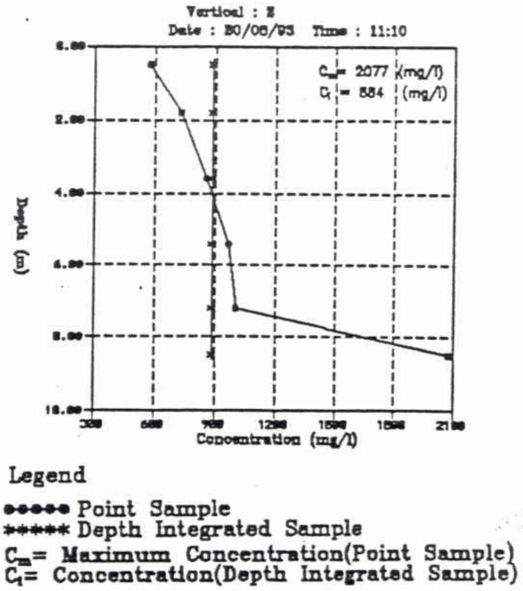


Figure 2.8 Suspended sediment concentration by point measurements versus depth integrated sample.

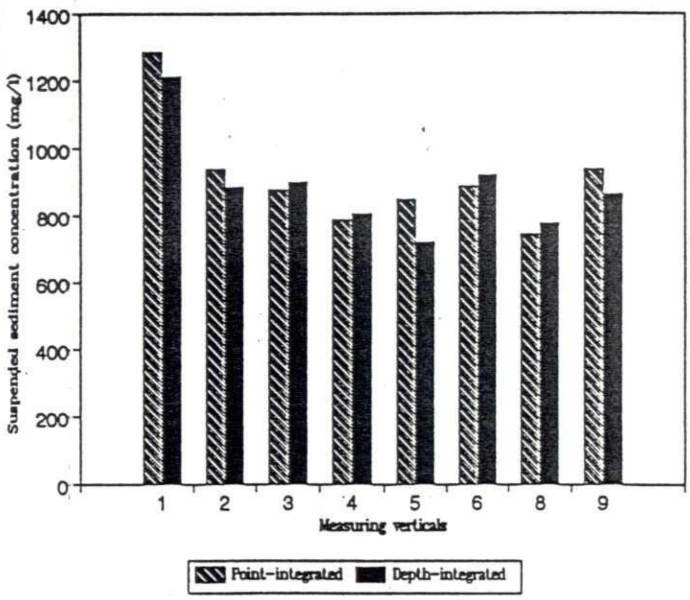


Figure 2.9 Bar chart comparison of depth average suspended sediment concentrations based on point samples versus depth integrated concentrations

In most instances the depth integrated suspended sediment concentration, Figure 2.9, is very close to the average concentration obtained by point measurements.

2.6.3 Suspended sediment concentration versus turbidity recording

Applying an optical turbidity meter is attractive because of direct reading and no transport and analyses of samples. Moreover, as the optical sensor is mounted on a carrier, point, depth and width integration is possible. The instrument is also very suitable to record time series. To see, in how far the turbidity meter can be applied, comparison is made with the concentration measurements by pump sampling.

In general, there appeared to be a wide scatter between the relative turbidity profile and pump bottle measurements of suspended sediment concentration. However, in the low concentration range, between 800 to 1300 mg/l or in the turbidity range 8% to 12%, good correlation exists, see Figure 2.10. The scatter is larger in higher concentration ranges. This is probably caused by the insensitivity of the optical turbidity meter to sand and coarser fractions. During high flow conditions, the coarser sediments contribute significantly to the suspended sediment concentration, possibly without affecting the turbidity notably.

The conclusion is that the application of optical turbidity measurements is limited. The best possibilities on the rivers are in the lean season. The technique may also be feasible in the tidal areas. More work is needed to establish the boundaries of applicability.

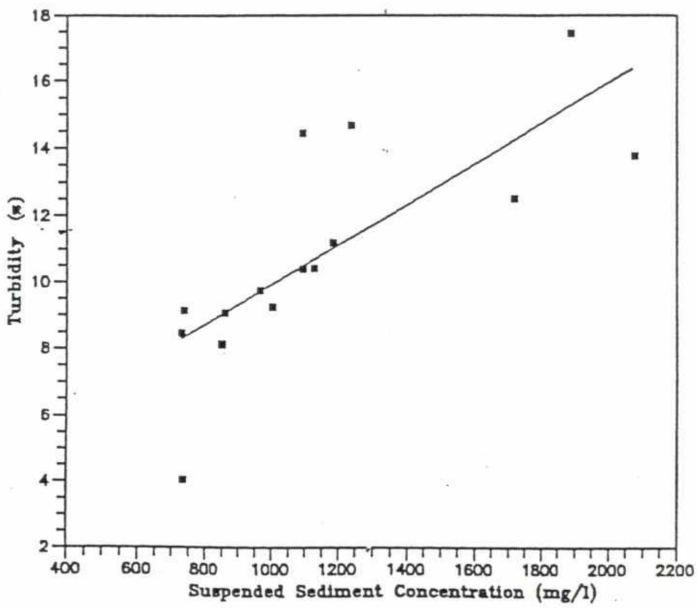


Figure 2.10 Turbidity measurements versus suspended sediment concentrations by pump sampling.

2.6.4 Backscatter and suspended sediment concentrations

During acoustic discharge surveys (with ADCP) also the backscatter is measured. The more particles there are suspended in the beam of sound, the stronger the reflections (= backscatter) are. Hence backscatter is a measure for sediment concentrations. World wide research is going on to develope suspended sediment meters based on this principle. However, it may take five to ten years before something reliable becomes available. In the mean time in the River Survey Project the backscatter is used in two ways :

- **Qualitatively**
  The on-line pattern of the backscatter (see test Gauging Report Appendix 13) is used for planing of the sediment measurement using the previous mentioned method (e.g. for selecting the best locations of the verticals in a transect)

- **More quantitatively**
  Trying to establish more quantitatively a relation between the backscatter (in dB) and the suspended sediment concentration (part of our study programme).

It is concluded that at the moment the acoustic sediment measurements cannot replace the pump-bottle technique. However, optimization of other techniques by backscatter measurements seems possible.

2.7 Bed load transport measurements.

Bed load transport measurements were tested applying two methods :
- Dune-tracking
- Trap sampling

The first method is based on the measurement of the propagation of bed-forms and the relation between the propagation and the bed load transport. The second method is a direct measurement of the sediment transport very close to the river bed. Experience with both methods are described in the following sub-sections.

2.7.1 Dune-tracking

At the proposal stage bed load transport measurements by dune-tracking were suggested. Dune-tracking was done during the test gaugings of August 1993, for results see Test Gauging Report, Appendix 14.

Experience from the test gauging as well as from measurements at the other 10 sites have clearly shown that dune-tracking is not possible under all the physical conditions in the rivers.

The main problems regarding dune-tracking are:

- o Moving dunes are scarce in time and space
- o Dunes may not at all be moving in the dry season. During high flow conditions, like 4 m/s as experienced in the Ganges River, dune formations are not necessarily formed or washed away
- o Existing 2D bed load transport calculation methods are not applicable when complicated dune patterns are available. Special calculation methods need to be developed
- o It is uncertain which part of the dune propagation is actually caused by bed load. This aspect is addressed in the study programme, topic 9.4; ref. Study Report 1, September 1993.

2.7.2 Trap sampling

During contract negotiations the Consultant was requested to add a trap sampler type to the survey spread for testing during phase 1.

During the mobilization a Helley-Smith (HS) trap sampler was installed on the DHA vessel. It turned out to function very well during dry season flow conditions, and consequently a Helley-Smith sampler was installed aboard the DHC vessel also.

During the Test Gaugings in August 1993 the Helly-Smith sampler was tested. For the results see Test Gauging Report, Appendix 10.

Experience during the flood season has shown that operation of the Helley-Smith sampler becomes critical during high flow conditions. Deployment to the river bed is possible, but sampling results show a huge scatter, which is believed to be caused by a combination of scooping and scouring when the sampler approaches and stays on the river bed. Another problem is the timing during the high flows. It is difficult to 'feel' when the sampler touches the river bed. Other problems are the mesh width verses the size of the sediment particles. And last but not least in the high flows, the instrument is used far outside its calibration range.

2.7.3 Alternative methods

It is clear from the experience with the two methods described above that in some cases their applications are limited. Especially in the high flow ranges at locations without dunes, other methods need to be considered.

The Delft Bottle is recommended by the PA, as a possible alternative method. This instrument is procured and will be tested in 1994. Other possibilities are under study.

3. Proposed instruments and methods

In this chapter the proposed instruments and methods are described, starting with a review of the methods as envisaged in the proposal stage of the Project, see Section 3.1. Then the desired modifications are discussed based on the experience gained so far on the river and on the results of the International Workshop 1993, see Section 3.2. In that section the differences between the pre-project selection and the 1993 proposal are highlighted. Then the various proposed methods are described in Section 3.3 and finally a summary of proposed techniques is given in the last section.

3.1 Pre-project selection

Table 3.1 summarizes the techniques of different measurement methods and equipment involved in the so-called "reference method" and "recommended method" as envisaged in the proposal stage of the Project.

Methodology	Reference Method		Recommended Method	
Type of Measurement	a-procedure	b-procedure	c-procedure	d-procedure
Positioning	Sextant + anchoring	DGPS stationary	DGPS	DGPS
Water-level (+Wave height)	Water-level staff gauge	Pressure cell	Pressure cell	Pressure cell
Bathymetry	Echo-sounder single frequency	Echo-sounder single frequency	Echo-sounder dual frequency	Echo-sounder dual frequency
Discharge	Area-velocity method	Area-velocity method	Moving boat	Moving boat
- Current velocity	Propeller	EMF	EMF	EMF + ADCP
- Direction	Floats			
- Area	Echo-sounder	Echo-sounder	Echo-sounder	
Suspended sediment	Water sampling	Pumping	Optical + ref. sampling by pumping	Optical + ref. sampling by pumping + ADCP + depth integrating
Bed load	Dune-tracking with dual frequency echo-sounder	Dune tracking with dual frequency echo-sounder	Dune tracking with dual frequency echo-sounder	Dune tracking + side scan + dual frequency echo-sounder + trap sampling
Bed material	Bottom grab	Bottom grab	Bottom grab	Bottom grab

Table 3.1 Summary of measuring methods (Pre-project selection May 1992)

The main difference between the reference and the recommended methods is the procedure for discharge measurements where the reference method follows the area - velocity concept and the recommended method follows the moving boat procedure.

The reference method may be divided into more traditional a-procedure and a technically improved and possibly more accurate b-procedure.

The recommended method distinguishes a c-procedure and a d-procedure. The main difference between these procedures is in the moving boat type of discharge measurements using either EMF only or a combination of EMF and ADCP.

During an evaluation clarification meeting between the CEC and the tenderer (24 March 1992) it was agreed to add trap sampling as a technique to be tested for bed load transport measurements when the project started (8 June 1992) the Consultant procured a Helly-Smith sampler for the purpose. Moreover a bottle type of depth integrating suspended sediment sampler was added to be tested.

The instrument configuration for the reference and for the recommended method respectively, followed by the River Survey Project up to now, is described in the Test Gauging Report, October 31, 1993. The 1° Interim Report, February 1993 of the River Survey Project also provides a detailed description of each equipment component.

3.2 Modifications

Testing and intercomparison of instrument performance started in October 1992 and since then many measurements have been executed using various techniques for reasons of comparison. As flow conditions were low in October (1992 was a very dry year), final testing was done in the monsoon of 1993 (August). The results hereof were presented in November 1993 during the International Workshop on the "Morphological Behaviour of the Major Rivers in Bangladesh." Also the techniques to be used in phase 2 of the River Survey Project were proposed (Iversen 1993). Especially during the field trip, when the participants of the workshop inspected the equipment and attended some measurements, it became clear that in general the proposed techniques were appreciated. However, it was suggested to add a collapsible bag type of depth integrating suspended sediment sampler (already mentioned in the T.S) to the equipment, especially for use in the deeper channels.

From the test gaugings, the experience gained during working on the rivers in Bangladesh for about 1½ year and the International Workshop it was concluded that the main part of the methods, selected in the pre-project period, appeared to be appropriate. However, some modifications are required. They are discussed hereafter.

3.2.1 Water-levels (AWLR modifications)

Soon after the start of the project it became clear that an acoustic type of Automatic Water Level Recorder could be an interesting alternative for the pressure type proposed. An acoustic sensor was found and tested (first in Europe later in Bangladesh) in combination with the pressure type. The set-up is such that the same main components (recorder, logger) can be used in combination with either the pressure sensor or the acoustic sensor.

3.2.2 Suspended sediment

The optical turbidity measurements gave suspicious results especially in the high flow ranges, and is therefore discarded as a general method for the routine measurements. The optical method will be further tested during the special measurements. Instead of the optical method, the depth integrated method is extended besides the bottle sampler also the collapsible bag type will be applied.

3.2.3 Bed load transport

The two measuring methods dune-tracking and trap sampling showed to have their limitations during the high flows in the monsoon of 1993.

In the 3-4 m/s flow velocity range the trap sampler is hardly to operate in a reliable way and when there are no dunes on the river bed (possibly washed away) alternative methods need to be applied. Such alternatives are under study and will be tested in the monsoon of 1994. So the methods for the bed load measurement will be modified in the near future.

3.2.4 Bed material

The Van Veen bottom grab appeared difficult to operate in medium to high flows in the main channels. Therefore another type of bottom grab was added: the US BM-54, a fish-shaped sinker with a coil spring powered bucket mounted inside. This sampler was applied with good results.

3.3 Proposed techniques phase 2

In this section a description is given of the proposed techniques for phase 2 of the River Survey Project. The same sequence as used previously, (See Table 3.1) is applied in the following sub-sections.

3.3.1 Positioning

Implementation of the improved reference method as well as the recommended methods requires a very accurate positioning system. This is supported by field experience with navigation in the complex river system. In particular during the period after the flood season, when the water-level in the rivers are falling drastically and the navigation depths change rapidly. Occasionally day time field measurements on the river become delayed and navigation back to the berthing site takes place during night hours in complete darkness. Under these circumstances navigation is completely based on the positioning system.

For positioning the River Survey Project has selected the Differential Global Positioning System DGPS, see Fig 3.1.

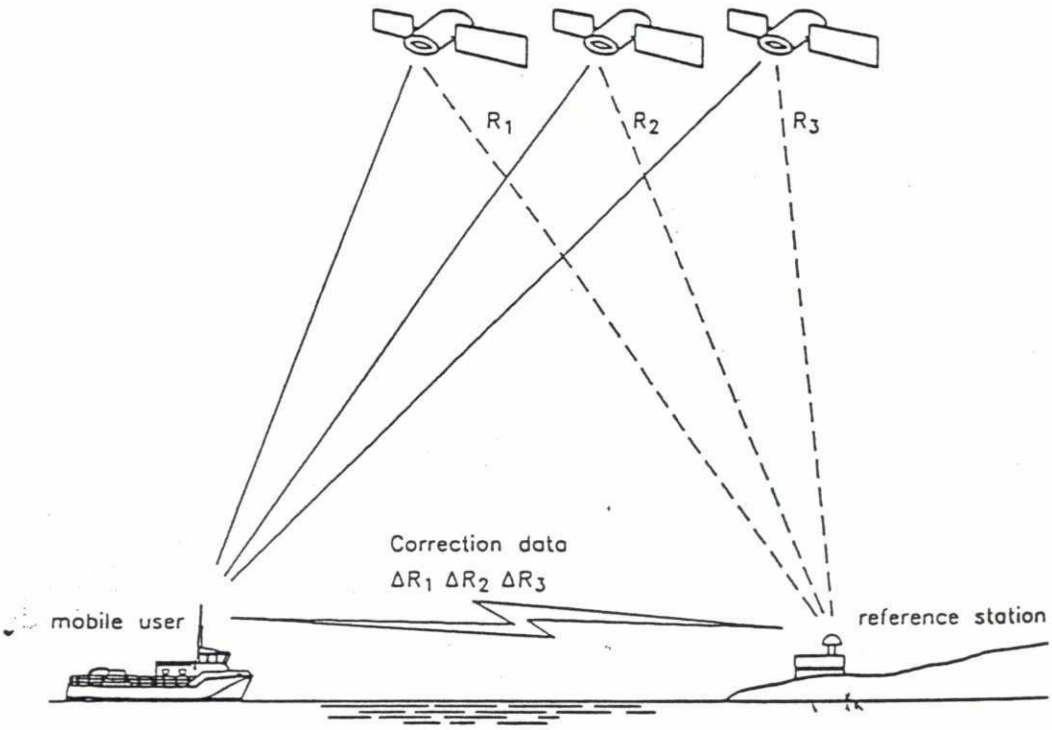


Figure 3.1 Differential Global Positioning System (DGPS) based on pseudo-range correction.

The hardware configuration consists of a reference station to be installed in the individual horizontal reference points ashore and a receiver unit on the survey vessel.

By the beginning of the River Survey Project the positioning system had to be operated without the reference station. This caused inaccurate positioning, and thereby inaccurate current velocity and discharge measurements when using the moving boat method.

After final clarification and determination of co-ordinates for the bench-marks to be used for the installation of the reference stations, the performance of the DGPS system has been very accurate (see Section 2.2). Therefore, the DGPS system is recommended for future deployment in the River Survey Project survey spread.

3.3.2 Water-level recording

According to the Contract, the River Survey Project shall install and operate a total of 11 (eleven) automatic water-level recorders (AWLR) in the main river system.

The main purpose of installing these AWLR is to provide accurate water-level data (half hourly readings, both on - and off-line) and to relate the water-level to discharge and sediment transport gauging as well as to relate bathymetric surveys to the selected reference level.

The Technical Proposal for the River Survey Project included only pressure cells to be deployed for water-level measurement.

From an operational point of view the acoustic type of water-level recorder has also advantages. Therefore, it was decided to make a trial with simultaneous measurements with an acoustic sensor and a pressure cell at the Bahadurabad site. Installation details and comparison of measurements are described in Section 2.3 and Annexure 1.

Base on field experience it is now known that the acoustic sensor is not disturbed by heavy rainfall. The whole installation including sensors and data logger is above the water-level, and thereby accessible for repair work and general checking. It is also known that the pressure cell, which is installed near the river bed, is quite vulnerable to structural damage by erosion and sedimentation. The results show that the acoustic and pressure cell type water-level recorders have the same accuracy.

From an operational and maintenance point of view and in order to secure continuous measurements, the River Survey Project therefore recommends whenever possible to deploy the self contained acoustic water-level recorder and as an alternative the pressure cell in areas not endangered by erosion.

3.3.3 Bathymetric surveys including river bed profiling

The bathymetric survey system consists of a positioning system, as described in Section 3.2, and a single (210 kHz) or a dual (30kHz and 210 kHz) frequency echo-sounder interfaced via an on-line computer.

So far three echo-sounding systems have been deployed by the River Survey Project. Two systems are permanently installed in the DHA and the DHC vessel and one system is mobile and mainly used in the shallow draft aluminium boat. The mobile system may easily be transferred to other boats.

Echo-sounding is carried out using a survey grid of transverse lines supplemented with a few longitudinal lines for detection of sand-dune formations.

All the recorded data are stored in digital format allowing for a more detailed printout during the subsequent data processing in Dhaka.

The maximum paper speed of the echo-sounders installed aboard is limited. Detailed bed form observations based on original records require a low sailing speed. This is obtained by navigating against the current.

In areas with soft deposits on top of a more dense river bed material a two layer picture is clearly recorded with the dual frequency echo sounder, see Figure 3.2.

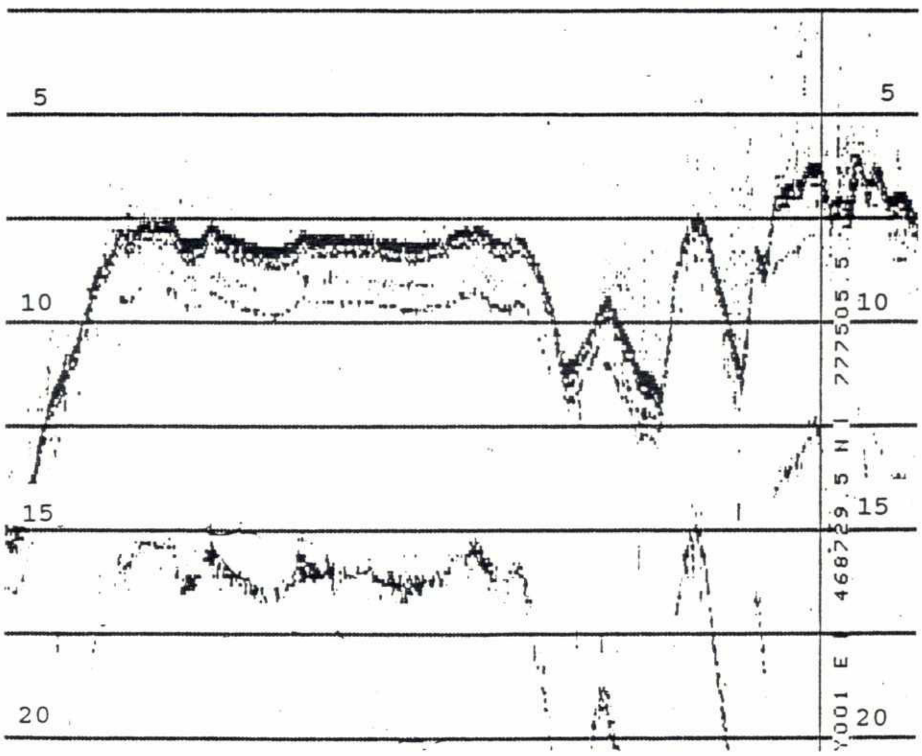


Figure 3.2 Dual frequency echo-sounding in a soft deposit area.

Based on field experience during the recent flood season the echo-sounders have been working well and no major loss of acoustic contact with the river bed has occurred.

It is thus recommended to maintain the present bathymetric survey configuration for future use.

Interest has been expressed in a more detailed recording aboard the survey vessel for direct visual observations. The need for this should be further investigated before a final decision on additional equipment is made.

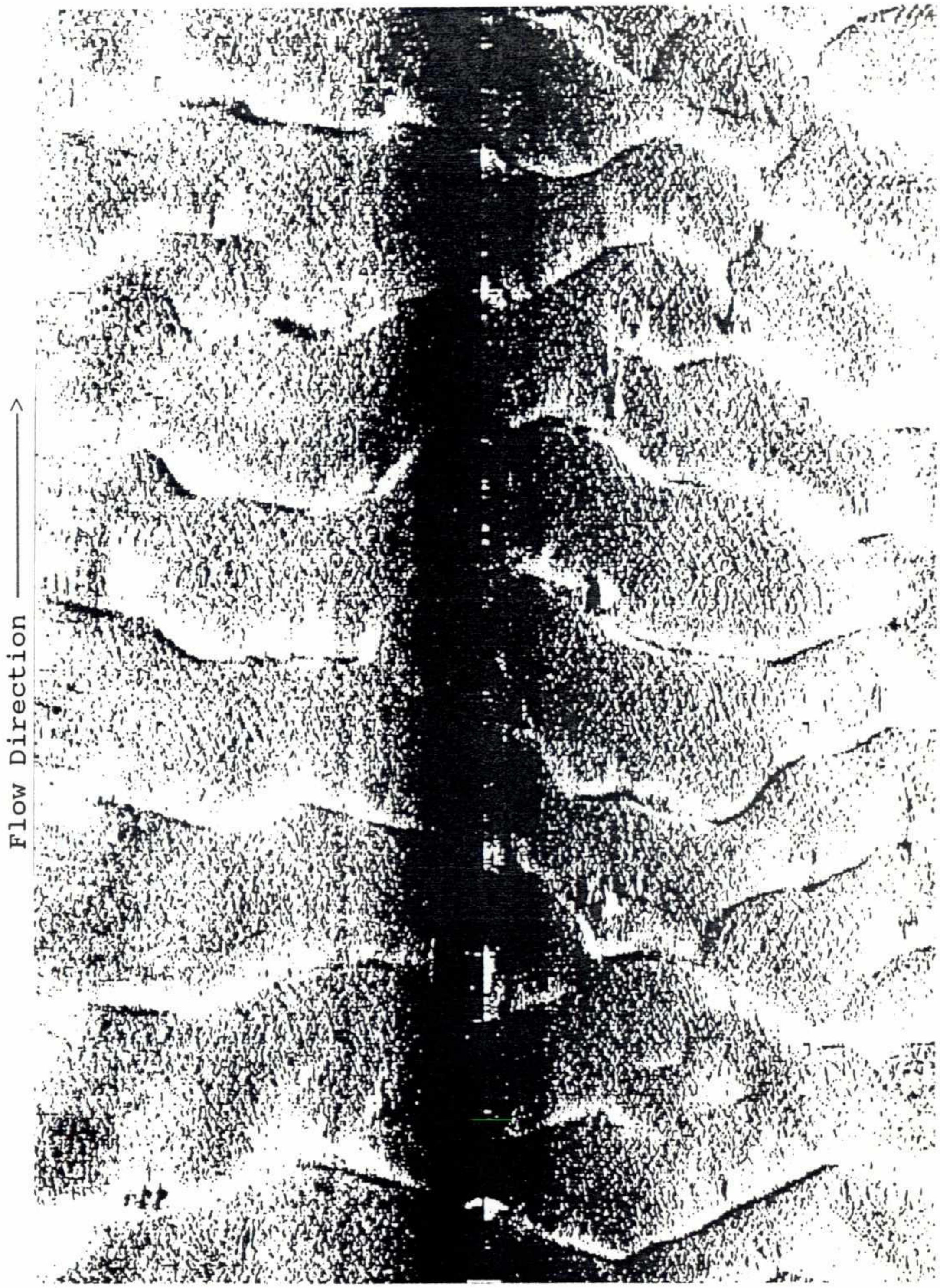
Interest is also expressed in having an echo-sounder with chart speed adapted to the vessel-speed, leading to undistorted horizontal chart scales. The extra investments required seem not justified in the present configuration where the echo-sounder is linked with the DGPS.

