

**FAP24**

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# RIVER SURVEY PROJECT



Final Report - Annex 2

## Sustainable Survey Techniques

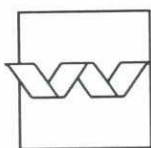
November 1996

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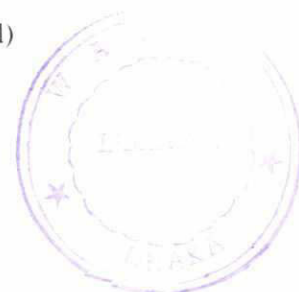
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## Acronyms and abbreviations

|               |                                                                                  |
|---------------|----------------------------------------------------------------------------------|
| ADCP          | Acoustic Doppler Current-Profiler                                                |
| AWLR          | Automatic Water Level Recorder                                                   |
| BIWTA         | Bangladesh Inland Water Transport Authority                                      |
| BOQ           | Bill of Quantities                                                               |
| BTM           | Bangladesh Transverse Mercator (a geodetic grid)                                 |
| BUET          | Bangladesh University of Engineering and Technology                              |
| BWDB          | Bangladesh Water Development Board                                               |
| CEC           | Commission of the European Communities (presently the EC)                        |
| DELFT         | DELFT HYDRAULICS, The Netherlands                                                |
| DGPS          | Differential Global Positioning System                                           |
| DHA, DHB, etc | Names of FAP24 survey vessels                                                    |
| dhi           | Danish Hydraulic Institute                                                       |
| EC            | The European Commission (formerly the CEC)                                       |
| EGIS          | Environmental and GIS Support Project for Water Sector Planning (formerly FAP19) |
| ELAC          | Brand name of an echo sounder instrument                                         |
| EMF           | Electromagnetic Flow Meter                                                       |
| FAO           | Food and Agriculture Organization                                                |
| FAP           | Flood Action Plan                                                                |
| FAP24         | FAP project no. 24 (= The River Survey Project)                                  |
| FFWC          | Flood Forecasting and Warning Centre (of BWDB)                                   |
| FPCO          | Flood Plan Coordination Organisation (presently merged with WARPO)               |
| GIS           | Geographic Information System                                                    |
| GPS           | Global Positioning System                                                        |
| GTS           | Grid Trigonometrical Survey (name of a bench mark network)                       |
| HYMOS         | Name of a hydrological software package and of an RSP database                   |
| IO            | Inter-Ocean (manufacturer of the S4 and other survey instruments)                |
| ISO           | International Organization for Standardization                                   |
| IUCN          | International Union for the Conservation of Nature                               |
| LAZ           | Name of a specific echo sounder instrument                                       |
| MEX           | Brand name of a turbidity meter                                                  |
| O&M           | Operation and maintenance                                                        |
| PA            | Project Advisor                                                                  |
| PEMS          | Name of an EMF instrument                                                        |
| PSD24         | Processed Survey Data of FAP24 (name of a data base)                             |
| PWD           | Public Works Department (and name of a reference level)                          |
| RDI           | RD Instruments (manufacturer of an ADCP instrument)                              |
| RSP           | River Survey Project (FAP24)                                                     |
| RSPMU         | River Survey Project Management Unit                                             |
| RTK           | Real-time kinetic (positioning)                                                  |
| SEBA          | Name of a propeller type current-meter                                           |
| SLW           | Standard Low Water (a reference level)                                           |
| SOB           | Survey of Bangladesh                                                             |
| SPE           | Standard pulsation error                                                         |
| SWMC          | Surface Water Modelling Centre (of the Ministry of Water Resources)              |
| S4            | Brand name of an electromagnetic current-meter                                   |





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|         |                                                       |
|---------|-------------------------------------------------------|
| TOR     | Terms of Reference (of RSP)                           |
| UNEP    | United Nations Environmental Programme                |
| UTM     | Universe Transverse Mercator (a geodetic grid)        |
| VHF     | Very high frequency                                   |
| USBM-54 | Type and brand name of a bed-sediment sampler         |
| WARPO   | Water Resources Planning Organization                 |
| WGS84   | World Geodetic System (a geodetic grid used with GPS) |
| WMO     | World Meteorological Organization                     |
| WWF     | World Wildlife Fund                                   |

## Glossary

Terms or explanations marked with an asterisk (\*) relate specifically to the RSP. Cross-references are printed in *italics*.

**Absolute accuracy:** The *accuracy* of a value when compared with a general standard. The absolute accuracy is important when comparing data from different contexts, such as different projects or survey programmes. To be distinguished from *relative accuracy*.

**Accuracy (of a survey instrument):** The compliance between a *true* and a measured value, expressed in the physical unit of the value, and often expressed as the (estimated) standard deviation. For a given instrument, the accuracy is normally related both to the instrument itself and to the actual procedure for its application, notably including the applied *calibration* procedure. The accuracy can often be improved by repeating a measurement several times.

**\* ADCP moving boat method (or ADCP-DGPS method, or ADCP-EMF method):**  
The same as *recommended method*.

**Alluvial river:** A river proceeding on its own sediment deposits.

**Analysis (of river data):** Processing, involving a sometimes comprehensive transformation, in order to arrive at the intended information that was the objective of the measurements. Data analysis is often carried out stage-wise and in different contexts. In general, data analysis involves both hidden and explicit assumptions about the relation between primary data and final results. (As one example, a flow rate can be calculated assuming that a set of current-measurements were made simultaneously, even if it took a whole day). Such assumptions can affect both the *accuracy* and the *validity* of the results. A suitable *quality* is supported by an adequate *transparency* of the analysis.

**Andreasen settling tube test:** A standard method for determination of settling velocity distribution of suspended sediments, by successive bottom withdrawal of small sub-samples from a large-volume (25 l) sample of suspension. The sub-samples are taken after a fixed schedule that can extend over several days. For each sub-sample, the sediment concentration is determined (by micro-filtering), whereafter the settling velocity distribution can be calculated. Also, the grain size distribution can be calculated by a relation between the settling velocity and the grain size.

**Backscatter registration (by an ADCP):** Registration of the intensity of the reflected signal, which is related to the grain size distribution and the concentration of suspended material of the water column. For a given grain size distribution, a well-defined relationship can be established between the backscatter registration and the sediment concentration. The method is new and is not yet fully proven, but can potentially provide details about the sediment transport. \* Its viability in the rivers of Bangladesh was examined during the RSP.

**Bathymetric survey:** Mapping of riverbed or seabed elevations (normally by water depth measurements by echo sounding).

**Bed material:** Sediment (fine or coarse) deposited by the river and composing the riverbed. To be distinguished from *suspended bed material*, which is coarse suspended sediment (\* with a grain size above 0.063 mm).

**Bedforms (of a river):** Morphological features of the river bed, for example sand dunes.

**Bed load:** *Bed material* transported immediately above the river bed, and in almost continuous contact with it, carried forward by rolling, sliding or hopping.

**Bin (of an ADCP instrument):** The volume over which each velocity *sample* is averaged. The ADCP measurements cover a conical water column that is divided into segments (bins) of equal heights. The bin height depends on the selected mode of operation (within the limits of the depth *resolution* of the instrument, which is in turn related to its *frequency*).

**Bottom tracking (of an ADCP instrument):** Just like the instrument can measure the movement of the water relative to the vessel, it can also measure the apparent movement of the river bed relative to the vessel. This is called bottom tracking. Bottom tracking gives an accurate description of the vessels trajectory across the river during the flow gauging.

\* During high flows, RSP experienced that the river bed was "moving" (due to a high bed load); under such conditions, bottom tracking was not possible, so the relative positioning had to be carried out by DGPS instead.

**BTM (Bangladesh Transverse Mercator) grid:** A geodetic projection of the Mercator type, which features a true projection of angles and a slightly distorted projection of distances. The grid is aligned with the 90° east meridian. The scale distortion is small, and the grid coordinates, *eastings* and *northings*, are approximately orthogonal. They are given in m or km from a defined point of origin located southwest of Bangladesh (whereby all coordinates within Bangladesh become positive).

**Calibration (of a survey instrument):** Measurement of a set of values that are, at the same time, also measured by other, more accurate means, in order to determine a systematic *error* of the instrument (for subsequent compensation).

**Concentration (of sediments in a sample):** Mass or volume of sediments in a *sample* relative to the mass or volume of the entire *sample*. Can be expressed for example as weight percentage, volume percentage, or kg/m<sup>3</sup>.

\* **Concentration method (for sediment transport gauging):** Calculation of the sediment transport by multiplying a *concentration* with a *flow* rate, which have been measured simultaneously, but independently. (To be distinguished from the *transport method*).

**Consistency (of survey data):** Compliance between the *quality* of different data sets, produced by different methods, at different places, or at different times.

**Current-velocity:** The rate of movement of the water (in m/s). The velocity is a vector, which is either described by a speed and a direction, or by 2 or 3 orthogonal components.



**Data assimilation:** Statistically optimized estimation of the state of a system that is *over-specified* by a combination of time series of measured state variables and (physical) relations between them. Data assimilation can be done by integration of field measurements and model simulations, with the objective of improving their joint *quality*.

**Datum:** A defined vertical reference level (for water levels, bed levels, or land elevations), for example *SLW* or *PWD*.

**Density:** (1) mass per unit volume (for example given in  $\text{kg/m}^3$ ), (2) number of measurements per unit area or unit distance (opposite of spacing).

**Depth reduction (of bathymetric soundings):** Conversion of depth measurements to the applied *datum*. \* The RSP measured depths by echo sounding relative to the survey vessel (or relative to the surface of the river). The depth reduction (to *SLW datum*) was made by gauging of the water level at a place where *SLW* was defined, specifying the actual water level *slope* during the measurements and assuming that this slope represented the slope of the *SLW* between the water level gauge and the survey vessel.

\* **Deterministic description:** A process description based on the laws of physics, aiming at a true description of effects, if the processes are understood and the causes are known.

**Deviation (of a survey instrument, a survey procedure, or a calculation method):** The difference between the *true* and the measured value. The deviation is inversely related to *accuracy* and *validity*. It can be random (stochastic) or systematic.

\* **Discharge:** (1) integrated net *flow* through a fixed cross-section of a river, (2) net sediment transport through a fixed cross-section of a river.

\* **Easting:** East coordinate in the BTM grid, given in m (six digits) or km (three digits). Easting = 500 km + the distance (positive towards east) from the  $90^\circ$  east meridian. Hence, per definition, the  $90^\circ$  east meridian has an easting of 500. For example, the easting of Gulshan (at the SOB primary bench mark) is 542.

**Empirical knowledge:** Knowledge based on observation.

**Error (of a survey instrument, a survey procedure, or a calculation method):** (1) same as *deviation*, (2) a *deviation* with an unacceptable magnitude.

\* **Feature mapping:** Mapping of land surface characteristics (embankments, structures, vegetation, etc.), for example for interpretation of satellite imagery.

**Flow (in a river):** Volume transport per time unit, expressed in  $\text{m}^3/\text{s}$ , either locally (at a point), or over a cross-section.

**Frequency (1) (of data logging):** Number of units (for example *samples*) per time interval. (2) (of an echo sounder or an ADCP): The frequency of the transmitted and reflected sound wave. \* The RSP used 30 kHz and 30/210 kHz echo sounders, and 300 kHz and 600 kHz ADCPs.

**Gauge:** A device for measuring water level or pressure.

**Gauging:** Measurement at a fixed point.

\* **Geodetic survey:** Mapping of geodetic coordinates (of bench marks, reference stations, and so on).

**Hydrograph:** A time series of water levels at a fixed location (either measured or calculated by a model).

**Length scale:** A distance that is characteristic for a specific phenomenon (for example a wave or a sand dune). In order to describe the phenomenon, a fair number of measurements must be done within one length scale.

**Mapping:** Measurements covering a certain area. To be distinguished from *gauging*.

**Model:** A simplified description of a part of the real world, preferably on a well-defined basis.

**Morphology (of a river):** (1) its shape, (2) the study of states, processes and effects related to the shape of a river.

**Moving boat method:** Flow gauging by a continuous single-point current *record*, measured from a vessel crossing the river from one bank to another, first in one direction, and afterwards in the opposite direction.

\* **Near-bed sediment transport:** Sediment transport in the lowest part of the water column, where the concentration of *bed material* is usually highest, but where sediment sampling and flow measurements are for practical reasons particularly difficult.

\* **Northing:** North coordinate in the BTM grid, given in m (6 digits) or km (3 digits). The northing equals the distance to equator minus 2000 km. For example, the northing of Gulshan (at the SOB primary bench mark) is 631.

**Off-line processing (or post-processing) (of survey data):** Data processing carried out after completion of the field work.

**On-line processing (of survey data):** Real-time data processing onboard the survey vessel, one objective being to monitor the data *quality* and data coverage, so that measurements can be repeated immediately, if needed. \* The RSP applied on-line processing of position, current, flow and depth data.

**Optimal exposure time:** Most suitable integration time to be applied during flow measurements by a current-measuring device at an acceptable level of accuracy. The integration time is necessary in order to reduce the standard pulsation error (see also standard pulsation error) which is caused by turbulence in flow.



\* **Optimization:** A process of finding the most favourable solution to a problem that will meet the predetermined quantified objectives. To obtain an optimal solution, the technique should be screened against some multiple criteria such that an optimal option can be pursued.

**Over-specified system:** A system where the number of relations exceeds the number of variables. For example, if both the surface slope, the geometry and the current are measured in a section of the river, the flow becomes over-specified. (Opposite of *under-specified*).

**Peak (in a data series):** One single registration that deviates significantly from a smooth pattern formed by preceding and subsequent registrations.

**Procedure (for a river survey):** The combination of instruments, software and practices applied for arriving from one point in the data flow to a subsequent point, for example for different types of field measurements, collection of *samples*, laboratory analysis, and data analysis.

**PWD = Public Works Department datum:** A horizontal datum applied by PWD, BWDB and others. It is defined by a network of SoB and BWDB benchmarks with a specified elevation above PWD. Its zero level is located 0.46m below the Mean Sea Level defined in 1909.

**Quality:** The compliance between a desired and an actual property (or set of properties). Within river surveys, quality characteristics can comprise *accuracy, consistency, resolution, transparency, validity*, costs, and several other aspects.

**Range (of a survey instrument):** The interval between the lowest and the highest value it can register.

**Rating curve:** A specific *stage-discharge* relation for a given cross-section and a given *gauge* location, used for calculating time series of flow or sediment transport on the basis of time series of water level and discrete measurements of flow and/or sediment transport.

\* **Raw data:** Primary survey data, as produced in the field, such as onboard the survey vessel, in the state in which they are received by the RSP data processing office in Dhaka upon completion of the field work. Some raw data have been organised, edited and converted by *on-line processing* onboard the vessel.

\* **Recommended method = ADCP moving boat method:** Flow gauging from a moving boat by ADCP, supplemented by an EMF deployed near the surface, with DGPS positioning.

**Record:** Set of related data, either a time series (for example of water level), or an array (for example of position, depth, and current-velocity), or a time series of arrays.

\* **Reference method:** Flow gauging by single point measurements from a moored vessel in a number of verticals across the river (e.g., by an S4 electromagnetic current-meter and/or by an Ott propeller-type current-meter). The flow is calculated by a velocity-area method.

\* **Registration:** Same as measurement and same as recording, is sometimes distinguished from observation (which involves some elements of arbitrary judgement).



**Relative accuracy:** The *accuracy* of two values when compared with a common, but not necessarily general standard, for example two recordings by the same instrument with an unknown, systematic error. The relative accuracy is important when comparing different values, for example when determining the distance between two vertical profiles by subtracting their positions, or when determining a river bed erosion by subtracting two successive bed level measurements. The relative accuracy of many measuring methods is better than (and is always at least equal to) the *absolute accuracy*.

**Resolution (of a survey instrument):** The smallest increment of the *true value* that can be registered. The variation can be in time, space, or with respect to the measured value (current speed, water level, etc). The resolution is not related to the *accuracy*. For a given instrument, the resolution is normally related to the procedure for its application. A distinction can be made between nominal and actual resolution, the latter being affected by the deployment of the instrument and by the physical environment. For example, an S4 current-meter (in its standard *range*) has a resolution of 0.2 cm/s if mounted on a fixed frame, but less if suspended by a cable. As another example, the actual resolution of a staff gauge is affected by waves. The resolution of most propeller-type current-meters represents one revolution of the propeller.

\* **Routine gauging:** Repeated measurements by the RSP of flow and sediment transport (by the *recommended method*) at eleven cross-sections in the main rivers of Bangladesh.

**Runline:** A well-defined line along which measurements are carried out. It is good practice to retain runlines for successive surveys, in order to improve the *validity* of comparisons between the results.

**Sample (1) (of water, suspended sediments, or river bed sediments):** A portion of water, suspension, or the riverbed collected for laboratory analysis, (2) (by an electromagnetic instrument): A single-pulse registration. Such samples are often averaged over some period of time in order to improve the *accuracy* of the registration. Often, this averaging is done by the instrument itself, so that only the average value is stored. For many such instruments, the sampling *frequency* and the averaging period can be selected by the user within certain intervals, depending on the purpose and the physical environment.

\* **Sand dune tracking:** A method for determination of *bed load*. The progression of sand dunes is measured by repeated mappings (by side scan sonar and/or echo sounder), and the associated volume transport is calculated, assuming (1) one-directional transport, and (2) no transport takes place below the base level of the dunes.

**Settling velocity:** The (downward) velocity of a sediment particle in still water. The settling velocity depends on the grain size, density, and shape of the particle, and on the viscosity (or temperature) and density of the water. It can be measured (in a settling tube) or calculated (from the grain size, often assuming that the particles are spherical).

**SLW = Standard Low Water datum:** A datum representing the water level that is exceeded 95% of the time. Hereby, the slope of the datum (approximately) follows the dry season *slope* of the river surface, inclining downwards towards the sea. The present SLW was defined at a number of gauge locations by BIWTA in 1990.

\* **Special surveys:** Surveys executed by the RSP for dedicated non-routine purposes, normally related to the study component of the Project.

**Spheroid (for geodetic mapping):** An assumed, simplified, but geometrically well-defined shape of the earth. An example is 'Everest 1830', which is applied by Survey of Bangladesh. Several variants of this spheroid exist and have been applied on different occasions.

\* **Staff gauge levelling:** Transfer of *datum* across a channel by simultaneous staff gauge readings for a certain period of time at each bank. In case of unknown or irregular *surface slopes*, the *validity* of this method is doubtful.

**Stage:** Water level at a given location with respect to a certain datum, e.g., at a *gauging station*.

**Standard pulsation error:** Represents statistical uncertainty of a turbulent flow field and is given in relative standard deviation at 67% confidence level. It occurs due to limited exposure time of a current-measuring device. The error decreases as the exposure time is increased (see also optimal exposure time).

**Surface slope:** The (local or general) inclination of the river surface, relative to a horizontal plane, and positive in the downstream direction. For a given cross-section (with a given roughness and a given hydraulic radius), the slope is related to the flow in a well-defined way. \* Typical average slopes of the rivers of the RSP survey area are between 2 cm/km (Upper Meghna) and 8 cm/km (Jamuna).

\* **Survey:** A specific programme of (related or unrelated) field measurements.

\* **Survey spread:** A set of facilities (instruments, software and hardware for data registration, position control, communication, data administration, power supply, etc.) installed onboard a vessel.

\* **Survey technique:** The way a measurement is executed including type of vessel, instruments, methods and operational aspects.

\* **Sustainability:** Sustainability of a survey technique means that the technique applied can be continued in the future by a certain institution in a certain environment. To attain sustainability the techniques should be screened against some multiple criteria. Since some criteria are transient in nature, it is necessary that a technique applied be re-evaluated after certain time as the ranking applied against each criteria may change depending on the societal and technological development.

**Threshold value (of a survey instrument):** The smallest *deviation* from zero (of the *true value*) that can be registered.

**Time scale:** A time interval that is characteristic for a specific phenomenon (for example a turbulence pattern or a tidal variation). A description of the phenomenon requires a fair number of measurements within one time scale. By averaging a *data record* over several time scales, the phenomenon will become concealed.



**Topographic survey:** Mapping of land elevations.

**Transparency (of a survey or data analysis procedure):** The insight conveyed to the data user about how the data were produced, for example for assessing the *validity* of the data for a given, possibly unforeseen, purpose. An acceptable transparency is obtained by documentation and can be supported by using standard methods

**\* Transport method (for sediment transport gauging):** Direct registration of the sediment transport by a sampling device (for example a Delft bottle) that has been designed and calibrated so that the mass or volume of a collected sample reflects the sediment transport. (To be distinguished from the *concentration method*).

**True value (of a physical characteristic within river hydraulics):** An ideally correct value, determined without any errors whatsoever. A true value can be instantaneous or averaged over a certain period of time, and it can relate to an infinitesimal point or be averaged over a certain length, area or volume.

**\* Umbilical:** Single-string suspension cable for an aggregate device for sediment sampling by pumping, current, depth and tilt measurements, and turbidity measurements. The umbilical consists of a tube (for flow), surrounded by conductors for power supply and transmitted signals. It replaces a number of separate tubes, cables, etc., that could become entangled during deployment.

**\* Uncertainty doubtful data:** errors due to unknown sources or un explained natural variability.

**Validation (of survey data):** Confirmation of the data *accuracy* by comparison with independent measurements of the same values. For example, an acoustic water level recorder may be validated against staff gauge data. Validation can provide for elimination of systematic *errors* related to the survey procedure, and can, if carried out regularly, identify the time of occurrence of errors appearing as stepwise deviations between time series.

**Validity (of survey data):** The compliance between a desired value and an actual value. Even if both are *accurate*, the validity can be low, for example due to time and space variations (such as measuring current for determination of flow in a few points and over a few seconds only).

**Wash load:** Part of the suspended sediment transport which are washed down the river without having any continuous exchange with the riverbed. Conventionally, silt and clay (diameter < 0.063 mm) are considered as wash load.



# 1 Introduction

## 1.1 Introduction to the River Survey Project

The River Survey Project (RSP, or FAP24) was initiated on June 9, 1992, and is scheduled for completion on June 8, 1996. The Project has been executed by the Flood Plan Coordination Organisation (FPCO) under the Ministry of Irrigation, Water Development and Flood Protection, presently the Ministry of Water Resources. By the end of 1995, FPCO merged with the Water Resources Planning Organization (WARPO) under the same Ministry and WARPO took over the project execution. Funding was granted by the European Commission (formerly the Commission of the European Communities). The Consultant is a joint venture of DELFT HYDRAULICS and the Danish Hydraulic Institute (DHI), in association with Osiris, Hydroland and Approtech. Project supervision is done by a Project Management Unit with participation of FPCO/WARPO, a Project Advisor, and a Resident Project Advisor. The objective of the Project is to contribute and provide support services to different fap programme, as well as to other national planning, design, and impact assessment activities within the domain of water resources and river engineering.

The Project consists of three categories of activities:

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

The proceedings of the RSP are described in several report series that cover the overall progress, surveys, studies, general professional issues, and administrative matters. The final reporting is organised as follows:

- The Main Final Report, which contains a summary of the background, a short overview of the activities within each project component, and overall recommendations
- Annexes to the Final Report, covering
  - Annex 1 Surveys
  - Annex 2 Sustainable survey techniques
  - Annex 3 Hydrology
  - Annex 4 Sediment transport
  - Annex 5 River morphology

A listing of all RSP reports is given in the Main Report.

## 1.2 Scope of this Annex 2

The objective of the survey component of the River Survey Project as laid down in the Terms of Reference (section 3.1) reads: "To collect reliable all season hydrological, morphological and hydrographic data at key locations in the country's main river systems, with emphasis given to collection of data during the monsoon season, introducing improved or new technology where appropriate".

The field measurements comprised operation of a network of water level gauges in the main river systems of Bangladesh, a routine gauging programme of flow and sediment transport measurements, a programme of bathymetric surveys for morphological monitoring, and a programme of non-routine measurements for dedicated study purposes.

In combination with Annex 1: Surveys, this Annex 2 presents the findings of the survey component of the Project. While Annex 1 mainly describes the actual data production, together with some specific experience and impressions, Annex 2 describes the related knowledge generated about appropriate execution of river surveys in Bangladesh. On this basis, a set of recommendations is given on sustainable survey techniques for routine monitoring of the rivers in Bangladesh.

## 1.3 Previous work

The survey component of the RSP is closely related to the river monitoring that has been carried out for decades by the BWDB.

The BWDB operates a network of staff gauges that covers the entire main river system of the country. The comprehensive routine gauging programme of the BWDB comprises flow measurements, sediment transport measurements, and morphological monitoring at fixed standard cross-sections along the rivers.

This gauging programme is realized using rather traditional survey techniques, which have their limitations particularly in high flows. Reasons for those who established the Terms of Reference of the River Survey Project to ask for more and more accurate data needed for the Flood Action Plan (ToR, Section 1.4).

Nevertheless, the BWDB monitoring is precious because it provides dense long-term data records, the consistency of which are largely confined by natural developments of the physical environment. This information can in no way be substituted by the results of the fixed-term field measurements of the present Project, although these measurements have perhaps in general been made by more sophisticated means and to a higher degree of detail. Rather, the RSP programme can supplement the BWDB monitoring in certain respects, in order to enhance the knowledge about the behaviour of the rivers.

## 1.4 Summary of relevant activities carried out under FAP24

This Annex 2 covers three of the study topics selected for Phase 2 of the RSP:

- Optimization of hydraulic measurements (previously reported in *RSP Special Report 11*);
- Optimization of sediment measurements (previously reported in *RSP Special Report 12*); and
- Sustainable survey techniques.

The scope of these study activities were, together with many other ones, presented briefly in *RSP Study Report 1: 'Selection of study topics for Phase 2'*. In a dialogue with FPCO and RSPMU, the activities were included as study topics 9.2, 9.3, and 9.6 of the Phase 2 study programme, as presented in *RSP 'Final Report Phase 1'*.

These study activities are in turn based on the survey component of the Project:

- Planning and mobilisation of the field programme, and the initial field trials and test gauging;
- The planning and the continued development of procedures for data analysis, data reporting, and data storage;
- The routine gauging programme: Water level gauging, gauging of flow and sediment transport, and morphological monitoring by repeated bathymetric surveys;
- Special surveys carried out as a supplement to the routine gauging programme, notably those special surveys that were carried out in order to develop and refine the RSP field procedures.

Another important part of the basis for this Annex 2 is the comparisons made in the course of the Project between RSP and BWDB instrumentation and procedures for routine gauging of flow and sediment transport, and also joint surveys for morphological monitoring of standard cross-sections, as undertaken by BWDB.



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## 2 Rationale

### 2.1 General

Any strategy for development - be it by successive small steps or by one big leap - must address three basic, related questions: (1) Where are we? (2) Where do we want to go? And (3) How do we get there? The present report presents a set of findings that relates to these questions, but without covering any of them entirely. Rather, some options are outlined that may extend the basis for decisions on routine monitoring of the main rivers of Bangladesh.

In this way, it is intended to present some observations made and some experience gained during the RSP, and to make this knowledge available to the continued efforts to consolidate the national competence in this field.

A variety of options and constraints relate to any river survey programme, but they are widely different for a permanent general routine gauging programme and for a fixed-term venture like the RSP. Therefore, the experience of the RSP has a confined validity with respect to the technical aspects of river surveying, and little validity beyond those aspects.

### 2.2 Sustainability of a survey technique

A survey technique is a combination of a set of tools and a procedure for their application for a given purpose. Hereby, a survey technique is one element of a survey technology, which, in addition to the technique, comprises the knowledge required for its intended application, both theoretical skills and practical experience, and also the organisational framework.

In this study, a sustainable technique is characterised by (1) being suited for a given purpose, and (2) being suited for implementation and consolidation in a given context. An optimal technique is, for the purpose of the present study, defined as the best choice among available options, considering a number of quality criteria. These criteria can be purely technical, but can also include general operational aspects, capability requirements and costs. Also, the sustainability can be included in the basis for the optimization.

A sustainable technique may not necessarily be optimal, for example if the context for its consolidation is in conflict with other optimization criteria. On the other hand, an optimal technique is sustainable only if it is suited for implementation and consolidation, and not otherwise. Several sustainable techniques can be conceived as true alternatives, or depending on the time horizon for implementation and consolidation. Also, there can exist critical constraints other than the purely technical ones, such as capacity requirements, or the compatibility with established skills and practices. Whenever pursuing an optimal solution, it must be kept in mind that 'the best can be the enemy of the good'.

### 2.3 Objectives of routine gauging

One characteristic of a sustainable survey technique is that it is suited for some given purpose. Hereby, the objectives of the gauging become a decisive aspect for the selection of techniques. While this fact is trivial, the question of the objectives of a permanent monitoring programme is quite significant.

28 Such objectives can vary with time, and important future objectives can well be obscure at present. As one example the morphological studies undertaken by the RSP, to support other projects of the Flood Action Plan can be mentioned. For this purpose, in the 1992-96 project period more detailed routine surveys, especially in high flow conditions and series of special measurements were executed. The important flood forecasting presently undertaken by BWDB's Flood Forecasting and Warning Centre requires (almost) real-time water level and rainfall data, a need which was not hitherto foreseen. While the measurements as such were also suited for this new purpose, an adaption of the data flow was required. Another example of a new objective of an existing routine gauging programme is the enhanced need of water quality monitoring, which is induced by the increasing utilisation of the lean season water resource.

The objectives can be compatible, complementary, or even in conflict with each other, and can indicate widely different techniques. For example, monitoring of lean season water resources and water quality can necessitate tidal surveys in downstream reaches, but may, on the other hand, require less heavy gear as compared with flood season streamflow gauging.

Without an objective, a survey technique (or a survey programme) cannot be optimized, because the objective is the reference against which alternatives can be compared. A summary of objectives, in general terms, is given in Table 2.1, which considers routine gauging in Bangladesh. The general objectives can be broken down into more detailed and more operational objectives, outlining targets for different quality aspects, such as accuracy, data coverage, etc., which in turn can serve as a basis for selection of survey techniques. One example of a basic quality criterion is that the accuracy of the value to be measured is acceptable as compared with the intended use of the data.

|                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hydrology:                         | <ul style="list-style-type: none"> <li>• Overall water balance for general water resources planning and management</li> <li>• Flood monitoring and flood forecasting</li> <li>• Lean season water balance (irrigation demand and supply)</li> <li>• Basis for water quality monitoring (related to household water supply, irrigation, industrial supply)</li> <li>• Operation of regulators and dams</li> <li>• Hydraulic design basis for bank protection, regulation, and planning and management of physical infrastructural facilities (ferry ghats, bridges, embankments, etc.)</li> </ul> |
| Sediment transport and morphology: | <ul style="list-style-type: none"> <li>• General land use planning and management (land erosion and accretion)</li> <li>• Navigational depths of waterways</li> <li>• Morphological design basis for bank protection, regulation, and planning and management of physical infrastructural facilities (ferry ghats, bridges, embankments, etc.)</li> </ul>                                                                                                                                                                                                                                        |

Table 2.1: Objectives of routine gauging

Further, it plays a role whether the survey programme is oriented as an empirical or a deterministic approach. In case of an empirical approach, the measurements are directed towards the effects, and the collected data must be self-sufficient with respect to time and space coverage of these effects. This indicates a fine network of gauging stations and a complete set of measurements to be carried out at regular intervals for a long period of time. Synthesis of results is done by statistical analysis of the time series. In a deterministic approach,



the measurements are directed towards the processes, and the data must be adequate for describing the cause-effect relations within their range of validity and practical interest. This indicates a survey effort that is concentrated in time and place, aiming at a complete or even over-determined process description, and continuous rather than discrete measurements. Results are generalised by the laws of physics, theoretical relations, or by deterministic (usually numerical) modelling, possibly involving data assimilation techniques.

The empirical approach is well suited for hindcasting, whereas the deterministic approach is well suited for forecasting and for impact analysis, including prediction of effects under circumstances that deviate from the present hydraulic conditions.

The differences between the two possible orientations of a data collection programme emerged clearly during the interaction between the survey component and the study component of the RSP. The routine gauging programme of the Project could, together with bwdb data, provide a basis for many empirical studies, but were not always adequate for studies of physical processes. Therefore, the additional programme of dedicated non-routine surveys was conceived and executed in the course of the project.

An example of the former category is water-level gauging five times per day at a station for ten years, intended for statistical analysis of the water level exceeded in a return period of five years. An example of the latter category is mapping of the geometry of a reach of the river, simultaneous measurements on a few occasions of flow and water level slope, and continuous water level gauging at a few locations, followed by a hydrodynamic model simulation of the flow. (Hereby, the system is over-determined, as far as the geometry, the current-velocity and the water-level slope are related, but are measured independently).

In recent years, several river monitoring programmes (e.g. those of some Indian states) have developed from a purely empirical to a partly empirical and partly deterministic framework, induced by a demand of data for flood forecasting and real-time regulation purposes.

The two approaches are summarised in Table 2.2, which shows how they deviate with respect to the type of field data collection for a given objective, and also with respect to resource allocation.

| Framework                                 | Empirical                                                  | Deterministic                                                                   |
|-------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------------------|
| Overall objective of monitoring programme | Monitoring of effects, resource registration, design basis | Prediction of effects, impact analysis, planning basis                          |
| Direct objective of measurements          | Effects                                                    | Processes                                                                       |
| Scope                                     | Long-term network monitoring                               | Concentrated, dedicated campaigns, plus selected time series for generalisation |
| Data series                               | Typically discrete                                         | Typically continuous                                                            |
| Data analysis                             | Statistical analysis                                       | Deterministic models                                                            |

Table 2.2: Comparison between empirical and deterministic framework

## 2.4 Context

The sustainability of a survey technique relates to a specific context, which comprises two categories of aspects:

- the physical environment; and
- all other aspects, such as infrastructure, institutional capacity and capability, relative costs (of equipment, fuel, skilled labour, unskilled labour, etc.), and the global level of technological development.

For practical purposes, the former category can be taken as a given, while all other aspects will inevitably vary in time, gradually or stepwise. A technological achievement (such as for example the GPS satellite positioning system) can render a previous technique (Decca positioning) obsolete within a period of a few years, if the new option is appropriate and sustainable at the same time. Similarly, a financial constraint can be removed instantaneously by some budget re-allocation within a government system, or temporarily by a foreign development grant. Infrastructural constraints and relative costs are also bound to change. Therefore, what is sustainable today may not be sustainable in the future.

In the present report, the characteristics of the river system are considered an important basis for a selection of survey techniques. Another part of the same basis is the range of techniques that are available. In this respect, the RSP has gained experience with the more traditional survey techniques applied in the river system and with improved or new technology introduced where appropriate by the RSP, in accordance with one of its objectives (TOR, Section 3.1). The third part of the basis is the set of implicit or explicit constraints that relate to the preservation of existing techniques, as well as to the possible implementation of new ones. As explained above, these constraints will not be discussed in depth in the present report, because the specific experience of RSP in this regard does not relate to a sustainable permanent routine gauging programme. The rationale is illustrated in Figure 2.1.

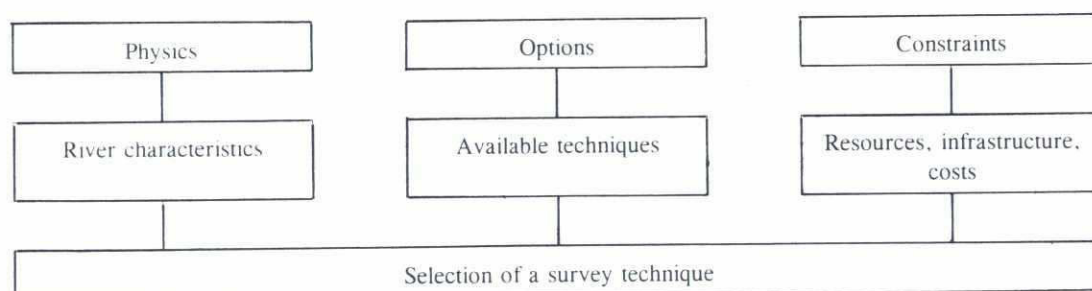


Figure 2.1: Basis for selection of a survey technique



### 3 River characteristics and field surveys

River characteristics are an important consideration for selection of equipment and method in hydraulic field surveys. The nature of survey planning, the type of equipment mobilization, and actual execution of the measurements are dependent on the hydraulic characteristics of the rivers. For more complicated rivers, as in Bangladesh, the surveys are difficult. In particular, the flow structure in large alluvial rivers is three-dimensional and turbulent (Peters and Goldberg, 1989), which makes accurate measurements difficult. We highlight some relevant river characteristics in the context of sustainable survey techniques.

- Multiple channels occupy most reaches of Bangladesh rivers, especially the Jamuna and the Padma Rivers. There is no easy navigation between them especially during low river stages. The confluence and off-take flow situations created by multiple channel junctions, river bends, and transitional reaches (wide to constricted or constricted to wide) cause accelerating and decelerating flows and makes it difficult to locate an ideal measuring station. Shallow, wide secondary or storage channels are difficult to navigate and measure. Also, channels and banks migrate at such a high rate that during one measurement interval a completely new channel configuration could form, necessitating repeated reconnaissance.
- Bangladesh rivers are fine sand-bed rivers. The median sediment diameter varies from 90  $\mu\text{m}$  in the Padma River to 220  $\mu\text{m}$  in the Jamuna River. Consequently, the threshold velocity for sediment mobility is low, approximately 0.2 m/s (Hjulstrom, 1935).
- Due to the low threshold velocity, the rivers are highly mobile with continuous reworking and deformation of their beds and banks. Activity increases during peak river stages in the monsoon months.
- Locally, flow velocities often exceed 3.5 m/s during the peak river stages. Suspended sediment concentration often exceeds 1000 mg/l.
- In addition, there is a high variability of hydraulic and sediment parameters in space and time. For example, the seasonality of rivers creates an important difference in wet cross-sectional areas. High sediment concentrations, specially during the monsoon season, may require special instruments to counter common instrument sensitivities.
- For surveys in Bangladesh rivers which are located in the lowermost reach of the fluvial system covering both tidal and nontidal reaches, it is necessary to design a different survey spread.

Table 3.1 summarizes some known values of different hydraulic and morphologic parameters in the rivers covered by the RSP. It comprises the Brahmaputra-Jamuna River system, the Ganges River system, the Padma River system and the Meghna River system. The Table shows a wide range of variability of independent and dependent variables among the rivers covered by the RSP.



| Morphologic Parameters                        | Ganges             | Gorai              | Jamuna             | Old Brahmaputra    | Dhaleswari           | Padma              | Arial Khan | Upper Meghna       |
|-----------------------------------------------|--------------------|--------------------|--------------------|--------------------|----------------------|--------------------|------------|--------------------|
| <b>Independent Var.</b>                       |                    |                    |                    |                    |                      |                    |            |                    |
| $Q_{st}$ (m <sup>3</sup> /s)                  | 11,000             | 1,400              | 19,600             | 500                | 600                  | 28,000             | 2,600      | 4,800              |
| $Q_{bl}$ (mt/a)                               | 196                | -                  | 499                | 7                  | -                    | 890                | -          | 13                 |
| $Q_{bt}$ (mt/a)                               | -                  | -                  | -                  | -                  | -                    | -                  | -          | -                  |
| Bed-material grain size ( $d_{50}$ , $\mu$ m) | 120                | 179                | 220                | 180                | 150                  | 90                 | 147        | 180                |
| Bed-material sort. coeff(-)                   | 1.40               | 1.45               | 1.52               | 1.80               | 1.57                 | 1.52               | 1.57       | 2.54               |
| <b>Dependent Var.</b>                         |                    |                    |                    |                    |                      |                    |            |                    |
| Width (m)                                     | 5,000              | -                  | 11,000             | 330                | 256                  | 7,000              | -          | 1,000              |
| Depth (m)                                     | 4.5                | -                  | 5.0                | 7.0                | 9.0                  | -                  | -          | 4.7                |
| Slope (-)                                     | $5 \times 10^{-5}$ | $4 \times 10^{-5}$ | $7 \times 10^{-5}$ | $7 \times 10^{-5}$ | $4.5 \times 10^{-5}$ | $4 \times 10^{-5}$ | -          | $2 \times 10^{-5}$ |
| Form Number (-)                               | 1.111              | -                  | 2,200              | 47                 | 28                   | -                  | -          | 213                |
| Meander Wavelength (m)                        | 29,000             | 9,200              | -                  | 5,500              | -                    | -                  | 4,160      | 9,000              |
| Channel Sinuosity(-)                          | 1.2                | 1.7                | -                  | 1.4                | 1.5                  | 1.1                | 1.8        | -                  |
| Brice Braiding Index (-)                      | -                  | -                  | 4 - 6              | -                  | -                    | -                  | -          | -                  |

$Q_{st}$  = Mean annual suspended sediment load,  $Q_{bl}$  = Mean annual near-bed/bed sediment load.

Table 3.1: Time- and space-averaged various morphologic parameters of the major rivers in Bangladesh obtained from various sources.

Various sediment and morphologic parameters vary widely in space and time in the main rivers of Bangladesh. These parameters are useful for preliminary selection, testing, and procurement of hydraulic and sediment measuring instruments. Some of these parameters are known from previous studies (NEDECO, 1967; Coleman, 1969). Some of these earlier findings as well as contemporary information from FAP studies are summarized by FAP24 in *Study Report 3 (RSP, 1994)* and by Barua (1994). Table 3.1 shows a summary of these parameters, and their variability, assembled from various sources.

Sediment transport factors are critical for studying and predicting the morphological behaviour of rivers. Textural properties of bed-material such as bed-material size, standard deviation and sand-silt percentage are important independent variables for sediment transport and morphologic relations. Similarly, total sediment transport, its division into size fractions, and the ratio of suspended-load to bed-load are important. Different physical and mineralogical properties of sediments are also independent variables in many relations. For Bangladesh rivers, most of these factors are neither known nor measured. Suspended sediment transport data, however, are available from BWDB. Some further information on bed-forms are

compiled in Table 3.2 which were taken from Coleman (1969).

| Bed-forms                 | Ripples                               | Megaripples                          | Dunes                                                               | Sand waves                              |
|---------------------------|---------------------------------------|--------------------------------------|---------------------------------------------------------------------|-----------------------------------------|
| Height, H (m)             | < 0.3                                 | 0.3 - 1.5                            | 1.5 - 7.6                                                           | 7.6 - 15.2                              |
| Length, L (m)             | < 1.5                                 | 3.1 - 152.4                          | 42.7 - 487.8                                                        | 182.9 - 914.6                           |
| Ripple Index (H/L)        | 1:5 - 1:20                            | 1:6 - 1:100                          | 1:30 - 1:60                                                         | 1:25 - 1:100                            |
| Maximum migration (m/day) | –                                     | 247                                  | 158.5                                                               | 640.2                                   |
| Average migration (m/day) | 3.1                                   | 122.0                                | 67.1                                                                | 204.3                                   |
| Depth of water (m)        | < 30.5                                | < 30.5                               | 3.1 - 30.5                                                          | 9.2 - 36.6                              |
| Water turbulence pattern  | small surface eddies in shallow water | small surface boils in shallow water | large surface boils                                                 | large surface boils                     |
| Plan view of crestline    | linguloid                             | straight, linguloid and lunate       | irregular in shallow water, straight or gently curved in deep water | straight but commonly curved downstream |

Table 3.2: Bed-forms in the Jamuna River as reported by Coleman (1969).

It should be realized that most sediment transport relations are not based on theory but are empirically derived; this means that the relations apply only to the cases for which they are derived. The coefficients of these relations have to be determined from observations in the rivers where they will be applied. Therefore, sediment measurements are essential for validating the known transport relations.

The river-wise variability of some hydraulic parameters is further shown in Table 3.3. The ranges in water level, velocity and discharge, as they relate in space and time, are important because each instrument and method has its own range within which it can measure accurately. Data in Table 3.3 represent the measurement stations located at Bahadurabad on the Jamuna River, Mymensingh on the Old Brahmaputra River, Tilly on the Dhaleswari River, Hardinge Bridge on the Ganges River, Kushtia Railway Bridge on the Gorai River, Baruria on the Padma River, the Arial Khan off-take, and Bhairab Bazar on the Upper Meghna River. The largest variation occurs in the Ganges River. The highest velocity was measured in the Ganges River near Hardinge Bridge, while the highest flood-time discharge was recorded in the Padma River at Baruria. Confluences and bend scour holes kept maximum depth measurements in the considered river-reaches to about 40m. The largest width measurement was taken over the major channel of the multi-channelled Jamuna River.

| River system       | River           | Water level range (m) | Maximum velocity (m/s) | Discharge variability (1000 m <sup>3</sup> /s) | Maximum depth (m) | Maximum width (km) |
|--------------------|-----------------|-----------------------|------------------------|------------------------------------------------|-------------------|--------------------|
| Brahmaputra-Jamuna | Jamuna          | 6                     | 3.5                    | 8 - 100                                        | 40                | 5                  |
|                    | Old Brahmaputra | 6                     | 3.0                    | 0 - 10                                         | 30                | 1                  |
|                    | Dhaleswari      | 5                     | 3.0                    | 0 - 15                                         | 30                | 1                  |
| Ganges             | Ganges          | 7                     | 4.0                    | 1 - 70                                         | 40                | 3                  |
|                    | Gorai           | 7                     | 3.0                    | 0 - 20                                         | 30                | 1                  |
| Padma              | Padma           | 6                     | 3.0                    | 10 - 120                                       | 40                | 5                  |
|                    | Arial Khan      | 5                     | 2.0                    | 0 - 15                                         | 20                | 1                  |
| Meghna             | Upper Meghna    | 5                     | 2.5                    | 0 - 30                                         | 30                | 1                  |

Table 3.3 Range of water level, velocity, discharge, depth, and width in the major rivers of Bangladesh

Water levels in different Bangladesh rivers vary seasonally with the lowest levels occurring from February to April, and the highest occurring from July to August. The water level slope is important for hydraulic computations and for use in bathymetric surveys. The Upper Meghna River had the lowest slope at  $2.3 \times 10^{-5}$ , while the upper reaches of the Brahmaputra-Jamuna River had the highest slope at  $7.6 \times 10^{-5}$ . In addition, local slopes are important indicators of morphological developments (Peters, 1993). The local and the seasonal slopes have been recognized (RSP, 1996a).

Most importantly, many instruments developed either in Europe or America were primarily designed to sample a certain river under a particular environment (i.e., specific to a given country). Deploying these instruments to other environment should therefore be made after careful considerations of the factors mentioned. Climatic factors are also relevant in this respect. The mean January air temperature of Bangladesh varies from 16°C in the north to about 19.5°C in the south (Rashid, 1991). Mean July air temperature varies from 27.5°C in the south to about 29°C in the north. Due to southwest monsoon, the mean summer relative humidity is as high as 80. It comes down to 59 during the winter northeast monsoon. These important river characteristics were recognized at the initiation of this project and influenced the selection of equipment and methods as described in the technical proposal of the River Survey Project (RSP, 1991).



## 4 Measurements in large alluvial rivers

On the basis of the river characteristics outlined in the previous chapter, the present Chapter gives a general summary of requirements, quality aspects and constraints in connection with measurements in large alluvial rivers, like the ones of Bangladesh.

These aspects were considered in connection with the initial planning and the subsequent development of the RSP routine gauging, and a substantial additional insight was gained during its execution. The project did not solve all problems encountered, and in certain cases, it did even not identify a viable solution. Still, the efforts have resulted in an (sometimes highly) improved understanding of the scope of field measurements in the Bangladesh rivers, and hereby an extended basis for selection of appropriate survey techniques.

Moreover, most sediment transport relations are not based on theory but are empirically derived; this means that the relations apply only to the cases for which they are derived. The coefficients of these relations have to be determined from observations in the rivers where they will be applied. Therefore, sediment measurements are essential for validating the known transport relations.

In addition, many instruments developed either in Europe or America were primarily designed to sample a certain river under a particular environment (i.e., specific to a given country). Deploying these instruments to other environment should therefore be made after careful consideration. The purpose of this section is to highlight certain environmental conditions of Bangladesh rivers which are important for the selection of instruments. Particularly relevant in this respect is the climate of Bangladesh. The mean January air temperature of Bangladesh varies from 16°C in the north to about 19.5°C in the south (Rashid, 1991). Mean July air temperature varies from 27.5°C in the south to about 29°C in the north. The mean summer relative humidity is high, about 80, as a result of the southwest monsoon. On the other hand, due to the northeast monsoon, the winter relative humidity is lower, appr. 59.

### 4.1 The geometry of the river and the floodplain

For practical survey purposes, the geometry of a river can be divided into:

- planform, channel alignment;
- channel cross-section geometry;
- riverbed elevations (including slope and bedforms); and
- floodplain elevations.

The geometry of alluvial rivers (in their natural state) change with time. These changes are a main part of the basis for planning of survey programmes and selection of survey techniques, representing at the same time a part of the scope of the data collection and a constraint on the data validity.

An example of a morphological development is shown in Figure 4.1, which is based on RSP surveys at Bahadurabad in November 1993 and November 1995. The figure shows how both the general planform and the detailed channel alignment changes with time. (In this example, a large part of the changes took place in the 1995 flood season).



Due to the inter-dependency between hydraulics, sediment transport and the morphology, a changing geometry renders any system description much more complex than when the geometry is constant in time. The relations between the processes become of a practical interest, so that a wide data basis is needed for an understanding. Therefore, data requirements for many practical purposes (resource planning, impact prediction etc.) become enhanced, both with respect to scope, and to space and time coverage.

There are other important implications of a changing geometry:

- Literally all data, perhaps excluding the net flow (which is always measured in directly), are in some way related to the geometry;
- Therefore, geometry changes will affect the data validity, including the validity of baseline surveys, and the consistency of time series;
- Rapid bed-level variations can affect the interpretation of bathymetric surveys carried out under high flows, because the set of data is not consistent;
- From a practical, operational point of view, bank erosion can endanger bench marks and water level gauges, while land accretion can render fixed gauging stations (or even cross-sections) useless, if the river decides on a new course.



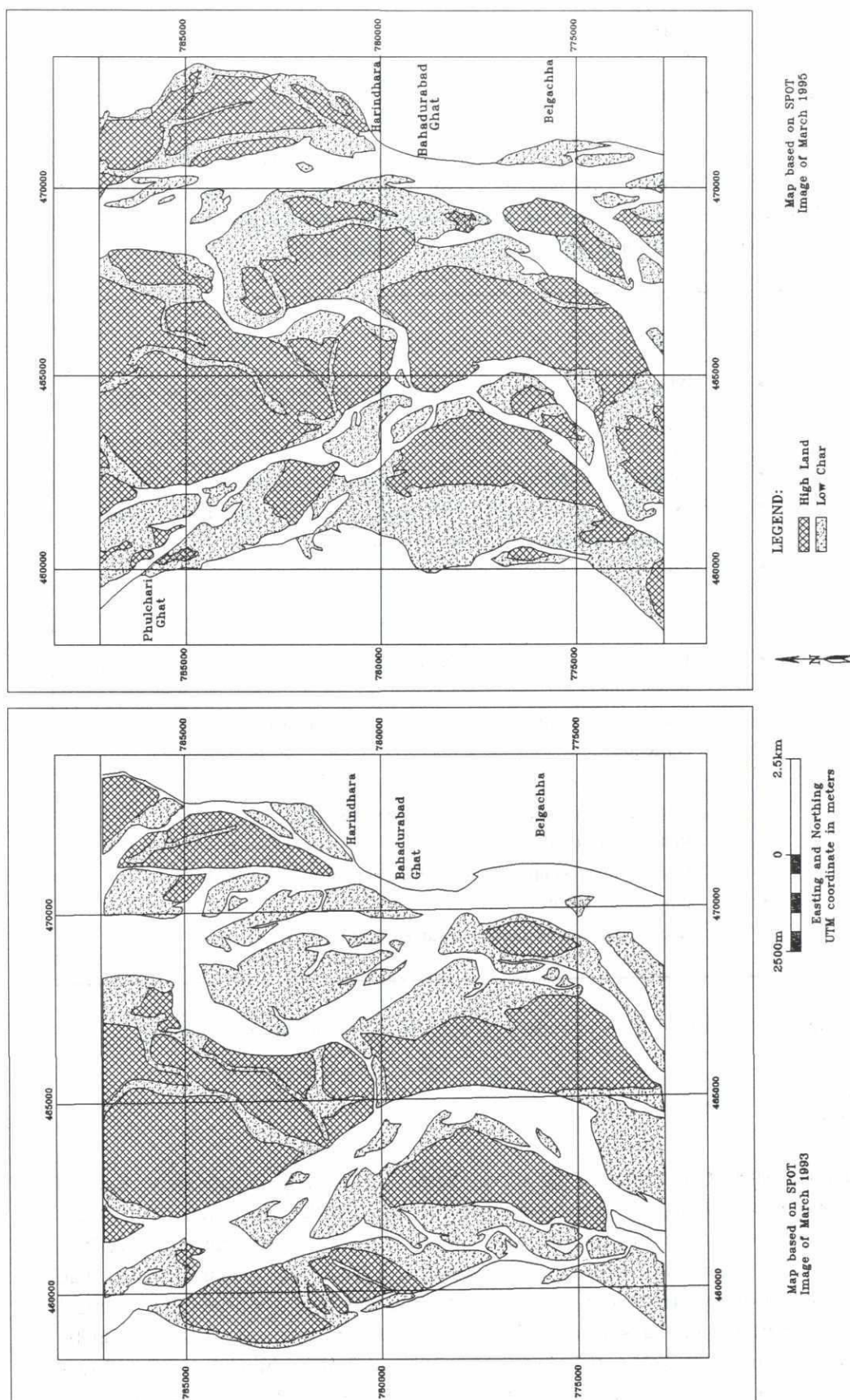


Figure 4.1: Variation of a river geometry (example, Bahadurabad, November 1993 and November 1995)



## 4.2 Survey vessels

### 4.2.1 Quality characteristics

A survey vessel is a mobile platform from where instruments can be handled and samples taken. The characteristics of a 'good' survey vessel depends on (1) its application, and (2) the physical environment in its operation area. Some properties of a survey vessel, with special regard to operation in large alluvial rivers, are listed in Table 4.1.

|              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Navigation:  | <ul style="list-style-type: none"> <li>• Stability</li> <li>• Manoeuvrability, incl. ability to maintain position in a strong current</li> <li>• Draft</li> <li>• Speed</li> <li>• Ability to anchor in a strong current and a moving riverbed</li> <li>• Navigation control system (positioning, radar support, orientation, route tracking, Helmsman's display of runlines)</li> <li>• Dynamic monitoring for data correction (draft, heave, sway)</li> </ul> |
| Survey work: | <ul style="list-style-type: none"> <li>• Space for survey work</li> <li>• Room for data processing, computers and electronics (with airconditioning)</li> <li>• Power supply</li> <li>• Facilities (davits and (power) winches) for instrument handling and sample collection</li> </ul>                                                                                                                                                                        |
| Operation:   | <ul style="list-style-type: none"> <li>• Communication (general and data transmission)</li> <li>• Reliability of propulsion system</li> <li>• Storage room (samples, consumables, supplies, spare parts)</li> <li>• Bunkering capacity</li> <li>• Accommodation for crew and survey staff</li> </ul>                                                                                                                                                            |

Table 4.1: Quality characteristics of a survey vessel as used in the RSP (excluding safety aspects)

### 4.2.2 Safety

Another quality aspect that relates to the survey vessel is the navigational safety. Even if *prudent procedures and appropriate precautions* are by far the most important safety elements, the vessel itself will influence the safety risk and the associated preventive weather down time. For example, the stability of the vessel is a basic safety characteristic. The sensitivity of the propulsion system to damage by fishing nets is of a considerable practical interest when operating on large rivers. The risk of collision with other vessels can be reduced (but certainly not eliminated) by a radar system, and by good lanterns. (Radar reflectors are of less value in Bangladesh, where few vessels use radar). The hull of the vessel should be strong enough that it is not very sensitive to occasional grounding.

