FAP24

Government of the People's Republic of Bangladesh

Water Resources Planning Organization

European Commission

Delft Hydraulics

Danish Hydraulic Institute

Hydroland

Approtech

Osiris

RIVER SURVEY PROJECT

Final Report – Annex 1

Surveys

November 1996

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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)
BWDB	:	Bangladesh Water Development Board
CEC	:	Commission of the European Communities (presently the EC)
DGPS	:	Differential Global Positioning System
DHA, DHB etc.	:	(names of FAP24 survey vessels)
EC	:	the European Commission (formerly the CEC)
EG&G	:	(name of an instrument manufacturer)
EGIS	:	Environmental and GIS Support Project for Water Sector Planning (formerly FAP19)
EMF	:	electromagnetic flow meter
FAP	:	Flood Action Plan
FAP24	:	FAP project no. 24 (= The River Survey Project)
FINMAP	:	(a Finnish survey company)
FPCO	:	Flood Plan Coordination Organisation
FFWC	:	Flood Forecasting and Warning Centre (of BWDB)
GIS	:	geographic information system
GPS	:	Global Positioning System
JICA	:	Japan International Cooperation Agency
JMBP	:	Jamuna Multi-Purpose Bridge Project
LAN	:	Local Area Network
MEX	:	(brand name of a turbidity meter)
O&M	:	operation and maintenance
PA	:	Project Advisor
PSD24	:	(= Processed Survey Data of FAP24) (name of a data base)
PWD	:	Public Works Department (and name of a reference level)
RSP	:	River Survey Project (= FAP24)
RTK	:	real-time kinetic (positioning)
SLW	:	Standard Low Water (a reference level)
SoB	:	Survey of Bangladesh
SWMC	:	Surface Water Modelling Centre
S4	:	(brand name of an electromagnetic current-meter)
ToR	:	Terms of Reference (of FAP24)
UoL	:	University of Leeds
UTM	:	Universe Transverse Mercator (a geodetic grid)
USBM-54	:	(type and brand name of a bed sediment sampler)
VHF	:	very high frequency (radio wave length band)
WARPO	:	Water Resources Planning Organization
WGS84	:	World Geodetic System (a geodetic grid used with GPS)
XRD	:	X-ray determination (of sediment mineralogy)

Glossary

Terms or explanations marked with an asterix (*) relate specifically to the RSP (River Survey Project). 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.

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

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) composing the riverbed. To be distinguished from suspended bed material, which is coarse suspended sediment (* with a grain size above 0.063 mm). In alluvial rivers, the bed material has been deposited by the river.

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

Bed load: *Bed material* transported immediately above the riverbed, 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 riverbed 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 riverbed 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 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^3).

*** 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, or 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 overspecified by a combination of time series of measured state variables and (physical) relations between them. Data assimilation can be done by combined analysis 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 kg/m³), (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*. * 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.

* **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 (6 digits) or km (3 digits). Easting = 500 km + the distance (positive towards east) from the 90° east meridian. Hence, per definition, the 90° east meridian has an easting of 500. For example, the easting of Gulshan (at the SoB primary bench mark) is 542.

Error (of a survey instrument, a survey procedure, or a calculation method): The difference between a *true* and a measured value, or between a desired and an actual value. Errors are inversely related to *accuracy* and *validity*. They can be random (stochastic) or systematic. The stochastic error can often be reduced by repeating a measurement several times'

Flow (in a river): Volume transport per time unit, expressed in m³/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 echosounder or an ADCP): The frequency of the transmitted and reflected sound wave. * RSP used 210 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, etc.)

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

Hydrostatic levelling: Datum transfer by means of a still fluid (water) in a long tube, for example across a river. Provided (i) that the air pressure is the same at both ends of the tube, and (ii) that the fluid has a homogenous density (unaffected by e.g. temperature gradients), the fluid surface at each end will adjust to the static pressure, as determined by the gravity field along the tube, so that the two surface levels adjust to a horizontal surface.
* The method was not applied by RSP.

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*.

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 = 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. * RSP applied on-line processing of position, current, flow and depth data.

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 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 0.46 m 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.

* **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 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 riverbed erosion by subtracting two successive bed level measurements. The relative accuracy of many measuring methods is better than (and is always at least equal with) 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 RSP of flow and sediment transport (by the *recommended method)* at eleven cross-sections on 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 riverbed 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 in 95 percent 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 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 the case of unknown or irregular *surface slopes,* the *validity* of this method is doubtful.

Stage: Water level at a given location, e.g. at a *gauging* station.

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.

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.

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: Transport of suspended fines (* with a grain-size diameter below 0.063 mm)

1 Introduction

1.1 Introduction to the River Survey Project

The River Survey Project (RSP, or FAP24) was initiated on June 9, 1992, and had a duration of four years. The project was 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, at which time WARPO took over the project execution. Funding was granted by the European Commission (formerly the Commission of the European Communities). The Consultant was a joint venture of DELFT HYDRAULICS and the DANISH HYDRAULIC INSTITUTE (DHI), in association with Osiris, Hydroland and Approtech. Project supervision was done by a Project Management Unit with participation by FPCO/WARPO, a Project Advisor, and a Resident Project Advisor.

The objective of the project was to contribute to the basis of the 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 consisted 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;
- a training component.

The proceedings of the River Survey Project 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:

- A Final Report, Main Volume, 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

1: Surveys
2: Sustainable survey techniques
3: Hydrology
4: Sediment transport
5: River morphology

A listing of all River Survey Project reports is given in the Main Report.

1.2 Scope of the present Annex

In combination with Annex 2: Sustainable survey techniques, the present Annex 1 presents the findings of the survey component of the Project.

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

The present Annex 1 describes the proceedings of this field programme and the related data processing and data reporting. The development of the scope and approach is reviewed, facilities and procedures are summarised, and an outline is given of the extent of the data collection.

Further, some observations from the field work are made, in order to pass on a part of the experience that was gained during its execution. The implications of this experience in a wider context are discussed in Annex 2, where also recommendations are given on surveying the rivers of Bangladesh.

The collected data are presented in separate data books (RSP Special Reports 22 and 23) and are stored in the data bases of the Project.

1.3 Previous work

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

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

The BWDB monitoring is precious because it provides dense long-term data records, the consistency of which is 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 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

Activities that form the basis for the present Annex 1 are predominantly all the ones within 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.

Also, several dedicated bridging activities have taken place between the survey and the study component of the Project. The former has supplied data to the latter, not only by the routine gauging, but also beyond the scope of this programme by a separate programme of so-called 'special surveys' that was recommended and approved by the RSPMU as a modification of the specified scope of work for accommodation of specific non-routine data demands. In turn, the study component included activities that specifically aimed at reviewing and developing field procedures for routine monitoring of river hydrology, sediment transport, and river morphology.

2 Summary of the RSP field survey component

2.1 Objective

The objective of the RSP field survey component is *'to collect reliable all-season hydrological, morphological and hydrographic data at key locations on the country's main river systems with emphasis given to collection of data during the monsoon season, introducing improved or new technology where appropriate'* (ToR Section 3.1).

2.2 Framework

Soon after Bangladesh had gained independence in 1971, the Bangladesh Water Development Board (BWDB) embarked on a comprehensive monitoring programme of river flow, sediment transport, and river morphology. The monitoring takes place in a network of gauging stations and standard cross-sections that cover the entire river system of Bangladesh. On the one hand this grand effort reflects the complexity of the behaviour of the rivers of Bangladesh and, on the other hand, the national significance of those rivers. The programme has produced a resource pool of river data that is unique by any standard.
Against this background, the river survey activities of the RSP aimed at producing a targeted supplement to the ongoing BWDB monitoring. This is expressed as follows in the ToR (Section 1.4):

'Although hydrological, morphological and hydrographic data are routinely collected by concerned Bangladeshi organizations... the limitations of existing boats and survey equipment mean that some essential data needed for the planning of Action Plan projects are either insufficiently accurate or are not collected. The River Survey Programme would carry out necessary surveys using modern equipment and technology, undertake special studies of the behaviour of the river system, and provide specialised training in river survey techniques to Government staff'.

'The results of the surveys and studies will be used (a) as an input to the regional water resource planning studies, feasibility studies and other projects being undertaken under the Flood Action plan, (2) as a benchmark against which to assess changes in river hydrology and morphology resulting from the construction of embankments, river training, bank protection and other project works under the Action Plan' (ToR Section 3.2).

The aim of the survey component of the RSP was pursued by

- Executing a fixed-term routine monitoring programme in order to extend the interpretation of the BWDB river data by a different time and space coverage and by different measuring techniques;
- Introducing certain new river survey technologies that had not previously been used in Bangladesh, while examining their viability in the actual context.

In the course of the project, FPCO/WARPO and RSPMU agreed to adapt the RSP survey component by including:

- Execution of special, dedicated river surveys for specific study purposes.

2.3 Scope

Many events, among which a late project start, as well as natural, technical and administrative implications, delayed the implementation of the survey programme. Decisions about equipment, survey methods and programmes had to be postponed. The moderate water level during the 1993 monsoon season, and the extremely low water levels during the 1992 and 1994 monsoon seasons, had a significant impact on the achievement of the survey programme. Examples of measurements 'missed' because of unforeseeable hydro-meteorological conditions are (i) overland flow gauging, impossible during the first 3 years of the project, and (ii) missed 1993 monsoon routine gaugings, because the test gauging could not be executed in the 1992 monsoon season (the test gauging took finally place in August 1993, thereby delaying the mobilization of the full survey spread).

The very low monsoon season discharges in 1992 did not allow a thorough assessment of the methods, equipment, vessels and instruments to be used in Phase 2 of the project. (For the same reason, no final decision could be taken about the study topics because of the lack of observations and information during flood events). This is why the Project Advisor proposed a transition phase for the period June 1993 - May 1994, during which a minimum survey programme would be implemented, awaiting the final set-up of the survey component.

Since June 1994, the beginning of the 3rd project year, the complete set-up of vessels, equipment and instruments became available, though some decisions about survey methods were still pending. Final decisions were taken based on special surveys, conducted during the period June to August 1994, again a low monsoon season. In all, the technical and administrative difficulties along with the low monsoon season discharges during the first three years of the project prompted a reallocation in the original Bill of Quantities (BoQ).

The BoQ, as contained in the Contract, is summarized in Table 2.1. In the course of the Project, several needs of adjustment of the BoQ items for surveys have been established in close coordination between FPCO/WARPO, EC, the RSPMU, and the Consultant. A first re-allocation of BoQ items for surveys, prepared in October 1994, was approved by EC in April 1995. The revised BoQ showed as a balance an unallocated amount, which would remain available for new initiatives. A second revision of the BoQ for surveys (and studies) was prepared in the course of 1995, and agreed between the contracting parties through a Rider to the Contract for the River Survey Project. Details of the final revision of the BoQ are also presented in Table 2.1.

The final reallocation in the BoQ for surveys and studies has been worked out in close cooperation with RSPMU and with the aim to ensure a proper achievement of the objectives of the River Survey Project.

Explanations on the non-used funds and the agreed reallocation are summarized below. Particularly, the number of special surveys was increased for reaching the objective of contributing to *'an improved understanding of the behaviour of the main rivers in Bangladesh'*.

- ***Routine flow and suspended sediment gauging:*** Some gaugings could not be performed during Phase 1 because of the late start of the project, while also during the 1993 monsoon season a number of gaugings were 'missed' for reasons explained above. The number of gaugings was increased during the fourth year, as justified by the occurring exceptional flood events.

  During Phase 2, routine flow suspended sediment gauging was mainly carried out following the 'recommended method'. Of each type of routine gauging 10 measurements were carried out following the 'reference method'.

- ***Overland flow and sediment gauging:*** This gauging could not be performed during the low monsoon seasons 1992, 1993 and 1994, but extensive measurements took place during the high 1995 monsoon season.

- ***Bed load transport gauging:*** Part of the bed load gaugings could not be performed due to late start of the project and because of a delay in the decision making concerning gauging procedures to be adopted. The number of bed load gaugings was increased during the fourth year, as justified by the occurring exceptional flood events.

- ***Flow gauging:*** Additional water discharge gauging was performed at Bahadurabad, in view of the need of collecting additional flow data for solving the pending problems with BWDB's rating curve for this location. Therefore, despite the delays at the beginning of the project, extra routine flow measurements were executed above the provision for the latter BoQ item.