3.3.4 Mapping of river bed configuration including detection of dune patterns by the side scan sonar

The dual frequency side scan sonar system, temporarily installed aboard the DHA vessel, has proven its usefulness under the prevailing flow and sediment concentrations during the dry season. An example of a typical record from the left river channel at Bahadurabad is shown in Figure 3.3. The side scan sonar produces an image of the river-bed configuration whereby relative sand-dune lengths, heights and orientation can be evaluated. Based on the side scan sonar images it is possible to plan and optimize an echo-sounding survey.

The best quality of side scan sonar records is obtained during the dry season. During the flood season when higher concentrations of suspended sediment occur, the images become very hazy and difficult to interpret.

In conclusion the side scan sonar is still considered the most suitable type of instrument for classification of river bed-forms (upto certain size). It is proposed to keep the side scan sonar in the survey spread for surveys related to study topics.



Scale 1:500

Figure 3.3 Side scan sonar records of sand waves in the Jamuna river, January 31, 1993.

3.3.5 Discharge and current velocity measurements

The recommended method distinguishes between a c-procedure using EMF only and a d-procedure using a combined EMF and ADCP instrumentation, see Table 3.1. However, an exclusive ADCP deployment is also an option.

The difference in data coverage of the two survey methodologies is illustrated in Figure 2.3, Chapter 2.

The combined ADCP and EMF instrumentation provides a very high data coverage within the shortest time i.e. an "instantaneous" current distribution over the cross-section, a so-called transect is established. Additionally on-line information is supplied on the total discharge of the transect.

In order to execute the most accurate discharge measurements, in highly variable (spatial and temporal) flow conditions, it is considered of great importance to make an "instantaneous" and detailed coverage of the river cross-sections, see Figure 2.1 in Section 2.3.

The ADCP uses it lowest recording, the so-called bottom track, to measure the vessel speed over the ground. The vessel speed is used to convert the relative flow velocity into an absolute velocity (the flow velocity over the ground).

During the initial stages of the project there was quite some concern about the function of the ADCP under high suspended sediment concentration and mobile bed conditions. It was feared that the high concentration levels would reflect the acoustic signals and thereby cause a loss of acoustic contact with the lower water column and invalidate the discharge measurements.

It has turned out that the ADCP very seldom is loosing the bottom track. On the contrary the ADCP has proved able to track a moving river bed. While staying on anchor bottom track velocities in the range 0.3 m/s - 1.0 m/s were measured during a 45 minute period. This implies that during high flow conditions the bed load is so massive, that the ADCP measures the velocity of a very dense suspension transported in a level slightly above the stationary river bed. In other words the ADCP detects a moving river bed. Figure 3.4 shows examples of moving river bed velocity measurements.

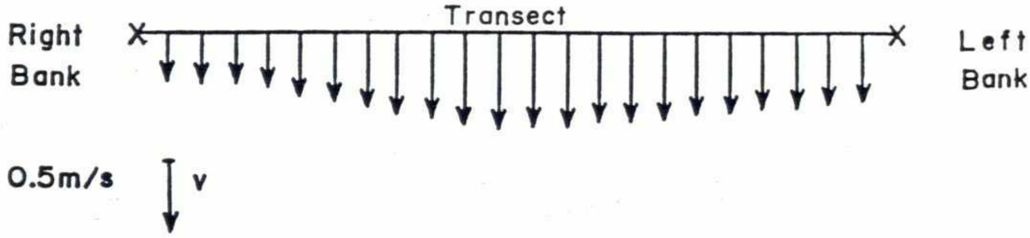


Figure 3.4 Moving river bed velocities according to the ADCP's bottom track (illustrative example).

In case of a moving river bed the zero velocity reference, provided by the bottom track, is lost and the current velocity and discharge measurements are then based on the movement of the survey vessel as measured by the DGPS positioning system. Also in the moving boat method with EMF only, the vessel speed is derived from the DGPS positioning data.

The existing ADCP operates with a 300 kHz transducer. It is recommended to add a 600 or a 1200 kHz ADCP to the survey spread. This instrument provides a higher resolution of records and covers a larger part of the water column than the 300 kHz ADCP, but may generate troubles in areas with high turbulence and sediment concentrations, see Annexure 5.

Based on the measurement results and operational experience from the test gauging as well as from the first year of measurements at other locations, it is recommended to employ the following instrument configurations for routine discharge and current velocity measurements:

- ADCP and EMF for main river channels.

- ADCP or EMF separately for smaller channels and flood plains. This includes a pure EMF/DGPS set-up mounted in a shallow draft boat to cover the shallow areas.

Finally for inter-calibration of instruments, and for special measurements (for support of morphological studies) it is recommended to maintain the S4 or Ott current meter. Also float tracking has some specific applications and will be kept operational.

3.3.6 Suspended sediment transport measurements

Suspended sediment transport measurements will be based on an integration of the current velocity distribution, measured by the moving boat method, and the suspended sediment concentrations, measured by depth integrated suspended sediment sampling.

The flow measurements are described in Sub-section 3.3.5. The suspended sediment concentrations are measured by depth integrated sampling in selected verticals in the cross-section.

The depth integrated sampling by lowering and recovering of the bottle sampler or the bag sampler is simple and fast in execution and is recommended for future deployment. The use of bottle sampler will be limited to water depths up to approximately 6 m. For deeper sections the bag sampler is used.

For more detailed measurements including a careful sampling of vertical profiles and as close as possible to the river bed, it is recommended to maintain the existing combined system of S4 pressure cell depth measurement and sediment sampling by pumping via the umbilical. The S4 pressure cell allows for the most accurate measurement, of the instrument depth.

ADCP backscatter measurements for illustration of the relative distribution of suspended sediment will form a natural part of the data collected by the ADCP in the field. Calculation of suspended sediment transport based on ADCP backscatter records may become possible in the course of the next few years. It is therefore recommended to store backscatter records for future analysis.

ADCP backscatter records of relative suspended sediment distribution in the transect will be used on-line in the field for planning of sampling locations.

Use of the optical turbidity meter is not recommended for general use in the routine measurements, but will be kept in the spread for special measurements.

3.3.7 Bed load transport measurements

Bed load transport measurements are still considered the most difficult and time consuming part of the survey operation and so far the optimum solution has not yet been determined. The two methods applied have both their pros and cons, as discussed in Section 2.7. Their applicability is indicated in the following figure :

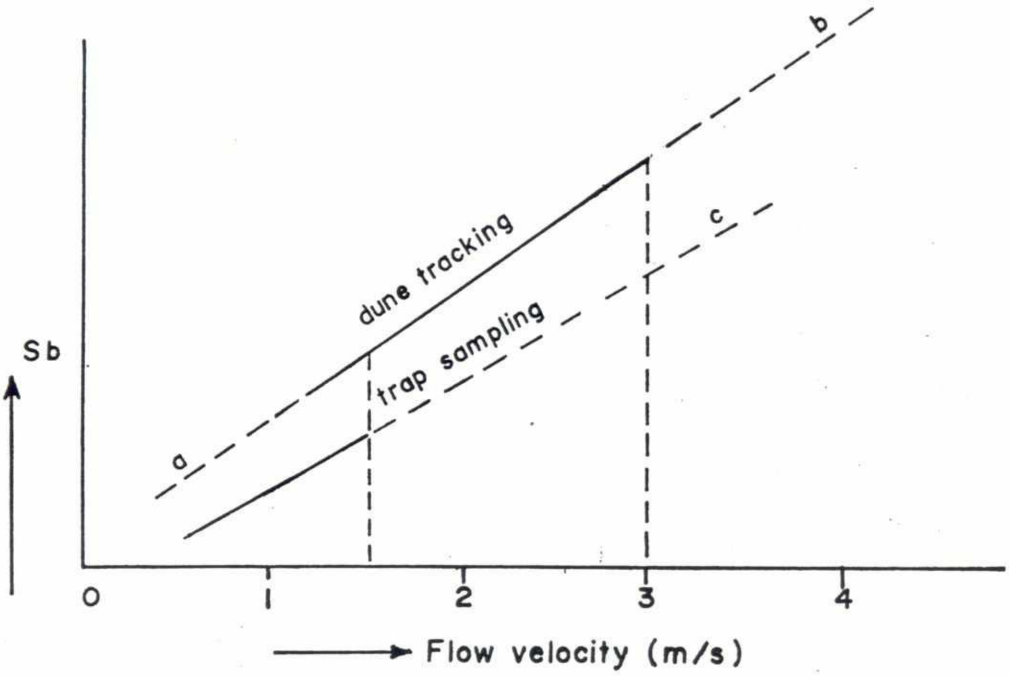


Figure 3.5 Illustration of measurement methods applicable from the low to the high flow regime.

The various dotted line sections in Figure 3.5 indicate :

a) that dune-tracking in the lean season (when mean velocities drop below 1.5 m/s) is rarely applicable as propagating dunes are scarce
b) that dunes may be washed out in high flows
c) that the trap sampling becomes difficult in the high flows.

The picture shows that the two methods do not cover all conditions. Especially during high flows when the accuracy of trap sampling is questionable and dunes are washed away an alternative method should be applied. Such an alternative is the Delft Bottle, proposed by the Project Advisor, which is procured and will be tested during the monsoon of 1994. Other alternatives are under study at the moment. For instance also ultrasonic sensors (e.g. AZTM) are considered to be placed on the river bed. Anyway, a lot of effort is put into obtaining a reliable picture of the sediment transport profile over say half a meter above the river bed. So the recommended approach is :

- o Helley-Smith trap sampling (always, also in the high flows until a better alternative is available)
- o Dune-tracking when and where possible
- o Testing of the Delft Bottle and possibly other alternatives
- o Study on optimization of sediment transport measuring techniques as proposed in Study Report 1, September 1993:
  - topic 9.3
    Improvement of sediment measuring techniques, both suspended load and bed load.
  - topic 9.4
    Dune - tracking and methods to assess which part of the dune propagation is caused by bed load.

3.3.8 <u>River bed material sampling</u>

In June 1993 the US BM-54 bed material samplers were installed on the DHA and the DHC, respectively, as an alternative to the Van Veen grab, which can only be operated in relatively low flow conditions.

The operational experience with the US BM-54 has proven its applicability. Even the high current velocities, experienced during the test gauging, did not prevent to collect bed samples in all vertical profiles.

It is therefore recommended to deploy this type of bed sampler in the future survey equipment configuration and to use the Van Veen grab as a supplement in shallow areas with low flow conditions.

3.4 Summary of proposed methods

3.4.1 Methods for phase 2 of the River Survey Project

The proposed methods, discussed in the previous Section 3.3, have been summarized in the following table. Table 3.2 is given in the same format as Table 3.1 for easy comparison

Type of measurements	Proposed method		
	Routine measurement		Special measurements
	Main channels	Minor channels	
Positioning	DGPS	-do-	-do-
Water-level	- accoustic - pressure -	-do- -do- -	-do- -do- staff gauge
Bathymetry	echo-sounder	-do-	-do-
Discharge	moving boat	-do-	-do- vel-area
Velocity	ADCP + EMF ADCP - - -	- -do- EMF - -	-do- -do- -do- S4, Ott float
Suspended sediments	depth integrating collapsible bag - - - ADCP	-do- depth-integrating bottle sampler - - -	-do- -do- pump bottle optical -do-
Bed load	dune tracking H-S trap sampling - ? ?	-do- -do- - ? ?	-do- -do- Side scan Delft Bottle alternative ?
Bed material	US BM-54 -	-do- Van Veen grab	-do- -do-

Table 3.2 Summary of proposed methods (November 1993)

In Table 3.2 the type of survey is distinguished : the routine surveys (as outlined in the Bill of Quantities) and the special measurements done to support a certain study topic (and paid from the extra work budget). Moreover the routine measurements are split into measurements in main channels and minor channels.

The above selection is also based on the fact that anchoring should be kept at a minimum. Only for the bed load measurements using a Helly-Smith trap sampler or a Delft Bottle, anchoring is required.

3.4.2 Sustainable methods

It is emphasized that the selected techniques to fulfil the River Survey Project objectives are not necessarily the same as the sustainable techniques envisaged for the Bangladeshi organizations in the future. This is caused by limited financial resources or by different technical objectives, asking for different accuracies.

The following aspects have to be considered for the final selection of sustainable techniques for Bangladeshi conditions :

- The economy of the techniques
- Availability of spare parts including possibility for import of equipment
- Capability of maintenance facilities
- Training requirements
- Timing for implementation

Consequently the techniques to be used by the River Survey Project during the remaining 2 years and the final selection of sustainable techniques to be used in the future in Bangladesh are considered separate issues.

4. Survey programme and survey capacity

4.1 Introduction

After selecting the appropriate survey techniques (Chapter 3), questions should be addressed how many instruments are needed of each type, how many vessel are required, etc. Therefore on the one hand the work load should be defined (Section 4.2) and on the other hand the duration of the various survey activities need to be assessed (Section 4.3). This leads to numbers of required equipment, vessels and instruments (Section 4.4) and finally to a workplan (Section 4.5).

4.2 Work load

The main survey activities in phase 2 of the River Survey Project can be summarized as follows :

- o water-level measurements
- o routine gaugings of water and sediment flow
- o bathymetric surveys
- o special measurements to support study of certain processes
- o training

The first three activities have been outlined in specific tables of the BoQ. The last two activities will be invoiced under extra work.

The water-level measurements are a separate activity which does not affect the use of the survey fleet. Therefore this activity is not further considered in this section.

4.2.1 Routine gaugings

According to the quantitative amendments in the Contract which were elaborated in February 1992, a reduced survey frequency for routine measurements of discharge and sediment transport as compared to the original BoQ should be made.

A summary of the reduced number of measurements required for each of the 11 gauging sites in the flood and dry season, respectively, is listed in Table 4.1 below. The individual locations are shown in Figure 4.1. It should be noticed that the lower stations at Baruria, Bhairab Bazar and the Arial Khan off-take are influenced by tide in the dry season. Therefore 25 or 13 hourly discharge measurements are required.

Measurement Station	River	Location	Number of measurements per year	
			Flood Season	Dry Season
MAIN RIVERS				
Station 1	Brahmaputra	Bahadurabad	8	5
Station 2		Sirajganj	8	5
Station 3		Aricha	2	o
Station 4	Ganges	Hardinge Bridge	8	5
Station 5	Padma	Baruria	8	3(+2)
Station 6		Mawa	2	o
MINOR RIVERS AND OFF-TAKES				
Station 7	Old- Brahmaputra	Mymensingh	4	3
Station 8	Dhaleswari	Tilly	4	3
Station 9	Gorai	Kushtia Railway Bridge	4	3
Station 10	Arial Khan	Off-take	4	2(+1)
Station 11	Meghna	Bhairab Bazar	3	2(+1)

(+x) Tidal measurements during the low water period; 25 hours or 13 hours measurements.

Table 4.1 Number of routine gaugings per year.

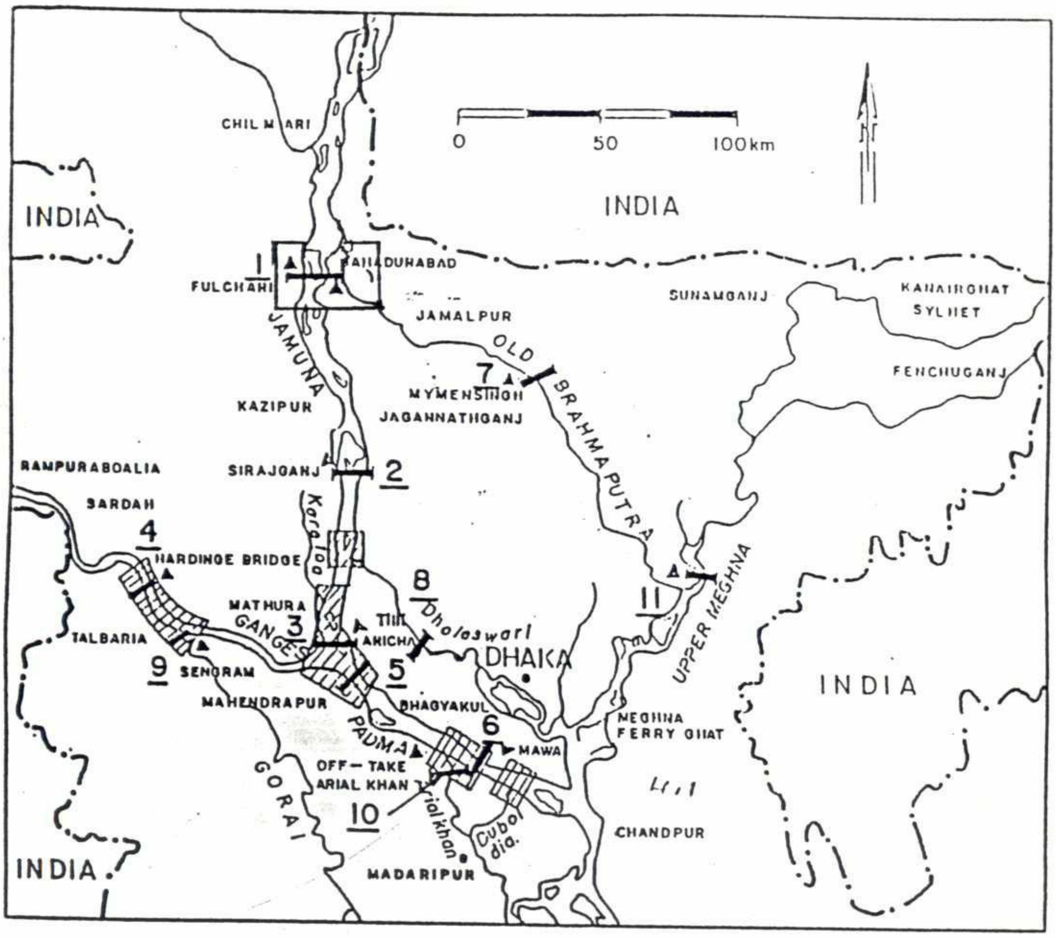


Figure 4.1 Location map of routine gauging and bathymetric sites

4.2.2 Bathymetric surveys

The contract specifies that at seven sites bathymetric surveys shall be executed both before and after the monsoon. In total three pre-monsoon and three post-monsoon surveys will be done. The total area to be covered each season is 850 km² (with an interspacing of sounding tracks of 200 m). The details are given in Table 4.2, whereas the locations are indicated in Figure 4.1.

Survey site	Survey area	Number of surveys	
	km²	Pre monsoon season	Post monsoon season
Off-take of Old Brahmaputra	100	3	3
Off-take of Dhaleswari	100	3	3
Outlet of Hurasagar	100	3	3
Confluence area of Ganges, Brahmaputra and Padma	300	3	3
Off-take of Gorai	100	3	3
Upper stretch of Gorai	100	3	3
Off-take of Arial Khan/Dubaldia	50	3	3

Table 4.2 Total number of bathymetric surveys to be carried out during phase 2 according to the contractual requirements.

4.2.3 Special measurements and training

Special measurements are envisaged to support a certain study topic. In Study Report 1 of the River Survey Project, dealing with the selection of study topics for phase 2 a number of these special measurements are listed (Table 10.2). Just a few examples are given below:

- additional measurements in Bahadurabad (partly together with BWDB)
- detailed measurements at off-takes
- measurements of flow and sediment distributions at bifurcations
- detailed measurements for further improvement of measuring techniques.

Besides these special measurements also time for survey training on the river is envisaged. However, in view of the work load the activities are not that important. The main issue is that 50 vessel days of a fully equipped hydrometric vessel may be spent in total for special measurements and training. This means in fact that in the order of 1 day per month extra survey capacity is required for special measurements and training.

4.3 Survey speed

To assess the capacity of a survey unit (one survey vessel plus a work boat) the speed of survey has to be elaborated viz.

- o the duration of one routine gauging
- o the duration of a bathymetric survey
- o the sailing speed

4.3.1 Duration routine gauging

For the duration of the routine gaugings the monsoon conditions are decisive. Based on the experience obtained in 1992/1993 the following duration is assessed:

Bahadurabad/Sirajganj/Aricha	5 days
Hardinge Bridge/Baruria/Mawa/Bhairab Bazar	3 days
Mymensingh/Tilly/Kushtia/Arial Khan	3 days

Survey times are including initial reconnaissance work at the site.

In the multichannel stations on the Jamuna a lot of extra time is required for transport in between the channels, as sometimes (depending on the water-level) considerable detours around chars and shoals have to be made. This holds for Bahadurabad, Sirajganj and Aricha.

4.3.2 Duration of bathymetric surveys.

The usual speed over the ground applied during sounding work is 4 knots (=2m/s).

A 'standard' bathymetric job covers an area of 100 km² with a track interspacing of 200 m, hence, a total track length of 500 km.

The nett sounding time is therefore,

$$\frac{500 * 10^3}{2 * 3600} = 70 \text{ hours}$$

Moreover preparation time is needed for checking bench-mark, staff gauges and reference station, so the real duration is obviously higher, but is very much depending on the fragmentation of the area. A network of small channels leads to many short sounding tracks, so is more time consuming.

On average the duration of a standard bathymetric job is about 2 to 2½ weeks.

4.3.3 Vessel speed

In view of survey capacity the maximum vessel speed of about 12 knots for the DHA and 14 knots for DHC appeared to be hardly relevant. The average safe sailing speed is much lower. On average during the monsoon of 1993 the following sailing speeds were realised :

downstream about 8 knots
upstream about 4.5 knots

For sailing from station to station only a fraction of the available engine power is used mainly because the river is in general unmarked and no up-to-date navigation charts are available. So, instead of vessel speed the actual sailing time is measured during the monsoon of 1993 and collected in Table 4.3.

Route 1:
Bahadurabad - Siranganj - Aricha - Mawa - Arial Khan -Bhairab Bazar

From / To	Bahadurabad	Siranganj	Aricha	Baruria	Mawa	Arial Khan	Bhairab Bazar
Bahadurabad		7	12	13	18	19	32
Siranganj	13		5	6	11	12	25
Aricha	22	9		1	6	7	20
Baruria	23	10	1		5	6	19
Mawa	32	19	10	9		1	15
Arial Khan	36	22	13	12	3		14
Bhairab Bazar	44	32	23	22	13	12	

Route 2:
Aricha - Hardinge brigde - Kustia

From / To	Kustia/Gorai	Hardinge Bridge	Aricha
Kustia/Gorai		2	9
Hardinge Bridge	3		7
Aricha	15	12	

Table 4.3 Actual sailing time during the monsoon (hours)

The figures are collected from the phase 1 survey spread (DHA + DHC). The figures are excluding time for change of pilots. For that purpose 10 to 15% of the sailing time should be added.

The table shows that sailing time between two consecutive stations takes maximum one day.

4.4 Recommended survey spread

4.4.1 Vessels

Based on the experience from the test gauging as well as from other measurements carried out during the 1993 flood season it has been concluded, that the contractual obligations in terms of field measurements can be fulfilled by extending the existing survey fleet with one survey vessel (DHB) plus a small workboat and additional equipment, see Table 4.4. Hereby the four vessels are able to work independently.

The existing phase 1 fleet consists of the :

DHA	a former patrol vessel
DHC	a catamaran
DHD	an aluminium (portable) boat and a
Zodiac	an inflatable used for transport

To realise the lean season surveys in 1993/1994 the DHD has been upgraded already from a transport boat to a small survey boat which is used for the smaller river sites and can be moved using a trailer.

The additional survey vessel the DHB will form with a new small workboat DHE a new survey unit which can be operated independently. For the workboat more than just an inflatable will be procured in order to have some spare capacity.

The survey fleet is schematically shown in Drawings 1 to 4.

4.4.2 Instruments

The major input of additional instrumentation comprises:

- One DGPS positioning system
- One DGPS reference station
- One echo-sounder
- One 600 or 1200 kHz ADCP
- Two EMF systems
- Two pump-bottle systems
- Three depth integrating sediment samplers

These systems will be portable allowing for easy transfer of instruments between survey units and sites. Thereby the flexibility and the survey capacity is increased.

The distribution of the instruments over the survey fleet is illustrated in Table 4.4 with an indication of the additional instruments required as

The distribution of the instruments over the survey fleet is illustrated in Table 4.4 with an indication of the additional instruments required as compared to the present phase 1 set-up.

Equipment	Survey vessels			
	DHA Patrol	DHC Cat.	DHD Alu. craft	DHB truck
GPS Positioning system:				
Trimble 4000, 9 channel -	X			O •
Trimble Navtrac, 6 channel -		X	X	
Bathymetric survey:				
Elac Laz 4420 (echo sounding)	X			
Simrad EA 300 P (echo-sounding)		X	X	O •
Point current measurement:				
Ott meter (mechanical)	X			
S4 InterOcean (electromagnetic)	X	X	X •	•
Integrated current measurement:				
ADCP (vertical)	X	•	•	O •
EMF (horizontal)	X	O •	•	O •
Float tracking (horizontal)	X	X	X	O
Suspended sediment measurement:				
Pump bottle sampling	X	X	O	O
Depth integrated sampler	X	O	O	O
MEX 3 Turbidity meter	X			
Bed load sediment transport measurement:				
Helley-Smith trap samples	X	X		O
Sand-dune tracking by echo-sounding	X	X	X •	O •
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	O
Walkie talkies	X	X	X	O

• Portable systems
- Upgraded to DGPS by land based reference stations; Trimble 4000 SE/RL
X Existing equipment
O Additional phase 2 equipment

Table 4.4 Recommended instrumentation aboard the four survey vessels for phase 2.

4.5 Workplan

4.5.1 General

In order to illustrate in sufficient detail how the survey spread is utilized during the flood and dry season, a workplan following the contractual obligations has been elaborated, see Drawings 5 and 6.

In the flood season the workplan emphasizes the required numbers of routine measurements and indicates spare time available for extra work (special measurements and training), maintenance and repair, unworkable weather and rest.

In the lean season the bathymetric work in April, May and November December gives the main part of the work load.

4.5.2 Flood season

The flood season covers the period June to October. The workplan reflects the consultants experience of the time needed to cover the individual routine gauging sites, plus a margin for extra work, unforeseen delays (such as breakdowns of equipment and unworkable weather) and rest.

In broad lines the workplan shows that the fleet will be distributed into three units which are operating independently :

DHA + DHC (+Zodiac)	= Jamuna
DHB + (DHE)	= Ganges/Padma/Meghna
DHD	= Dhaleswari/Old Brahmaputra

During the flood season measurements in 1993 it turned out that navigation to Mymensingh and Tilly was difficult and time consuming. For example the entrance from the Jamuna river to the Tilly gauging site in the Dhaleswari off-take is closed for navigation. Since the cross-sections at Tilly and Mymensingh are very narrow, in the order of 300 m to 500 m width, and relatively shallow it has been decided to cover these areas with the alu craft, which is transported between the sites on a trailer.