It is self-evident that the vessel should be supplied with adequate safety equipment: life vests and life buoys with lanterns, signal rockets, life raft, and radio communication (although, in Bangladesh, the radio should not be relied on, as emergency signals are not always picked up, or action taken if they are).

Different types of violent storms occur in Bangladesh: depression type storms (June through September), thunderstorms (March, April, May and October), and northwesterlies, *Kal Baisakhi*, (March to May). Thunderstorms and northwesterlies come suddenly and are difficult to predict. The well-known cyclones are potentially devastating, but are normally confined to the coastal zone, where they occur at rare intervals (on the average 0.7 per year somewhere in Bangladesh, with wind speeds above 62 km/hour). Mostly, cyclone warnings are issued beforehand.

- Grounding (particularly at falling stage)
- Propeller or propeller shafts damaged by fishing nets
- Collision with other vessels
- Falling overboard (particularly at night, or during bad weather)
- Capsizing during storms

Table 4.2: Safety risks in Bangladeshi rivers

#### 4.2.3 Selection of survey spread and survey vessel

There are two ways of establishing the required compatibility between the vessel and the survey spread. One is to select a survey spread, and to select the vessel accordingly. (This was what was done by the RSP). Another way is to suit the survey spread into the vessels available. In Bangladesh, for example, this could involve use of country boats (while in many other countries, fishing boats would be a natural choice). These approaches differ with respect to qualities, the former being superior with respect to a more open choice of survey technique, and a good data collection capacity and accuracy, at a cost of reduced flexibility and versatility. Also, substantial costs are involved for procurement and operation of a survey vessel.

### 4.3 Positioning and vertical control

Whenever field data are collected, knowledge about their origin is equally important as the values themselves. For example, nobody has any interest in knowing that a current-speed was 0.78 m/s, if it is not known where and when this occurred.

For technological reasons, time control is straightforward; measurements can be planned to take place at a certain time on a given day, the time can be observed accurately during the measurements, and it can be registered and communicated by an unambiguous general standard afterwards (or with position control). To reach a position specified on a map requires that this map is consistent with the applied positioning method. To monitor the position during



the work can require a complex technology, depending on the place and the desired quality. To document and communicate the location afterwards requires a reference that is well-defined and accessible to the data user. When working on the large rivers of Bangladesh, none of these requirements is trivial.

An additional characteristic challenge is that, in many places, during high flows, the planform and the cross-section geometry of a river section can change within short periods of time. Therefore, in addition to describing when and where the current-speed was 0.78 m/s, it can also be required to describe the associated planform and depth contours of the river where the measurement was made.

#### 4.3.1 Horizontal control

Two aspects of river survey positioning are:

- Maps and coordinate systems; and
- Operational position control.

The key quality criteria are (1) consistency, and (2) accuracy.

The consistency can be confined to a project or a programme, and such consistency is a decisive quality aspect for all data applications that involve comparisons. In the case of a water level registration, the consistency must at least extend over the entire time series, and preferably over an entire network of gauges. In the case of bathymetric mapping for purely navigational purposes, the consistency must at least extend over the entire mapping (but does not need to extend over successive ones, provided that they are not intended for comparison).

Inter-programme consistency can be supported by means such as a temporary staff gauge bench mark, which is well-defined, and which can be retained for many years. This temporary bench mark is of a decisive value, even if its coordinates are unknown. General (or universal) consistency is a separate, additional quality aspect. This requires that the temporary bench mark be levelled relative to a well-defined (national) datum which is accessible to any data user.

Similarly, the positioning accuracy can be relative or absolute. When measuring the flow through a cross-section of the river by a velocity-area method, the distance between the verticals is an important value; it may (for the sake of the flow recording itself) be less critical, however, when the cross-section has only been located within a margin of a few hundred m along the river. Hereby, the quality of the flow data depends primarily on the relative (rather than on the absolute) positioning accuracy.

#### 4.3.2 Maps and coordinate systems

Maps are required for any planning of surveys, and can highly support the operational position control. Also, and equally important, maps are required for describing the physical context of the surveys, and for interpreting the data.



A practical quality criterion for a map (to be used for field work in a river network with a dynamic morphology) is that it is reasonably updated. For the sake of documentation, the time of the underlying field survey should be well-defined (as is normally the case for satellite-based maps). Another requirement is that the map is based on a coordinate system that is consistent with the one selected for the operational positioning. Inconsistencies in this regard will inevitably affect the possibility to decide beforehand where the measurements are going to take place.

The availability and use of a national or global reference is particularly important when comparing data from different sources, such as BWDB and BIWTA routine gauging data, dedicated surveys, satellite imagery, or calculated results of numerical models, for example at SWMC. Any routine gauging data can serve such purposes, whether it is foreseen or not, so their origin should either be registered relative to a general, well-defined coordinate system, or, as a minimum, in a way that is suited for subsequent conversion.

The considerations may appear trivial, but their significance became apparent already in the early stage of RSP, and emerged repeatedly in the course of the project.

#### 4.3.3 Operational position control

The previously suggested basic data quality criterion is that the accuracy of the value to be measured is acceptable, relative to the intended use of the data. Practical derived data quality criteria of the positioning technique is that the error contribution related to the positioning accuracy does not conflict with the above basic data quality criterion, and is not predominant relative to other errors.

The criteria are illustrated in Table 4.3, together with suggested practical positioning accuracy standards.

Consider, for example, a water level registration at a fixed gauge location. If the intended value is the water level itself, for example for a flood level statistics, and the surface slope is 10 cm/km (0.0001), and the positioning accuracy is 50 m, the error becomes  $50\text{m} \times 0.0001 = 0.5\text{ cm}$ , which is acceptable for many purposes, both in relation to the desired knowledge about the water level and in relation to the error contribution by the gauge itself. The same is the case if the water level is registered not for its own purpose, but in order to transfer a datum during a bathymetric survey. If, however, the purpose is to measure a local water level slope, the positioning becomes more critical. The slope is measured as the difference between two water-level gauges divided by the distance between them, and if this distance is short, the position-related error becomes significant.

| Measurement                                                             | Position-related error contribution                         | Suggested PA |
|-------------------------------------------------------------------------|-------------------------------------------------------------|--------------|
| Water level                                                             | PA x local surface slope                                    | 50 m         |
| Water level slope                                                       | PA x local surface slope divided by distance between gauges | 10 m         |
| Current (by fixed-point or moving boat measurement)                     | PA x lateral current-speed variation                        | 5 m          |
| Flow area (of cross-section segment for velocity-area flow calculation) | PA x water depth                                            | 5 m          |
| Current (by drogue tracking)                                            | PA / time increment                                         | 5 m          |
| Sediment concentration                                                  | PA x lateral concentration variation                        | 5 m          |
| Depth                                                                   | PA x riverbed gradient                                      | 5 m          |
| Salinity measurements                                                   | PA x horizontal salinity gradient                           | 100 m        |
| PA = positioning accuracy                                               |                                                             |              |

Table 4.3: Suggested accuracy standards for horizontal positioning

#### 4.3.4 Vertical control

For many river survey activities, the vertical positioning is equally or even more critical than the horizontal position, but is, for physical and technical reasons, more intricate. Vertical positioning involves:

- Vertical control (relative to a general, fixed reference level); and
- Depth registration (relative to the surface of the river).

The quality of the vertical control is related to the absolute accuracy of the vertical positioning, while the quality of the depth registration is related to its relative accuracy.

A traditional tool for vertical control is a network of bench marks that have been levelled relative to each other. In Bangladesh, such networks are maintained by SOB, BWDB, and BIWTA. Several other networks or single bench marks exist that have been established for specific purposes in the course of time.

#### 4.3.5 Depth registration

For certain measurements, one part of the measuring error is related to the depth registration. This is obviously the case for depth measurements, but also for any measurements that describe a vertical distribution, such as current-measurements for flow calculations and sediment sampling for sediment transport calculations.

The depth-related error during vertical profiling is highly variable, depending on the vertical variation of the value to be measured. Extreme vertical variations can occur locally for salinity (across the interface of a salt water wedge), and for suspended bed sediments near the riverbed. The case of a salt water wedge is reasonably manageable, because it (normally) appears as a well-defined two-layer system, where the vertical variation within each layer is moderate, and the layer thickness is of a magnitude that can be resolved with an acceptable accuracy. With respect to the near-bed sediment transport, the depth registration is critical, because a major part of the entire transport through a cross-section takes place in a zone, which is characterized by a high vertical concentration gradient (Figure 4.2), and where, at the same time, it is difficult to handle the instruments, due to the proximity of the riverbed. This matter will be discussed in more detail elsewhere in this report.

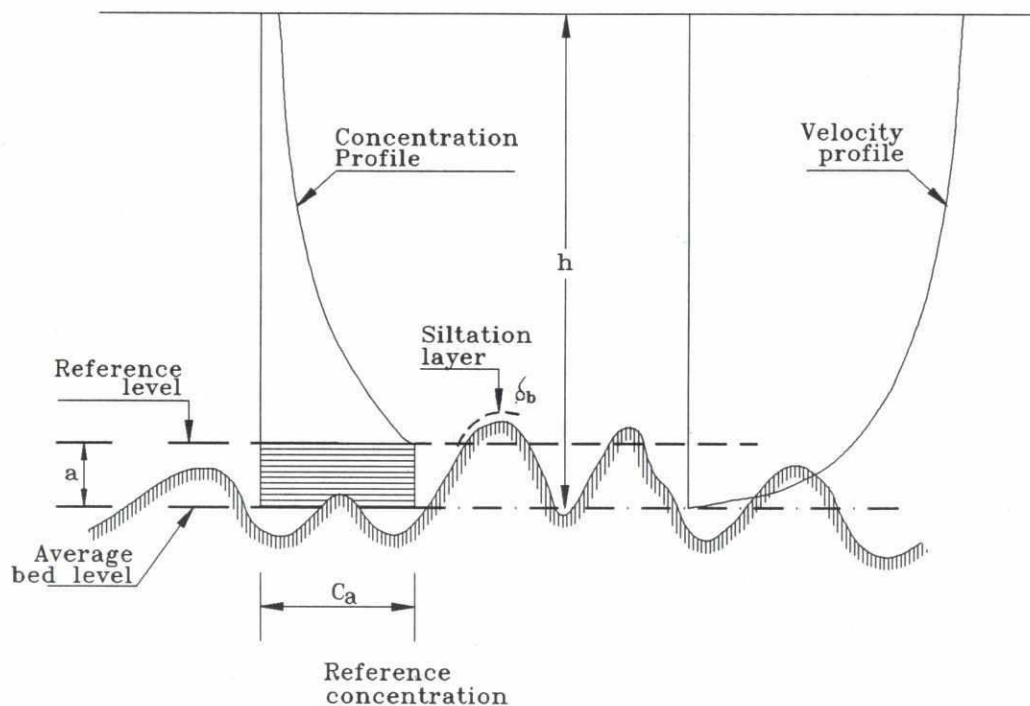


Figure 4.2: Example of a vertical distribution of suspended bed material

Similarly, the depth-related error during vertical current-profiling depends on the regularity of the current-distribution. The depth-related error is small in case of an ideal logarithmic distribution, growing larger (and less known) for an increasingly irregular profile. In the latter (but not the former) case, the depth-related error contribution can be reduced by measuring in a large number of points in each vertical. (In both cases, however, measuring in a fair number of points will reduce the instrument-related error).



## 4.4 Selection of equipment and methods

The present section presents, in general terms, some quality characteristics of survey equipment and methods that relate to routine gauging in large alluvial rivers in general and to the Bangladesh river system in particular.

### 4.4.1 General

The quality of a measuring device is basically related to the quality of the produced data, since data production is the only reason for its application. The data quality may be divided into:

- 1 accuracy;
- 2 data validity; and
- 3 data consistency.

The criteria are related, because the consistency reflects, in a wider sense, the time variation of validity and accuracy deficiencies. For long-term gauging programmes, the data consistency is a particularly important quality characteristic, because the long-term consistency is seldom self-evident for long-term programmes, but is a prerequisite for inter-comparison of long time series. An example of a risk of a consistency deficiency would be if a mechanical instrument be replaced by an electronic one, or if a standard cross-section be relocated.

Each of the quality characteristics (which may in turn be sub-divided, as explained later in the present report) are, to a varying extent, determined by the following determinants:

- Instrument performance; and
- Procedures (survey and data processing).

This can be illustrated by a matrix, as shown in Figure 4.3.

|             | Accuracy             | Validity             | Consistency          |
|-------------|----------------------|----------------------|----------------------|
| Instruments | (error contribution) | (error contribution) | (error contribution) |
| Procedures  | (error contribution) | (error contribution) | (error contribution) |

Figure 4.3: Quality determinants of survey data

The instrument performance comprises:

- accuracy;
- range;
- resolution (time, space, the value itself);
- data collection capacity; and
- other aspects, such as operation and maintenance, risk of breakdown or malfunctioning, costs, etc.

From another point of view, the consistency criterion can be extended by an aim of 'inter-programme compatibility', which can be looked upon as a separate quality aspect. This criterion reflects that instruments and procedures should, as far as possible,

- be standardised within the programme;
- fit with each other (with respect to accuracy, data coverage, resolution, etc.); and
- be retained in the course of time, unless a change is evidently preferable, and, if so, appropriate consideration should be given to consequences of the change.

As one example, a high-capacity current-velocity instrument (like an ADCP) should be applied together with a positioning system with an equally high capacity (like a dynamic DGPS system). The criterion is already inherently covered by the quality aspects mentioned above, but may be emphasised separately, because of its significance in connection with long-term routine gauging.

#### 4.4.2 Instrument errors

An instrument error is a data quality deficiency caused by the applied instrument. All instruments have errors, and the risk of the data quality being affected by instrument errors is inherent in any type of survey work. The error becomes of a practical interest if it interferes with the basic quality criterion of the 'data quality being acceptable relative to the use of the data'.

For practical quality control purposes, a distinction can be made between (1) gradual errors, and (2) stepwise errors. An error that is gradual in time is called a drift. Examples of a gradual error are an unstable gyro compass, a pressure sensor (for depth registration) influenced by the water temperature, or a propeller-type current-meter with increasingly worn bearings. An example of a stepwise error is an alignment error of an ADCP instrument that has been removed from its tubewell for maintenance and reinstalled with a slightly different orientation, or a stage shift registered erroneously by a staff gauge that has been relocated due to bank erosion.

Gradual and stepwise errors occur with both mechanical and electronic instruments, and the quality control should address both types. A gradual error can be reduced by distributing it evenly over the span of its occurrence (in time, or over a range of the value to be measured). A stepwise error can be located in time, as a basis for subsequent correction (or rejection) of the affected part of the data, provided that the control is carried out at regular intervals.

Instrument errors can be identified and remedied in two supplementary ways:

- Calibration (measurements under controlled conditions); and/or
- Validation (comparative, independent measurements in the field)

An appropriate calibration requires that the 'true' value is established with an accuracy that is indeed adequate for detection and compensation of a registration deviation. This statement may be trivial; but it is, for example, not uncommon that a propeller current-meter is calibrated under conditions and by procedures that are inferior relative to the reliability of instrument, whereby a (false) correction can be introduced, which can reduce the accuracy, rather than increase it. Therefore, it is good practice to keep track of calibration efforts, and



to make their implementation transparent, for example if a subsequent calibration, against expectations, should indicate that a former one was not accurate.

(One example is the common (and prudent) practice of regular calibration of a propeller-type current-meter). In fact, such instruments are quite reliable, as long as they are not damaged, and properly maintained. Regular cleaning and changing the bearing oil is important in the rivers of Bangladesh with their high silt content. Their calibration factors should not be changed without careful consideration, and, if they are changed, it should be kept in mind that the possibility remains that the calibration (and not the instrument) was erroneous. The circumstance that the calibration was applied in a laboratory rather than in the river is not in itself sufficient evidence that an observed deviation is true.

#### 4.4.3 Water depth and bed level

The water depth is in most cases measured by an echo sounder, which records the time lag between a transmitted and received sound signal. Also, an ADCP can register the depth (by basically the same technique, but much less accurately).

There are three objectives of this type of measurement:

- Mapping of depths, for navigation charts;
- Mapping of overall river geometry, for integrated process descriptions, such as hydrodynamic modelling; and
- Mapping of bed elevations, for morphological monitoring.

The typical depth resolution of a good echo sounder is less than 1 cm, while the instrument error, when used from a vessel, is estimated at around 5 cm plus or minus 1 percent. This equals, for example, an error of 10 cm at a depth of 5m. Error contributions comprise small, uncontrolled movements of the vessel, including unregistered heave movement and draft variations depending on speed and loading, and uncertainties regarding the sound velocity. The velocity of sound in water depends on the pressure, temperature, and salinity. In rivers, the pressure effect is insignificant (because all depths are moderate). The salinity effect is nil as long as the measurements are made in freshwater, but not otherwise. In shallow freshwater, the sound velocity increases by 0.6 percent (or 6 cm per 10m) if the temperature increases from 25°C to 30°C.

The horizontal resolution along the runline equals the speed of the survey vessel divided by the registration frequency. If, for example, measurements are made every second, and the operational speed is 4 knots, one registration will be made for every 2m of runline. The horizontal resolution perpendicular to the runline depends on the selected line spacing, with a lower limit determined by the positioning accuracy.

A consistency consideration gives as a practical quality criterion that the survey should be able to describe typical true depth variations over the selected length increment (1) along the runline and (2) between adjacent runlines. This criterion indicates the relation between instrument performance, operational speed, and line spacing. However, the criterion is only fully operational if the bed level variation is known. Alternatively, the desired quality can be expressed in terms of runline length increment, line spacing and depth resolution, and the acceptable uncertainties for positioning and depth registration.



#### 4.4.4 Water level

From a practical point of view, considering the normal gauge performance and typical data applications, the critical quality requirements of a water-level recording are:

- 1 the absolute vertical level; and
- 2 the time resolution.

An accurate vertical level reflects the combined demands of inter-station consistency, for example for slope calculations, and of long-term consistency, for any type of time series analysis. The adequacy of the time resolution can be considered (1) for the gauging programme in general, and (2) for periods of flow measurements at the gauging station, intended for stage-discharge correlation.

In comparison with these requirements, the accuracy of the water level registration itself is less critical, with the possible exemption of special scientific purposes. The water level of a large alluvial river is influenced by effects such as local wind stress and atmospheric pressure fluctuations, which can contribute by decimeters of water level, and density variations due to temperature variations and sediment load, which in the Bangladeshi rivers can contribute by centimetres of water level. To the extent that such effects are not recorded and included in the system description, they will appear as noise in the registration; for example, a resolution of a staff gauge of a few cm will not affect the quality of the registration. It would not make sense, for example, to pursue an accuracy of 1 cm without measuring the local wind at the gauging station.

For operational monitoring purposes, real-time water level registration is desired. In the years up to the early 1990s, BWDB (Surface Water Hydrology-II) gradually developed a real-time monitoring network which now comprises around fifty stations, covering a large part of Bangladesh. Recently, in addition to this, a telemetric system with 9 new and 5 old stations has been established with automatic water level registration. A further extension of this network is presently under advisement.

Relevant aspects with respect to site selection for water level gauging are:

**Hydrological validity:** The main objective of a water level station is to collect stage information, which is often used either to establish stage-discharge rating curves, to measure water level slopes, or to reduce bathymetric soundings to a reference datum. Therefore, stations should be located close to the discharge transect when a stage-discharge relationship is desired, and preferably at the centre of a bathymetric sounding area when depth reduction is desired.

**Availability of a fixed structure:** If a stable fixed structure exists near deep water, it is an attractive location. The structure can be for example a bridge pier, a jetty, or support for a tension line.

**Riverbed stability:** A stable riverbed is required for several reasons. First, the stability of the platform depends on the stability of the riverbed on which its foundation is laid. Therefore, the riverbed should not experience excessive erosion, and it should not be so soft as to allow sinking of the platform. Second, the morphological developments should not be such that the

water course changes its location and the sensor becomes isolated in stagnant water. Third, moving bars and chars by erosion and siltation should not be such they can bury the AWLR sensors.

**Flow field intensity:** The site should be away from intensive flow fields for two reasons. First, the structural stability should not be threatened by the lateral loads caused by flow velocities. Second, when a pressure sensor is installed, the flow velocity generates an extra pressure adding an error to the recorded pressure head.

**Accessibility:** The accessibility of the site is especially important in view of the operation and maintenance activities.

**Safety:** The site should be safe against possible theft of equipment, and against impact of vessels caused by anchoring. Hence, it should be located in a safe place away from the navigational fairway. Also, the structure should be protected against loading caused by floating debris.

The time resolution must be adequate for describing commonly occurring stage variations. Hereby, it is noted that the extreme (or at least the high) stage variations are of a particular interest in relation to many data applications, and are also decisive for the required time resolution of the registration. One consideration in this connection is to what extent staff gauges read only during the daytime can provide an adequate quality. This is because a time resolution finer than twelve hours can render traditional staff gauges unpractical, whereby large additional costs can be incurred.

The relationship between stage and discharge is non-linear, with an exponent of between two and three (at Bahadurabad, see the *RSP Special Report 4: 'Stage-discharge relationship for the Jamuna River at Bahadurabad'*). Therefore, inaccuracies incurred by interpolation of the water level are amplified when the data are used for flow estimates by rating curves. Also, this aspect calls for a reasonable time resolution, and particularly so during execution of a flow gauging.

A distinction can be made between non-tidal and tidal stations. As an example of the former category, at Bahadurabad, a stage rise of 0.6 m/day occurs once every second year, and a rise of 0.9 m/day was observed once in a 29 years (in 1974). The maximum fall is about half of the maximum rise. For details, please refer to the *RSP Special Report 4: 'Stage-discharge relationship for the Jamuna River at Bahadurabad'*. Even higher rises can occur at stations that are exposed to flash floods.

At tidal stations, a suitable resolution can be related to the predominant tidal period. The tide in the Bay of Bengal (and the Lower Meghna and the Ganges Delta) are predominantly semi-diurnal (half-daily, with a main period of 12.4 hours). A semi-diurnal tide requires registrations at least every 30 minutes for a resolution.

A different aim of a suitable time resolution is to provide for a certain over-determination, for the purpose of identification of erroneous readings.



#### 4.4.5 Flow

Flow registration is a main objective of any routine river gauging programme, because flow data are required for a variety of important practical purposes. Flow data are applied as time-averaged values, such as mean daily flow, for planning and design purposes, and as 'instantaneous' values for deterministic system descriptions, including calibration of hydrodynamic models.

Flow registration can be made by (1) a velocity-area method, (2) a float tracking method, (3) a traditional moving boat method, and (4) an ADCP-based moving boat method, like the one applied by the RSP. As for methods (dilution, electromagnetic, etc) and accuracies of the methods a considerable library exists: Dickinson 1967, ISO 1979, WMO 1980 and Pelletier 1988, to mention a few. The choice of the method is not always straightforward. Sometimes the river conditions ask for a combination of methods in one gauging station (comprising a main channel, a secondary channel and flow over the flood plain). Sometimes the method is dictated by external conditions (Devroey 1962). In any case, for all the methods it holds that the main quality aspect is the accuracy of the registration.

This accuracy, in turn, is determined by:

- the relative positioning accuracy;
- the vessel orientation and the instrument alignment (for instruments that measure velocity components relative to the vessel);
- the accuracy of the depth registration; and
- the accuracy and validity of the current-velocity registration, which should be considered in the context of the natural variability of the flow.

As compared with these contributions, the significance of the absolute positioning and the time registration is negligible.

The accuracy of the current-velocity registration is related to the instrument performance and the measurement procedure, for example the applied registration period. At non-tidal stations, the validity of the registration depends on the cross-sectional flow distribution and time variation, the number of vertical profiles in the cross-section, and the number of points in the vertical profile. At tidal stations, an additional validity aspect is the time resolution and the time coverage. All these aspects are discussed in detail elsewhere in the present report.

In large alluvial rivers, an additional, secondary quality characteristic is the duration of the flow gauging. A flow registration by a traditional velocity-area method can require a long time. If the water level and the flow change significantly during the gauging, the data processing will become more complex, and additional uncertainties will be introduced by the required combined time and space normalisation of the data. Hereby, measurements at non-tidal stations will become affected by some of the data processing implications that are inherent at tidal stations, but which can be disregarded at non-tidal stations, if the duration of the flow registration is short, as compared with the time scale of flow variations. For the experience in other large alluvial rivers in the world, reference is made to Peters 1981 (Zaire), Richey et al 1986 (Amazon), Mead et al 1983 (Orinoco) and Mead and Stevens 1990 (Mississippi).



This is also why, from an operational point of view, each channel of a braided river should be regarded as a separate entity. The processes may well differ between the channels, for example as reflected by different stage-discharge relationships, but also purely practical reasons apply, such as the time required for making a whole cross-section (as compared with the time required for making each channel), and the time required for transferring from one channel to another. For example, if one channel is measured Tuesday and the next Wednesday, the flow and the stage can shift so much overnight that grouping the data will adversely affect the quality.

Another secondary quality aspect of some practical significance is the need of anchoring. In case of a strong current and a mobile riverbed, anchoring can be risky, or even impossible. Normally, anchoring is recommended in connection with velocity-area gauging.

#### 4.4.6 Suspended sediment transport

Measurement of suspended sediment transport is another traditional routine gauging activity. A variety of methods exists, with widely different characteristics, qualities and shortcomings, as elaborated elsewhere in the present report. A common characteristic for all proven methods is that they involve sampling of a portion of suspended sediments, either in connection with a concentration-velocity method (pumping system, integrating bottle, or Binckley sampler), or a transport method, where the mass of the sediment sample is empirically related to the transport rate (Delft bottle). In all cases, the total transport through the cross-section is calculated by an area integration of point or line measurements of the transport rate.

For coarse suspended sediments (or suspended bed material), but not for suspended fines (or wash load), the vertical variation is pronounced, but also, the lateral variation and the time variation are of a practical interest, both in relation to the use of the data and in relation to the measurements, for example for determining the cross-section-average transport. Also, the grain-size distribution as well as the mineralogical and physical properties of the sediments, are of significant practical interest.

As with flow measurements, the main quality criterion of suspended sediment sampling is the accuracy, which comprises:

- the relative positioning accuracy (spacing between verticals);
- the accuracy of the depth registration; and
- the validity of the sampling, relative to a range of grain sizes or settling velocities.
- the sampling accuracy in view of the natural spatial and temporal variability of the transport.

As compared with these quality characteristics, the absolute positioning, the time registration, and the laboratory analysis of collected samples are of secondary significance, because of the relative performance of available techniques.

Spatial variability includes for instance the changing variation of concentration and transport along a measuring vertical, the changes over the various bedforms, overloading due to local erosion (sand plumes). These bedforms and local scour have short time scales, which also implies important temporal variations. These dynamic processes are dominant in big alluvial sandbed rivers and therefore important for the selection of sediment measuring devices and methods (exposure time).

Secondary quality aspects are (1) the time required for covering a full cross-section, and (2) whether anchoring is required or not. For velocity-concentration methods, the quality of the velocity measurement is of equal significance as the quality of the sediment sampling. Moreover, it is assumed that the speed of the particles equals the flow velocity. This may be true for the fine sediment fraction, but it is questionable for the coarse sediments (Peters 1994).

Sediment transport gauging at tidal stations is particularly difficult. Here, the validity criterion is extended to comprise not only the instantaneous transport, but also the net transport, and a special need is required for an adequate time resolution.

A new, not yet fully proven technique is mapping of the cross-sectional distribution of suspended sediments by ADCP backscatter intensity. The technique was applied as a supplementary method by the RSP. The quality determinants of this technique deviate from the sampling techniques. The validity criterion is particularly important, because the backscatter intensity signal is an under-specified function of grain size and concentration. Another inherent quality characteristic is the depth range, which imposes a practical restriction, since the method cannot cover the lowest 4 to 10% of the water column, depending on the type of ADCP applied.

#### **4.4.7 Near-bed transport**

The near-bed transport of suspended material represents a substantial part of the bed material transport through a cross-section, and, apart from that, is of high morphological significance due to the proximity of the riverbed. At the same time, it is difficult to gauge, be it by direct methods, involving collection of samples, or by indirect methods based on monitoring of the progression of bed forms.

Near the riverbed, both the transport rate and the sediment properties can deviate from what can be predicted from distributions higher in the water column. Both velocity gradients and concentration gradients are steep, and often the flow as well as the lateral concentration distribution are irregular.

Such irregularities affect the validity of the measurements, for example when relating sediment concentrations to flow velocities for calculating the transport rate by a concentration-velocity method. Due to the finite (and deviating) time and space resolution of instruments and samplers, the sediment particles can appear as if they were moving with a velocity that is different from the current-velocity. A different implication is that the flow irregularities impede the handling and the position control of instruments and samplers. If a device is applied that is resting on the riverbed, it can be exposed to scour. ADCP backscatter registration does not cover the lowermost part of the water column.

Another difficulty is that near-bed sediment registrations can potentially be affected by the anchor of the vessel, i.e. if the anchor is located immediately upstream of the measuring point, so that the unnatural resuspension of bed material caused by its movements can affect the registration. Also, the measuring device itself is likely to bring sediments into suspension, and a risk exists that such sediments can occasionally contaminate the measurements.



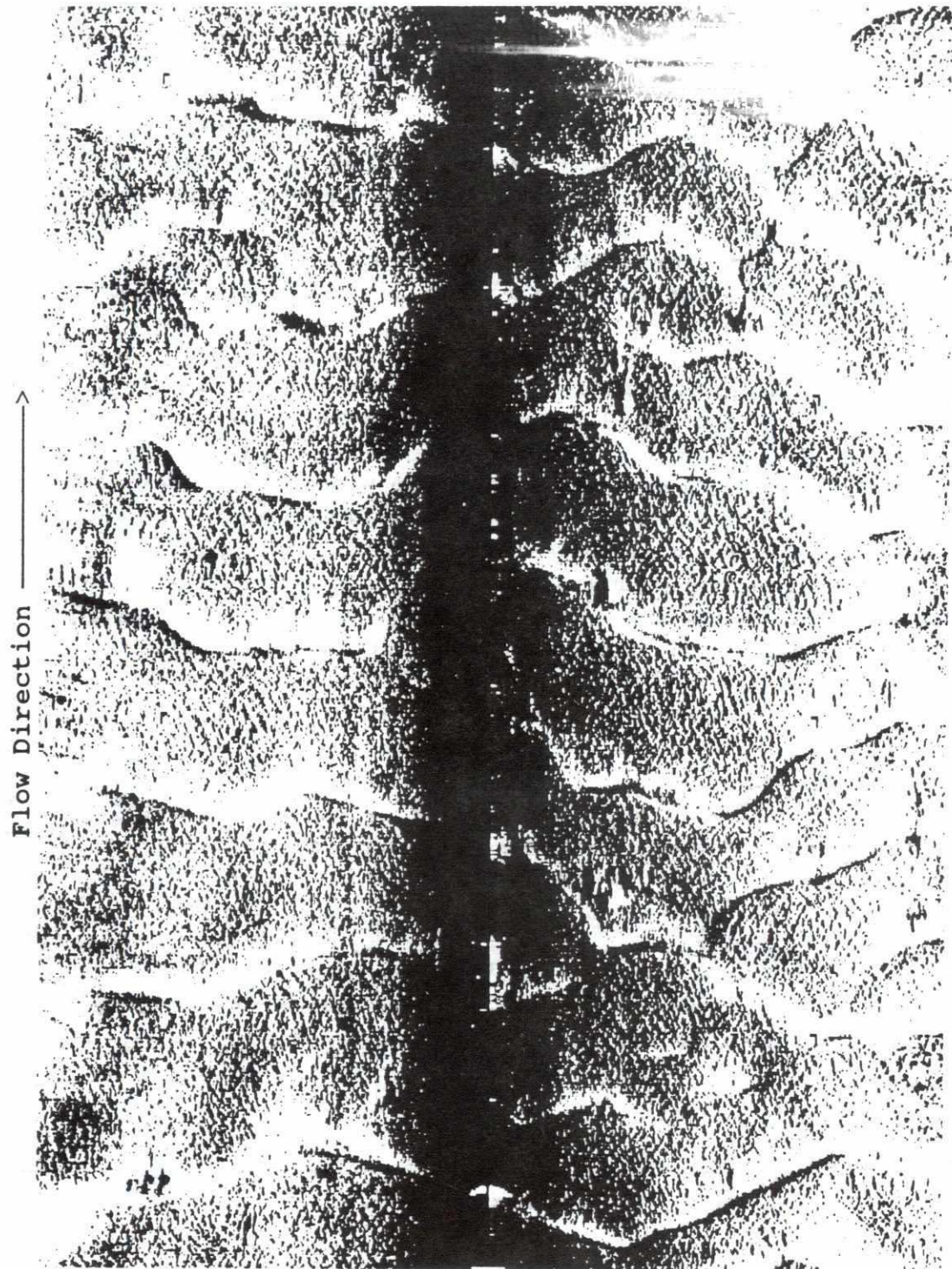
The critical quality aspects are:

- the accuracy of the depth registration relative to the riverbed;
- the validity of the sampling itself; and
- the accuracy of the sampling in view of the natural spatial and temporal variability of the near-bed transport, and
- the consistency (time, height above the riverbed, space resolution, averaging period) between the sampling and the associated current-velocity registration (in case of velocity-concentration measurements).

The validity relates to a specific range of grain sizes or settling velocities, but also, in particular, to the registered transport relative to its near-bed distribution. The quality aspects are highly influenced by the performance of the instrument or sampling device.

The validity of the sampling is critically related to the vertical sampling coverage and resolution relative to the riverbed. Even if the sampling level above the riverbed can be controlled accurately, for example at 5 cm or 15 cm, this is no safeguard that the data describe the near-bed transport with the desired quality. Figure 4.4 shows an example of a bed-form mapping illustrating small moving megaripples with a height of about 0.5 m, so clearly higher than the height of the near-bed transport zone. The length of these ripples is about 10 metres long (being of the same order as the water depth and the length of the survey boat). Under such conditions, which are characteristic of many parts of the Bangladesh rivers, the validity of any single-point or single-profile near-bed transport measurement remains a matter of concern. With large-scale dunes (i.e. with length of more than five times the water depth) positioning of the sampler on the higher part of the dune (Peters 1971) or at a number of places over the length of the dune (Van Rijn 1986) becomes possible. Improved positioning gives better accuracy but is more time consuming.





Scale 1:500

Figure 4.4: Megagripples mapped by side scan sonar (Example, Bahadurabad, December 1993).  
The figure shows an area of 70 m by 100 m



A different validity aspect is related to the patchiness of the near-bed transport, resulting in steep gradients or even stepwise changes in time and space, caused by bed forms or related to sediment plumes. These physical processes have to be taken into account especially to develop an appropriate gauging strategy, thus reducing the data coverage in space and time.

For concentration-velocity methods, the quality of the velocity registration is as equally decisive as the quality of the sediment concentration determination. Here, the important aspect is the consistency between the two measurements (rather than the accuracy of the current-velocity registration). The consistency can be supported by (1) applying different methods that supplement each other, partly compensating specific shortcomings, and (2) applying an appropriate averaging (over time and space), which filters out a part of the small-scale irregularities.

Indirect determination of near-bed transport can be done by tracking of sand dunes, although the 'true' transport rate determined in this way is different from the one determined by sampling on or above the riverbed. Critical quality aspects are (1) the time and space resolution, which should be adequate for describing the dimensions and the progression of the sand waves; and (2) the accuracy of the transport calculation, which is subject to a number of assumptions, such as that the transport be one-dimensional (to the extent that this is not true, the system becomes underspecified); and (3) the accuracy of the bed-load computation as both bed load and suspended load are causing the bedform propagation. Already Hubbel (1964) describes that sediment transport (bed load) is not one-to-one related to the propagation of dunes. This was explained using a picture of an idealized dune field moving through a cross-section ( $x - x'$ ), see Figure 4.5.

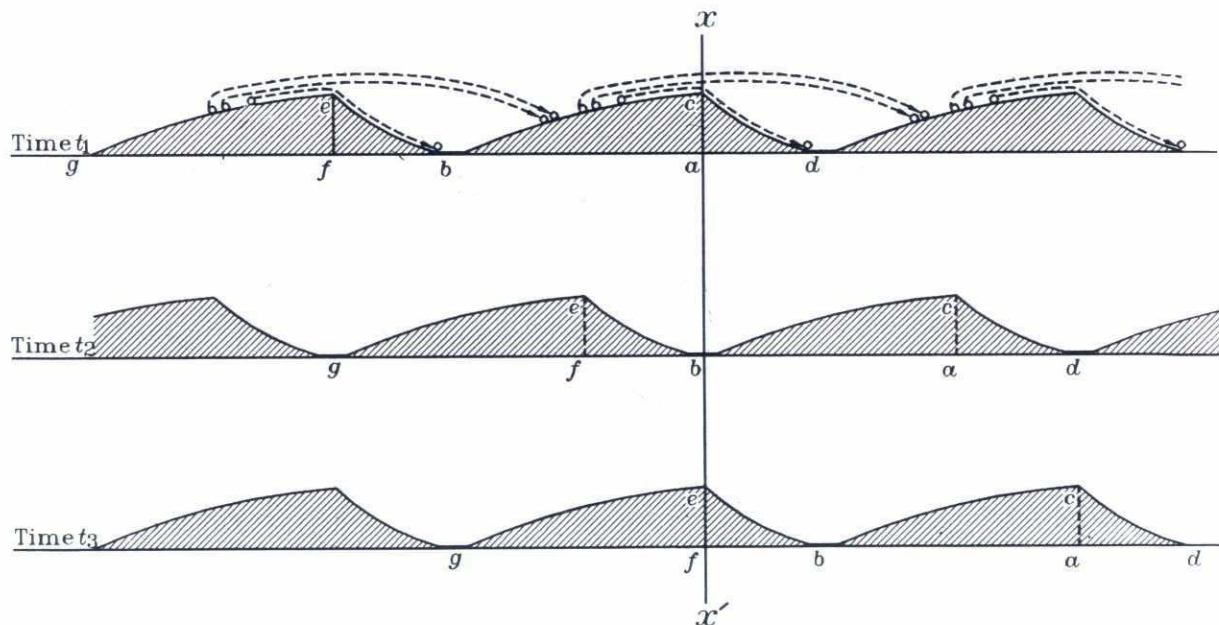


Figure 4.5 Idealized diagram of dune movement (from Hubbel, 1964)

It is assumed that only one of every three particles eroded from a dune is deposited onto the downstream side of the same dune and the other two move on to the next dune.

The main problem how bed load relates to dune propagation is described by others, e.g. Peters (1971). The problem was also addressed in the initial study programme of the RSP, but was not taken up as dune tracking was not selected for routine measurements of bed load: see further under subsection 5.4.3.

#### 4.4.8 Sediment properties

A distinction can be made between:

- grain size and settling velocity characteristics; and
- mineralogical and other physical properties.

The former category is a traditional gauging activity, which was part of the RSP routine gauging programme. A variety of techniques exist for the sampling, and procedures for the laboratory tests are standardised and well proven. The main quality criterion is the validity of the sample, relative to the general characteristics of suspended, near-bed, or bed sediments as they occur in the survey area, and as they vary in time and space. For suspended sediments, another key aspect is the validity in relation to the sediment transport, whether this be determined by a velocity-concentration method or by a direct transport method. This is because, for practical reasons, the grain size distribution of a collected sample can very well deviate from the true distribution. The accuracy of the laboratory analysis is a separate quality aspect, which, although secondary (with respect to influencing the overall quality) may be of some practical significance, particularly for settling velocity analyses.

A pilot study conducted by the RSP indicates a high practical significance of further information about sediment properties (in addition to the grain size or settling velocity characteristics), such as mineralogical composition, density, and shape. The study is reported in the *RSP Special Report 14: 'Mineralogical and physical properties of river sediments'*.

No operational quality criteria can be suggested for this gauging activity, which has so far not been executed on a routine basis. Rather, the general objective applies, that the data quality should be acceptable as compared with the intended use of the data.

It may be speculated, though, that the validity of the sample location is of particular significance because variations may occur over small distances, depending on the flow pattern and the bed forms.

Another quality aspect to be kept in mind is the consistency (and the transparency) of the laboratory analyses, because mineralogical and physical properties (for example the particle shape) can be determined by a variety of methods that are not fully standardized, and the performance of which are not always proven or understood in every detail.

For methods of sediment-size analysis reference is made to Figure 4.6 (Van Rijn 1986)





| Instrument                  |            |       | Bed material sample |      | Suspended sediment samples |      | Required sample size | Inaccuracy |
|-----------------------------|------------|-------|---------------------|------|----------------------------|------|----------------------|------------|
|                             |            |       | silt                | sand | gravel                     | silt |                      |            |
| Photo camera                |            |       |                     |      | *                          |      | —                    |            |
| sieves                      | dry        |       |                     |      | *                          | *    | 1-1000 gr            | 10%        |
|                             | wet        |       | *                   | *    |                            | *    | 0.1-10 gr            | 10%        |
| pipet withdrawal tube       | laboratory |       | *                   |      |                            |      | 0.5-3 litre          | 10%        |
|                             | field      |       |                     |      | *                          |      | 3 litre              | 20%        |
| bottom withdrawal tube      | laboratory |       | *                   |      |                            |      | 2 litre              | 10%        |
|                             | field      |       |                     |      | *                          |      | 2 litre              | 20%        |
| accumulation tubes          | VAT        |       |                     | *    | *                          | *    | 1-10 gr              | 10%        |
|                             | MAT        |       |                     | *    | *                          | *    | 1-10 gr              | 5%         |
|                             | BAT        | small | *                   |      |                            |      | 0.5 litre            | 5%         |
|                             |            | large |                     | *    | *                          |      | 0.1-10 gr            | 5%         |
| Coulter counter             |            |       | *                   | *    |                            | *    | 0.5 litre            | 10%        |
| (in-situ) laser diffraction |            |       | *                   | *    |                            | *    | 0.01-1 gr            | 10%        |
| (in-situ) video camera      |            |       | *                   | *    |                            | *    | 0.01-1 gr            | 10%        |

Figure 4.6 Instruments for sediment-size analysis (from Van Rijn, 1986)

In general, an important consideration is which part of the analysis can be done in the field and which part has to be sent to the laboratory. An important factor herewith is the possible reduction of sample numbers and/or volumes in view of transport. For the methods used in the RSP please refer to Section 5.6.

## 4.5 Measuring network

The design of the measuring network should in principle address (1) the river system itself, and (2) the objectives of the gauging programme. The former is "a given", and is 'known', whereas the latter can vary in time and is only partly known (in the case of long term general gauging programmes). Therefore, it makes sense to address the former part of the decision-basis, while considering the objectives in less specific, but still operational terms: description of the time and space variation in the river system of the water level, flow, sediment transport, and morphology.

Different requirements are imposed by different categories of data applications. An adequate coverage of the flood season stage and discharge is necessary for purposes related to floods, hydraulic design, and hydraulic and morphological impact studies. Applications within water resources planning, and environmental monitoring and impact assessment, are more dependent on lean season flow data. Stations that are suitably located for gauging of high stages and high flow are not necessarily ideal for lean season gauging, and vice versa.

A basic quality of a routine gauging network is to accommodate a broad range of national data requirements. Therefore, for any conceivable resource allocation, the network will inherently appear as a compromise between the conflicting aims of coverage and density.



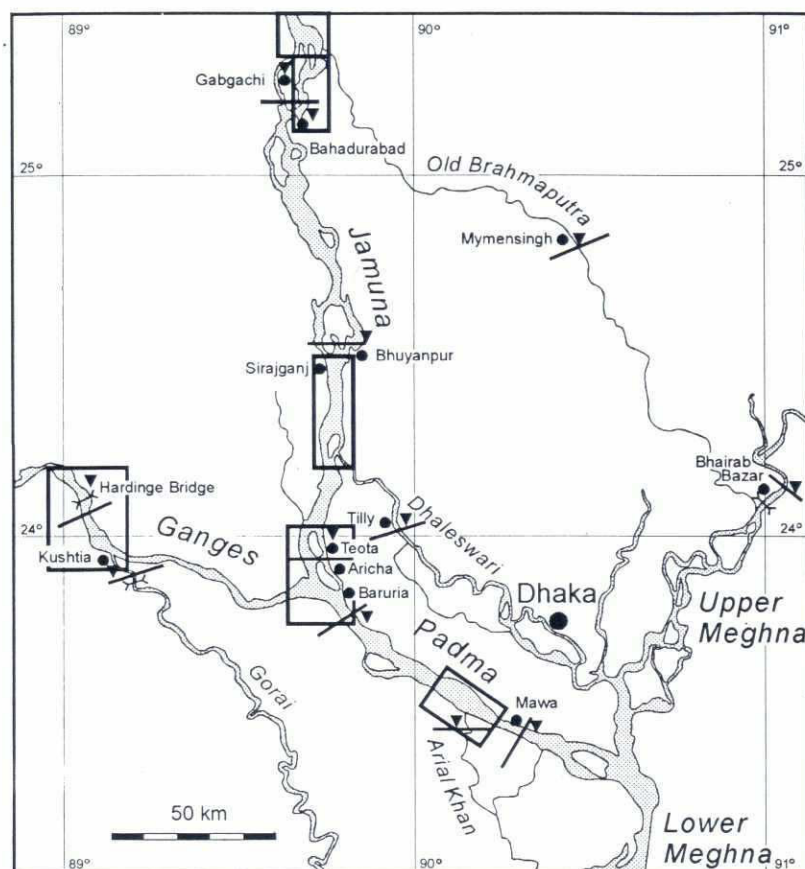
This is one reason why different, coordinated networks are usually applied for different gauging activities, such as staff gauges, AWLRs, flow gauging, sediment transport gauging, waterways monitoring, morphological monitoring, and environmental monitoring. The general quality of the entire gauging programme can be observed by combining the different gauging programmes in such a way that they support each other. As an example, a combined network can comprise a large number of staff gauges, a few AWLRs, and a fair number of standard cross-sections for flow and sediment transport gauging, the stations being located so that good relations can be derived between stage, discharge and sediment transport.

Another network design aspect is whether the monitoring programme appears as a predominantly empirical (field data oriented) approach, or a predominantly deterministic (process description oriented) approach. This is not only a matter of taste and tradition, but depends highly on both the river system itself and on the use of the data. A simple system, where processes are well understood and well described, will tend to favour a deterministic monitoring programme, which could be based on a few stations with a large spacing. A complex system, where different processes interact, will enhance the data demand, so that a higher network density is required for a similar level of knowledge. From the point of view of the use of the data, planning and design applications can well be accommodated by a fully empirical data basis, while impact assessment, flood forecasting, and any other applications that involve real-time operation or prediction will indicate a process-oriented description.

In connection with a deterministic description of a river system, it is noted that if inflows and outflows between (flow gauging) transects are higher than the uncertainty of the flow recording at the gauging transect, the system is empirically underspecified (with respect to flow measurements); otherwise, the system is overspecified. Overspecification increases the general data quality and provides a possibility for identification (and, possibly, correction) of inconsistencies.

The network for water-level recording and routine gauging of flow and sediments as outlined in the Bill of Quantities of the RSP is presented in the following figure. For further details please refer to Section 6.2.





File: stu17101.cdr

- ▼ Automatic water level recorder (AWLR)
- Transect for routine gauging of flow and sediment transport
- Bathymetric survey area

Figure 4.7 Bangladesh river system with RSP measuring sites

## 4.6 Measuring frequency

Similarly, the measuring frequency must be considered with a combined background of the dynamics of the river system and the intended use of the data produced. In addition to natural seasonal and short-term variations, the frequency can be selected with a view to possible regulation within the river system. An adequate quality is often related to:

- the resolution of the general time variation (e.g. for calculation of monthly discharge volumes);
- an appropriate description of extreme stages and peak flows; and
- an appropriate overall resource allocation between components of the gauging programme.

The time resolution of the gauging programme as such is jointly determined by the gauging frequencies of the different components, such as staff gauge readings (maybe several times per day) and flow and sediment transport gauging (maybe several times per month).

The peak flow gauging is critical with respect to time resolution. This is because the predominant physical processes are partly different from the ones prevailing during low and medium flow. Peak flow regime can involve overbank flow, different routing of the discharge,





backwater effects, and an active interaction between hydrodynamic and morphological processes causing abrupt stage shifts.

Therefore, statistical extrapolation or deterministic prediction are often unreliable and always unproven if based on low and medium flow data. Also, the time scale of flow and stage variation will be smaller during high flows, which will affect the data accuracy even if medium and high flow conditions are consistent. An adequate quality requires a small time increment of the flood season routine gauging, or possibly even a targeted programme that adjusts to the actual flow conditions. In Bangladesh, the basis for such targeting could be the real-time monitoring of stages done by FFWC in the flood season.

Tidal effects and salinity effects, occurring in the lean season, are other examples that the relative significance of the processes can deviate from one season to another.

## **4.7 Survey operation**

### **4.7.1 Selection of survey techniques**

Survey operation in large alluvial rivers is affected by time and space variations of the physical environment, and to do measurements in an appropriate way in the dry season imposes requirements that deviate from the ones in the flood season. The related data quality implication is that procedures must either adapt to the flow regime, or, if fully standardised, must be selected as some sort of a compromise between partly deviating aims.

For example, a sediment sampler that is otherwise a good choice may be less suited under extreme current-velocities. Another example is relative positioning by ADCP bottom tracking, which normally provides a good accuracy, but which is not possible in case of a strong current over a fine sandy riverbed. This shortcoming should not prevent the use of bottom tracking whenever possible, but necessitates the availability of an alternative (DGPS positioning) when not.

Techniques and routines can be changed for several other good reasons, one trivial example being that some equipment is worn down and needs to be replaced. Sometimes, a new technique becomes available in the course of the general technological development, such as GPS positioning replacing Decca positioning.

For such reasons, the consistency and the transparency of the field work methodology become important data quality characteristics. Shifting between different survey techniques can improve the data quality, but there is always a consistency cost involved. Not only the techniques, but also the rules for the choice between them should be defined and described, and the origin of the produced data should be communicated to the data user.

### **4.7.2 Logistics**

Logistical aspects of survey operation comprise access to the station, staff transport and accommodation, handling of samples, data transmission, supply of fuel and other consumables, and communication. Such aspects are highly cost-related, and could in theory be fully countered, if abundant resources were available; for example by using helicopter transport between stations, or simply by the availability of ample staff and survey facilities. In practice, however, logistical constraints can be decisive to the data quality, for example if they interfere with a desired time and space coverage of the survey programme.

A separate quality effect of logistical constraints is the inherent time lag between the measurements are made and the data are available to the user. This aspect is obviously critical in connection with real-time monitoring (of floods or flow), but is also of a high practical interest in connection with general routine gauging. For example, unusual or extreme recordings can be verified, only if they are realised within a short time.

From a purely economic line of thought, the total duration of the data flow represents a loss of interest that can be related to the costs of the survey operation in the same period. The value of a survey does not materialise until the results can be used for their intended purpose.

#### 4.7.3 Operational quality control

An important feature of the survey routine is the operational (or on-line) quality control that takes place while the measurements are made. The important objective of this first stage of the entire data quality control is to identify obviously erroneous or missing measurements, so that they can be replaced immediately.

A consistent positioning can be verified by graphical route tracking, manual or (preferably) computer-based, which will clearly highlight the inevitable occasional abrupt off-sets, and which can (partly) verify the data coverage during bathymetric surveys. Electronic data signals can be checked on-line by automatic routines, that for example label and report out-of-range values, stepwise shifts, repeated constant values, and other doubtful or obviously wrong registrations. Measurements that do not involve electronic data registration can be checked manually, for example by plotting a vertical current-speed distribution.

## 5 Evaluation of surveys: RSP experience

During the short time span of the River Survey Project from June 1992 to June 1996, the RSP deployed several hydraulic and sediment measuring instruments in the Bangladesh rivers. Figure 5.1 shows the instruments and facilities used by the RSP. This chapter gives an evaluation of the performance of the vessels, instruments and methods in the routine operations and some special motivated measurements. A significant part also includes evaluation of the BWDB gauging methodology based on some joint measurements.