- ***Hydrographic (bathymetric) surveying:*** Till October 1994, 9 hydrographic surveys were performed, whereafter the activity gained momentum through two cycles of surveys at 7 locations during the 1994/1995 lean season i.e. one post-monsoon 1994 and one pre-monsoon 1995 cycle. Additional surveys were performed at Bahadurabad and at Gorai off-take during the 1995 flood season. The second 1995/96 lean season survey cycle was cancelled because changes in the bathymetry appear to be fairly insignificant during the lean season. These changes have been one of the reasons to favour hydrographic surveying during the monsoon season, which was not foreseen in the TOR but anticipated in the Technical Specifications (Section 3.2.1 General).

  The bathymetric survey area covered in the lean season appeared at several locations to be less than anticipated in the BoQ, e.g. because certain areas are inaccessible during low flows. Otherwise, part of the surveys were carried out at a higher density of survey lines for which the contract provides price multiplication factors (ref. Table BoQ Ph. 2/6.1), while topographic (char land) surveys were carried out during the lean season 1995/96.

- ***Physical properties:*** The Contract provides only a budget for a 'limited analysis' of physical properties. The number of samples subjected to such limited analysis was reduced from 500 to 140 and part of the remaining funds used for a 'full analysis' of 58 samples, for which a new unit rate was established.

- ***Day-work for hydrometric vessel:*** In the original BoQ the number was 100, whereafter it was cut to 50 and later increased to 146 in accordance with the revised orientation in the project to concentrate on the special measurements for studies, as recommended by the Project Advisor and accepted by all parties. Special measurements focused on understanding of the sediment transport processes and optimization of discharge and sediment transport measurement techniques, both key issues for the Project. The optimization of measurement techniques has particular importance for the recommendation of sustainable and reliable measurement techniques for future use by the BWDB.

  During the last project year, special surveys for study purposes were required, for example for the optimization of measurement techniques, for comparison of BWDB and RSP flow measurements at Bahadurabad and at other locations to finally settle the problems with Bahadurabad's rating curve, and to collect ample flow and sediment data at Gorai Off-take for the calibration and validation of a 2D-morphological model.

- ***Day-work for hydrographic vessel:*** The number of day-work for hydrographic vessel in the original BoQ was 100 and was later cut down to 0, with the idea to modify it later on the basis of findings in Phase 1 and in the first hydrographic surveys. The morphological analysis of the first bathymetric charts produced under the project showed the need to complement the bathymetry with flow patterns. These were established through float tracking, for which the vessels operated as hydrographic vessels. Under this BoQ item also several bedform mappings were made on Jamuna River between Bahadurabad and Aricha.

- ***Sediment sampling and analysis:*** The efforts for sediment sampling and analysis, including a comprehensive bed material sampling, were increased in agreement with RSPMU and WARPO. There is evidence of selective sediment sorting and transport that needed to be further investigated. The number of sediment size analyses provided in the BoQ was much below what is actually performed in line with routine and special surveys.

- ***O&M of water-level gauges:*** According to the ToR, water-level gauging was only considered in relation with flow gauging. However, FAP24 has operated twelve AWLR stations (including attached staff gauges), as well as staff gauges at six locations near Bahadurabad for slope measurements related to rating curves and other study purposes. One additional gauge was installed downstream Bhairab Bazar for correction of backwater effects in the rating curve, while three additional staff gauges were installed for monitoring of water levels around the Gorai off-take, to collect data for the calibration of a 2D-morphological model. The BoQ has been adjusted accordingly, and a new unit rate was established for the invoicing of the O&M of staff gauges for continuous slope measurements.

BoQ item	Initial Contract	Rider 1 (Total no.)
Water-level GAUGING		
I/4.1a checking BM	47	47
I/4.1b&II/5.1b recording gauge installation, O&M		
o procurement/installation	12	12
o O&M of AWLRs (months)		303
o O&M of staff gauges (months)		174
I/4.1c complementary acitivities		
o new/additional bench marks	5	2
o temporary staff WL gauge	10	15
o additional levelling for bench marks (km)	100	74
TEST FLOW & SEDIMENT GAUGING -BAHADURABAD, PH. 1		
I/4.2a(1) test flow gauging	3	3
I/4.2b(1) test sediment gauging	3	3
ROUTINE FLOW & SEDIMENT GAUGING - BAHADURABAD, PHASE 1		
I/4.2a(2) routine flow gauging	6	4
I/4.2a(4) overland flow gauging	4	
I/4.2b(2) routine suspended sediment gauging	6	4
I/4.2b(4) suspended sediment gauging, overland	4	
I/4.2(d) bed load gauging	10	6
BED MATERIAL SAMPLING, LABORATORY, DAY-WORK FOR HYDROMETRIC VESSEL, PHASES 1 & 2		
I&II/4.2e bed material sampling	400	800
I&II/4.2f(1) sediment size analysis	1,000	6,760
I&II/4.2f(2) physical properties		
o limited analysis	500	140
o full analysis		58
I&II/4.3 day-work hydrometric vessel	50	146

Table 2.1: Bill of Quantities (continued)

BoQ item	Initial Contract	Rider 1 (Total no.)
ROUTINE FLOW GAUGING, FOR 3 YEARS		
II/5.2a(1) (a) i Bhadurabad, Sirajganj	78	105
II/5.2a(1) (a) ii Aricha	6	7
II/5.2a(1) (b) Hardinge Bridge	39	30
II/5.2a(1) (c) i Mawa	6	12
II/5.2a(1) (c) ii Baruria	39	34
II/5.2a(1) (d) Bhairab Bazar	18	20
II/5.2a(1) (e) Old Brahmaputra, Dhaleswari, Gorai	63	57
II/5.2a(1) (f) Arial Khan	21	18
sub-total	270	283
(note: incl. 10 gaugings according to reference method)		
OVERLAND FLOW GAUGING		
II/5.2a(3) overland flow gauging	40	12
ROUTINE SEDIMENT GAUGING, SUSPENDED LOAD		
II/5.2b(1) (a)i Bahadurabad, Sirajganj	78	74
II/5.2b(1) (a) ii Aricha	6	6
II/5.2b(1) (b) Hardinge Bridge	39	30
II/5.2b(1) (c) i Mawa	6	12
II/5.2b(1) (c) ii Baruria	39	32
II/5.2b(1) (d) Bhairab Bazar	18	19
II/5.2b(1) (e) Old Brahmaputra, Dhaleswari, Gorai	63	57
II/5.2b(1) (f) Arial-Khan	21	18
sub-total	270	248
(note: incl. 10 gaugings according to reference method)		
OVERLAND SEDIMENT GAUGING		
II/5.2b (3) overland sediment gauging	40	22
ROUTINE SEDIMENT GAUGING - BED LOAD		
II/5.2d bed load transport gauging (Phase 2)	260	242
HYDROGRAPHIC SURVEYS, PHASE 2, FOR 3 YEARS		
II/6.1 hydrographic charts (km2)	5,100	2,425
II/6.2 additional cross sections		
II/6.3 day-work hydrographic vessel		50

Table 2.1 (continued): Bill of Quantities

2.4 Execution

In the ToR (Section 4.1), the RSP was divided into two phases:

- Phase 1 (Year 1), comprising review of available data, checking of water-level gauges, mobilisation of equipment, first flood season measurements and detailed planning of the main programme;
- Phase 2 (Years 2-4), comprising comprehensive hydrological and hydrographical (bathymetric) surveys.

For reasons mentioned in Section 2.3, however, the Project was executed as follows:

- Phase 1 (June 1992 - December 1993): Mobilisation, pilot surveys of flow, sediment transport and bathymetry, bench mark verification, water level and routine flow and sediment transport gauging at Bahadurabad, test gauging in order to compare the 'recommended method' and 'the reference method', planning of the Phase 2 programme
- Phase 2 (January 1994 - June 1996): Mobilisation for extended survey capacity, water-level recordings and routine flow and sediment transport gauging over the entire project area, bathymetric surveys, miscellaneous special surveys

The *'reference (velocity-area flow gauging) method'* and the *'recommended (ADCP-based flow gauging) method'* are explained in Section 4.3.1.

Within each phase, the work has been divided into a monsoon season programme (June through October) and a lean season programme (November through May). The hydrological year in Bangladesh proceeds from April through March.

A location map of the project area is shown in Figure 2.1.

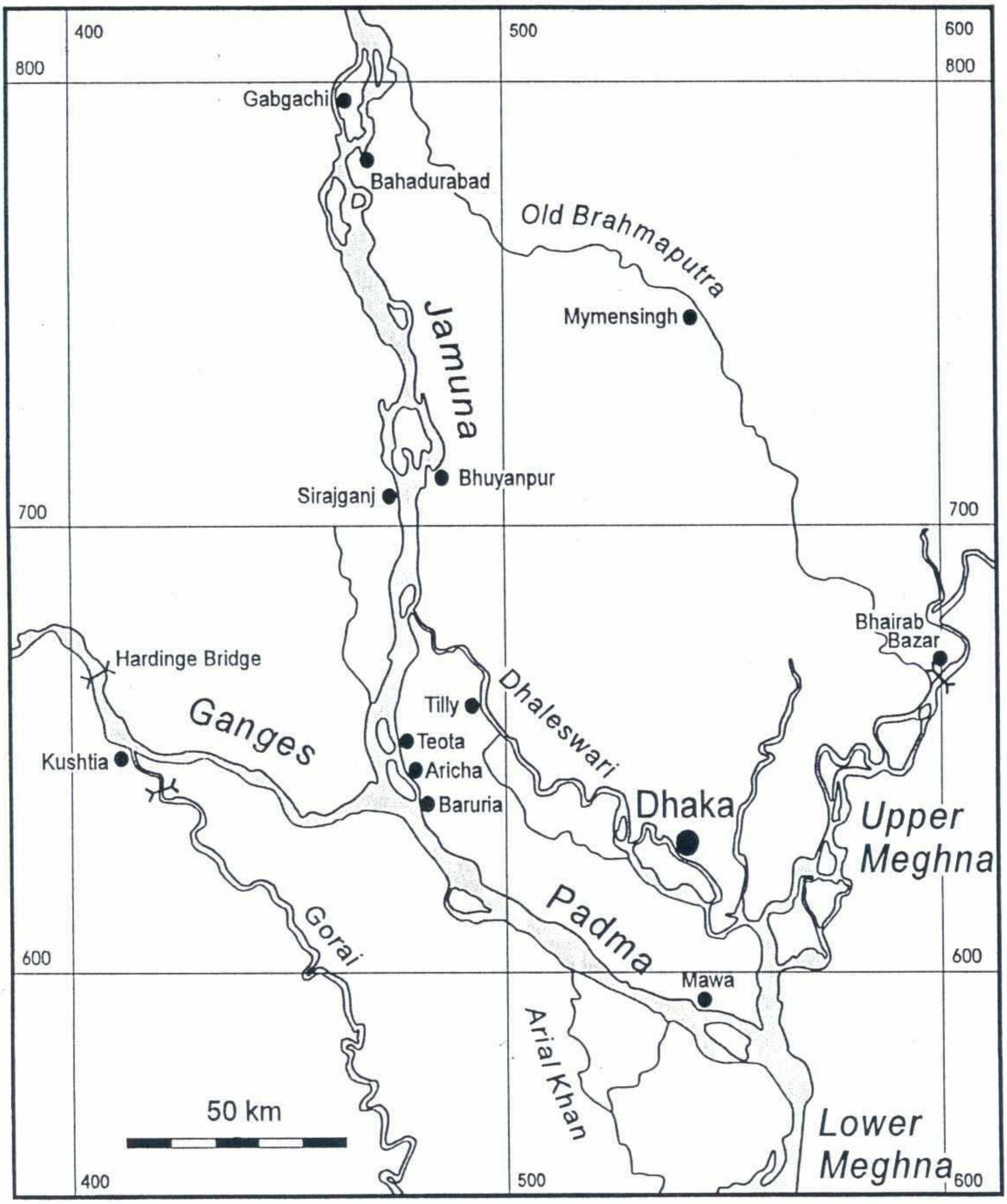


Figure 2.1: Location map

The RSP river survey component comprised the following activities:

- Mobilisation and test gauging;
- Water-level gauging (twelve AWLRs and nine staff gauge stations);
- Routine gauging of flow and sediment transport at eleven cross-sections;
- Special surveys for different specific purposes;
- Bathymetric monitoring of seven areas;
- Topographic (land) surveys.

A short outline the implementation of the survey programme is given in Table 2.2 and on the bar chart in Figure 2.2. Please refer to Chapter 5 of the present Annex 1 for details about the programme.