The workplan also shows that considerable 'spare time' is envisaged :

DHA + DHC	: 43 days
DHB	: 25 days

As mentioned above these days are used for extra work, unforseen and rest.

The DHD has only limited measuring duties but will be used as a workboat for the remaining time.

The rotation schedule during the monsoon is presented in Drawing 5.

4.5.3 Dry season

In 1993/1994 the consultant started his first dry season programme, where measurements are carried out in all the 11 gauging stations.

Due to the fact that general navigation between sites as well as execution of surveys in some of the rivers becomes very difficult - impossible at certain locations - the workplan for this season becomes accordingly complex.

The main rivers, the Jamuna and the Padma, are navigable. The same applies for the Meghna to Bhairab Bazar. There and in the Arial Khan off-take, tidal measurements have to be carried out, see Table 4.1 and Figure 4.1.

The Ganges river stage may become so low that navigation up to the Hardinge Bridge is hardly possible. This may call for a special arrangement where deployment of instruments will take place from the alu craft. A similar situation occurs in the Gorai off-take and at Tilly and Mymensingh.

The bathymetric work in April, May and November, December of 850 km^2 per season asks for 850/100 (2 to 2½) ≈ 20 hydrographic vessel weeks/season

Consequently to complete the work within the available 2 month, at least 3 vessels need to be used for the job.

The proposed rotation schedule is illustrated in the workplan for the dry season Drawing 6.

List of reference

- **Pilot Bathymetric Survey**, (in preparation) River Survey Project FAP 24, DELFT HYDRAULICS & Danish Hydraulic Institute et al., December 1993.

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

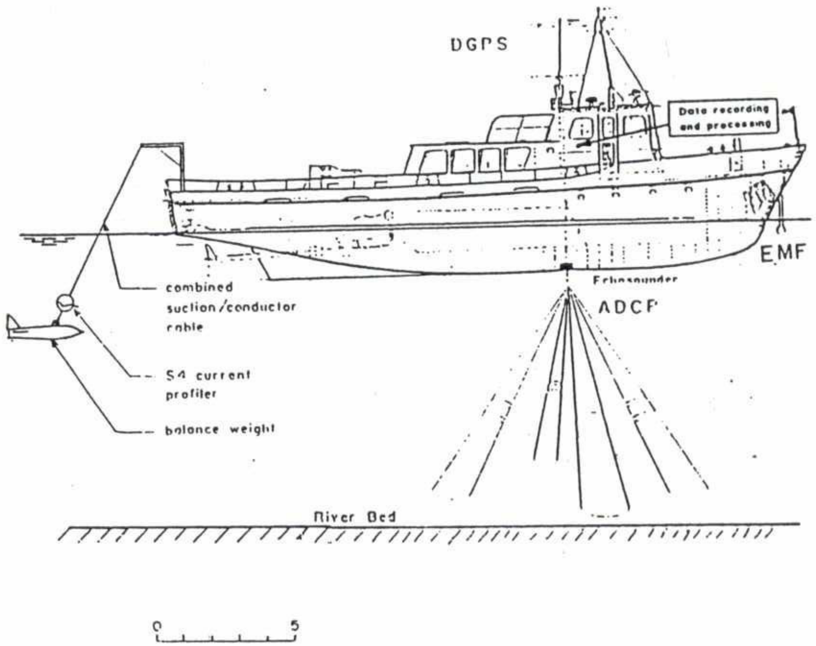
- **Test Gauging Report**, Survey Procedures and Data Presentation, River Survey Project FAP 24, DELFT HYDRAULICS & Danish Hydraulic Institute et al., October 31, 1993.

- **Working Paper No. 1**, internal technical note, River Survey Project FAP 24, October 1993.

- **Revised Inception Report**, River Survey Project FAP 24, DELFT HYDRAULICS & Danish Hydraulic Institute et al., October 1992.

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

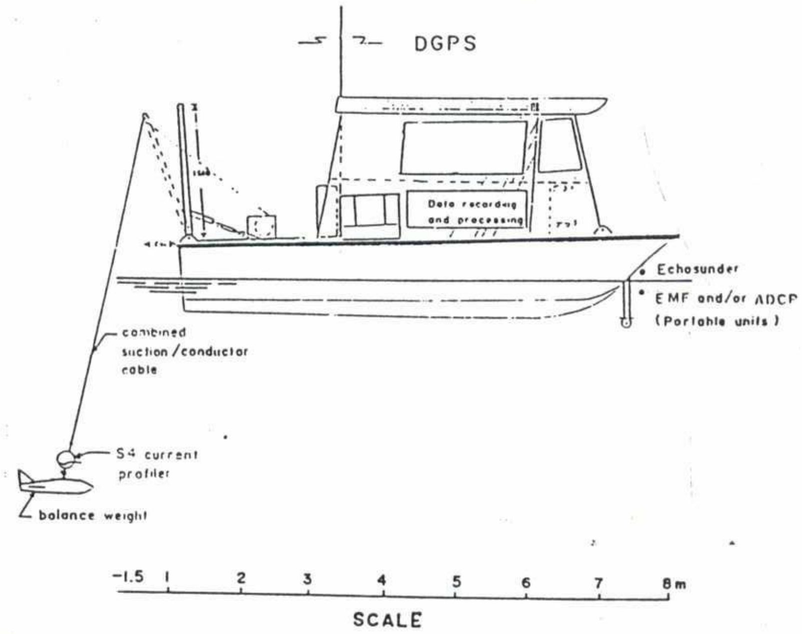
Drawings



DHA Features:

- o Positioning by DGPS
- o Dual frequency echo sounding including sand dune tracking
- o Discharge measurements by the moving boat method using EMF and ADCP
- o Current velocity profiling
- o Suspended sediment transport measurements by depth integrated or singular point sampling by pumping
- o Suspended sediment concentration measurements by turbidity meter
- o Bed load transport sampling
- o Bed material sampling
- o Specialized measurements :
  - Side scan sonar
  - Other instruments still to be defined in relation to the study programme

FAP 24 RIVER SURVEY PROJECT DELFT-DHI		Selected Survey Techniques	
File:	Date:	Survey Vessel A (DHA)	Dr.1
Scale:	Init:		



DHC Features:

- o Positioning by DGPS
- o Single frequency echo sounding including sand dune tracking
- o Discharge measurements by the moving boat method using EMF and/or ADCP
- o Current velocity profiling
- o Suspended sediment transport measurements by depth integrated or singular point sampling by pumping
- o Bed load transport sampling
- o Bed material sampling

FAP 24 RIVER SURVEY PROJECT DELFT-DHI	Selected Survey Techniques	
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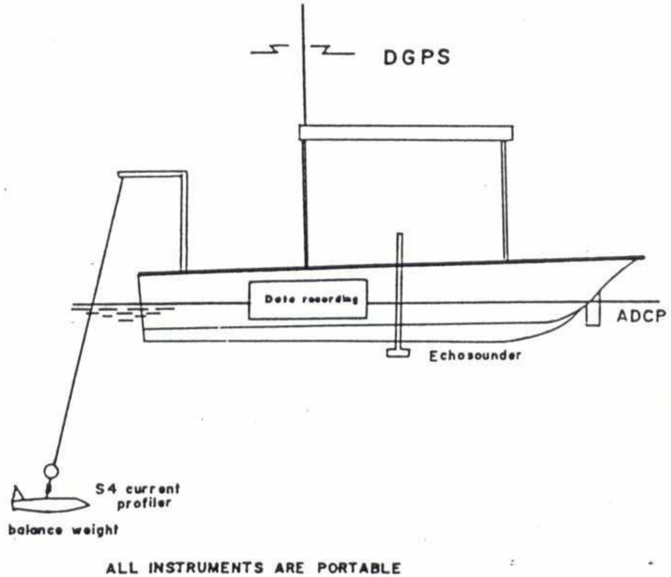

DHD Aluminium Craft Features:

- o Positioning by DGPS
- o Single frequency echo sounding including sand dune tracking
- o Discharge measurements by the moving boat method using ADCP
- o Current velocity profiling
- o Suspended sediment transport measurements by depth integrated or singular point sampling by pumping
- o Bed load transport sampling
- o Bed material sampling

ALL INSTRUMENTS ARE PORTABLE UNITS

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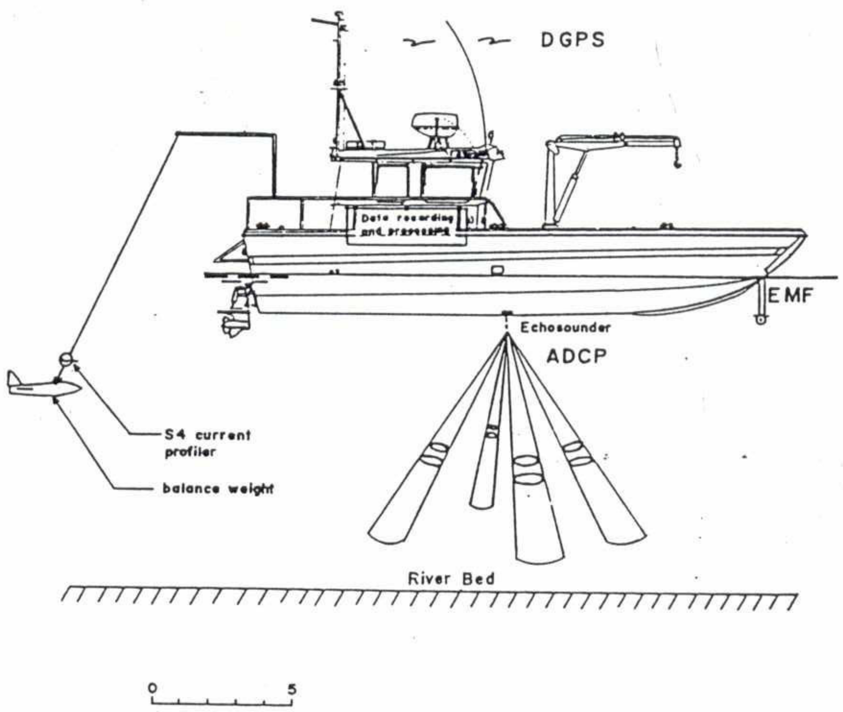
File:	Date:	Survey Vessel D (DHD) (Aluminium Craft)	Dr.3
Scale:	Init:		



DHB Features:

- o Positioning by DGPS
- o Single frequency echo sounding including sand dune tracking
- o Discharge measurements by the moving boat method using EMF and/or ADCP
- o Current velocity profiling
- o Suspended sediment transport measurements by depth integrated or singular point sampling by pumping
- o Bed material sampling

ALL INSTRUMENTS ARE PORTABLE UNITS

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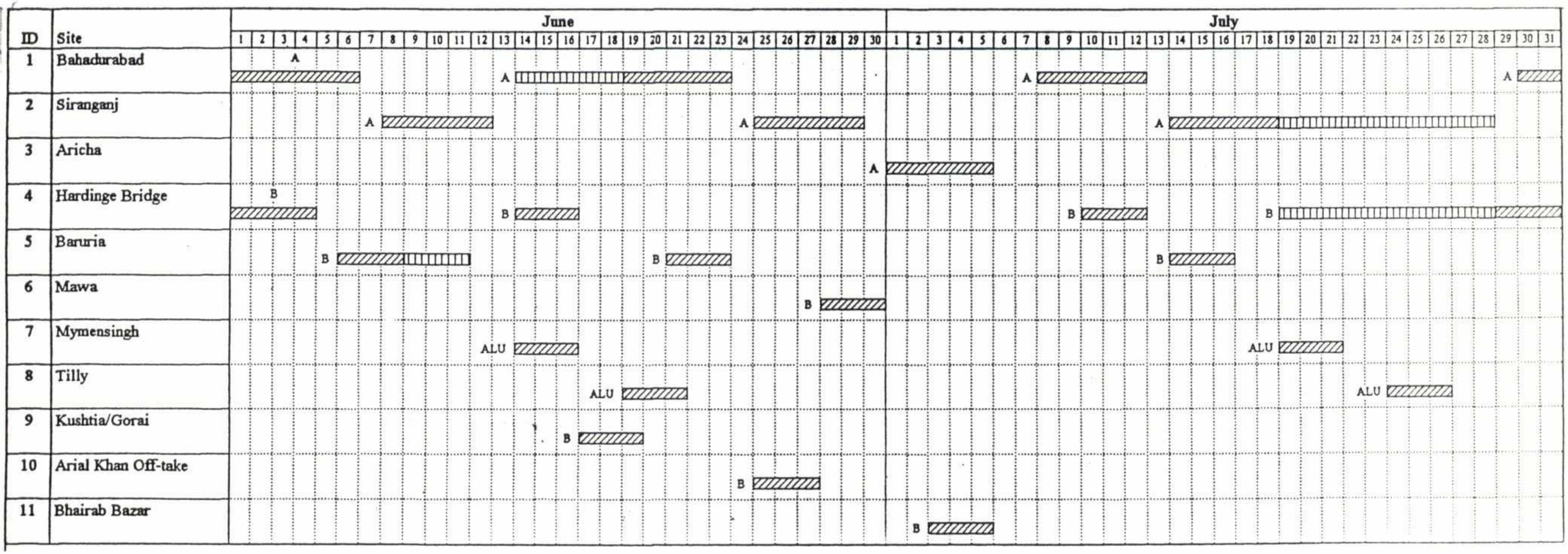
File:	Date:	Survey Vessel B (DHB)	Dr.4
Scale:	Init:		



Legend:

Routine Gaugings :

Study & Maintenance:

A: A-UNIT

B: B-UNIT

FAP 24 RIVER SURVEY PROJECT

DELFT-DHI

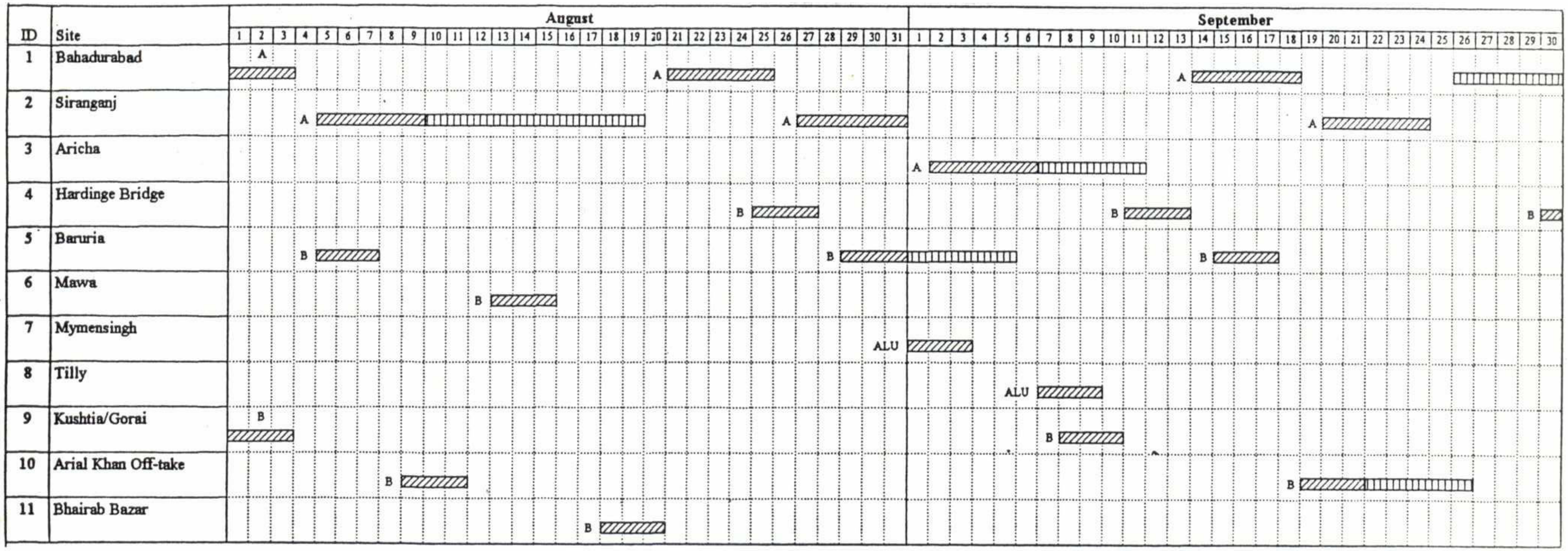
Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland

Slection of Survey technique

Workplan - Flood Season

Dr.5A

File:	Date:
Scale:	Init:



Legend:

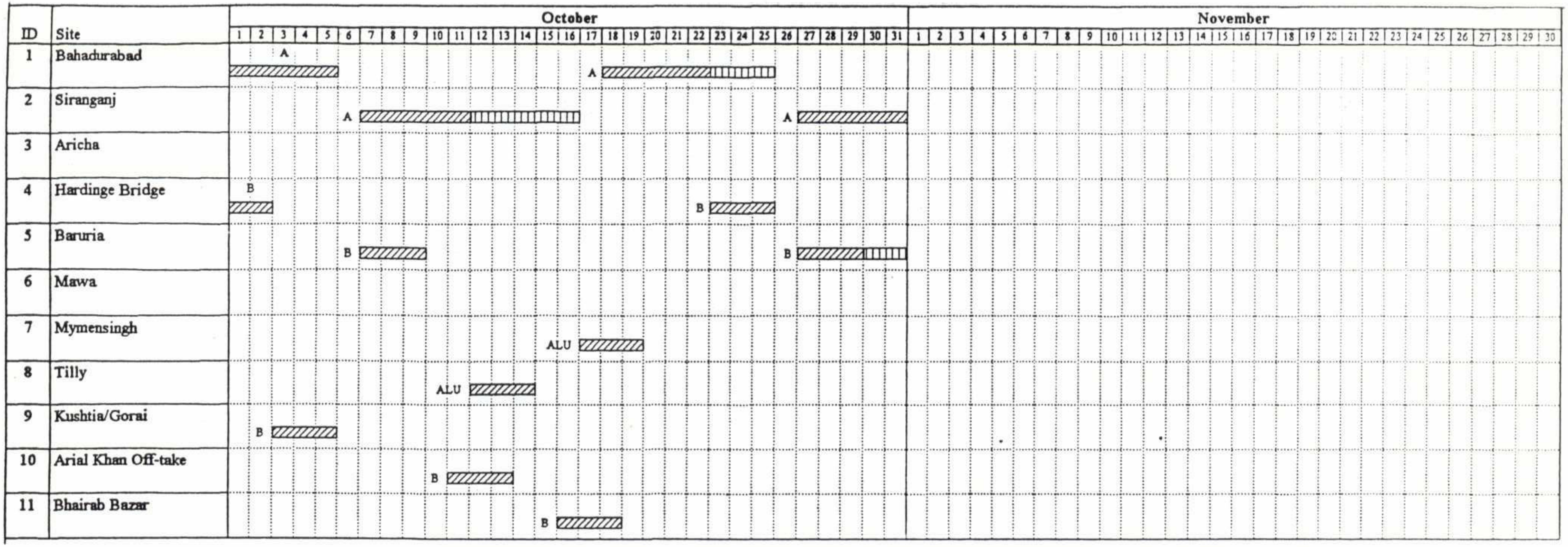
Routine Gaugings :

Study & Maintenance:

A: A-UNIT

B: B-UNIT

FAP 24 DELFT-DHI	RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland	Slection of Survey technique
File:	Date:	Workplan - Flood Season
Scale:	Init:	Dr.5B



Legend:

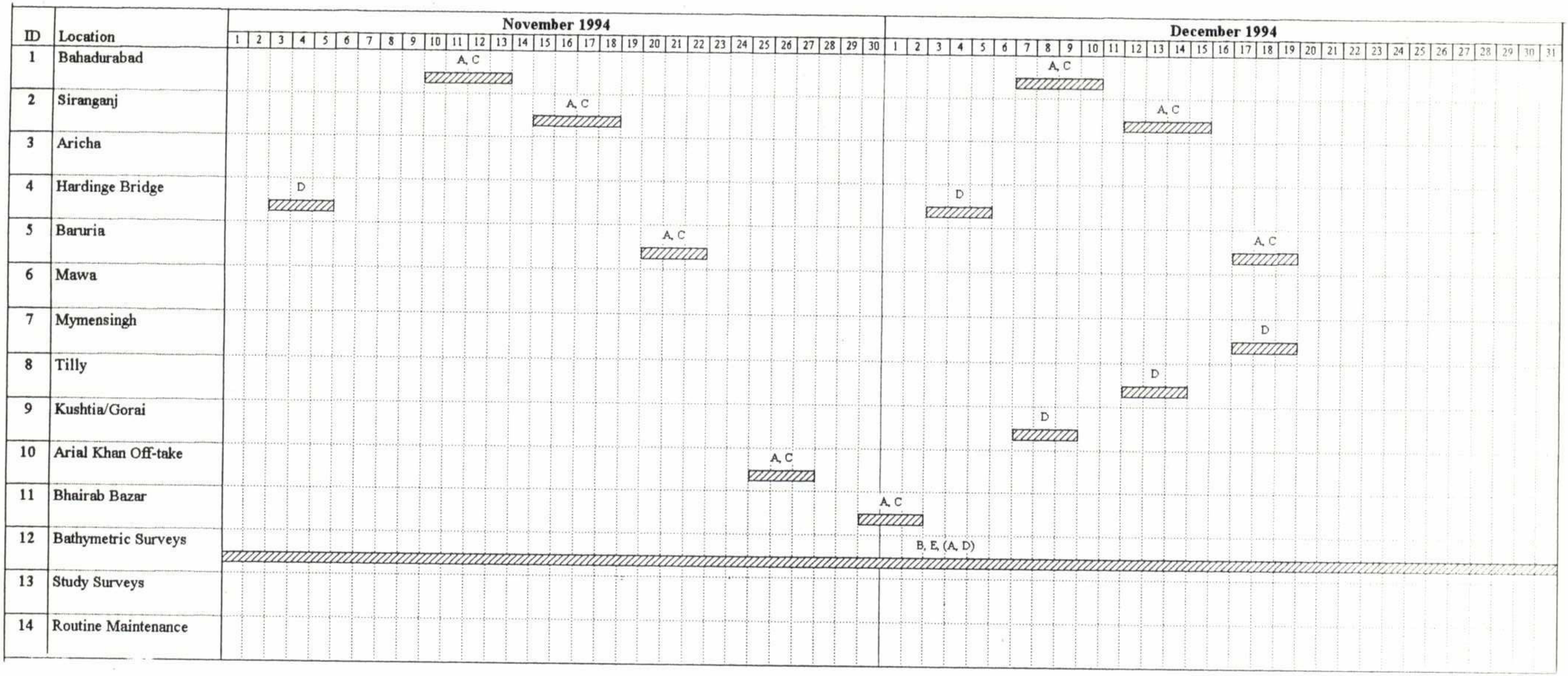
Routine Gaugings :

Study & Maintenance:

A: A-UNIT

B: B-UNIT

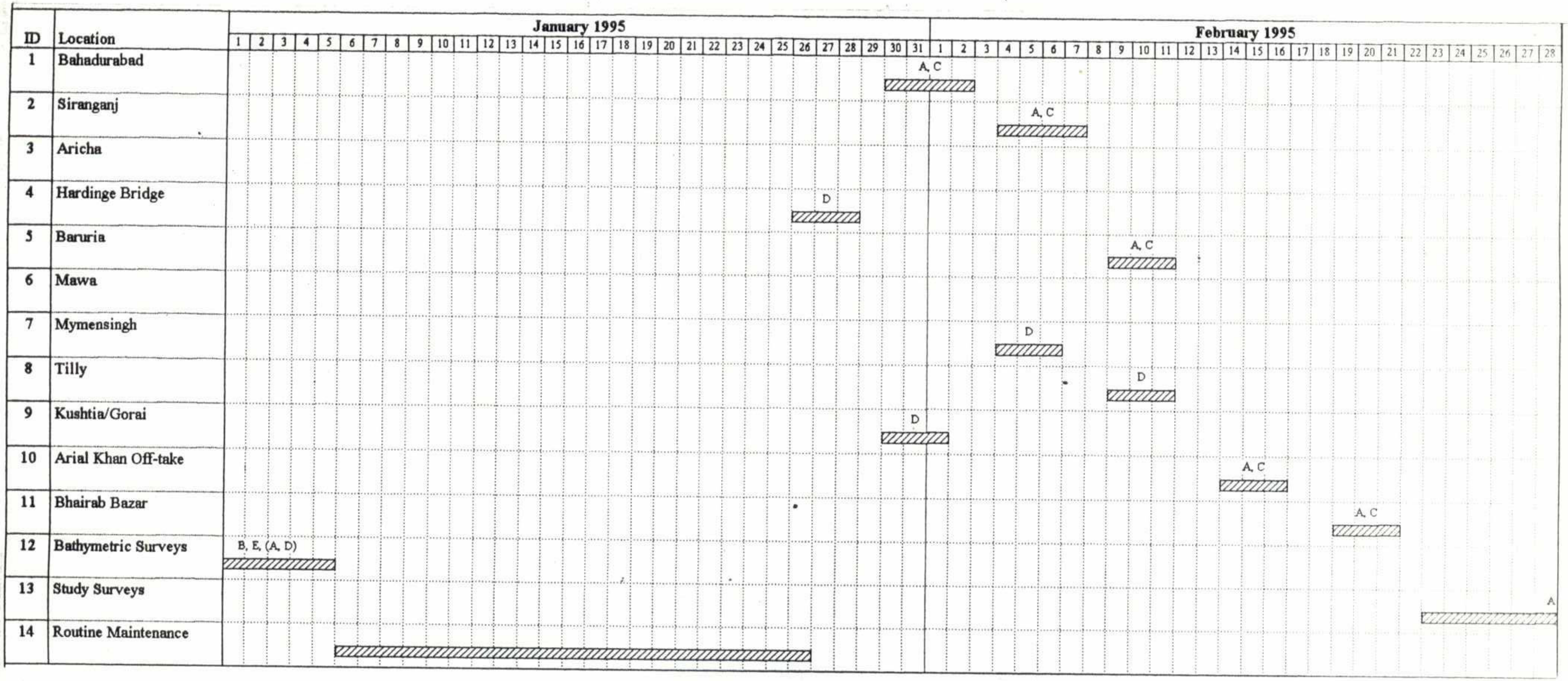
FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland	**Slection of Survey technique**
File: / Date:	
Scale: / Init:	**Workplan - Flood Season** / Dr.5C