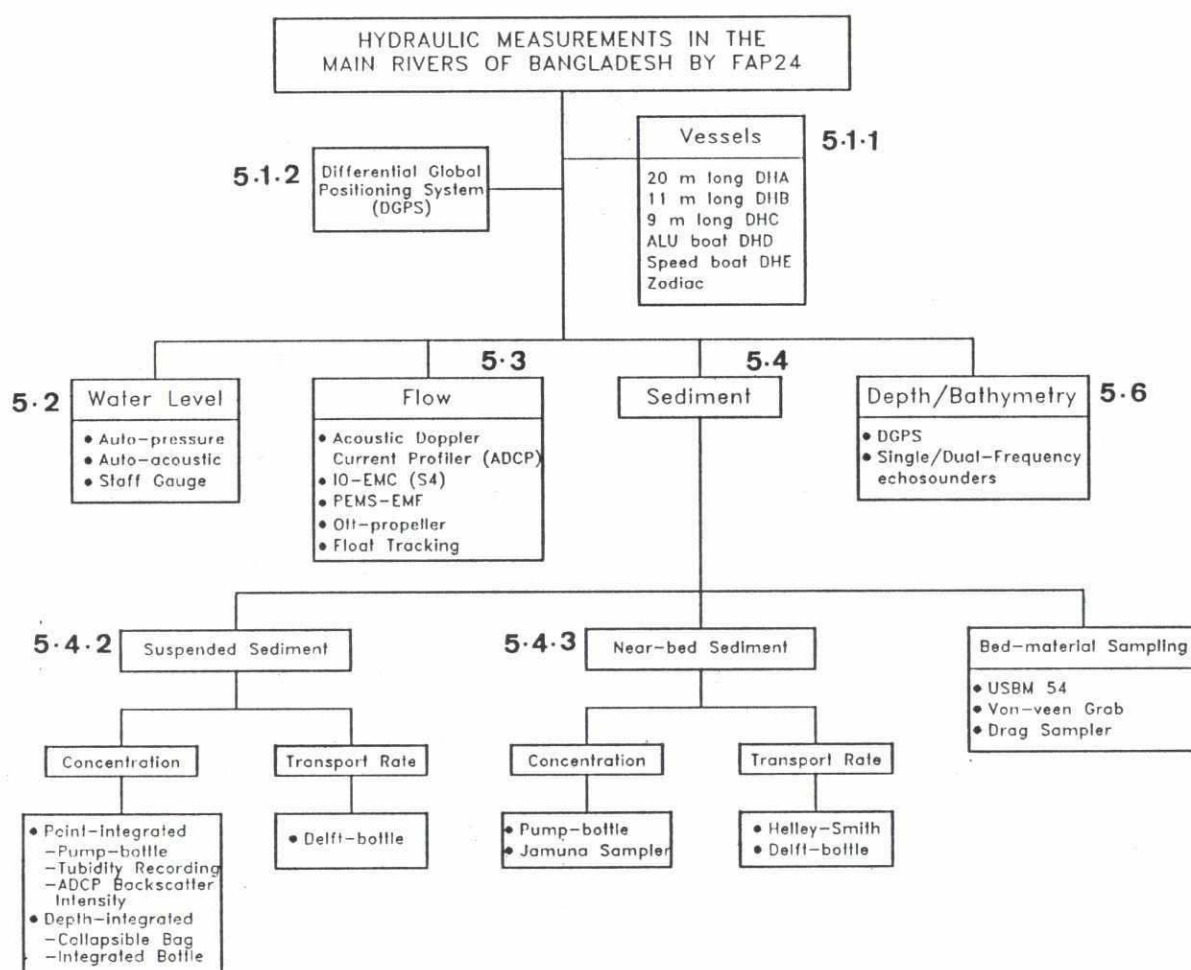


Figure 5.1 Facilities and hydraulic instruments deployed by the RSP in Bangladesh Rivers.  
(note: Figures besides frames refer to the pertaining sections in this chapter)



## 5.1 Survey vessels and positioning

### 5.1.1 Survey vessels

The largest RSP survey vessel was the DHA. It had a draft of 1.5 m, a screw-type propulsion system, crew-sleeping accommodations, wheel-house space for data-logging and on-line data processing, deck space, and winches and davits for deploying instruments and sampling. After installing different survey instruments, it became a well-equipped vessel able to carry out discharge measurements, bathymetric surveys, and sediment measurements. The installed survey instruments included:

- 300 kHz ADCP
- Trimble 300E DGPST receiver
- ELAC LAZ 4420 dual frequency echo sounder
- S4 electromagnetic current-meter with a winch (for vertical profiling), deployed at the aft of the vessel
- EMF electromagnetic sensor for surface current registration, deployed at the bow of the vessel
- various communication facilities

The DHA was equipped for the project with a steering machine, a computerized navigation system and a joystick control to facilitate accurate manoeuvring through turbulent flow fields. The system appeared reliable and steering characteristics of the vessel were excellent. At the beginning of the project the anchoring system was replaced by a heavy duty system which enabled anchoring in high flows. During the project hardly any damage occurred to the system. This was achieved by developing special manoeuvring procedures while requiring skills to retrieve the anchor when buried by passing bedforms.

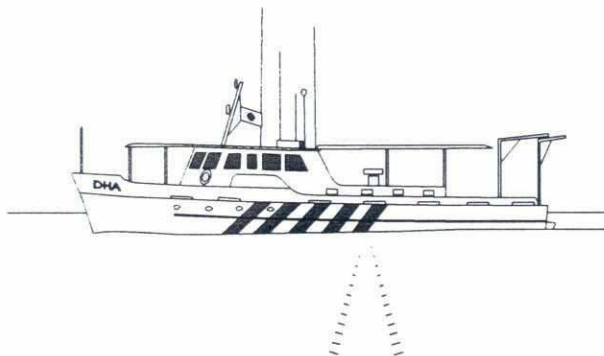


Figure 5.2: RSP survey vessel DHA

The DHB was a flat-bottomed vessel with a draft of 1.0m and a Z-drive propulsion system that was procured during Phase II of the project. Deck-space and other facilities were limited on this vessel. It was equipped with the following similar capacities as DHA:

- 600 kHz ADCP
- Navtrack DGPS receiver
- SIMRAD EA 300 P single frequency echo sounder
- S4 electrom. current-meter for vertical profiling, deployed at the aft of the vessel
- EMF electrom. sensor for surface current registration, deployed at the bow of the vessel.
- different communication facilities

The DHB bow was equipped with a ramp (which is usual for workboats and landing crafts) enabling easy access to the vessel. However, the flat bow made the vessel not suitable for negotiating waves. Moreover, it was found that with these bow shapes combined with shallow draft, a lot of air passes underneath the hull which made the use of inbuilt sounding transducers not a success. The DHB performed according to expectations.

The DHC was a catamaran, selected for its particular suitability in shallow water. It was equipped with a Navtrack DGPS receiver, a SIMRAD single frequency echo sounder, and various communication hardware. The catamaran shape made the vessel a nice, stable working platform with ample space. The small load capacity, however, hampered the operation (for instance, only limited bunkering possible). The low-lying platform makes the vessel less suited for working in waves. The inboard/outboard propulsion with so-called z-drives was sensitive and broke down occasionally. The DHD and DHE were equipped, when needed, with portable positioning systems, single frequency echo sounders, and propeller-type current-meters for measuring discharge in shallow water and for carrying out bathymetric surveys.

### 5.1.2 Positioning

Traditionally, Bangladesh agencies use two types of positioning systems for hydraulic and hydrographic measurements. BIWTA and BWDB use Decca navigation system for bathymetric surveys. For transect discharge gauging, BWDB use sextants. The nominal accuracy of the Decca navigation system is 100m, but in practice, this accuracy is not maintained everywhere. The system is not well maintained, and the applied maps are old.

The accuracy of sextant system depends on the observer and conditions in the field. Sextant sighting is usually effective on smaller channels and rivers when measuring short distances by observing angles. The absolute positioning is rendered difficult because maps are old, and the rivers have in many places shifted their location. On large rivers, such as the Jamuna, the system is not accurate.

The RSP introduced the DGPS, a system that offers an accuracy range of  $\pm 3\text{m}$  in static mode. The DGPS system applied by the RSP determined the position relative to shore-based reference stations that monitored and modulated the GPS signals to the desired accuracy level and transmitted the corrections to the vessel.

Applying a DGPS system for absolute positioning requires that the absolute position of the shore-based reference station is known. But, no such stations existed prior to this study. In addition, the projection system used a WGS84 ellipsoid, which differs from the Everest ellipsoid used by Bangladesh. Therefore, the initial test phase of the project comprised establishment of reference stations by land surveying. Also, a conversion procedure had to be established for conversion of WGS84 coordinates to the BTM system (which is based on the Everest ellipsoid). The reference stations were installed at Fulchari near Bahadurabad, Sirajganj, Aricha, Hardinge Bridge, and Mawa.

The system performed fully according to expectations. The operation and maintenance of the reference stations, especially the power supply appeared to be the weakest component of the system.



## 5.2 Water levels and slopes

### 5.2.1 Staff gauges

The advantage of the staff gauge is the limited installation and maintenance costs. Furthermore, its principle is simple and easily understood by people lacking technical education. The reliability of the results strongly depends on the human factor. Data may get lost due to human failure (illness and negligence) and get corrupted by human errors (misreading, bad time-keeping, shift errors and non-recording). For verification purposes, multiple staff gauges can be operated at the same station. Besides, a secondary station can, at an extra cost, be set up nearby to be operated by an independent gauge reader. The distance to such secondary station must be small enough to ensure correlation between the readings, and large enough to avoid cooperation between the gauge readers.

### 5.2.2 Recording gauges

A recording gauge station consists of three basic components: (1) a mounting platform or frame, (2) a sensor, and (3) a data recorder. The data recorder operates with the help of a time element and a gauge height element. Recordings are either on paper (analogue) or by binary mode memory (digital).

Recording gauges are usually named according to their sensors. The usual types are:

- float-well type
- bubble type custom built platforms; and
- pressure cell type
- acoustic type

In a float-well type, the water stage is sensed by a float in a stilling well. The float sensor consists of a tape or a cable passing over a pulley. The sensor floats in a stilling well and is attached to one end of the cable, and a counter-weight is attached to the other end. The float follows the rise and fall of the water level and drives the pulley which is connected to a level recorder. The float measures basically the water level relative to a fixed platform. The water level in the well must, of course, be equal to that in the river. Therefore, the connection between the well and the river, through well perforations or an intake pipe, may not get clogged by plant growth or settling of sediments.

No velocity head errors may be present, requiring a well-designed stilling-well perforation pattern or an intake pipe nozzle. These aspects put even more limiting requirements to the site selection than for the staff gauge station. Also, the stilling-well tube must be vertical, stiff and stable, making the system rather costly. For the operation of the mechanical model, no electronic instruments are required. This might be an advantage as personnel with proper knowledge and experience in electronics may be difficult to find. A disadvantage is the vulnerability of mechanical instruments, in particular to wear and corrosion.

A gas purge system that transmits the pressure head of water to a manometer is known as a bubble gauge. A gas, usually nitrogen, is supplied through a tube, and bubbles freely into the stream through an orifice at a fixed elevation in the stream. The gas pressure in the tube



is equal to the piezometric head on the bubble orifice at any stage height. More details can be found in WMO (1980).

The submerged pressure sensor, mounted at a fixed level, converts pressure to a proportional electrical signal. The pressure at any depth consists of the barometric air-pressure acting on the water surface and of the hydrostatic water pressure, which is proportional to the immersion depth and to the specific weight of the water. As the pressure sensor has no moving parts, and wave-induced pressure fluctuations can be filtered by the electronics or the software, there is no need to install it in a stilling-well.

A pressure sensor is virtually a no-flow system; the deflection of the membrane is extremely small. This has the advantage that the sensor, if buried due to unexpected sedimentation, will still yield accurate results, provided that the ground water flow-induced pressure gradients are small. Of course, the sensor membrane must be protected by a filter to avoid grain pressures in addition to the water pressure. Vented gauge-type sensors directly compensate for barometric pressure variations.

If the simpler (and cheaper) absolute pressure sensors are used, a second pressure sensor must be incorporated in each system. This affects accuracy, costs and power requirements, but makes the sensor cable simpler. Alternatively, one central barometric pressure reading can be made for the whole network. In that case, the air pressure compensation is carried out afterwards, in the office, and a direct validation check upon retrieval in the field becomes more difficult.

For data collection, the pressure sensor is connected to a data logger. This logger can be equipped with a removable data memory or a communication interface for data retrieval. Worldwide application of many different data loggers in combination with a pressure sensor has proven the reliability of such equipment. Installation of the system requires a structural element to attach the sensor to, a guidance for the sensor cable, and a structure to which the electronics and power supply case can be fitted.

A recent development is the use of low power acoustic sensors for hydrological applications. One advantage over most other systems is that no parts are immersed into the water, and that water density variations have no influence. However, due to a dependency on the speed of sound in air, and inherent sensor properties, the basic accuracy is somewhat limited. Under extreme conditions, rainfall may cause data loss due to reflections from multiple rain drops. The recording can be affected by surface waves to an extent that depends on the distance to the water surface (the footprint of the acoustic beam increases with distance), the wave length, and the wave height.

Installation of the acoustic sensor requires a support for the sensor, which gives it an unobstructed 'view' of the water surface. In particular at low water, when the distance to the water surface can be as large as 10m, the sensor should be protruding at least 2m beyond any structural element. Bridges and space frames of power masts are convenient structures to host the acoustic water level measuring system. Standard protection measures for the associated electrical cable and electronics is adequate. The electronics and the logger software are largely the same as for the pressure sensor system, which is an advantage from a logistic and operational point of view.

Considering the advantages and disadvantages of the different AWLR types, and based on experience in Bangladesh, the pressure cell and acoustic type AWLRs were selected for the RSP stations. In both cases, a data-logger is used for level-recording. It comes mounted in a polyester box enclosure, together with two battery packs and interlocking electronics on a printed circuit board.

### 5.2.3 RSP gauging

Based on various considerations, and as specified in the Bill of Quantities (Tables 4.1.b and 5.1.b), the RSP established a network of 11 gauging stations, covering the discharge measurement transects and the bathymetric survey sites. The selected strategy was:

- Pressure cell sensors mounted on custom-built platforms;
- Acoustic sensors mounted on available fixed structures or custom-built platforms; and
- Staff gauges at each station to supplement the auto-recorders.

At each AWLR station, two staff gauges were also operated. Reading of the river stage by AWLRs was done at 30 min interval. The staff gauges were read at three hour intervals, starting at 06 h and ending at 18 h. Hence, five readings were recorded daily, during daylight only. Below, a brief description is given of the different sensors selected.

| Number | River System       | River           | Station                      | Sensor              |
|--------|--------------------|-----------------|------------------------------|---------------------|
| 1L     | Brahmaputra-Jamuna | Jamuna          | Bahadurabad                  | Pressure            |
| 1R     |                    | Jamuna          | Gabgachi                     | Pressure & Acoustic |
| 2      |                    | Jamuna          | Sirajganj/Bhuapur            | Pressure            |
| 3      |                    | Jamuna          | Teota (Aricha)               | Pressure            |
| 4      |                    | Old Brahmaputra | Mymensingh                   | Acoustic            |
| 5      |                    | Dhaleswari      | Tilly                        | Pressure            |
| 6      | Ganges             | Ganges          | Hardinge Bridge              | Acoustic            |
| 7      |                    | Gorai           | Kushtia Railway Bridge       | Acoustic            |
| 8      | Padma              | Padma           | Baruria                      | Pressure            |
| 9      |                    | Padma           | Mawa                         | Pressure            |
| 10     |                    | Arial Khan      | Offtake                      | Pressure            |
| 11     | Meghna             | Upper Meghna    | Bhairab Bazar Railway Bridge | Acoustic            |

Table 5.1: AWLR gauge sites of the RSP.

For the locations of these stations please refer to Figure 4.7



#### 5.2.4 Pressure sensor instruments

The RSP applied a pressure gauge developed by DELFT HYDRAULICS. In this gauge, an Ott-Heel pressure transducer is used, which measures against atmospheric pressure. This implies that the difference between water + air pressure on the wet side and barometric air-pressure at the vented reference side of the sensor is measured, making the instrument inherently insensitive to air pressure variations. The reference pressure is supplied through an air-vent tube in the sensor cable. Extension of this type of sensor cable is complicated because also the air-vent tube has to be extended without leakage or blocking. To avoid condensation in the air-vent tube or in the sensor, the air entering the tube must be dry, which is achieved by applying a silicagel desiccant cartridge. Additionally, the access from the atmosphere to the air-vent tube is provided with a teflon filter pellet which allows air to pass but blocks humidity.

A tube, integrated in the connection cable, conveys the air pressure to the transducer. The sensor cable enters into the air-vent box, from where connections are made to the data logger. The pressure transducer may be mounted at a fixed elevation in two ways, either fixed to a structure, or lowered in a tube. In either case, the transducer should be pointing vertically downwards with the cable running upwards. The stage record is influenced by the flow velocity, which introduces an additional, dynamic pressure head. At 1 m/s, the contribution is about 0.05 m, and at 2 m/s it is about 0.20 m.

#### 5.2.5 Acoustic sensor instruments

The acoustic sensor measures its distance to the water surface. It is mounted on a frame at some distance from the bridge pier to obtain an obstruction-free sound path to the water surface and back. The distance is determined by the beam angle of the sound and the lowest water level. Multiplication of the turnaround time of the sound burst by the speed of sound gives the distance of travel, which is divided by 2 to get the range.

In air, the speed of sound varies strongly with temperature. Therefore, a simultaneous temperature measurement must be made. The temperature sensor is mounted inside a radiation shield to avoid radiation effects, especially due to heating by the sun and radiation loss at night. Stratification of the air mass between the sensor and the water surface, and inaccuracies in the temperature measurements, have some degrading effect on the accuracy of the water-level measurement. This effect is smaller during the flood season, as measured ranges are much shorter then. The temperature-induced error is about 1.7 mm/°C per meter of range. Over-estimation of the temperature yields an under-estimation of the water level. The applicable range of the applied acoustic sensor was between 0.6m and about 10m.

The cantilever frame for the acoustic sensor, used at most stations, basically consists of a horizontal extension pipe with a downward running vertical pipe attached at the far end. At the lowest end of the vertical pipe, the acoustic and temperature sensors are mounted. The structure is designed so that the acoustic sensor is at a distance of about 3m from the bridge pier. The height of the sensor is adjusted so that the sensor is at a level of no more than 10m above the lowest water level during the lean season and well above the highest water level to be expected in the monsoon. Where both specifications cannot be simultaneously met, the instrument is installed at monsoon level. However, where possible, a bi-level support was



made, which is operated in a low position during the lean season and in a high position during the monsoon.

### 5.2.6 Gauge site selection

A thorough site selection procedure for water-level stations is a prerequisite. First of all, the site must be adequate from the hydrological point of view. In addition, particularly for long-term data collection, the reach of the river at the measuring station must be stable, in order to avoid the risk of loss of data and equipment due to local erosion or sedimentation. For routine data collection, the instrument must be easily accessible during both the monsoon and the lean season. Whatever data collection method is selected, in any case a staff gauge is to be installed. Hence, there must be a village nearby, where a suitable gauge reader can be found. As any reading is to be reduced to some adopted datum, it should be an advantage if a properly established bench mark, connected to the national level system, could be found within a reasonable distance.

The rivers of Bangladesh are unconfined and freely migrating with continuous modification of their banks and chars by erosion and siltation. This implies that any structure built for the purpose of protection can either be vulnerable to erosion or to siltation. Neither of these aspects is desirable, because, while erosion may endanger the structural stability, the siltation may hinder low-stage reading. The followings aspects are important in this regard:

- Free river migration implies that a structure can either be scoured, eroded and collapsed, or dried up during the low river stage. Erosion and scour hazards demand that the structure should have a deep and secured foundation. However, construction of such a foundation increases the cost to several times the purchasing cost of an AWLR. Such a costly foundation cannot always be justified. Moreover, the siltation problem may make a structure redundant anyway after some time. In case of free river migration, the life time of a structure can be quite short, the time-length depending on the choice of the location.
- Because of the high seasonality of the Bangladesh rivers, the low-draft country boats change their navigation routes so as to follow the shortest possible way, often along the bank. This makes structures along the banks vulnerable to collision by vessels. As described below, this actually happened in some cases for the RSP structures. The changing nature of the navigation routes makes it tricky to choose a location.

For example, consider RSP's selection of a gauge location at Bahadurabad. To choose a suitable location here is difficult, considering the fact that the Jamuna is known as a braided river with rapid channel migration and sand bar movement, and that there are no fixed structures in the vicinity that can be used to mount the equipment on.

From earlier field visits and FAP studies (amongst others by FAP21/22), a number of locations were preliminarily selected. Based on such information, alternative potential sites were identified and visited several times. Table 5.2 shows the advantages and disadvantages of the different locations. In the end, sites 1 and 5 were selected.

| Location                                                | Advantages                                                                                          | Disadvantages                                                                                                    |
|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 1. Jamuna left bank 500m upstream from Bahadurabad Ghat | 1. Near the discharge transect<br>2. Relatively stable bankline<br>3. BWDB staff gauge is installed | 1. An unstable char propagating downstream                                                                       |
| 2. Old Brahmaputra River Offtake                        | 1. Data could be useful for offtake studies                                                         | 1. Far from the discharge transect<br>2. Relatively unstable area                                                |
| 3. Manos Regulator at Balashi Ghat                      | 1. Fixed wing walls of the regulator exist<br>2. Kamarjani BWDB staff gauge is located nearby       | 1. Far from the discharge transect<br>2. Despite the existence of the wing wall, the bankline is heavily eroding |
| 4. Fulchari Railway Ghat                                | 1. At the discharge transect                                                                        | 1. Bankline eroding despite efforts to stabilize it                                                              |
| 5. Char Gabgachi                                        | 1. At the discharge transect                                                                        | 1. Slightly eroding bankline                                                                                     |

Table 5.2: Advantages and disadvantages of different locations near Bahadurabad

But also in other locations, site selection appeared difficult and not very successful. The reason is that the main criteria notably moderate flow, morphologically stable, and no navigation are in general rather contradictory. When it was found that the quality of the staff gauge readings was considerably better during low flow than during high flows, a strategy was developed of a combined use of staff gauges and AWLR, accepting that the AWLR falls dry during the lower river stages. By accepting this strategy, considerably better and safer locations could be selected.

### 5.2.7 AWLR platforms

Based on the earlier experience with platform design, a design concept finally evolved. In principle, the design was the same for all the platforms. An example is shown in Figure 5.3. The platforms consist of three basic units:

- (1) The tower itself founded into the ground;
- (2) The sensor fixing arrangements; and
- (3) The data-logger housing.

The tower consisted of the following basic elements:

- A triangular frame with three 100 mm GI pipe legs driven 10-20m into the ground
- About seven angular frames equally spaced and braced to the GI pipe legs;
- Cross-bracing angles;
- A ladder; and
- A platform on the top with railing.

The sensor fixing arrangements consisted of the following (see Figure 5.4):

- A 76 mm GI pipe attached to one of the legs;
- A 70 mm PVC placed inside the GI pipe;
- The pressure sensor is attached to the PVC pipe.

The data-logger housing is made up of the following:

- A cubical box 1x1x1 m;
- A perforated bottom plate ;
- Heat insulation inside the box containing the cockosheet and air-gap;
- A steel frame for data logger installation;
- Ventilation pipes;
- A solid brass rod to prevent lightning damage; and
- An antenna fixation arrangement.

At locations where railway bridges could be used, individual designs were made for each bridge pier according to its configuration. Figure 5.5 shows as an example the fixing arrangements for the acoustic sensor at Hardinge Bridge.



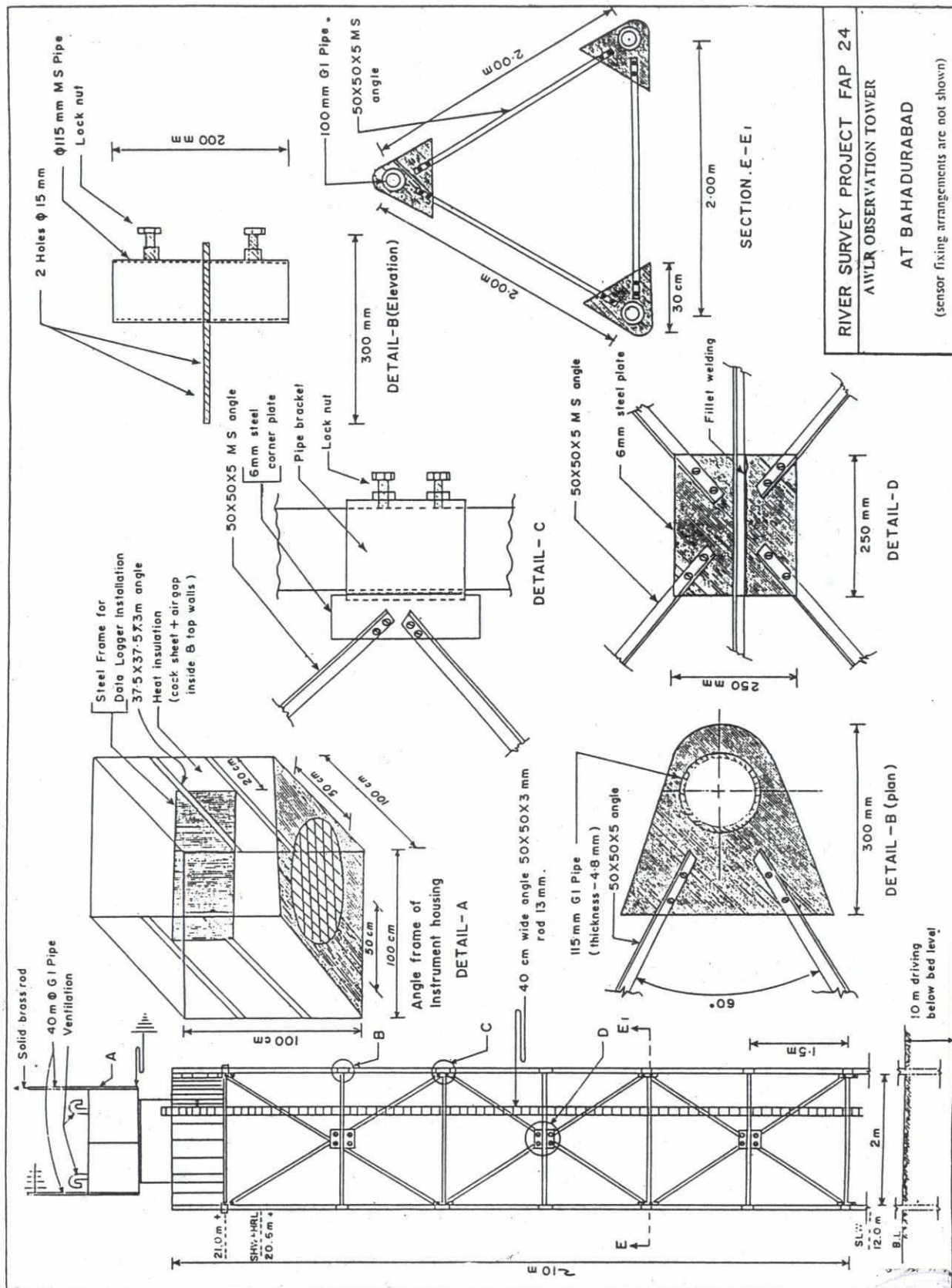


Figure 5.3: AWLR platform at Bahadurabad

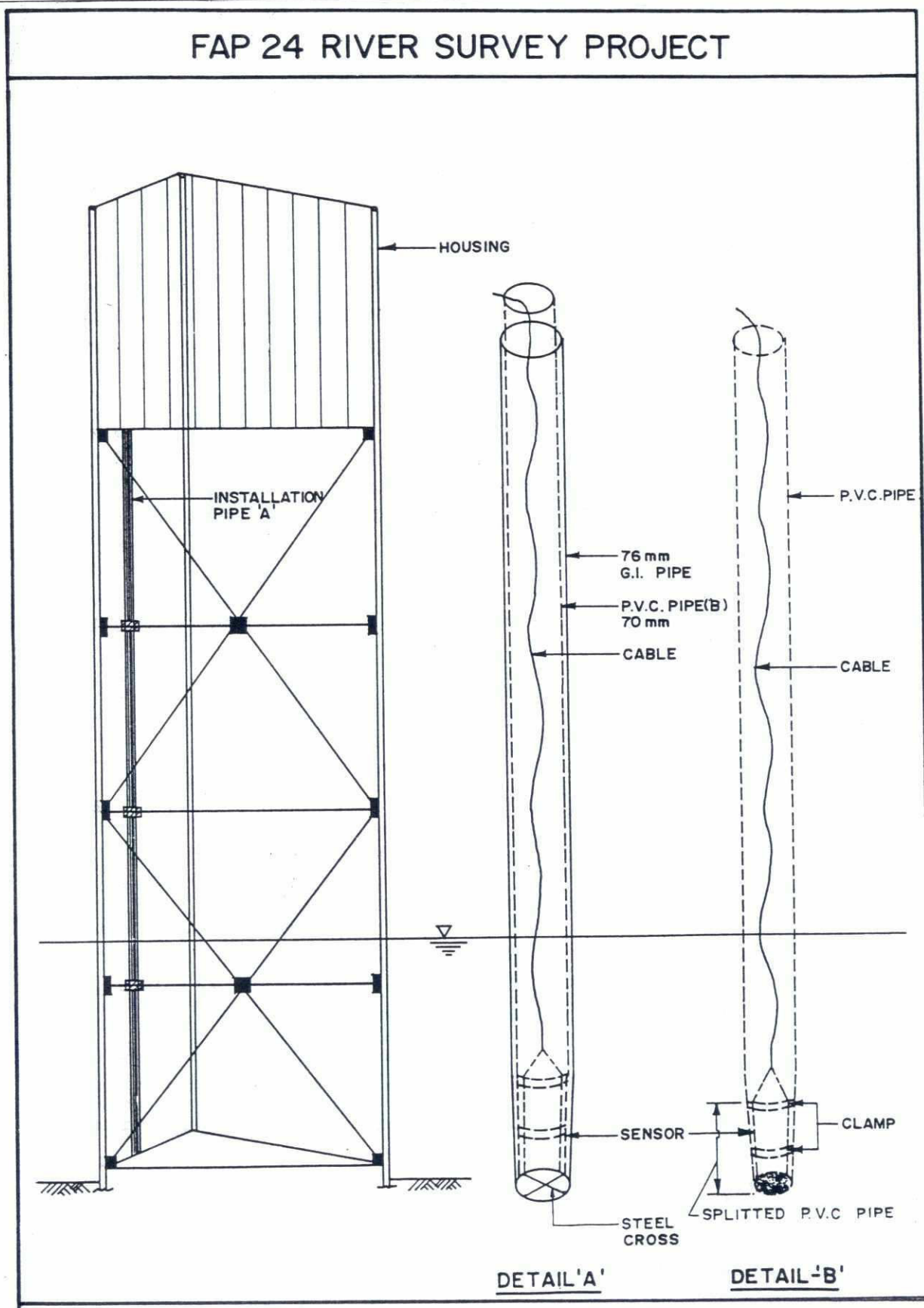


Figure 5.4: Pressure sensor fixing arrangement at AWLR towers

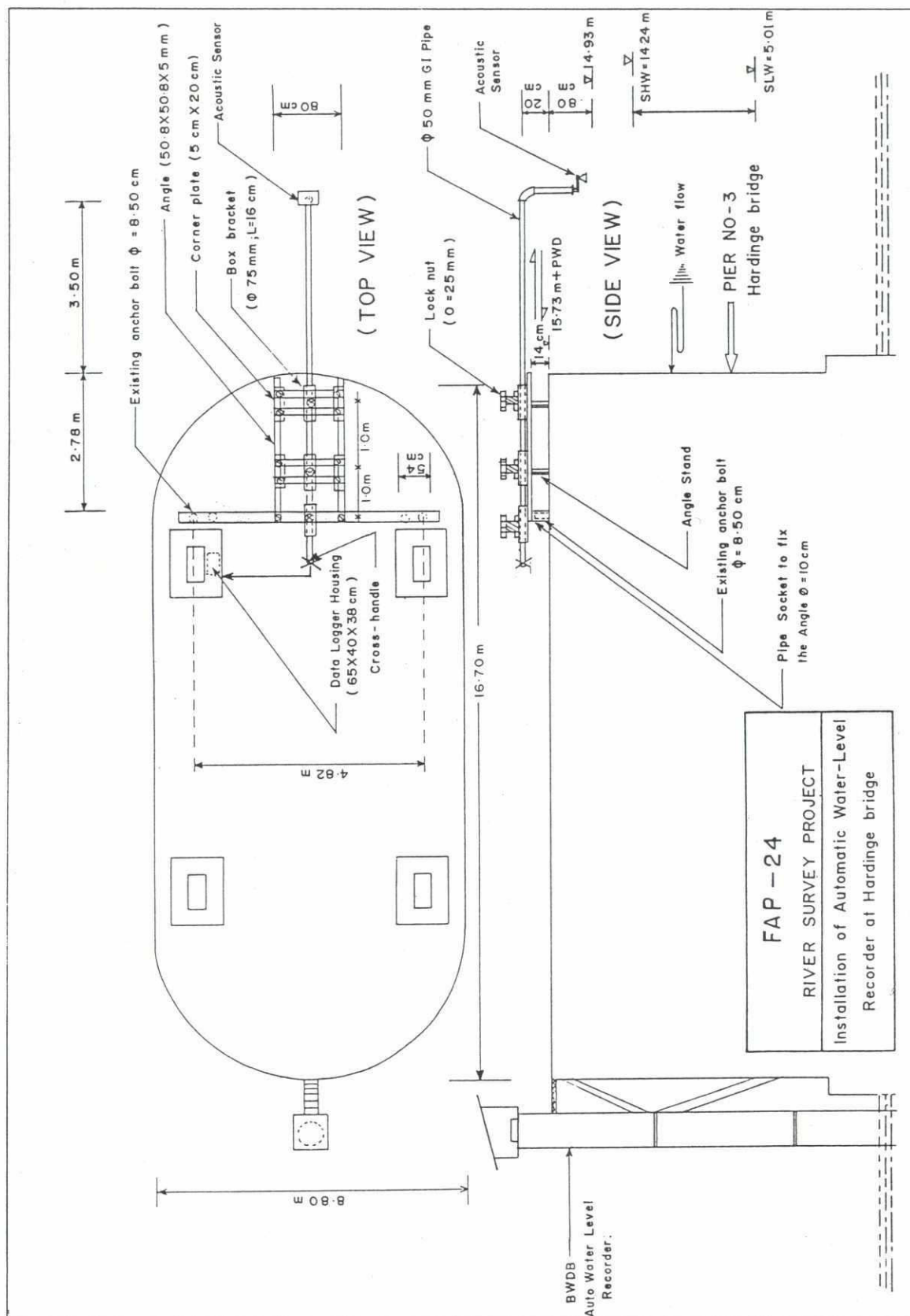


Figure 5.5: Mounting of acoustic sensor at Hardinge Bridge



The success of the platforms designed by the RSP was mixed. In the course of the project, some platforms collapsed. The reasons of platform failure were:

- Navigation hazards: During high river stage, motorised and sailing country boats follow a navigation route close to the river bank. These boats are hardly equipped with adequate navigational aids. Therefore, the platforms which are most often located near the bank are vulnerable to their impacts, especially at night. The RSP experience shows that this can often be the most important factor.
- Secondly, morphological development, either scour or siltation, is an important factor. In the short period of observation, primarily between 1994 and 1995, the morphological factor did not play a major role in the collapsing of structures. Only the tower at Bhuapur appeared to have collapsed due to scour.
- Experience shows that construction defects (or fraudulent construction) can lead to the failure. For example, it was observed that it was difficult to connect two pipes (the full thread should be covered in the joining), which lead to a failure (such as the one shown in Figure 5.6). However, in all the cases, the impacts of boats triggered the failure.



Figure 5.6: Collapsed AWLR platform at Baruria

### 5.2.8 Operation and maintenance

The data return and the quality of a water level collection network strongly depend on operational procedures. Frequent service visits by dedicated staff are essential. In particular, the staff gauge zero-level should be connected to the local bench mark at each visit and with great care, as this is one of the keys for data quality assurance and validation.

All RSP stations had one or more gauge readers. These aides have to be properly instructed, trained and guided. Careful annotation procedures as well as proper time keeping, including timely gauge reading, must be frequently reviewed. In order to ensure smooth operation and maintenance of AWLRs, guards/gauge readers are employed at each station. Staff gauges are installed at each station and are read every three hours from 6:00 in the morning to 18:00 in the evening. The purpose of staff gauge installation at AWLR stations, and reading of the same during daytime hours, is to maintain a double check against data loss due to any mishap such as structural failure of platform structure, failure due to sudden erosion and collapse of structure, theft of data-logger, etc. The daytime guard, therefore, has the additional responsibility of taking staff gauge readings every three hours.

### 5.2.9 Service procedures

Regular service visits to the stations of the water level data collection network were made for a number of reasons:

- to carry out technical maintenance work;
- to retrieve collected data; and
- for reference purposes, i.e., to establish and update the required references of the readings in level and time.

The routine maintenance work comprised:

- Data off-loading (monthly);
- Check of system clock and sensor function (monthly);
- Battery voltage check and replacement of battery packs (if needed);
- Inspection of sensor fittings, housing and cables;
- Change of dehumidifier in the ventilation box; and
- Occasional maintenance painting of the housing and housing support structure.



In the lean season the interval between such visits was about a month or less. During the monsoon the intervals were shorter and strongly dependent upon river behaviour. Actually, the stations were visited as often as available manpower, transport facilities and local conditions permitted.

At rising and falling water levels, the staff gauges were repositioned accordingly, anticipating the likely change in level. At some AWLR stations, the sensor was moved to another elevation to avoid outranging.

For each visit, a *Service Report* was made, giving the details of the technical status of the station, its functioning, and any particulars of interest regarding data yield, quality, continuity, etc.



### 5.2.10 Levelling of staff gauges

To allow for a quick and accurate levelling, temporary bench marks (TBMs) were established at all stations in an early stage of the project and were connected to the national datum. These TBMs were made from an abutment of a railway bridge, a step of a stone staircase, a pipe hammered into the ground, etc.

The levelling of the staff gauges was executed with great care, going from the local temporary bench mark to the staff gauges and back again. Results were immediately calculated and checked for correctness. Also, the apparent elevation of the AWLR sensor was calculated and compared with values of previous visits, if available.

### 5.2.11 Data collection from the gauge reader

In connection with the data collection, the data of both staff gauges must be screened and compared with each other for differences in water level, as some types of error may be detected by a simple comparison, such as outliers and level jumps. Level drifts and similarly varying differences cannot and must not be corrected without additional information.

### 5.2.12 Data validation in the field

The validity of the collected data was assessed in a number of steps. Upon retrieval in the field, the data were visualized in a graphical representation of the readings versus time. Distinct errors such as sensor over-range, recording of error codes, and spikes in the data could then be recognized. This allowed the operator to take immediate action on site, if technically possible.

In order to monitor the stability in time of the staff gauges and the AWLR station, the elevations of both staff gauges were connected to a bench mark by levelling. Furthermore, the staff gauges and the AWLR were read simultaneously. The staff gauge reading, translated to water level relative to datum, can be mapped on the AWLR reading. Thus, the zero level of the AWLR sensor can be established. In the field, the calculated reference levels of staff gauges and AWLR were compared with similar values from previous visits. In the event of an apparent difference, adequate measures could be taken immediately.

### 5.2.13 Data management

From each station, readings were available from two sources: AWLRs and staff gauges. These records were to a great extent independent. The common factor was their connection to the local bench mark. It is of great importance that this connection is made with great precision and care.

The validation process was formalized in strict procedures. In general terms, it was executed as follows: staff gauge and AWLR data were retrieved from their dedicated files. From a third file, the reference file, reference levels of staff gauge and AWLR were read, as well as the pre-set margin of acceptance of the differences between staff gauge and AWLR readings. Based upon various criteria, the valid water level was, under application of the criteria, selected from the AWLR and staff gauge data.



The selection criteria comprised:

- the physical limits;
- the time window; and
- the difference between AWLR registrations and staff gauge readings.

The procedures related to these criteria are described in *RSP Special Report 2: 'Water level gauging'*.

#### 5.2.14 Evaluation

A non-recording staff gauge is the most widely used around the world. Strong and weak arguments in favour and against this method are shown in Table 5.3. Main arguments in favour of it are as follows: (1) the gauge can be cheaply and easily installed without *a priori* investigation or knowledge of the stream course, (2) it can be easily shifted, (3) it is easy to get a gauge reader and (4) the gauge needs hardly any maintenance. Main arguments against it are as follows: (1) reliable data cannot always be obtained because of incorrect reading, interruptions and bad time-keeping (dependent on gauge-reader watch), and (2) only day time data can be obtained. Despite its limitations in accuracy and reliability, the gauge will continue to be used either as an independent unit or as a support to an automatic gauge.

Also, Table 5.3 shows an evaluation of the pressure and acoustic sensors used by the RSP. Evidently, the mode of observations by the two sensors is an improvement as compared with the float-well type system, the main reason being their direct compliance with modern digital computing. With a good operation and maintenance programme, and a trained crew, the sensor performance was found to be working satisfactorily.

## WATER-LEVEL GAUGING BY THE RSP – EVALUATION OF OPTIONS

| Gauging                                 | Reliability                                   | 1) Platform stability                               | Shifting                           | Environmental Sensitivity                              | Density of Records                            | Susceptibility to Interruptions   | Time-keeping                    | Operation and Maintenance                         | 4) Price (ECU) |
|-----------------------------------------|-----------------------------------------------|-----------------------------------------------------|------------------------------------|--------------------------------------------------------|-----------------------------------------------|-----------------------------------|---------------------------------|---------------------------------------------------|----------------|
| Non-recording staff gauge               | Not very reliable (dependent on gauge reader) | No platform, but supports are vulnerable to erosion | Can be shifted easily              | Can work everywhere                                    | Sparse day time records                       | Very susceptible to interruptions | Dependent on gauge reader watch | Hardly any maintenance except occasional shifting | 100            |
| 5) Auto pressure sensor and data logger | Reliability proven                            | Vulnerable to platform failure                      | Platforms cannot be shifted easily | Vulnerable to siltation, humidity and air vent failure | Desired dense digital records can be obtained | 2) usually no interruptions occur | Reliable electronic clock       | Needs battery changes and data offloading         | 4000           |
| 5) Auto acoustic sensor and data logger | Reliability proven                            | Vulnerable to platform failure                      | Platforms cannot be shifted easily | Vulnerable to temperature and humidity                 | Desired dense digital records can be obtained | 2) usually no interruptions occur | Reliable electronic clock       | Needs battery changes and data offloading         | 7000           |
| 3) Automatic float-well type            | Reliable analogue data                        | Vulnerable to platform failure                      | Platforms cannot be shifted easily | Vulnerable to siltation of inlets                      | Continuous record (digitization necessary)    | 2) usually no interruptions occur | Reliable clock                  | Needs battery, paper and pen changes              | 3000           |

- 1) Use of a fixed structure in all cases can avoid the use of a platform
- 2) Unless there are failures of platforms, batteries or electronics, there are no interruptions.
- 3) This type of is considered because BWDB and BIWTA use them.
- 4) This estimate does not include platform construction and installation costs, the RSP platform costs about 4000 ECU
- 5) Data can be transmitted on-line to the survey vessel by installing a transmitter at an additional cost.

Table 5.3: Evaluation of water-level gauging options

## 5.3 Gauging of flow

### 5.3.1 Flow gauging at non-tidal stations

The RSP applied two supplementary methods for routine flow gauging:

- The so-called ADCP-EMF moving boat method, used in main channels; and
- The velocity-area method, used in small channels, and in connection with sediment transport measurements by the concentration-velocity method.

In addition, drogue tracking was applied for mapping of surface current-patterns.

Below is an outline of the techniques applied, together with a summary of experience about their performance and suitability.

### 5.3.2 The ADCP-EMF moving boat method

The moving boat discharge gauging method used by the RSP is referred to as the '*ADCP-EMF moving boat method*'. This is to distinguish it from the conventional moving boat method (where a moving boat measures velocity at one measuring point at a fixed depth across the transect, first in the one direction and afterwards in the opposite one). The ADCP-EMF method used by RSP samples the 'entire' vertical current-profile as the boat sails one time across the channel (except for the lowermost part, as described below).

The principle of the method is shown in Figure 5.7. The components of the gauging routine are listed in Table 5.4.

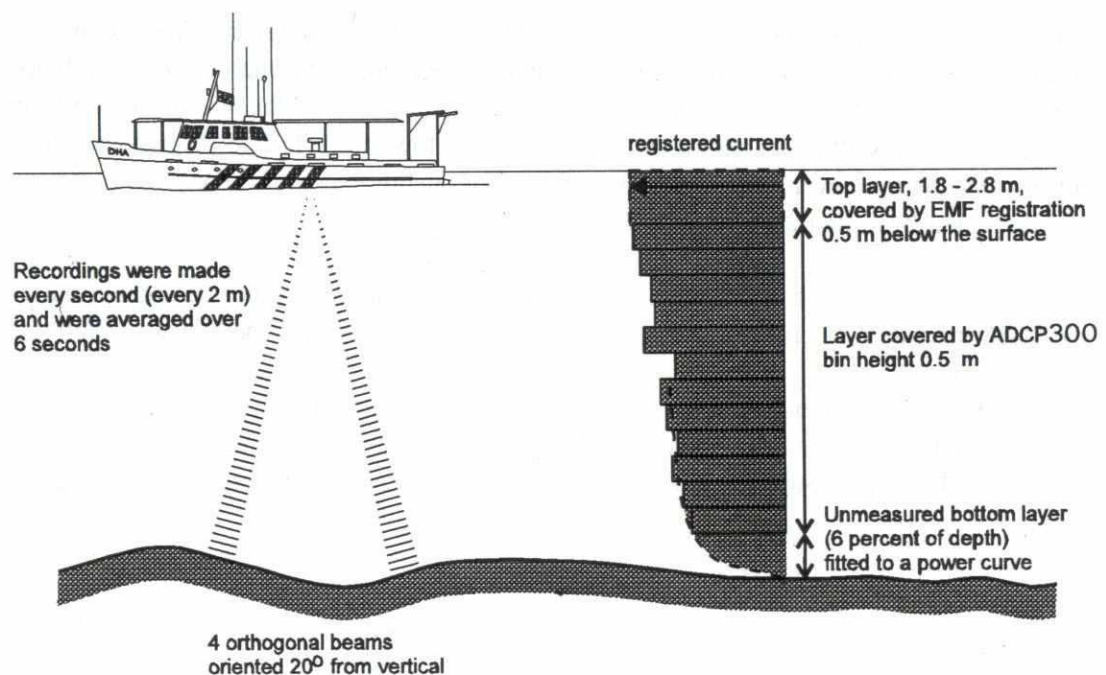


Figure 5.7: The ADCP-EMF moving boat method



- activating reference stations and checking positioning quality
- determining or checking transect perpendicularity at discharge transects
- ensuring that water level gauging stations functioned well
- preliminarily checking instruments and software
- actually executing work and logging data
- on-line data processing and recording on PC hard disks
- storing data and making two back-up tapes
- maintaining a record of executed observations in the log-book

Table 5.4: Activities of an RSP routine flow gauging by the ADCP-EMF moving boat method

The test phase and subsequent surveys proved that the ADCP-EMF method is fast and can be used during adverse hydraulic conditions, such as a flood. Also, because of its 'instantaneous' and detailed coverage of the flow field, it is much less dependent on a regular cross-sectional flow distribution. As opposed to the conventional moving boat method, transversing does not need to follow a straight course (although this was done wherever possible). This is of some significance in the Bangladesh rivers, where a straight, regular cross-section is not always immediately at hand, both due to hydraulic irregularities and due to navigational obstacles, such as shallow banks or fishing nets.

The method can perform a high relative positioning accuracy by bottom tracking, under conditions where the bed load transport was not too high. During high flows, the riverbed was 'moving', meaning that the fixed bed could not be detected. Under such conditions, the system underestimated the flow velocity because the measurements were made relative to a moving riverbed. That problem was solved by measuring the position by a DGPS rather than relating it to the moving bed. Another problem was that, since the moving sediment layer was recognized as the bed, the ADCP underestimated the depth. That, however was insignificant to the discharge estimate.

The ADCP instrument leaves unmeasured zones in the top and bottom layers. The size of these layers depends on the ADCP type (frequency and beam angles) and the way of installation (transducer depth). In the case of the DHA vessel, with an ADCP 300 the size of the top layer was reduced by installing an additional EMF at 0.5 m below the surface to record the surface current. The bottom layer, comprising 6% of the water depth (but a few percent of the flow), was estimated by fitting a power curve (Chen, 1991).

A final problem was that in the shallow channels, the method could not be applied due to vessel draft limitations. Instead, in those channels, the velocity-area method was applied.

When during the 1995 monsoon for the first time in the project period extreme high waters were encountered, it was confirmed that the ADCP-EMF-DGPS system was suitable for flow gauging during peak flows. Results are summarized in the survey bulletins (see SPR 22 and 23).

| Station     | Dates          | Bulletin |
|-------------|----------------|----------|
| Bahadurabad | 20 June 1995   | 9063     |
| Sirajganj   | 7-10 July 1995 | 9066     |
| Bahadurabad | 7-10 July 1995 | 9067     |
| Bahadurabad | 15 July 1995   | 9068     |
| Sirajganj   | 14 July 1995   | 9069     |
| Bahadurabad | 14 August 1995 | 9075     |
| Bahadurabad | 17 August 1995 | 9076     |

Table 5.5: Peak flow measurements

### 5.3.3 The velocity-area method

The velocity-area method is the standard method used by BWDB. There are two basic ways of estimating the discharge as outlined in the ISO(1979) report. Using a mean-section method, the average of the depth-mean velocity is multiplied by both the average depth at the two verticals and the spacing between the two verticals.

$$q = \left[ \frac{v_i + v_{i+1}}{2} \right] \left[ \frac{d_i + d_{i+1}}{2} \right] [b_{i+1} - b_i]$$

where  $q$  = discharge between the verticals  $i$  and  $i+1$   
 $v_i$  = depth-averaged velocity at vertical  $i$   
 $d_i$  = depth at vertical  $i$   
 $b_i$  = distance of the vertical  $i$  from a certain reference location

In a mid-section method, the depth-averaged velocity of a vertical is multiplied by both the depth of that vertical and a width comprising the mid-points between the reference vertical and the two adjacent verticals.

$$q_i = v_i d_i \left[ \left( \frac{b_{i+1} - b_i}{2} \right) - \left( \frac{b_i - b_{i-1}}{2} \right) \right]$$

where  $q_i$  = discharge surrounding vertical  $i$   
 $v_i$  = depth-averaged velocity at vertical  $i$   
 $d_i$  = depth at vertical  $i$   
 $b_i$  = distance of the vertical  $i$  from a certain reference location

In large channels, the method requires a long time for completing the discharge measurements, unless a number of vessels are available to do the measurements jointly.

The RSP applied the mid-section velocity-area method for shallow channels using Ott/Valeport current-meters, floats, or the S4 current-meter.

### 5.3.4 Instrumentation for velocity measurements

Velocity measurements, used for discharge estimations, were made in eleven transects distributed over the main river system. The ADCP-EMF moving boat method was used as the basic method in the main rivers. In the distributaries, a velocity-area method was followed, using an S4 current-meter or an Ott or a Valeport propeller current-meter.



- Acoustic Doppler Current Profiler (RD Instruments) (broadBand 300 and 600 kHz)
- Electromagnetic recording current-meters (InterOcean S4 and PEMS-EMF)
- Propeller-type direct reading current-meters (Ott and Valeport)
- Drogue tracking

Table 5.6: Current-velocity instruments applied by the RSP

***Acoustic Doppler Current Profiler (ADCP)***

This instrument registers the flow velocity using the principle of the Doppler effect:

$$F_D = 2F_s \left( \frac{V}{C} \right) \cos A$$

where  $F_D$  = Doppler frequency shift;

$F_s$  = transmitted frequency of the sound when everything is still;

$V$  = relative velocity between the sound source and the sound receiver;

$C$  = speed of the sound wave; and

$A$  = angle between the relative velocity vector and the acoustic beam.

When  $F_D$  and the angle  $A$  are measured, and  $F_s$  and  $C$  are known, the relative velocity  $V$  can be determined. If the velocity of the vessel is known either from bottom track or from the DGPS, the absolute velocity of the scatterers can be computed. Applying the principle, each beam computes one velocity component. With three-beam ADCP, three velocity components  $u$ ,  $v$ , and  $w$  are measured. The RSP used a set-up with four beams to measure velocity and to compensate for errors. The selected instruments were broadband ADCPs with 300 and 600 kHz frequencies. The former was mobilised for Phase 1, giving priority to the safety of operation in heavily sediment-laden waters, where its better penetration was expected to be decisive. Based on the Phase 1 experience, however, the higher frequency instrument was selected for Phase 2, because of its better vertical resolution. Both instruments functioned as expected.

Rotation and translation of the ADCP were measured by different devices. Heading rotation was measured by a gyro compass, and pitch and roll rotation were measured inside the ADCP electronically. The movement of the instrument over the riverbed was measured on-line by bottom tracking. In high sediment transports during the monsoon, bottom tracking results in underestimating the flow velocities. In those case, data were corrected off-line by using the data from the DGPS system.

During Phase I of the project, a 300 kHz RDI-ADCP was installed on the DHA. This ADCP was operated with a bin size of 0.5 m; 10 pings (profiles) were made in five to six seconds. The first bin was located about 2.8m below the surface and the last bin was located at the 94% water-depth level. The average of the 10 pings was stored at about five to six second intervals. The standard deviation of the acquired velocity was 30 cm/s for each individual ping. It was reduced to 9.5 cm/sec for the time-averaged value over five to six seconds.



During the test phase of the project, some implications of the limitations of the selected ADCP became clear. It was not able to measure higher than 2.8m from the water surface or with a bin size less than 0.5m, and the instrument was not portable.

Based on this experience, a 600 kHz RDI-ADCP was installed in the DHB. The advantage of this instrument were that the unmeasured surface zone was reduced to 1.8m, and the bin height was reduced to 0.25m. The instrument was portable and could be deployed in other vessels.

To measure point-velocity, electromagnetic and mechanical rotor current-meters were used. The electromagnetic instruments were the Inter-Ocean S4 current-meter and the DELFT HYDRAULICS PEMS-EMF. The mechanical rotor-types used were the Ott and the Valeport propeller meters. A brief description of these instruments follows:

### ***Electromagnetic current-meters***

An electromagnetic sensor works according to Faraday's Induction Law:

$$E = \psi I v$$

where E = electromotive force  
 I = magnetic field intensity  
 v = flow velocity  
 $\psi$  = a factor

A magnetic field is generated by a pulsed current-meter through a small coil inside the body of the sensor. In the PEMS-EMF, two pairs of diametrically opposed platinum electrodes sense the voltage produced by the flow past the sensor. The sensor is designed so that these voltages are proportional to the horizontal orthogonal components of the velocity vector at the plane of the electrode. The accuracy of the instrument is  $\pm 1\%$  of the reading, or  $\pm 0.5$  cm/s. It can measure velocity in the range of 0 to 3.5 m/s. During routine flow gauging, the instrument serves as a supplement to the ADCP. For this purpose, it is deployed at the bow of the vessel to sample 0.5m below the surface.

The InterOcean S4 works on the same principle. It was equipped with additional sensors to measure water-depth, instrument orientation (by a flux gate compass, for velocity direction), tilt, and temperature and conductivity. It was deployed to measure vertical current profiles, especially during sediment sampling. During such measurements, the vessel was anchored. With a resolution of 0.2 cm/s, the range of the instrument was from 0 to 3.5 m/s, which can be increased up to 6 m/s at the cost of a reduced resolution. Its accuracy was  $\pm 2\%$  of the reading, or  $\pm 1$  cm/s. Two orthogonal current components are registered. The orientation of the instrument was measured by flux-gate compass with a resolution of  $0.5^\circ$  and an accuracy of  $2^\circ$ , so that the absolute current-speed and direction are determined.

Within the volume of the induction field, the registration of electromagnetic current meters can be affected by interference by the hull of the vessel, or by the proximity of the riverbed. Safe distances between the InterOcean S4 and the vessel or the riverbed are 1.5 and 1.0 m respectively. For the FEMS-EMF these values are 0.03 and 0.01 m only.



### ***Mechanical rotor current-meter***

Ott and Valeport propeller-type meters were mobilized to measure vertical flow velocity profiles while anchored, especially in shallow areas when using a shallow-draft vessel. A similar technique is widely used by BWDB. The operation principle of the current-meter is that the rotation of the propeller is proportional to the flow velocity. A calibration formula was made after testing the equipment in calibration tanks. The main disadvantage of these current-meters was their inability to measure direction.

### ***Drogue tracking***

Flow velocity can be measured by drogues (floats) according to the principle that the float velocity is equal to the ambient flow velocity. This is achieved by choosing a float that has an appropriate dimension and a specific weight. The drogue is released in the water and its position is traced at some suitable intervals of time. From the measured travel distance and time, the velocity is computed:

$$V = \frac{\Delta s}{\Delta t}$$

This method provides a so-called Lagrangean description of the flow, by illustrating the trajectory of the moving water, as basically opposed to the Eulerian description of the current-vector at a fixed point.