Phase 1 (June 9 1992 - December 31 1993)	
Project start	June 9, 1992
Arrival of equipment (1st consignment)	August 4, 1992
Arrival of main survey vessel (DHA)	August 22, 1992
First survey (at Bahadurabad, by BWDB's 'Anwesha')	September 6-20, 1992
Verification tests at Bahadurabad	October 21 - 28, 1992
First routine flow and sediment transport gauging at Bahadurabad	January 14-16, 1993
Installation of first AWLRs (at Bahadurabad and Gabgachi)	June 1-2, 1993
First bathymetric (pilot) survey at Bahadurabad	June 20 - July 3, 1993
Test gauging of 'recommended' and 'reference method'	August 16-22, 1993
Finalisation of scope of Phase 2 river surveys	December, 1993
Phase 2 (January 1, 1994 - June 8, 1996)	
First Phase 2 routine flow and sediment transport gauging (at Bahadurabad)	January 29 - February 1, 1994
First 'special survey' (turbulence measurements at Bahadurabad)	March 31 - April 1, 1994
First additional flow measurement at Bahadurabad	June 23, 1994
First 'bed form inventory' survey (Bahadurabad → Aricha)	August 19-20, 1994
Last routine gauging (at Hardinge Bridge)	March 2, 1996
Completion of the vessel survey programme (bathymetry at Gorai Off-take)	April 6, 1996
Completion of AWLR gauging	May 20, 1996
Project completion	June 8, 1996

Table 2.2: Milestones of RSP river survey activities

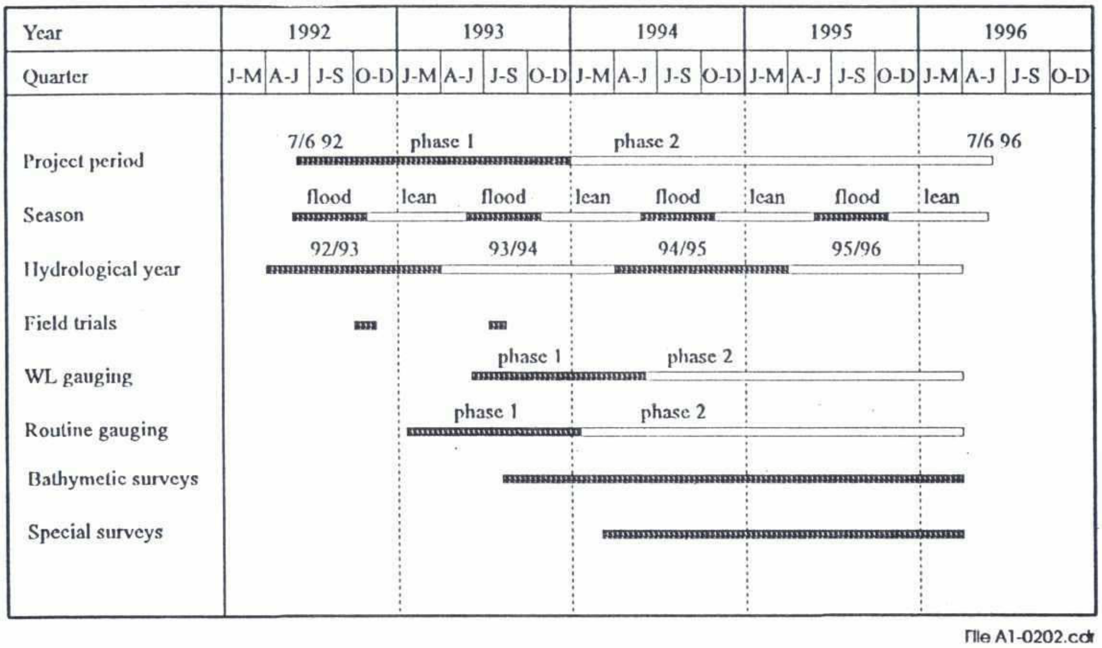


Figure 2.2: Bar chart of river survey activities

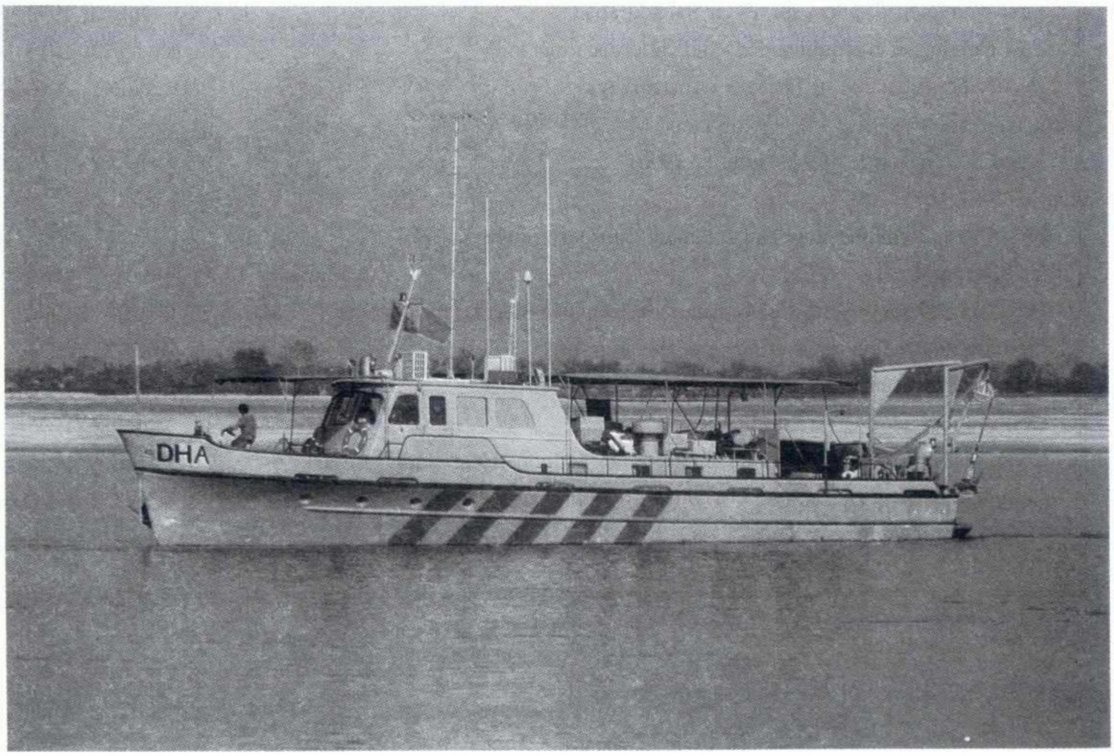


Figure 2.3: FAP24's Survey vessel DHA

3 Survey facilities and capacity

3.1 Summary

The survey spread of the RSP reflects the various categories of field work:

- Long-term water-level recordings at fixed positions;
- Vessel-based measurements of flow and sediment transport, including routine gauging and special surveys;
- Bathymetric surveys;
- Land surveys: Bench mark elevations, bank contours, topographic surveys.

This Chapter provides an outline of the instrumentation selected for these purposes.

3.2 Water-level gauges

Three different types of water-level gauges were applied by the Project:

- Acoustic (ultrasonic) AWLRs (five locations)
- Pressure cell AWLRs (eight locations)
- Staff gauges (22 locations)

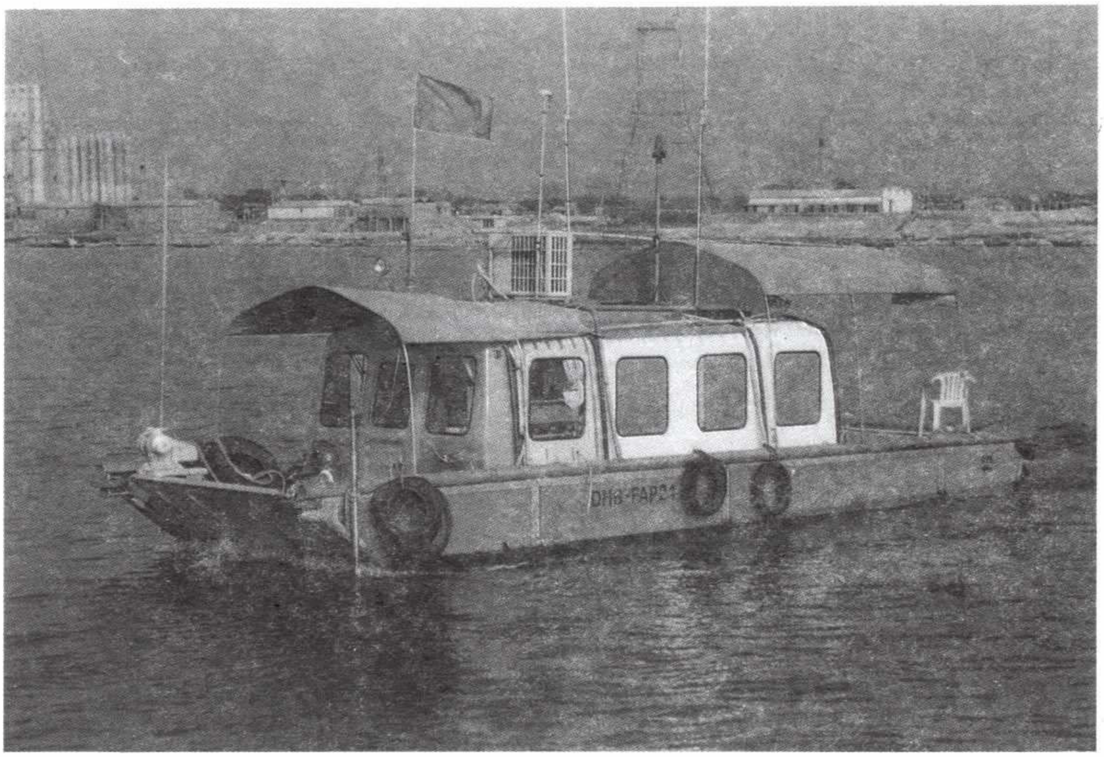


Figure 3.1: FAP24's Survey vessel DHB

At one location (Gabgachi on the Jamuna River, near Fulchari), a pressure cell and an acoustic type AWLR were installed at the same place for a direct comparison of their performance. As agreed with FPCO/PMU, a set of two staff gauges was installed at all AWLR locations, in order to ensure a reliable gauging at all stages. These staff gauges also allowed for routine validation, such as identification of possible stepwise zero level shifts, as well as a supplement during breakdowns. Therefore, between them, the 35 gauges mentioned above cover 22 locations only. One of the stations (a staff gauge at Gobindi, near Fulchari) was abandoned in May, 1995, due to poor data quality. The data from this station have been discarded.

The AWLRs were installed at bridge piers where possible (Hardinge Bridge, Gorai, and Bhairab Bazar). For these installations, acoustic type sensors were applied. At the other locations vented pressure cell sensors were used, and the instruments were mounted on platforms erected in the river for the purpose.

All staff gauges were read at 6-9-12-15-18 hours, whereas the AWLRs registered the water level every 30 minutes. Routine inspection of the gauges were done every month.

The water-level recordings are given in the *RSP Special Report 2: 'Water-level gauging stations'*.

3.3 Survey vessels

Three survey vessels - DHA, DHC, and DHD - were mobilised for Phase 1 of the project, and two additional ones, DHB and DHE, were added for Phase 2. Specifications for the vessels are given in Table 3.1 below.

Name	DHA	DHB	DHC	DHD	DHE
Length overall	20.2 m	11.2 m	8.7 m	4.9 m	5.2 m
Beam	4.7 m	3.2 m	6.3 m	1.9 m	2.2 m
Draft	1.2 m	0.9 m	0.8 m	0.8 m	0.8 m
Speed	12 knots	15 knots	12 knots	12 knots	20 knots

Table 3.1: Survey vessels

3.4 Instrumentation of survey vessels

The equipment configuration deployed by the River Survey Project is listed in Table 3.2 below.

Equipment	DHA	DHB	DHC	DHD	DHE
DGPS positioning system:					
Trimble 4000, 9 channel	X	X	X		
Trimble Navtrac, 6 channel				X	X
Bathymetric survey:					
Elac Laz 4420 (echo sounding)	X				
Simrad EA 300 P (echo sounding)		X	X	X	
Atlas Deso 14					X
Point current-measurement:					
Ott propeller current meter	X				
S4 InterOcean (electromagnetic)	X		X	X	
Valeport propeller current meter				X	X
Integrated current-measurement:					
300 kHz ADCP (vertical profiles)	X				
600 kHz ADCP (vertical profiles)		X			
EMF (horizontal profiles)	X	X	X		
Float tracking (horizontal profiles)	X	X	X	X	X
Suspended sediment measurement:					
Pump bottle sampling	X		X	X	
Integrating bottle	X	X			
MEX 3 turbidity recorder	X				
Bed load sediment transport measurement:					
Helley-Smith trap sampler	X	X	X	X	
Sand-dune tracking by echo sounding	X	X	X	X	X
Delft bottle	X				
Riverbed sediment sampling:					
Van Veen grab	X		X		
USBM-54	X				
Drag sampler				X	X
Side scan sonar:					
EG&G Model 260	X				
Communication:					
SAFECOM satellite telex link	X	X			
VHF radios	X	X	X	X	X
Walkie talkies	X	X	X	X	X

Table 3.2: Instrumentation of the survey vessels

Key characteristics of the positioning equipment and the applied recorders are given in Table 3.3. The accuracies listed in this table are intended as guidelines to the data users. They are estimates based on comparative field tests with different instruments and procedures, and by evaluation of the consistency of the results. Therefore, the values relate to the actual physical conditions encountered and the actual operating procedures applied during the field work of the RSP.