Legends

A: A-Vessel
B: B-Vessel
C: C-Vessel
D: D-Vessel (alu)
E: E-Vessel

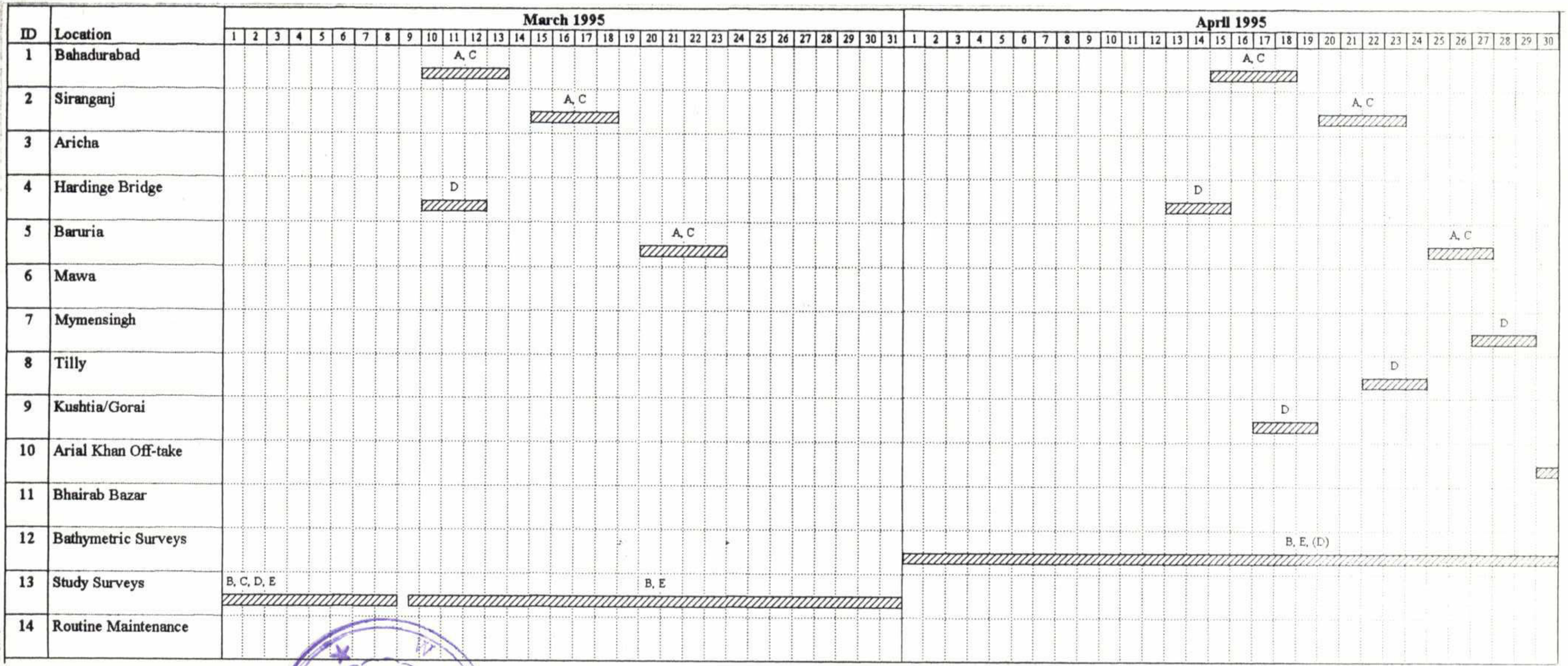
FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland	**Selection of Survey Techniques**
File: / Date:	**Workplan - Dry Season**
Scale: / Init:	Dr. 6A



Legends

A: A-Vessel
B: B-Vessel
C: C-Vessel
D: D-Vessel (alu)
E: E-Vessel

FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		**Selection of Survey Techniques**
File:	Date:	**Workplan - Dry Season**
Scale:	Init:	Dr. 6B



Legends

A: A-Vessel

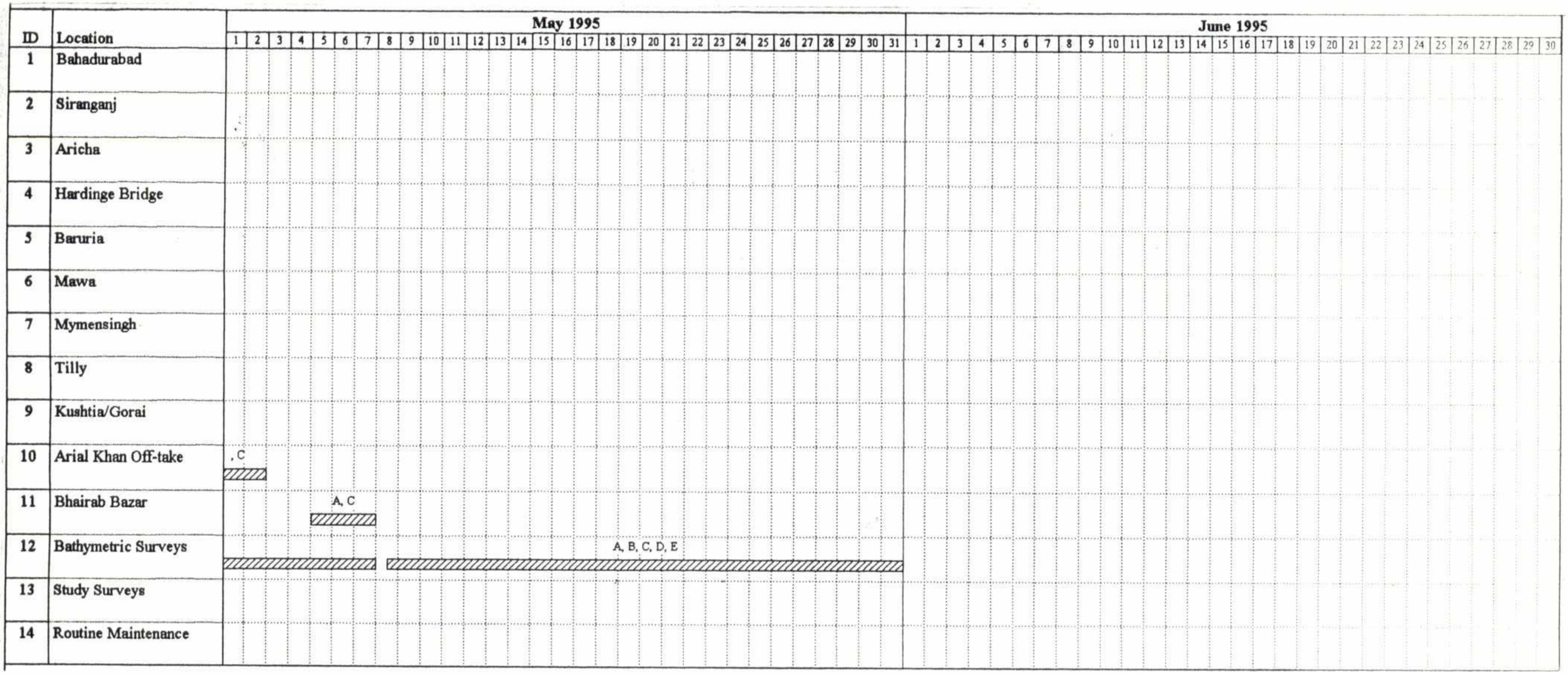
B: B-Vessel

C: C-Vessel

D: D-Vessel (alu)

E: E-Vessel

FAP 24 DELFT-DHI RIVER SURVEY PROJECT Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		**Selection of Survey Techniques**	
File:	Date:	**Workplan - Dry Season**	Dr. 6C
Scale:	Init:		



Legends

A: A-Vessel
B: B-Vessel
C: C-Vessel
D: D-Vessel (alu)
E: E-Vessel

FAP 24 RIVER SURVEY PROJECT DELFT-DHI Delft Hydraulics/Danish Hydraulic Institute in association with Osiris/Approtech/Hydroland		Selection of Survey Techniques
File:	Date:	Workplan - Dry Season
Scale:	Init:	Dr. 6D

Annexures

Annexure 1

Technical Recommendation and Verification of the acoustic type of AWLR

C8

WORKING PAPER NO. 1

Technical Recommendation and verification of the acoustic sensor type of AWLR

October 20, 1993.

Technical Recommendation and verification of the acoustic sensor type for the automatic water-level recorders (AWLR).

1. Background

According to the Contract the River Survey Project (FAP 24) shall install and operate a total of 11(eleven) automatic water-level recorders (AWLR) in the main river system within the project area; ref. Figure 1.1.

The main purpose of installation of these AWLRs is to provide accurate water-level data (both on - and off-line) and relate it to discharge and sediment transport gauging as well as for depth reduction of bathymetric surveys.

The Interim Report of the River Survey Project provides a detailed description of the possible sites for water-level gauging.

A more detailed site reconnaissance for selection of final installation locations is carried out at this moment and a final recommendation on locations will be issued in November, 1993.

By July 1993, three AWLRs were installed at the Bahadurabad cross-section in the Jamuna River, one at Bahadurabad ghat in the left channel and the other two on the central island at Gabgachi at the right channel; ref. Figure 1.2. The two AWLRs in Gabgachi consisting of a pressure type and an acoustic type were installed on the same platform for reasons of comparison. The details of site selection, installation, and operation and maintenance procedures are described in RSP (1993b). The following sections present only a summary of the two stations technical installation and some analyses of records obtained from the two stations for verification.

2. Station in Jamuna River left channel at Bahadurabad

After consideration of a total of 6 possible sites, a relatively stable channel section could be identified on the Jamuna River left channel at Bahadurabad cross-section. The station is located at about 500 m upstream from the Bahadurabad railway jetty where a BWDB staff gauge is in operation. An AWLR, equipped with a pressure sensor and a data-logger was installed at this station.

The data-logger is housed on a triangular frame structure located at about 70 m inland from the bankline. A cable integrated with a polyamide tube connects the sensor and the data-logger. Other installation details are shown in Figure 2.1. The data-logger registers the water-level at every 1/2 hours.

The sensor was installed as low as the actual water-levels permitted. The elevation of it was measured to be at 12.35 m + PWD, which is 0.32 m above SLW according to INTERCONSULT (1991), and 0.12 m above SLW according to NEDECO (1967).

The AWLR became operational on 2 June 1993. Unfortunately the operation stopped on 22 July probably due to some scouring at the pipe structure itself. Repair has to await the coming dry season.

Some examples of obtained water-level records, are presented in Figure 2.2a showing the plot of water-levels recorded at every 30 minutes on 3 June 1993. It indicates the nature of rise and fall of water-level in detail.

Figure 2.2b shows daily water-levels obtained from records at every 0600 hours in the morning from 15 June to 21 July 1993. In order to evaluate the performance of the obtained records, the AWLR readings are correlated with staff gauge reading in Figure 2.3.

The Figure shows a good correlation with a 1 to 1 relation.

3. Station in Jamuna River right channel at Gabgachi

At the same cross-section another location for water-level recording is selected in the right channel at Gabgachi, ref. Figure 1.2. This location was chosen in a shallow channel at about 100 m inside the bankline. The purpose of this AWLR is to record water-levels during the high river stage only, leaving the low river stage to be measured by a non-recording gauge or another arrangement.

A triangular frame structure which carries both the sensors and the data-loggers in a housing on top has been installed at this location. Figure 3.1 shows the details of this structure.

To evaluate the performance of different AWLRs, an acoustic as well as a pressure sensor is included in the arrangement. The pressure sensor elevation is 17.62 m + PWD and the acoustic sensor elevation is 21.76 m + PWD. Both the sensors register water-level at an interval of 30 minutes.

The AWLRs at this location became operational on 4 July 1993 and has been in operation since then.

Figure 3.2a shows the half-hourly water-level at Gabgachi obtained from AWLR records using pressure sensor on 4 July 1993. Figure 3.2b shows the half-hourly water-level measured by the acoustic sensor on 17 July 1993. Figure 3.3 shows a comparison between the records as measured by the acoustic sensor and pressure cell respectively. It indicates an excellent match between the two. From this Figure it can also be concluded that the acoustic AWLR functioned continuously and was not interrupted by the sometimes heavy rains during the 1993 monsoon downpour. Finally, evaluations are made between the AWLR records and staff gauge readings which are shown in Figures 3.4 and 3.5. While a 1 to 1 correlation is obvious from the plot, some errors in the staff gauge readings can be noted.

4. Conclusion and recommendation

Based on the water-level records and experience obtained so far it can be concluded that the acoustic and pressure cell type recorder measures with the same accuracy and reliability.

The measurements by the acoustic sensor were not disturbed by the heavy rainfall. Another experience was that the pressure cell recorder being a submerged installation - as expected - is quite vulnerable to structural damages by erosion as well as to sedimentation.

From an operational and maintenance point of view and in order to secure continuous measurements, the River Survey Project therefore recommends to include the self contained acoustic type units, where the whole installation including the sensors is above the water-level, and thereby accessible to repair work and general checking.

REFERENCES

Delft Hydraulics, 1992. Manual of water-level logger (version 1.08), 89pp.

INTERCONSULT (Norway), 1991. Determination of standard low water and standard high water-levels in Bangladesh (Vol. II, Technical Report). Bangladesh Inland Water Transport Authority, Dhaka, 89pp.

NEDECO (Netherlands Engineering Consultants), 1967. Surveys of inland waterways and ports, East Pakistan Inland Water Transport Authority.

River Survey Project (RSP), 1993a. Interim Report #1 (Vol. I, II and III). Flood Plan Coordination Organization, Government of Bangladesh.

River Survey Project (RSP), 1993b (in preparation). AWLR stations: site selection, installation, and operation and maintenance. Flood Plan Coordination Organization, Government of Bangladesh.

Phase I	River	Location
Station I	Brahmaputra	Bahadurabad
Phase II:	**River**	**Location**
Station 1	Brahmaputra	Bahadurabad
Station 2		Serajganj
Station 3		Aricha
Station 4	Ganges	Hardinge Bridge
Station 5	Padma	Baruria
Station 6		Mawa
Station 7	Old Brahmaputra	Mymensingh
Station 8	Dhaleshwari	Tilly
Station 9	Gorai	Kushtia (Railway Bridge)
Station 10	Arial Khan	Offtake
Station 11	Meghna	Bhairab Bazar

Phase I - Station 1 includes test gauging.

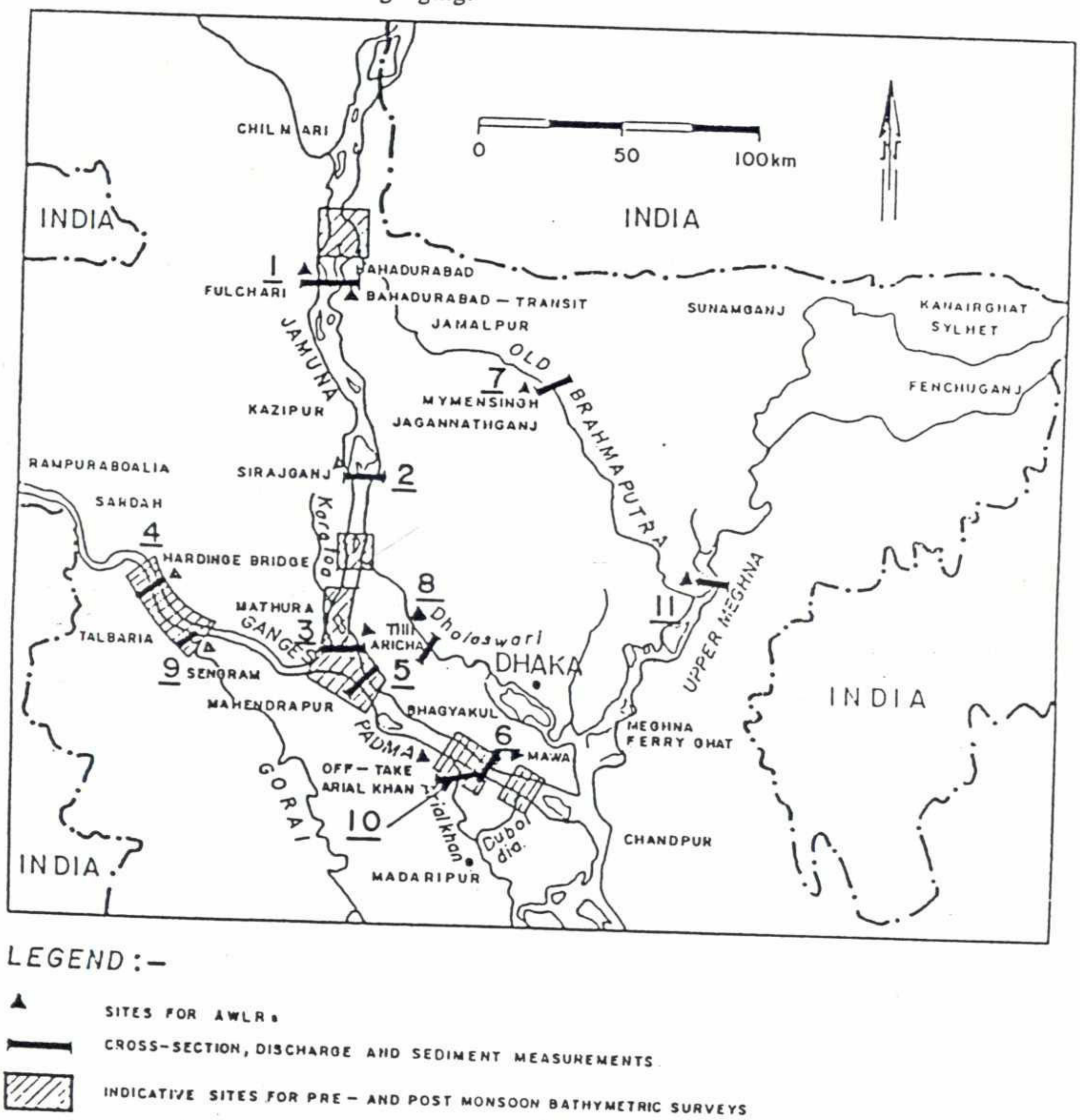


Figure 1.1 General sites for installation of automatic water level recorders.

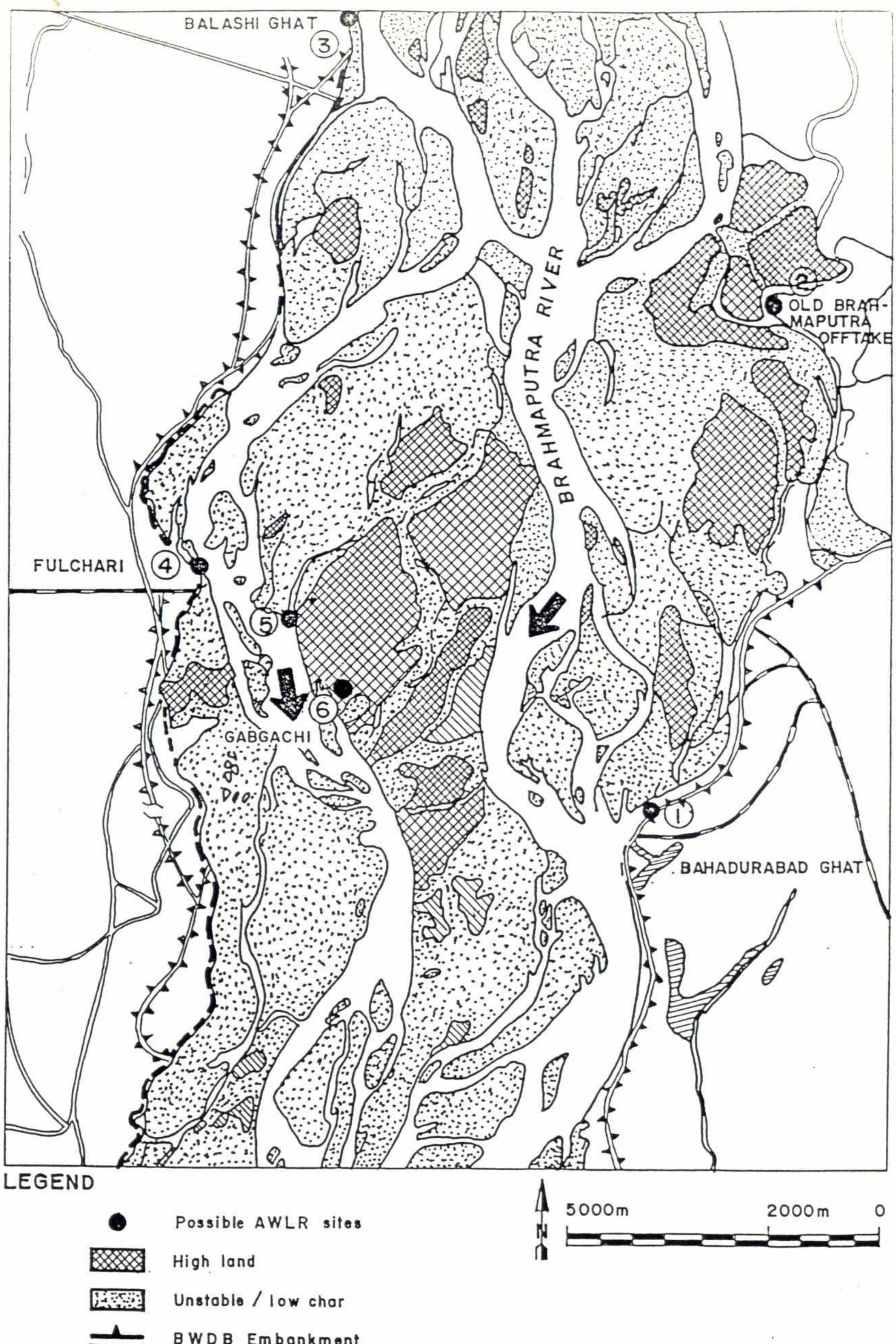


Figure 1.2 Specific locations for installtion of automatic water level recorders of Bhahdurabad site; location (1) and (6).

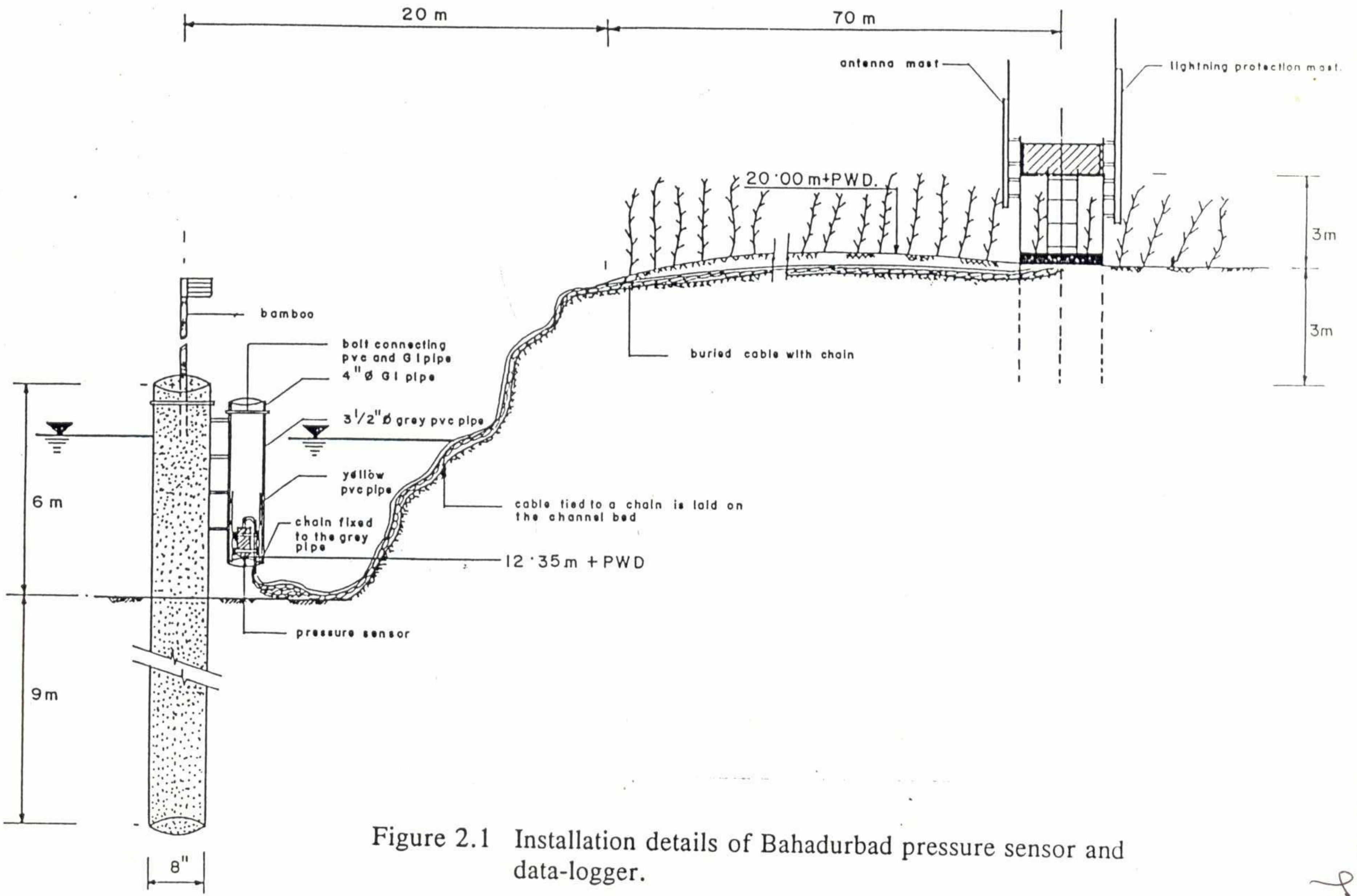


Figure 2.1 Installation details of Bahadurbad pressure sensor and data-logger.