A good accuracy requires that the displacement of the float is large as compared with the positioning accuracy. This, in turn, requires a time increment that is related to the current speed. Hereby, the time and space resolution of the method depends on the current-speed.

Obviously, the above computed velocities represents an average velocity over the depth level interval of the vane. The vane must be rather big in order to reduce the effect of wind drift (which becomes excessive if the wind drag force is significant as compared with the current drag force). Therefore, the method is not well suited for describing the vertical variation of the current, and in general it cannot provide detailed information about time and space variations. In the Jamuna with its strong varying riverbed, deep floats are too often grounded and therefore very unpractical. Surface floats cannot be followed by the survey boat. Floats with a draft of 1 to 1.5 m appeared most practical. The relation between the float velocity and the depth-averaged values can be found in the literature or from own measurements. Tracking of multiple floats can indicate parallel, diverging, or converging flow lines, and the data are well suited for validation of hydrodynamic models with their inherent finite length and time increments.

#### **5.3.5 Evaluation of flow gauging techniques**

The performance of the different flow gauging techniques applied by the Project was examined by a number of special surveys, as listed in Table 5.7. (For details about the data collection, reference is made to the *RSP Data Books*).



| Date          | No.   | Location      | River        | Measurement type                                                                  |
|---------------|-------|---------------|--------------|-----------------------------------------------------------------------------------|
| 31/3 - 1/4 94 | 9000  | Bahadurabad   | Jamuna       | Turbulence and optimal measuring time                                             |
| 12-13/4 94    | 9000B | Aricha        | Jamuna       | -----do-----                                                                      |
| 13/8 94       | 9017  | Bahadurabad   | Jamuna       | -----do-----                                                                      |
| 18-22/10 94   | 107   | Bahadurabad   | Jamuna       | RSP-BWDB joint measurements                                                       |
| 17-18/2 95    | 134   | Mawa          | Padma        | RSP-BWDB 26-hours tidal measurements                                              |
| 17-20/3 95    | 139   | Bhairab Bazar | Upper Meghna | -----do-----                                                                      |
| 22/5 - 1/6 95 | 9062  | Bahadurabad   | Jamuna       | Inter-comparison velocity measuring instruments                                   |
| 16-20/7 95    | 9070  | Bahadurabad   | Jamuna       | RSP-BWDB joint measurements                                                       |
| 26-30/7 95    | 9072  | Bahadurabad   | Jamuna       | Density of numbers of points in a vertical and numbers of verticals in a transect |
| 19-22/10 95   | 9089  | Mawa          | Padma        | RSP-BWDB joint measurements                                                       |

Table 5.7: Surveys for examination of flow gauging techniques

During these surveys, the flow gauging performance was analyzed relative to three basic sources of errors that can influence a velocity measurement or a derived quantity such as the discharge in turbulent flow (suggested by Mueller 1989):

- Instrument and calibration errors;
- *Error Type I* (by ISO 1983), which involves statistical uncertainty that depends upon the properties of the random velocity field, and on the sampling time that determines the integration time for the statistical mean; and
- Method errors that are used to evaluate derived quantities. For the velocity-area method of discharge estimation, this error is due to the limited numbers of sampling points in a vertical (*Error Type II*) or to the limited numbers of verticals in a transect (*Error Type III*).

It is noted that the analysis was based on field tests under conditions that are typical to the large alluvial rivers in Bangladesh. Hereby, an insight was gained with respect to the instrument performance in the actual physical environment, rather than about the potential instrument performance under ideal operating conditions, which would require either field tests under selected, particularly favourable conditions, or laboratory tests under controlled conditions.



### 5.3.6 Instrument performance

The performance of a current-recorder can be related to the following seven criteria (Mueller, 1989):

- the range of velocities to be measured;
- the instrument's calibration;
- its time and space resolution;
- its sensitivity to magnitude and velocity direction;
- its behaviour in a high turbulent flow field;
- the water properties; and
- the field application of the instrument.

Such quality considerations were taken into account when selecting, mobilizing, and evaluating the instruments. Comparisons between various techniques were executed various times during the RSP. For instance, during the test gaugings (RSP 1993) but also during various special surveys. As an example the comparison between the two ADCP instruments (300 kHz aboard DHA and the 600 kHz aboard DHB vessel) may be mentioned. On 30 April 1995 the two vessels were tied together and anchored in the Jamuna near Bahadurabad and flow measurements were executed, using the standard shortest exposure setting of the instruments, being 5.6 s (10 pings). Comparisons were made between the bins at mid depth, resulting the following graph. As might be expected the nearly instantaneous measurements at nearby but different locations show a lot of scatter. However, the trend (and also mean values) averaged over several minutes) shows a high consistency between the recordings; see also Table 5.9.

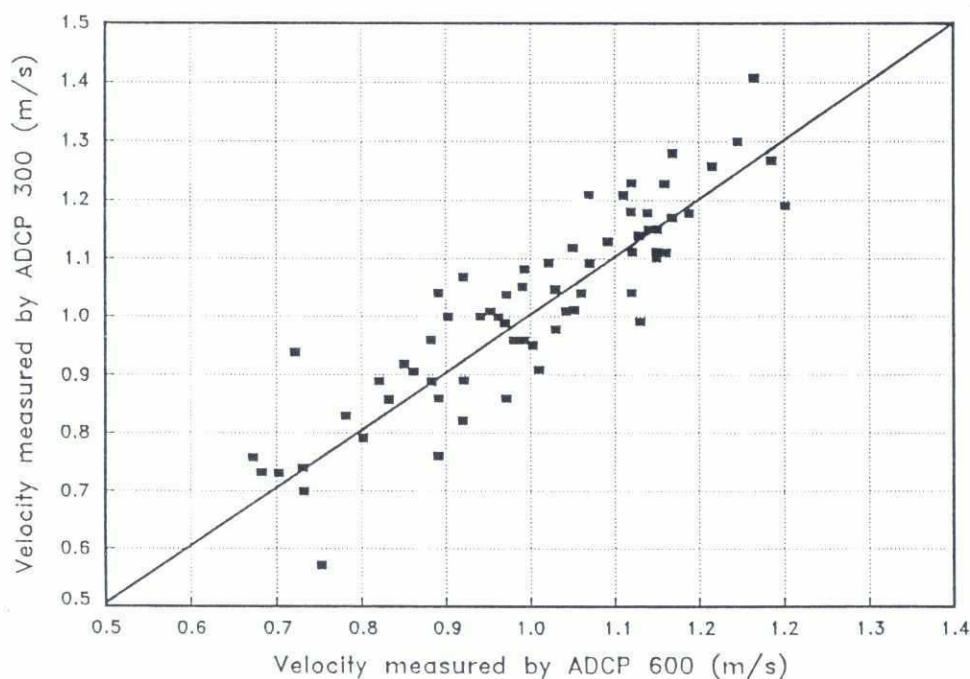


Figure 5.8: Comparison between simultaneous ADCP-300 and ADCP-600 registrations

A main problem is encountered when comparing instruments based on measuring results in a river. The variation of a registration is caused by the natural variability of the signal, which is only partly measured because of exposure time, instrument limitations and other sampling

inaccuracies. Important questions are in how far the registration is composed of of stochastic independent samples and whether any stochastic model is applicable. The PA suggested that nearer the riverbed more skewed distributions may be expected. Another aspect is related with the objective of the measurements (are averaged or instantaneous values desired?) As for routine measurements often average values are required. The variation of the recording, expressed in terms of standard deviations are often determined and called "errors" (see for instance WMO 1994 and Van Rijn 1986, Mueller 1989). This engineering approach is followed also hereafter. However, it is noted that if instantaneous information is required, the recording with the highest standard deviation (made by a perfect instrument used properly) may appear to be most accurate.

In April 1995, two series of comparative measurements were made in the Jamuna River near Bahadurabad (RSP 1996a). Seventy-two samples were taken at 50 s instrument exposure time. In one set of measurements, ADCP, S4, and Ott-propeller current-meters were deployed simultaneously at 50% water-depth. In another set of measurements, the EMF and the Ott were deployed at one metre below the surface. Table 5.8 shows instrument uncertainties at 67% confidence level and comparative indications of them.

| Instrument and Parameter | Time-mean values |          | Relative standard deviation |
|--------------------------|------------------|----------|-----------------------------|
| ADCP velocity            | 0.83 m/s         | -        | $\pm 4.6\%$                 |
| S4 velocity              | 0.87 m/s         | -        | $\pm 5.1\%$                 |
| EMF velocity             | -                | 0.92 m/s | $\pm 2.5\%$                 |
| Ott-propeller velocity   | 0.81 m/s         | 0.96 m/s | $\pm 6.5\%$                 |
| ADCP direction           | 189°             | -        | $\pm 1.0\%$                 |
| S4 direction             | 193°             | -        | $\pm 1.3\%$                 |

Table 5.8: Relative standard deviation of different velocity measuring instruments at 67% confidence level

The relative differences of the time-mean values are given in the following table:

|                                                                                                        | Ott-propeller | ADCP-300 |
|--------------------------------------------------------------------------------------------------------|---------------|----------|
| ADCP-600                                                                                               |               | + 1.3 %  |
| Ott-propeller                                                                                          |               | + 2.1 %  |
| IO-EMC (S4)                                                                                            | - 7 %         | - 4.8 %  |
| PEMS-EMF                                                                                               | + 4.3 %       |          |
| Notes:                                                                                                 |               |          |
| - The deviations are observed during short-term field comparisons at velocities between 0.7 and 1 m/s. |               |          |
| - Read the ADCP 300 = ADCP 600 +1.3%, etc                                                              |               |          |

Table 5.9: Observed deviations between different current-meters

With respect to current-direction, a deviation of 4° was observed between the S4 and the ADCP.

The overall consistency between the velocity measurements varied and remained within a margin of only seven percent. It is difficult to determine why such a small variation occurred



or to know which instrument reflected the natural flow field more accurately. Certainly, one reason is that the nonhomogeneity of flow affected the instruments that were deployed at different locations. But that does not fully explain the systematic deviation between the registrations. Also, the basic instrument characteristics play a role.

During the project on several occasions velocity profiles were measured with different instruments, also enabling comparing of the shape of the profiles. For example, during the test gaugings (RSP 1993), but also later for instance during the joint measurements of July 1995 with the BWDB (ADCP versus Seba, see SPR 11) and during the special measurements also of July 1995 (ADCP versus S4, see SPR 12, Annex G8). The shape differences appeared to be not very systematical. Only the ADCP tends to measure lower near-bed velocities than the Seba. This subject could not be taken up in detail as the standard method (ADCP) does not give near-bed velocities and no special device (current-meter in a frame) was available in the project. Nevertheless, the subject is important as different shapes may lead to different shear-stress velocities.

The flow, when measured by any point-measuring device, is affected by three effects:

- The movement of the survey vessel (sway, roll, pitch);
- Flow irregularities caused by the presence of the vessel; and
- Small-scale flow fluctuations (the problem of flow homogeneity).

The electromagnetic sensors are not significantly affected by the roll and pitch as these effects are registered and compensated, or filtered out by averaging. But, the results are affected by the presence of the vessel.

Mechanical rotor current-meters, such as the Ott or the Valeport propeller-types, are affected by all three factors. Studies show that propeller-type current-meters measure as much as 10% more velocity in highly turbulent flow (Jepson, 1967; Gordon and Bornhoft, 1991). Discharge measurements (980 m<sup>3</sup>/s) in the Rhine River near Brohl in 1991 indicated similar discrepancies between a 1200 kHz Broadband ADCP, and an Ott propeller current-meter (Gordon & Bornhoft, 1991). Comparison of one velocity profile indicated that the Ott velocities were 9% higher than the ADCP, and that the discharge measured by the Ott was about 10% higher. Similar results were obtained in Jepson's laboratory experiments (1965). He found that Ott over-registered velocity by as much as 10% due to velocity fluctuations on the axis of the Ott current-meter.

#### Evaluation of optimal measuring time

When measuring discharge, an error usually occurs due to the limited exposure time of the sensor. This *Type I error* (ISO, 1983) is known as a *standard pulsation error* that occurs due to the turbulent flow field being more intense at the bed than at the surface. This error can be examined by considering different windows of time. Studies by Carter and Anderson (1963) confirmed that the standard pulsation error lessens as the exposure time increases.

Their studies indicated that at 60% water depth, the standard error ( $\epsilon$ ) is related to the exposure time ( $\tau$ ) as,

$$\epsilon = 16.6 \tau^{-0.28}$$





The standard error is in percentage and the exposure time is in seconds. The relation indicates that with 50s exposure time, the standard error is 5.6%. Although such studies and error ranges were found elsewhere in the world, no such data were gathered for Bangladesh rivers. However, the RSP made several special surveys for determination of flow field turbulence and optimal exposure times.

Special measurements were made at three locations in the Jamuna River near Bahadurabad on 1 April and 13 August 1994, and at the Ganges-Jamuna confluence near Aricha on 13 April 1994. The measurements were executed during the rising and peak river stages.

The exposure time relative to the time scale of turbulence is used to determine the standard pulsation error for ADCP and EMF velocities. To determine the standard pulsation error, three regions of the boundary layer were chosen for measurement: one near the wall-region representing 88 percent to 93 % water-depth, one in the free-stream region representing 5% water-depth, and one in the intermediate region. The results are given in Table 5.10; it is seen that a higher pulsation error was found near the riverbed. An example of the error as a function of time is given in Figure 5.9.

| Fractions of depth (h) | Standard pulsation error (SPE)  |                    |                     |
|------------------------|---------------------------------|--------------------|---------------------|
|                        | Equation                        | 50 s exposure time | 100 s exposure time |
| 5% h                   | $\epsilon_v = 26 \tau^{-0.44}$  | $\pm 4.7\%$        | $\pm 3.4\%$         |
| 28 - 68% h             | $\epsilon_v = 80 \tau^{-0.65}$  | $\pm 6.3\%$        | $\pm 4.0\%$         |
| 88 - 93% h             | $\epsilon_v = 269 \tau^{-0.76}$ | $\pm 13.8\%$       | $\pm 8.1\%$         |

Table 5.10: Standard pulsation error at different water-depths measured by ADCP and EMF

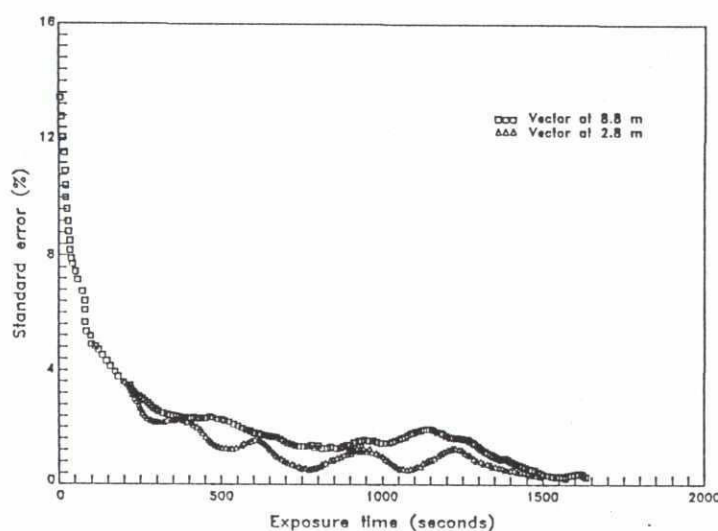


Figure 5.9: Relation between standard pulsation error and exposure time (Example, Bahadurabad, left channel, August 13, 1994)

The Figure shows that with exposure times of 300 s or more an error of 2.5% or less is obtained, which is smaller than the 4% as mentioned by Mueller (1989).

The exposure time of 100 s as applied by the RSP implies an error of 5.5% which is considered acceptable for routine gauging. For smaller exposure times the errors increase rapidly.

Please refer to *RSP Special Report 11: 'Optimization of hydraulic measurements'* for an in-depth discussion of the tests, their results, and an analysis of optimal measuring time.

Further, the surveys indicated that the Type II error, which is due to the limited numbers of vertical measuring points, appeared to be insignificant. The maximum variation was only about 5%. The last result was that the Type III error, which is due to the limited numbers of measuring verticals in a transect, was significant if a few verticals were sampled. These observations and their significance are elaborated in a subsequent chapter.

### 5.3.7 Flow gauging at tidal stations

#### Background

To establish a good set of data at a station which is significantly influenced by tidal flow, requires far more extensive measurements and resources than are required at a station without tidal influence. Close to the sea, the conditions may also be influenced by salinity intrusion, but this does not occur within the RSP project area.

In the case when the flow and sediment transport are carried out by numerical modelling, the data collection may be planned so that the results are suited as input and calibration/-verification data.

The tidal surveys of the RSP were carried out at selected stations during the dry season where the tidal effects are most pronounced. Three phases of measurements were carried out. The early measurements (Phase 1) in 1993-94 at Bhairab Bazar, Baruria and at Arial Khan Off-take were the least extensive and did not cover entire tidal periods. These "pilot surveys" were used to select locations and survey strategy for the more extensive surveys at Bhairab Bazar and Mawa in 1995. The last tidal surveys were carried out at Mawa in February 1996.

The BWDB makes bi-weekly 15-hour tidal discharge measurements at Mawa and at Bhairab Bazar stations during the January-April period. These data are collected for developing rating curves. The BWDB carried out their tidal measurements simultaneously with the RSP at Bhairab Bazar and Mawa in 1995 and 1996 (spring tide). This gives the opportunity to make comparisons between the two sets of data.

#### Objectives

The main objectives of the RSP tidal measurements were to enable:

- assessment of the performance of traditional methods;
- assessment of the need for detailed measurements for improvement of water and sediment transport balances; and
- assessment of the net flow and sediment transport rates in different tidal situations.

The first objective was pursued through comparisons with BWDB data. Regarding the second objective, the repeated ADCP transects were well suited for establishing the water balance over a short period (the duration of the tidal measurements). Sediment balances, however, require very dense measurements across the river covering the entire measuring period. When it comes to long-term balances and evaluation of long-term tidal storage (split of the net flow

in its tide-related and drainage/runoff-related parts), the present measurement campaign does not provide the necessary long-term data.

### RSP tidal surveys

The term "tidal survey" is used about a survey which, as a minimum, includes a number of discharge measurements, covering a substantial part of one tidal period. With this definition the tidal surveys listed in Table 5.11 were carried out by the RSP.

| Station            | Period              | Survey no. | Duration (hrs) | No. of verticals |
|--------------------|---------------------|------------|----------------|------------------|
| Bhairab Bazar      | 27-28 April 1993    | 5          | 26             | 0                |
| Bhairab Bazar      | 10 February 1994    | 34         | 14             | 8                |
| Baruria            | 21-22 March 1994    | 43         | 13             | 11               |
| Arial Khan Offtake | 18-19 April 1994    | 53         | 26             | 4                |
| Baruria            | 3-5 May 1994        | 56         | 13             | 12               |
| Mawa               | 17-18 February 1995 | 134        | 26             | 2                |
| Arial Khan Offtake | 23 February 1995    | 136        | 13             | 4                |
| Bhairab Bazar      | 17-20 March 1995    | 139        | 26             | 1                |
| Mawa               | 30-31 January 1996  | 254        | 26             | 6                |
| Mawa               | 7-8 February 1996   | 256        | 26             | 6                |

Table 5.11: RSP tidal surveys

The *RSP Data Books* give an overview of the results of each survey and selected data files are kept in the PSD24.

The initial surveys were processed largely in the same way as the routine gaugings. Later, more effort was made to cover the flow and sediment transport in space and time. Briefly described, the later tidal surveys included the following types of measurements:

- Measurement of the flow distribution and discharge at short intervals over 26 hours using ADCP/EMF and DGPS. ADCP backscatter signal was used to select locations for stationary verticals;
- measurement of the vertical flow distribution at stationary verticals using ADCP/EMF and S4 current-meter;
- measurement of sediment data at stationary verticals, including:
  - bed samples for bed sediment size;
  - Helley Smith and Delft bottle samples for near bed transport and sediment size (measure sediment flux);
  - pump bottle samples (measure sediment concentrations) for suspended sediment transport and vertical distribution;
  - bulk suspended sediment samples for determining size distribution of sediment (not always included);



- dune trackings (not always included), comprising repeated surveys of selected lines along the flow; and
- direction using echo sounder and DGPS.

In the 1995 tidal measurements, one vessel (DHA) was anchored in the main channel doing one stationary profile, while another (DHC) was anchored in a secondary channel, also measuring one stationary profile. A third vessel (DHB) was taking care of the moving boat discharge measurements and also the dune trackings.

In the 1996 tidal surveys, a main change to the survey programme was to leave out the dune trackings because they had proved less useful. This gave more time to the DHB vessel, which then in between discharge measurements lay by an anchored country boat at one of three preselected additional verticals for stationary profile measurements. The measurements at the three additional verticals are less frequent than the measurements at the two permanent stationary verticals. The intention was to cover the relatively wide cross-section at Mawa (more than 2 km wide) better with respect to lateral sediment transport distribution, and thereby make it possible to estimate the components of sediment transport for the entire cross-section.

At Mawa, the tidal influence is strong, with flow reversal during a short period of the flooding tide. Flow reversal does not take place at Bhairab Bazar. The measurements in 1995 at Bhairab Bazar showed very little sediment transport with only weak correlation with the flow. The sediment transport at Mawa was higher and clearly correlated with the tide. Both measurement series were carried out during spring tide. This is why the measurements in 1996 concentrated on Mawa, but included measurements at neap tide as well as during spring tide.

### Flow measurements

Figure 5.10 shows the variation of the water-level difference over a tidal cycle, together with the measured discharge (due to the missing connection of the right bank gauge only the variation, not absolute values of differences should be considered). The relation between flow and water level through a tidal cycle is illustrated in Figure 5.11.

The discharge was measured approximately half-hourly during 26 hours. The purpose was to cover a full diurnal (daily) tidal cycle of 24.8 hours. The average discharge can be found either by integrating over 12.4 hours, or by integrating over 24.8 hrs. In this case, where the tide is predominantly semi-diurnal (half-daily), it does not make much difference: The average discharge is 4000-4200 m<sup>3</sup>/s. In Figure 5.12 the total discharge is split into an average discharge and a time varying tidal component. The tidal component is seen to have a high flooding discharge of up to more than 5000 m<sup>3</sup>/s of a short duration, and an ebb component of less than 2500 m<sup>3</sup>/s, but with a longer duration.

Velocity measurements 1 m above the bed using the S4 current-meter at the two permanent stationary profiles (DHA and DHC) were carried out together with sediment sampling. The flow velocity records show that the magnitude of the flow velocities 1 m above bed is nearly the same at the two locations (between 0.1 m/s ingoing and 0.5 m/s outgoing). At the secondary channel (DHC), a small phase difference was observed between the flow velocity near the bed and the discharge: The near bed flow velocity was 10-15 minutes ahead of the discharge. At the main channel the phase difference was insignificant.

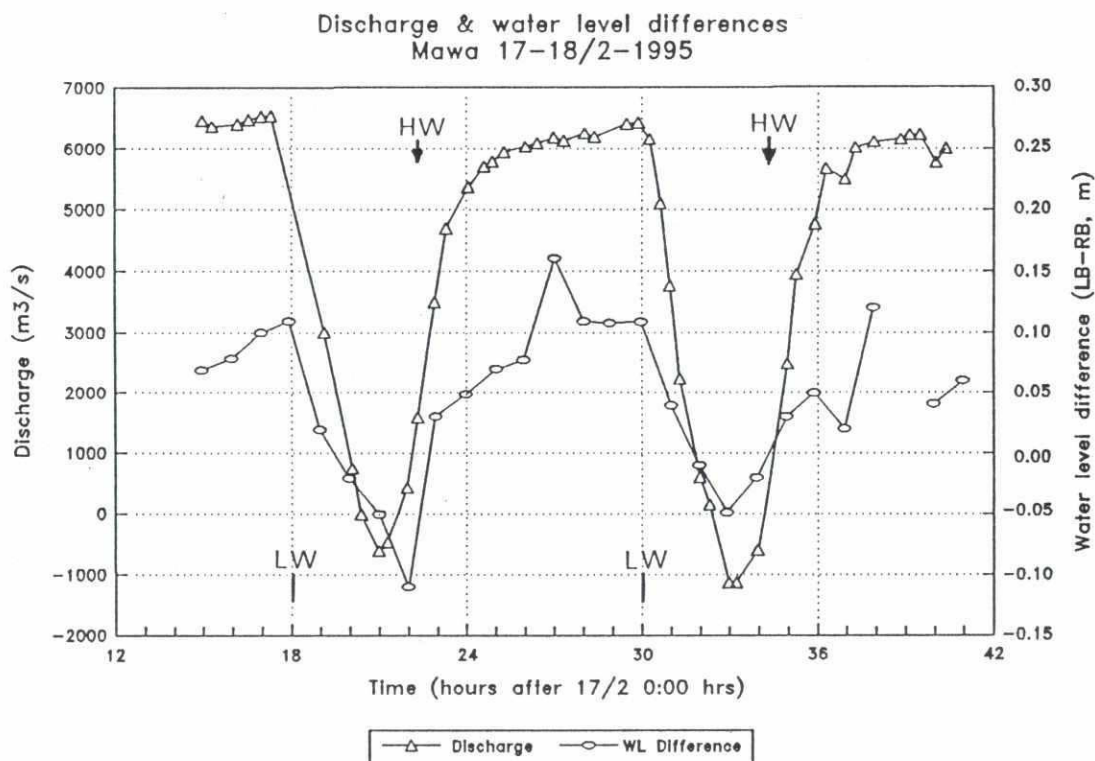


Figure 5.10: Time series of tidal flow and water-level difference (example, Mawa 17-18/2 1995)

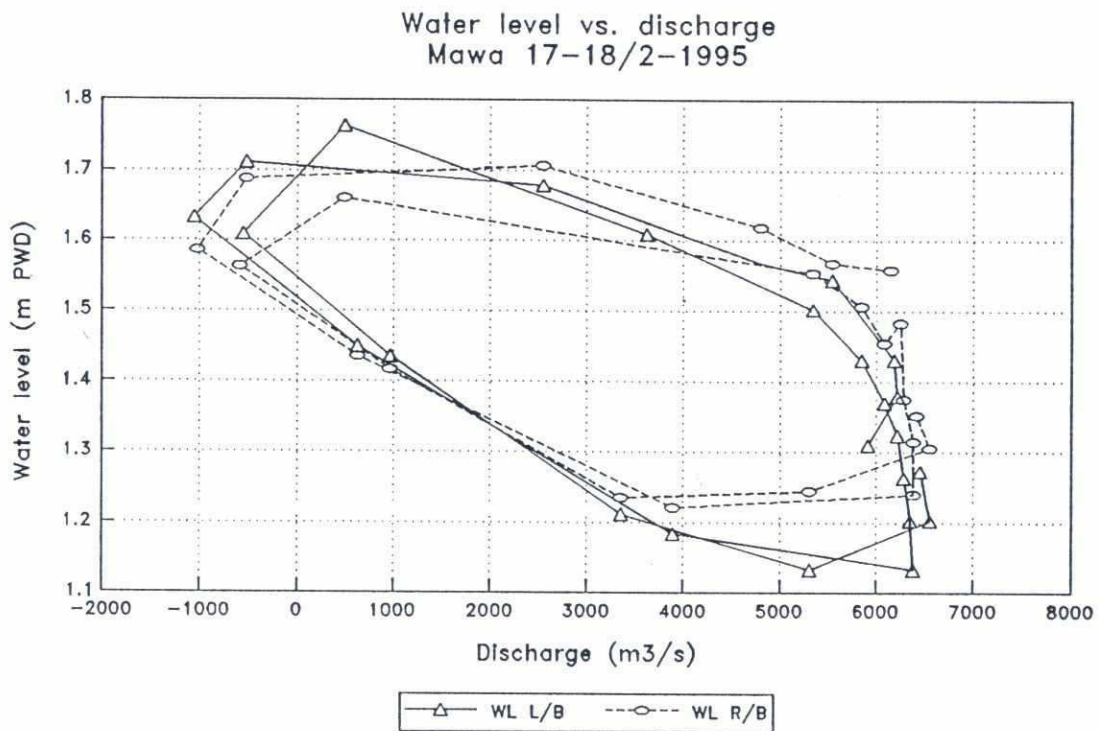


Figure 5.11: Variation of flow and water-level difference (example, Mawa 17-18/2 1995)

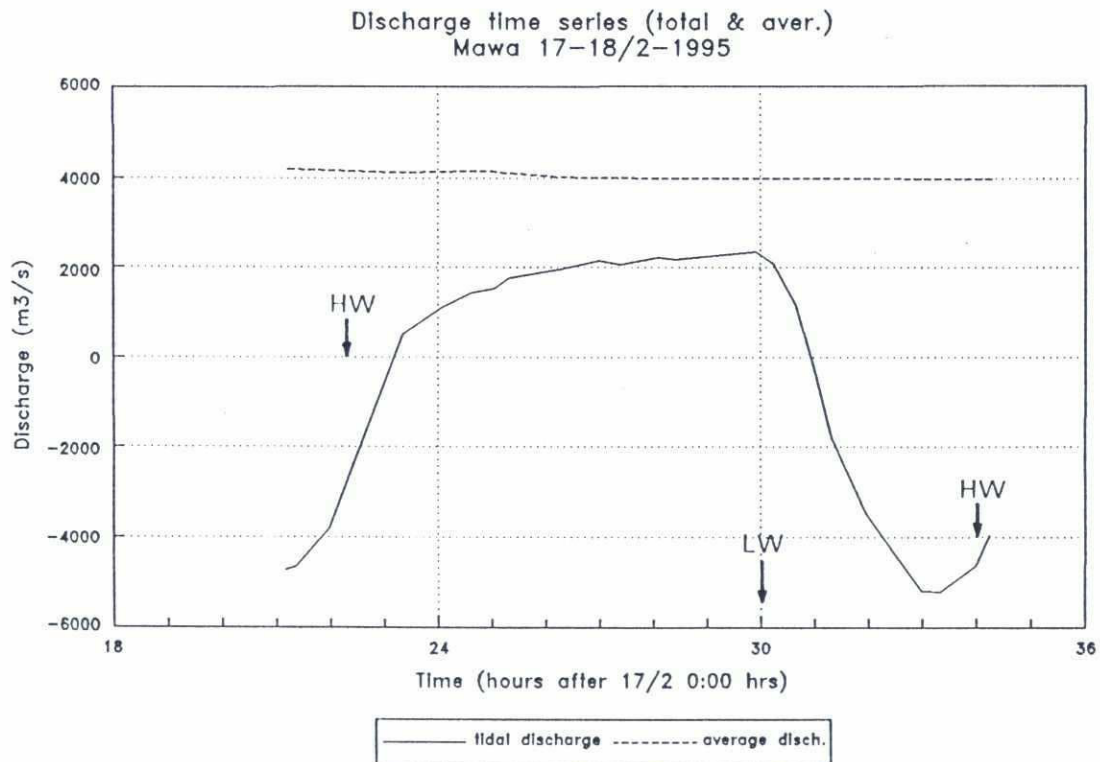


Figure 5.12: Time series of tidal flow and net flow (example, Mawa 17-18/2 1995)



Comparison of the grain sizes of the pb vs DB25 reveals that the pb is catching more of the finer fractions as the DB is loosing this part (Figure 5.17). From the different sieving curves it was found that in these conditions the DB was missing 80% of the finer fraction, which is half of the total (according to the pb) at this level.

The measurements of May contain the same comparison. The main conclusions are:

- The transport of the DB varies more than according to the pb, although the MEX indicates a constant transport over the measuring period. The possible reason for this is the position of the DB. The pb remained on the same spot, while the DB had to be lifted after each sample and to be replaced afterwards.

## 5.4 Gauging of sediment transport

### 5.4.1 Instruments used by the RSP

The RSP applied different types of instruments as listed in Table 5.12.

| Scope                                | Instruments                                                                                                                                                                                                                                                                           |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Suspended sediment                   | <ul style="list-style-type: none"> <li>• Pump sampling system</li> <li>• Integrated bottle</li> <li>* • Collapsible bag sampler</li> <li>• Optical turbidity meter</li> <li>• ADCP (300 kHz) (backscatter intensity)</li> <li>* • ADCP (600 kHz)</li> <li>* • Delft bottle</li> </ul> |
| Near-bed transport and bed transport | <ul style="list-style-type: none"> <li>• Pump sampling system</li> <li>* • Delft bottle</li> <li>• Dune tracking with echo sounder and side-scan sonar</li> <li>• Helley-Smith trap sampler</li> </ul>                                                                                |
| Bed material sampling                | <ul style="list-style-type: none"> <li>• US BM-54 scoop sampler</li> <li>• Van Veen grab sampler</li> <li>* • Drag sampler</li> </ul>                                                                                                                                                 |

\* additions in second phase of the project

Table 5.12: RSP sediment measuring instruments

BWDB applies a Binckley trap sampler for suspended sediment measurements.

### 5.4.2 Suspended sediment measurements

The instruments for suspended sediment measurements were selected on basis of Consultants experience, also with river projects in Bangladesh and following (partly) the international guidelines, see for example Table 5.13

- |      |                                                                                                                                                                                            |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (1)  | The sampler should be streamlined to minimize disturbances to normal flow velocity.                                                                                                        |
| (2)  | The intake velocity should equal the ambient velocity.                                                                                                                                     |
| (3)  | The sampler mouth should face into the current, therefore, the sampler should be parallel to the current's direction.                                                                      |
| (4)  | The sampler mouth should be away from the zone of flow disturbance caused by the sampling structure and gear.                                                                              |
| (5)  | Sampler filling arrangements should be so smooth that there is no sudden in-rush or gulping of water. In addition, the air escaping from the sampler should not hinder the entry of water. |
| (6)  | For a point-integrated sampler, the collected sample should not be contaminated with samples from any other depth.                                                                         |
| (7)  | The sampler should be designed in such a way that it is possible to take a sample exactly when and where it is needed.                                                                     |
| (8)  | The sampler should be portable, yet sufficiently heavy to minimize stream drag and deflection of the cable from the vertical.                                                              |
| (9)  | The sampler should require minimum care in maintenance and operation.                                                                                                                      |
| (10) | It should be ensured that the sample is removed from the sampler without loss.                                                                                                             |
| (11) | The volume of the sample should be sufficient to obtain sediment concentration and grain-size distribution.                                                                                |
| (12) | Depth-integrated samplers should be lowered and raised at a uniform rate, equal to a certain fraction of the depth-averaged velocity.                                                      |

Table 5.13: Requirements of a suspended sediment sampler (ISO 1977)

At the start of the RSP, the sampling of suspended sediments and the sediment transport gauging was based on a combination of a (point-integrated) pump system and a (vertically) integrating bottle.

The components of the pump system are listed in Table 5.14. Several shortcomings of the system were encountered, such as electromagnetic interference between the pump and the current-meter. Therefore, various modifications were made in the course of the project, as described in *RSP Final Report Annex 1: 'Surveys'*.

- |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• A gravity depressor with an intake nozzle and a pump with varying capacity.</li> <li>• A turbidity sensor.</li> <li>• An S4 current-meter with orthogonal current sensors, flux gate compass, tilt sensor, and pressure gauge (for depth registration).</li> <li>• An umbilical suspension cable (with a tube for pumping, and conductors for power supply and transmission of signals), with fairings for vibration suppression, and mounted on a power winch with water and signal outlets.</li> </ul> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 5.14: Components of the RSP pump system

At the end of Phase 1, it was not possible to recommend a system that complied with all the requirements. As a practical compromise, it was decided to base the sampling on the integrating bottle, except for one vertical in each cross-section, which should be sampled both by this sampler and by the pump system. The intention was to pursue a suitable compromise

between the two opposing quality criteria of (1) accuracy and (2) covering the entire cross-section in a reasonably short time.

In Phase 1, the integrated bottle was found to have sampling limitations in water depths over 6 m. Therefore, it was decided to introduce the collapsible-bag sampler during Phase 2 of the project. The sampler was procured from Colorado State University.

In high sediment concentrations, the ADCP was found to lose bottom track, but a mitigating method to determine the ground speed of the vessel (not via bottom tracking but with the DGPS positioning system) was made operational. Moreover on-line software was installed onboard the vessels to give a warning when the bottom track was lost. The ADCP backscatter intensity signal was initially used qualitatively to detect high gradients in the sediment distribution in the cross-section. This information was used for selecting the measuring verticals. The backscatter intensity was stored in a computerized data base for further analysis.

In the last part of the project from these analyses a reasonable relation between backscatter intensity and concentration of the coarse sediment fraction was found (for one type of ADCP and for one station) which gives the perspective of a quantitative use of the ADCP for concentration measurements in the near future.

The MEX3 turbidity meter gives excellent results in the finer fraction and more scattered data in the sand fraction as may be expected. The instrument is used to produce time series of sediment concentrations during special surveys.

#### **Performance of suspended sediment samplers**

Acceptable accuracies from different instruments are fundamental for a good estimate of sediment transport. Suspended sediment concentration and transport from some routine measurements were used to evaluate the performance of the various survey methods in absolute terms and relative to each other.

Further, the RSP examined the accuracy by finding the relative standard deviation of some stochastically independent samples collected in a natural river flow by different instruments at a certain interval at a certain depth. The Binckley silt sampler, the pump sampler, the collapsible bag sampler and the Delft bottle were tested in this way. It is important to note that natural fluctuations (if any) are included in the standard deviation estimate, which should, for that reason, be treated as the deviation from the time mean value, called error hereafter, see further the discussion in 5.3.6 and 5.4.5 on this subject.

For details about the instrument performance, please refer to *RSP Special Report 12: 'Optimization of sediment measurements'*, from where the following summary has been extracted.



### **Binckley instantaneous silt sampler**

The Binckley sampler is an instantaneous silt sampler. It is a horizontal cylindrical sampler having a uniform bore. It is lowered in the water in open conditions and is closed by pulling a wire when it reaches the desired water depth. This sampler was not used by the RSP, but has been applied by BWDB since 1956.

A joint BWDB/RSP measurement was made on 19 July 1995 near Bahadurabad. Twenty samples were taken every three minutes using the BWDB Binckley sampler at a 60% water depth. These samples were analyzed for sand and silt fractions to determine the relative standard error of the sampler. The standard error was found to be  $\pm 72\%$  for sand and  $\pm 23\%$  for silt. The analyses show that to attain an error level of  $\pm 20\%$  in the sand fraction, at least 13 or more samples should be taken by a Binckley silt sampler.

### **Pump sampler**

The field routine begins with assurance of a pumping rate such that the intake velocity is equal to the ambient velocity. Unless the hydraulic coefficient is close to unity, the validity of the sample is affected. Another activity is splitting the pumped sample on-board the vessel deck. This is necessary because pumping for a long period (i.e., 300s) may involve collection of a large sample which can not be contained. Therefore, splitting ensures a hydraulic separation of a large sample into smaller container volumes.

Sampling errors can occur if:

- a hydraulic coefficient is greater or smaller than unity;
- sorting of sediments takes place inside the hose or umbilical chord; and/or
- sorting of sediments takes place during splitting of the sample.

On 20 July 1995, a pump sampling exercise was done in the Jamuna River near Bahadurabad. Twenty-one samples were taken every three minutes at 60% water depth using an integration time of 100 s. The pump samples were analyzed similarly to the Binckley sampler; a standard error of  $\pm 14\%$  was estimated for the sand fraction, and  $\pm 4\%$  for the silt fraction. In terms of relative deviations and standard errors, the performance of the pump sampler was better than the Binckley silt sampler.

### **Depth-integrating samplers**

A depth-integrating sampler is lowered towards the riverbed to be raised again to the surface at a uniform transit rate. The device samples continuously during both periods of slow-speed transit. The transit rate is usually suggested as 40% of the ambient velocity. There are several varieties of depth-integrating sampling devices. The ones used by the RSP were an integrating-bottle type sampler and a collapsible-bag sampler.

The bottle sampler has an intake nozzle that points towards the flow and an air exhaust that points away from the flow. Water enters through the nozzle at hydrostatic pressure and fills the bottle to the level of the exhaust tube entrance. This limits the volume that can be collected by the sampler. The standard sampler can be effectively used only in depths under 4.5m (Yuqian, 1989). However, this depth limitation can be increased by using a larger bottle. The ambient depth-averaged velocity of the vertical must be equal to the average intake velocity



through the nozzle. The volume of samples at each point will then be proportional to the local velocity. Since there is no opening or closing device on the intake nozzle, the sampler continues sampling while in the water. The measuring errors of this device are due to:

- non-uniform lowering and hoisting rates;
- the transit rate being too high or too low, so that the hydraulic coefficient is not equal to unity; and
- an excessive depth is covered, so that the capacity of the bottle is exceeded.

The collapsible bag implemented by the RSP is described by Nordin (1994). The sampling system has the following parts: (1) sampler frames to hold a 3- or 8-liter plastic bottle, (2) a perforated 3- or 8-liter plastic bottle, (3) streamlined plastic caps that screw on the bottles and nozzles, (4) lightweight plastic bags, (5) streamlined sounding weights, and (6) hanger bars.

The uniform transit rate is usually set as less than 40% of ambient flow velocity, and Nordin (1993) reported transit rates of less than 20% of ambient velocities in large rivers such as the Mississippi and the Amazon. The advantage of a collapsible bag is that it does not have a depth-limitation (depending on the plastic bottle size). However, the sampler is susceptible to plastic bag leakage.

A time series of thirteen samples was collected by the collapsible bag sampler near Bahadurabad on 2 April 1995. These samples were not systematically collected like the pump and the Binckley sampler. Given this information, the relative standard error in this case was estimated at  $\pm 19\%$  for the sand fraction. Except in the first two samples, the hydraulic coefficients were low, and they were nearly uniform. Therefore, the influence of the hydraulic coefficients were negligible in these cases. As compared with other methods, the depth-integrated collapsible bag underestimated the sand concentration by about 49%.

#### **Delft bottle**

A Delft bottle is a point-integrating or depth-integrating sampler, which can sample suspended load (suspended in a cable and stabilised by a tail), as well as near-bed load (when mounted on a frame).

Within a certain time (2-5 minutes), a water-sediment mixture enters through the nozzle and flows out from the back of the sampler leaving behind the suspended sediments coarser than approximately 100  $\mu\text{m}$ . Nozzle sizes of the Delft Bottle are usually classified as big or small. A big-sized nozzle (internal diameter 0.22 mm) is used for flow velocities less than approximately 1.0 m/s, while a small nozzle (internal diameter 15.5 mm) is used for flow velocities higher than approximately 1.0 m/s. A straight nozzle is used for suspended sediment sampling and a bent nozzle is used for near-bed sediment sampling.



The transport rate is calculated from the weight of the sample. Errors can be caused by:

- incorrect intake velocity compared to the ambient velocity causing a hydraulic coefficient different from 1;
- loss of sand due to the difference between the total sand volume entering the nozzle and the part that is settling inside the bottle;
- inefficiency of the sampler to collect sediments less than approximately 100  $\mu\text{m}$ ;
- additional (unintended) sampling during raising and lowering of the instrument during point-integrating sampling; and
- sediment losses during removal of the sand catch.

A set of twelve measurements was done by a big-size straight nozzle Delft Bottle on 2 April 1995 near Bahadurabad. The overall (instrumental and natural variation) error was indicated by the relative standard deviation, which was, in this case,  $\pm 10\%$ . The example shows that the consistency of the Delft bottle is better than the other samplers. However, it did not correctly represent particles less than about 0.125 mm.

#### **ADCP backscatter intensity**

The Acoustic Doppler Current Profiler transmits sound bursts down to the riverbed. The sound is partly reflected by scatters in the flow like plankton and sediments. From every increment (bin) in the vertical this secondary reflection is measured. The lowest bins cannot be measured as the secondary reflections is whiped out by the primary reflection from the river bed. Also a top layer of the vertical is an unmeasured zone in relation with the transducer depth (similar with echosounders). Hence, the ADCP measures part of the vertical, see also Subsection 5.3.2. The intensity of the secondary reflection (measured in dB) is related to the amount of scatters in the water, which is at least partly the same as the sediment concentration. Although the ADCP was selected primarily for velocity/discharge profiling initial the qualitative and later the quantitative use became more important in the course of the RSP.

For the assessment of the relation between backscatter intensity and sediment concentration reference is made to Annex 5 of the Main Report. Some results are presented in 5.4.5.

#### **Comparison between pump system and integrated bottle**

The RSP routine gauging comprised sampling of suspended sediment measurements by the integrated bottle at several verticals. Based on ADCP backscatter, about eight to twelve such verticals were chosen in large channels (width > 500m). In smaller channels, four verticals were sampled. In one reference vertical, simultaneous samples were collected by the depth-integrated bottle and the point-integrated pump. In large channels, a six-point sampling method was followed by the pump-method. The six points were near the surface (at 0.2h, 0.4h, 0.6h, and 0.8h, h = water depth), and near the bottom (roughly 0.5m above the bed). Three-point measurements were made at 0.2h, 0.6h, and 0.8h. The DHA vessel was used for measurements in the Jamuna River at Bahadurabad and in the Padma River at Baruria. Either the DHB or a local country boat was used in the Ganges River at Hardinge Bridge.



It appeared that significant deviations between the methods occurred occasionally. In general, however, the agreement between the methods was good for the silt fraction, and fair for the sand fraction, where results based on the pump system could be between 33 % lower and 22 % higher than results based on the integrated bottle.

#### **Comparison between pump system and collapsible bag**

Similar comparisons were made between the pump system and the collapsible bag sampler. Data were taken from the reference verticals of different transects in the Jamuna and the Padma Rivers. As with earlier observations, the agreement between the systems for the silt fractions was reasonable. For the sand fractions, however, the differences between the two systems were appreciable. In one analysis of selected routine gauging results, the average difference was collapsible bag sand concentration being 49 % lower than the pump sand concentration. This observation was in line with what was observed between the pump and the integrated bottle at Bahadurabad and Baruria, though the difference was larger in this case.

#### **Comparison between pump system and Delft bottle**

A comparative sampling was made near Bahadurabad in August 1994. The Delft bottle measurements were taken 0.35m above the riverbed, and pump-sampling was done 0.5m above the bed. The samples were collected at nearly the same time. The local transports at 0.5-1.0mm, 0.25-0.5mm, 0.125-0.25mm, 0.063-0.125mm, and < 0.063mm size fractions were compared.

The results of the comparison were quite consistent. In all the tests, the Delft bottle gave a somewhat higher transport rate for (almost) all grain-size fractions, except the finest, where the Delft bottle gave a lower transport rate. This fits with the expectation that the transport should be higher near the riverbed. Indications were that the transport rate played a role. Particles above 0.063 mm were well represented by the Delft bottle at low transport rates, while at high transport rates, the method would underrepresent particles finer than 0.125 mm.

#### **Comparison between pump system and turbidity**

Some calibration exercises of the MEX-3 turbidity meter were made; hereby, the turbidity was compared with the suspended sediment concentration. The results were somewhat ambiguous. Indications were that the turbidity sensor works perfectly well in the silt ranges, but not very well in the presence of sand, especially in the high concentration ranges.

#### **Comparison between pump system and ADCP backscatter intensity**

Point-integrated concentration data are available for comparison with ADCP backscatter profiles in reference verticals from different routine transects. The backscatter signal depends both on the grain size and on the concentration, so unless one of these is known, the backscatter registration is ambiguous. As a supplement to other methods, however, the backscatter registration is quite powerful for describing the detailed time and space variation of the suspended sediments, with the inherent shortcoming that the near-bed zone is not covered. The RSP's experience within backscatter registration is elaborated in *RSP Special Report 12, Annex D: 'Estimation of suspended sand concentration from ADCP backscatter'*.

### 5.4.3 Near-bed sediment transport measurements

#### Bed load versus near-bed transport

Bed-load transport occurs in a thin layer above the bed under the influence of gravity. Investigators differ in their definition of this "thin boundary". For example, Einstein (1950) defined bed-load as transport of sediments occurring above the bed in a layer of 2 particle diameters. Bagnold (1956) defined bed-load as the sediment transport in which the successive contact of particles with the river bed were strictly limited by the effect of gravity. Investigations by Abbot and Francis (1977) indicated that a maximum saltation height of 10 particle diameters can occur. Van Rijn (1984) assumed that the bed-load layer is limited by the saltation of particles which is directly proportional to the transport stage. He assumes that the saltating particles reach half of the bedform height. It should be noted that the descriptions of saltation are mainly based on laboratory observations.

It is impossible to take measurements of bed-load as defined above in sand-bed rivers. However, sediments moving near the bed are important for river morphology (Peters and Goldberg, 1989) and they can be measured. Observations in the Zaire River suggest the existence of a moving near-bed layer. It is up to several decimeters thick and its sediment contribute to bed changes. Consequently, measuring sediment transport and sediment concentration is the most difficult part of river surveying. The natural variability of these parameters is large, thus hampering a fair calibration of the available instruments and necessitating a large number of observations to determine a reliable average value. With regard to the height of a measuring point above the river bed, surveyors are facing limited means to determine the exact elevation of this constantly changing bed. Moreover, the stability of any measuring device on the river bed is questionable. Consequently, it has to be accepted that sediment measurements show a larger scatter and have limited accuracy. This is probably the reason that no required accuracy for sediment observations was defined in RSP's Terms of Reference or Technical Specifications.

Another problem is that the so-called bed load samplers like BTMA and Helley-Smith measure much more or much less than bed-load, depending on the adopted definition of bed-load. To avoid this confusion, the recommendations of the PA were followed (Peters 1994) and the measurements were focused on near-bed transport rather than on bed-load. This was in line with earlier observations done in the Zaire River (Peters and Goldberg, 1989) where it was stated, *This observations suggest the existence of a layer up to several decimeters thickness, corresponding to that part of the moving sediment contributing to the bed changes (bed load transport and saltation).*

From the beginning of the project a certain flexibility with bed-load transport gauging was envisaged (Remarks 19 and 19A of the Reduced Bills of Quantities). There it is stated that different rules could be developed after the test gauging and when experience is gained. This happened and the bed-load gauging of phase I, became the near-bed sediment transport measurements of phase II. Particularly it meant that the measurements were not focusing on the lowest few cm any more, but on the lowest few dm.

The thickness of the near-bed transport layer has to be assessed from measurement. Both in low and high flow conditions (SPR12 Annexures G5 and G8 respectively) it was found at Bahadurabad that the near bed transport was slightly increasing from 0.35 to 0.15 m above



the river bed, while a considerable increase occurred between 0.15 and 0.05 m above the river bed. From a practical point of view 0.2 m was chosen for the thickness of the near bed layer. It should be emphasized that this value is varying depending on river conditions (location, stage, etc.). More investigations on the subject are recommended.

### Phase 1

Regarding bed-load transport, a combination of two methods was planned at the beginning of the Project:

- Indirect sediment transport observations by means of dune-tracking was proposed by the consultant. For this type of observation, the water depth would be measured using a dual frequency echo sounder, type ELAC Laz 4420. The reason for dual frequency is to simultaneously obtain the thickness of any silt layer and the elevation of the riverbed; and
- Direct bed-load sampling by means of a sampler was requested by the contractor as an alternative to dune tracking. The consultants choice was the Helley-Smith sampler.

This type of observation would provide information about the applicability on Bangladesh rivers as well as make it possible to determine the grain-size distribution of the bed-load sediment. After evaluating the Helley-Smith sampler in Phase 1 of the project, however, and after realising the significance of the near-bed transport, the Project Adviser recommended testing a Delft bottle, which can make near-bed sediment transport measurements on a sledge down to a level of 5 cm above the riverbed, even in high flows.



Figure 5.13:  
The Delft bottle

Further, in Phase 1, dune tracking did not prove its anticipated viability, due to the absence of dunes at appropriate locations. For instance dunes were found only in the left channel, not in the right channel or only in the thalweg, not in shallower parts of the cross-sections, etc. The main problem, however, is that not only bed load contributes to the propagation of the bedforms as discussed earlier (Section 4.4.7).

Consequently at the end of phase 1 it was concluded that dune tracking is not a suitable method for routine measurements.



## Phase 2

Experience in Phase 2 showed that the Delft bottle added valuable information on sediment transport close to the river bed. Like every instrument which is placed on the river bed some limitations were encountered, especially concerning the position of the instrument with respect to the bed forms. In case of smaller bedforms like ripples and megaripples random positioning creates additional inaccuracies. In case of dunes special procedures can be applied to position the instrument on the higher part of the dune which result in more reliable results (Peters 1971), see also hereafter under "bedforms and near-bed transport..

Another issue is that the samples taken with the Helley-Smith and Delft bottle should not be too large. In case of large transport this leads to short measuring times and consequently more inaccuracies. This leads to taking more samples (repositioning problem) or using near-bed pump sampling which was introduced at the end of 1994 to facilitate measuring over up to ten minutes at the same location.

## Instruments

For the pump sampler reference is made to subsection 5.4.2. For the Delft bottle see Figure 5.13.

The system required for dune tracking operated perfectly. The steering system of the survey vessel consisting of a steering machine, an auto-pilot, joystick control and a computerized navigation system made that accurate sailing along the same track is possible, even through very turbulent flow. The navigation system included DGPS positioning, pre-programming of sailing tracks and a left-right indicator.

This system and the skill of the crew made bed-form tracking with a high accuracy (repeating tracks with a high uncertainty of a few m), a relatively simple operation.

The Helley-Smith trap sampler was designed for measuring bed-load transport in coarse sand bed rivers or gravel bed rivers. A comparison between the Delft bottle and the Helley-Smith trap sampler showed that, in general, the Helley-Smith sampler underestimated the near-bed transport, one reason being that the Helley-Smith sampler has a mesh size of 0.25 mm, through which finer particles (which are dominant in the Bangladesh rivers) escape. As a consequence, the median grain size is overestimated. Apart from that, and considering that the Helley-Smith sampler is closer to the riverbed than the Delft bottle (at sampling level + 5 cm), the results were well correlated.