Normal ranges for operational speed are listed in Table 3.4 for different survey activities.

Instrument		accuracy 1)	resolution 2)	sampling duration/ averaging period	sampling interval
DGPS (dynamic mode)		3 - 5 m	< 1 m	< 1 s / < 1 s	1 s
AWLR (pressure cell)	3)	1 cm	< 1 cm	< 1 s / 1 min	30 min
AWLR (acoustic)	3)	1 cm	< 1 cm	< 1 s / 1 min	30 min
Echo sounder		5 cm + 1 %	< 1 cm	<< 1 s / << 1 s	1 s
ADCP		5 - 10 cm/s	5 - 10 cm/s	<< 1 s / 6 s	1 s 4)
EMF	5)	2 %	1 cm/s	<< 1 s / 6 s	1 s 4)
S4	6)	2 %	1 cm/s	<< 1 s / 3 x 50 s	-
Ott current-meter		3 - 10 % 7)	1 - 2 cm/s	50 s / 3 x 50 s	-

Note: All values are approximations. The values relate to the specific deployment, procedures, and application conditions during the River Survey Project, and do not directly reflect the potential capability of each instrument. The overall accuracy of a recording can be different from the listed values due to for example repeated measurements (which can improve the overall accuracy), or validity and time scale effects (which can reduce the overall accuracy)

< = 'less than', << = 'much less than'

1): Standard deviation between true value and registered value
2): Smallest increment of the true value that can be registered by the instrument
3): 1 sample every 5 s, average for 12 samples (1 min) is stored
4): 6 s average value is updated every s
5): When used for cross-sectional transects or 'moving boat method'
6): When used for individual vertical current-profiles
7): Mainly depending on the mooring of the vessel

Table 3.3: Characteristics of some key instruments applied by the project

Operation	Speed	
Routine flow and sediment transport gauging	2 - 4 knots	1 - 2 m/s
Bathymetry and longitudinal transects during routine gauging	3 - 5 knots	1.5 - 3 m/s
Bedform inventory (longitudinal depth contours between stations)	10 - 15 knots	5 - 8 m/s
Values are indicative		

Table 3.4: Operational speed during surveys

The ADCP instrument records the instantaneous vertical current-profile by an acoustic Doppler technique. The velocity is registered by three orthogonal components over a series of depth intervals (called 'bins'). The bin height depends on the selected mode of operation and is 0.5 m. The uppermost 1.7 and 2.7 m of the water column are not covered by DHB and DHA, respectively. Therefore, a supplementary single point EMF current-meter is used for near-surface recordings. The measuring depth of this current-meter is 0.5 m. Also, the deepest 6 percent of the water column are not covered by the instrument (Table 3.5).

The internal coordinate system of the ADCP and the EMF, and thus also the speed and direction of the recorded current, is relative to the instrument and hereby relative to the vessel. In addition to the vertical current-profile, the ADCP can measure the movement of the vessel relative to the riverbed by so-called bottom tracking. The bottom tracking is highly accurate; one controlled test carried out by the RSP showed a deviation of only 7 m over 2000 m.

So, the speed and direction of the current relative to a fixed coordinate system (such as BTM) can be obtained in two ways: (1) by ADCP bottom tracking, or (2) by registration of the position and the orientation of the vessel by DGPS and a flux gate compass. The former method is applied for the ADCP under favourable measuring conditions (typically in the lean season), whereas the latter method is applied in the case of a strong current when the riverbed moves, and in any case also for the EMF recordings. The required coordinate transformation is done in connection with the on-line data processing for the purpose of monitoring, and also, separately, as a part of the post-processing.

The performance of the DGPS-ADCP method was validated during comprehensive field trials that were carried out as a part of the project in late 1992 and in the 1993 flood season. The results of these trials are presented in *RSP Survey and Study Reports 3 and 4* and are discussed in *RSP Special Report 11: 'Optimization of hydraulic measurements'*. A brief summary of the findings is given in Section 4.3 of this Annex 1. To the opinion of the Consultant, the method has fully lived up to its expected accuracy and data collection capacity.

	Type of ADCP	
	300 KHz	600 KHz
Vessel	DHA	DHB
Transducer depth	1.2 m	0.8 m
Unmeasured top layer	2.7 m	1.8 m
Bin height	0.5 m	0.25 m
Transducer angle	20 deg	20 deg
Unmeasured bottom layer	6 %	6 %

Table 3.5: ADCP characteristics

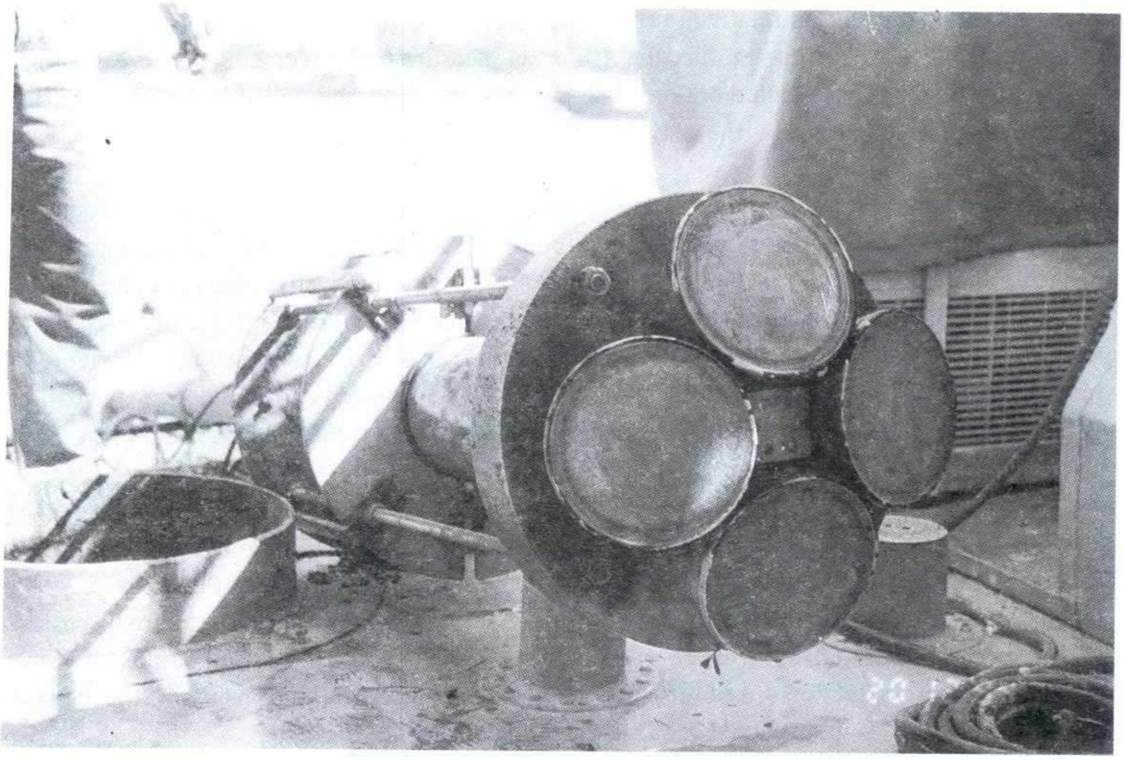


Figure 3.2: 300 kHz ADCP Transducer lifted from its tube well

3.5 Suspended sediment samplers and near-bed transport measurements

At the request of the PA, a particular effort was made to test and compare different methods of sampling suspended sediments and of direct measurements of the sediment transport rate, including the near-bed transport.

For the purpose of measuring suspended load, the following instruments were mobilized:
(1) the Delft bottle,
(2) the point-integrated pumping method,
(3) the depth-integrated bottle,
(4) the depth-integrated collapsible bag, and
(5) optical turbidity recording. In addition,
(6) ADCP back-scatter signals were used to indicate the suspended sediment concentration qualitatively. Table 3.6 shows the different samplers. The Binckley sampler is included, because it is used by BWDB.

Sampler	Concept
• Binckley sampler	Instantaneous, concentration method
• Pump system • Optical (by turbidity meter) • Acoustic (by ADCP backscatter)	Point-integrated, concentration method
• Delft bottle	Point-integrated, transport method
• Integrating bottle • Collapsible bag	Depth-integrated, concentration method

Table 3.6: Suspended sediment samplers considered for comparison

The near-bed sediment samplers include the Helley-Smith sampler and the Delft bottle. These were adopted as a supplement or substitute to the originally planned bed load monitoring by sand dune tracking.

Method/sampler	Concept
• Sand dune tracking	Indirect volumetric transport calculation
• Helley-Smith sampler	Point-integrated, transport method
• Delft bottle	Point-integrated, transport method

Table 3.7: Methods for bed load and near-bed transport considered for comparison

Several inter-comparison and test gauging exercises were carried out with the following objectives:

- to examine the general performance of the various instruments;
- to optimize their use as compared to time scales of concentration fluctuations, sediment properties, and minimization of the non-measured near-bed zone;
- to evaluate their suitability relative to general monitoring purposes and specific measurement objectives.

Results of the comparisons are reported in *RSP Special Report 12: 'Optimization of sediment measurements'*.

For routine and non-routine gauging purposes within the RSP, the samplers indicated in Table 3.2 were included in the survey spreads. Their application for routine gauging is described in Section 4.4.

3.6 Geodetic surveys

Geodetic surveys were carried out by traditional survey technology using instruments as listed in Table 3.8. Satellite-based GPS positioning was tested, but was not implemented for routine purposes within the project.

Application/instrument	Accuracy
Second order levelling	
• Topcon Auto-level AT-G3	Level: 1-1.5 mm/km, depending on mode
Topographic surveys	
• Topcon Electronic Total Station GTS-303	Angle: 5" Distance: 3 mm + 2 mm/km
GPS positioning	
• Trimble 4000 SE GPS receiver/datalogger	Level (differential static mode): 1 cm + 2 mm/km Position (differential static mode): 1 mm/km

Table 3.8: Geodetic survey equipment

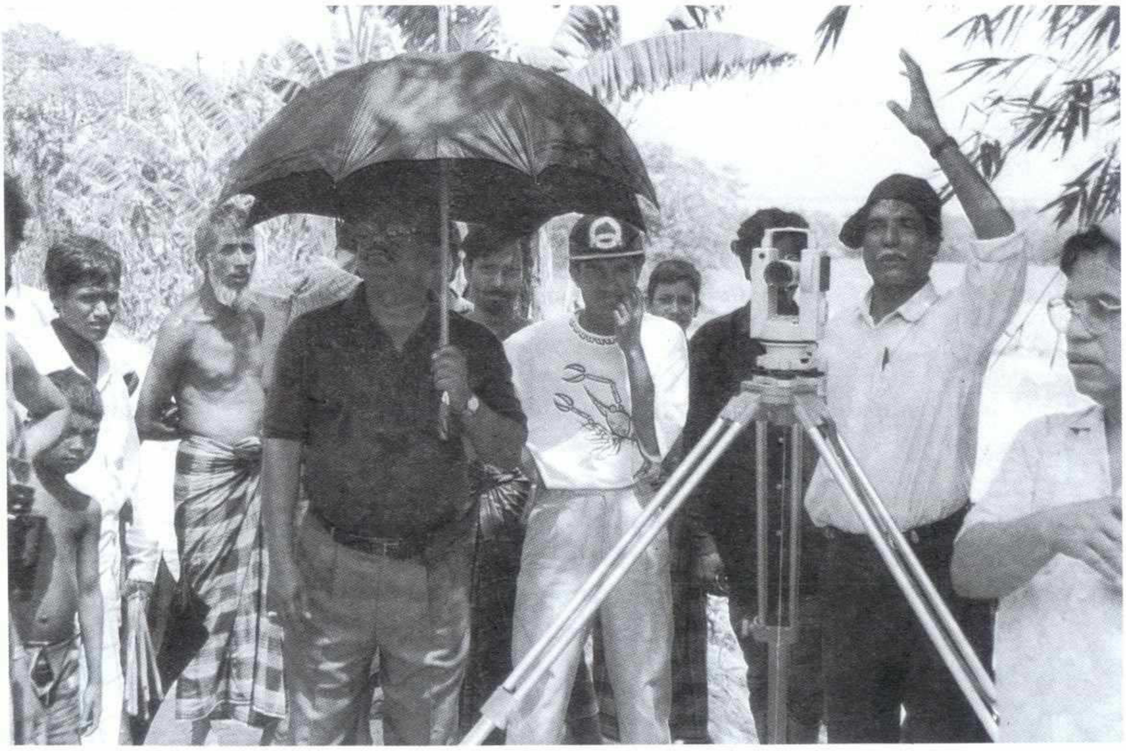


Figure 3.3: The Geodetic Survey Team

4 Survey procedures

4.1 Rationale

A survey procedure is a combination of a set of tools and the organisation of the work. For the purpose of this report, a distinction is made between field measurements, laboratory analysis, and off-line data processing. This distinction is purely a matter of convenience since for each type of data production, the entire process is a series of linked operations.