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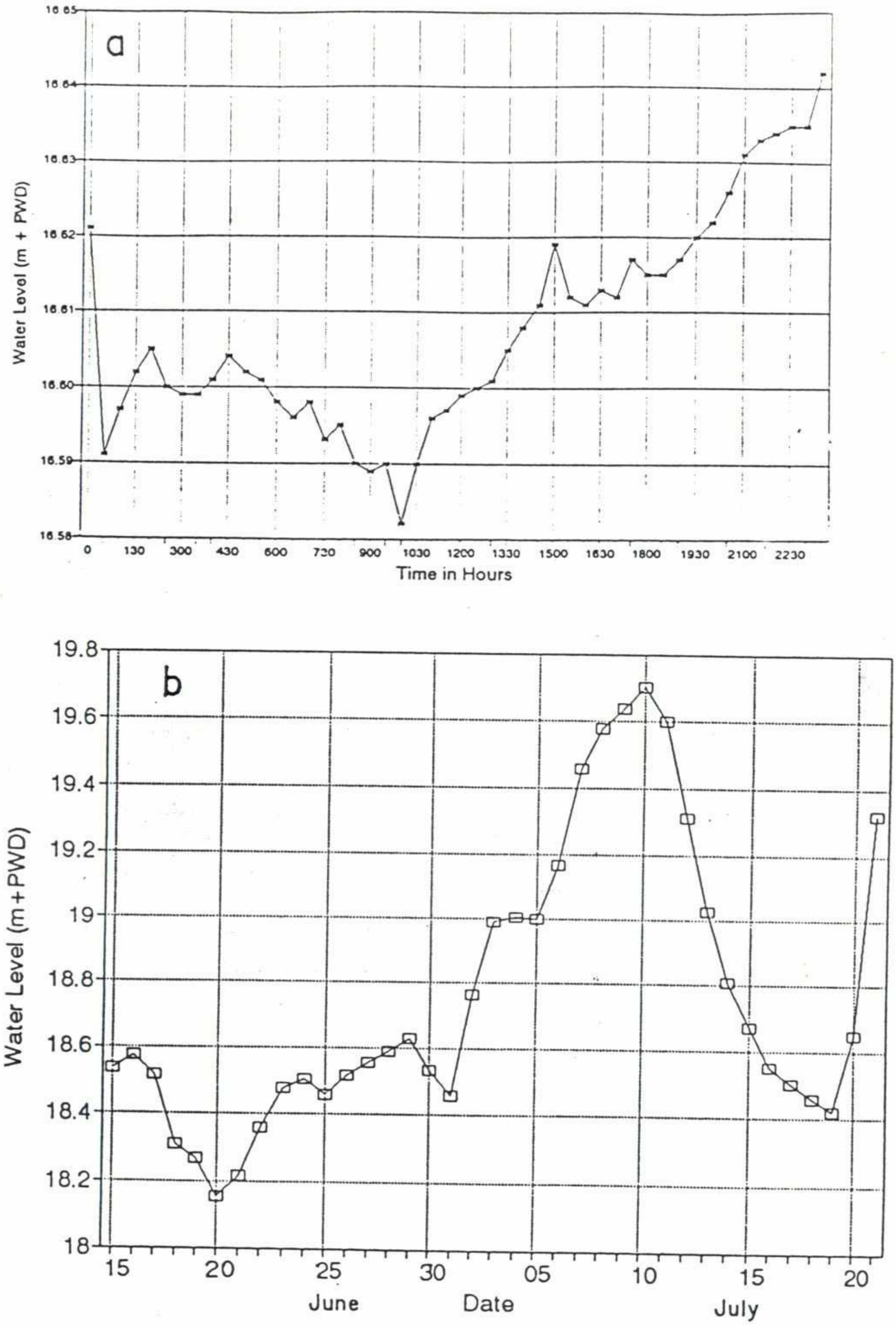

Figure 2.2 AWLR readings at Bahadurabad.
a. 1/2 hourly reading on 3 June 1993.
b. Daily reading recorded at 0600 hrs in June-July 1993.

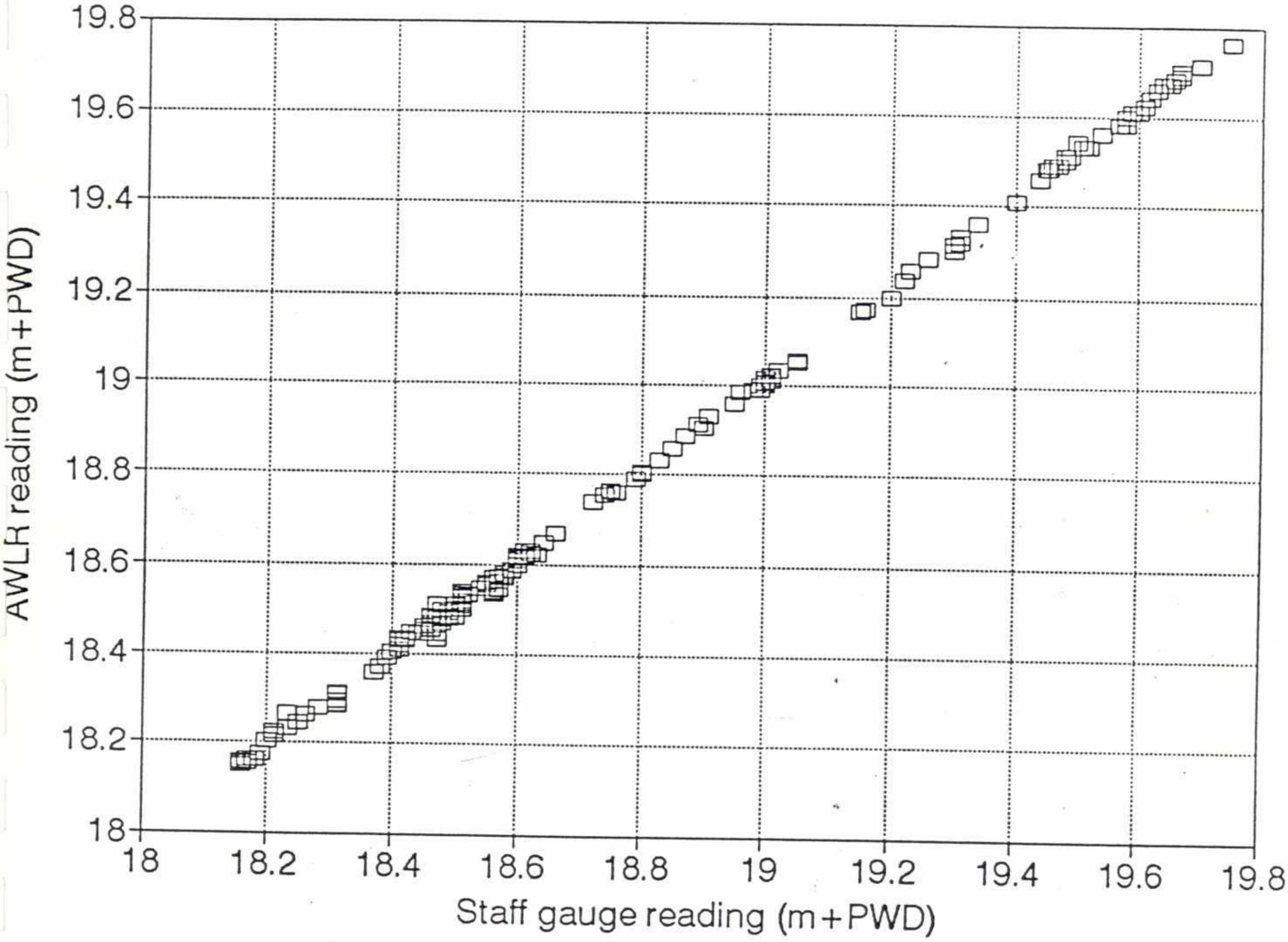

Figure 2.3 Correlation between AWLR reading and staff gauge reading for Bahadurabad station with data from 15 June to 21 July 1993.

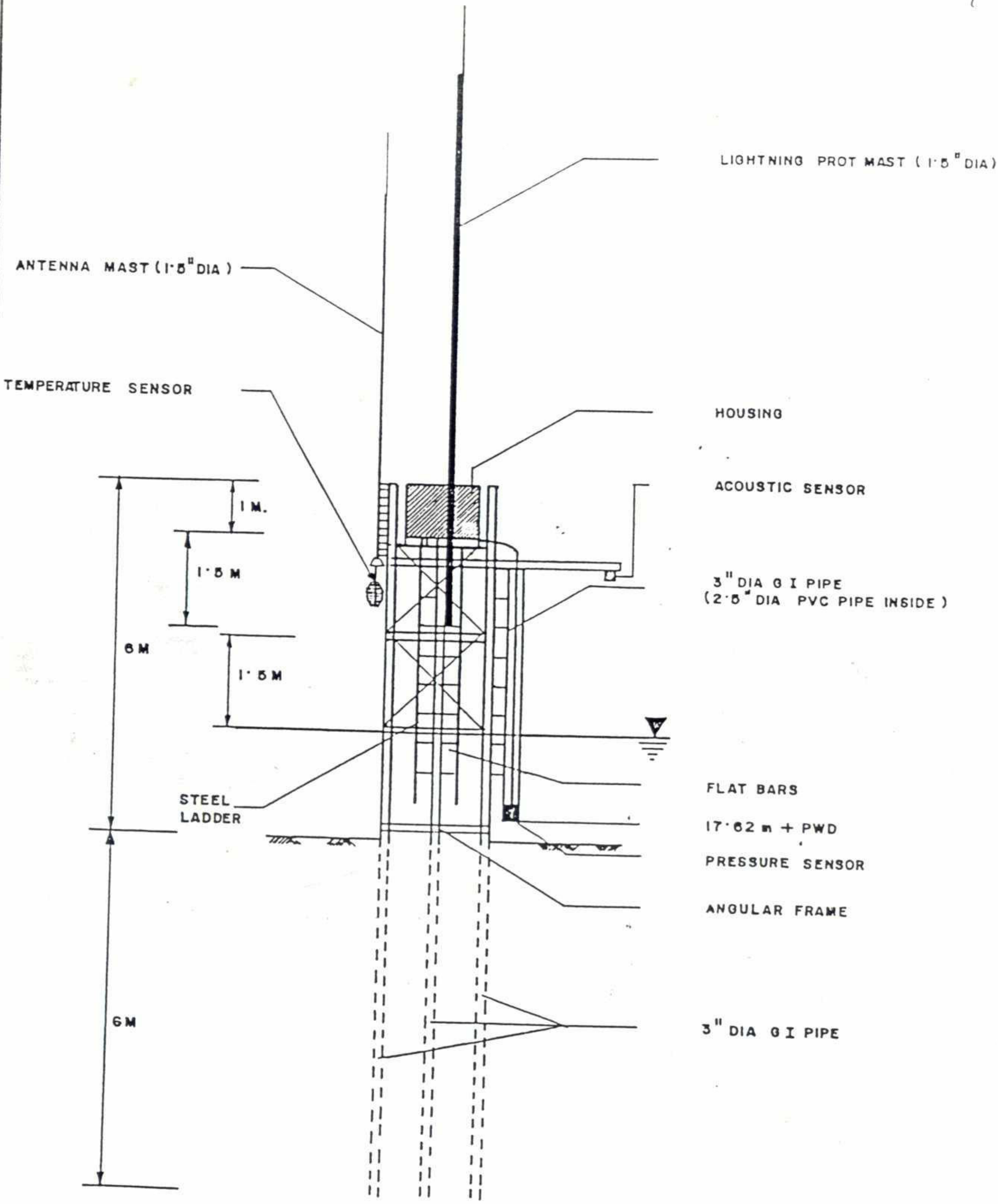

Figure 3.1 Installation details of Gabgachi gauge pressure and acoustic sensors and data-logger.

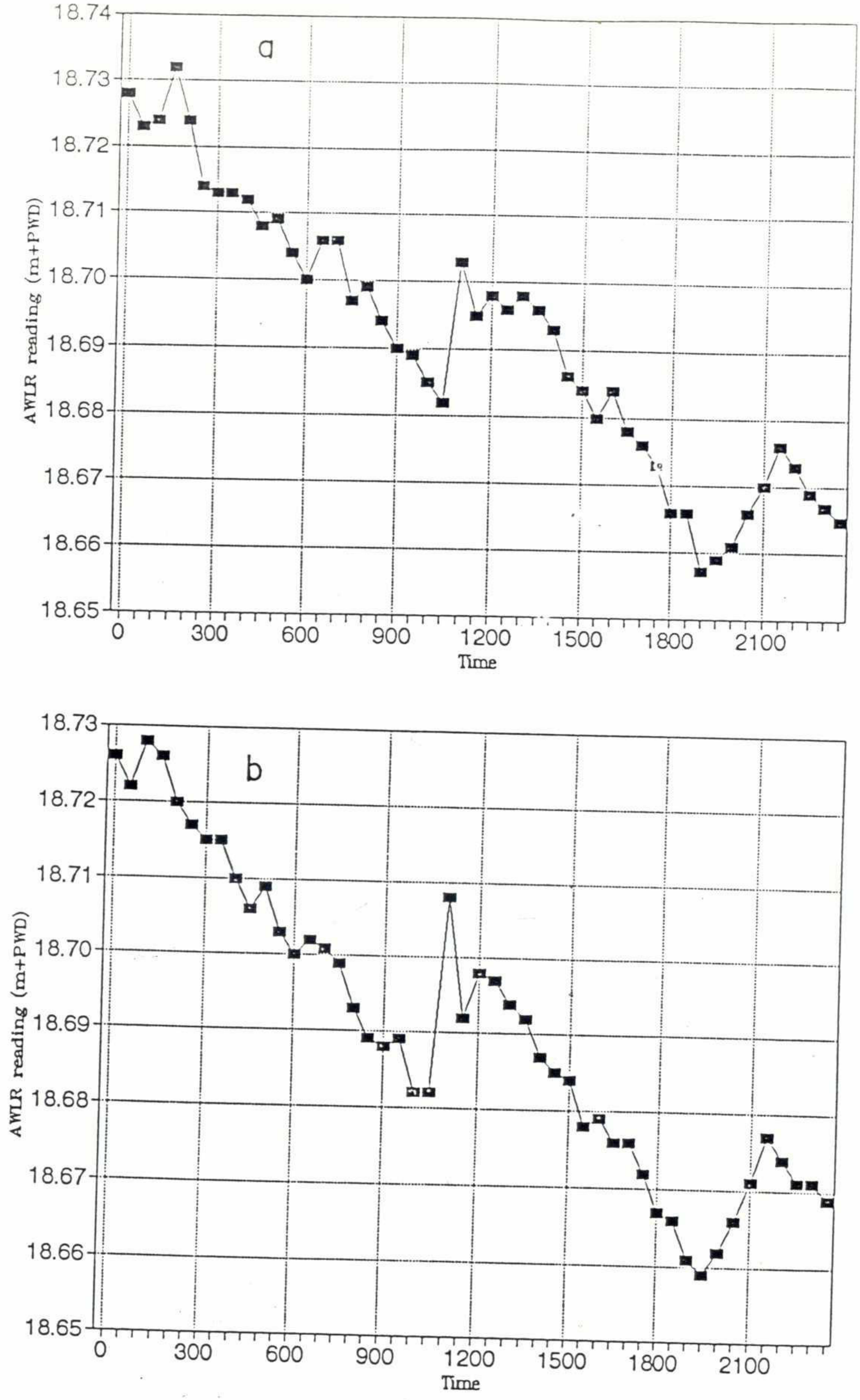

Figure 3.2 AWLR reading at Gabgachi on 17 July 1993.
a. 1/2 hourly pressure sensor record.
b. 1/2 hourly acoustic sensor record.

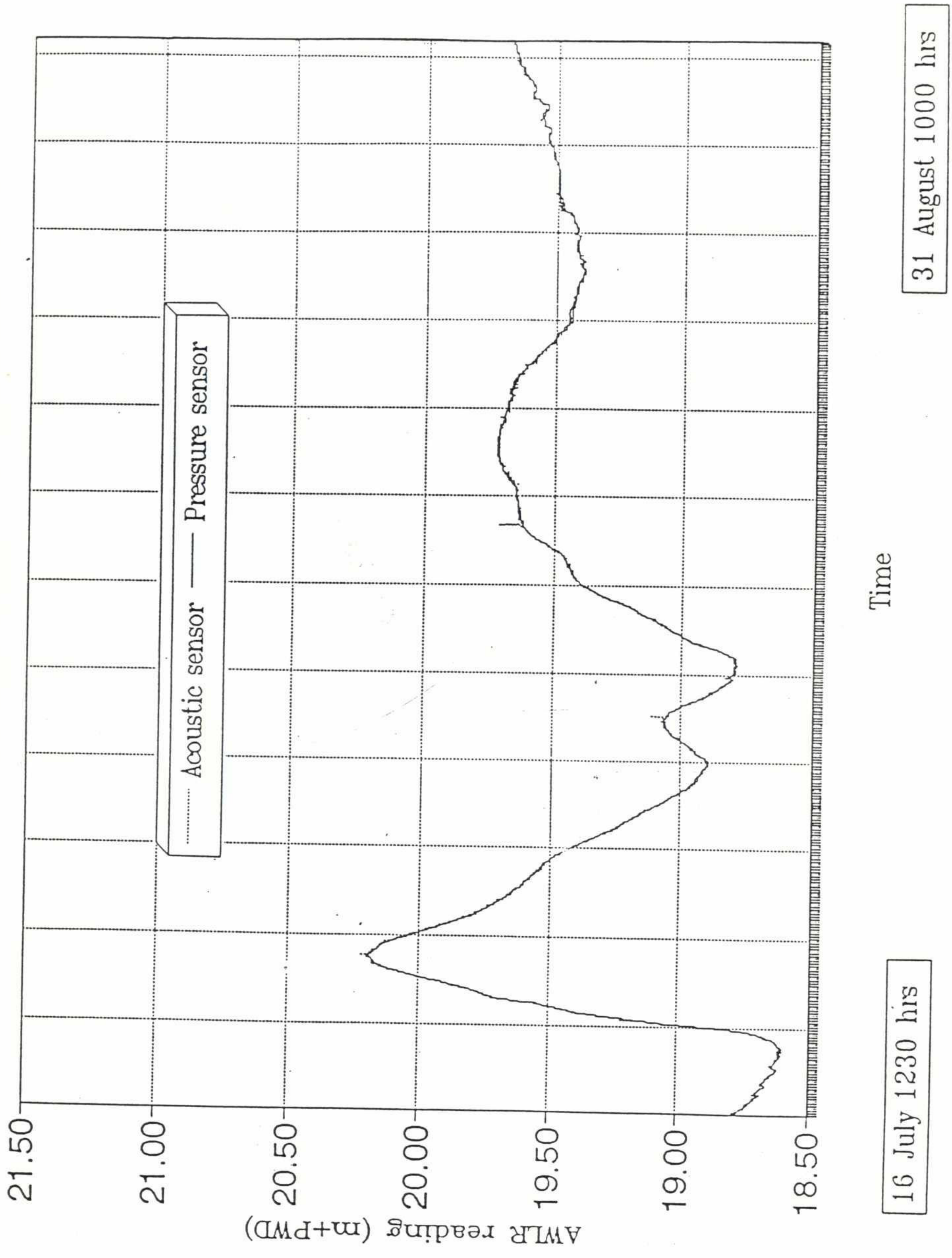

Figure 3.3 AWLR reading at Gabgachi recorded 1/2 hourly from 16 July to 31 August 1993 by the pressure and the acoustic sensors.

9D

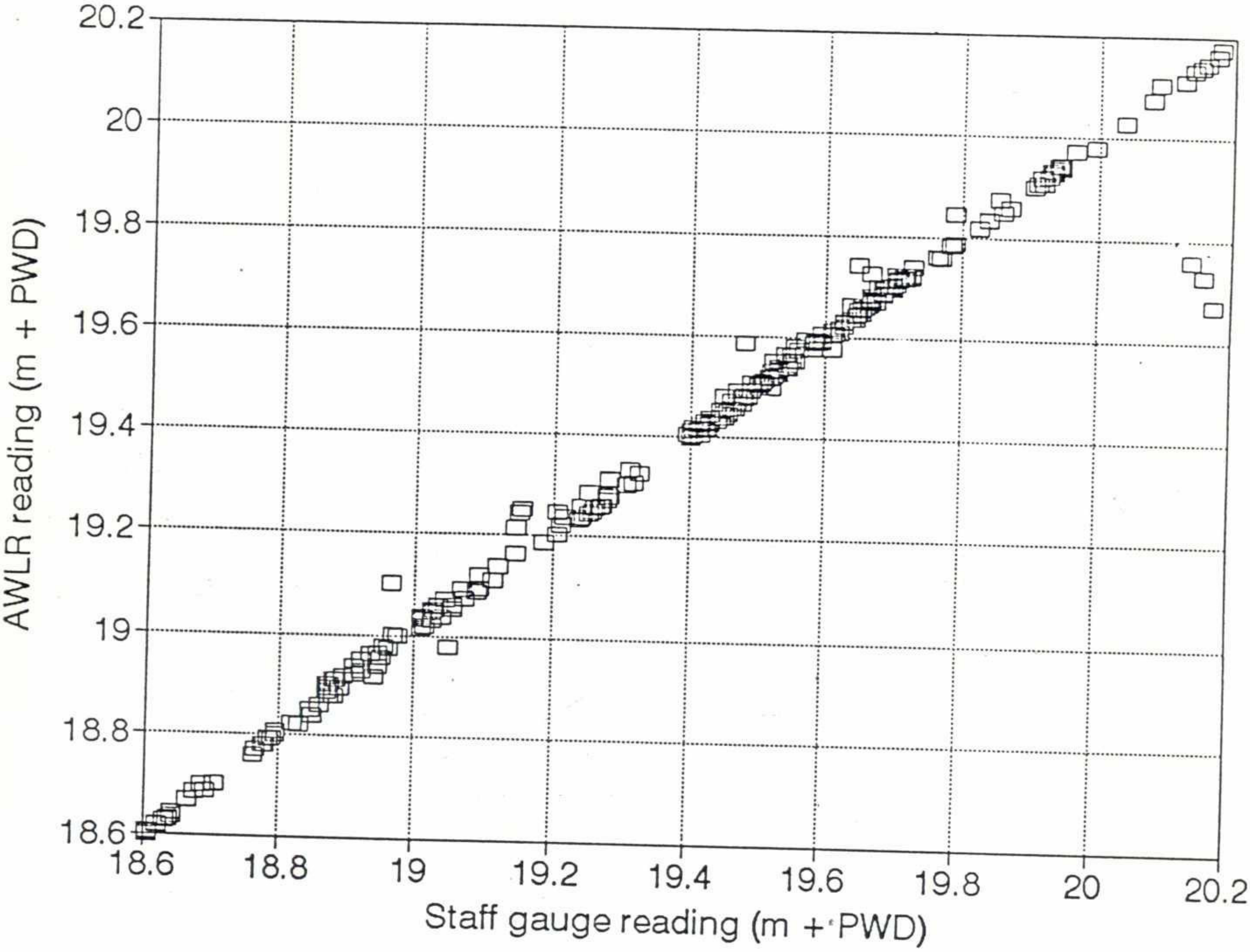

Figure 3.4 Correlation between AWLR reading (pressure type) and staff gauge reading with data from 4 July - 31 August 1993.

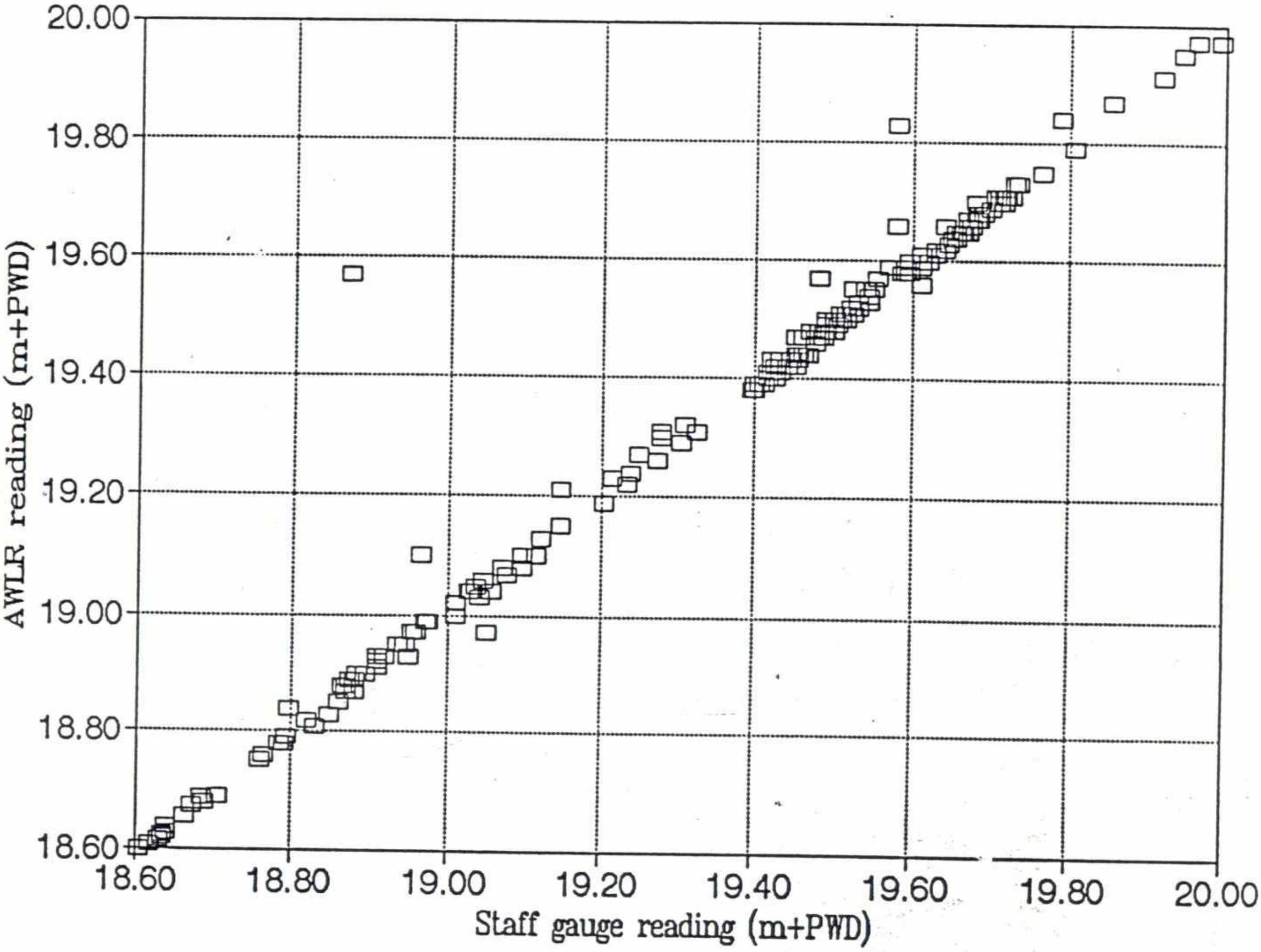

Figure 3.5 Correlation between AWLR reading (acoustic type) and staff gauge reading with data from 16 July to 31 August 1993.