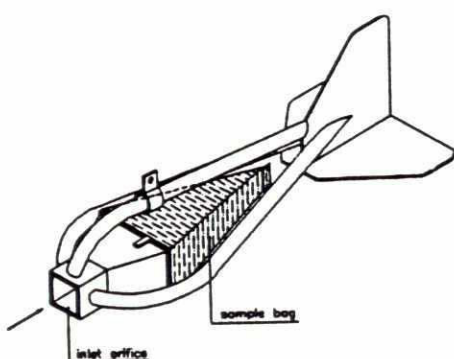


Figure 5.14:  
The Helley-Smith sampler



### Experience with Instruments

- As learned in the first phase, the H-S sampler is difficult to judge in the high flows because of possible scooping and problems with the determination of the sampling time. On the other hand, the instrument is very useful in the mid-flow ranges (1 to 2 m/s), as coarse transport concentrates then in the lowest cm of the vertical where only the H-S sampler can be used.
- The DB in the frame could be operated with ease. A number of small improvements, suggested by the PA, were realized.
- The bottom plates of the standard frame of the Delft bottle were too small in the fine sands of the Jamuna. Therefore, the recommendation of the RSPMU was followed to enlarge the plates by welding 'skis' under the plates.
- The vertical position of the intake nozzle appeared not very rigid, which is specially required when measuring at 0.05 m above the riverbed. Uncertainties of a few cm are then not acceptable. Therefore, fixation of the bottle to the hanging bar was improved by increasing the width of the bar. Both the connection between the bottle and the bar and the connection between the bar and the frame became better and more stable.
- In the high flows, the drag of the DB was also considerable and it took a lot of experience to determine the sampling period like the H-S.
- The scatter of the transport according to the Delft bottle at 0.05 m above the riverbed appeared to be considerably more than the scatter at 0.15 m above the river bed.
- As observed earlier the H-S is losing the finer parts of the sediments which are passing the 250  $\mu\text{m}$  mesh width of the sampling bag. Practically, all the fractions < 125  $\mu\text{m}$  are lost but a considerable part of the 125 - 250  $\mu\text{m}$  fraction is caught.
- In low flows the H-S sampler can be handled with ease. There has been no scooping and the sampling period was long and could be determined accurately. However, there is hardly any transport of coarse sediments when the flow is lower than say 1 m/s. When only a few grains are moving and if a few are missed, the error is high. But the low transports are not significant on overall considerations. From these considerations and earlier observations during the high flows, the H-S is preferred in the mid-flow ranges.
- The representativity of the DB in the frame is questionable, when the sampler is used on an irregular river bed. After each measurement, the sampler has to be lifted to take the sample out and then lowered again. The question is whether the sampler comes back to the same position on the river-bed. From the irregularities on the river-bed, it is known that local bed slopes (e.g. at the lee-side of a dune), are sometimes in the order of 45 degrees, which means depth variations of meters variations of meters when the inaccuracy of the horizontal positioning is a few meters (extreme situation), often the DB is used 2, 3 or 4 times in one measurement vertical and nearbed transports are plotted then nicely at 0.05, 0.15, 0.25 and 0.35 m above the river-bed. It is noted that especially on deep water (say 15 m) and high currents (> 2 m/s), it is clear that positioning of the instrument within a few meters is hardly possible. The only way to avoid these problems is by attempting to select an appropriate area within a relatively flat river bed.  
This type of uncertainties is obviously not specific for the DB. They are valid for other samplers as well.
- The losses through the DB are in broad lines nearly everything below 63  $\mu\text{m}$  and part of the 63 - 125  $\mu\text{m}$  fraction.



### Bed-forms and near-bed transport

In August 1994, some special sediment transport measurements were taken with the Delft bottle on a sledge over a dune profile. Samples were taken on the crest, stoss, and lee side of the dune, which was located in the left channel of the Jamuna River near Bahadurabad. One measurement was taken on a flat bed in the right channel of the river. In all cases, the transport was dominated by the 0.125-0.25 mm fraction, with the reservation that fractions below 0.125 mm are in general not well represented by the Delft bottle. The measurements indicate that a high transport took place at the crest of the dune, followed by stoss side transport, and then transport at the trough. At all three of these locations, the local transport over the vertical was very regular. At the lee side of the dune and at the flat bed, the vertical transport distribution was highly irregular.

This exercise indicates the difficulty in interpolating or extrapolating near-bed transports. Since a large variation of transports takes place over a bed-form, considerable overestimation or underestimation is possible. For example, when the measurements over a dune crest are used to interpolate transports between measuring verticals, overestimation can occur. The contrary may happen when the lee side or flat-bed measurements are used. Such difficulties are inherent when measuring near-bed transport by sampling methods in large alluvial rivers.

### Comparison between Helley-Smith sampler and Delft bottle

Both during routine surveys and various special measurements near-bed transport measurements were executed with the Helley-Smith sampler and the Delft bottle. From these measurements important conclusions are:

- In general, the Helley-Smith sampler underestimated near-bed transport rates. This conclusion was reached by comparing the Helley-Smith transport rates with the Delft bottle transport rates at 5 cm and 15 cm above the bed. Figure 5.12 shows the comparison between the Helley-Smith flux and the Delft bottle flux at 5 cm above the bed; the underestimation was clearly noticeable. The primary reason for the underestimation is that the Helley-Smith sampler has a mesh size of 0.25 mm, through which finer particles (which are dominant in Bangladesh rivers) escape. For coarser fractions, however, the reason for the underestimation is not as obvious. The Helley-Smith sampler is measuring higher transport rates for fractions sized 0.125-0.25 mm. The transport estimates for the 0.25-0.50 mm size fractions were not so obvious. Out of 7 samples analyzed, 5 samples indicated that the Helley-Smith sampler overestimated the transport rate for fractions sized 0.25-0.5 mm. This is understandable, since the Helley-Smith measured more to the bed than the Delft bottle at 5 cm above the bed. As the finer particles escape the Helley-Smith sampler, the median grain size of the sampler becomes more than the Delft bottle sampler.



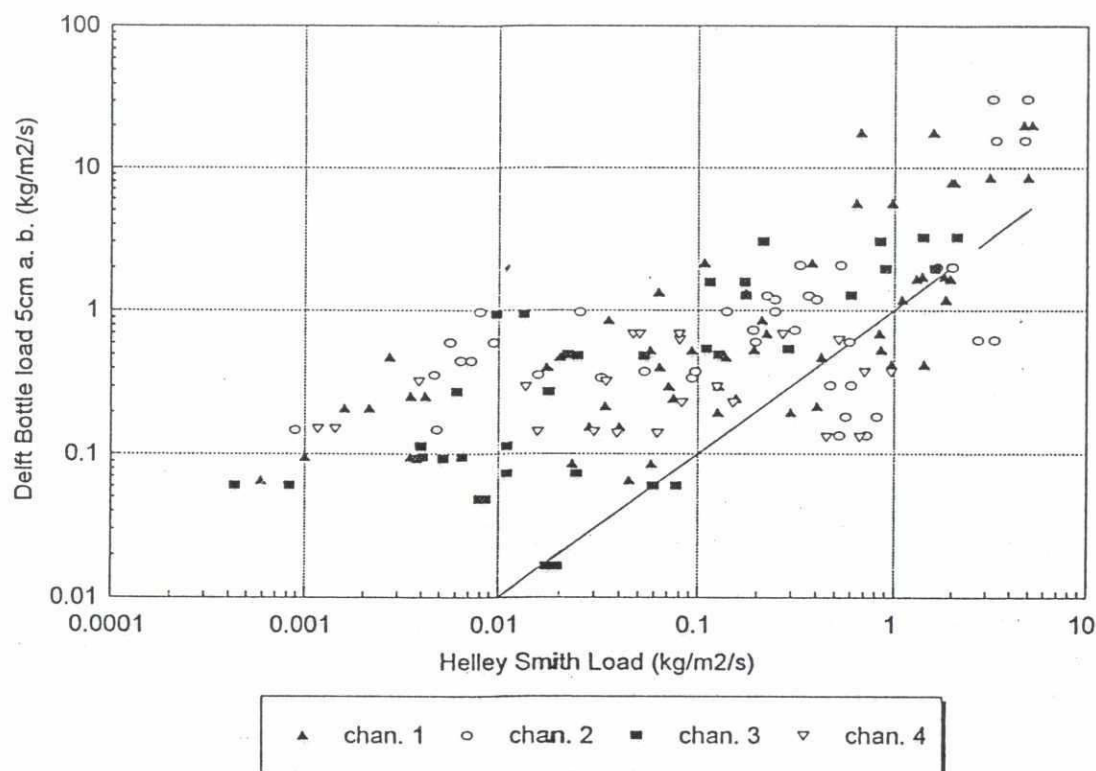


Figure 5.15 Comparison of sand transport measurements at 5 cm above bed with Helley-Smith transport in the Jamuna River at Bahadurabad on August to November 1994

In April 1995, in low flow conditions, the same comparisons were made. The main conclusions were:

- The variability of the transport is increasing towards the river-bed, see 5.4.5. The H-S results were consequently more scattered than the DB catches.
- The transport is increasing towards the river-bed, see Figure 5.16. The average transport of the H-S is smaller than the average catches of the DB. The DB transport between 0.35 and 0.15 m is rather constant, while only in the lowest point, a sudden increase can be observed.
- The grain sizes are increasing towards the river-bed, see Figure 5.16. This is a very consistent pattern, which can be observed many times (using one type of sampler). When using different types of samplers, the different loss of the different samplers play an important role, see Figure 5.17. From the Figure it can be seen that the grain-sizes of the DB catches at 0.05 m above the river-bed are much finer than those of the H-S.

In May 1995, the time-series measurements of the DB and H-S were made in strong flows (1.5 - 2.5 m/s). Important conclusions were:

- H-S transport was much lower than the DB.
- Variation of the H-S was considerable, but with a few (say 3 or 4) samples, a reasonable estimate is possible.

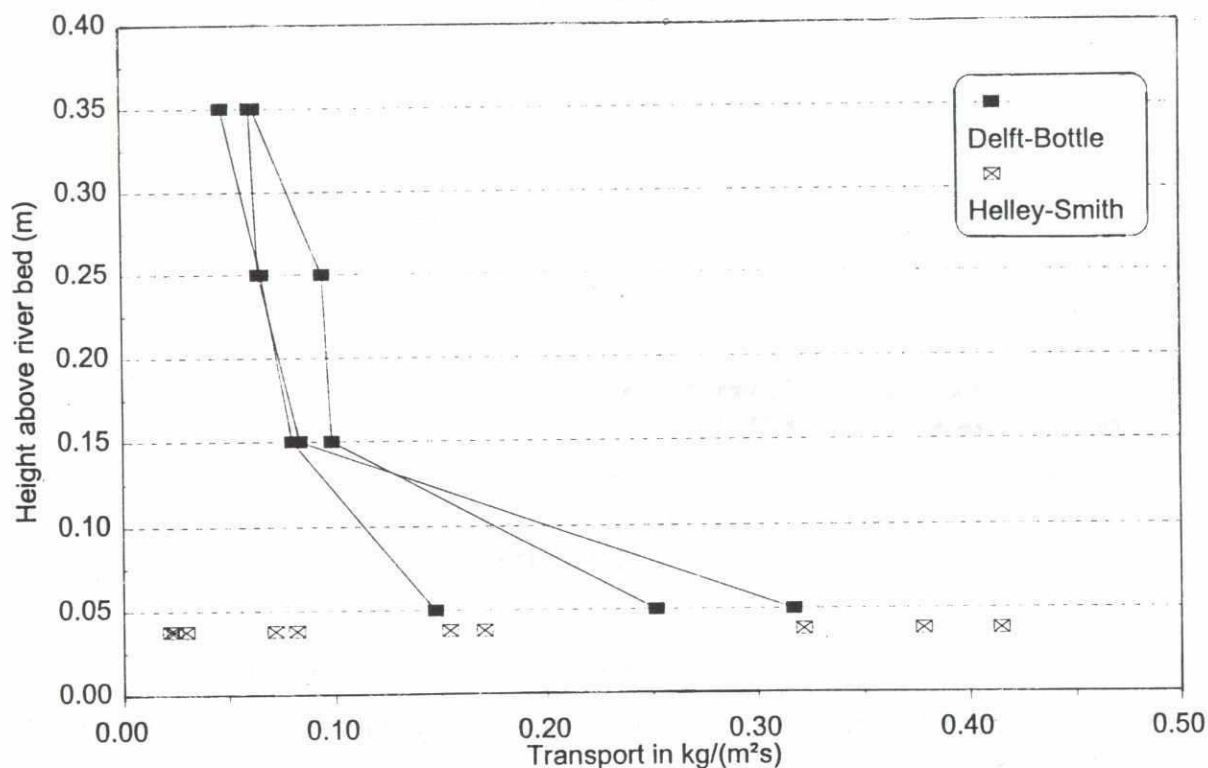
- Also, in these flows, the transports as measured with the DB are consistent. The pattern shows again that only in the last say dm, the transport increases considerably. Also the consistent increase of the grain sizes towards the river-bed was noticed.

#### **Comparison between pump system and Delft bottle**

Various special measurements on near-bed transport were done to compare the pump system with the Delft bottle. Such measurements were for instance those of August 1994, April 1995, May 1995 and July 1995. These surveys are presented in SPR 12. Some results are:

- During the measurements of 3, 4 August 1994 the pump-bottle was lowered 0.5 m above the river bed, while the DB was positioned in the frame at 0.35 m above the river bed so not exactly at the same vertical position. Nevertheless, the main results indicate the losses of the DB in the lower fraction.
- In April 1995, also pump-bottle measurements were done, with the carrier on the river bed which means that the intake nozzle was 25 cm above the river bed. So at this position the measurements with the pump-bottle and the Delft bottle are at the same position in the vertical. A few bulk samples (of 25 litre) with the pump-bottle were taken to enable grain size analyses. The results are presented in the following figures.

### Jamuna River, Bahadurabad 3 April 1995



### Jamuna River, Bahadurabad 3 April 1995

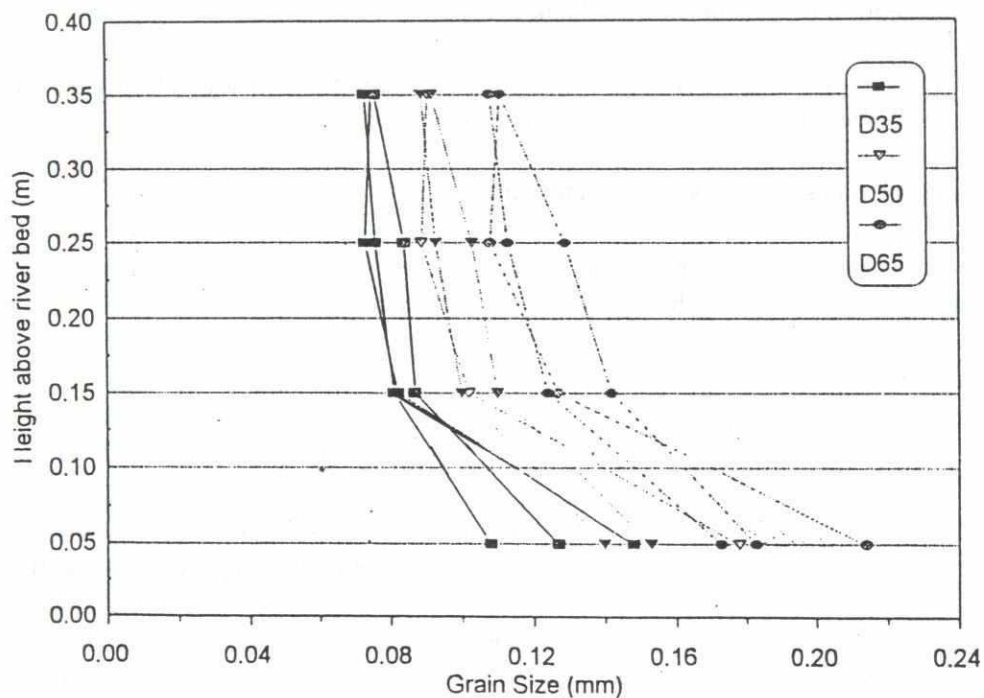
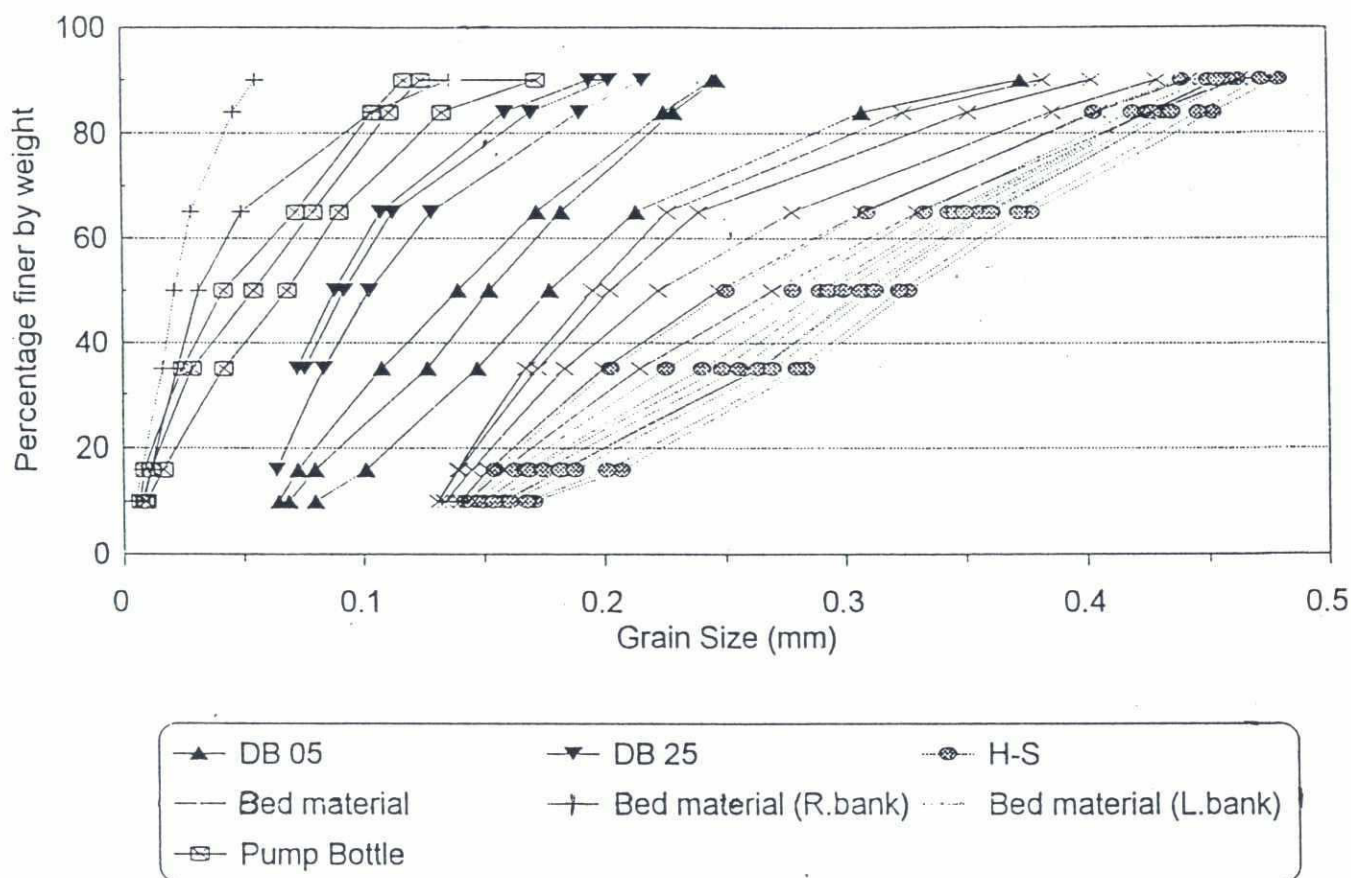


Figure 5.16 Near-bed sediment transport and grain sizes measured by Delft bottle on 3 April 1995 in the Jamuna River left channel near Bahadurabad





Note: All samples, except the bed material ones, were taken in vertical 1 (left channel; water depth 6.6m; distance from bank 225 m)

Figure 5.17 Grain size distribution of Delft bottle, Helley-Smith and bed-material samples collected on 3 April 1995 in the Jamuna River left channel near Bahadurabad

#### 5.4.4 Sediment measurements at tidal stations

During the tidal measurements not only flow gauging was executed as reported under 5.3.7 but also the following sediment characteristics were considered:

- grain sizes;
- concentrations; and
- transport rates.

Figure 5.18 shows that grain sizes of the Delft Bottle samples are similar to the grain sizes of the bed sediment and fairly constant over the tidal cycle (not much dependent on the flow velocity). It also shows that the grain sizes of the Helley Smith samples are significantly higher than the grain sizes of bed samples and Delft Bottle samples. This agrees well with the findings presented in *RSP Special Report 12: 'Optimisation of sediment measurements'* that the Helley Smith catches only the coarser fractions of the sediment transport. The figure further indicates that the grain size of Helley Smith samples increases with flow velocity. It is, however, doubtful whether this indicates anything about the grain size of the near-bed sediment transport.

Figure 5.19 shows that the grain sizes of the various fractions are largely independent of the flow velocity, except for the  $d_{90}$ , which varies distinctly with the variation in flow. This seems to indicate that the grain sizes of the suspended sediment increases when the flow velocity increases. It is interesting that this is not well reflected in the variation of the median grain size,  $d_{50}$ , but only in the  $d_{90}$ , ie in the size of the coarsest 10 per cent of the suspended sediment.

Figure 5.20 illustrates the variation with time of measured sand concentrations at different levels. Both the total concentrations and the sand concentrations vary with the tide, but the sand fraction most pronouncedly so, and especially near the bed (1m above bed). The sand fraction generally contribute to the total concentrations by less than 10%, except nearest to the bed (1m above) where it reaches approximately 20 per cent near maximum ebb flow. The figure indicates a phase lag of the concentration behind the discharges of the order of a few hours. In the secondary channel, there was no distinct variation with the tide, and the concentration was generally somewhat smaller here than in the main channel.

Figure 5.21 shows the variation of the sediment flux as measured by Delft Bottle 5 and 15 cm above the bed. It also shows the corresponding variation in grain size of the samples. There is a significant variation of the measured fluxes with the tide, but no distinct difference between measurements at the two levels.

The sediment transport over the entire cross-section can not be assessed with sediment measurements at only two verticals, as it was attempted in 1995. In 1996, therefore, a small number of sediment measurements were carried out at three additional verticals in order to be able to estimate the integrated sediment transport for the whole river cross-section.

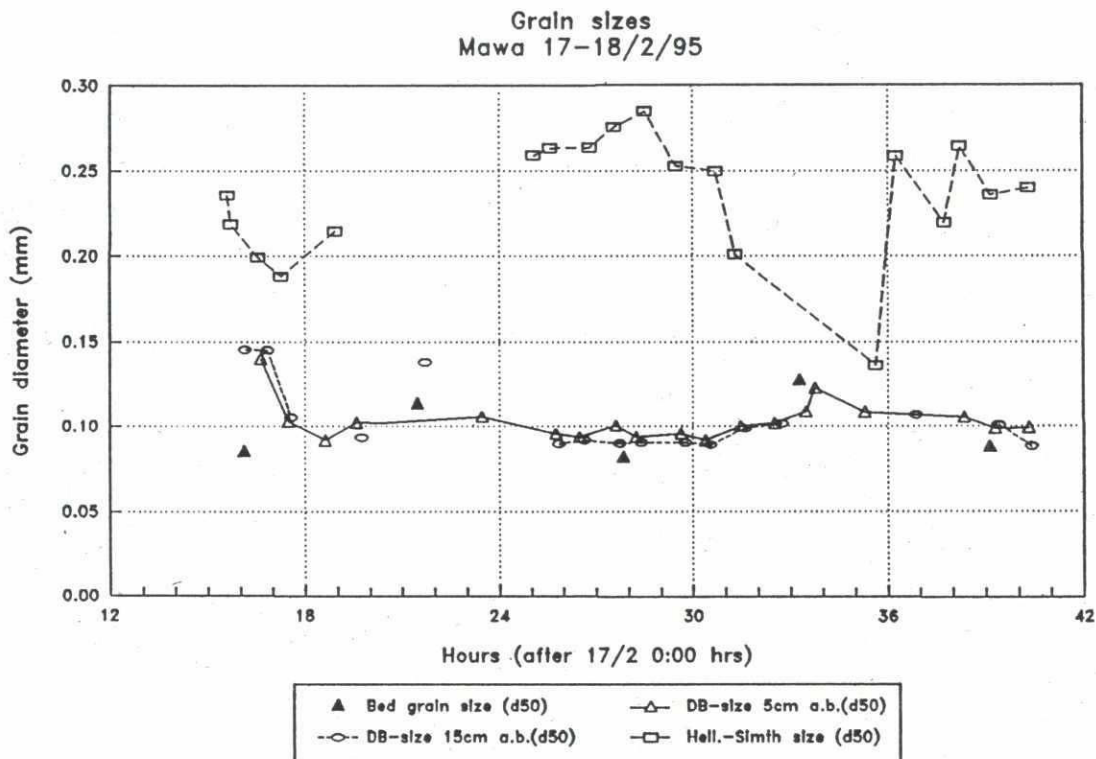


Figure 5.18: Tidal variation of median grain sizes of near-bed sediment (example, Mawa 17-18/2 1995)

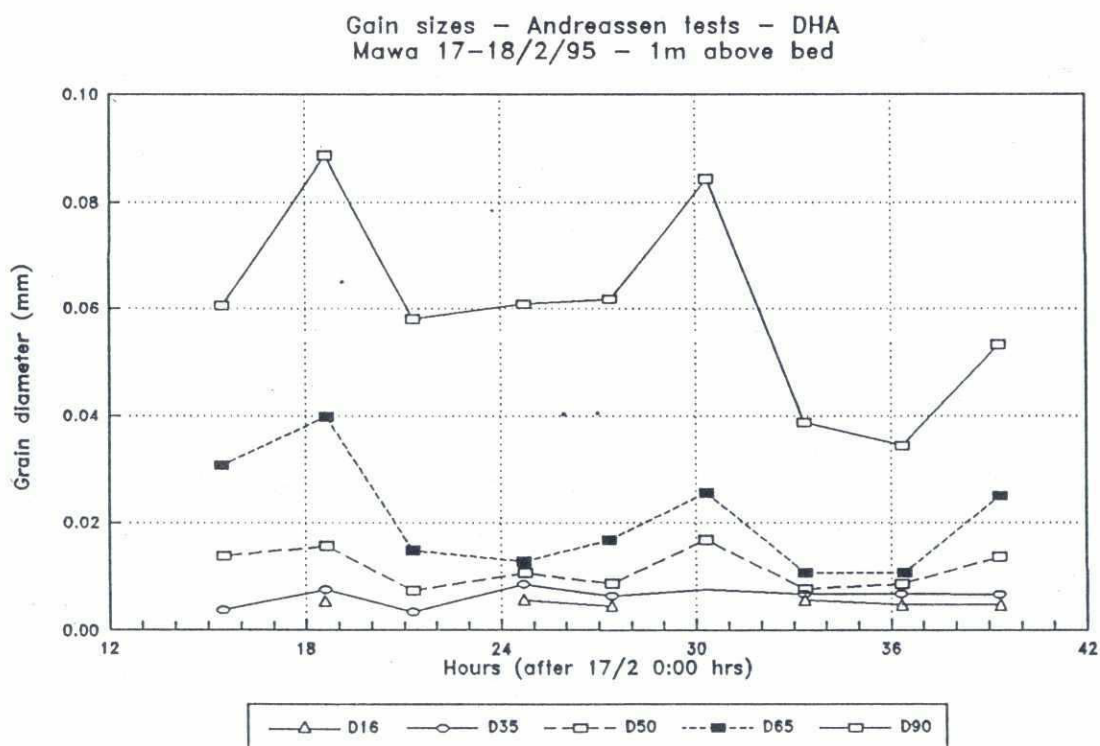
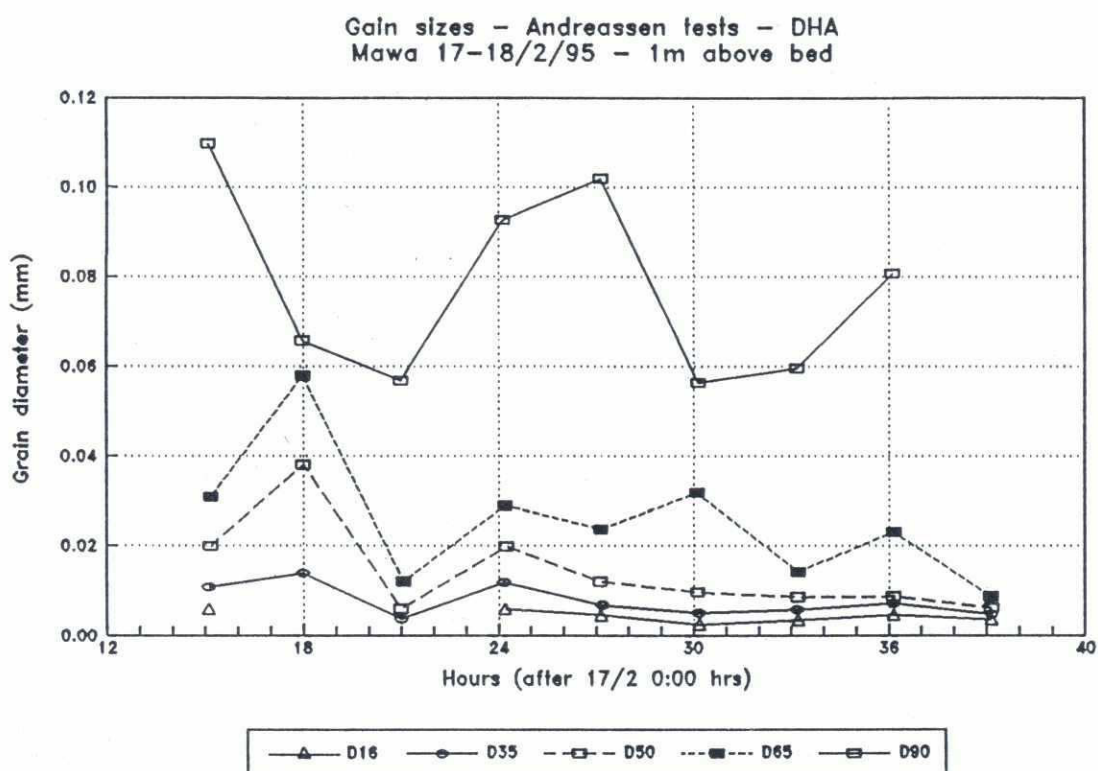


Figure 5.19: Tidal variation of grain sizes 1 m and 9 m above the bed (example, Mawa 17-18/2 1995)



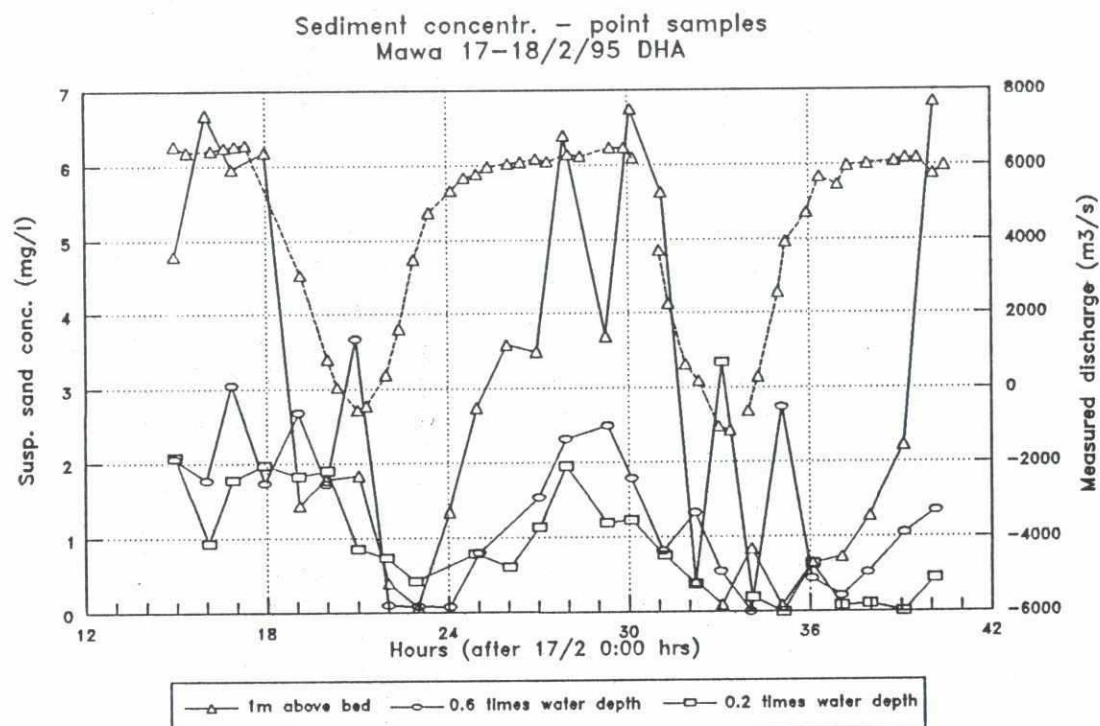


Figure 5.20: Tidal variation of suspended bed material (example, Mawa 17-18/2 1995)

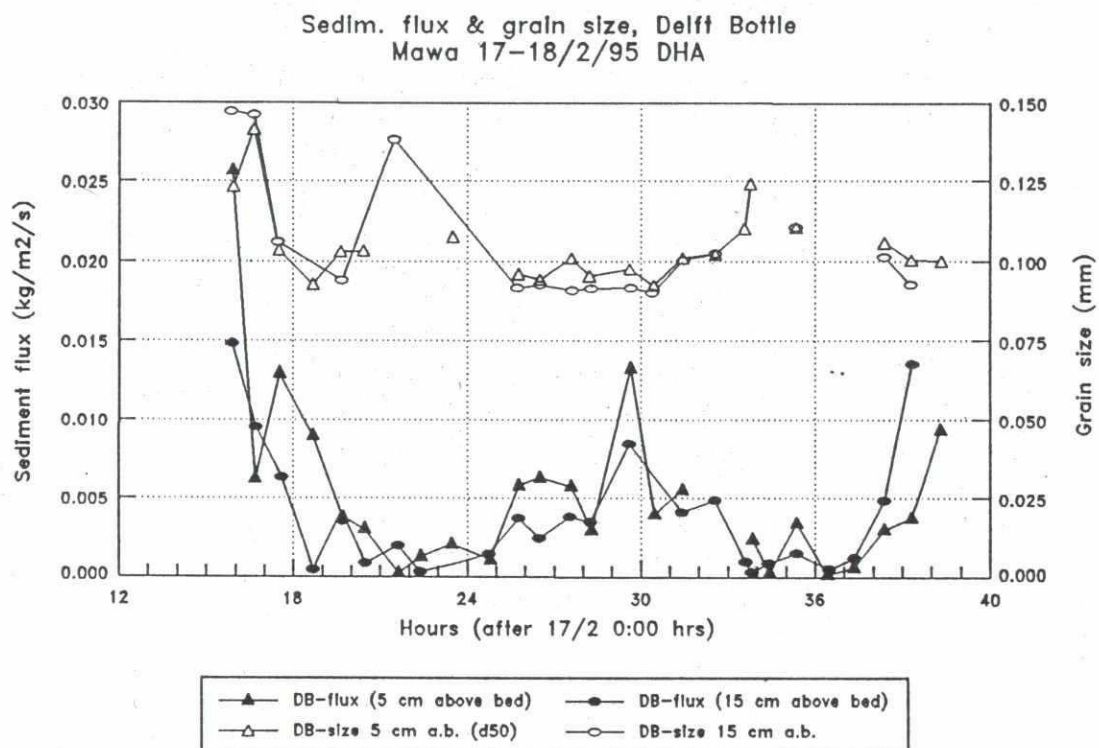


Figure 5.21: Tidal variation of near-bed sediment transport (example, Mawa 17-18/2 1995)

## Dune tracking

As a part of the 1995 tidal surveys, repeated dune trackings were carried out along a predefined survey line in order to possibly detect migrations or modifications of bed form caused by the combined flow conditions.

For a comparison between the bed levels at different times to be made, it is necessary to carry out a horizontal as well as a vertical correction. This because begin and end points of the survey lines may deviate by up to 50 metres. The horizontal correction was carried out as follows: A typical "average" line was defined. Then all the survey lines were projected onto this line. In principle, this involves a length adjustment factor as well as a shift of the starting point. But, because the direction of the lines were almost the same, the length adjustment factor was found to be 1.00 for all lines.

The vertical correction was carried out by reducing the bed levels to PWD. The water level from the AWLR at the left bank was used. Effects of a tilting water level (up to 0.25 m across the river) were not included.

Bed forms were observed occasionally. They were typically 90-110 metres long and up to 2 metres high. There was no clear sign of changes in dune shape during the measurements, possibly because the accuracy of the mapping (around  $\pm 5$ m horizontally and around  $\pm 0.1$ m vertically) did not allow for a resolution of such changes.

### 5.4.5 Accuracy and variability

Before reaching the user, suspended sediment data (either concentration or transport data) have undergone two distinct and separate operation, the sampling and the laboratory analysis. Therefore, any error can be a combination of errors from both of these processes. The sources of errors are as follows:

- *instrumental;*
- *sampling;*
- *field processing; and*
- *laboratory processing.*

The errors from these sources can be of two types, systematic and stochastic (random). While instrumental errors are primarily systematic, the other errors can be both systematic and stochastic. Some typical systematic instrumental errors are:

- *optical method representing primarily silt;*
- *acoustical method representing primarily sand; and*
- *Delft bottle representing primarily particles greater than 0.1 mm.*

Some sampling errors are:

- *different relative sampling rate (intake velocity/ambient flow velocity);*
- *contamination of samples during handling and transport;*
- *vibration and flow disturbance at the nozzle entrance;*
- *lowering of the sampler to an incorrect depth (for point-integrating methods); and*
- *partial depth-integration.*

Some field recording and processing errors are due to:

- *splitting of the sample;*
- *loss during sample removal;*
- *wrong field recording of time and place.*

Some errors due to laboratory processing are related to:

- *splitting of the sample into size fractions;*
- *measuring water volume and weighing of samples and filter paper;*
- *the sieve diameter;*
- *the assumed Stoke's diameter;*
- *wrong laboratory sample identification or reference.*

A main problem is encountered when analyzing the stochastic "error" from measuring results in a river. The variation of a registration is caused by the natural variability of the signal (e.g. of the concentration) which is partly measured (depending on exposure time) and other sampling inaccuracies. Other related questions are in how far the registration consists of stochastic independent samples and whether a stochastic model (and what model) is applicable. The PA noted that possibly the near surface variation is more symmetrical whereas near river bed skewed distributions may be expected. Another aspect is related with the objective of the measurements (e.g. are averaged or instantaneous values desired?). This should be kept in mind when applying an engineering approach in which errors are expressed in terms of standard deviations.

Variation from mean values are often expressed as standard deviation and called errors, see discussion in 5.3.6.

Errors range from 0 to 100% or higher. A 100% error means that the value of the standard deviation is as high as the mean value. Random errors can be minimized by improving the measuring facilities and the operational skills of the survey crew. Studies by Van Rijn (1986) indicate that pump-systems have the lowest overall errors and trap samplers have the highest.

One of the major sources of sampling error is the non-isokinetic sampling. Isokinetic sampling means that the relative sampling rate (intake velocity/ ambient velocity) is unified. The error from this source can be systematic or random. USGS studies (1978) indicate that there are errors in concentration estimates at different relative sampling rates. These studies also show that the relative sampling rate should remain between 0.8 and 1.2, so that the error remains within  $\pm 5\%$ . Above or below that sampling rate, the errors become unacceptably high. Studies by Nelson and Benedict (1950) show that the grain sizes of suspended sediment have a strong influence on the accuracy of sampling; the influence is appreciable for particles greater than about 0.06 mm.



To illustrate the variation of the suspended coarse sediment transport in low and high flows (being part of the so-called error) some ADCP registrations were analysed, see Figure 5.22 and Figure 5.23. The measurements were executed near Bahadurabad in December 1994 and July 1995 respectively. Important phenomena are illustrated by these figures such as:

- the considerable increase of the variation in higher flows, and
- the increase of the variability towards the river bed.

This confirms other observations done at other places in the world such as on the Amazone (Richey et al, 1986), the Orinoco (Meade et al, 1983), the Mississippi (Meade and Stevens, 1990) and the Zaire (Peters, 1981).

The figures also illustrate the reduction of the variability if using longer exposure times. This kind of information is useful to assess the appropriate exposure time (depending on the desired accuracy of mean-time values).

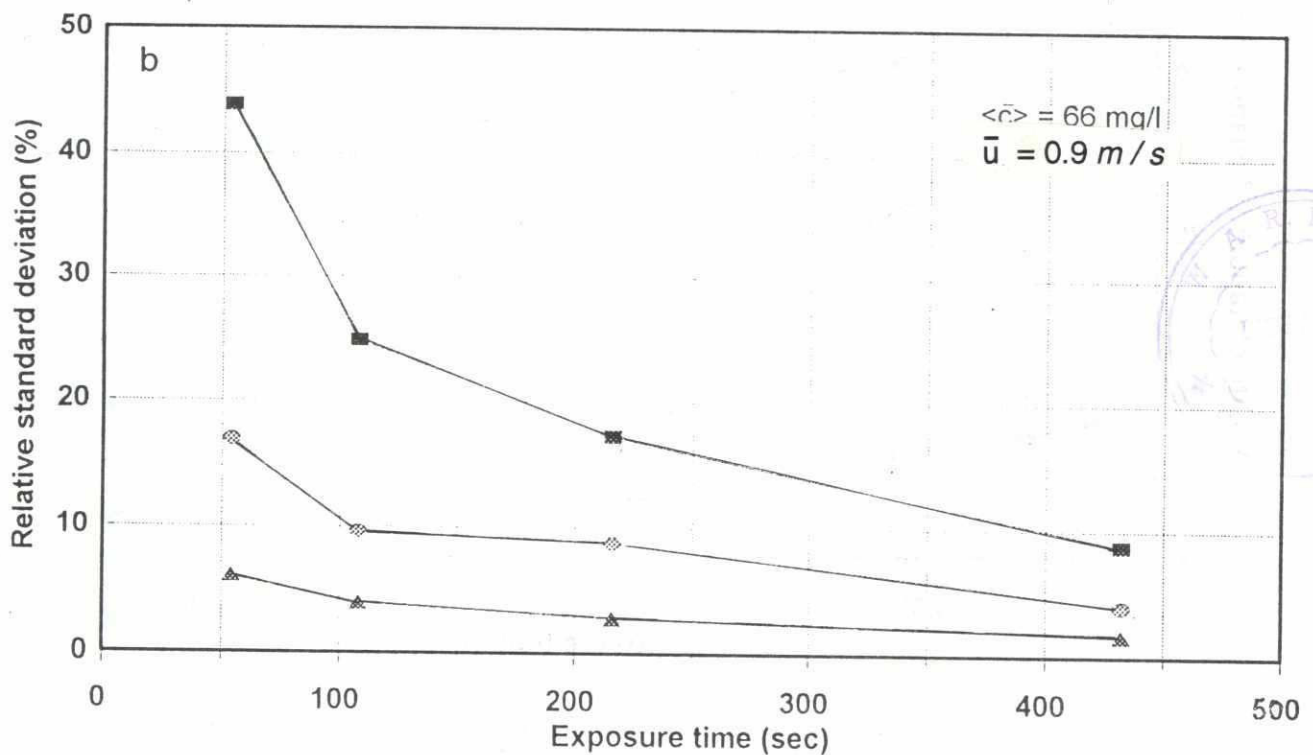
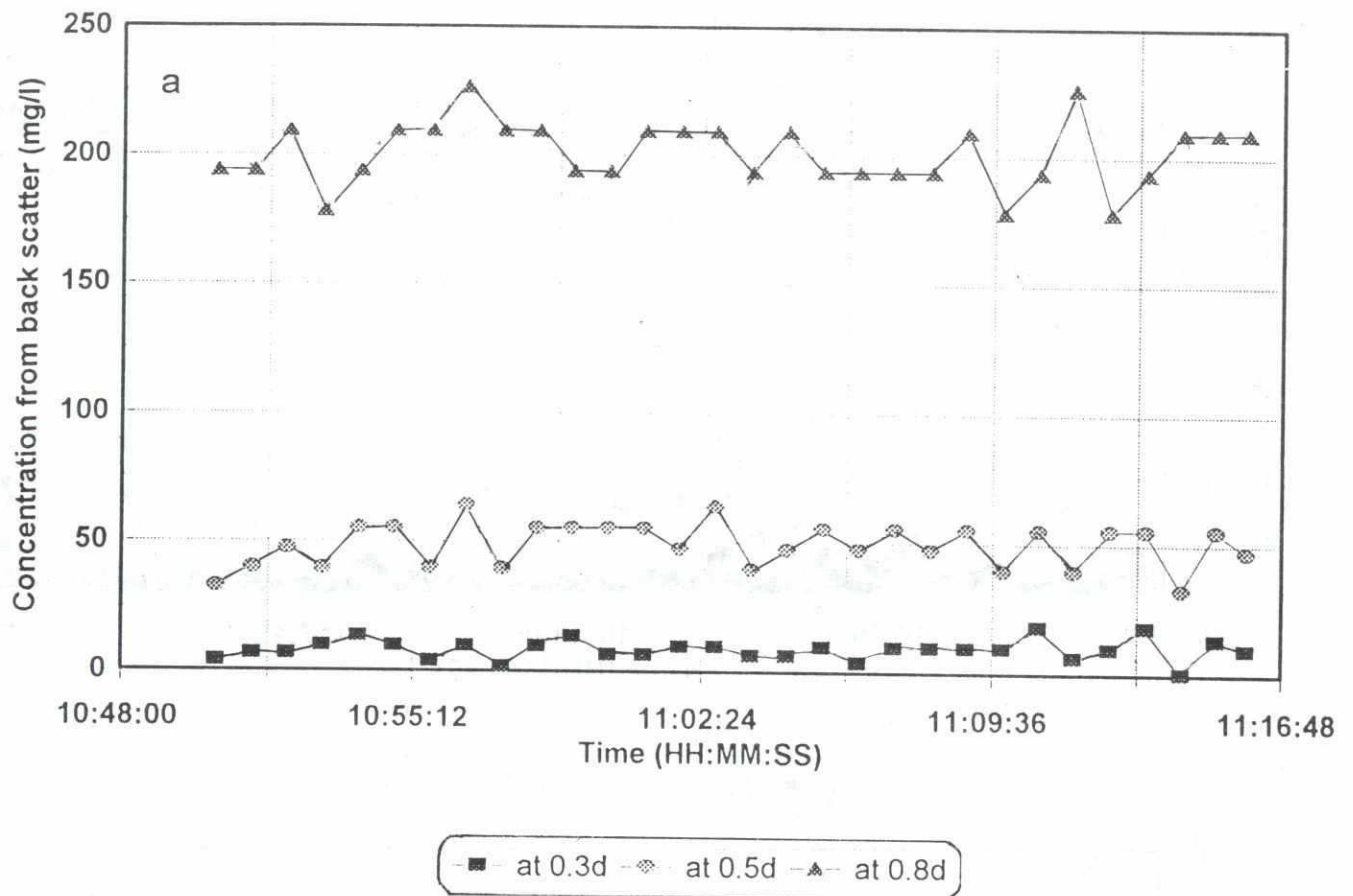


Figure 5.22 Variation of suspended sediment concentration in low flow, Bahadurabad, December 1994. (a) variation of suspended sediments (from ADCP backscatter intensity) (b) relative standard deviation versus exposure time

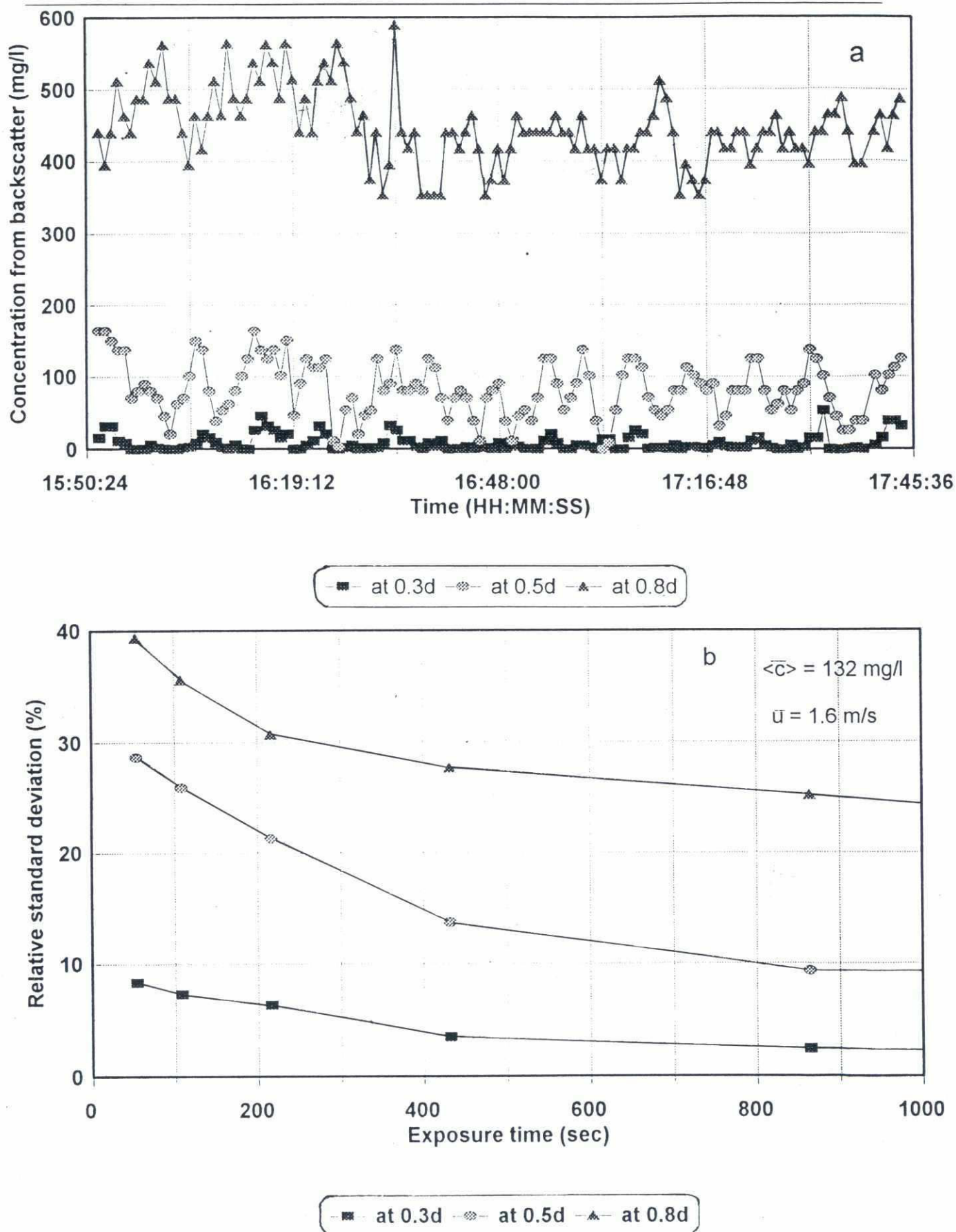


Figure 5.23 Variation of suspended sediment concentration in higher flows, Bahadurabad July 1995. (a) variation of suspended sediments (from ADCP backscatter intensity), (b) relative standard deviation versus exposure time



## 5.5 Joint BWDB/RSP measurements

### 5.5.1 Flow and sediment transport

#### Background

The first results of the RSP discharge measurements in 1992 and 1993, (plotted on the last available BWDB rating curve for Bahadurabad), indicated that the RSP measured lower discharges than BWDB during higher river stages at Bahadurabad. A '*Committee on Shift in the Rating Curve at Bahadurabad*' was established to examine the matter, with representatives from BWDB (Surface Water Hydrology I & II), FPCO, BUET, and RSP. One recommendation of this committee was to carry out a series of joint BWDB and RSP measurements. Hereby, the main objective was to identify possible systematic instrumental or methodological deviations. More specifically, the objectives were as follows:

- to identify differences in the measurements of the cross-sectional profile;
- to identify differences in the velocity measurements;
- to identify differences in flow angles; and
- to identify the influence of incorrect depth-measurements due to the cable geometry of the flow meter.

The programme of joint measurements is shown in Table 5.15. The results are presented in *RSP Special Report 19: 'Joint measurements hydrology'*. An extract is given below.

|      |                 |              |                            |       | 1) |                   |
|------|-----------------|--------------|----------------------------|-------|----|-------------------|
| 107  | Bahadurabad     | 17/-23/10 94 | routine gauging            | 17.26 | -  | 16.88             |
| 134  | Mawa            | 17-18/2 95   | routine gauging (tidal)    | 1.4   | -  | 1.1 <sup>2)</sup> |
| 139  | Bhairab Bazar   | 17-20/3 95   | routine gauging (tidal)    | 1.7   | -  | 1.5 <sup>2)</sup> |
| 9070 | Bahadurabad     | 16-20/7 95   | special comparative survey | 19.19 | -  | 19.34             |
| 9086 | Hardinge Bridge | 3/10 95      | special comparative survey | 12.76 |    |                   |
| 9089 | Mawa            | 19-22/10 95  | special comparative survey | 4.17  | -  | 4.31              |
| 9092 | Bahadurabad     | 7-8/11 95    | special comparative survey | 15.56 | -  | 15.62             |

1) water levels in m + PWD

2) HW respectively LW

Table 5.15: Joint BWDB/RSP measurements

#### Joint survey at Bahadurabad, July 1995

The joint survey at Bahadurabad in July 1995 may serve as an example of the joint measurements.

For this survey, the BWDB preselected the transects and verticals (as defined by the angles to the land markers). This was done because it was much easier for the RSP (using DGPS) to adjust to the BWDB transect than for BWDB (using sextant and land markers) to adjust to the RSP transect. Starting the measurements from the right channel, BWDB measured a total of eight channels in the transect, three of which were main channels. There were a total of 64 verticals in the main channels. At four verticals the measurements were repeated. The number of verticals measured per channel by the two parties is given in the following table:

|               | BWDB | RSP |
|---------------|------|-----|
| right channel | 26   | 12  |
| mid channel   | 8    | 8   |
| left channel  | 34   | 17  |

Table 5.16: Number of verticals in main channels

The flow velocity was measured at two points, 0.2 and 0.8 of the total depth, using a new SEBA current-meter suspended from the survey catamaran. The suspended sediment samples were taken with a Binckley silt sampler. The total water depth in a vertical was read from the SEBA winch counter.