In general, a good survey procedure fulfils the following aims:

- Validity of measurements: Compliance with the desired scope with respect to (1) time and place, (2) frequency of the measurements, (3) data coverage, and (4) time resolution as compared with the given time scales of the parameters to be measured, as well as the processes to be examined by the measurements;
- Appropriate quality: Documentation of the data collection, accurate positioning, traceability of samples and registrations, low frequency of errors, and transparency of data and data flow;
- Resource optimization: Compliance between tools and means (including costs and operating risks), the logistical constraints, and the given physical environment;
- Compliance with the specific physical environment and the specific operating conditions.

Whilst it is possible to optimize the procedures for a survey with a specific purpose, these criteria imply that a general monitoring programme will always be a compromise between different aims and priorities.

The planning of the River Survey Project was made on the following general basis:

- The scope of the data collection, as specified in the contract;
- The difficult physical operating environment and the logistical constraints.

Within these considerations priority was given to several aspects:

- A high data collection capacity of the survey spread;
- Accurate positioning;
- A streamlined and transparent data flow all the way from the sensor to final data base storage;
- A low risk of down time and instrument failures (partly pursued by provision for alternative contingency methods, as envisaged in the ToR).

In accordance with the aim of *'introducing improved or new technology where appropriate'*, a combination of traditional and new technology was selected, as elaborated in this Chapter.

4.2 Positioning and geodetic reference

4.2.1 Geodetic grid

The geodetic reference system listed in Table 4.1 has been selected for implementation. There were two reasons behind the choice:

- The intention of direct compatibility with measurements by BWDB, other agencies, and related FAP projects;
- Compatibility with existing reference points and bench marks in the field.

Geodetic reference:	BTM (Bangladesh Transverse Mercator)
Datum:	PWD (Public Works Department), used in general SLW (Standard Low Water), used for bathymetry mapping

Table 4.1: Geodetic reference and datum applied by RSP

The BTM grid is a transverse Mercator type of grid whereby, roughly speaking, angles are projected correctly, while distances and true north are slightly but rather evenly distorted. The PWD datum is a horizontal type of reference level, as established by traditional levelling by a level tube relative to the local gravity field. The PWD zero level is located around 46 cm below an estimated Mean Sea Level. The SLW (Standard Low Water) datum is applied by BIWTA for mapping of waterways, for which purpose it is obviously well suited. In a rough sense, the SLW reference level is parallel with the dry season water level in the river system, and the PWD and the SLW reference levels are not directly convertible.

There was a practical difficulty in connection with the implementation of the selected coordinate system. The BTM projection is generally applied in Bangladesh, but it is used in combination with different spheroids. Datum shift parameters are available for previous grids, but not always for the ones of a more recent origin, and therefore, coordinates established by different agencies and different FAP projects are not entirely compatible.

In consultation with FPCO, the so-called 'modified Everest' spheroid was selected for the purpose of RSP, as it was anticipated at that time that it would be adopted as a standard within the FAP programme, and perhaps by SoB for general mapping purposes. Datum shift parameters from WGS84 were re-constructed by the RSP by own field measurements, as the official values were not released. The grid used by the RSP is specified in Table 4.2.

As it happened later on, this spheroid was later on shelved by SoB. Thus, in contrast to all good intentions, RSP added its own contribution to the selection of grids that were used for the purpose of the FAP programme. The difference between RSP coordinates and the geodetic grid applied by SoB is of the order of 10 m.

BTM projection:		
Scale factor	:	0.9996
Central meridian	:	90° E
False easting	:	500,000 m
False northing	:	–2,000,000 m
Latitude of origin	:	0° (Equator)
'Modified Everest Modified' spheroid:		
Semi-major axis a	:	6,377,298.524 m
Semi-minor axis b	:	6,356,097.518 m
Inverse flattening 1/f	:	300.8017
Spheroid datum shifts from WGS84 (un-official estimates by RSP):		
Rotation x	:	0
Rotation y	:	0
Rotation z	:	0
Translation x	:	–288 m
Translation y	:	–735 m
Translation z	:	–255 m
Scale	:	0 ppm
Reference: Hoyer, H. (1994 and 1995)		

Table 4.2: Geodetic grid applied by RSP

In the field, vertical levels and horizontal positions were identified relative to the BWDB network of bench marks, as specified by FPCO. In some cases, where linkage with the BWDB network was not practical, levels were established relative to bench marks established by FINMAP under the FAP18 project. Occasional comparisons were made between the networks of BWDB and FINMAP, as well as with networks established by SoB/JICA and FAP6, although these were not used by the RSP. This work is described in *RSP Special Report 1: Validation of staff gauge bench marks*.

4.2.2 Topographic surveys

Topographic surveys were carried out by conventional land survey techniques. Benchmark validation was carried out by so-called second-order levelling with an estimated accuracy of $\pm$ 5 mm x [distance in km]$^{1/2}$. All sections were closed during levelling.

4.2.3 DGPS

Particularly for the bathymetric survey programme, where results from successive surveys are subtracted from each other for determination of accretion and erosion, the positioning accuracy is critical. This is illustrated in Figure 4.1, which indicates the effect of the positioning off-set during such measurements. The figures shows that a small positioning error can induce a significant distortion of the delineation of observed erosion and accretion areas. Therefore, an accurate positioning is even more important for morphological monitoring than for navigational charting, and particularly so in case of irregular bedforms.

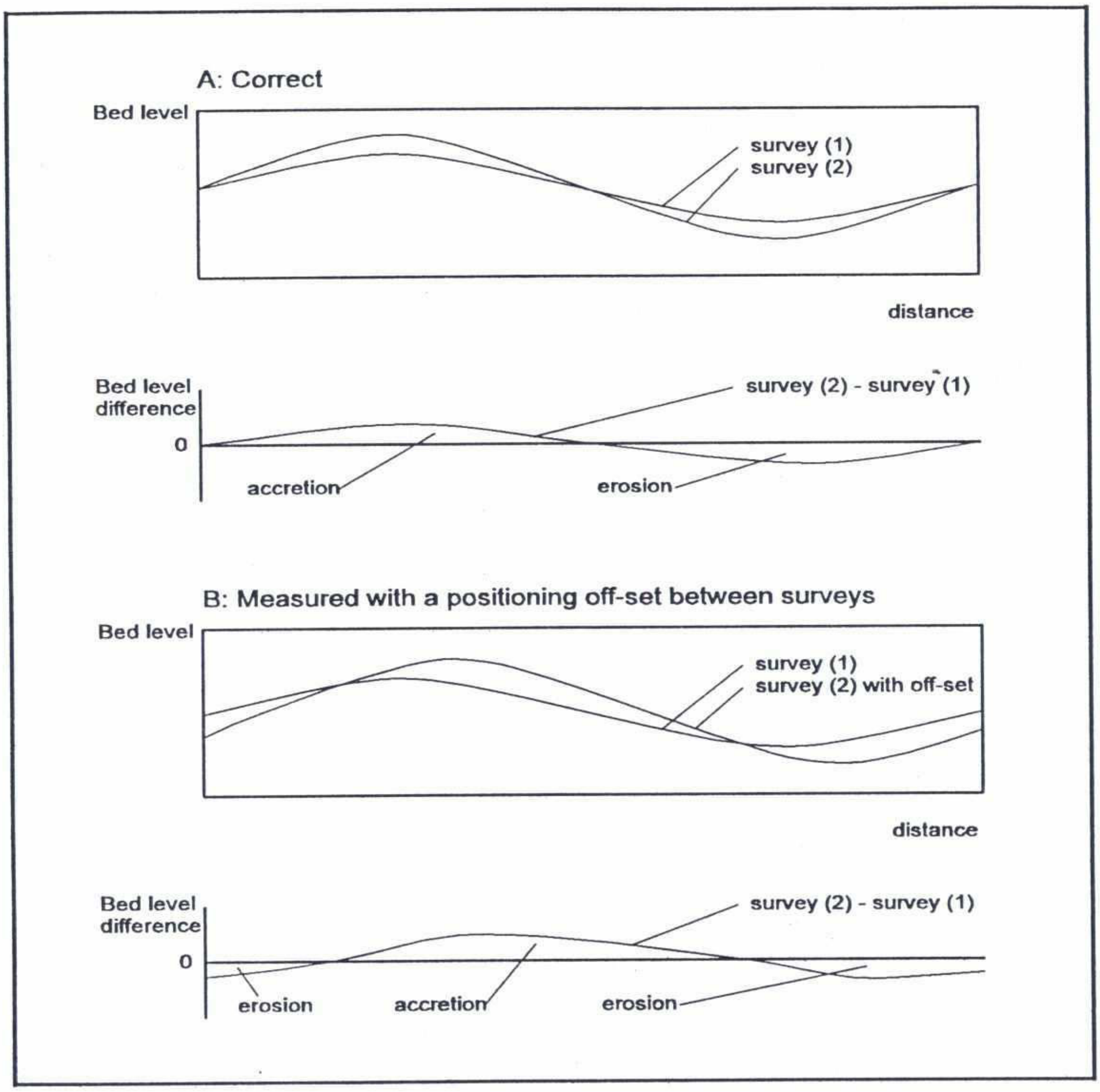


Figure 4.1: Effect of positioning off-set during bathymetric surveys

Throughout the project, the survey vessels were positioned by DGPS relative to fixed reference stations on land. The reference stations were established relative to bench marks, as described above. Due to the need of radio transmission between the reference station and the survey vessel, the reference stations were located as high as possible, for example on the roof of buildings.

Under the actual operating conditions, the absolute accuracy during dynamic DGPS positioning is estimated at 3 – 5 m whereas the relative accuracy (or resolution) is less than 1 m.

4.3 Test gauging 1992-1993

4.3.1 Background

The Technical Specifications of the Tender Documents prescribed that *'different gauging methods have to be tested ... The Consultant may present alternative gauging methods ... These must be evaluated in comparison with the reference method during the test gauging'* (Section 3.1.3). During the Consultant's proposal preparation and the subsequent contract negotiations, two procedures were considered for routine gauging:

- A so-called 'reference method', reflecting current good practices in river surveying. By this method, flow measurements are made by traditional single point measurements (e.g. by an S4 electromagnetic current-meter and/or by an Ott propeller-type current-meter) from a moored vessel, and the flow is derived by a velocity-area method;
- A so-called 'recommended method', proposed by the Consultant, reflecting recent technological achievements in the field. By this method, flow measurements are made from a moving boat by ADCP and/or EMF.

A provision was made in the Contract for either strategy (or for some suitable combination), and the outcome of a comparative test gauging in the initial phase of the project was part of the basis of the selection.

Another objective of the test gauging was to select suitable methodologies for sediment sampling and determination of sediment transport.

For the sake of validity, the test gauging had to be carried out during a reasonably high flow. In connection with the timing of the project start relative to the flood season, this implied that the test gauging took place on two occasions: A preliminary field trial was made at Bahadurabad on October 21-28, 1992, and the proper test gauging took place on August 16-22, 1993, also at Bahadurabad (in the left channel of RSP Flow Transect 1).

The Project Advisor provided comprehensive guidance and highly valuable advice during the planning, execution and evaluation of the test gauging.

4.3.2 Scope

The scope of the test gauging programme was to compare alternative gauging procedures with respect to two complementary quality characteristics: Accuracy and resource optimization. This, in turn, implied:

- Assessment of consistency, accuracy and validity of each method;
- Optimization of spatial coverage: the number of vertical profiles per transect, the number of measuring points per vertical profile, and the validity considering the effect of plan form and bed forms;
- Optimization of time resolution relative to the short-term, medium-term and seasonal variation of each parameter: Sampling duration per single point measurement, overall duration of an entire transect gauging, and number and timing of gaugings over the year.