Annexure 2

Number of Measuring Points in a Velocity Vertical

TEST GAUGING REPORT

NOTE

NUMBER OF MEASUREMENT POINTS IN A VELOCITY VERTICAL

NOVEMBER 1993

BY ZAHIR KHAN

Number of measurement points in a velocity vertical

Introduction

The determination of the correct depth-mean velocity in a vertical is important for the calculation of the discharge using the velocity area method.There are four main sources of uncertainties in determining the discharge.

- o uncertainty in the current-meter rating.
- o limited time of exposure of the current-meter.
- o limited number of measurement points in a vertical.
- o the fourth is arising due to the approximation by interpolation of the horizontal velocity distribution between the verticals.

This section is dealing with the third source of uncertainty only.

Approach

The analysis consists of the comparison between the mean velocity based on six points and the velocities obtained using the existing computation rule for three points,two points and one point in a vertical assuming that the six points method represents the true value,the differences with the other methods are computed including the standard error of estimates.The effect of the method on the total discharge is determined.

Analysis of the velocity profile

For this investigation,velocity observations at six points in each vertical are used that are made during test measurements by S4 current-meter in the Jamuna River at Bahadurabad.Velocity profiles with six points are drawn for each vertical. Assuming

- o linear variation between the measuring points and
- o constant from the first measuring point to the surface,
- o extrapolation of velocity profile to the bed is made according to power profile (Fig.1).

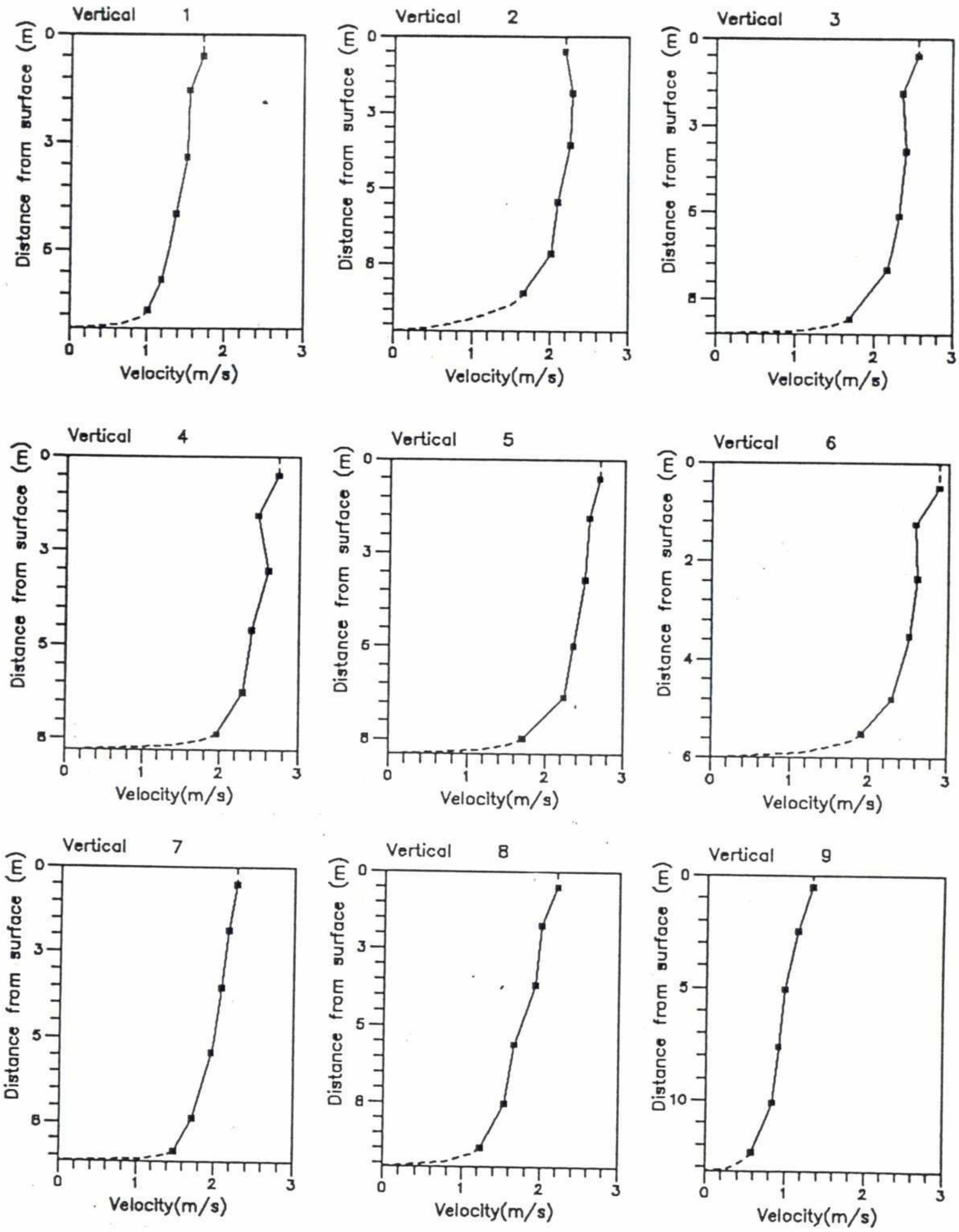

Figure 1A Velocity profiles in the verticals, Bahadurabd (Left channel), 20 to 22 August

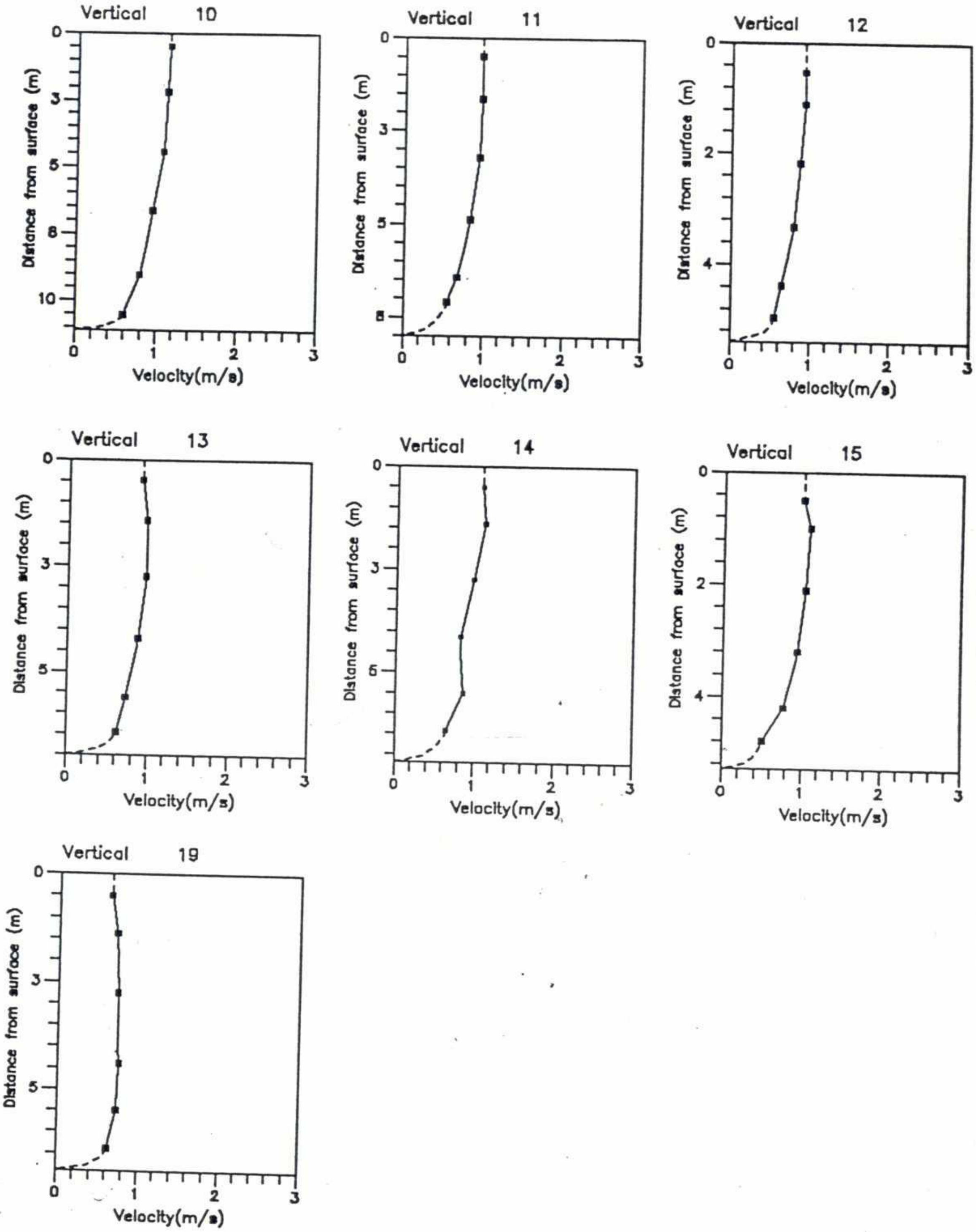

Figure 1B Velocity profiles in the verticals, Bahadurabd (Left channel), 20 to 22 August

The depth-mean velocity is calculated for each vertical applying the following equation and is assumed to be the true depth-mean velocity.

$$\overline{V} = \frac{1}{d} \{\sum_{i=1}^{n} \frac{(V_i + V_{i-1})}{2} (d_i - d_{i-1}) + 0.857 V_n (d - d_n)\}$$

the last term in the equation is due to power profile $v_x = v_n\{x/(d-d_n)\}^{1/c}$ with c=6 (Ref.1)

v_x= point velocity in the extrapolated zone at a distance x from the river bed.

vn= velocity at the last measuring point at a distance (d-dn) from the river bed.

Mean velocities for three points, two points and one point have been calculated for each vertical by using the following computation rules recommended by ISO (Ref.2)

For three points

$V_3 = 1/3(v_{0.2}+v_{0.6}+v_{0.8})$ (Ref. 2)

For two points

$V_2 = .5(v_{0.2}+v_{0.8})$ (Ref.2)

For one point

$V = v_{0.6}$ (Ref.2)

The mean velocity obtained from these computation rules are compared with the mean velocity from the six point method for each vertical. The relative differences are compared including the mean value and the standard error of estimate, see Table 1.

Vertical no.	Mean velocities				Relative difference (%)		
	Six-point (V6)	Three-point (V3)	Two-point (V2)	One-point (V1)	(V6-V3)/V3	(V6-V2)/V2	(V6-V1)/V1
1	1.401	1.383	1.384	1.380	1.30	1.20	1.52
2	2.038	2.070	2.064	2.081	-1.54	-1.29	-2.06
3	2.258	2.275	2.247	2.330	-0.73	0.50	-3.09
4	2.408	2.390	2.385	2.400	0.73	0.94	0.31
5	2.352	2.390	2.395	2.380	-1.58	-1.79	-1.16
6	2.449	2.463	2.440	2.510	-0.58	0.37	-2.43
7	1.975	1.977	1.977	1.977	-0.08	-0.08	-0.07
8	1.741	1.717	1.750	1.650	1.41	-0.52	5.50
9	0.945	0.940	0.959	0.900	0.54	-1.52	4.92
10	0.958	0.959	0.964	0.949	-0.11	-0.66	0.99
11	0.829	0.833	0.830	0.840	-0.48	-0.08	-1.27
12	0.788	0.792	0.790	0.796	-0.49	-0.20	-1.05
13	0.850	0.860	0.850	0.880	-1.21	-0.05	-3.45
14	0.907	0.923	0.966	0.835	-1.65	-6.10	8.62
15	0.893	0.933	0.930	0.940	-4.31	-3.97	-4.99
19	0.703	0.736	0.725	0.757	-4.48	-3.08	-7.16
Mean	%				-0.83	-1.02	-0.30
Standard error	%				1.74	2.00	4.16

- V6 = The depth-mean velocity with six points
- V3 = The depth-mean velocity with three points
- V2 = The depth-mean velocity with two points
- V1 = The depth-mean velocity with one point
- Only three points are in vertical 16 and 17 and one point in 18

Table 1 Comparison of 'true' depth-mean velocity (six-point velocity by profile integration) and the velocity computed based on existing rules

Analysis of discharge

The total discharges over the cross-section are calculated by applying the mean section method using six-point, three-point, two-point and one point depth-mean velocities. Comparison is made between the discharge calculated using six-point depth-mean velocity and the discharges from three- point, two-point and one point depth-mean velocity, see Table 2.

Total discharge				Difference		
Q(m3/s) with six-point	Q(m3/s) with three-point	Q(m3/s) with two-point	Q(m3/s) with one-point	(Q6-Q3) (%)	(Q6-Q2) (%)	(Q6-Q1) (%)
26050.77	26599.90	26630.18	26539.35	-2.11	-2.22	-1.88

Q6= Discharge based on six-point depth-mean velocity
Q3= Discharge based on three-point depth-mean velocity
Q2= Discharge based on two-point depth-mean velocity
Q1= Discharge based on one point depth-mean velocity

Table 2 Total discharges based on different velocity profile discretisations, Bahadurabad (Left channel), 20 to 22 August

Discussion

Table 1 shows that with the increasing numbers of points per vertical the error in depth-mean velocity is decreasing,but the calculated error are surprisingly small.Obviously the three-point and two-point methods are more reliable than the one point method.From the view point of the accuracy of discharge,it can be seen that all three methods may be sufficient for the determination of mean velocity V,depending of course on the accuracy required. Considering the standard error in mean velocity the use of the one-point method is questionable.Both two-point and three-point methods can be used to make velocity profile in the type of conditions considered here.Obviously,these conclusions have no general value.For other stages and locations similar analyses have to be done.

References

1. Hymos (hydrological databse management programme)manual

2. ISO 748-1979, Liquid flow measurement in open channels - Velocity-area methods

Annexure 3

Preliminary optimization of sediment gauging procedures

1 General

1.1 Purpose of sediment transport test gauging

Test gauging was performed in the Jamuna River at the section of Bahadurabad during the period 20-22 August 1993.

The purpose of the test gauging is to optimize the measurement procedure in terms of:

- shortness of total gauging time
- minimum number of vertical profiles
- minimum of sampling points per vertical profile
- minimum sampling time

1.2 Approach

The test gauging procedure for sediment measurements was as follows

- the verticals were selected from the ADCP's on-line suspended sediment concentration profile.
- verticals were more dense for the cross-section where the suspended sediment concentration was relatively higher and vice versa.
- in total 19 verticals were selected
- suspended sediment sampling was carried out as point sampling
- 6 points in a vertical was selected for depths larger than 5 m and 3 points for depths lesser than 5 m
- grain size analysis has been carried out for suspended bed material load, bed load and for bed material

Selection of measuring points in a vertical has been proposed by standards issued by various countries. Simplified methods differ from the multipoint methods in that samples are taken at fewer points in the interest of lessening the work involved in taking and processing samples. Such methods should be adopted only after results obtained with them are checked against measurements obtained with multipoint or other accurate methods. In this analysis, the Straub method and the Chinese standard are followed for optimization the number of sampling points per vertical.

The number of verticals required for sediment discharge measurement depends on the size distribution and concentration distribution of the sediment, as well as on the desired accuracy for data collection. Verticals should be spaced closely in zones of large transverse variation in sediment concentration and in the main current (WMO,1989). The test gauging 93 was mainly related to this concept. The ADCP's online profiles give a basis for this transverse variation of the suspended sediment

Two indexes are followed for optimization the number of verticals which are discussed in the following chapters.

2 Data used and primary analysis

2.1 Data collection

The test gaugings was taken place during the period 20-22nd August 1993 in the left channel of the Jamuna River at Bahadurabad.

Selection of verticals
The selection of verticals was based on the transverse distribution of the suspended sediment. The moving boat method using ADCP's sediment menu gives transverse distribution of the sediment concentration (dB) on the monitor in colours. The verticals were selected densely in the zone of high concentration and less in the zone of low concentration.

Current measurement
The moving boat method using ADCP measures velocities in different components which can be visualised on-line.

With the survey vessel on anchor the current was measured in each selected vertical using the S4 instrument. Six point measurements were carried out for the depth greater than 5m and 3 point method was carried out for the depth less than 5m.

300 seconds integration time for each velocity sampling with record of sampling at each 50 seconds interval was used.

Suspended sediment sampling
Suspended sediment samples were collected at the same location/depth where the velocities were measured and was done simultaniously. It was done by by sampling into 0.5 l bottles with also simultaneous turbidity readings.

Grain size
The bed material was collected by the US BM-54. The bed load was collected by Helley-Smith sampler. The suspended sediment was collected at the lowest point in each suspended sediment sampling vertical.

2.2 Data Analysis

Suspended sediment concentration
The collected samples of suspended sediments are analysed in the laboratory. No distinction was made between the suspended bed material transport and the wash load. The concentration was measured by Millipore micro-filtering method.

Results of the Total suspended sediment concentration (including wash load) at each verticals and concentration profiles are shown in Volume I.

The transverse distribution of total suspended sediment along the cross section are shown together with the sampling verticals in Figure 1. The verticals are relatively dense in the section having high sediment concentration. The concentration of suspended sediment between the lowest measured point and the reference level (the theoretical border between suspended and bed load transport) was difficult to measure. A theoretical approach was made to compute the concentration at the reference level (see ANNEX 1) by using concentration profile and prediction method.

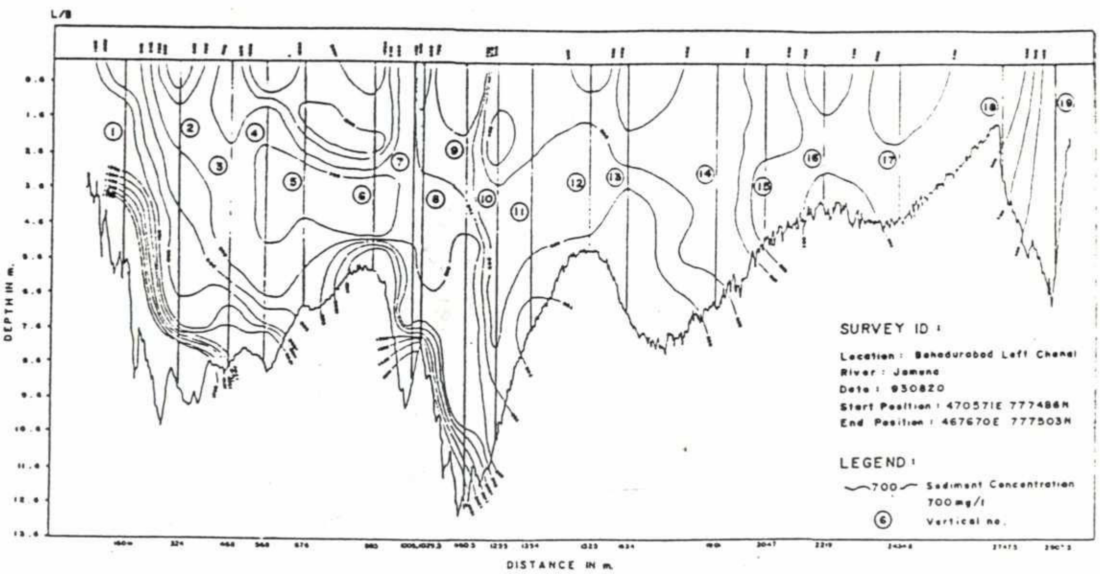

Figure 1 Transverse suspended sediment distribution

Grain size

The following analysis was carried out in the laboratory:

- Grain size distribution of suspended sediments, by Andreasen settling tube and wet sieve analysis
- Grain size distribution of bed load (Helley-Smith), by sieve analysis
- Grain size distribution of bed material (US BM-54), by Andreasen tube and sieve analysis

When the percentage of fine sediment in a sample was found less than 16, no analysis of the fine sediment was carried out.

Results of the analysis comprising grain size tablea and distribution curves are shown in Volume I.

2.3 Computation of total suspended discharge

The total suspended sediment dischsrge per meter width q_s, the dependent variable, at each vertical are used as an indicator to optimize sampling procedure in terms of space and time.

The suspended sediment transport is calculated as the depth integration of the product of velocity (U) and concentration (C) at each point in a vertical. To compute the suspended load it is necessary to specify reference level. Below that level the transport is considered as bed load transport. Estimation of suspended measured discharge without consideration of the concentration C_a at reference level could under estimate the actual transport. The values of C_a has been calculated form the equation of the concentration profile by extrapolating from the lowest measured point. C_a could also be calculated from the equation of Van Rijn. Detail formulas and steps for computing suspended sediment discharge are mentioned in ANNEX 1. The total measured sediment transport is 22,588 kg/s.

The sediment rating curve (Figure 2) read as:

$$q_s = 0.30\,(U*h)^{1.42}$$

Where,
- q_s = suspended sediment discharge per unit width
- U = average velocity over the depth
- h = water depth at respective vertical

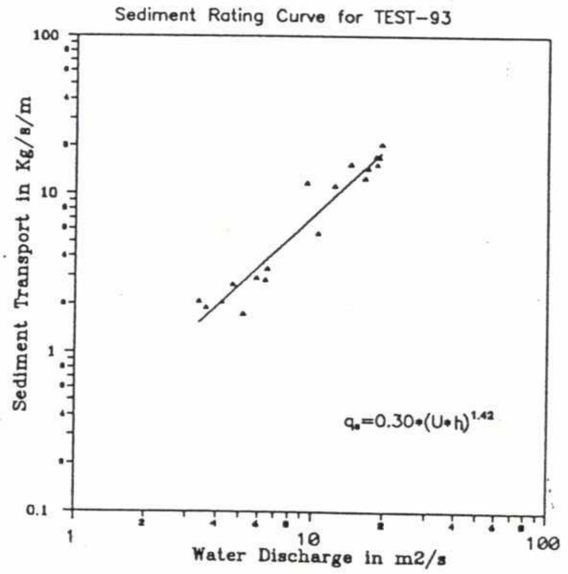

Figure 2 Suspended sediment rating curve at Bahadurabad (Test-93)

3 Optimization

The optimization of test gauging was carried as follows

- Optimization of sampling point in a vertical
- Optimization of number of verticals in a cross-section
- Optimization of time

3.1 Optimization of sampling points in a vertical

Selection of measuring points in a vertical has been proposed by standards issued by various countries. The number of points can vary according to the depth of the river and the size of sediment in suspension. Methods may be classified into six-point and simplified methods.

During Test gauging 93, mostly a six-point method was followed in order to increase the accuracy and to provide a good base line for comparison with other simplified methods.

a) Straub Method:

In this method, samples are taken at 0.2 depth and 0.8 depth and the values are weighted 5/8 and 3/8 respectively (ISO, May 1982). The mean sediment concentration in a vertical read as:

$$\overline{C_s} = \frac{3}{8} C_{0.8d} + \frac{5}{8} C_{0.2d}$$

Where C_s = the sediment concentration in mg/l averaged over the vertical
h = depth of water from water surface

The sediment discharge computed by this method form the measured data shows good correlation with the measured sediment discharge (6-point) with R^2=0.98 (Figure 3).

The total discharge computed is 21,671 kg/s which is 4.2 percent less (Table 2) than the discharge computed from the measured six points method.

b) Chinese standards:

In this method fractions of depth **k** is considered as a weight to be applied to the products of the velocity and sediment concentration which can be written as:

in which q_s is the sediment discharge per unit width in kg/s/m;
C_i is the sediment concentration at the measuring point in kg/m³;

$$q_s = \frac{d}{N}\sum_{i=1}^{N} k_i C_i U_i$$

U_i	is the velocity at the measuring point in m/s
k	is the weighting factor for i th sample;
N	N is the sum of the weighting factors at a vertical.

Values of the factor k, as recommended in the Chinese standards (Ministry of Water Conservancy, 1975b), are given in Table 1

Number of measuring points in a vertical	N	Measuring at relative depth										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
5	10	1		3				3		2		1
3	4			2				1		1		
	3			1				1		1		
2	2			1						1		
1	1						1 or	1				

Table 1 Values of depth factor k used for weighted concentration according to Chinese standards

The above formula applies to the method which measures velocity and sediment concentration simultaneously at each sampling point.

The 2-point Chinese method is plotted against the measured sediment discharge in Figure 4, having correlation R^2 = 0.97 and 3-point with the measured having correlation R^2 = 0.98 (Figure 5).

Using 2-point method gives sediment discharge 22,488 kg/s which is 0.60 percent less than the measured sediment discharge. 3-point method gives sediment discharge rate 22,394 kg/s which is 0.90 percent less than the measured sediment rate. Table 2, indicates the sediment rate at each vertical and also the total sediment rate.