The RSP measured the discharge twice along the BWDB transect using the ADCP-EMF moving boat method. The position of the survey vessel was determined by DGPS. In the shallow areas near the banks and chars, the flow velocity was measured by a Valeport current-meter operated on the DHE vessel. After the completion of a transect, the RSP returned to the BWDB verticals and took flow velocity measurements by ADCP-EMF in anchored position. Sediment samples were collected at 0.2 and 0.8 water depth. In the period that the RSP measured at one vertical from an anchored survey vessel, the BWDB measured at five verticals using dynamic positioning of the vessel. The applied techniques are summarised in Table 5.17.

| Item                                      | BWDB                                                                  | FAP24                                                                           |
|-------------------------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Vessel                                    | Catamaran                                                             | DHA and DHE (shallow water)                                                     |
| Sampling mode on a vertical               | No anchoring                                                          | ADCP-EMF moving boat in deep channels and anchored while using S4 current-meter |
| Vessel positioning                        | One angle measurement using sextant                                   | DGPS                                                                            |
| Depth/transect profiling                  | Length of current-meter wire at the verticals                         | Continuous profiling by echo sounders                                           |
| Current-meter positioning in the vertical | Length of current-meter wire                                          | Complete profiling by ADCP-EMF and by pressure sensor while using S4            |
| Flow velocity                             | SEBA propeller type                                                   | ADCP - acoustic Doppler<br>EMF, S4 - electro-magnetic                           |
| Flow direction                            | SEBA directional current-meter/ or measuring at the surface by floats | ADCP in 3 orthogonal directions<br>S4 in 2 orthogonal directions                |
| Points in a vertical                      | 20% and 80% of water-depth                                            | Vertical profile by ADCP, 6 points by S4                                        |

Table 5.17: Intercomparison of BWDB and FAP24 instruments and methods

The hydraulic data were analyzed by the RSP and compared with BWDB's field sheets data. The results of the analysis are summarized in Table 5.18.

|                                   | Width (m) | % deviation in width | Area   | % deviation in area | Discharge (m <sup>3</sup> /s) | % deviation discharge |
|-----------------------------------|-----------|----------------------|--------|---------------------|-------------------------------|-----------------------|
| <b>Fulchari main channel</b>      |           |                      |        |                     |                               |                       |
| RSP                               | 3100      | +5.3                 | 15,500 | +10.5               | 13,800                        | -5.8                  |
| BWDB                              | 2935      | -5.6                 | 13,900 | -11.7               | 14,600                        | +5.5                  |
| <b>Bahadurabad main channel 1</b> |           |                      |        |                     |                               |                       |
| RSP                               | 1920      | -10.4                | 15,600 | +4.8                | 34,600                        | +3.5                  |
| BWDB                              | 2121      | +9.4                 | 14,900 | -5.0                | 33,400                        | -3.6                  |
| <b>Bahadurabad main channel 2</b> |           |                      |        |                     |                               |                       |
| RSP                               | 1700      | +1.8                 | 8,720  | +10                 | 6,700                         | -9.0                  |
| BWDB                              | 1670      | -1.8                 | 7,850  | -11                 | 7,300                         | 8.2                   |

Note : + higher, - lower

Table 5.18: Comparison of joint measurements in July 1995

In all three main channels, the area measured by the RSP was 5 to 10% larger than the area measured by BWDB. The probable reasons for this are: (1) riverbedforms, (2) an inadequate number of verticals in the cross-section for area estimating by BWDB, and (3) different depth registrations and measurement locations between the RSP and BWDB. Indications were that the depth registrations of BWDB were less than of the RSP, and that the BWDB verticals in the left channel were not located exactly on the transect, but even in the other two channels, where the BWDB verticals were close to the transect, the areas were different. This can be due to the observed bedforms, which affect the accuracy of the flow area when calculated on the basis of a relatively few verticals. The wire angle of the SEBA current-meter applied by BWDB remained within 8 to 12°, which does not significantly affect the resulting depth.



Figure 5.24:  
The catamaran  
applied by the BWDB

In approximately fourteen verticals the flow velocity measured by the RSP was 5% to 20% lower than the one measured by BWDB. This difference is slightly more than the estimated accuracy of the flow velocity measurement itself, which is approximately 10%. The accuracy in the flow angle measured by BWDB is about 5° to 10° in the same direction as the sequential



verticals. A  $10^\circ$  difference is high and certainly has some influence on the calculated discharge in oblique flow.<sup>k</sup>

During the measurements in a vertical, the catamaran moves about 20 to 30m upstream and downstream during its dynamic position, depending on the flow velocity and the distance to the marker of the transect. Provided that these movements are slow and regular they may have only a small influence on the calculated discharge, but a net relocation of 20-30m within a measuring period of 100 s represents an erroneous speed contribution of  $\pm 0.20$ - $0.30$  m/s. Also, the depth can change within this distance. It may be speculated that the movement of the catamaran increases with an increasing current-speed.

After completion of the discharge measurements, some comparative measurements were taken at an anchored position, showing that the Ott and SEBA instruments of BWDB registered a lower flow velocity than the ADCP and S4 instruments of the RSP. The contradiction that during transect measurements the BWDB measured sometimes higher and during the final comparative measurements lower flow velocities than the RSP may be explained, at least partly, by the anchoring differences.

### Evaluation of flow measurements

#### *Anchoring and positioning*

The accuracy of sextant positioning implies that the distance between poles 2 and 3 should be sufficiently large, and the angle should not be too small. Moreover, the visibility (e.g., wide rivers and rain) is important. Other factors are the skill of the helmsman and the calibration of the sextant.

The relative accuracy of the dynamic positioning of BWDB can be highly supported by deploying a light marker buoy during the measurements, so the vessel can be positioned relative to this buoy instead of relative to distant land marks.

The relative accuracy of the DGPS is related to the number of readable satellites and the atmospheric conditions.

#### *The cross-section profile*

The BWDB measured the depth using a winch counter for the wire of the current-meter. The wire angle was usually not measured; however, the field registration sheet had a column for the angles. There is no doubt that the overestimation of the depth determined by using the wire length directly can be significant, and can be reduced at no cost by applying a simple correction for the wire angle (as a function of type of instrument, depressor weight, current-speed, and wire length). After measuring the depth aboard the BWDB boat, the required instrument level was calculated (0.8h and 0.2h) and the wire length was adjusted accordingly using the winch counter.

The RSP's ADCP transducer was installed flush with the underside of the survey vessels, whereby its level was fixed within a margin of a few decimeters. The same was the case with the EMF, which was installed in front of the bow of the DHA at a fixed depth, usually 0.5m below the water surface. The S4 was used from a suspension cable, and its depth was measured with a pressure cell.

### *Current-velocity*

Considering the performance of the applied instruments, the current-velocity (when measured at a certain point in the flow during a sufficient long period) should hardly deviate between the different instruments used by BWDB (Ott or SEBA) and the RSP (ADCP/EMF or S4).

The observed differences may be due to the natural temporal variability of the flow, the different sampling periods, and the calibration of the current-meters.

|                          | BWDB  | RSP   |
|--------------------------|-------|-------|
| SEBA, Ott current-meters | 100 s | –     |
| ADCP/EMF                 | –     | 6 s   |
| S4                       | –     | 100 s |

Table 5.19:

Sampling periods for flow measurements

When using the ADCP-EMF moving boat method, the velocity is measured while crossing the river. The individual recordings are instantaneous (6s sampling time), but in the flow calculation, they are averaged over a certain subsection of the transect, typically covering a time increment of 20-30s and a length increment of around 50m. Hereby, the accuracy is improved, because the repeated measurements are stochastically related. The averaging period is relatively short, but a good consistency has been demonstrated between the verticals (e.g., *SEE RSP Special Report 19: 'Joint measurements, hydrology'*). Nevertheless, some systematic deviation can be introduced by this procedure (as well as by alternative ones).

### *Flow direction*

In general, the BWDB used non-directional current-meters for velocity measurements. The flow angle was measured between the flow direction and the measuring line using a surface float and applied at 0.2 and 0.8 depths for the perpendicular components.

An inspection of many RSP vector plots shows that the vertical variation of the flow angle is small. Variations occur, but are mostly confined to local parts of the cross-section, such as boundaries between sub-channels. These boundaries often coincide with the flow transition zone separating the flows in the various sub-channels. Since the variations of the flow direction along the vertical are only local phenomena, the effect on the total discharge is assumed to be negligible. In other words, the error made when assuming that the flow direction over the vertical is constant is minor.

### *Horizontal resolution*

The horizontal variation of the flow in magnitude and direction is considerable. The velocities range from 0.5 to 2.0 m/s; the angles range from 20° to 120°. Therefore, an adequate horizontal distribution of measuring verticals is required to resolve the variations. The relatively high number of verticals, as measured by the BWDB, seems appropriate and justified for covering the horizontal variations.



| Channel               | Number of<br>verticals | Width<br>(m) | Average spacing<br>(m) |
|-----------------------|------------------------|--------------|------------------------|
| Fulchari channel      | 37                     | 2871         | 78                     |
| Bahadurabad channel 5 | 25                     | 2153         | 86                     |

Table 5.20:  
Spacing of BWDB  
verticals (example)

### Recommendations

The following recommendations are made on the basis of the joint flow measurements:

- to consider whether an echo sounder can improve the accuracy of the measurement of the channel cross-sectional area;
- to register the wire angle and apply a correction;
- to improve the measuring method of the flow direction; and
- to improve the positioning system and to consider implementation of GPS or DGPS positioning in order to improve the accuracy of width measurement.

### Evaluation of sediment transport measurements

#### Background

In connection with the joint measurements programme, sediment transport measurements were made at the BWDB transects at Bahadurabad and Mawa in July and October 1995, respectively. Bahadurabad is BWDB's only discharge and sediment gauging station in the Jamuna River. These data are used for various practical planning and design purposes; therefore, it is important to maintain a good quality of the sediment gauging technique as well as of the sediment transport data.

#### Survey at Bahadurabad, July 95

During the joint measurements at Bahadurabad in July 1995, BWDB used their routine methods to take the suspended sediment measurements. Sediment samples and flow velocity measurements were taken simultaneously in a vertical at depths of 0.2 and 0.8 by a Binckley silt sampler and an SEBA current-meter respectively. BWDB measured flow velocity in a total of 64 verticals in all the channels intersected by the transect of BWDB; the sediment concentration was measured at every second vertical. The RSP followed the BWDB verticals and measured suspended sediment concentration and flow velocity simultaneously at depths of 0.2 and 0.8 by pump sampling and ADCP respectively. The RSP could not complete all the BWDB verticals since the RSP routine comprised anchoring the vessel during the measurements (which is somewhat time-consuming).

The deflection angle of the supporting cable of the Binckley sampler was measured a few times; the angle ranged from 30 to 45° at 0.2 depth and from 40° to 60° at 0.8 depth. The flow velocity ranged from 0.9 to 2.8 m/s in the verticals. The comparison of results showed that BWDB measured remarkably less suspended sand than the RSP at both 0.2 and 0.8 depths. The concentrations measured by BWDB at 0.2 and 0.8 depths did not differ much, while the ones measured by the RSP did (the lower-level concentrations being higher). Further, the difference between concentration measured by the RSP and BWDB increased as the flow velocity increased.



### *Evaluation and recommendations*

The observed deviations can be explained by the large vertical angle during sediment sampling by BWDB. Therefore, the samples were not collected at 0.2 and 0.8 depths, but at lower depths. The problem was supposed to be solved by dynamic positioning in such a way that the sampler is dropped in upstream locations and the sample is taken while the vessel is floating and reach the measurement location (FAO, 1969). The procedure should be strictly followed. In addition, as discussed earlier in different sections, the instantaneous nature of the sampler provides a higher sampling error. This can be addressed by taking a number of samples at the same location.

## • 5.5.2 Morphology

### **Background**

The Morphology and Research Circle of the BWDB executes cross-sectional profile measurements of some 34 transects along the Jamuna River. These sections have been monitored annually since 1966. The data, forming a reasonably long time-series, provide a very useful information about the morphological processes, and have been used in various projects and by researchers.

There is a potential for upgrading of the monitoring, with respect to the overall data quality, measurement techniques, data analysis, and documentation. Therefore, in January, 1994, a joint BWDB/RSP survey of a specific standard cross-section was agreed on between the BWDB Morphology and Research Circle and the RSP.

The BWDB standard cross-section J#13\_1 in the Jamuna River was selected for this purpose, and the survey took place 24-26 March, 1995. The joint activities comprised two parts, one being the field measurements and the other being the post-processing of the data.

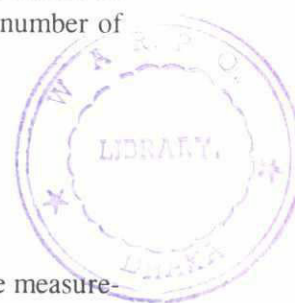
The objective was to obtain an impression of the BWDB standard cross-section survey methodologies, and the accuracies of the presented resulting data. Hereby, particular attention was given to identifying the monuments/pillars on both banks, the land area survey procedure, the wet area survey procedure, a comparison of BWDB and RSP results, data elaboration in the office, and sources of possible errors in the field and in the office.

The joint survey is described in *RSP Special Report 20: 'Joint measurements, morphology'*, from where the following summary has been extracted.

### **BWDB survey procedure**

#### *Identification of the cross-section*

The cross-sections for the Jamuna River were defined already in 1965 and 1966, and no information regarding the applied criteria for their identification could be retrieved. Presumably, an interspacing of about four miles, and an orientation almost perpendicular to the course of the river in those years have been the main conditions. Local circumstances may have forced the survey team involved to deviate slightly from these requirements.



In the early seventies, five additional cross-sections were introduced in between cross-sections J#12 and J#13, with an interspacing of about one mile, for a study of a barrage near Bahadurabad; however, these additional soundings are not performed regularly.

It should be realized that the present courses of the river branches may well differ considerably from the state in 1965+1966, so that the cross-sections defined at that time are not necessarily perpendicular to the present main courses.

#### *Horizontal and vertical control*

The location of a cross-section is fixed in the field by two monuments/pillars at one bank of the river and a third one at the other bank. The elevations of both left bank monuments/pillars for the examined cross-section J#13-1 were expressed in m+PWD. Their positions are not related to the national grid, but are defined by the names of the land owners, the mouza, the police station, and the district in which each monument/pillar is placed.

The monuments of cross-section J#13-1 were located at a considerable distance from the main channel(s) of the river. For example, monuments M-1 and M-2 were located about 3.5 km from the present bank line, while the distance between the right bank of the right channel and monument M-3 was some 2.6 km.

The orientation of a cross-section has been defined when erecting the monuments, but is checked during the yearly survey. All bearings are expressed relative to magnetic north, using a compass in the past and a theodolite with a built-in compass at present. The bearing for cross-section J#13-1 had been registered at 261 degrees, while, during this survey, a bearing of 259°14' was recorded. This bearing was found by positioning the theodolite over monument M-1 and focusing on a 5m bamboo positioned at monument M-2. The distance between the monuments of this cross-section was 189m only, but, due to a levee in between, it was not possible to aim directly at the nail on monument M-2. The difference between the official and the practical bearing of this survey line represents a deviation of about 500m at monument M-3, at a distance of 16.4 km.

The reference levels of the monuments/pillars were connected with PWD bench-marks in the mid-sixties. If there is a shifting of monuments, the reference plane is transferred from a nearby GTS or BWDB bench-mark.

Starting at monument 1, the vertical control is maintained by a levelling instrument, measuring the elevation of various temporary pegs, until the first channel is reached. There are no means for intermediate checking.

#### *Measuring the dry part of a cross-section*

The basic procedure for measuring the dry part of a cross-section is the same for surveying the floodplain starting at monument 1, as for surveying a char, starting at the water line:

- The survey line is established from the nails in the two monuments by means of a theodolite with a built-in compass;
- Temporary pegs are placed at conspicuous points where there is a discontinuity in the longitudinal profile. Their position relative to the survey line is controlled by means of the theodolite;
- The distances between the pegs are measured by means of a measuring tape;



- The elevation of the ground is determined by means of a levelling instrument. The interspacing is about 60m for level ground and less in case of level discontinuities;
- This procedure is repeated until the next water line is encountered. Then, the elevation of the water line is determined; and
- When crossing a channel, the survey line is controlled by means of the theodolite, while the vertical control is maintained by assuming that the elevation of the water line on both sides of the channel is the same.

#### *Sounding of the water part of a cross-section*

After determination of the elevation of the water line, as described above, the water part of a cross-section is sounded as follows:

- The survey line is indicated by erecting two bamboos of different height in the line of the cross-section, with an interspacing of some 20 to 40 meters;
- A base line perpendicular to the line of survey, with a length of about 150 to 300m, depending on the width, is established;
- The theodolite is positioned at the end of this base line;
- the shallow section (up to a depth of about 0.6m) is sounded by wading, while the location is determined by reading the angle between the base line and the levelling staff;
- A portable Raytheon echo sounder is installed on board a motorized country boat with a draft of 0.5m;
- The transducer is hand-held along the side of the country boat, only secured by a tether line. The vertical position is controlled by a mark on the transducer pipe. The vertical orientation depends on the experience and attention of the staff member in charge;
- The country boat starts sailing from the opposite bank towards the bank where the base line has been established;
- The man at the echo sounder commands for a fix or mark at major discontinuities in the bed profile. Following this command, a bamboo with a flag is raised by a man on the roof of the country boat and the man at the theodolite is expected to read the angle. The marks are indicated on the echo sounder recording paper by a marker line, and at the theodolite by an entry. When these two sources do not match, there is no other information available for correction (such as the time);
- Meanwhile, the helmsman controls the in-line position of the boat;
- when arriving at the nearest bank, the remaining shallow section is again surveyed by wading; and
- The vertical control is maintained by measuring the elevation of the water level at one bank only.

#### *The RSP survey procedure*

The land survey was performed by an electronic distance meter. After calibration, this instrument can display on a digital monitor the co-ordinates, distance, and the vertical and horizontal angles of the point where the reflector is placed. For calibration, at least two points of known co-ordinates are required, whereafter the measurements are made relative to a point with known co-ordinates. During the joint measurements, the calibration and the positioning of the first point were made relative to two survey vessels placed at three different locations that were positioned by DGPS. The level was calibrated assuming a zero gradient of the water level. From this point, the first land part and the shallow water part of channel 1 was sur-



veyed. The next point was positioned relative to the first one and was checked relative to the two survey vessels.

The water part of the transect was surveyed by echo sounder and DGPS positioning system. Hence, the water part of the survey line consists of several points with known coordinates and depths of water. The vessel sailed approximately with a predefined bearing, from near the points where the land survey ended.

#### *BWDB data processing*

The raw data from the BWDB survey are kept in two certified notebooks. One is called the '*Field Book*', which is the complete document of the water part survey. The other book is the '*Level Book*'. Here, the back, intermediate and fore level readings are recorded with corresponding chainages. Later, the levels are converted to the PWD reference level. In the '*Level Book*', various features (such as the toe or top of road/embankment, the high bank, and the water line) are recorded against the corresponding point. Hereby, the '*Level Book*' contains almost the complete features of the land part survey. Between them, the '*Field Book*' and the '*Level Book*' form the complete field documentation of a BWDB standard cross-section survey. The standard procedure of the primary data processing is that the raw data in the '*Field Book*' and the '*Level Book*' are processed by the surveyor in the Sub-Divisional Office. This involves reduction of level readings to PWD datum, distributing the closing errors in both the vertical and the horizontal direction, and, for the water part survey, converting theodolite angles and offsets into chainages, and reducing the water depth from the echo sounder to PWD level.

The next part of the data processing comprises copying the primarily processed data from the '*Field Book*' and the '*Level Book*' into the '*Data Processing Sheets*', and plotting the ground level in PWD datum against the chainage from the left or the right bank monument in the '*Comparison Map*'. In the '*Data Processing Sheets*', the levels are entered with their corresponding chainages, while the important features are noted in the remarks column. Generally, the comparison plots contain four consecutive years of survey plots of a standard cross-section.

Another sheet, named the '*Channel Characteristics Sheet*', contains channel-wise information, such as the water width, the maximum depth, the average depth, the cross-sectional area, etc. Channels that are dry during surveys in the lean period are excluded in the '*Channel Characteristics Sheet*'. Typing, compiling and printing the '*Data Processing Sheet*', the '*Channel Characteristics Sheet*', and the '*Comparison Map*' provide the final format of the processed data, as published by the Morphology Division of BWDB.

#### **Analysis of the joint survey data**

The analysis comprised (1) a comparison between the BWDB and the RSP surveys, (2) a comparison between both surveys and SPOT images, and (3) a comparison of BWDB surveys in different years.

The monuments of a BWDB cross-section are not defined by geographical coordinates, so it is difficult to fix the cross-section on satellite images. During the joint measurement, however, the starting point of the RSP survey (with known geographical coordinates) was a point also applied by the BWDB survey. Hereby, this point and the observed bearing could be located on the tracing of SPOT images.

The comparison showed that the difference between the lines increased gradually and stepwise along the chainage, and that the maximum shifting was about 150m. In one channel, the lateral variation was negligible, while the recorded riverbed levels differed considerably, maybe due to an error introduced during the distance measurement in the water part of the BWDB survey.

The measurements were compared with the tracing of SPOT images of 24 March 1995. The time lapse between the SPOT images and the survey was only two days, and the corresponding water-level variation was 0.02m (at Bahadurabad). A considerable deviation was found with respect to the water lines determined by BWDB (a lateral error of more than 150m during the 2240m length of the joint survey).

The overall agreement was fairly good, with differences of the extreme two channels relative to the SPOT images remaining within 100m. However, internal inconsistencies were sometimes higher, and were distributed in an irregular way along the transect. The reason behind this type of error cannot be explained without knowing the closing error of BWDB and its compensation over the cross-section.

A comparison between BWDB surveys of 1993, 1994 and 1995 showed a fair consistency, with certain exceptions, indicating that the surveys of different years did not follow exactly the same line, or a deviating reference level.

### 5.5.3 Discussion and evaluation

#### General

While the overall performance of the BWDB monitoring is impressive, a margin remains for further quality improvement, as indicated by the following observations and suggestions.

The reason for establishing the monuments outside of the floodplain of the river is understandable. However, the absence of any intermediate points, although vulnerable, eliminates the possibility for any intermediate check. Consequently, a possible error is not detected until arriving at the third monument at the other river bank, making it close to impossible to adjust or to correct the data in an appropriate way.

The absence of a basic line elaboration in the field precludes a means of correction, if errors are detected in the office during data processing. No impression could be obtained of the magnitude of the closing error when finally arriving at the last monument, and the procedure for handling the closing error was not fully transparent.

The position of monuments/pillars of the BWDB cross-sections should be defined within a general geographical co-ordinate system, for example the BTM. This would highly facilitate the use of the results for different purposes, by allowing for a good and easy identification of the cross-sections on maps, satellite imagery, or chainages.



### Surveying the dry part of a cross-section

The bearing of the cross-section was fixed by two monuments on the left bank of the river. At cross-section J#13-1, the monuments were only 189m apart. Still, it was impossible to make a direct sighting, so a vertical bamboo pole was applied to mark the position of the one monument. With the applied procedure, this type of deviation from year to year with respect to bearing can dislocate the survey line by up to nearly 500m at its end.

Distances are measured by a measuring tape. The surveyor in charge has to record the number of times that he has travelled over the full length of this tape. Under the hard conditions in the field, it is rather likely that some errors are made. Examples of such errors were observed.

Just as there is a possibility of a closing error in the vertical direction, similar closing errors are likely with respect to the direction of the survey alignment and the lateral deviation between the survey line and the fixed alignment. It is not clear how those errors are compensated.

### Sounding of the water part of a cross-section

The following observations were made:

- The bamboo poles with flags marking the line of survey were positioned with an interspacing of 20 to 50m only; during sounding, a deviation of up to 40m out of line was estimated. In between two consecutive fixes, this type of deviation from the survey line can cause an error that is two to three times as large.
- The time lag between marking the fix on the echogramme and measuring the angle at the theodolite was sometimes considerable.
- The assumption that the water level is the same at both banks of a channel may not be correct. The more the cross-section alignment deviates from the perpendicular direction, the higher the possibility of a water level difference across the river.

#### 5.5.4 Recommendations

The following recommendations can be made regarding the BWDB surveys:

- At least two monument/pillars of each BWDB cross-section should be defined by geographical co-ordinates;
- Intermediate pillars or monuments should be erected on the floodplain closer to the river, as well as on permanent or semi-permanent chars, and should be levelled, to serve as an intermediate check of the horizontal and vertical control;
- A field calibration of the echo sounder should be made before and after a days survey. In case of a distinct difference, a full range calibration by means of the calibration bar should be executed;
- Fixes and depth marks should be recorded on a time base, so that missing fixes can subsequently be identified;
- For positioning of the soundings in the water part survey, two theodolites should be applied instead of one, and the base line should be extended in both directions;



- A basic line elaboration of the data should be executed in the field for a check on errors. For this purpose, the survey team needs information about all pillars (elevation and distance); and
- A transparent data validation and documentation system should be established and implemented in the Morphology Division or in the Morphology and Research Circle office.

## 5.6 Hydrographic surveys

### 5.6.1 Data requirements for morphological studies

In the context of the River Survey Project hydrographic surveys are envisaged as an important activity to support the morphological studies. The Terms of Reference specifies this issue as follows (Section 4.2.a.5):

*"A programme for future observation and monitoring of morphological changes will be established, using river surveys and satellite imageries. In view of rapid morphological changes in the river during the flood season (...) significant changes only become visible after floods and therefore it is proposed that surveys are carried out immediately after and before each major flood wave and, if considered necessary, during flood stages".*

In general hydrographic charts are compiled of various types of information:

- bathymetric data
- topographic data
- hydraulic information (water levels, flow)
- other information (buoys, landmarks, etc.)

In the following subsections a number of these issues are elaborated.

### 5.6.2 Data applications of bathymetric surveys

Typical applications of bathymetric survey data are as follows:

- Preparation of navigational charts. Hereby, the 'safe depth' is determined. Emphasis is given to waterways, shipping lanes and other navigable areas.
- Morphological monitoring. This requires repeated mappings of the surface of the riverbed over the impact area of the morphological processes, normally up to the highest stage, which in turn indicates mapping by a combination of bathymetric and topographic surveys.
- Applications that involve hydrodynamic modelling: flood forecasting, studies of hydrodynamic, morphological or environmental impact, and other analyses that require prediction of future developments.

These applications impose partly different requirements on the survey procedure, the coverage in time and area, and the processing and presentation of results.

Considering the costs of bathymetric mapping, as many purposes as possible should be accommodated at the same time.

In the confined case of navigational charts of river reaches in Bangladesh, neither the absolute vertical accuracy nor the related overall consistency are crucial. The skipper navigating on a river probably does not care about last year's safe depth, nor about the bed level elevation at Bahadurabad relative to the one at Aricha. The main qualities of such charts in Bangladesh are (1) high density and a good relative accuracies of the depth measurements, (2) suitable absolute horizontal positioning accuracy, and (3) short production time and rapid dissemination (because of the fast morphological changes). For morphological monitoring (of waterways development and for other purposes), both the accuracy and the year-to-year consistency of the levels are decisive. Mathematical modelling requires a complete coverage of the mapping, possibly at the cost of a reduced resolution. A particular quality for this application is a strictly horizontal reference level, if possible better than represented by PWD datum, where significant deviations from horizontal occur in practice, as demonstrated by several validation surveys (for example, see *RSP Special Report 1: 'Validation of staff gauge bench marks'*).

A suitable coordinate system for the mapping would be either WGS84 or BTM, the former being well-defined within the GPS satellite positioning (which will soon completely replace the Decca system for navigation in Bangladesh), and the latter being related to the former in a well-defined way. The RSP applied the BTM grid.

For navigational charts, SLW datum (giving depths relative to an imaginary water surface) is well suited, whereas PWD datum (giving elevations relative to an imaginary horizontal plane) is entirely unsuitable. For morphological monitoring, the choice is less important, since a main part of the information is produced by differences between successive surveys, whereby the reference level becomes neutral. For hydrodynamic modelling, PWD datum is well suited (whereas SLW datum is not suited), because PWD is oriented relative to (i.e. perpendicular to) the gravity field.

Both in the case of navigational mapping and morphological monitoring, the depth measurements should be as accurate as possible. In case of navigational mapping, the positioning should have an accuracy that is better than the positioning applied by the vessels using the charts. The consistency is of minor interest only. For morphological monitoring, the consistency of the positioning is more important than the accuracy, provided of course that the consistency extends over the entire data volume and analysis. In the present study, for example, data are produced by traditional bathymetric surveys and by satellite mapping, so a suitable consistency must be maintained between the two sets of data.

For navigational charts, a dense basic data coverage is essential, so that the fairway depths become 'safe'. This can be done by a combination of a small line spacing, by multi-beam echosounding, and by echo sounding supplemented by side scan sonar mapping. Such procedures were not applied during the RSP surveys (which aimed at producing data for morphological studies).

Data processing for navigational charts identifies the 'safe depth', which is the 'minimum depth at the applied length scale'. The depth contours are smoothed envelopes of the minimum depth within each contour. For the purpose of morphological monitoring, the depths are central estimates (of the average depth at the applied length scale), and depth contours are smoothed curves connecting points of an equal depth.



### 5.6.3 RSP bathymetric surveys

The RSP completed 38 bathymetric surveys at seven locations. These are listed in Table 5.21. The programme is described in *RSP Special Report 3: 'Bathymetric surveys'*.

| Year                       | 93   |       | 94   |       | 95   |       | 96   | Total |
|----------------------------|------|-------|------|-------|------|-------|------|-------|
| Season                     | lean | flood | lean | flood | lean | flood | lean |       |
| 1 Bahadurabad              |      | 2     | 1    |       | 2    | 1     | 2    | 8     |
| 2 Karmajani                |      |       |      | 1     | 2    | 1     | 1    | 5     |
| 3 Dhaleswari Off-take      |      |       |      |       | 2    |       | 1    | 3     |
| 4 Hurasagar Outlet         |      |       | 1    |       | 2    |       | 1    | 4     |
| 5 Gorai Off-take           |      |       |      | 1     | 2    |       | 1    | 4     |
| 6 Jamuna/Ganges Confluence |      | 1     | 1    |       | 2    | 4     | 1    | 9     |
| 7 Arial Khan Off-take      |      |       | 1    |       | 2    |       | 2    | 5     |
| Total                      |      | 3     | 4    | 2     | 14   | 6     | 9    | 38    |

Table 5.21: Summary of RSP bathymetric surveys

The surveys were made along fixed runlines that were maintained by the DGPS system. To the extent possible, these runlines were retained from one survey to another, in order to allow for a good determination of the morphological development.

At the initiative of the PA, a suitable line spacing was evaluated on the basis of the August-September 1993 survey at Bahadurabad. It was concluded that a line spacing of between 100m and 200m provided an acceptable description of the riverbed and was suited for the different data applications. Hence, the line spacing was selected to be 100m at the two adjacent areas of Bahadurabad and Karmarjani, and 200m elsewhere.

For the direction of sounding near Bahadurabad East-West directions were taken, which is perpendicular to the main river direction. For data interpretation (drawing contour lines) a sounding direction perpendicular to the direction of the individual channels has some advantages.

A disadvantage of such a method, however, is that tracks may easily cross each other in bend of wide channels using a small interspacing in the river axis. For data interpretation, also at places where data is missing, the use of satellite imageries appeared very useful.

Only during some special measurements, soundings perpendicular to channels and longitudinal soundings were executed (The longitudinal soundings were often done to have more information about the bed-forms).



Identification of the bank line during the surveys took place by direct measurements, where possible, or by positioning relative to the vessel by estimating the distance from the vessel to the river bank at each end of each survey line. At the request of the PA, see subsection 5.6.5, a supplementary mapping of flow lines (by drogue tracking) was implemented from July 1995.

All the bathymetric survey work was performed with DGPS. Trimble 4000 and Trimble Nav-track units were used. A VHF telemetry link was established for transmission of differential corrections between the reference stations and the respective receivers aboard the survey vessels. The system gives immediate positions in the World Geodetic System WGS84. These values are transformed into BTM coordinates by a PC based on-line software package (Hydro), which also controls the actual navigation.

A Robertson SKR82 gyro compass interfaced to the on-line navigation computer was used to provide heading control for the A-vessel.

The on-line computer cycle was set to its optimum of 1 second. Thus the depth data were recorded every second corresponding to 2m horizontal distance at a navigation speed of 4 knots, which was the normal survey speed. The fixing interval was also 1 second. Every fix was sent to the printer for hard copy. An A3 track plotter was used to record the vessel's progress on paper charts in scale 1:10.000 with the survey lines pre-plotted.

The RPS applied two type of echosounders the dual frequency (30/210 kHz) ELAC LAZ 4420 on the DHA, the single frequency (200 kHz) SIMRAD EA 300 P on the DHB, DHC and DHD and the (200kHz) ATLAS Deso 14 on the DHE to record analogue and digital depths. The resolution of the instruments was better than 1 cm. The beam widths varied from 7° to 24°.

The draught of the transducers was regularly measured in calm conditions. Regular checking of the draught of the survey vessels was also done, as well as occasional bar checks. Only small differences of a few cm were recorded. The echo sounders were interfaced to the navigation computers and fix marks were sent from the computers with fix number, date, time, line file number and positions.

#### 5.6.4 Topographic surveys

Topographic work in the context of the RSP is to add information (especially levels) of the dry part of the river bed to the bathymetric data. As the main part of especially the Jamuna River is dry in the pre- and post monsoon months, during which the main part of the bathymetric work is executed, the possible topographic survey area is extremely large. Hence, it is important to develop an efficient method and to test and apply that for special purposes such as study surveys.

The Technical Specification on the subject read (Section 3.2.4).

*"For the dry parts of the river, at the time of survey, the consultant has to present a methodology to reproduce, at least costs, the minimum topographic information necessary for the analysis of the morphologic changes in the different river stretches. They will comment on which morphologic features should have to be surveyed by topographic methods".*

In the beginning of the project tests have been performed, (December 1992), with three different methods:

- traditional levelling
- using a total station
- using DGPS

The second method was preferred, it was faster than the traditional one, while the vertical co-ordinate from the DGPS was not accurate enough (in 1992).

Another method considered was to measure bank lines with a "path finder", a portable DGPS system. However, in practice this appeared also time consuming (days), which makes data interpretation difficult as the banklines should be taken during the steepest rise and fall (e.g. 0.5 m/day) to achieve an appropriate set of contour lines.

Only in case the bank lines can be followed by motorbike the system should be kept in mind.

Consequently during the main part of the project the method with the total station was preferred. To reduce further the topographic work, the method of so-called feature mapping was discussed. In the morphological context it means that banklines and char levels are not taken according to a fixed grid. From observed shapes the minimum required points for a reasonable reproduction of shapes are judged in the field. It implies that the number of measuring points along, for instance, straight bank lines and flat surfaces may be reduced drastically.

By the end of the project the real-time kinetic DGPS became available on the market, enabling accurate vertical control from a moving platform.

It is expected that after a few years this system is portable enough and the costs are low enough to be used for feature mapping on chars.

Topographic surveys were carried out by the RSP as indicated in Table 5.22. The surveys determined spot elevations along survey lines that were aligned with the bathymetric survey runlines, in the direction across the river. The line spacing was 500m. The point increment along the line was 100-200m for regular surfaces and less in case of irregularities. The survey lines extended from the river bank (or banks), and the water level was determined as well as the ground elevation. The location of the lines, and the two first points of each line were established by DGPS. On this basis, the horizontal and vertical coordinates of the points along the line were determined by a Topcon total station. With the procedures applied in the field, the accuracy is estimated at 3m (horizontally) and 2-3 cm (vertically). The range of the total station was around 1200m.

The surveys included a mapping of topographic features, with the objectives of optimizing topographical work, providing supplementary information to the bathymetric contour maps and as support for interpreting satellite imagery (jointly undertaken by EGIS and RSP, see *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data'*). For this purpose, features were classified as indicated in Table 5.23.



| Location                 | Period            | Survey no. |
|--------------------------|-------------------|------------|
| Gorai Off-take x):       | 15/1-14/2 95      | 9044       |
| Bahadurabad              | 25/11-20/12 95    | 8032       |
| Bahadurabad              | 25/12 95 - 6/1 96 | 8032       |
| Bahadurabad              | 9-14/3 96         | 8032       |
| Kamarjani                | 7-16/1 96         | 8034       |
| Kamarjani                | 15-18/3 96        | 8034       |
| Ganges/Jamuna Confluence | 22-31/3 96        | 8037       |

x): Feature mapping was not included in this survey

Table 5.22: Topographic surveys by RSP

- Banklines
- Char contours (levels)
- Soil type: silt or sand, dry or moist
- Vegetation/non vegetation
- Crop type: paddy, wheat, jute, sugar cane, firewood, tobacco, spices, pulse, mustard, others
- Structures: buildings, roads, dikes, ditches, embankments, etc.

Table 5.23: Feature classification as applied by RSP

### 5.6.5 Determination of flow lines

It is common practice to add information on hydrographic charts (Peters 1993a).

On request of the PA float tracking has been implemented in conjunction with the bathymetric surveys and flowlines were added to the charts as from July 1995, as listed in Table 5.24. The drogues had a depth of 2 m. Generally, shallow-draft vessel are employed, equipped with DGPS for positioning and Hydro software for the logging of positions. The following method was adopted:

1. Two drogues were tracked by each boat simultaneously
2. Separation between drogues at the time of dropping along a cross section was about 400 to 500 m in the larger rivers. When the cross-river distance between flow lines would become too large or too small, the drogues were re-positioned.
3. Fixing of the positions of drogues was done at an interdistance of about half the width of the river or earlier, depending on how fast the alternate drogues could be reached by the vessel
4. In case of excessive separation of the drogues, due to one moving slower than the other, the fastest drogue was picked up.
5. Availability of an on-line plotting facility was found to be essential to ensure a good coverage of the total survey area.

It was experienced that it was possible to track two drogues by a single boat, but, except when both drogues are in the thalweg, the speed of the work is limited by the speed of the



slower one. When there is a considerable difference in speed between the drogues, the risk of losing one (or both) is evident.

Processing of the field data consisted of plotting the flow lines on the basis of consecutive DGPS positions of the drogues, at the same scale as the corresponding contour maps (1:10.000 or 1:20.000).

Flow velocities were calculated and plotted on the basis of positions and time between two consecutive fixes.

| Area                     | Period      | Survey no. |
|--------------------------|-------------|------------|
| Bahadurabad              | 26-31/7 95  | 9071       |
| Gorai Off-take           | 11-14/8 95  | 9077       |
| Gorai/Kushtia            | 11-15/10 95 | 9080       |
| Bahadurabad              | 18-23/11 95 | 9094       |
| Kamarjani                | 5-19/12 95  | 9095       |
| Ganges-Jamuna Confluence | 25/1-4/2 96 | 9096       |

Table 5.24: Drogue measurements

### 5.6.6 Data processing and reporting

During the off-line data processing in the RSP Project Office in Dhaka, every data file has been subject to the following processing steps:

- Manual/semi-automatic check for spikes, errors etc.;
- Correction of errors as appropriate, by deletion, interpolation and/or filtering
- Reduction of data sets to include only useful information, so superfluous and insignificant measurements were deleted;
- Offset corrections relating to the entire data set. Based on the water level at the reference gauge, the data were reduced to SLW.

For calculation of accretion and erosion areas and volumes, and for the sake of numerical modelling, a discretisation of the data is convenient. Also, to the extent that it is based on averaging, the discretization will improve the accuracy (at the cost of a reduced horizontal resolution). At the same time, the size of the data files is reduced. Within RSP, all bathymetric data were transformed into finite (50m by 50m) grid arrays by interpolation. Hereby, the depth values represent (estimated) average depths within the grid increment. The grids of successive mappings have the same origin and the same orientation.

The data were presented in the following ways:

- Index maps of each survey;
- Bathymetry charts, scale 1:10,000 or 1:20,000; and
- Contour plots, scale 1:10,000 or 1:20,000 and 1:50,000.

Computerized production of contour plots appeared initially difficult for instance because of DGPS positioning errors, etc. Also the generation of appropriate contours near the chart boundary asked for software adaptations.

These bottlenecks were overcome and a powerful package could be applied. However, it should be noted that the computerized plot always needs checks and interpretation. Often manual adaptations and additions are needed.

The data were stored in two ways for special or more detailed analyses:

- Files of edited sets of all recordings of position, depth, and time along the survey lines (so-called xyz-files); and
- Files of averaged and interpolated depths and bank contours in a fixed (50m by 50m) grid covering the entire survey area (called DT2 and CT2 files)

#### 5.6.7 Evaluation of accuracy

The survey procedure applied by the RSP involved the following accuracy determinants:

- The accuracy of the depth registration itself, as related to the performance of the echo sounder, draft variations, and influenced by water temperature fluctuations, by the riverbed properties, and by the weather during the survey work. Based on performance tests, this accuracy was estimated at  $5\text{ cm} \pm 1\%$  of the depth;
- Deviations related to the positioning accuracy (of  $\pm 3\text{--}5\text{ m}$ ), depending on the slope of the riverbed. This effect would typically contribute by around 10 cm in shallow areas, but less than that at depths larger than around 10m, due to smoothing caused by the beam width. It is noted that the use of DGPS effectively reduced this potential error contribution as compared with any alternative positioning method;
- Deviations related to the accuracy of the water level registration at the applied reference gauge. Assuming that the zero value is true, this accuracy is estimated at  $\pm 5\text{ cm}$  (considering local wind set-up around the gauge, and Coriolis effects);
- Deviations related to the transfer of the water level between the reference gauge and the vessel, as determined by the surface slope irregularities. This contribution is tentatively estimated at  $\pm 2\text{ cm/km}$ , as a typical value.

It is noted that the relative accuracy is several times better than the absolute accuracy, as determined by the different deviations. Part of the error is systematic, and the random part of the error is reduced in connection with the averaging of individual recordings that takes place during the data processing. An impression of the relative accuracy of the surveys is obtained when comparing successive surveys from the same area, for example in order to identify erosion and accretion rates and impact areas in connection with the morphological studies. Such comparisons were made repeatedly during the Project. They indicated a high consistency, with relative accuracies better than 0.1-0.2m.

#### 5.6.8 Recommendations

The procedure applied by the RSP was based on modern, but standardized survey techniques. Particularly the introduction of dynamic DGPS positioning supported the overall accuracy and facilitated the navigation control and on-line data processing. The project encountered some quite practical difficulties in connection with the off-line data processing, which did not become streamlined until a late stage in the project. The workload was larger than anticipated, and the initial quality control routines had to be reinforced.

Particular practical difficulties were encountered in connection with the high flow surveys. The value of the produced data was high, because they supplied detailed information about the morphological processes, and also, these surveys could cover a much larger part of the



river than the lean season surveys. The difficulties were caused by the changes of the riverbed (and even the planform) that took place during the work, so that the detailed consistency was reduced. Therefore, it is suggested that future high flow surveys are confined to small areas, but possibly on more occasions.

The depth reduction (to SWL, or, for that sake, to any other reference level) was made by traditional means, relative to a reference gauge with a known datum. In the future, this procedure may be replaced by three-dimensional so-called RTK (real time kinetic) DGPS, which determines not only the horizontal position, but also the vertical elevation (relative to the WGS84 grid). Hereby, it is no longer required to know the water level during the survey, and backwater effects and slope irregularities between the reference gauge and the survey vessel become of no consequence. This technique was not available until a late stage of the project, for which reason it was not implemented.

When using the traditional depth reduction based on the water surface, the network of gauges should be dense, and the gauges should be carefully levelled relative to each other. Extrapolation (beyond this network) should be confined, and the distance from the vessel to the reference gauge should be limited. The transparency of the depth reduction is much more important than an attempt to comply strictly with a nominal datum, which remains a matter of definition, and which in reality seldom accurately reflects, for example, a horizontal surface or a lean season water level profile.

In the rivers of Bangladesh, the concept of a 'bankline' is ambiguous, particularly in case of accreting areas with small gradients. Except for steep, eroding banks, a reasonably elevated bankline can seldom be surveyed from a vessel, but requires a supplementary land survey of the shallow or temporarily dry areas (Figure 5.25).

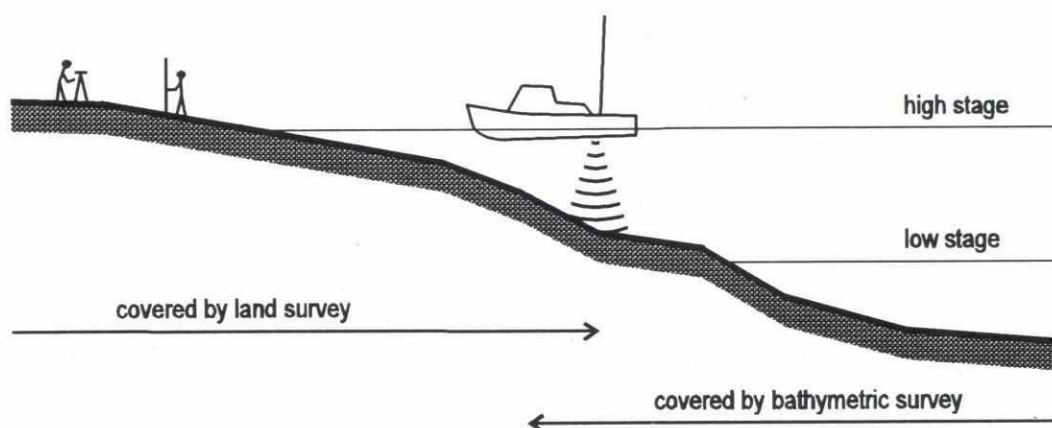


Figure 5.25: Overlap between land surveys and river surveys

Surveys for navigational purposes should take place at the end of the flood season, where the morphological changes take place at a slower rate. The data analysis, map production and dissemination should take place within the shortest possible time, in order to enhance the value of the results. When covering larger areas, this inevitably requires a well-designed work



plan, giving priority to selected areas, a comprehensive automatization, and development of streamlined procedures all the way from the field measurements to the end user's receipt of the results.

## 5.7 Overland flow and floodplain sedimentation

### 5.7.1 General

The general objective of the overland flow and floodplain sedimentation measurements was to improve the understanding of:

- Water and sediment balances along river stretches,
- Overland flow patterns in view of impact assessment of man-made changes on the development of rivers and floodplains, and
- Processes of floodplain sedimentation.

Overland flow occurs when river water starts to flow over the floodplain of the river during peak flows in the monsoon season. Three types of overland flow can be distinguished: flow over chars in the river, spill flow (by-pass), and overbank flow. Flow over chars is flow over shallow flooded bars and chars in the main river. Spill flow is flow that leaves the river via spill over banks and that may or may not return to the main river further downstream. Overbank flow flows directly over the banks of the channels of the river. The flow enters the floodplain if the stage is higher than the bankfull stage. In addition, rainfall, and sometimes groundwater flow, contribute to the inundation of the floodplain. Turbid overland flow originating from the river carries sediment which may settle in the floodplain. This sedimentation is called floodplain sedimentation.

In the 1995 flood season, the RSP carried out a pilot study of overland flow and floodplain sedimentation on the left bank of Jamuna (southeast of Bahadurabad). The study built on previous work in the same area by FAP19 (the Geographic Information System Project). The study area was 5 km by 2 km. It covered part of the Active and Young Jamuna floodplains and part of the Older Jamuna floodplain.

The measurements and the results are presented in *RSP Special Report 15: 'Overland flow and floodplain sedimentation'*.

### 5.7.2 Selection of study area

Due to the space variation of the processes, and the aim of a fair validity of the results, the location of transects and sampling plots must be selected carefully, hereby paying attention to both the processes to be investigated and to the local measuring conditions.

The following considerations relate:

- the expected flood regime and the expected sedimentation pattern in the area;
- the natural setting, especially the physiography and the relief of the area;
- the variation in soil types in the area;

- the relatively few disturbances to natural conditions by roads, embankments and other structures;
- the availability of sufficient data, especially detailed maps; and
- the accessibility of the study area during floods and at other times.

The sampling plots should be located at places where the floodwater will be drained completely after each peak flow, as it is difficult to collect sediment from an inundated plot without damaging the sample.

### 5.7.3 Procedures

The applied procedures are summarised in Tables 5.25 and 5.26 below.

|                                                                                  |                                        |
|----------------------------------------------------------------------------------|----------------------------------------|
| Vessel:                                                                          | Country boat                           |
| Flow measurements:                                                               | By floats, or a Valeport current-meter |
| Positioning:                                                                     | By GPS                                 |
| Depth:                                                                           | By lead line                           |
| Suspended sediment sampling:                                                     | Surface samples by bottle              |
| Suspended sediment analysis:                                                     | Concentration, grain-size distribution |
| Measurements were made at a 500m increment along transects across the floodplain |                                        |

Table 5.25: RSP overland flow and sediment transport measurements

|                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• Permeable mats (0.5m by 0.5m) (3 on each sampling plot)</li> <li>• Sediment traps, covered when not inundated (3 on each sampling plot)</li> <li>• Brick dust layers (0.50m by 0.50m) for registration of the thickness of the sediment layer over the topsoil (3 on each sampling plot)</li> </ul>                                                   |
| <p>Samples were analyzed for sedimentation rate, grain-size distribution, shape, and mineralogical composition</p> <p>Measurements were made on 6 sampling plots (10m by 10m) on the left bank of Jamuna, near Sharishabari (southeast of Bahadurabad)</p> <p>Flood water samples were collected weekly and were analysed for suspended sediment concentration and grain-size distribution</p> |

Table 5.26: RSP floodplain sedimentation measurements

### 5.7.4 Evaluation

In special situations the rainfall can affect the registrations in the period between the complete drainage of the flood water and the collection of the sediment sample. The sampling devices should be covered when not inundated, and the samples should as often as possible be collected right after each inundation. Comparison with the sediment traps indicated that the sediment collected on permeable cloth and brick dust layers could erode when the overland flow velocity exceeded around 0.6 m/s. Apart from such effects, the results concorded within a margin of 10%.

In the study area the floodplain sedimentation rate was not uniform. Even within the plots, the sedimentation layer thickness was uneven. The results show that the three similar devices in a sample plot were necessary to eliminate scatter in the results of any individual device.





Asselman and Middelkoop (1995) measured floodplain sedimentation in a small floodplain along the Rhine and Meuse Rivers. They used artificial grass mats of 50 x 50 cm. These traps were placed in a semi-regular grid consisting of several transects and a few clusters. The spacing between the transects was about 100m. The sample spacing in the transects was about 50m. Within a cluster the spacing between the traps varied between 1 and 10m. To determine the total amount of sediment deposited on the floodplain they used kriging as a spatial interpolation method. Kriging is a form of weighted local averaging. It is recommended to consider such an approach for future floodplain sedimentation measurements in Bangladesh.

## 5.8 Sediment properties

### 5.8.1 Analyses within the RSP routine gauging programme

The RSP routine gauging programme comprised determination of suspended sediment transport and bed-load transport, as well as sediment grain-size distributions, and vertical distributions of sediment concentration and grain-size/settling velocity distribution. For these purposes, the routine gauging included collection of a variety of sediment samples for analysis as listed in Table 5.27.

| Sampling                                                                                                                                                                                                                                                 | Method                              | Analysis           |                    |                                              |                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|--------------------|--------------------|----------------------------------------------|----------------|
|                                                                                                                                                                                                                                                          |                                     | Silt concentration | Sand concentration | Grain-size/settling velocity distribution 1) | Transport rate |
| Suspended sediment                                                                                                                                                                                                                                       | Collapsible bag, integrated bottle  | +                  | +                  |                                              |                |
|                                                                                                                                                                                                                                                          | Pump sampling                       | +                  | +                  | A                                            |                |
|                                                                                                                                                                                                                                                          | Delft bottle                        |                    |                    |                                              | +              |
| Near-bed sediments                                                                                                                                                                                                                                       | Pump sampling                       | +                  | +                  | S                                            |                |
|                                                                                                                                                                                                                                                          | Delft bottle                        |                    |                    | S                                            | +              |
|                                                                                                                                                                                                                                                          | Helley-Smith                        |                    |                    | S                                            | +              |
| Bed material sampling                                                                                                                                                                                                                                    | USBM54, Van Veen grab, drag sampler |                    |                    | S                                            |                |
| A: Andreasen tube determination of settling velocity distribution (particles below 0.063 mm) and by dry sieving (particles above 0.063 mm). This analysis is made for selected samples only<br>S: By dry sieving (or wet sieving for cohesive sediments) |                                     |                    |                    |                                              |                |

Table 5.27: Sediment analyses for routine gauging

The analyses were made in the RSP sediment laboratory, which had equipment for the following standard analyses:

- concentration of suspended sediment (by micro-filtering);
- grain-size/settling velocity distribution of suspended sediments and riverbed sediments (by Andreasen settling tube);



- grain-size distribution of suspended sediments and riverbed sediments (by dry or wet sieving, mesh widths 1-0.5-0.25-0.125-0.063 mm);
- pipette analysis of grain-size distribution of small samples (used for non-routine purposes only).

The facilities and the applied procedures are summarised in *RSP Final Report, Annex 1: 'Surveys'*. Samples for settling velocity/grain sizes were separated by sieving through a 0.063 mm sieve. In case of bed material samples the sample is dried first and goes then for dry sieving. The residue in the pan ( $< 0.063$  mm) goes for settling tube analysis.

In case of bed samples with a high content of fine sediments this method fails, as fine particles tend to stick together during drying. Then wet sieving is done first by flushing the bed material sample through the 0.063 sieve. Thereafter the coarse fraction goes for dry (occasionally wet) sieving and the fine fraction for settling tube analysis. In case of a suspended sediment sample, the sample goes through the 0.063 mm sieve and thereafter the sand fraction goes for dry (occasionally wet) sieving and the fine fraction is analyzed in the settling tube.

The information obtained by these standard methods was adequate for a gross description of transport rates and processes. The uncertainties with respect to transport rates and settling velocities were mainly related to the collection of the samples in the field, rather than to the quality of the analysis, whereas the quality of the grain-size distributions of riverbed sediments was mainly related to the validity of the collected samples, rather than to the analysis.

It appeared that the applied standard ('2-series') sieves were not optimal for analysis of the relatively well-sorted sand in the rivers. In many cases, only the 0.25 mm and 0.125 mm sieves fell within the range of the grain sizes. The sieves should provide a better resolution of grain sizes between 0.063 mm and 0.40 mm.

An elaboration of the bed material sampling is given in *RSP Special Report 8: 'Bed material sample analysis, Ganges, Old Brahmaputra and Jamuna Rivers'*.

The project did not examine the potential of alternative or supplementary analysis methodologies, although several potentially auspicious methods were contemplated. Examples are listed in Table 5.28. For an outlook of practical sediment analysis methodologies, reference is made to Van Rijn (1986).

|                                                                     |                                                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Aerometer analysis                                                  | A relatively fast, practical and well-proven analysis of grain-size distribution, particularly of riverbed sediments. Best suited for the coarse and medium silt fractions.                                                                                                                                                                                     |
| Visual accumulation tube (VAT)                                      | Suitable for sand, and coarse/medium silt in high concentrations. Coverage of a wide range of grain sizes can require a preceding sorting (by sieving). Suited for use in the field, e.g. for a fast examination of concentration and grain-size distribution as a basis for on-location adjustment of sampling volume and duration.                            |
| Microscope measurements of grain size (and grain-size distribution) | A not fully proven method. Its advantage is related to the need of a much smaller sample. The method is faster than settling tube tests, but the resulting grain-size distribution may be less accurate.                                                                                                                                                        |
| Owen Tube sampling                                                  | Here, the settling tube test in the lab is replaced by sorting the sample by grain size in the field. Inconveniences and errors related to transport of the sample are avoided. Working conditions are generally better in the lab. An Owen Tube is difficult or impossible to handle in a strong current. The method is not suitable for the finest sediments. |

Table 5.28: Alternative or supplementary sediment analysis techniques

### 5.8.2 Mineralogical and physical properties

In addition to the in-house routine sediment analyses, the RSP carried out a programme of mineralogical analyses and extended analysis of physical properties. The aim of this programme was to examine a number of aspects in connection with river sediments, such as:

- linkages between physical and mineralogical properties;
- relationship between mica and heavy minerals;
- seasonal variation of physical properties in rivers;
- spatial variation of the mineralogical properties of the sand fraction;
- correlations between river and floodplain sediment;
- topographical variation of physical properties; and
- variation of properties within river bank profiles.

The programme, the results, and an analysis of the findings are presented in *RSP Special Report 14: 'Mineralogical and physical properties of river sediments'*.