One consideration during this type of activity is the need of a general, unambiguous reference for comparison. As per definition, the methods and detailed procedures to be compared are not fully compatible, and when two different values are produced say of the instantaneous cross-transect flow, the following questions arise: Which value is the more accurate? And, how much more accurate is it? For this type of measurements, the basis for comparison becomes inherently less accurate with an increased validity, such as when relocating from the flume tank to the field, and further when extending the comparison from instantaneous single point results to the entire cross-section.

This is one reason why the test gauging programme was of a particular significance. A valid comparison of results produced by alternative methods requires insight into the length and time scales of the variability of the phenomena to be surveyed, as well as an awareness of the partly stochastic and partly systematic nature of the measurement deviations. Such insight is not only valuable for the sake of comparison between different methods, but is equally valuable for the understanding of the results obtained by any of these methods.

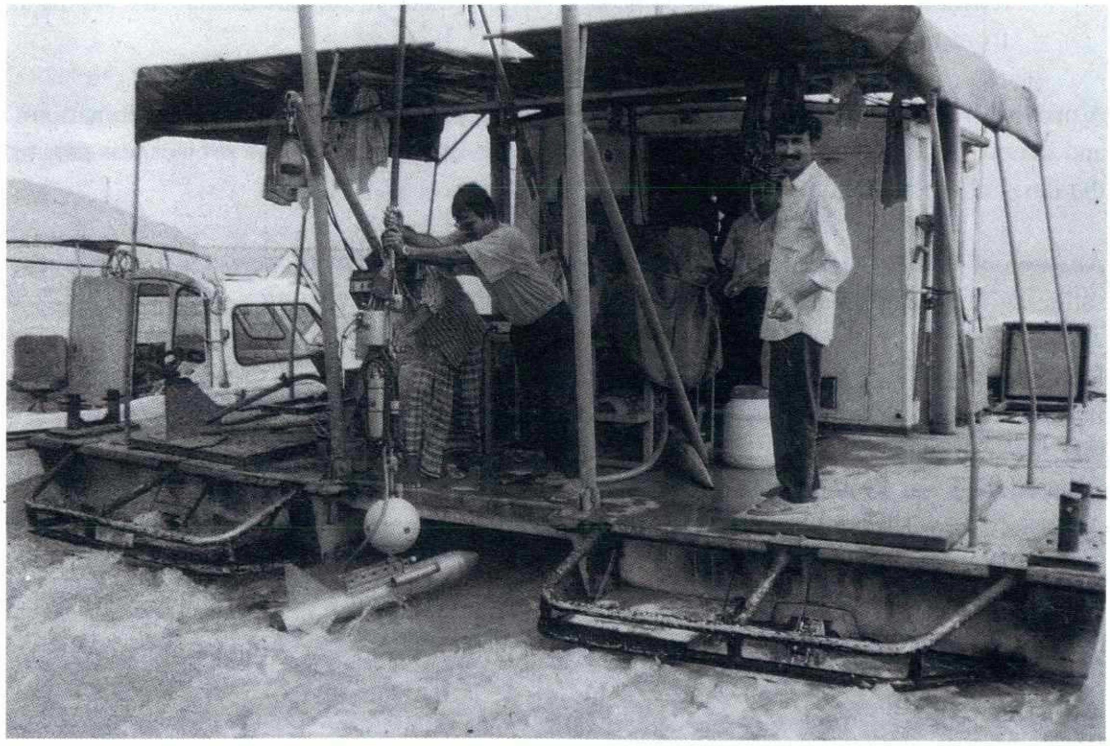


Figure 4.2: Photo from test gauging, August 1993

4.3.3 Findings on flow gauging

Considering the time required for a flow gauging by the reference method, and the difficulties with anchoring, it is of a particular interest to confine the number of points per vertical profile, and the number of verticals per cross-section. This must be done with due consideration to the objective (and the required accuracy) of the gauging on the one hand, and to the actual flow conditions on the other, a fully regular cross-sectional gravitational flow distribution requiring much less effort than a highly irregular flow field.
The findings of the test flow gauging may be summarized very briefly as follows:

- Flow gauging by moving boat, with ADCP and EMF, was characterized by a high consistency, repeated gaugings giving nearly identical results: 9 successive gaugings remained within a margin of 5 percent from their average total discharge. This is illustrated in Figure 4.3, which compares the gauging giving the highest total flow with the gauging giving the lowest total flow;
- In this channel, the current speed varied significantly both across the river and over the water column. In general, the vertically averaged speed was well correlated with (and hereby represented by) the surface speed. The current-direction varied significantly across the river, but not so much over the water column;

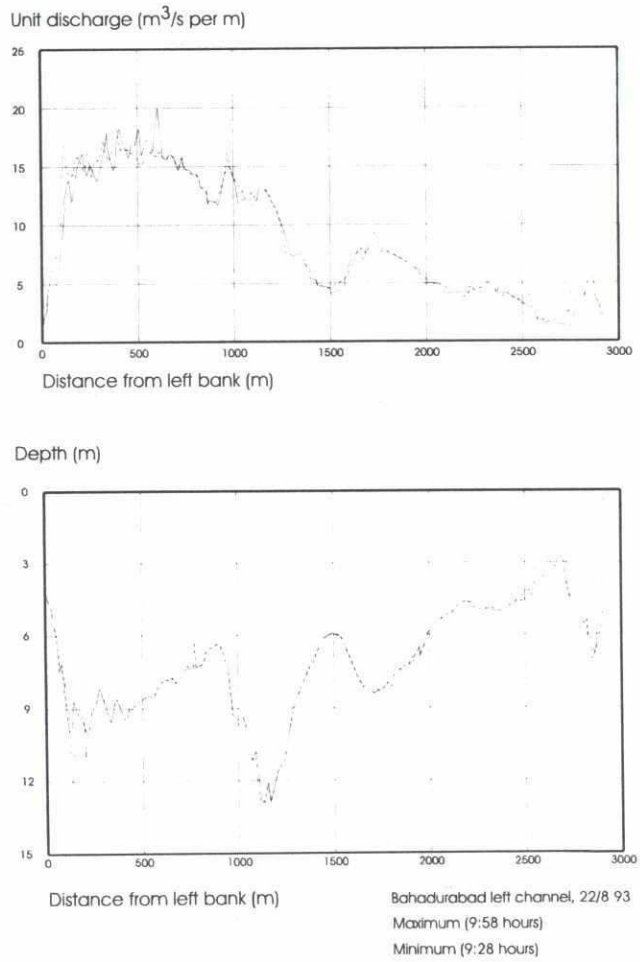


Figure 4.3: Consistency of the recommended method: Comparison between the ADCP flow transects that recorded the highest and the lowest total flow during the nine successive gaugings

- The rather regular vertical current-distribution encountered during the test gauging indicated a limited number of points per profile. In the channel selected for the the test gauging, the estimated vertical average speed deviated by up to 1 percent when reducing the number of points from 6 to 3, 2, and 1, whereas the estimated flow deviated by 2 percent. However, the 1-point measurements had a standard deviation significantly above those of the 6-, 3-, and 2-point measurements (ref. Annex 2 of *RSP Survey and Study Report 4: 'Selection of survey techniques')*
- In the channel selected for the test gauging, the horizontal flow variation was more regular within the shallow (and in this case the major) part of the cross-section. The spacing between the vertical profiles may be adjusted accordingly;
- When the reference and the recommended methods were compared for a single vertical, they gave closely similar results. When compared with respect to total cross-section flow, the results of the recommended method were on the average 7 percent above the results of the reference method.

It is noted that although the reference method of the test gauging resembles the flow gauging procedure of BWDB, there are distinct differences with respect to instrumentation and execution. The reference measurements of the test gauging were made from an anchored vessel by an S4 current-meter, which registers both the speed and direction of the current.
The consistency of the ADCP registrations was confirmed during a comparative test in Phase 2 of the project (November 1994). Here, the DHA and DHB vessels were tied together, and repeated ADCP flow gaugings by both vessels corresponded within a margin of 1-2 percent.

4.3.4 Findings on sediment transport measurements

The test programme was less conclusive with respect to the identification of a practical gauging procedure for suspended sediment transport. The variation over the cross-section was evaluated for the bulk sediment transport, but not with respect to grain-size distribution. Single point averaging and depth-integrating methods were compared and preliminary tests were carried out with bed load transport measurements.

4.3.5 Selection of gauging routine

The test gauging indicated that from an overall point of view the 'recommended' (moving boat) method was in general well suited for flow gauging, whereas the 'reference' (velocity-area) method was in general well suited for suspended sediment transport measurements, which take a much longer time. In case of significant flow fluctuations during the gauging, the velocity-area method gives a more consistent, and therefore, expectedly, a more correct description of for instance the total suspended sediment transport through a cross-section (unless the flow and the sediment concentration are entirely uncorrelated). Therefore, the 'recommended' method was extended by incorporating elements of the 'reference' method. Here, a provision was made for comparing and selecting between a moving boat and a velocity-area flow calculation after completion of the gauging, when the actual time variation of the flow was known. The experience gained during the programme justified this approach.

After the test gauging, the examination of survey methodologies continued throughout the project, both in the field and as a key component of the study programme. For an elaboration of the results, please refer to *RSP Survey and Study Report 3: 'Test gauging report, survey procedures and data presentation'*. Recommendations on techniques to be implemented were given in *RSP Survey and Study Report 4: 'Selection of survey techniques'*, and are presented in *RSP Final Report Annex 2: 'Sustainable survey techniques'*.

4.4 Applied survey procedures

4.4.1 Summary

A summary of applied survey procedures is given in Table 4.3.

Water-level gauging		
• AWLRS	:	Permanently installed self-recording pressure cell or acoustic type gauges, with monthly service check and data down-loading, and with staff gauges for back-up
• Staff gauges	:	Permanently installed gauges, read during daytime hours
Positioning		
• Horizontal control	:	By DGPS relative to reference stations established for the purpose
• Orientation and manoeuvring of vessels	:	By gyro compass and either ADCP bottom tracking (whenever possible) or DGPS (when not so)
Vertical control		
• On the river	:	Via water-level gauges relative to PWD bench marks validated for the purpose
• On land	:	Relative to PWD bench marks validated for the purpose
Routine flow and sediment transport gauging		
• Flow	:	By moving boat, using a combination of ADCP and single point EMF
• Suspended sediment concentration	:	Determined in the laboratory from samples collected and properties by pumping, and/or by integrating bottle or collapsible bag sampler, supplemented by in situ turbidity profiling
• Suspended sediment transport	:	Calculated from the above mentioned measurements of flow and concentration
• Suspended sediment transport (directly)	:	By Delft bottle
• Bed material properties	:	Analysis of samples collected by USBM-54 or by Van Veen sampler, or by a drag sampler (from small vessels and country boats)
• Near-bed sediment transport	:	By Helley-Smith sampler, or by Delft bottle
• Special surveys	:	By various dedicated procedures and routine procedures
Transect depth contours and bathymetric surveys	:	By echo sounding
Topographic (land) surveys		
• Positioning of reference stations	:	By DGPS relative to a known position
• Benchmark validation	:	By traditional geodetic surveying
• Flood plain and char topography	:	By traditional geodetic surveying (of levels) and DGPS (horizontal coordinates)

Table 4.3: Summary of standard survey procedures implemented by RSP

4.4.2 Location of gauging stations and transects

In general terms, the locations of the RSP gauging stations and transects were prescribed in the TOR of the project, both with respect to water-level gauging stations, transects for routine gauging, and bathymetric survey areas.

In all cases, the stations and transects were located at or near BWDB gauging stations or standard cross-sections, each of which form dense networks covering the entire main river system within the RSP operation area. This was to facilitate comparison between BWDB and RSP procedures. It also would enhance the value of the produced data by a good compatibility between BWDB long-term records and the high-resolution measurements by RSP, which could, as required, be extended by non-routine supplementary mapping. As it turned out, this combination was highly powerful.

In the field, the exact placement of water-level stations and transects took place based on traditional criteria, addressing the validity of the measurements and the convenience of operation:

- a well-defined, regular flow regime, unaffected by bends, bedforms, tributaries, diversions, transect depth irregularities, or shifts in cross-section area;
- exposure of AWLRs to bank erosion, accretion, and ship collision;
- location of AWLRs at places that allow to cover the complete (or, as a minimum, the entire flood season) hydrograph;
- reasonably easy access to water-level gauges (for inspection, servicing, and data downloading).

Regarding the AWLRs, it was often difficult to identify a suitable location. An AWLR is less flexible than a staff gauge in this respect, for example with respect to stage variation, and bank erosion and accretion. In several places, it was not possible to find a suitable all-year location. This issue is elaborated below.