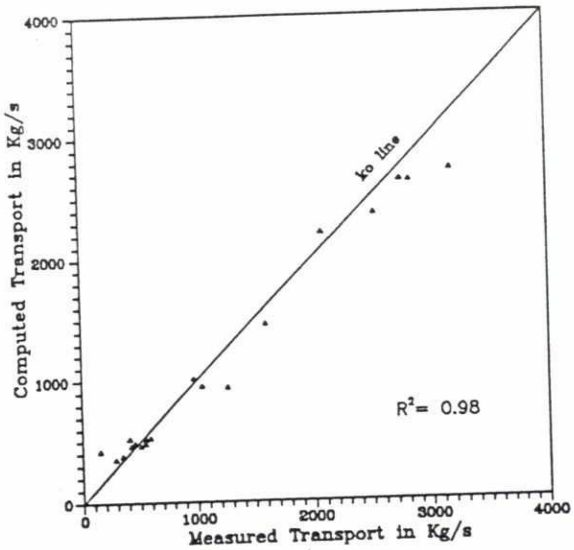

Figure 3 Comparision between Six-point and Simplified (Straub) methods

Vertical no.	Water Discharge Qw m3/s	Measured Sed Dis. Qs kg/s	Computed sediment discharge Straub M 2-point kg/s	Chinese 2-point kg/s	Chinese 3-point kg/s
1	2281	2831	2630	2634	3002
2	2662	3182	3041	3467	3117
3	2345	2080	2208	2274	2100
4	1978	1597	1452	1426	1412
5	2721	2752	2634	2837	2820
6	2809	2530	2363	1951	2005
7	1163	1045	948	1013	1023
8	1366	978	1012	997	974
9	1237	1266	940	1124	1126
10	994	546	484	516	527
11	885	452	487	501	497
12	697	289	355	306	314
13	1040	550	515	573	592
14	1215	587	531	657	648
15	766	425	464	473	497
16	720	410	521	501	516
17	789	507	464	607	627
18	677	212	241	219	219
19	948	349	380	373	378
Total	27294	22588	21671	22448	22394
Difference %			4.23	0.62	0.87

Table 2 Six-point and optimized (points in a vertical) sediment dischsrge

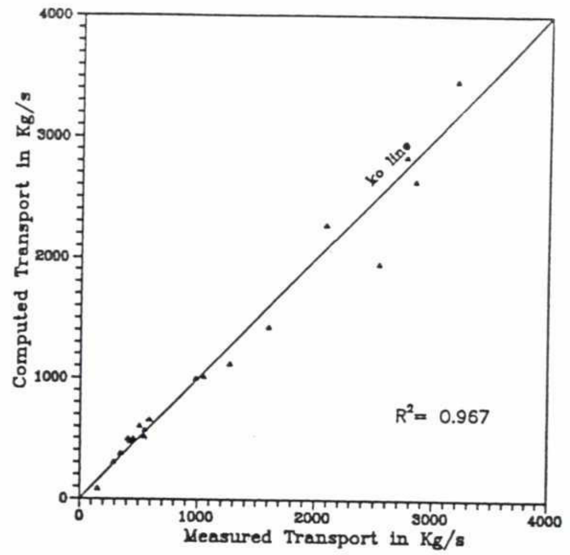

Figure 4 Comparision between Measured and Chinese (2-point) Methods

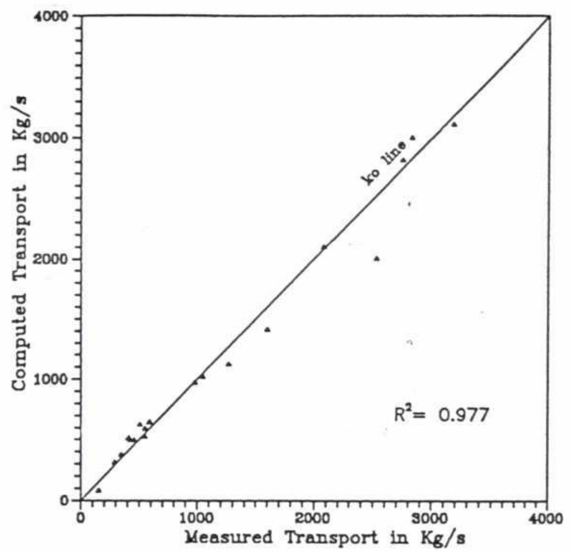

Figure 5 Comparision between Measured and Chinese (3-point) Methods

3.2 Optimization of sampling verticals

Suspended sediment discharge is computed by summing the products of the q_s and section width for each of the verticals. Proper arrangement of the verticals in the cross section has considerable influence on the accuracy if the transverse sediment distribution is uneven. The transverse sediment distribution of the measured suspended sediment is shown in Figure 1.

Analysis of a group of suspended sediment discharge measurements may show that the number of sampling verticals can be reduced without intolerable reduction in accuracy.

Following steps are followed to reduce the number of verticals:

Step-1 Square of the average velocity over total depth, U^2/h-Index

The U^2/h index indicates is how far the flow field is adopted to the shape of the cross-section. As long as the flow pattern is congruent, which may be expected for a range of stages, the transverse U^2/h distribution remains the same. The more regular the distribution and the more stable in time, the stronger reductions in the number of verticals are possible. In Figure 6, U^2/h is plotted over the cross section of the left channel at Bahadurabad. Apparently, U^2/h has slopes between verticals 1-6, between 6-9, between 9-18 and between 18-19. Sampling at verticals 1, 6,9,18 and 19 can led to computation of velocities and consequent discharges at other verticals (Table 3) or at new verticals. The measured total water discharge by sampling from 19 verticals is 27,294 $m^{3/s}$. The discharge from the optimized verticals is 28,321 m^3/s which is only 3.63 percent more than the measured discharge.

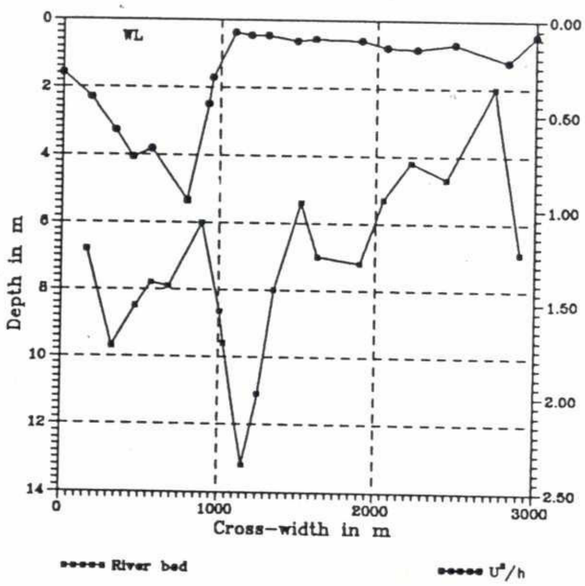

Figure 6 Transeverse distribution of U^2/h

Vertical no.	T. Depth m	Average Velocity m/s	v^2/d	Optimized Vertical no.	Computed v^2/d	Computed velocity m/s	measured Water Qw m3/s	Computed Water Qw m3/s	measured Sed Qs Kg/s	Computed Sed Qs Kg/s
1	6.80	1.386	0.283	1		1.386	2281	2281	2831	2831
2	9.70	1.993	0.409		0.434	2.053	2662	2743	3182	3233
3	8.50	2.228	0.584		0.568	2.197	2345	2312	2080	2072
4	7.80	2.377	0.725		0.660	2.270	1978	1888	1597	1568
5	7.90	2.320	0.681		0.761	2.451	2721	2875	2752	2840
6	6.00	2.393	0.954	6		2.393	2809	2809	2530	2530
7	8.65	1.957	0.443		0.567	2.215	1163	1316	1045	1159
8	9.60	1.712	0.305		0.488	2.165	1366	1727	978	1100
9	13.20	0.932	0.066	9		0.932	1237	1237	1266	1266
10	11.10	0.947	0.081		0.078	0.931	994	957	546	545
11	8.00	0.807	0.081		0.091	0.853	885	901	452	453
12	5.40	0.772	0.110		0.113	0.782	697	666	289	288
13	7.00	0.832	0.099		0.127	0.945	1040	1103	550	552
14	7.20	0.882	0.108		0.162	1.081	1215	1368	587	594
15	5.30	0.876	0.145		0.181	0.980	766	782	425	426
16	4.20	0.801	0.153		0.204	0.925	720	753	410	412
17	4.70	0.766	0.125		0.232	1.045	789	969	507	520
18	2	0.738	0.273	18		0.738	677	605	212	151
19	6.90	0.687	0.068	19		0.687	948	1029	348	349
Total							27294	28321	22587	22889
Difference %								3.63		1.32

Table 3 Optmization of verticals by using index U^2/h

Step-2 Sediment rating Index, $q_s/(U^*h)^n$

The sediment transport is proportional to the power of velocity. The sediment rating parameter per meter width $q_s/U^n = q_s/(U^*h)^n$ = constant at a vertical for a particular river. The value of "n" is 1.42 for measurement of Test Gauging 93 at Bahadurabad. This value is consistent to the other FAP's analysis and studies.

The Index $q_s/(U^*d)^{1.42}$ is used to see in how far the sediment transport is adopted to the flow field. The more regular the transverse distribution of the index the more reductions in number of velocity verticals are possible. The variation of this constant for the Test Gauging'93 is within the range 0.2-0.5 over the width (Figure 7). The average velocities which are computed at different verticals by using U^2/h (Step-1) are used in the rating index for estimation of sediment discharge at respective verticals. In Table 4, the measured suspended sediment discharge over the width is 22,587 kg/s and the computed sediment discharge is 23,590 kg/s which is 4.25 percent more than the measured sediment rate. The variation in sediment rate over the width by using Straub Method is 3.06 percent more than the sediment rate calculated with the original data.

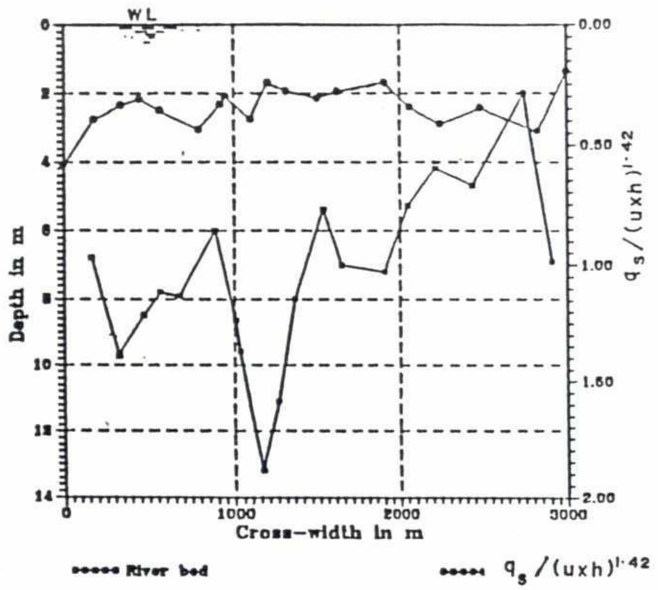

Figure 7 Transverse distribution of sediment rating parameter

Vertical no.	T. Depth m	Measured Velocity m/s	Computed velocity m/s	Measured Sed trans kg/s/m	Measured ratio qs/qw^n	Computed Sed trans Kg/s/m	Measured Sed Qs kg/s	Computed Sed Qs kg/s	Using Col 3 Straub M kg/s	Using col 4 Straub M kg/s
1	6.80	1.386	1.386	11.699	0.583	11.699	2831	2831	2630	2630
2	9.70	1.993	2.053	20.995	0.394	21.504	3182	3312	3041	2802
3	8.50	2.228	2.197	16.980	0.334	16.729	2080	2041	2208	2177
4	7.80	2.377	2.270	15.081	0.310	14.438	1597	1502	1452	1386
5	7.90	2.320	2.451	17.920	0.356	18.688	2752	2962	2634	2784
6	6.00	2.393	2.393	15.378	0.436	15.378	2530	2530	2363	2363
7	8.65	1.957	2.215	16.038	0.329	17.069	1045	1233	948	1130
8	9.60	1.712	2.165	14.150	0.298	17.212	978	1338	1012	1280
9	13.20	0.932	0.932	11.231	0.392	11.231	1266	1266	940	940
10	11.10	0.947	0.931	5.629	0.243	5.358	546	518	484	466
11	8.00	0.807	0.853	3.353	0.277	3.429	452	463	487	496
12	5.40	0.772	0.782	2.060	0.306	1.940	289	272	355	339
13	7.00	0.832	0.945	2.935	0.278	3.167	550	595	515	546
14	7.20	0.882	1.081	2.878	0.240	3.332	587	688	531	598
15	5.30	0.876	0.980	2.676	0.343	2.746	425	437	464	473
16	4.20	0.801	0.925	2.108	0.415	2.231	410	436	521	545
17	4.70	0.766	1.045	1.970	0.346	2.525	507	667	464	569
18	2	0.738	0.738	0.643	0.444	0.643	212	151	241	420
19	6.90	0.687	0.687	1.744	0.195	1.744	348	349	350	380
Total							22587	23590	21642	22326
Difference %								4.25		3.06

Table 4 Computation of suspended sediment from optimized verticals

3.3 Optimization of time of gauging

From the indexes U^2/h and $q_s/(U*h)^n$ it is evident that the sampling at verticals 1, 6, 9, 18, and 19 is sufficient to measure suspended sediment discharge in the left channel of Jamuna at Bahadurabad.

From field experiences, sampling (including velocity and sediment measurement by different instruments at six points in a vertical) takes one hour at each vertical. The time fro traveling, positioning and anchoring of boat takes 15-20 minutes. Therefore in total 2 hours for positioning and 5 hours for sampling required in future instead of 27 hours of sampling in 19 verticals. More 1 hour may required to have the ADCP profiles accross the section (includes two ways). Above time could be reduced by more two hours if the samples are collected at two points in a vertical. Hence in total 6 hours required for gauging when both sampling points in a vertical and number of verticals are optimized.

However, at each station during different season of the hydrological year, at the start of the measurements as much verticals should be considered to have relaible indexes and for that 27 hours may required for the channel size mentioned in this report.

4 Remarks and proposal for gauging procedure

4.1 General

Methods for evaluating the suspended sediment discharge by a combination of field measurement and analytical methods seem promising and should be studied further. Simplified methods should be verified with actual measured data, when available.

Suspended sediment discharge over an cross section is usually ensured by dividing the cross section into number of sections. For each measuring station, field data obtained by multipoint methods should be analyzed in order to establish simplified methods which can be employed during floods. Relationships established by U^2/d and the sediment rating equations obtained by multipoint methods and with the initial number of verticals should be established for conversion purposes.

Fluvial sediment samples should be analyzed in the field or laboratory for size distribution. An estimate of suspended sediment transport is to be made in atleast two groups which are a) coarser than .063mm and b) finer than .063mm. Sediment concentration as well as sediment discharge may be expressed for these two size groups. If the data are to be used to estimate sediment transport samples of suspended load, bed load and bed material should be analyzed for size distribution.

4.2 Optimization of Sampling point in a vertical

The Test Gauging'93 result shows that simplified methods seems reliable and accurate but need further confirmation with more data analysis. The present analysis shows, the 2-point Straub Method and 2-point Chinese Standard are consistent but 2-point Chinese Standard gives higher accuracy for the Test Gauging data. The 3-point Chinese standard also shows very high degree of accuracy.

4.3 Optimization of verticals

The number of verticals required for sediment discharge measurement depends on the size distribution and concentration distribution of the sediment, as well as on the desired accuracy for data collection. Verticals should be spaced closely in zones of large transverse variation in sediment concentration and in the main current (WMO,1989). The Test gauging 93 was mainly related to this concept. The ADCP's online profiles gives a basis for this transverse variation of the suspended sediment. Although verticals are selected more densely in the high concentrated zone which was not necessary.

The index U^2/d (Step 1)can be used for optimization of the verticals which are to be initially selected by the above methods. The velocity which will be derived from the said index can be used in the sediment rating index (Step 2) at a vertical for the computation of sediment discharge per meter width. The Test Gauging results shows an accuracy of 97 percent by using these indexes. Nevertheless, these indexes should be verified for more data and other transects.

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Annexure 4

Methods used for data analysis

D02

METHODS USED FOR DATA ANALYSIS

1. Computation of suspended sediment parameter

The pumping method was used for collection of suspended sediment into bottle. Simultaneous collection of water sediment samples and velocity measurements were carried at each point in a vertical. The sediment samples were collected in a vertical at six points: one at 0.5 m below the water surface and another close to the bottom of the river bed and remaining 4 inbetween. When the water depth is less than 5m, samples were collected from three points, one 0.5 m below the water surface and another close to the bed and the remaining one inbetween.

1.1 Fall velocity

The settling or fall velocity of the grain is the terminal rate at which it falls in a stagnent fluid, when the fluid drag on the particle equals its submerged weight.

Within Stoke ranges ($Re_D = \frac{\omega . D}{\nu}$ < 1), fall velocity read as:

$$\omega = \frac{1}{18} \Delta \frac{g}{\nu} D^2$$

Where

Δ =$(\rho_s - \rho) / \rho$
D =Diameter of sphere
ν =Kinametic viscosity

The kinematic viscosity coefficient υ is defined as :

$$\upsilon = \eta / \rho$$

in which :

υ = kinematic viscosity coefficient (m^2 / s)
η = dynamic viscosity coefficient (N_s / m^2)
ρ = fluid density (kg / m^3)

The kinematic viscosity coefficient is a function of temperature. The kinematic viscosity coefficient can be approximated by :

$$\upsilon = [1.1 4 - 0.031 (Te - 15) + 0.00068 (Te - 15)^2] 10^{-6}$$

Where, Te = 25 degree celcius

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1.2 Shield parameter

The particle movement is initiated when

$$\frac{\tau_{bcr}}{(\rho_s-\rho)gD} \geq \theta_{cr}$$

The θ_{cr} factor depends on the hydraulic conditions near the bed ($\frac{U_{*}.D}{\gamma}$), the particle shape, the particle position relative to the other particle. The hydraulic condition near the bed is a function of the Reynolds number R_{e*} $=(U_{*}.D)/\upsilon$. Thus $\theta_{cr} = F(R_{e*})$. The experiment of shields (1936) for $\theta_{cr} = F(R_{e*})$ related to a flat bed are most widely used

Yalin (1972) showed that the shields curve can be expressed in term of the dimensionless mobility parameter θ_{cr} and the particle parameter D_{*},

Where D_{*} =[(s -1).g/υ2]1/3.d50 = particle parameter

Applying these parameter, the shield curve can be represented as :

θ_{cr}	$= 0.24D*^{-1}$	For	$1< D* \leq 4$
θ_{cr}	$= 0.14D*^{-0.64}$	For	$4< D* \leq 10$
θ_{cr}	$= 0.04D*^{-0.1}$	For	$10<D* \leq 20$
θ_{cr}	$= 0.013D*^{0.29}$	For	$20<D* \leq 150$
θ_{cr}	$= 0.055$	For	$D* >150$

in which

θ_{cr} $=[\tau_{cr} / (\rho_s - \rho).g.d_{50}$ = critical shield parameter

τ_{bcr} = time average critical bed shear stress

1.3 Bed Roughness

When the flow over a smooth loose bed of non-cohesive sediment is increased gradually, then various bed forms appear. The change of the bed form is accompanied by a change of the shear stress. Many types of bed forms can be distinguished and basically all types in nature have three dimensional geometry.

The shear stress $\tau = \rho.g.h.i$ can be combined with Chezy equation

$u = c(h.i)^{0.5}$

$\tau = \rho.g\ (u^2/c^2)$

It is usual to divide the shear stress into two parts

τ' = shear stress present for plane bed

τ'' = extra shear stress due to the bed form

Hence,

$$\tau = \tau' + \tau''$$

Using similar definitions for the Chezy roughness

$$1/C^2 = 1/(C')^2 + 1/(C'')^2$$

Using Darcy - Weisbach friction factor (f) the similar expression becomes

$$f = f' + f''$$

Where C' = grain related Chezy roughness

C'' = form related Chezy roughness

1.4 Computation of Chezy roughness

Various prediction methods exist for calculating the Chezy effective roughness coefficient. Engelund & Hansen and the Van Rijn predictor but also cannot give close approximation for C value. Comparison of C values by the Engelund - Hansen and Van Rijn methods are shown in the main report. For Engalund & Hunsen C varies within the range of 40 - 90 $m^{0.5}/s$ where as with Van Rijn method Ranges between 38 - 90 $m^{0.5}/s$. Using the water surface slope "i" = $7.6*10^{-5}$ (FAP 24), C varies between 32-110 $m^{1/2}/s$. In the present analysis the value of C is taken as 60 $m^{0.5}/s$ which is the average value over the width.

The description of prediction methods are as follows

Engelund & Hansen

From the depth average velocity $\bar{U}(z,t)$ and water depth $h(z,t)$. The following steps are involved

1- Assume dune as bed form.

2- Assume h' for form height.

3- Compute $U*'$ from the equation

$$\bar{U}/U*' = 5.75 \log(4.8h'/D_{50})$$

where, D_{50} = median diameter

4- Compute ψ from $U*' = (\psi'.\Delta.g.D_{50})^{0.5}$

where, ψ' = dimensionless parameter

$$= \tau'/(\varrho.g.\Delta.D_{50})$$

again $\tau' = \varrho(U*')^2$

5- Compute ψ or from equation

$$\psi' = 0.06 + 0.4\,\psi^2$$

where, ψ = dimensionless parameter

$$= \tau/(\varrho.g.\Delta.D_{50})$$

6- Compute h' from $h'/h = \psi'/\psi = \tau'/\tau$

7- Compare point 6 and 2 and continue all steps above until those two points give the same value.

8- Compute $U* = (\psi.\Delta.g.D_{50})^{0.5}$

9- Compute Chezy roughness coefficient C from

$$C/(g)^{0.5} = \bar{U}/U*$$

Van Rijn (1984)

Van Rijn has analyzed large numbers of data on bed form dimension and roughness, mainly for dunes. His method based on bed - form and grain related parameter such as bed form length,height, steepness and bed material size. He considered equivalent roughness K_s for computation of Chezy value. Hence $K_s = K'_s + K''_s$

Where,

K_s = equivalent roughness

K'_s = $3D_{90}$

K''_s = roughness due to bed form

The steps are as follows

1- Compute $U*$ from $\bar{U}/U*' = 5.75 \log (12h/3D_{90})$

Where ,

h = water depth

U = depth average velocity

$U*'$ = shear velocity due to grain size

2-Compute $D*$ from $D* = d_{50}((s-1)g/\upsilon^2)^{1/3}$

Where,

$D*$ = particle parameter

s = specific density $\simeq$ 2.65(-)

υ = kinematic viscosity coefficient (m^2/s)

d_{50} = median particle diameter of bed material (m)

3- Compute θ_{cr} from the equation of Jan H & Andre which states as

$\theta_{cr} = 0.14\ D*^{-0.64}$ for $4 < D* < 10$

4- Compute τ_{bcr} from $\theta_{cr} = \tau_{bcr}/((\rho s - \rho).g.d_{50})$

Where,

τ_{bcr} = Time averaged critical bed shear stress

5- Compute $U*_{cr} = (\tau bcr/\rho)^{0.5}$ = critical bed shear velocity

6- Compute $T = [\ U*'/U*_{cr}\ ]^2 - 1$ = bed shear stress parameter

7- Compute dune height $H=0.11h(D_{50}/h)^{0.3}(1-e^{-0.5T})(25-T)$

8- Compute dune length $\lambda = 7.3h$

9- Compute equivalent roughness $Ks=3D_{90} + 1.1H(1-e^{-25H/\lambda})$

10- Compute Chezy coefficient $C = 18 \log (12h/K_s)$

2 Suspended load transport

2.1 Computation of suspended sediment discharge

The depth integrated suspended load transport is defined as the depth. integration of the product of velocity (U) and concentration (C) as follows (Figure 1)

$$q_{se} = \int_a^h UCdz$$

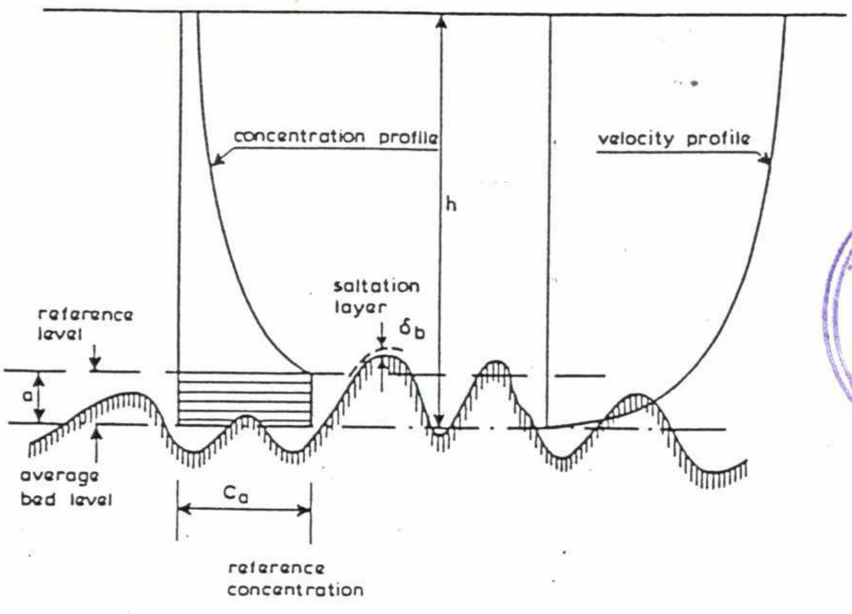

Figure 1 Schematization velocity and concentration profile

Application of the above equation requires information on the velocity profile, the concentration profile and a reference concentration (C_a) at a reference level (z = a) close to the bed.

There are two methods to compute the depth - integrated suspended load transport (Figure 2). Firstly, the partial method which gives the suspended load transport between the bed and highest sampling point using a linear interpolation between adjacent (measured) values. Secondly, the integral method, for computation of total suspended load transport between the bed and the water surface by fitting a theoretical distribution to the measured flow velocity and concentration profile.