Samples were collected from Teesta River, Brahmaputra, Upper and Lower Jamuna, Gorai, Meghna, and two locations in Padma River. Also, floodplain samples were analysed. The following sampling techniques were used:

- bed samples were collected by USBM54, Van Veen, and Scooping drag samplers;
- suspended samples were collected by pumping;
- near-bed samples were collected by Delft bottle or by pumping; and
- floodplain samples were collected by sediment traps.

The samples were analyzed for mineralogical and physical properties at Dhaka University's Geology and Soil Science Department laboratory. Grain-size analyses were carried out at the RSP laboratory. The extent of the full and the limited analyses are given in Table 5.29.

| Physical properties  | Method of analysis              | Full analyses | Limited analyses |
|----------------------|---------------------------------|---------------|------------------|
| Mineralogy           |                                 |               |                  |
| - Sand-size minerals | Light microscope                | +             | +                |
| - Silt-size minerals | Light microscope and XRD, resp. | +             | +                |
| - Silt-size minerals | XRD                             | +             |                  |
| - Clay-size minerals | XRD                             | +             |                  |
| - Trace minerals     | Light microscope                | +             | +                |
| - Rock fragments     | Light microscope                | +             | +                |
| Shape variables      |                                 |               |                  |
| - Angularity         | Microscope + shape chart        | +             | +                |
| - Sphericity         | Microscope + shape chart        | +             |                  |
| - Shape factor       | Microscope                      | +             |                  |
| Density              | Pycnometer                      | +             | +                |
| Grain size           | Sieving/settling tube           | +             | +                |

Table 5.29: Sediment analysis parameters and methods

Based on the RSP study, it is recommended that:

- The river sediment sampling programme be continued at the same sampling sites during the monsoon and dry seasons;
- Consideration be given to more sampling sites in the lower parts of the Jamuna River (immediately north of the confluence with the Ganges River), the Meghna River at the estuary and at its upper reaches, and in the Gorai/Madhumati Rivers in their saline tidal zones;
- Further investigations be made in the Teesta and Padma rivers to examine the upstream to downstream shifting of mica and heavy minerals, respectively;
- Floodplain sediment of the Ganges and Meghna Rivers be checked for mineralogical properties and compared with their respective river sediment characteristics;
- Further XRD analyses of silt and clay are not necessary as optical microscope analysis is better suited for the determination of the silt mineralogy. Unlike sand and silt mineralogy, clay mineralogy does not contribute significantly to understanding the river morphology; and
- An improved technique be developed for this kind of study. For example, prior to selection of sampling sites, an aerial photo interpretation should be carried out with recent photographs. River morphologists could be assigned to make a full description of the sampling sites.

## 5.9 Remote sensing

The River Survey Project collected SPOT View multispectral SPOT scenes from FPCO (presently WARPO) for the area covered by the Project (Fig. 5.26). These images obtained in 0°15' x 0°15' square format have a scale of 1:50,000. The images having a resolution of



10m x 10m used Transverse Mercator Projection system on Everest Spheroid. Two annual coverages are available, one taken during Spring (March-April) and the other taken during Autumn (October - November). The RSP collected the images from Spring 1989 to Autumn 1995. Detailed aspects of the SPOT and other images such as LANDSAT are described in *RSP study report 3 (RSP, 1994)*. Here, only some applications are highlighted.

- Identification of general channel pattern, high and low chars, sand bars and vegetated chars. Tracings of the features were used as index maps to indicate measurement locations.
- Indication and verification of measurement locations, distance measurements, etc.
- Verification of BWDB (Morphology directorate) cross-sections with SPOT scenes.
- Determination of chainages for computation of river slopes.
- Detection of temporal evolution by overlaying scenes from different times.
- Detection of spatial variation and planform along the channel reaches.
- Coupling SPOT images with bathymetric maps to derive both sub-aerial (from SPOT images) and sub-aqueous (from bathymetric maps) information.
- Indication of upwelling and macro-turbulent vortices.
- Indication of mixing mechanism of two water bodies in confluences.
- Indication of suspended sediment concentration streaks downstream of eroded areas.

Examples of the above uses can be found in various RSP study reports. Some general examples are given here to demonstrate the uses of the scenes. Figure 5.27 shows the March 1991 SPOT scene of the Ganges River at the Gorai River mouth. The same area is shown in Figure 5.28 taken three years later in 1994. Some changes can be seen in the channel and bar configuration of the Ganges River. The Gorai River mouth-bar, however, appeared to remain stationary.

Figure 5.29 shows the confluence of the Ganges and the Brahmaputra Rivers at Aricha in September 1994. The mixing of two water bodies can be noticed. For several kilometers downstream in the Padma River, the interface between the two water bodies can be noticed. In this situation it appears that the Ganges water is more turbid than the Jamuna water. On most occasions, however, the Jamuna water is more turbid than the Ganges water. The contradiction is observed here, because in September 1994 the Ganges River was experiencing a flood but no such flood-stage was existing in the Jamuna River.

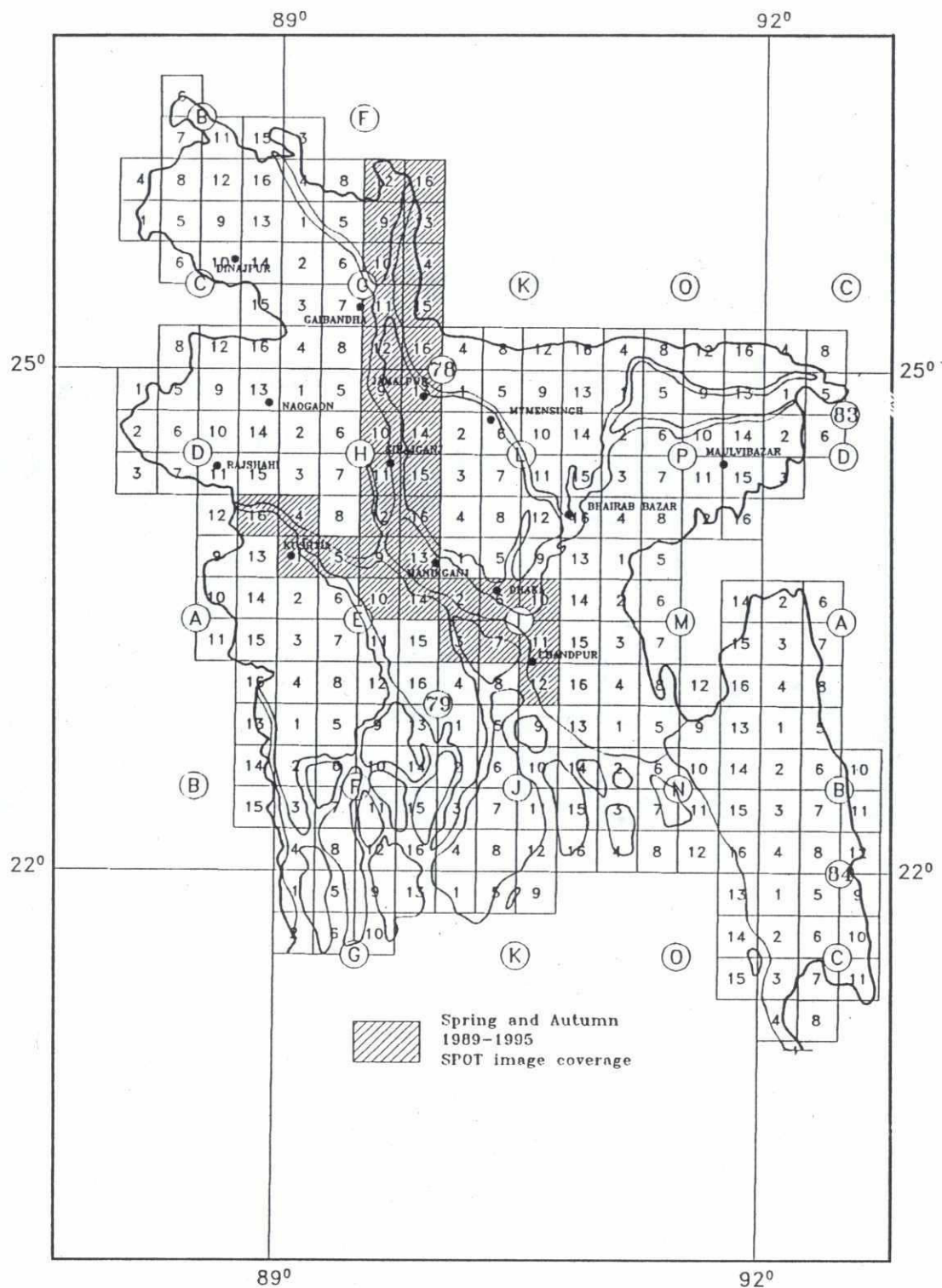


Figure 5.26: Index map showing the 1989-95 SPOT image coverage



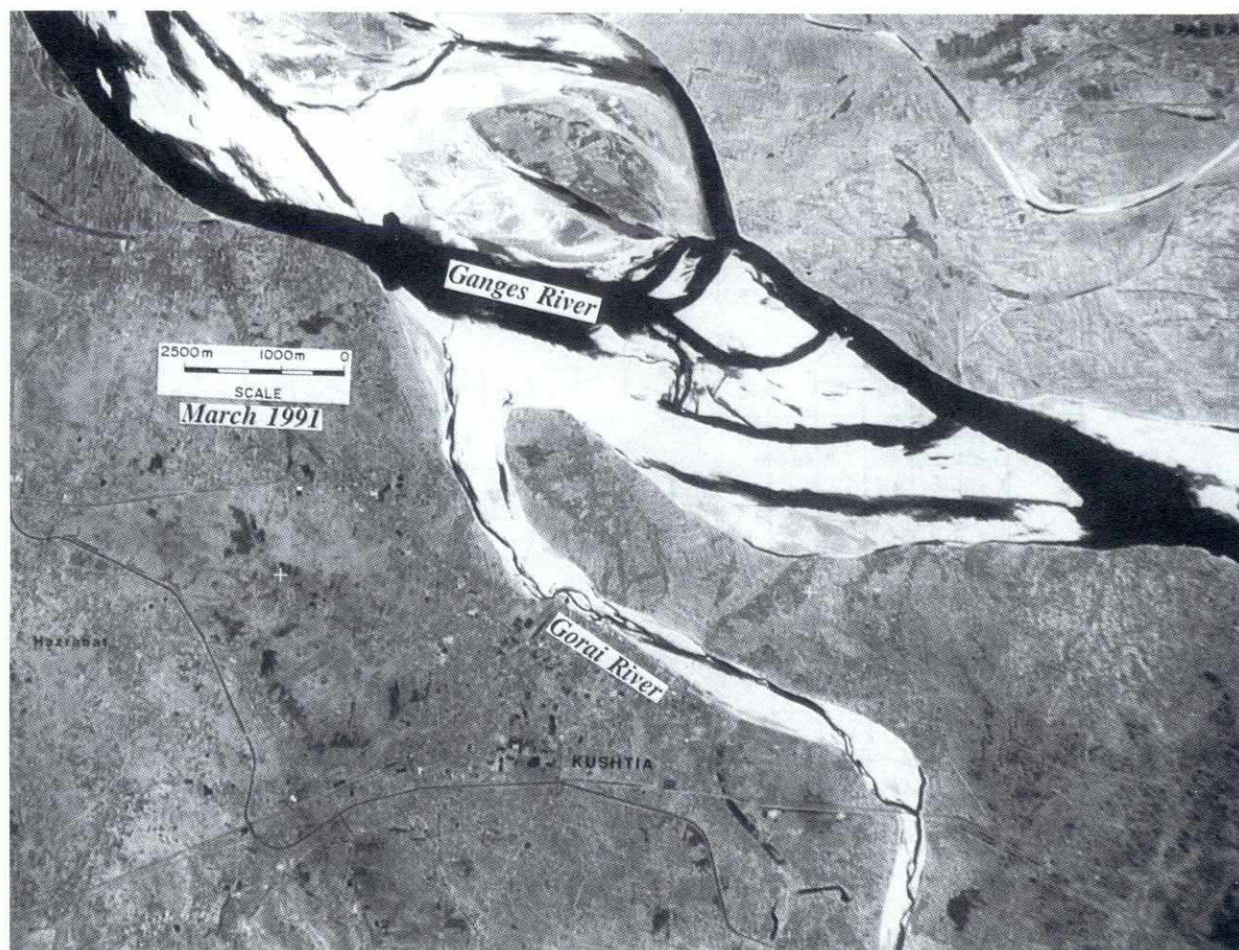


Figure 5.27: March 1991 SPOT scene of the Ganges River at Gorai River mouth



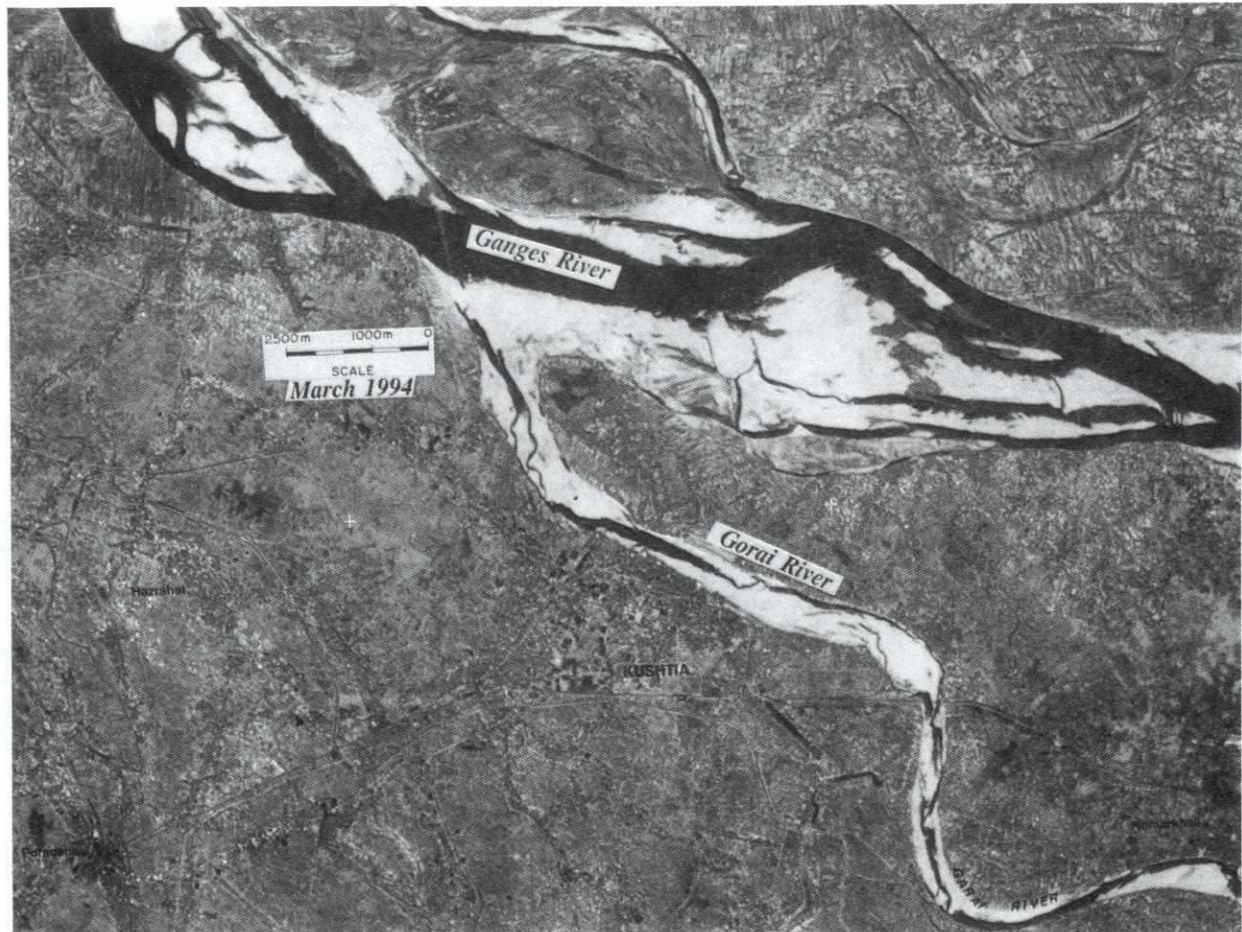


Figure 5.28: March 1994 SPOT scene of the Ganges River at Gorai River mouth

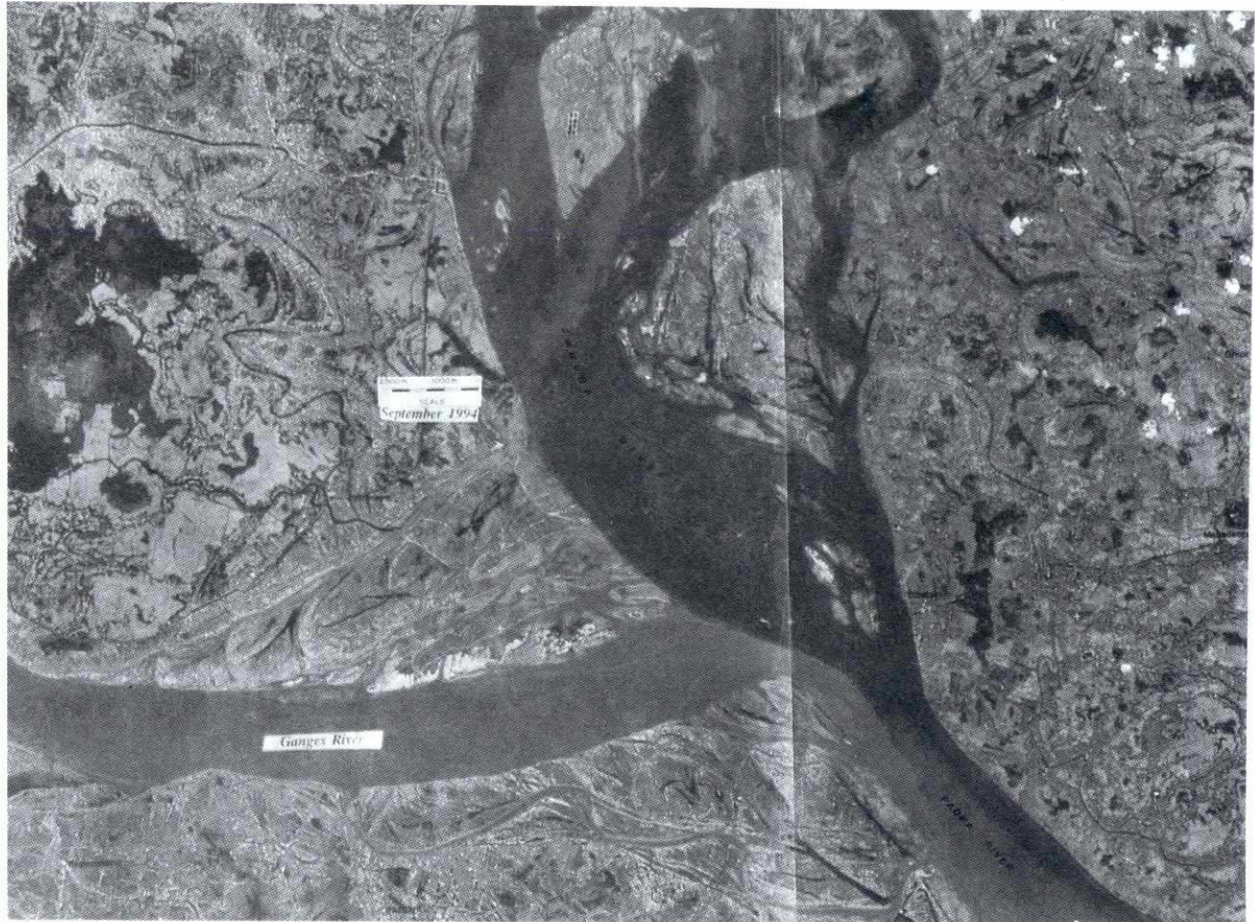


Figure 5.29: September 1994 SPOT scene of the Ganges-Jamuna confluence at Aricha



## 5.10 Data administration

With the production of 25 Gb of raw data, the RSP inevitably gained substantial experience in data administration. In the course of the project, a variety of user demands and data quality aspects were identified, different constraints were encountered and dealt with, and processing routines and procedures were planned, implemented, debugged, and adjusted. This took place with the well-known background of the rapid general technological development within computer hardware and software.

Towards the end of the Project, it was felt that a reasonably practical data administration had been implemented. The main data flow components are shown in Figure 5.30. The data flows for the various categories of measurements are described in *RSP Final Report Annex 1: 'Surveys'*.

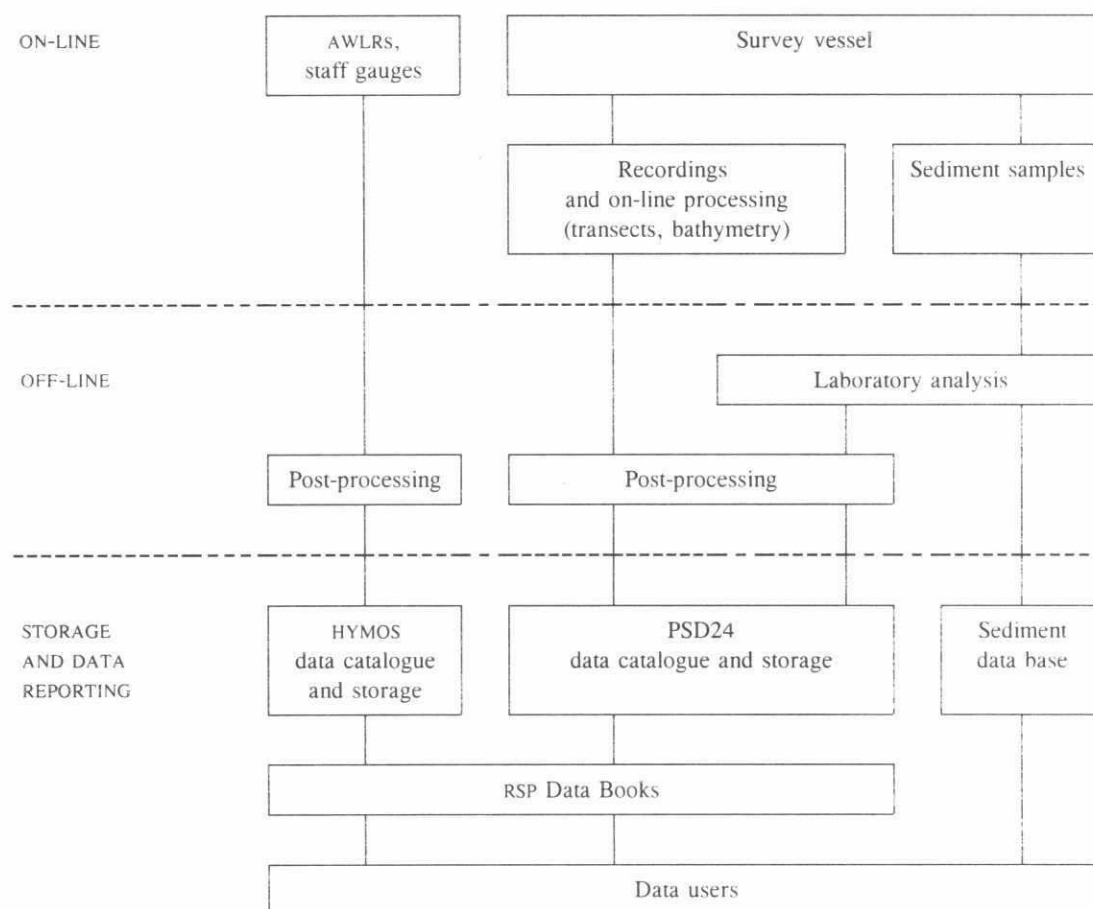


Figure 5.30: Data flow summary



### 5.10.1 Data processing

#### Water-level gauging

Processing of the RSP water level recordings comprised the following activities:

- downloading of AWLR data and collection of staff gauge data, with on-site inspection of data coverage and data quality (spikes, steps, drifts);
- digitising of staff gauge readings and conversion of AWLR readings;
- zero level conversion to PWD datum;
- data validation;
- editing of data files; and
- storage in the HYMOS database.

After storage, the data were available to different types of analysis and presentation, as exemplified in *RSP Final Report Annex 3: 'Hydrology'*.

One difficulty experienced by the RSP was the duration of the data flow, from the measurements which were taken to the final storage of validated data, which could in some cases take up to one year, even if data was downloaded at least monthly. This was mainly due to capacity constraints. Many applications of water level data require that the validated data are available within a much shorter time.

The validated data files are few (one for each gauging station and each year), and not too big. Being simple time series, they can be easily converted into different file formats, and, once available, they can be distributed to the end users without any practical problems.

Real-time transmission of water-level data was not implemented by the Project, but is now widely used by BWDB, which now operates some 50 stations in this way. (Literally, the monitoring is not strictly real-time, but the data are downloaded daily, which is adequate for many purposes). Real-time (or daily) data transmission has several advantages, both with respect to the use of the data, and with respect to quality control and immediate mitigation of detected data quality deficiencies.

#### Routine gauging of flow and sediment transport

As shown in Figure 5.30, the data processing for the routine gauging was divided into an on-line part and an off-line part. The on-line data processing was comprised of generating composite data files, containing data from the different sensors (Figure 5.31), labelling of data files for identification, and monitoring of data coverage and consistency. The off-line processing was comprised of editing, validation, storage, and reporting.

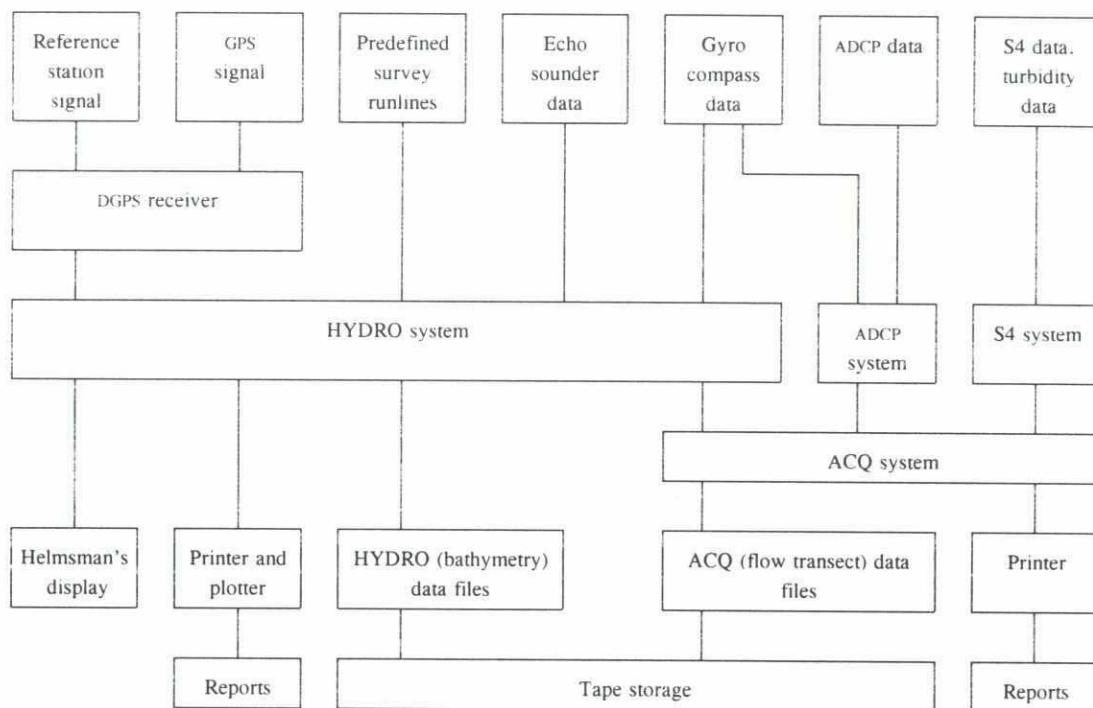


Figure 5.31: On-line data flow

In the future, it may be speculated that the on-line data processing component be extended to a nearly fully automated production of survey bulletins; for example, so that the maps and the file catalogues are prepared onboard the survey vessel, as well as a larger part of the data file conversion. This is the practice within marine bathymetric surveying, where vessels are larger, but should also now be within reach on small vessels. The advantages would include more strictly structured data processing and shorter production time. The data file validation can by necessity not be completed until after the field programme, because it partly involves inter-station comparisons.

In accordance with the Bill of Quantities, the RSP measurements were structured as a number of 'routine surveys', which were numbered from one and upwards. Each survey was comprised of 'one routine gauging', which was a set of flow and sediment transport measurements at a given location, according to the survey routines that had been developed between RSPMU and the Project. The RSP carried out a total of 252 such surveys.

For each survey, a Survey Report was prepared in the field, and for each survey, an RSP Survey Bulletin was prepared after completion of the data processing and storage.

The Survey Reports were used for internal purposes in connection with data processing, validation, and data reporting, as well as a support for adjustment of field procedures and work programmes. They contained:

- a chronology of activities;
- an outline of the data collection: where and when which measurements were made;
- data logging sheets and sediment sample collection sheets; and
- any other observations or information of interest in connection with the field work, such as performance of instruments and adequacy of work procedures.

The Survey Bulletins were prepared on the basis of the Survey Reports. They contained:

- a key plan (or plans, for multi-channel river cross-sections);
- a one-page extract of findings (cross-sectional average and horizontal distributions of flow and sediment transport);
- some additional data presentations (cross-sectional flow distributions, and sediment grain-size distributions); and
- a full listing of all data files (type, time, and place, both raw data and processed data).

The Survey Bulletins served as a documentation for the invoicing, and were directly compiled to form the data volumes of the RSP Data Books.

No specifications were available beforehand for the format of the Survey Bulletins and the Data Books, and this issue became a subject for discussion between the involved parties for several years, from submission of the *Phase 1 Final Report* and until the completion of the project. The format was extensively discussed with the PA, the RSPMU, representatives from BWDB and SWMC, and the internal data users, and it was implemented as a compromise between the different preferences. Hereby, priority was given to a full description of (1) where and when the measurements were made, and (2) where the results are stored. Other formats that the one selected may be equally or even more useful, particularly with respect to the extent of the data summaries. It is obvious, however, that their volume should not be extended because they are already bulky, almost too...

Possibly, in the future, the 'Data Books' may be replaced by 'Data CDs'. Preferably, one CD (or a few) should cover one (hydrological) year of measurements. This requires that the books be structured in a different way, as a small separate catalogue system with maps in a suitably compressed format. Much work would be required to structure this presentation, but once it had been done, the dissemination of results would be facilitated, and at the same time speeded up.

### **Bathymetric surveys**

Similarly, the processing of the bathymetric data was divided into

- an on-line component, producing composite x-y-z-t files for sets of runlines; and
- an off-line component, resulting in converted x-y-z files and finite grid depth tables, in both cases relative to the applied (SLW) datum.

Final data presentations were made on large-scale A0 hardcopies.

Several problems were encountered in the process. Initially, the off-line data processing took much too long, particularly in connection with debugging and datum conversion. Also, selection and implementation of suitable software for the contour plots required more attention than foreseen. In the process, the HYDRO software package was replaced by the Mike21 Pre- and Post-processing package (for this purpose, but not for the on-line processing). An additional advantage was that bathymetry files could be directly applied for numerical modelling, if so desired.



The hardcopy maps required a lot of work which was perhaps not fully justified, particularly considering the delays incurred by the necessary production time. In the future, it may prove more expedient to submit data as A4 key plans together with the data files. Hereby, the storage is facilitated, and the different users can edit and present the data in accordance with the different purposes.

### Evaluation

An important quality aspect in connection with data processing is its transparency. This is particularly the case with data flows like the ones implemented by the RSP for the flow and sediment transport gauging and also for the bathymetric surveys. These data flows are complex, and are not covered by established standards. The transparency, in turn, requires visible and well documented procedures for data conversion, checking, averaging, miscellaneous calculations (of flow, sediment transport, etc.), and contour delineation on bathymetric maps. Such procedures are not that difficult to develop, and many are available beforehand; but at the start of the RSP, their applicability in the new DGPS-ADCP context was not fully proven, and operational specifications for their performance were not available.

In the course of the project, two successive data flow frameworks were developed, one entirely within the UNIX environment (in Phase 1), and another within a combined UNIX and DOS environment (in Phase 2). The former was oriented towards the FIELDMAN catalogue system, and the latter towards the PSD24 database and standard DOS software (mainly the QuattroPro Spreadsheet). Specifications were established and modified in the process, and continued updates were required of check lists, guidelines and manuals. These developments contributed to an improved overall quality, the only purpose for implementing them, but at the inevitable cost of a reduced transparency until a late stage in the project.

#### 5.10.2 Quality control

With the large data volumes produced by modern computerised survey equipment, a high degree of automation is a necessity in connection with the quality control. Even if production time were of no consequence, and resources were abundant, a manual quality control would inevitably suffer from lack of consistency and transparency.

On the other hand, as it is well known the errors are neither consistent nor transparent. While 'an error' can be clearly defined, for example as 'an unacceptable deviation between a measured value and a true value', it cannot be described in unambiguous terms. Consider for example a single peak of 1m in a depth registration along a runline; such a peak may well be an error, but it is not completely certain that this is the case, even if the peak did not appear in adjacent runlines. As another example, a peak in a hydrograph may have been overlooked in the registration, but still, the hydrograph, appearing as a smooth curve, looks completely unsuspect, and the peak, if observed at one adjacent station only, will probably (wrongly) be judged as an error. Such risks of accepting erroneous data and discarding correct data exist both for manual and automatic validation and are not related to the data volume.

The RSP applied a stagewise data quality control:

- On-line control (where applicable), based on graphic (computer screen or plot) presentations, comprising monitoring of data coverage, and obvious inconsistencies, such as range checks, spikes, and stepwise changes in the data series;
- Off-line validation, based on graphic presentations, comprising consistency checks (for example staff gauges readings versus AWLR recordings, stage-discharge relations, consistency of bathymetric contour plots, and inter-station comparisons); and
- Control of survey bulletins, comprising consistency and completeness.

The on-line control comprised visual checks (on computer screens or hardcopies), and automatic checks (of ranges, peaks, stepwise changes, or extended constant registrations). This control was 'passive', in the sense that no corrections were implemented. This is not practical in the field, because of the risk of deleting (or changing) correct data, or of accepting erroneous data. Rather, doubtful measurements were identified, and were either labelled (for subsequent examination), or were simply repeated (for subsequent consistency check or selection).

The off-line validation comprised consistency checks (of hydrographs, current-profiles, and cross-section distributions of flow and sediment transport), stage-discharge comparisons (of flow, sediment transport and water levels), inter-station comparisons (of water levels), and comparisons between adjacent runlines of bathymetric surveys. Survey Bulletins were checked for consistency and completeness against the Survey Reports and against SPOT images and previous surveys and the same location, as described in *RSP Final Report Annex 1: 'Surveys'*.

The RSP experience clearly confirmed that quality control is a process that continues for as long as the data are being used. Certain errors will not emerge until a late stage in the analysis, such as inter-station comparisons, comparisons of data from different sources, or using the data in connection with numerical modelling. For example, this is the case with flow and water level data being used for rating curves, where outliers and loops can be true reflections of correct measurements, or can be caused by different types of measurement errors or other data inconsistencies. Another example is absolute zero level deviations, which will appear clearly if water level data are used for hydrodynamic modelling, but which can be literally impossible to detect otherwise (even if the zero levels have been carefully validated and are fully correct relative to the selected reference bench mark).

Therefore, a stage of the quality control may be complete, once a number of check procedures have been carried out; but the process as such continues, because there is an inherent element of quality control in any type of downstream data analysis. It is likely that institutions such as BUET, SWMC, FFWC, and others, regularly identify inconsistencies in hydrological data, also from years ago.

This fact has an important implication in connection with routine gauging. It is annoying when quality defects are detected at a late stage, for example after the Hydrological yearbook has been published, or the CD-ROMs have been distributed. Still, a provision should be made for subsequent reporting of defects and inconsistencies, once they have been detected. This may, for example, be done in separate 'data validation notes', listing stations, periods and data files where inconsistencies have been observed. Some Hydrological Yearbooks contain a short introductory chapter where the gauging stations are discussed briefly from this point of view, not only for the year covered, but also for previous years.



A good quality management partly depends on suitable attitudes. Even if every effort is made to prevent errors, it should be realised that they can still occur and slip through the control procedures. If so, they should not be ignored nor hidden, but reported openly, without casting blame on the persons or units that are 'responsible', and without animosity towards the (possibly external) person or agency that has detected a deficiency. On the contrary, giving notice about such deficiencies should be encouraged and acknowledged. For a good quality management an appropriate integration of field and office staff is prerequisite.

A practical circumstance in this regard is how to report or otherwise disseminate late information about data inconsistencies. One place to start is to define a visible point for reporting. This could be a person in charge, within a defined organisational unit, or maybe an e-mail address dedicated for this purpose. The information could simply be compiled in a folder, or entered into a separate section of the applied database. Once the information is compiled at one place, it will surely find its way to subsequent data users. Some time in the future, a BWDB 'hydrological data update' home page on the *World Wide Web* may be conceived.

### 5.10.3 Databases

There are four RSP databases:

- The Hymos system, which is an integrated software package (developed by Delft Hydraulics) for storage, analysis and presentation of water level data;
- PSD24 (Processed Survey Data of FAP24), which contains a (Paradox) data catalogue, and processed data from the routine gauging (in QuattroPro spreadsheet format); and
- The RSP sediment database, which contains results of all sediment analysis carried out by the RSP sediment laboratory (in QuattroPro spreadsheet format).
- Databooks of RSP.

They are described in *RSP Special Report 21: 'Guide to RSP databases'*. For the databooks see Special Reports 22 and 23.

#### HYMOS

The Hymos software package is a well-proven tool that performed as expected and according to its specifications.

#### PSD24

The PSD24 was developed within the Project at the beginning of Phase 2. It was designed in a dialogue with RSPMU, and after consultations with BWDB and SWMC. A main challenge was imposed by the need for a drastic reduction of the raw data volume, which was necessitated simply in order to access the data, not to speak of the possibility to compare data from different surveys. Another challenge was the aim of a comprehensive automation of the processing, which was desired both to reduce the time lag between data production and data availability, and to ensure transparency and avoid errors related to manual procedures.

It was selected to implement a quite comprehensive extent of data reduction and processing. The advantages were that the database became easily accessible (as specified in the Terms



of Reference), and that results were presented to the user in a ready form that, for many purposes, did not necessitate any further processing. The inherent costs were a reduced transparency and versatility, and the underlying primary data became less accessible for alternative processing by the 'advanced user'. As intended, the database became a practical engineering tool rather than a source of scientific raw material.

The development took place in a particularly dynamic interaction between the data using and the data producing groups of the Project. Specifications for synthesis, presentation, and storage were drafted, tested, reconsidered and revised, and numerous iterations were required to arrive at a result which was acceptable to the users without imposing prohibitive requirements on the processing.

The result, the PSD24 with its contents, is unique beyond any doubt. It is evaluated by the consultant as a good and readily accessible source of highly valuable results of the surveys.

One difficulty in connection with development of PSD24 was the unavoidable complexity of the underlying data files, and the variety of file formats. The raw data comprised the following types:

- time series (of water levels);
- x-y-z-t arrays (of cross-sectional depth contours);
- x-y-z-t arrays of time series (of current-velocity in vertical profiles);
- x-y-t arrays of current-profile (x-y-t) arrays (of flow across transects); and
- x-y-z arrays of sediment concentrations and grain-size distributions (from the sediment laboratory).

During the data processing, all these files were condensed and transformed into x-y arrays. The file format was selected as the one of the *QuattroPro* spreadsheet, from where the files can be converted to ASCII format. Many analyses and presentations can be made directly in the spreadsheet.

At the end of the Project, a training session was held about PSD24, with participation by BWDB, BIWTA, and SWMC, but no experience had been gained with external use of the database. The aim was that it should be accessible to a user with a minimum of PC knowledge, comprising the Windows operating system and the *QuattroPro* spreadsheet. Such user should be able to locate the data files, and to retrieve, compare, analyze and edit them as required, and to transfer them to any other desired application, within the *QuattroPro* spreadsheet or elsewhere, possibly after conversion to ASCII format. This could be done after a short introduction, and without support, although the file catalogue in the RSP Data Books would provide an outlook of the data and assist in locating them. More information can be obtained from the *RSP Special Report 21: 'Guide to RSP databases'*.

While using the PSD24 should be straightforward as intended, this is not the case with its operation. On the contrary, the operator must possess an in-depth knowledge of the underlying software, both in the DOS and the UNIX environment, in order to generate and add new data files, not to speak of changing the structure of the database, if this should for some reason be desired.



### **The sediment database**

This database is contained within the QuattroPro spreadsheet. Both its file structure and the data files are self-explanatory, so it can be used and operated by anyone with knowledge about this spreadsheet.

### **Evaluation**

The overall data administration framework of the RSP is not very well suited as a model for future applications. For historical reasons, the processing involves several shifts between the UNIX and the DOS environment. At the start of the project, the capacity of the DOS system was not adequate for handling the amounts of data, so a UNIX system was selected. Soon after, however, the data users within the project organisation expressed a preference for undertaking the final analysis in the DOS environment, where a variety of standard software (spreadsheets and graphic software) was available as attractive tools.

If the system had been designed today, it would obviously have been implemented entirely within one operating system. Today, both the DOS and the UNIX systems (as well as others) are adequate for this purpose, and both seem to become more powerful every year.

A suitable standard software package for similar purposes would be ArcView, which has been implemented by such organisations as EGIS, FFWC, and SWMC.

The RSP did not accomplish a full integration between data processing and data reporting. Due to time and capacity constraints, the production of Survey Bulletins and the preparation of PSD24 files was done by separate teams within the project organisations. This incurred a certain duplication of work that could be prevented by a streamlining of the internal procedures.



## 6 Sustainable Survey Techniques

### 6.1 Principles

Field surveys involving hydraulic and sediment data collection are expensive and time consuming. In addition, it needs considerable effort for a certain institution to develop the capability of accurately performing the surveys. Therefore, efforts should be carried out in an optimal and sustainable fashion, otherwise they can not continued. The measurements as a package, can be divided into four inter-related activities.

- Choosing a suitably distributed network of measuring stations;
- Choosing a suitable annual frequency of measurements;
- Selecting a suitable equipment and method;
- Ensuring an efficient operation and management of surveys.

Data elaboration is also an integral part of surveys and a proper scheme should be followed for a sustainable survey technique. This aspect is covered in Annex 1, therefore, it is not discussed here. To continue a survey work by an institution all these components should be sustainable. Figure 6.1 shows a scheme for reaching an optimal and sustainable hydraulic data collection strategy. It shows that a data collection strategy can only be pursued once they are screened for optimization and sustainability. The quality and quantity of a field data collection programme are dictated in terms of its objectives which are routine or data-base development, special studies or project purposes, and research. With proper consideration of the physical environment of the river an initial scheme of activities starts. These are evaluated on some optimization and sustainability criteria, and repeated if necessary in order to attain a data-collection strategy. The optimization process and the criteria applied for hydraulic and sediment measurements are reported in the *River Survey Project study reports 11 and 12 (RSP, 1996a, 1996b)*. In this report only the sustainability aspect is elaborated.

A sustainable survey technique means that the technique applied can be continued in the future as desired by a certain institution in a certain environment. This definition is adopted from a broader definition of sustainability by IUCN, UNEP and WWF (1991). According to them, “Sustainability – a characteristic of a process or state that can be maintained indefinitely”. However, any instrument or method should be re-evaluated after a certain time as the ranking applied against each criteria may change depending on the societal and technological development of the country. This happens because a technique is a transient phenomena changing with the technological development of a country. The technique can be continued if it satisfies the six criteria as we formulated in Table 6.1.

The *first* criteria is related to the affordability of investment and operation and maintenance costs and it implies that the concerned institution should be able to incur these expenses from the resources at its disposal. These resources can either be its own resources or external resources (grants or loans). Since the flow of an external resource can not be guaranteed or can not be justified for long, the concerned institution should develop its own affordability. Otherwise, the works cannot be sustained.



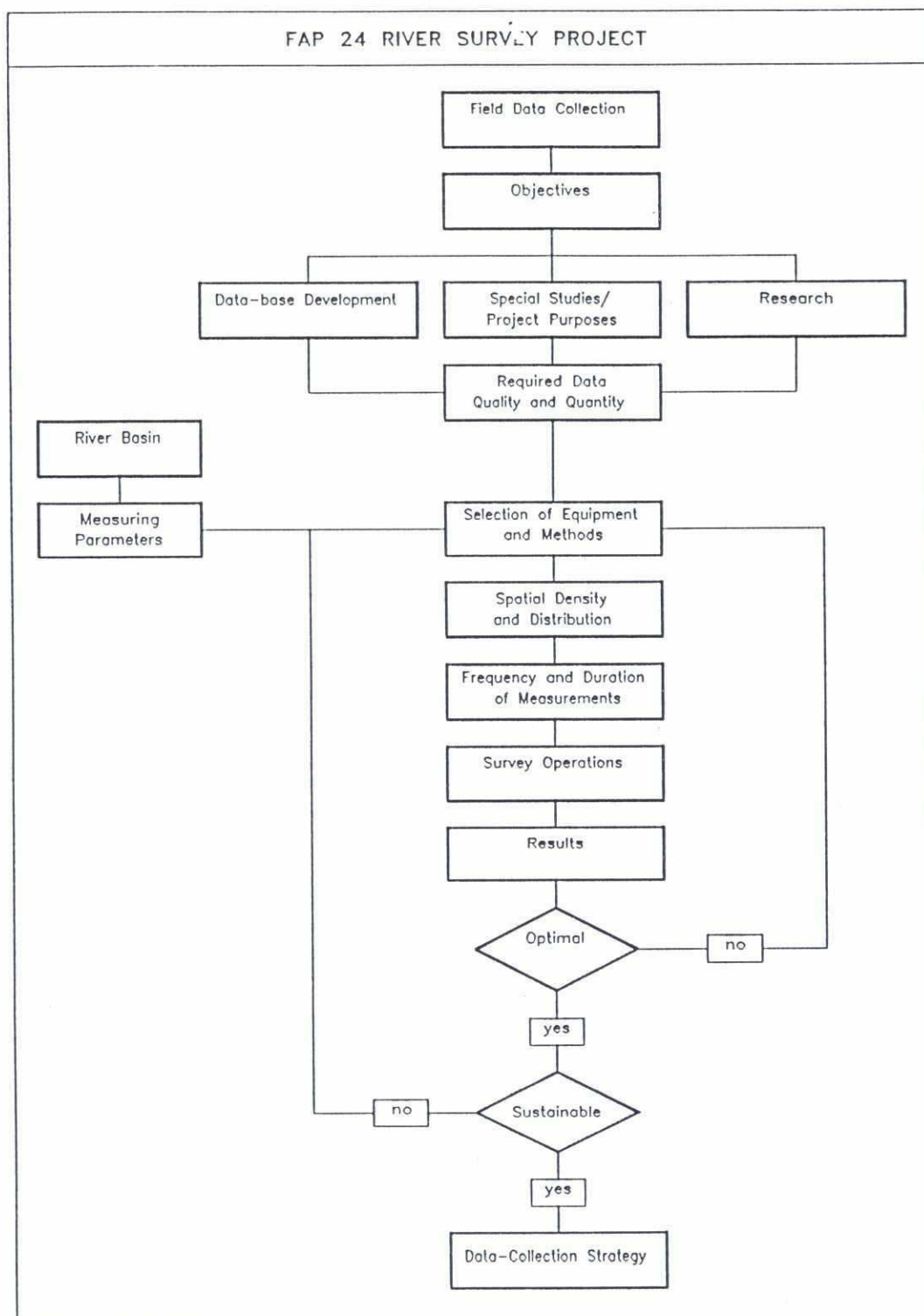


Figure 6.1: Schematic diagram showing the optimization and sustainability principle

The *second* criteria is concerned with the institutional capability in operation and maintenance. Often, the institutional capability is well developed for an existing situation. Any introduction of new equipment or method invariably means that the institutional capability should be developed through training in the framework of an overall human resources development.

The *third* criteria deals with the technological compatibility of the introduced equipment. An equipment needs repair, servicing and replacement of worn or damaged parts. Until it is compatible with the existing technological infrastructure of the country, the equipment can not be sustained. Depending on external assistance in this regard can not be justified for long.

The *fourth* criteria recognizes that to be sustainable, the equipment and method should be optimal. Figure 6.1 shows an internal optimization loop. The detailed optimization process of hydraulic and sediment measurements are reported in *RSP study reports 11 and 12 (RSP, 1996a, 1996b)*. Optimization is a process of finding the most favourable solution to a problem that will meet the predetermined quantified objectives. To attain an optimal solution, the measurements should be screened against some optimization criteria. This multi-criteria screening ensures that the technique should:

- have minimum investment, operation and maintenance costs;
- attain the required accuracy according to objectives;
- be operationally easy;
- take minimum measurement duration;
- have minimum maintenance, and
- represent the measuring parameters well.

The applied technique should give results which can be justified against the incurred expenses. This consideration forming the fifth criteria is very important for future continuation of the survey and implies that even if the equipment and method are expensive, if they generate high quality data they can be justified. Good quality data can be sold and part of the expenses can be recovered.

Finally, the technique applied should be environmentally suitable. An equipment and method which either degrade the environment or are degraded by the environment should be avoided.

| Sustainability Criteria |                                                              |
|-------------------------|--------------------------------------------------------------|
| 1.                      | Affordability of investment and O & M costs                  |
| 2.                      | Institutional capability in O & M                            |
| 3.                      | Technological compatibility                                  |
| 4.                      | Optimal technique and survey results                         |
| 5.                      | Justification of results against the incurred expenses       |
| 6.                      | Suitability of the technique on environmental considerations |

Table 6.1: Criteria for sustainable survey techniques.

The sustainability analysis was made with a clear objective that the technique suggested can be continued by major relevant government agencies in Bangladesh. Therefore, wherever possible we included equipment and methods in the analysis which were not used by the RSP. A sustainable network of measuring stations implies that the network should provide a sufficient and acceptable quality and quantity of data, and operation and maintenance of the stations should be justifiable in terms of O&M costs.

Similarly, a sustainable frequency of measurements suggest that unnecessary measurements should be avoided but necessary measurements should not. All these aspects are treated separately.

## 6.2 Measuring Network

Measurements in natural rivers comprise two basic groups of data collection which are stage-discharge and sediment transport.

Figure 6.2 shows the network optimization principle for hydraulic and sediment measurements. The measurements within a network should yield some satisfactory diagnostic relationships such as stage-discharge relationship or sediment rating curves for each station. The results from such relations of the network-stations should yield reasonable water balance or sediment balance results. In addition, the necessity of certain stations can be examined by establishing inter-station relationships.

In Bangladesh there are about 300 water-level stations and 80 discharge measurement stations of which 25 stations are covered with sediment measurements (BWDB, 1982). Data have been collected in these stations systematically since 1965 after FAO initiatives (FAO, 1969). Table 6.2 shows eleven measuring stations in the main rivers of Bangladesh which are covered by the RSP. Of these, eight are primary stations and three are secondary stations. BWDB does not cover stations at Sirajganj, Aricha or Arial Khan Offtake.

As proposed in Figure 6.2, a network optimization consists of three initial steps which are necessary before a final selection can be made. Depending on the purpose as described earlier, the steps are:

- 1 initial selection of a measuring site or transect as close as possible to conditions as prescribed in WMO (1994);
- 2 the measurements should yield a good stage-discharge relation or good sediment rating curves;
- 3 Time-integration of results obtained from measurements in the network should yield a reasonable water-balance or sediment-balance picture.

A measuring transect is chosen as far as practicable, according to the suggestions of WMO (1994) to avoid converging and diverging flow lines. The guidelines can be summarized as follows:

- a straight channel reach: channel length  $> 5$  times the channel width,
- uniform bed topography – no scour holes or shoals,
- no converging or diverging flow lines, no vortices, no backward flow or deadwater zones,
- transect normal to the main flow direction,
- sufficiently deep with respect to the sampling device,
- clear of obstacles – trees, bridges, piers, etc.



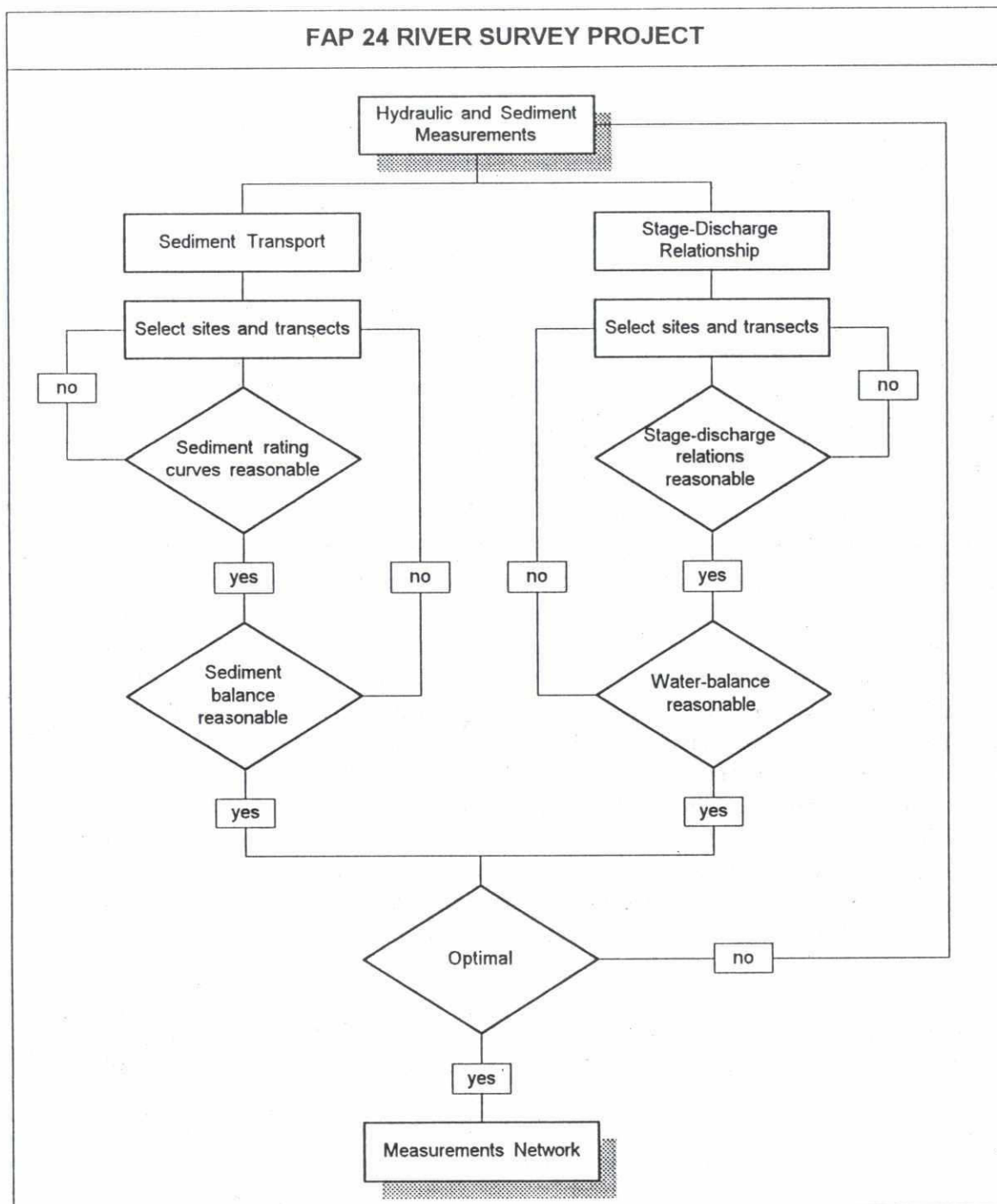


Figure 6.2: Network optimization principle

It should be appreciated why such guidelines are important. If one can measure at infinite numbers of points both vertically and horizontally across a transect, then a guideline such as given by WMO (1994) is not necessary. However, since measurements are carried out in finite discrete locations, it is necessary to interpolate (in some cases extrapolate) the parameters linearly between measured locations. With non-uniform flows such a linearity assumption does not hold. Therefore, measurements should be carried out in locations as far as practicable according to WMO (1994).