Regarding the gauging transects, the RSP set-up allowed for a particularly good runline control, so that, in principle, it was easy to maintain a transect runline from one gauging to another. In some cases, however, transects had to be shifted in the course of time, or between the lean and flood season, due to stage variations and morphological developments, or because the survey line was obstructed by fishing nets.

4.4.3 Water level

Both staff gauges and automatic self-recording gauges (AWLRs) were applied. Because of the difficulties to collect reliable data at all stages, it was agreed with FPCO/PMU to establish two staff gauges at each AWLR, also serving the purpose of validation, and as a supplement in case of malfunctioning. The staff gauges were read during daytime hours, at 6-9-12-15-18 hours.

Data downloading and servicing took place at monthly service visits, which comprised the following routine activities:

- Data downloading and data collection from the staff gauge reader;
- check of system clock;
- battery check;
- check of functioning of sensor;
- replacement of silicagel desiccator;
- inspection of sensor fittings, electronics housing, and cables;
- readings of AWLR and staff gauges;
- zero levelling of staff gauges (relative to the temporary bench mark of the station).

For additional information about the operation procedure, please refer to *RSP Special Report 2: 'Water-level gauging stations'*.

4.4.4 Routine flow and sediment transport gauging

The routine flow and sediment transport gauging was carried out by a combination of the 'recommended method' and the 'reference method'. The total flow and its cross-sectional distribution were measured by moving boat ADCP, while the suspended sediment transport was measured by a velocity-area procedure, based on discrete vertical S4 current-profiles.

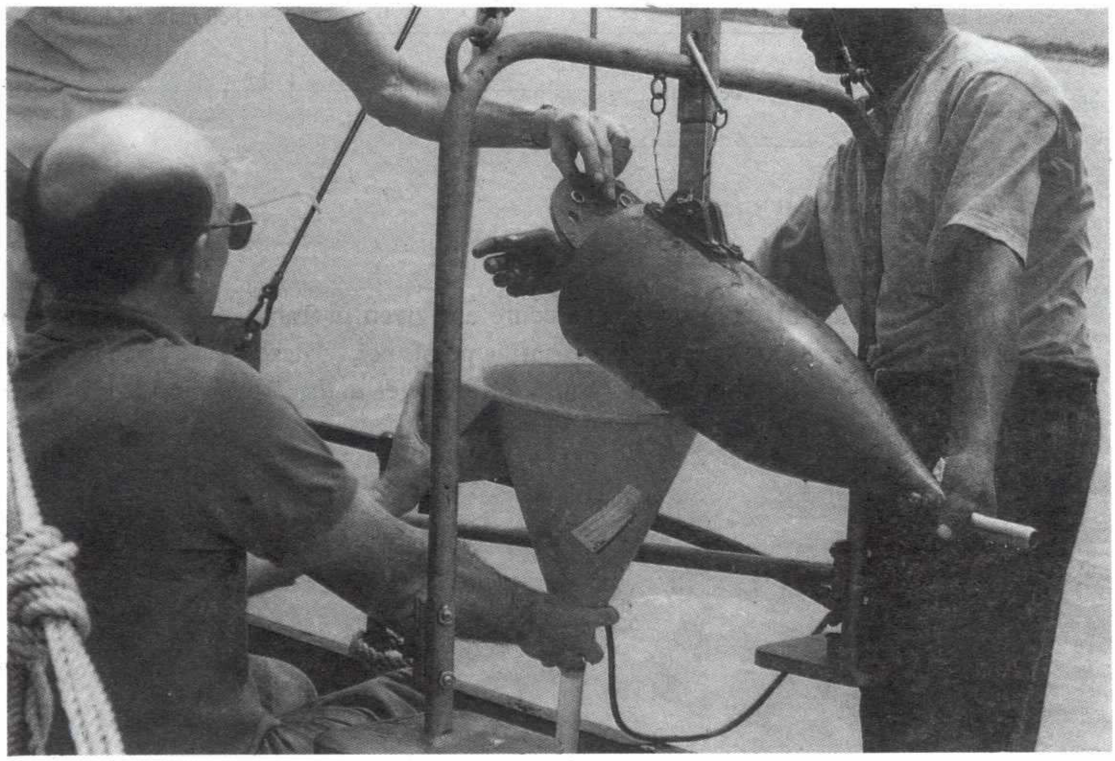


Figure 4.4: Working with the Delft bottle

In connection with the suspended sediment sampling, emphasis was given to consistency between flow recordings and sampling, by fixing the S4 current meter to the sampler. This S4 current meter was supplied with a pressure cell (for depth registration) and a tilt compensation facility. Adjustment of the intake flow velocity to the ambient flow velocity was provided for by using a (submerged) pump with an adjustable capacity. Initial problems with vibrations of the umbilical cable at high current-speeds were solved by a fairing attached to the cable (fixing the flow separation point on the leeside of the cable).

The vessel was anchored during sampling of suspended sediment and the simultaneous velocity measurements.

The sediment transport terms shown in Figure 4.5 origin from ISO standard 4363 and were applied for the purpose of the RSP. Wash load was characterised by a grain-size diameter less than 0.063 mm.

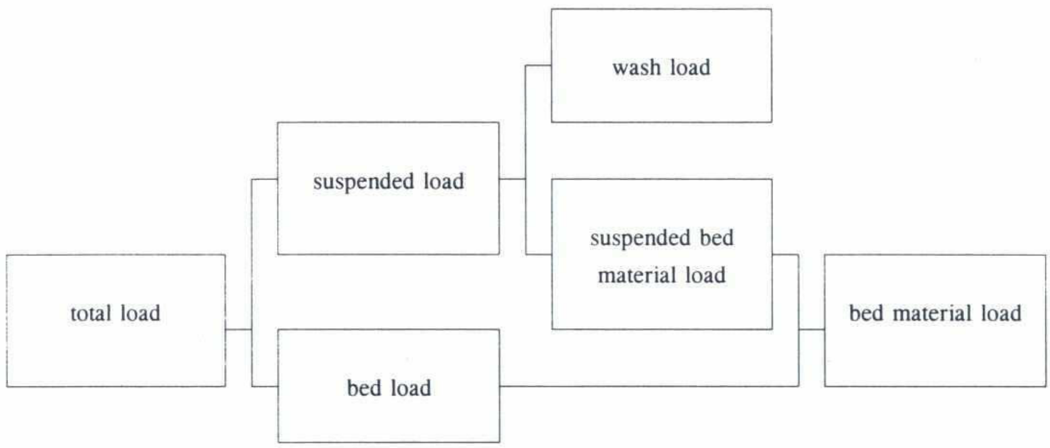


Figure 4.5: Sediment transport terms

The main components of the gauging procedure are given in Table 4.4. The number of verticals in a transect and the number of measuring points per vertical was selected as shown in Figure 4.6. For details about the procedure, please refer to *RSP Survey and Study Report 4: 'Selection of survey techniques'.*

1 Longitudinal echo sounder reconnaissance of riverbed features

2 Initial transects in each direction by ADCP, EMF, and echo sounder

3 Vertical profiles:
- (a) Current by ADCP and/or S4
- (b) Suspended sediment concentration by pump bottle, and/or turbidity meter, and/or integrated bottle, and/or collapsible bag
- (c) Pump bottle sampling for settling velocity analysis

4 Bed load and near-bed transport:
- (a) Helley-Smith sampler, and/or
- (b) Delft bottle

5 Bed material by US BM-54 sampler and/or Van Veen sampler
(Since June, 1995, a drag sampler was applied from the smallest RSP vessels and from country boats)

6 Concluding transects in each direction by ADCP, EMF, and echo sounder

Note: As indicated, not all components were applied at all surveys. Please refer to the *RSP 'Data Books'(Special Reports 22 & 23)* for a description of the actual programme of each survey

Table 4.4: Components of the recommended method for routine flow and sediment transport gauging

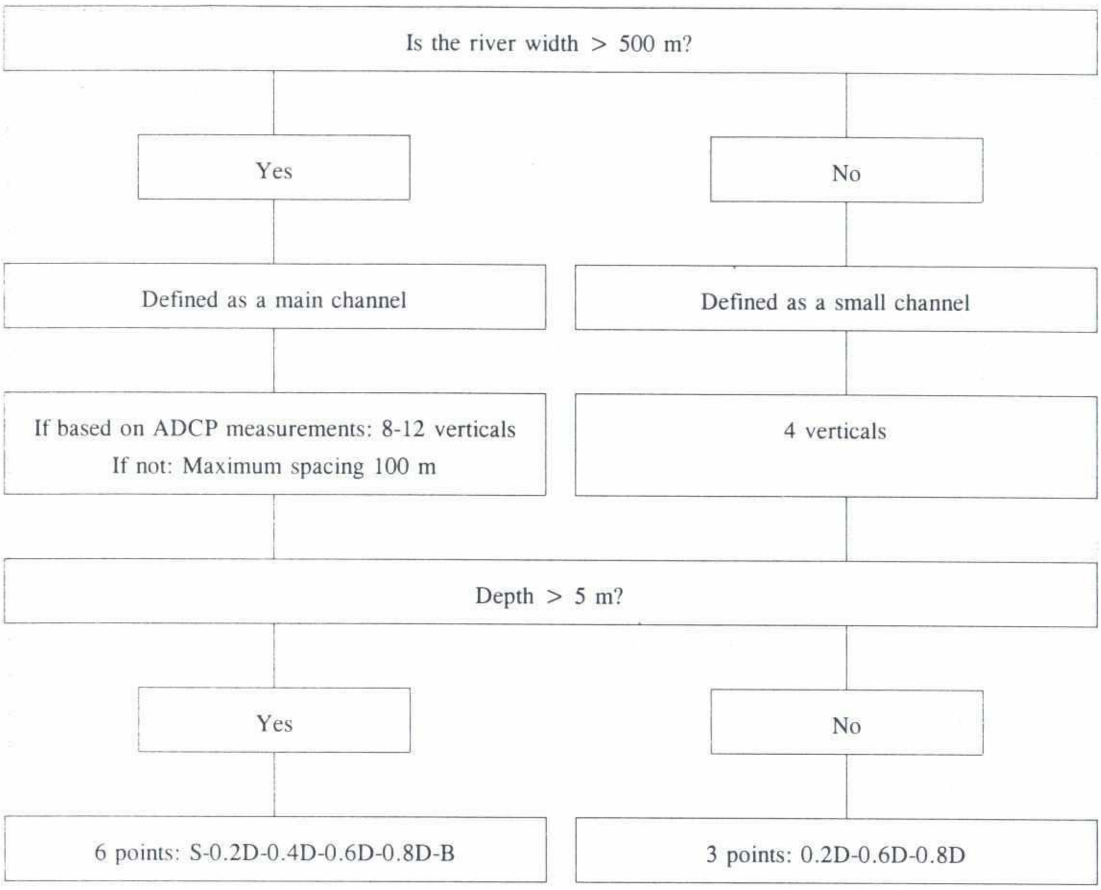


Figure 4.6: Measuring points in a transect

4.4.5 Bathymetry

The bathymetric surveys were mainly carried out for morphological river studies (Section 3.2.1 of the Technical Specifications of the Tender Documents). Therefore, they comprised detailed pre-monsoon and post-monsoon surveys of selected areas, rather than for example a general mapping of waterways for navigational purposes. In the course of the programme, certain additional high flow surveys were added in order to examine the morphological processes in more detail.

The reference level selected for the bathymetric mapping is Standard Low Water (SLW), which is basically defined by the water level that is exceeded in 95 percent of the time.

The SLW is defined at a number of locations where long-term water-level records have been available for the purpose (including most of the gauge locations listed in Table 5.11 in Section 5.6.1 below). The level depends on the data, and will, in principle, vary with time, and may not be fully consistent from place to place. Therefore, the required, well-defined chart datum is given as a nominal SLW datum, as defined at a specific place relative to PWD. The grid of SLW bench marks is relatively coarse, and its level is not defined elsewhere. For the purpose of the RSP surveys, it has been estimated to be parallel with the surface of the river at the time of the survey (Figure 4.7). The surface gradient (relative to PWD) is measured by staff gauges, so that a correction can be made for its variation from case to case, for example when comparing successive surveys.