For the present study both the methods are used with some modifications. The field concentration samples were collected mostly at 6 points in a vertical, one at 0.5m below the water surface and another at approximately 0.5m above the bed level and remaining inbetween. Computation with these points reduces to

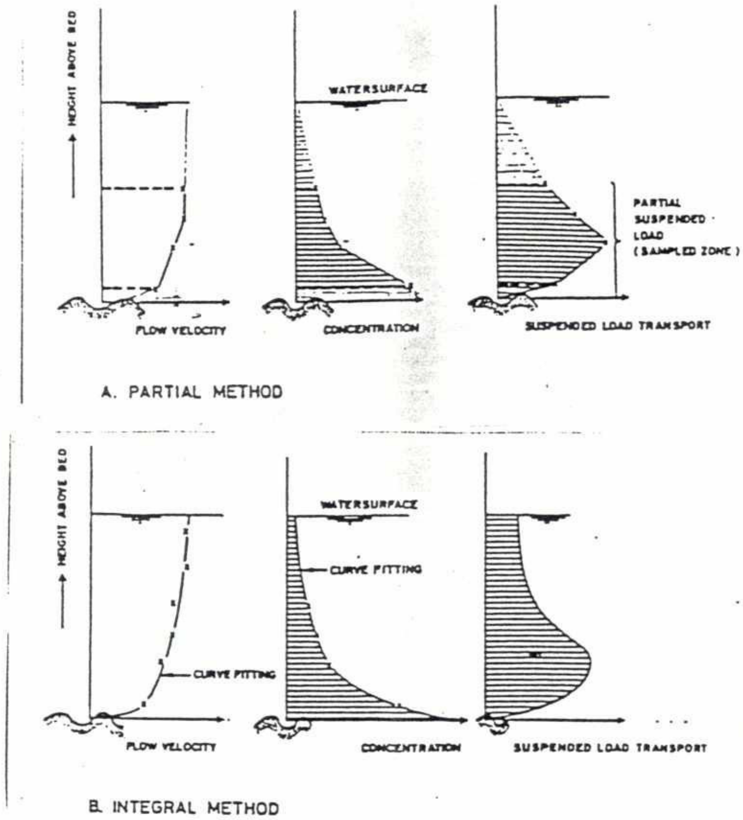

Figure 2 Computation of suspended sediment transport per meter width

quite extent the quantity of suspended sediment lies between the bed level and the lowest sampling point, and the water surface and the highest sampling point, therefore, in partial method too, the velocity and concentration profiles are used to compute the velocity and concentration at the bed level to have better estimation. Moreover, top neglected part is also consider by averaging between the top point and the zero measurement (at the surface). Therefore, partial method is the representative of the measured data for the computation of suspended sediment transport.

Partial Method

The suspended load transport per unit width (kg/sm) can be computed as

$$S_s = [\frac{1}{2}U_n C_n + \sum_{1}^{n} \frac{1}{2}(U_i C_i + U_{i+1} C_{i+1})(Z_{i+1} - Z_i]10^{-3}$$

n = number of points in a vertical

U_i = flow velocity (theoretical) at a reference level "a" above the bed (m/s).

Where,

a = 1/2 the dune height or K_s (the equivalent roughness)

C_i = concentration (theoretical) at point "a", the reference level (mg/lit).

Z_i = height above the bed of point "i" (m).

Integral method

By means of curve fitting, a theoretical distribution is fitted to the measured flow velocities and concentrations.

The velocity profile is

$$U_z = \frac{U_*}{k} \ln(\frac{Z}{Z_o})$$

In which,

U_* = bed shear velocity (m/s)

k = Von Karman constant = 0.4

Z_o = 0.033 k_s = zero velocity level above bed (m)

h = flow depth (m)

k_s = equivalent roughness of Nikuradse (m)

U_*, the bed shear velocity is calculated from depth average velocity $\bar{U}$, where $\bar{U}$ is

Where,

$$\overline{U} = \frac{1}{Z_n}\left[\frac{1}{2}(U_i Z_i) \sum_{1}^{n-1} \frac{1}{2}(U_i + U_{i+1})(Z_{i+1} - Z_i)\right]$$

U_i = lowest measuring point
n = number of measuring points in a vertical
Z_n = height above bed of highest sampling point (m)

The concentration profile can be describe as

$$\frac{C_z}{C_a} = \left[\frac{h-z}{z}\frac{a}{h-a}\right]^{\frac{w_s}{kU_*}}$$

C_a = reference concentration (mg/l) at height above the bed, which is computed from the measured concentration at the lowest point (z = 0.5m).
a = height (m) above the bed at which the reference concentration is defined.
w_s = fall velocity of suspended sediment (m/s)

The suspended load transport (kg/sm) follows as

$$S_s = 10^{-3} \int_a^h U_i C_i dz$$

Using the Simpson Rule, the integration results in

$$S_s = h - a \;/\; 3m(U_1C_1 + 4U_2C_2 + 2U_3C_3 + 4U_4C_4 + \ldots \ldots\ldots + 2U_{m-1}C_{m-1} + 4U_{mC}m + U_{m+1}C_{m+1})\; 10^{-3}$$

in which,
h = flow depth in (m)
m = (even) number of equidistant intervals (m = 10)
U_1 = flow velocity at height "a" above the bed (m/s)
C_1 = concentration at height "a"above the bed (mg/l)

2.2 Concentration profile equation

The equation reads:

$$\frac{C}{C_a} = \left(\frac{h-z}{z}\frac{a}{h-a}\right)^{Z_o}$$

This equation was first derived by Rouse.
Where,

C = is the concentration at a level Z

C_a = is the concentration at reference level "a" from the bed surface

Z_o = $(w_o / U_* k)$ is the exponent of sediment distribution equation.

Above is used for computation of theoretical concentration profile.

2.3 Velocity profile

For low sediment concentration ($C < 0.001$) and hydraulic rough condition, the logarithmic velocity profile can be rewritten as:

$$U_z = \frac{U_{*,c}}{k}\ln\left(\frac{z}{z_o}\right)$$

in which,

$U_{*,c}$ = current relates bed shear velocity.

z_o = $0.033\ k_s$ = zero -velocity level

k = Von Karman constant =0.4

$U_{*,c}$ is calculated from depth average velocity $\bar{U}$

3 Reference concentration and reference level

The flow over dune is non uniform and has acceleration at the upper slope and deceleration at the down slope. The bed load particles are transported along the bed by rolling, sliding and saltating at the upslope of the dunes. At the top of the dune, most of the bed load jumps over the crest and rolls down the leeside slope of the dune trough were they are buried and will only be mobilized again in a next transport cycle.

The concentration profile should be fitted as a schematized concentration profile, which is being an estimate of the spatially- averaged (over the dune length) concentration profile. The reference level can be computed as

a = $1/2\ \Delta$, where Δ is the dune height

a = k_s , k_s is the effective bed roughness

$a_{minimum}$ = $0.01\ h$, h is the depth of flow

For the present study $a = k_s = 0.12$ m has been used. k_s has been computed from the average of the 90% confidence values. The reference concentration (C_a) are computed from the measured concentration at the lowest point above the bed by using concentration profile where $C = C_z = C_{lowest\ value}$. From the measured data, it is observed that the wide variation of sediment concentration between the top measured point (which is very low) and the bottom measured point (which is very high). Therefore the bottom measured point can give the better estimation of the reference concentration C_a. According to Van Rijn, the reference concentration C_a reads as

$$C_a = 0.015 \frac{D_{50}}{a} \frac{T^{1.5}}{D_*^{0.3}}$$

in which,

C_a = reference concentration (volume)

a = reference level above the mean bed

D_* = dimensionless particle parameter

= $D_{50}\ [(s-1)g/\nu^2]^{1/3}$

s = specific density; ≃ 2.65 (-)

T = dimensionless bed shear stress parameter

= $(\tau_{b,c} - \tau_{b,cr})/\tau_{b,cr}$

$\tau_{b,cr}$ = critical shear stress according to shield (N/m^2)

$\tau_{b,c}$ = current related effective bed shear stress (N/m^2)

= $\rho g(\bar{U}/\acute{C})^2$

$\acute{C}$ = $18\ \log\ (12h/3D_{50})$ = grain related Chezy coefficient (m$^{0.5}$/s)

Appendix 4

Note on ADCP performance in the Jamuna River

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30.10.93.PaM

Note on ADCP performance during phase I in Jamuna/Ganges river of Bangladesh.

Background:

During the proposal phase of FAP24 it was decided to investigate alternative methods in form of high technology equipment to carry out discharge measurements in the rivers of Bangladesh.

The moving boat method by means of ADCP and EMF equipment was selected.

The ADCP concept is, by means of acoustic doppler technique, able to measure the water flow with respect to the river bed.
By measuring the doppler shifts between a series of acoustic pulse transmitted by the ADCP transducers and the backscattered sound from the water column as well as the echo from the river bed itself ,the ADCP is able to, by means, of sophisticated signal processing, to separate the velocity vectors in vessel velocity vectors and water velocity vectors with respect to the river bed. This acoustic doppler technique makes the ADCP able to carry out a transect across the river from bank to bank and measures current profiles with a high horizontal and vertical resolution.Due to the bottom track technique the ADCP measures also water depth as well as distance travelled over the river bed ,which in combination with the high resolution vertical current profiles for every 5 - 10 m along the track make the system able to calculate the accumulated discharge by integrating the velocity normal to path taken by the vessel.

The ADCP technique is unique in the way that it does not require any additional data in form of input from positioning system, echosounder, gyro compass etc. in order to calculate the discharge.

Due to the nature of the rivers in Bangladesh a ADCP system which operating on 300 KHz was selected during the mobilization phase of the project.

The main reason for selecting this rather low frequency was the concern of the high suspended sediment concentration, which could be expected during the flood periods and which could create problems for ADCP system to track the river bed.

The drawbacks, of selecting a 300 Khz system with a better penetration than e.g. a 1200 Khz system, are reduced coverage of the water column, less vertical resolution and increased standard deviation.
Although the software package includes algorithms to cover the missing part of the current profiles it was decided to include a EMF sensor to cover the top part (0 - 2.7 m) of the water column , which could not be covered by the ADCP due to immersion of the transducer and the selected frequency of the system.

The selection of the EMF sensor working in the MBM mode makes it possible to cover shallow areas, where immersion of the transducer and the pulse length of a 300 KHz system prevents the ADCP to collect data.

Phase I experience with the 300 KHz ADCP system:

The consultants has achieved considerable experience with the operation of the ADCP system in the rivers of Bangladesh during the first phase and the transition period of the River Survey Project.

Dry season.

Discharge measurements carried out at the Bahadurabad site during the first 7 months covering the dry season have proved the ADCP methodology to be, not only valid in the river of Bangladesh, but also reliable and superior to other system with respect to data coverage within the shortest measuring time. With ADCP system discharge measurements come close to the term "instantaneous discharge gauging". The main channels in Bahadurabad were covered by transect obtained during of 10 -15 minutes.The performance of the 300 KHz did not indicate any problem with respect to penetration and the system's bottom track facility has been operating reliably during the dry season.

Operation with a configuration file designed for the conditions in the Jamuna river make it possible to profile the river bed and measure vertical current profiles every 5 - 6 seconds while the vessel is crossing the river from bank to bank. Missing data in form of lost bottom track or orectic profiles has been observed very seldom during the dry season. Repetation of discharge measurement have been in the order of few present.

The 300 KHz system has its limitations in shallow areas due to the immersion depth of the transducer and the length of the acoustic transmit pulses.

Flood season.

During the transition period, which covered the flood period June to October , the 300 KHz ADCP system has been in operation at various sites in Jamuna, Ganges and Meghna river.

Measurements with the ADCP system has been carried out both in the dynamic transect mode and in stationary mode with the vessel at anchor.

Current velocities have exceeded 4 m at several sites during this period.

The measurements carried out with the 300 KHz ADCP system clearly indicates that the river bed becomes very active when the current exceeds 2 m. The suspension of bed material close to the bed is so dense that the ADCP detects this material as the river bed.
Since the material moves with the current (moving bed) the ADCP bottom track facility detect and interpret this phenomena as a vessel velocity vector 180 degrees to the direction of the current vector. Stationary measurements at anchor under DGPS control across the river section have detected ADCP bottom track velocities ranging from 1 cm/sec -- 90 cm/sec.

This false vessel velocity vector will cause the ADCP system to measure too low current velocities and thereby too low discharge during stationary profiling and dynamic transect measurements.

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The phenomena does not prevent the ADCP system from producing high resolution current/ discharge data, but the data must be corrected by applying a correct vessel velocity vector.

The consultants has developed a method to correct the ADCP data,by applying a correct vessel velocity vector obtained by means of the DGPS system. Together with ADCP heading data obtained via the vessel's Gyro compass and water depth data obtained from the echosounder, the ADCP data is corrected. At present this correction is carried out off-line.

Beside the moving bed problem, the high current velocities and the presence of turbulence in the flood season have caused an increase in missing or doubtful profiles.But the percentage of bad profiles in a transect is still very low,in the order of a few percent.

Test of a 1200 KHz ADCP system at Bahadurabad site in the dry season.

See PaM's report of Jan/Feb.93.

Conclusion & recommendation

The ADCP concept and the transect methodology has proved to be a valuable tool for discharge measurements in the rivers of Bangladesh.

Due to the dense data coverage and the short transect time the 300 KHz system is an excellent tool for:

- accurate discharge measurements in main channels
- evaluation of current and suspended sediment gradients over a cross section.
- discharge measurements in areas where flow conditions change rapidly (tidal areas).

The present 300 KHz Broad Band ADCP system provides accurate discharge figures on-line during the dry season.

The presence of high current velocities and suspended sediments during the flood season do not prevent the present 300 KHz ADCP system from producing high quality discharge data. However data has to be corrected due to moving river bed. For the moment being this correction is done off-line, but possibilities for on-line corrections are under investigation.

The 300 KHz system provides interesting data regarding moving river bed.

Tests with a 1200 KHz ADCP system carried out in Feb.93 indicates that, although this system does not have the same penetration as the 300 KHz system, it operates well during the dry season in the rivers of Bangladesh.

The 1200 KHz system with its better resolution, both horizontally and vertically, and ability to measure in shallow areas is an interesting alternative to the 300 KHz system for dry season measurements.

During the flood season the system will be vulnerable due to turbulence and high concentration of suspended sediment and it is doubtful if the system can produce data with the same quality as the 300 KHz system.

It is the consultants opinion that a careful selection and combination of different operation frequencies will proved the ADCP concept to be an excellent tool for river discharge measurements during all conditions .

Regarding acoustic measurements with respect to suspended sediment the ADCP system provides the user with reliable distribution data. Research with respect to establishment of correlation between traditional suspended sediment sampling and ADCP data is executed around the world.

Annexure 5

Test report on the 300 kHz and the 1200 kHz ADCP

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Feb.12-93.PaM

ADCP Test Report.

1. General.

The present note gives a description of the ADCP test surveys carried out in the left channel of Jamuna River at the Bahadurabad site in the period of Feb. 2 - 5. 93.

The River Survey Project, FAP24 operates at present a 300 KHz ADCP unit for discharge measurements in the cross sections of Bahadurabad.

The ADCP unit measures discharge by measuring a vertical current profile for each 10 meter horizontal distance, while the survey vessel is crossing the river from river bank to river bank. The vertical resolution of the current profiles is 0.5 meter.

The 300 KHz ADCP unit is not able to measure the top part (surface - 2.7 m depth) and the lowest part of the profile (6 % of water depth + 0.5 m) due to draft, blanking and side loops of the transducers.

The current in the top part of the cross section is estimated by extrapolation of the current value at 2.7 meter to the surface (Constant Method). However in order to verify the estimated current in the top layer an EMF (electromagnetic current sensor) is mounted in front of the vessel at level 0.5 meter below the surface.This unit also measures current in areas with less than 2.7 meter of water.

The lowest part of the current profile is estimated by applying a power fit curve to the measured part of the profile.

In the dry season, areas with water depths below 5 meters are covering a large part of the entire cross section, which limits the use of a 300 KHz ADCP unit.

In order to evaluate and improve the performance of the ADCP method during the dry season measurements, an ADCP 1200 KHz unit has been temporary imported and tested in the left channel of Bahadurabad.

The aims of the tests were the following:

- How close to surface could the 1200 KHz system give reliable current data.
- How well did the 1200 KHz track the river bed
- Maximum profile range.
- Verification of the ADCP program's algorithms for estimation of the discharge in

the top and bottom layer.

2. Test procedures.

In order to compare the 300 and the 1200 KHz units, the following test procedures were applied:

- The 1200 KHz ADCP unit was mounted in the front of the DHC vessel (catamaran type)
  Transducer draft was equal to 0.20 meter
  The unit was operating in the following configurations:

  Transect mode:

  - Blank after transmit = 0.25 m
  - Bin size = 0.25 m
  - Water pings per profile = 4
  - Bottom pings per profile = 2
  - WM mode = 0 (expert mode)

  This results in a current profile for each 2.5 - 3 sec. equal to a horizontal distance of approx.5 - 6 meter with a survey speed of 4 knot

  First bin was measured at 0.69 meter below surface.

  Profile mode: (vessel at anchor)

  - Blank after transmit = 0.25 m
  - Bin size = 0.25 m
  - Water pings per profile = 100
  - Bottom pings per profile = 20
  - WM mode = 0 (expert mode)

  resulting in a current profile each 48 - 50 seconds.

- The 300 KHz ADCP unit is mounted in a transducer valve at the bottom of the DHA vessel
  Transducer draft is equal to 0.85 m
  The unit is operating in the following configurations:

  Transect mode:

  - Blank after transmit = 1.0 m
  - Bin size = 0.5 m

- Water pings per profile = 10
- Bottom pings per profile = 9
- WM mode = 0 (expert mode)

This results in a current profile each 5 - 6 seconds equal to a horizontal distance of 10 - 12 m with a survey speed of 4 knot.

First bin is measured at 2.7 m below surface.

Profile mode: (vessel at anchor)

- Blank after transmit = 1.0 m
- Bin size = 0.5 m
- Water pings per profile = 165
- Bottom pings per profile = 60
- WM mode = 0 (expert mode)

This results in a current profile each 48 - 50 seconds.

In order to obtain the same conditions for the two system during testing, the catamaran with the 1200 kHz ADCP unit was tied to the side of the DHA vessel which carries the 300 KHz ADCP unit.

3. Tests carried out

Transect:

The DHA vessel,with the catamaran linked to the side carried out a series of transect runs across the river in the left channel south of Bahadurabad measuring simultaneously with the two ADCP systems.

The transects no. 1, 2, 3 & 4 were carried out at the cross section used by FAP24 during the routine measurements.

Transects no.5, 6, 7, 8 were carried out at offsets of 200, 400, 700 & 1000 m north of the cross section. The area 700 - 1000 m offset is exposed to heavy scouring with turbulent water noticed in the surface.

Table 1 below present the on-line results of the transect runs.

ADCP	File no.	Transect no.	Discharge	Remarks
0300 KHz	BTRA008R	1 FAP24 cr.section	3342 cum/sec.	Left to right bank
1200 KHz	PaM024R	1 FAP24 cr.section	3322 cum/sec.	Left to right bank
0300 KHz	BTRA009R	2 FAP24 cr.section	3348 cum/sec.	Right to left bank
1200 khz	PaM025R	2 FAP24 cr.section	3345 cum/sec.	Right to left bank
0300 KHz	BTRA012R	3 FAP24 cr.section	3218 cum/sec.	Fig.1A, R to L bank
1200 KHz	PaM028R	3 FAP24 cr.section	3277 cum/sec.	Fig.1B, R to L bank
0300 KHz	BTRA014R	4 FAP24 cr.section	3290 cum/sec.	Left to right bank
1200 KHz	PAM30R	4 FAP24 cr.section	3299 cum/sec.	Left to right bank
0300 KHz	BTRA018R	5 Offset 200 m N	3160 cum/sec.	
1200 KHz	PaM034R	5 Offset 200 m N	3421 cum/sec.	
0300 KHz	BTRA019R	6 Offset 400 m N	3342 cum/sec.	
1200 KHz	PaM035R	6 Offset 400 m N	3199 cum/sec.	
0300 KHz	BTRA020R	7 Offset 700 m N	3514 cum/sec.	Start of scour area, 1200 KHz system measures wrong current profiles in part of cross section.
1200 KHz	PaM036R	7 Offset 700 m N	2092 cum/sec.	
0300 KHz	BTRA021R	8 Offset 1000 m N	3231 cum/sec.	
1200 KHz	PaM037R	8 Offset 1000 m N	0729 cum/sec.	

Table 1. On - line discharge measurements.

4. Stationary profiling.

In order to verify the accuracy of the ADCP systems a comparison test against the OTT propeller current meter was carried out.

The vessels, still tied together side by side, were anchored in a location with a stable flow and manual profiling with the OTT current meter was carried out with measurements for each 0.5 m in the vertical.

At each point in the vertical, current velocity was measured 6 times with an average value for every 50 seconds.

The ADCP systems were also configurated to measure the average current profile over 50 seconds.

The table 2 below presents the results of the comparison test presents a plot of the resulting profiles.

Time	Depth m.	Ott cm/sec.	ADCP300 cm/sec.	ADCP1200 cm/sec.	Remarks
11:29	0.50	134	-	-	ADCP data not
		132	-		valid, too close
		130	-	-	to surface.
Mean velocity		132 cm/sec.	-	-	
11:33	0.70	135	-	129	ADCP 300 KHz
		131	-	122	data not valid,
		128	-	128	too close to surface
Mean velocity		131 cm/sec.	-	126 cm/sec.	
11:35	0.95	136	-	134	ADCP 300 KHz
		133	-	128	data not valid,
		125	-	132	too close to surface
		131	-	131	
Mean velocity		131 cm/sec.	-	131 cm/sec.	
11:41	1.70	127	-	128	ADCP 300 KHz
		132	-	123	data not valid,
		126	-	125	too close to surface
		126	-	127	
		130	-	129	
		129	-	128	
Mean velocity		128 cm/sec.	-	127 cm/sec.	
11:50	2.20	129	-	129	ADCP 300 KHz
		128	-	135	data not valid,
		125	-	126	too close to surface
		127	-	124	

Time	Depth m.	Ott cm/sec.	ADCP300 cm/sec.	ADCP1200 cm/sec.	Remarks
		119	-	134	
		128	-	124	
Mean velocity		126 cm/sec.	-	129 cm/sec.	
12:01	2.70	126	141	127	
		125	130	125	
		122	128	117	
		113	126	122	
		123	119	131	
		110	127	129	
Mean velocity		120 cm/sec.	129 cm/sec	125 cm/sec.	

Time	Depth m.	Ott cm/sec.	ADCP300 cm/sec.	ADCP1200 cm/sec.	Remarks
12:08	3.20	123	117	117	
		115	121	111	
		117	123	116	
		113	115	114	
		120	118	112	
		119	123	112	
Mean velocity		118 cm/sec.	120 cm/sec.	114 cm/sec	
12:19	3.70	111	111	116	
		115	111	115	
		115	114	113	
		113	118	119	
		103	112	105	
		112	118	114	
Mean velocity		112 cm/sec.	114 cm/sec.	114 cm/sec.	
12:27	4.20	108	109	107	
		115	121	107	
		110	111	112	
		094	115	115	
		120	099	113	
		106	110	115	
Mean velocity		109 cm/sec.	111 cm/sec.	112 cm/sec.	
12:37	4.70	105	104	112	
		104	113	109	
		110	108	099	

		118	105	099	
		104	104	106	
		112	109	102	
Mean velocity		109 cm/sec.	107 cm/sec.	105 cm/sec.	
12:46	5.20	101	107	092	
		109	096	099	
		102	098	103	
		104	105	103	
		101	099	097	
		102	104	097	
Mean velocity		103 cm/sec.	102 cm/sec.	099 cm/sec.	

Time	Depth m.	Ott cm/sec.	ADCP300 cm/sec.	ADCP1200 cm/sec.	Remarks
12:54	5.70	101	096	098	
		098	100	096	
		093	096	088	
		096	100	090	
		099	101	105	
		107	101	095	
Mean velocity		099 cm/sec.	099 cm/sec	095 cm/sec.	
13:04	6.20	096	094	072	
		096	092	085	
		086	089	092	
		082	100	094	
		077	101	104	
		091	091	101	
Mean velocity		088 cm/sec.	095 cm/sec.	092 cm/sec.	
13:14	6.70	081	082	092	
		082	095	100	
		096	104	089	
		098	076	089	
		080	086	089	
		076	086	097	
Mean velocity		085 cm/sec.	088 cm/sec.	092 cm/sec.	
13:22	7.20	084	091	086	
		077	079	080	
		072	086	083	

Time	Depth m.	Ott cm/sec.	ADCP300 cm/sec.	ADCP1200 cm/sec.	Remarks
		076	089	082	
		077	083	078	
		079	089	088	
Mean velocity		077 cm/sec.	086 cm/sec.	083 cm/sec.	
13:32	7.70	071	073	070	
		083	074	073	
		080	073	068	
		066	076	067	
		069	070	073	
		068	057	075	
Mean velocity		073 cm/sec.	071 cm/sec.	071 cm/sec.	
13.46	8.20	057	-	-	ADCP data not valid, too close to river bed.
		069	-	-	
		071	-	-	
Mean velocity		066 cm/sec.	-	-	

Table 2 Inter calibration of ADCP 300 ,1200 KHz and OTT current meter.

5. Conclusion.

The results of the tests carried out can be summarized to the following conclusions:

- The 1200 KHz unit is able to measure reliable current values as close as 0.7 m below the surface.

- The 1200 KHz ADCP unit is able to measure current profiles with a horizontal resolution 5 - 6 meter and a vertical resolution of 0.25 m.

- The 1200 KHz ADCP unit used during the test was a 30 degree system (transducers mounted in an angle of 30 degrees from the horizontal).
  This configuration is not superior to the 300 KHz , 20 degrees system, regarding valid data close the river bed.

- The transects carried out in the FAP24 area (transect no. 1,2,3 & 4) show good agreement in discharge values between the 300 and the 1200 KHZ systems.
  This indicates that the extrapolation algorithm (constant method) for calculation of the current in the top layer is correct.

- The 1200 KHz ADCP system tracked the river bed down to 16 meter, but the condition on the test site was also quite favourable with respect to low sediment concentrations.

- The 1200 KHz system had severe problems in the scour area and produced false current values and thereby wrong discharge values. (Transect no. 7 & 8).
  The failure of the 1200 Khz unit was not caused by high sediment concentration in the scouring area, water samples showed approx. 150 mg/l. only.
  Further evaluation of the profile data from that specific area is going on. Turbulence (visual observed in the surface) can be the reason.

- Verification test against the OTT propeller current meter indicates good agreement between the instruments

The main conclusion of the tests carried out is, that although the 1200 KHz system gives a better resolution both horizontal and vertical, the system will be vulnerable in areas with high turbulence/sediment concentration with respect to reliable bottom tracking.

During the flood period where high sediment concentrations can be expected the 300 KHz system, which due to its lower frequency has a better penetration, will produce more reliable data.

For dry season measurements and for minor rivers, the 1200 Khz is an interesting alternative to the 300 KHz system.

The 1200 KHz ADCP system ,with its high resolution and ability to measure in shallow areas, may be an excellent tool for flood plain measurements.