Measurements from the various chosen sites in this way should yield acceptable stage-discharge relations or sediment rating curves. If the results are not satisfactory, the site selection procedure is repeated until a satisfactory result is obtained. Herewith it should be noted that in large sand bed rivers these stable relationships may not occur. While making such decisions on either accepting or rejecting a certain station based on such considerations it is assumed that the measurements were made correctly. Using the data a water-balance or sediment balance for the gauging network is computed. If the balances are acceptable then they can be screened against several optimization criteria. If not, the activities are repeated. In this way three loops are suggested. To evaluate the stations with respect to their different relations as proposed in Figure 6.2, the 1987 flood year is considered. Using BWDB observations, stage-discharge relationships were established at Bahadurabad in the Jamuna River, at Hardinge Bridge in the Ganges River and at Baruria in the Padma River. Accumulated volumes for 1987 are  $387 \times 10^9 \text{ m}^3$  through the Ganges River at Hardinge Bridge,  $688 \times 10^9 \text{ m}^3$  through the Jamuna River at Bahadurabad and  $966 \times 10^9 \text{ m}^3$  through the Padma River at Baruria. The water-balance indicates that some 11% of the Padma River discharge is shared by different distributaries – the Old Brahmaputra River, the Dhaleswari River, and the Gorai River. The exercise shows a reasonable water-balance considering the un-accounted tributaries and distributaries and uncertainty ranges of these factors. A similar exercise with BWDB suspended sand transport data shows some unrealistic results. Here, sand-transport rating curves were established with 1987 BWDB data having 24, 21 and 14 data points, respectively for Bahadurabad, Hardinge Bridge and Baruria stations. Using these rating curves, the 1987 sand volumes are 55 million tons through Jamuna River at Bahadurabad, 29 million tons through the Ganges River at Hardinge Bridge, and 95 million tons through the Padma River at Baruria. The total transport through the Ganges and the Jamuna Rivers is 84 million tons which is 11 million tons lower than the transport at Baruria. The results indicate a degradation of the system which appears to be unrealistic. The unrealistic results indicate that the BWDB sediment gauging techniques need evaluation and improvement. Each station chosen by the RSP (as shown in Table 6.2) is discussed with respect to its status and importance for a sustainable survey technique in Bangladesh.

**Bahadurabad:** Bahadurabad is a primary discharge and sediment transport measuring station in the Brahmaputra-Jamuna River in Bangladesh. It is an important station for estimation of water resources of the country, especially in relation to cross-country flow. But in the multiple channels of the river, which changes in planform very rapidly, it is very difficult to measure accurately unless extra care is taken to cope with the changing situations. This station is covered both by the RSP and BWDB.

**Sirajganj:** Sirajganj is a secondary network station for discharge and sediment measurements. It forms a check on water and sediment balance of the Jamuna River. The present morphological situation of the river at Sirajganj is relatively a better site for measurements. The station is not covered by BWDB.

**Aricha:** Aricha is a secondary network station for discharge and sediment gauging. This station provides a check on water and sediment balance. The station is too close to the confluence of the Ganges and the Barhmaputra Rivers.



**Mymensingh:** Mymensingh is a primary measurement network in one of the major distributaries of the Jamuna River – the Old Brahmaputra River where discharge and sediment transport measurements are taken. The river course, abandoned two centuries ago by the present Jamuna River flow, occupies an important position in the sedimentology and river behaviour of the northeast and north-central regions. The transect taken near the Mymensingh Railway Bridge is a relatively ideal measurement network station and it is covered both by the RSP and BWDB.

**Tilly:** Tilly is a discharge and sediment measuring station in the Dhaleswari River and forms a primary measurement network station. It is one of the major distributaries of the Jamuna River draining and supplying water to the north-central region.

**Hardinge Bridge:** Hardinge Bridge is a primary discharge measuring station in the Ganges River. It is an important primary station required to monitor the cross-country flow through the Ganges River. The station is located in a constricted river bend and was found to be not an ideal location for stream-gauging. Relocation of the measuring site may be considered.

**Kushtia Railway Bridge:** Kushtia Railway Bridge is a primary network station on the Gorai River – a right-bank distributary of the Ganges River. The river is important for draining and supplying fresh water to the south-western region.

**Baruria:** Baruria is a primary measurement station located in the Padma River. From stream-gauging considerations, this station is also not an ideal one because it is effected by the confluence of the Ganges and the Jamuna and the river bend at the transect. Relocation of the measuring site may be considered.

**Mawa:** Mawa is a lower reach stream gauging station in the Padma River having a seasonal tidal effect. This station having secondary status is important only to check Baruria flow and tidal effect on sedimentation and river morphology.

**Arial Khan Offtake:** The Arial Khan is a right bank distributary of the Padma River. The station located at the offtake is seasonally tidal and has a primary status. It is important for estimating water resources in the southwestern region and monitoring delta development.

**Bhairab Bazar Railway Bridge:** Bhairab Bazar is a primary discharge gauging station in the Upper Meghna River. The station is seasonally tidal. It is an important station to estimate water resources of the northeast region and sedimentological behaviour of the Upper Meghna River.



| River System       | River           | Station             | Network status | Remarks                                                                                                                     |
|--------------------|-----------------|---------------------|----------------|-----------------------------------------------------------------------------------------------------------------------------|
| Brahmaputra-Jamuna | Jamuna          | Bahadurabad         | Primary        | Important for assessing the hydraulic and sedimentological behaviour of the river but difficult for gauging.                |
|                    | Jamuna          | Sirajganj           | Secondary      | Present condition is good for gauging.                                                                                      |
|                    | Jamuna          | Aricha              | Secondary      | The station is too close to the Ganges-Jamuna confluence.                                                                   |
|                    | Old Brahmaputra | Mymensingh          | Primary        | Important for assessing the hydraulic and sedimentological behaviour of the river.                                          |
|                    | Dhaleswari      | Tilly               | Primary        | Important for assessing the hydraulic and sedimentological behaviour of the river.                                          |
| Ganges             | Ganges          | Hardinge Bridge     | Primary        | Important for assessing the hydraulic and sedimentological behaviour of the river but may need relocation.                  |
|                    | Gorai           | Kushtia R.B.        | Primary        | Important for assessing the hydraulic and sedimentological behaviour of the river and monitoring delta development.         |
| Padma              | Padma           | Baruria             | Primary        | Important for checking water balance and sediment balance.                                                                  |
|                    | Padma           | Mawa                | Secondary      | Seasonally tidal.                                                                                                           |
|                    | Arial Khan      | Offtake             | Primary        | Seasonally tidal and important for assessing the hydraulic and sedimentological behaviour and monitoring delta development. |
| Meghna             | Upper Meghna    | Bharirab Bazar R.B. | Primary        | Seasonally tidal and important for assessing the hydraulic and sedimentological behaviour of the river.                     |

Table 6.2: Hydraulic and measurements network in the main rivers of Bangladesh. WR – water resources, NE – northeastern region, NC – north-central region, SW – southwestern region.

### 6.3 Measuring Frequency

This aspect addresses at what distribution and how many times a year, the measurements should be made. Prior to that it is necessary to optimize the measuring technique (DVWK, 1991) suggests that some 250 to 300 measurements should be taken per year to obtain a nice overview of sediment measurements.

How often in a year measurement should be taken is an important question and needs answering and optimization. It depends on the variability of measuring parameters. For Bangladesh rivers, the seasonality of rivers make the issue important. Figure 6.3 shows a scheme in which the optimization process of the frequency of measurements are proposed. The essential feature of the optimization process is to identify the discontinuity and distinctness in the variability of the parameter being measured and schematise different segments so as to avoid unnecessary measurements. Also, it is important to see which part of the segment is important for a certain purpose. Two loops are suggested which include examining the

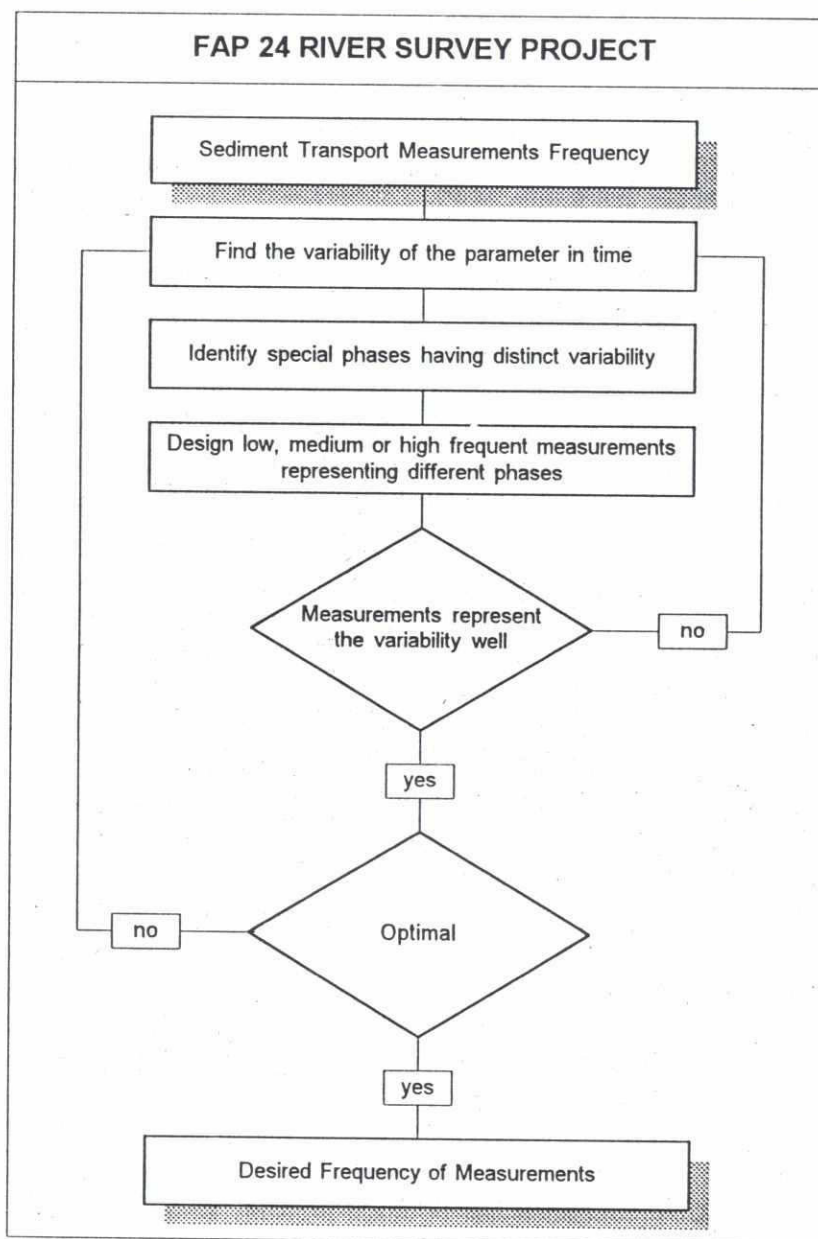


Figure 6.3: Optimization principle of the frequency of measurements



measurements on natural variability and screening them against some optimization criteria. In the Technical Specifications and the Bill of Quantities the frequency of the routine measurements were given. The flexibility to adapt these frequencies was built in the project through the project management FPCO-WARPO-PA-PMU. In the flood-stage period from June to October weekly measurements were suggested. For the rest of the season, fortnightly measurements were indicated. In this way some 36 set of data could be collected per year. However, during actual execution of a survey, measurements could be taken less frequently due to various constraints. In this chapter we attempted to identify distinct phases of the hydrograph which can be schematised for different frequency of measurements. This is necessary because stage-discharge relations and sediment rating curves were found to depend on the phases of the hydrograph (Khan and Barua, 1995).

Water-level and discharge hydrographs of major stations show some distinct phases representing the annual hydrograph. At first instance, it can be distinguished as tidal or non-tidal. Most of the measuring stations are non-tidal except the Padma River station at Mawa, the Upper Meghna River station at Bhairab Bazar, and Arial Khan Offtake. The variability of non-tidal and tidal stations are summarized in Tables 6.3 and 6.4 respectively. Table 6.3 shows the variability status of non-tidal rivers (considered Jamuna River at Bahadurabad) where various phases of the hydrograph are identified. Rising limb of the hydrograph from March to June has been identified to consist of a slow rising part in March to May and a rapid rising part in June. The overall peak river stage from July to September has been identified as consisting of varying peaks in July and August and a very slow falling stage in September. Similarly, the falling river stage has been identified as consisting of a rapid falling limb in October and a slow falling limb in November and December. January and February months represent a flat low river stage. Following these distinct phases of seasonal variability, measurement frequencies are suggested in Table 6.3. For the flat low river stage, we suggest taking low-frequency fortnightly measurements because very little hydraulic or morphological action takes place during this stage. For slow rising and falling stages, a medium-frequency weekly measurements are suggested. For other river stages representing either rapid stages or peak stages a bi-weekly (every four days) measurements are suggested. It should be noted that the scheme is applicable only for routine measurements required for long-term data-base development. For any other purpose, such as special studies or research, a different scheme should be designed depending on the objectives. In this way, 60 to 70 measurements will result from each station which are sufficient to develop or update a stage-discharge relationship or a sediment rating curve.

When many years of data indicate that the stage-discharge relations or sediment rating curves are stable or unchanging, a further optimization can be made probably resulting in less frequency of measurements. However, a careful watch should be made on episodic events such as an unusual flood or an earthquake. The variability of the Bangladesh rivers, either in rapid planform changes or in bed-form developments, indicate that a continuous updating of rating relations would be necessary. In fact this means that in certain river reaches stable relationships do not occur.



| Phases | Variability Status | Months            | Measuring Frequency |
|--------|--------------------|-------------------|---------------------|
| 1      | Slow rising        | March-May         | Medium (weekly)     |
| 2      | Rapid rising       | June              | High (bi-weekly)    |
| 3      | Varying peak       | July-August       | High (bi-weekly)    |
| 4      | Very slow falling  | September         | High (bi-weekly)    |
| 5      | Rapid falling      | October           | High (bi-weekly)    |
| 6      | Slow falling       | November-December | Medium (weekly)     |
| 7      | Flat low           | January-February  | Low (fortnightly)   |

Table 6.3: Optimal routine sediment measurement frequency for non-tidal stations in the Bangladesh rivers based on considerations of the Jamuna River at Bahadurabad.

For seasonally tidal stations such as Mawa and Bhairab-Bazar a different scheme should be followed which is indicated in Table 6.4. At these stations, a tidal variability is noticeable in the months from December to April. An annual scheme of measurements is shown in Table 6.4 incorporating weekly spring and neap tidal measurements from December to April. A tidal measurement indicates that such measurements should be taken hourly for a full tidal cycle (preferably 26 hours). Establishing a rating relation for such stations is difficult but the residual flows should be related both to the river stage and to the spring-neap tidal phases.

| Phases | Variability Status          | Months         | Measuring Frequency      |
|--------|-----------------------------|----------------|--------------------------|
| 1      | Non-tidal slow rising       | May            | Medium (weekly)          |
| 2      | Non-tidal rapid rising      | June           | High (bi-weekly)         |
| 3      | Non-tidal varying peak      | July-August    | High (bi-weekly)         |
| 4      | Non-tidal very slow falling | September      | High (bi-weekly)         |
| 5      | Non-tidal rapid falling     | October        | High (bi-weekly)         |
| 6      | Non-tidal slow falling      | November       | Medium (weekly)          |
| 7      | Tidal                       | December-April | Spring-neap weekly tidal |

Table 6.4: Optimal routine sediment measurements frequency for tidal stations at Mawa, Bhairab Bazar and Arial Khan Offtake.

For further information about the tidal measurements see Subsections 5.3.7 and 5.4.4

## 6.4 Equipment and method

The analysis includes several equipment and methods used by the RSP and other government agencies in Bangladesh. Table 6.5 shows the list of equipment which are presently used by BWDB and BIWTA. Based on the RSP experiences as discussed in Chapter 5, advantages and disadvantages of each equipment and method were listed in several Tables. A multi-criteria scoring system for sustainability is based on all these considerations.

| Equipment and method    | Measuring parameters | Government agencies                             |
|-------------------------|----------------------|-------------------------------------------------|
| Sextant                 | positioning          | BWDB                                            |
| Decca                   | positioning          | BIWTA                                           |
| Rod suspension          | depth                | BWDB                                            |
| Cable suspension        | depth                | BWDB                                            |
| Float-well auto gauge   | water level          | BWDB and BIWTA                                  |
| Traditional moving boat | discharge estimation | BWDB introduced the system with UNDP assistance |
| Binckley silt sampler   | suspended sediment   | BWDB                                            |

Table 6.5: Equipment and methods which are used by various government agencies in Bangladesh and considered for sustainability analysis in the report.

### 6.4.1 Positioning

The RSP introduced the Differential Global Positioning System (DGPS) in Bangladesh. The system uses reference stations to monitor and modulate GPS signals. The GPS itself can also be used for positioning.

For hydrographic surveying two other systems are used by Bangladesh agencies. The BIWTA uses Decca positioning for navigation and positioning during bathymetric survey. The BWDB uses a sextant for positioning of survey vessels during discharge and cross-sectional measurements.

The advantages and disadvantages of the systems are described in Table 6.6. It is obvious from the table that the DGPS has a clear advantage in terms of accuracy.

| Instru-<br>ment | Advantages                                                                                                                                                                                                                           | Disadvantages                                                                                                                                                                                                                                                                                    |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GPS             | <ul style="list-style-type: none"> <li>portable and easy to operate receivers</li> <li>hardly any maintenance</li> <li>simple dry-cell replacement when empty</li> <li>recently introduced in many projects in Bangladesh</li> </ul> | <ul style="list-style-type: none"> <li>accuracy <math>\pm 30</math> m.</li> <li>subject to occasional strategic blocking of signals.</li> </ul>                                                                                                                                                  |
| Trimble<br>DGPS | <ul style="list-style-type: none"> <li>accurate within <math>\pm 3</math> m</li> <li>not subject to strategic blocking</li> <li>introduced by the RSP in Bangladesh</li> </ul>                                                       | <ul style="list-style-type: none"> <li>receivers are not portable.</li> <li>dependence on reference station operation and maintenance.</li> <li>accurate geodetic coordinates of the reference stations should be established.</li> </ul>                                                        |
| Decca           | <ul style="list-style-type: none"> <li>experience exists with BIWTA and BWDB</li> </ul>                                                                                                                                              | <ul style="list-style-type: none"> <li>accuracy <math>\pm 100</math> m.</li> <li>dependence on Decca Master and slave stations operation and maintenance.</li> <li>positioning depends on special Decca parabolic charts.</li> <li>the system is getting obsolete and out of use.</li> </ul>     |
| Sextant         | <ul style="list-style-type: none"> <li>experience exists with BWDB</li> <li>robust and trouble-free equipment</li> </ul>                                                                                                             | <ul style="list-style-type: none"> <li>dependent on the crew-expertise on measuring angles and subject to human error.</li> <li>maintenance of beacons and dependent on the accuracy of distance measurements between beacons.</li> <li>not suitable for positioning in large rivers.</li> </ul> |

Table 6.6: Advantages and disadvantages of different survey positioning instruments in Bangladesh.

Table 6.7 shows the multi-criteria sustainability scores of three positioning instruments, the sextant, Decca and DGPS. In terms of affordability the sextant has a clear advantage because it is the cheapest among the three. It is followed by Decca and DGPS. Fast development of DGPS is expected to lower the prices of the equipment. Similarly, the sextant has a more institutional capability than the others because the BWDB has been using the system for a long time. The sextant is the most technologically compatible equipment as compared to the others. It is a mechanical instrument and compatible with the present technological advancement of the country. The advantages of a sextant are countered by a DGPS, which gives a justified result against the incurred expenses. In total count, DGPS and the sextant are equally sustainable.



| Instruments | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|-------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Sextant     | 3                 | 6                        | 3                        | 1              | 2                       | 2                       | 17    |
| Decca       | 2                 | 4                        | 1                        | 2              | 4                       | 1                       | 14    |
| DGPS        | 1                 | 4                        | 2                        | 3              | 6                       | 1                       | 17    |

Table 6.7: Multi-criteria sustainability scores of positioning instruments considering the present state-of-the-art development.

#### 6.4.2 Riverbed profiles

Measurements of riverbed profiles or depths were made by single and dual frequency echo sounders by the RSP. The BWDB uses mostly the rod suspension, cable suspension or an echo sounder. Therefore, all these three systems of measurements were compared and advantages and disadvantages are shown in Table 6.8. Rod and cable suspension are primitive devices and can only be used to obtain a rough estimate during navigation.

| Instrument       | Advantages                                                                                                                                                             | Disadvantages                                                                                                                                                                                                                                                                                                                                                |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rod suspension   | <ul style="list-style-type: none"> <li>cheap and the device can be made easily</li> </ul>                                                                              | <ul style="list-style-type: none"> <li>very approximate and only can provide a rough estimate</li> <li>vulnerable to wrong depth-marking on the rod</li> <li>can not be applied in deep water and in high flow velocity</li> <li>an angle correction is often not easy to make</li> <li>can overestimate the depth when the rod is buried</li> </ul>         |
| Cable suspension | <ul style="list-style-type: none"> <li>cheap and the device can easily be made</li> </ul>                                                                              | <ul style="list-style-type: none"> <li>very approximate and only can provide a rough estimate</li> <li>vulnerable to wrong depth-marking on the cable</li> <li>cannot be applied in high flow velocity</li> <li>an angle correction in high flow velocity is often not easy to make</li> <li>can overestimate the depth when the weight is buried</li> </ul> |
| Acoustic         | <ul style="list-style-type: none"> <li>gives accurate estimate of depth</li> <li>not limited to deep water, high velocity or any other hazardous situations</li> </ul> | <ul style="list-style-type: none"> <li>relatively expensive</li> </ul>                                                                                                                                                                                                                                                                                       |

Table 6.8: Advantages and disadvantages of various depth-measuring devices

However, as shown in Table 6.9, rod and cable suspension has a clear advantage in affordability, institutional capability and technological compatibility. An acoustic sensor, on the other hand, provides a justified result by giving an accurate result at the incurred expenses. In total count, an acoustic system has a slightly higher score than the others.

| Instruments      | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|------------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Rod-suspension   | 3                 | 6                        | 3                        | 1              | 2                       | 3                       | 18    |
| Cable-suspension | 3                 | 6                        | 3                        | 1              | 2                       | 3                       | 18    |
| Acoustic         | 2                 | 4                        | 2                        | 3              | 6                       | 2                       | 19    |

Table 6.9: Multi-criteria sustainability scores of depth measuring devices considering the present state-of-the-art development.

#### 6.4.3 Water levels and slopes

The RSP used some advanced techniques such as auto-pressure sensor and auto-acoustic sensor recording water level stages in Bangladesh rivers. These sensors together with level-log data recorders were mounted on specially built platforms at eleven locations along the major river systems. In addition, manual staff gauges were used as supplements. The BWDB and BIWTA mostly use float-well type auto gauges. Table 6.10 shows the advantages and disadvantages of these devices. Clear advantages of the-used auto-sensors are in their data-storage for about six months.

| Instrument      | Advantages                                                                                                                                                                                                                                                                        | Disadvantages                                                                                                                                                                                                                                         |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Auto-pressure   | <ul style="list-style-type: none"> <li>accurate reading</li> <li>can be adjusted to a desirable frequency of observation</li> <li>digital record</li> <li>Level-log can store data up to six months</li> <li>reliable electronic clock</li> </ul>                                 | <ul style="list-style-type: none"> <li>needs platform and support for the sensor and the level-log.</li> <li>vented-air tube is vulnerable to blocking.</li> <li>the platform is expensive to relocate.</li> </ul>                                    |
| Auto-acoustic   | <ul style="list-style-type: none"> <li>accurate reading</li> <li>can be adjusted to a desirable frequency of observation</li> <li>digital record</li> <li>sensor above the water</li> <li>Level-log can store data up to six months</li> <li>reliable electronic clock</li> </ul> | <ul style="list-style-type: none"> <li>needs platform and support for the sensor and the level-log.</li> <li>the sensor has to hang clear of the structure to avoid acoustic interference.</li> <li>the platform is expensive to relocate.</li> </ul> |
| Auto Float well | <ul style="list-style-type: none"> <li>accurate reading</li> </ul>                                                                                                                                                                                                                | <ul style="list-style-type: none"> <li>needs a well for the float and the counter-weight and support for the recorder.</li> <li>analogue record - needs frequent paper and pen change.</li> <li>the platform is expensive to relocate.</li> </ul>     |
| Manual staff    | <ul style="list-style-type: none"> <li>cheap</li> <li>can be easily relocated</li> </ul>                                                                                                                                                                                          | <ul style="list-style-type: none"> <li>sparse day-light record.</li> <li>not accurate, dependent on gauge reader.</li> <li>time-keeping dependent on gauge reader watch.</li> </ul>                                                                   |

Table 6.10: Advantages and disadvantages of various water-level measuring devices

As shown in Table 6.11, all the devices have close scores on sustainability consideration. The clear advantages of manual staff gauges are in its affordability, institutional capability and technological compatibility. But as with other equipment, the sensors used by the RSP give a justified result.



| Instruments     | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|-----------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Auto-pressure   | 1                 | 4                        | 2                        | 3              | 8                       | 1                       | 19    |
| Auto-acoustic   | 1                 | 4                        | 2                        | 4              | 8                       | 1                       | 20    |
| Auto Float-well | 1                 | 6                        | 3                        | 2              | 6                       | 1                       | 19    |
| Manual staff    | 3                 | 8                        | 4                        | 1              | 2                       | 2                       | 20    |

Table 6.11: Multi-criteria sustainability scores of water-level measuring devices considering the present state-of-the-art development.

#### 6.4.4 Discharge

The RSP introduced the moving boat method using ADCP and EMF velocity sensors to gauge discharge in large rivers. In smaller rivers, a velocity-area method was followed utilising an Ott-propeller current-meter. Float-tracking was specially used for indication of flow lines. Table 6.12 shows the advantages and disadvantages of the various instruments used. Sustainability scores were presented in Table 6.13. As expected, based on the present state-of-the-art development of the considered instrumentation, Ott-propeller or similar mechanical rotor current-meters is the sustainable one. It should be noted that the scores are based on average field conditions. Extreme conditions (e.g. peak flows) may affect the scores.

| Instruments        | Advantages                                                                                                                           | Disadvantages                                                                                                                                                                                                                                                   |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RDI-BroadBand ADCP | <ul style="list-style-type: none"> <li>accurate velocity profile measurement</li> <li>data in three orthogonal components</li> </ul> | <ul style="list-style-type: none"> <li>expensive and fast developing stage.</li> <li>unmeasured zone in the top and bottom layers.</li> <li>computes scatterer velocity.</li> </ul>                                                                             |
| IO-EMC (S4)        | <ul style="list-style-type: none"> <li>accurate point-velocity measurement</li> <li>data in two orthogonal directions</li> </ul>     | <ul style="list-style-type: none"> <li>expensive.</li> <li>vertical velocity not available.</li> </ul>                                                                                                                                                          |
| PEMS-EMF           | <ul style="list-style-type: none"> <li>accurate point-velocity measurement</li> <li>data in two orthogonal directions</li> </ul>     | <ul style="list-style-type: none"> <li>expensive.</li> <li>vertical velocity not available.</li> </ul>                                                                                                                                                          |
| Ott-propeller      | <ul style="list-style-type: none"> <li>cheap and easy to operate</li> </ul>                                                          | <ul style="list-style-type: none"> <li>only speed is given, no direction is available.</li> <li>affected by the roll, pitch and translation of the vessel.</li> </ul>                                                                                           |
| Float-tracking     | <ul style="list-style-type: none"> <li>cheap and easy to operate</li> <li>Lagrangian velocity field</li> </ul>                       | <ul style="list-style-type: none"> <li>approximate velocity.</li> <li>dependent on the accuracy of positioning and time-keeping.</li> <li>subject to wind-drag if not properly designed.</li> <li>subject to interrupted motion in shallower depths.</li> </ul> |

Table 6.12: Advantages and disadvantages of various velocity measuring devices.



| Instruments    | Afford-<br>able x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|----------------|---------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| RDI-ADCP       | 1                   | 6                        | 2                        | 5              | 10                      | 1                       | 25    |
| IO-EMC (S4)    | 3                   | 6                        | 2                        | 3              | 8                       | 1                       | 23    |
| PEMS-EMF       | 2                   | 6                        | 2                        | 4              | 8                       | 1                       | 23    |
| Ott-propeller  | 4                   | 10                       | 5                        | 2              | 6                       | 3                       | 30    |
| Float-tracking | 5                   | 10                       | 5                        | 1              | 2                       | 3                       | 26    |

Table 6.13: Multi-criteria sustainability scores of velocity measuring devices considering the present state-of-the-art development.

Table 6.14 shows the advantages and disadvantages of different discharge estimation methods. The primary advantage of the moving boat methods are their fast estimation of discharge. Velocity-area method, on the other hand, is a known and straightforward method which has a universal applicability.

| Methods                 | Advantages                                                                                                                                  | Disadvantages                                                                                                                                                                                                                 |
|-------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ADCP moving boat        | <ul style="list-style-type: none"> <li>fast estimation of discharge</li> <li>does not depend on the perpendicularity of transect</li> </ul> | <ul style="list-style-type: none"> <li>expensive</li> <li>measurements are limited by shallow water</li> </ul>                                                                                                                |
| Traditional moving boat | <ul style="list-style-type: none"> <li>fast estimation of discharge</li> </ul>                                                              | <ul style="list-style-type: none"> <li>measurements at one point</li> <li>measurements are limited by shallow water</li> <li>sailing is required perpendicular to flow</li> <li>affected by irregular vessel speed</li> </ul> |
| Velocity-area           | <ul style="list-style-type: none"> <li>known and straightforward method</li> </ul>                                                          | <ul style="list-style-type: none"> <li>takes longer time than the moving boat methods</li> <li>many vessels are required in multiple-channel rivers</li> </ul>                                                                |

Table 6.14: Advantages and disadvantages of various discharge estimation methods.

In Table 6.15 the sustainability scores are shown against each method. The velocity-area method, having a clear advantage in most of the considered criteria, appears a winner.

| Methods           | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|-------------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| ADCP moving boat  | 1                 | 2                        | 1                        | 3              | 2                       | 1                       | 10    |
| Trad. moving boat | 1                 | 2                        | 1                        | 2              | 2                       | 1                       | 9     |
| Velocity area     | 3                 | 6                        | 3                        | 1              | 4                       | 2                       | 19    |

Table 6.15: Multi-criteria sustainability scores of discharge measuring methods considering the present state-of-the-art development.

### 6.4.5 Suspended sediment

Various advantages and disadvantages of suspended sediment measuring devices are shown in Table 6.16. They represent the experiences of the RSP. Binckley Silt Sampler is used for comparison only as it is used by BWDB. Various errors (relative standard deviation in percentage) indicated are taken from the literature (e.g. Van Rijn and Schaafsma, 1986; Nordin, 1994). For further discussions on this approach plus refer to subsection 5.3.6

| Sampling Device             | Advantages                                                                                                                                                                                                                                               | Disadvantages                                                                                                                                                                                                                                                                                                        |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Delft Bottle                | <ul style="list-style-type: none"> <li>Sturdy and reliable.</li> <li>Moderately easy to operate and nearly maintenance free.</li> <li>Not sensitive to damage by heat and humidity.</li> </ul>                                                           | <ul style="list-style-type: none"> <li>Represents particles &gt; 0.1 mm only.</li> <li>Errors are usually in the range of 50%.</li> <li>Some crew expertise is needed to measure volume, adjust nozzles and rear openings.</li> </ul>                                                                                |
| Pump-bottle                 | <ul style="list-style-type: none"> <li>Represents all particle sizes in iso-kinetic conditions.</li> <li>Moderately easy to operate.</li> </ul>                                                                                                          | <ul style="list-style-type: none"> <li>Vulnerable to pump and hose breakdown and pump-speed modulation.</li> <li>Pump hose may clog with high concentration.</li> <li>Crew expertise is needed to adjust the pump-speed to the ambient flow.</li> <li>Errors are usually in the range of 20%.</li> </ul>             |
| Acoustic - ADCP backscatter | <ul style="list-style-type: none"> <li>Very easy to operate.</li> <li>Concentration profile can be obtained in a relatively short time.</li> <li>Has a great potential use for future applications.</li> <li>No field processing is required.</li> </ul> | <ul style="list-style-type: none"> <li>Represents primarily sand.</li> <li>Vulnerable to electronic and software failure.</li> <li>Vulnerable to heat and humidity.</li> <li>Crew expertise is needed for hardware and software use.</li> <li>Calibration is at the developing stage.</li> <li>Error 50%.</li> </ul> |
| Optical - MEX 3             | <ul style="list-style-type: none"> <li>Very easy to operate.</li> <li>Has a great potential use for monitoring of suspended silt.</li> <li>No field processing is required.</li> </ul>                                                                   | <ul style="list-style-type: none"> <li>Represents primarily silt.</li> <li>Vulnerable to electronic and software failure.</li> <li>Crew expertise is needed for hardware and software use.</li> <li>Error 50%.</li> </ul>                                                                                            |
| Integrated Bottle           | <ul style="list-style-type: none"> <li>Sturdy and reliable.</li> <li>Easy and nearly maintenance free.</li> <li>Represents all particle sizes in iso-kinetic conditions.</li> </ul>                                                                      | <ul style="list-style-type: none"> <li>Often, its application is limited by high water-depth.</li> <li>Crew expertise is needed to ensure a uniform lowering and raising rate of the bottle.</li> <li>Error 10% ~ 100%.</li> </ul>                                                                                   |
| Collapsible Bag             | <ul style="list-style-type: none"> <li>Represents all particle sizes in iso-kinetic conditions.</li> <li>Moderately easy and nearly maintenance free.</li> </ul>                                                                                         | <ul style="list-style-type: none"> <li>Teflon bag may leak.</li> <li>Crew expertise is needed to ensure a uniform lowering and raising rate of the bottle.</li> <li>Error 10% ~ 100%.</li> </ul>                                                                                                                     |
| Binckley Silt Sampler       | <ul style="list-style-type: none"> <li>Easy to operate and nearly maintenance free.</li> </ul>                                                                                                                                                           | <ul style="list-style-type: none"> <li>Represents instantaneous suspension status.</li> <li>Vulnerable to leakage.</li> <li>Error in the range of 100%.</li> </ul>                                                                                                                                                   |

Table 6.16: Advantages and disadvantages of various suspended sediment measuring devices.

Table 6.17 shows the sustainability scores of the devices. The instantaneous Binckley sampler has a slight edge over the others primarily because cost is lowest, and it has the institutional capability of BWDB. The device is also more technologically compatible than the others. Delft Bottle, pump-system, integrated bottle and collapsible bag have close scores.

| Prin-<br>ciple                           | Instru-<br>ments              | Afford-<br>able<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comp-<br>tbl<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suit-<br>able<br>x 1 | Total |
|------------------------------------------|-------------------------------|------------------------|--------------------------|------------------------------|----------------|-------------------------|------------------------------|-------|
| Time-<br>integrated -<br>point           | Transp:<br>Delft<br>Bottle    | 4                      | 10                       | 4                            | 5              | 12                      | 7                            | 42    |
|                                          | Conc:<br>Pump                 | 2                      | 10                       | 5                            | 3              | 14                      | 7                            | 41    |
|                                          | Back-<br>scatter:<br>Acoustic | 1                      | 6                        | 3                            | 4              | 4                       | 6                            | 24    |
|                                          | Turbidity:<br>Optical         | 3                      | 6                        | 3                            | 3              | 4                       | 6                            | 25    |
| Time-<br>integrated<br>over the<br>depth | Conc:<br>Integrated<br>Bottle | 6                      | 8                        | 6                            | 7              | 8                       | 7                            | 42    |
|                                          | Conc:<br>Collapsible<br>bag   | 5                      | 8                        | 6                            | 6              | 10                      | 7                            | 42    |
| Instant-<br>aneous                       | Conc:<br>Binckley<br>sampler  | 7                      | 14                       | 7                            | 4              | 4                       | 7                            | 43    |

Table 6.17: Multi-criteria sustainability scores of the suspended sediment measuring devices considering the present state-of-the-art development.

#### 6.4.6 Near-bed transport

In order to define a sustainable technique to measure near-bed sediment transport in Bangladesh rivers, the advantages and disadvantages of all the various techniques applied are presented in Table 6.18.

Dune tracking was considered at the initiation of the project simply because it avoids direct measurements. However, dunes are not ubiquitous. They are neither present during all river stages nor present uniformly across a transect. Therefore, it is only possible to compute bed-load transport using dune tracking per unit width for a particular stage and for a particular section of the transect. The total bed-load transport can not be computed by using the method.

The Helley-Smith sampler is not suitable for near-bed sampling in the fine sand-bed river because the sampler does not sample correctly the particles less than about 250  $\mu\text{m}$ . Comparatively, a conventional pump sampler is better, however, it is difficult to sample close to the bed.



| Technique or device      | Advantages                                                                                                                                                                                                                                                                                        | Disadvantages                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dune tracking            | <ul style="list-style-type: none"> <li>no mooring problems.</li> </ul>                                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>dunes not always present.</li> <li>rapid change of dune shape.</li> <li>three-dimensional effects.</li> <li>contribution of bed load transport on dune migration uncertain.</li> </ul>                                                                                                                                                                                  |
| Helley-Smith sampler     | <ul style="list-style-type: none"> <li>easy handling.</li> <li>direct measurement of near-bed load.</li> </ul>                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>location with respect to bed forms unknown and necessary to lift the instrument for each observation.</li> <li>large scatter in results.</li> <li>does not represent particles finer than about 250 <math>\mu\text{m}</math> correctly.</li> </ul>                                                                                                                      |
| Delft Bottle on a Sleigh | <ul style="list-style-type: none"> <li>rather easy handling.</li> <li>direct measurement of near-bed load.</li> <li>various sampling heights above the riverbed possible.</li> </ul>                                                                                                              | <ul style="list-style-type: none"> <li>location with respect to bed forms unknown and necessary to lift the instrument for each observation.</li> <li>short observation time.</li> <li>calibrated up to a flow velocity of 2 m/s.</li> <li>does not represent particles finer than about 100 <math>\mu\text{m}</math> correctly.</li> <li>risk for losing sediment while retrieving the instrument.</li> </ul> |
| Pump sampler             | <ul style="list-style-type: none"> <li>rather easy handling (but more arrangements required).</li> <li>high efficiency for fine sediment.</li> <li>continuous measurement possible without lifting the instrument.</li> <li>constant (but unknown) position with respect to bed forms.</li> </ul> | <ul style="list-style-type: none"> <li>location with respect to bed forms unknown.</li> <li>long sampling period only possible when large volume sample containers are available (unless a sample splitter is applied).</li> <li>sampling only possible at 0.25 m above the riverbed.</li> </ul>                                                                                                               |
| Jamuna sampler           | <ul style="list-style-type: none"> <li>see pump sampler.</li> <li>sampling possible in a range from 0.05 to 0.45 m above the riverbed.</li> <li>flow velocity at intake nozzle known.</li> </ul>                                                                                                  | <ul style="list-style-type: none"> <li>location with respect to bed forms unknown.</li> <li>long sampling period only possible when large volume sample containers are available (unless a sample splitter is applied).</li> </ul>                                                                                                                                                                             |

Table 6.18: Advantages and disadvantages of near-bed sediment techniques tested within the RSP

Many problems faced during near-bed sediment sampling were attempted to be solved during the development of the Jamuna sampler. The Jamuna sampler, which is the special case of a pump sampler, is at an initial stage of development and testing. Test at medium flow conditions showed a tendency for "digging" of the instrument which implied a decreasing (but unknown) distance to the riverbed. This can be compensated by mounting a sensor to measure this distance and an electro motor to adjust the elevation of the nozzle accordingly. If such an adjustment is contemplated, then it is recommended to add also a remote control device for shifting the nozzle over the range of 0.05 to 0.45 m above the riverbed, especially during study surveys.

Table 6.19 shows the sustainable near-bed sediment measuring technique. It shows that Delft Bottle on a sleigh is a sustainable technique for measuring near-bed sediment.

| Instruments                             | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|-----------------------------------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Transport:<br>Delft Bottle<br>on Sleigh | 2                 | 6                        | 3                        | 3              | 4                       | 2                       | 20    |
| Transport:<br>Helley-<br>Smith          | 3                 | 6                        | 3                        | 2              | 2                       | 2                       | 18    |
| Conc:<br>Pump<br>(Jamuna<br>Sampler)    | 1                 | 4                        | 2                        | 1              | 6                       | 2                       | 16    |

Table 6.19: Multi-criteria sustainability scores of the near-bed sediment measuring devices considering the present state-of-the-art development.

#### 6.4.7 Sediment properties

Knowledge of the physical properties of sediments are important for obtaining or using transport relations. In addition, the properties are important for studying the morphological behaviours of rivers. The most relevant properties are,

- sand-silt percentage
- grain-size distribution
- density
- shape factor
- porosity
- mineralogical properties

Sand-silt percentage of the river borne sediments depends on the characteristics of the drainage basin, mobility of the river-reaches. It varies considerably in time and space. The ratio varies during the season, one place to another based on local flow conditions, and over the water column. It is an important dynamic property and has been used to indicate channel planform. Schumm (1968) showed that meander wave-lengths are inversely proportional to the silt-clay percentage. This ratio also indicates the conventional distinction between bed-material load and wash load. Therefore, the ratio should be determined for bed-material samples, bed/near-bed load and suspended load.

Grain-size distribution is the most required property of sediment samples. The median diameter, sorting coefficient and others are used for obtaining or using transport relations. Since the property varies extensively in space and time, it is determined routinely for bed-material samples. For suspended and near-bed sediments, the property is determined as required.

The other properties like density, shape factor, porosity and mineralogical properties vary slowly in space and time. Therefore, they need to be determined in order to characterize the rivers but need not be repeated like other properties. Since quartz is the abundant mineral in river borne sediments a density of 2650 kg/m<sup>3</sup> is usually used unless known otherwise. Bangladesh rivers, appear to be influenced by the presence of heavy minerals. Investigations by the RSP indicate that a density of 2750 kg/m<sup>3</sup> should be used for Bangladesh rivers (RSP, 1996).

How is it best to collect a representative bed-material sample for the determination of such properties? The RSP used three bed-material samplers, the Van Veen grab, the USBM-54 and a drag sampler. In Table 6.20, the relative advantages and disadvantages of these samplers are presented. The USBM-54 has a clear advantage in terms of its accuracy.

| Instruments   | Advantages                                                                                                                                 | Disadvantages                                                                                                                                                                                            |
|---------------|--------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Van Veen Grab | <ul style="list-style-type: none"> <li>easy to operate.</li> </ul>                                                                         | <ul style="list-style-type: none"> <li>often fine sediments leak out.</li> <li>the sampler does not open in hard sand bed or soft mud.</li> <li>difficult to operate in high flow velocities.</li> </ul> |
| USBM-54       | <ul style="list-style-type: none"> <li>does not leak</li> <li>operates well in hard sand bed, soft mud or high flow velocities.</li> </ul> | <ul style="list-style-type: none"> <li>should be operated cautiously as injuries may occur.</li> <li>requires a good winch.</li> </ul>                                                                   |
| Drag sampler  | <ul style="list-style-type: none"> <li>easy to operate.</li> <li>easy to fabricate locally.</li> </ul>                                     | <ul style="list-style-type: none"> <li>disturbed and therefore a less representative sample is obtained.</li> </ul>                                                                                      |

Table 6.20: Advantages and disadvantages of bed-material samplers.

In Table 6.21 sustainability analysis of the samplers was made considering the present state-of-the-art development. It can be seen that USBM-54 has the highest score, but the differences are relatively small.

| Instruments   | Affordable<br>x 1 | Instd.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|---------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Van Veen Grab | 2                 | 6                        | 2                        | 2              | 4                       | 1                       | 17    |
| USBM-54       | 1                 | 6                        | 2                        | 3              | 6                       | 1                       | 19    |
| Drag sampler  | 3                 | 6                        | 3                        | 1              | 2                       | 1                       | 16    |

Table 6.21: Sustainability scores of bed-material samplers considering the present state-of-the-art development.



## 6.5 Operational management of surveys

A vital part of the survey operations involves its management. It looks into the following:

- designing survey spread according to the requirement;
- administering survey vessels, crew and hydrographers;
- overlooking book-keeping of survey records (such as log books);
- arranging logistics;
- overlooking the proper transfer of the data and samples from the field to the processing office;
- maintaining survey vessels and instruments in operable conditions;
- maintaining day-to-day contact with survey operations and providing necessary backstopping.

A sustainable operational management implies that the manager should be given enough power and operational flexibility in accordance with the responsibility he has. This is an institutional aspect. The institution should develop its capability through human resources development so that the survey works can be efficiently managed.

## 6.6 Human resources development and institutional aspects

Any sustainable survey technique implies that the concerned institution would have the required capability to continue the technique. An institution should have the following capabilities:

- Skilled and motivated personnel who understand the survey and are confident of doing the work independently;
- A well-conversant vessel crew;
- Technological skill to operate and maintain the vessels and instruments;
- Skilled and motivated personnel to do the data elaboration works;
- Operational management capability;
- Financial viability of the institution.

Often the technological and managerial skills are not available with Bangladesh institutions. Therefore, these skills have to be developed through a training programme of human resources development.

The RSP imparted some training in this regard. The recipient of this training include the following.

- Special lectures on measurements to BWDB personnel at the Bhagyakul Training Institute;
- On-the-job training to the hydrographic surveyors of the north-east measurement division, Surface Water Hydrology I of BWDB;
- On-the-job training to the assistant engineers of Surface Water Hydrology II on data elaboration;
- Rigorous on-the-job two-week training to the employees of several relevant institutions in May 1996, so that the data collected by the RSP could be processed and used by them. The trainees included:
  - two participants from WARPO;
  - three participants from BWDB;
  - two participants from SWMC;
  - one participant from BIWTA;
- Special training to SWMC participants on raw data processing and use,
- Special training to Bangladesh employees on various aspects.

## 6.7 Sustainable survey technique considering a future scenario

As outlined in Section 5.1, a sustainable survey technique needs re-evaluation as certain criteria are transient in nature and their ranking may change depending on the technological development. These advances in development can be discussed via two perspectives. One is that globally instruments and techniques are in a continuous process of improvement and development. In the process, limitations of old equipment and technique are overcome and new techniques are proposed. Depending on the merit of such development society should be able to absorb these developments. Second is related to the country where affordability, institutional capability and technological compatibility, etc., are also changing in the direction of progressive development. Consider, for example, the case of Bangladesh in a decade from now. Hopefully, the affordability of the country will increase and Bangladesh will be able to choose an equipment or technique based on its merit, not just the cheapest one. Similarly, the institutional capability in operation and maintenance is expected to increase. This however, depends basically on how the policy of human resources development is pursued. Presently, a completely discouraging situation exists and, hopefully, that will change in future. Technological compatibility will change in a similar fashion. More and more advanced equipment will be technologically compatible in Bangladesh.

| Instruments        | Affordable<br>x 1 | Instt.<br>Capabl.<br>x 2 | Tech.<br>Comptbl.<br>x 1 | Optimal<br>x 1 | Just.<br>Results<br>x 2 | Env.<br>Suitable<br>x 1 | Total |
|--------------------|-------------------|--------------------------|--------------------------|----------------|-------------------------|-------------------------|-------|
| Auto-pressure      | 3                 | 8                        | 4                        | 3              | 8                       | 1                       | 27    |
| Auto-acoustic      | 3                 | 8                        | 4                        | 4              | 8                       | 1                       | 28    |
| Auto<br>Float-well | 3                 | 8                        | 4                        | 2              | 6                       | 1                       | 24    |
| Manual staff       | 3                 | 8                        | 4                        | 1              | 2                       | 2                       | 20    |

Table 6.22: Multi-criteria sustainability scores of water-level measuring devices considering a future scenario of development.

Based on these considerations, the water-level measuring devices were re-evaluated in Table 6.22. It can be seen that the manual staff gauge is not sustainable any more in contrast to Table 6.11. Devices utilizing pressure or acoustic sensor become sustainable in that situation. It should be realized, however, that in a decade from now, the devices used by the RSP will change and improve further. Therefore, one should consider these findings as applicable to the principles of equipment chosen rather than on a particular brand or type.

A similar analysis can be made for another set of measuring equipment and the findings are shown in Table 6.23.

| Items                          | Sustainable survey technique in a future scenario                      |
|--------------------------------|------------------------------------------------------------------------|
| Positioning                    | DGPS                                                                   |
| Riverbed profile               | Echo sounder                                                           |
| Water levels                   | Automatic sensors                                                      |
| Velocity measurements          | Electronic sensors                                                     |
| Discharge estimation methods   | Moving boat or velocity-area methods using electronic velocity sensors |
| Suspended sediment measurement | Pump bottle                                                            |
| Near-bed sediment measurement  | Delft Bottle, Jamuna Sampler                                           |
| Bed-material sampling          | USBM-54                                                                |

Table 6.23: Sustainable survey instruments and methods for Bangladesh rivers considering a future scenario.



- On water-level gauging, an automatic device using pressure or acoustic sensors was found to serve the project purposes best because of its high accuracy and reliability. However, problems were faced with keeping the platforms stable due to high mobility of the rivers in Bangladesh. The experience suggests that for using recording gauges mounting platforms should be established in a safe, sheltered and high area in order to gauge high river stages only. The high river stage which is often hazardous and risky for a manual staff gauge reader, cannot be obtained accurately by a non-recording staff gauge. The low river stage can be obtained by using a manual staff gauge (but this is less desired in tidal areas). From sustainable point of view the staff gauge is still the best choice followed by an acoustic sensor AWLR mounted on a fixed platform.

- The RSP used several velocity measuring devices from float tracking and mechanical rotor current-meter to electronic equipment such as electromagnetic sensors and the ADCP. Intercomparison of the instruments indicated that the devices give comparable results. One disadvantage of the used Ott-propeller current-meter is that it does not register direction and it is affected very much by the movement of the vessels. Therefore, while such mechanical rotor current-meters can be used, the electronic sensors have greater appeal with respect to their high accuracy, and should be considered. The ADCP/EMF moving boat method of discharge estimation proved its efficiency as a fast method, especially in high flows. However, present development of ADCP precludes its use in shallow draft vessels, so that smaller channels continued to be gauged by the velocity-area method. Therefore, while the velocity-area method should be considered as a widely applicable method, the moving boat methods using electronic sensors should be considered for application in complicated situations such as in large alluvial rivers and in tidal conditions.

- For suspended sediment sampling, several options have close sustainability scores. Although the Binkley sampler becomes a clear winner because of its institutional (BWDB) capability and technological compatibility, the sampler is not acceptable for accurate sampling. Depth-integrated samplers, especially the Collapsible bag can be used for all routine operations in large rivers. The pump sampler is the most accurate sampler, but unfortunately, the pumping method as applied for the highly energetic environment of the Bangladesh rivers is relatively expensive. The Delft Bottle is a reliable and sturdy sampler, but the sampler has a bias in that it does not represent particles smaller than about 100  $\mu\text{m}$ . The ADCP technique to determine via the backscatter intensity the suspended sediment appeared very promising.

- For near-bed sediment measurements, among the three options - Delft bottle, Helley-Smith and pump system for RSP - the Delft bottle on a sleigh is a clear winner. But the instrument has a limited applicability because of its bias. In the future the pump sampler on a carrier such as the Jamuna sampler should be considered for near-bed sediment sampling for special studies. As the near-bed transport is an important part of the total transport, it is recommended to establish the near-bed/total transport ratio, as far as feasible for varying flow and various locations by special measuring campaigns. For routine measurements the near-bed measuring techniques are not recommended.

## 7 Conclusions and Recommendations

During the short time-span of the River Survey Project (1992-1996), various routine and special measurements were performed along the main rivers of Bangladesh and their distributaries. On most occasions, various instruments and techniques were tested and optimal option was pursued. In addition, the performance of some BWDB gauging techniques was tested in collaboration with them. These exercises gave the Project a unique opportunity to evaluate the techniques on various considerations. Table 7.1 provides a summary of the sustainable survey technique as analyzed and presented in Chapter 6.

| Items                          | Sustainable survey technique at present scenario                      |
|--------------------------------|-----------------------------------------------------------------------|
| Positioning                    | Sextant and DGPS                                                      |
| River bed profile              | Echo sounder                                                          |
| Water levels                   | Manual staff gauge, auto-acoustic sensor                              |
| Velocity measurements          | Propeller type current meters                                         |
| Discharge estimation methods   | Velocity-area method                                                  |
| Suspended sediment measurement | Binckley sampler, Delft Bottle, Integrated bottle and Collapsible bag |
| Near-bed sediment measurement  | Delft Bottle                                                          |
| Bed-material sampling          | USBM-54                                                               |

Table 7.1 Summary of sustainable survey techniques considering the present state-of-the-art development.

For each equipment and method, the following conclusions and recommendations can be made.

- Accurate positioning is very important for obtaining acceptable results during a survey. We found that a DGPS system has a great advantage over the others on various considerations. The instrument is developing fast worldwide, has been introduced by several projects in Bangladesh and may appear cost-effective in the future. If the system is adopted by BIWTA, a network of some fixed reference stations could be established throughout Bangladesh and be used by various users.

- On the depth-measuring devices, obviously a single-frequency echo sounder is the best and provides the expected accurate results. Rod or cable suspension can only be recommended as a guidance for navigation. They should not be used for hydro-graphic surveys. It is not necessary that a dual frequency echo sounder be used in routine operations. The device is relatively more expensive than the others.

- For bed-material sampling, the USBM-54 should be used because of its high accuracy and wide applicability, especially for study surveys. For routine measurement the drag sampler is a good alternative.

All these recommended techniques should be applied together with a suitable selection of measuring networks and a sustainable frequency of measurements. Accurate gauging of hydraulic and sediment transport parameters is critical at the primary gauging stations. Some stations such as Hardinge Bridge and Baruria may need relocation because of their erratic behaviour.



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