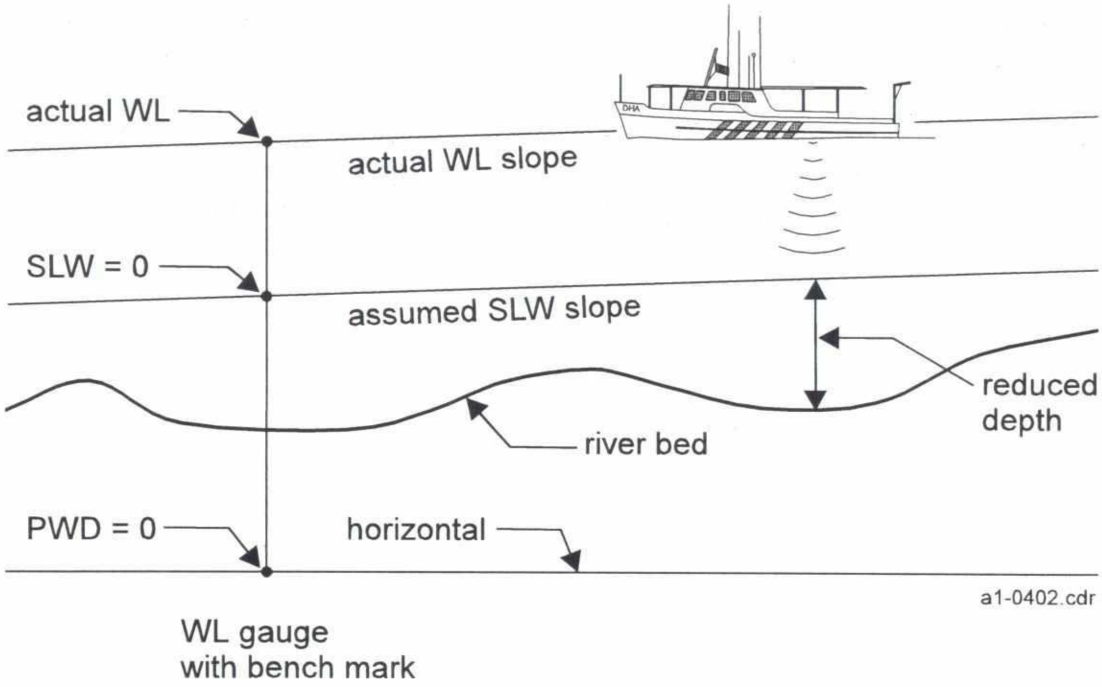


Figure 4.7: Depth reduction, definition sketch

The line spacing during such surveys is always a compromise between survey area coverage and resolution of details. More irregular bedforms require a closer line spacing for an appropriate resolution. In 1993, the PA initiated a comparison between different line spacings, in order to optimize the survey procedure. On this basis, it was decided to apply a line spacing of 100 m at Bahadurabad, and 200 m elsewhere. On certain occasions, however, a line spacing of 100 m was applied for other areas than Bahadurabad.

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. Also, for the same reason, positioning during successive surveys were made relative to the same reference stations. Hereby, possible systematic errors caused by inconsistencies between absolute positions of different reference stations were eliminated.

During the surveys, banklines were mapped from the survey vessel by observing the distance between the end of the survey line and the river bank.

4.4.6 Topographic surveys

In accordance with their different objectives, the topographic surveys were carried out by two widely different procedures:

- Occasional determination of reference station coordinates, and determination of WGS84/BTM datum shift parameters, was done by stationary DGPS;
- All levelling, including bench mark validation and topographic mapping of river banks and chars, was done by 'traditional' land survey techniques, supported by DGPS positioning.

Alternative means of topographic mapping were considered for the purpose of the project, such as (1) land elevation contours established by bankline surveys at different stages, and (2) mapping based on satellite imagery. However, although potentially practical, these means were not found suited for implementation within the framework of the project. A study of the viability of combining bathymetry data and satellite imagery was carried out as a separate activity as reported in *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data'*.

5 Survey programme

The present chapter gives an overview of the river survey programme as made, divided into categories of measurements. Phase 1 and Phase 2 activities are described jointly because many Phase-1 activities continued in Phase 2 (such as water level, routine flow and sediment transport gauging, and bathymetric surveys).

5.1 Summary of survey programme

The scope of the field survey programme was prescribed in the TOR of the project. The programme was executed with adjustments as described in Section 2.3, and as agreed with the Client and with RSPMU. In brief, the adjustments of the programme as compared with the TOR have comprised additional staff gauge measurements, an extension of the bathymetric monitoring programme in terms of number of surveys, but a reduction of the number of areas, and a transfer of survey capacity from routine gauging to non-routine surveys.

The scope of the field survey activities is shown in Table 5.1, and a chronology of main activities is given in Table 5.2. The various activities are elaborated in the following sections.

Mobilisation and preparatory activities
- General mobilisation for Phase 1
- Pilot survey by 'Anwesha'
- Test gauging
- General mobilisation for Phase 2

Water-level gauging
- Twelve automatic water-level recorders (AWLRs) at eleven locations
- Ten additional staff gauges (nine of these in the Bahadurabad area)

Routine transect gauging of flow and sediment transport
- Monsoon season gauging at eleven cross-sections
- Lean season gauging at eleven cross-sections

Special surveys
- Additional flow measurements at Bahadurabad (as a supplement to the routine flow gauging)
- A 'bed form inventory programme' of longitudinal depth profile monitoring
- Other special surveys, serving a variety of specific purposes

Bathymetric surveys
- Bathymetric monitoring of seven areas

Topographic (land) surveys
- Benchmark verification
- Bankline surveys
- Char topography

Table 5.1: Scope of the river survey programme

The detailed planning of the execution of the programme was made season by season in a close and constructive dialogue with RSPMU.

Phase 1 (June 9 1992 - December 31 1993)

Award of contract, start of procurement	May 22, 1992
Team Leader's arrival, project start	June 9, 1992
Arrival of equipment (1st consignment)	August 4, 1992
Arrival of main survey vessel (DHA)	August 22, 1992
First survey (at Bahadurabad, by BWDB's 'Anwesha')	September 6-20, 1992
Verification tests at Bahadurabad	October 21 - 28, 1992
Start of pilot gauging programme	October 29, 1992
Additional ADCP tests on Lower Meghna	December 14-24, 1992
Additional field tests and first joint BWDB/RSP measurements at Bahadurabad	January 5-17, 1993
First routine flow and sediment transport gauging at Bahadurabad	January 14-16, 1993
Joint BWDB/RSP measurements at Hospital Ghat (upstream of Khulna)	April 8-9, 1993
Joint BWDB/RSP measurements at Bhairab Bazar	April 26-28, 1993
Start of 1993 monsoon season programme	June 1, 1993
Installation of 2 AWLRs at Bahadurabad and Gabgachi	June 1-2, 1993
Installation of 3 additional staff gauges near Bahadurabad	June 15-22, 1993
First bathymetric (pilot) survey at Bahadurabad June 20 -	July 3, 1993
Reconnaissance of cross-sections for Phase 2 gauging programme	July 18 - August 2, 1993
Test gauging, comparing the 'reference method' and the 'recommended method'	August 16-22, 1993
Joint BWDB/RSP measurements at Bahadurabad	August 23-24, 1993
Second bathymetric (pilot) survey at Bahadurabad	August 25 - September 5, 1993
Start of 1993/94 lean season programme	November 1, 1993
International Workshop in Dhaka,	November 6-9, 1993
Technical and administrative finalisation of scope of Phase 2 river surveys	December, 1993

Phase 2 (January 1, 1994 - June 8, 1996)

First Phase 2 routine flow and sediment transport gauging (at Bahadurabad)	January 29 - February 1, 1994
Installation of 8 AWLRs	May 10 - June 30, 1994
Completion of Phase 2 mobilisation	June 30, 1994
First 'special survey' (turbulence measurements at Bahadurabad)	March 31 - April 1, 1994
Start of 1994 monsoon season programme	June 1, 1994
Installation of 5 additional staff gauges near Bahadurabad	June 1, 1994
Installation of 2 AWLRs	July 21-24, 1994
First additional flow measurement at Bahadurabad	June 23, 1994
First 'bedform inventory' survey (Bahadurabad → Aricha)	August 19-20, 1994
Start of 1994/95 lean season programme	November 1, 1994
Installation of 1 staff gauge (at Mir Char on the Lower Meghna)	May 31, 1995
Start of 1995 monsoon season programme	June 1, 1995
Start of 1995/96 lean season programme	November 1, 1995
Last routine gauging (at Hardinge Bridge)	March 2, 1996
Completion of the vessel survey programme (bathymetry at Gorai Off-take)	April 6, 1996
Completion of AWLR gauging	May 20, 1996
Project completion	September 8, 1996

Table 5.2: Chronology of the river survey programme

5.2 Mobilisation and preparatory activities

5.2.1 Mobilisation

The mobilisation for the Phase 1 field programme was a main 'critical path' activity, which started immediately upon award of the contract. The mobilisation proceeded until well after the field work had begun, and comprised:

- Procurement and refurbishing of the DHA survey vessel (in The Netherlands);
- Construction of the DHC (catamaran) survey vessel (in Singapore);
- Identification, procurement and home office testing of survey equipment (in Denmark);
- Development of on-line data acquisition and processing facilities and software (in Denmark);
- Preparation for positioning, selection of geodetic grid, acquisition of bench mark coordinates, and planning of reference stations (in Dhaka);
- Selection and adjustments of off-line data processing facilities and software (in Denmark);
- Field reconnaissance for logistical implications, and location of gauging transects and water-level recorders (initially mainly in the Bahadurabad area);
- Establishment of the project office, with communication, transport, sediment laboratory, and data processing facilities (in Dhaka);
- Liaison with FPCO, BWDB, other FAP projects in progress, and relevant agencies and organisations (in Dhaka);
- Planning and execution of the test gauging programme (in Dhaka and Bahadurabad, respectively);
- Detailed planning of the Phase 1 survey programme (in Dhaka);
- Mobilisation of a staff guest house (in Gaibanda, opposite of Bahadurabad).

For details about the mobilisation, please refer to *RSP General Report 1: 'Inception Report'*, and *RSP General Report 2: '1° Interim Report'*.

5.2.2 Pilot survey by 'Anwesha'

The timing of the project start relative to the 1992 monsoon season indicated a need of an early pilot survey prior to the mobilisation of the DHA vessel and the commencement of the routine gauging. This was done as a separate activity by BWDB's survey vessel 'Anwesha'. The pilot survey took place at Bahadurabad from September 6 to September 20, 1992. The following activities were completed:

- Hydraulic reconnaissance of the survey area: Banks, flow channels, and bed forms;
- Logistical reconnaissance: Access, positioning, anchoring, and berthing and bunkering facilities;
- A test gauging programme describing the cross-sectional flow distribution, and length and time scales of velocity fluctuations;
- One complete flow gauging.

The pilot survey and its findings are described in *RSP Survey and Study Report 1: 'Additional survey, September 1992'*.

5.2.3 Test gauging programme

An important part of the preparatory activities was the test gauging programme, which is described in Section 4.3.

5.3 Water-level gauging

The RSP installed and operated 12 AWLRs at 11 stations; one station was equipped with two instruments for the sake of comparative testing. These stations were distributed over the entire river system.

In many cases, the AWLRs were placed at or near BWDB staff gauge stations in accordance with one objective of the gauging, which was to supplement the long-term records available for these stations.

In addition, ten additional separate staff gauges were installed and operated, most of which for determination of local water-level slopes (in the Bahadurabad area), and as a support to the bathymetric surveys. Three of these were abandoned in the course of the programme: Char Parul and Thantania Para due to river erosion, and Gobindi due to general low data quality. One additional staff gauge was installed in Upper Meghna (in May 1995) for examination of backwater effects at Bhairab Bazar.

The gauges and their operation periods are listed in Tables 5.3 and 5.4. The gauge locations are shown in Figures 5.1 (entire river system) and 5.3 (Bahadurabad area).

Not included in these tables and figures are three gauges deployed at Bahadurabad from November 8 to November 23, 1995 in connection with a morphological survey, and three gauges deployed at Gorai Off-take from June 1 to December 31, 1995, for a study of the off-take dynamics.

Between them, the water-level gauges have been in operation for 493 station-months by the time of their demobilisation on May 20, 1996.

Summary results of the water-level gauging are given in the RSP Data Books. The complete results are stored in the HYMOS database (see Section 8.4).

The water-level gauging programme is described in *RSP Special Report 2: 'Water-level gauging stations'*. Some observations made in connection with the programme are given in Section 10.2 of this Annex 1.

Station		River	Appr. location	Easting	Northing
1	Kabilpur 1)	Jamuna, at Bahadurabad, right channel	7.5 km upstream of Fulchari	461260	792960
1	Shanki Bhangha		1 km upstream of Fulchari	458562	786874
1	Gobindi		2.3 km downstream of Fulchari	460335	782780
1	Gabgachi 2)		Mid char opposite of Fulchari	464053	782918
1	Bhagir Char		4.5 km downstream of Fulchari	461085	780474
1	North Kathiamari 3)	Jamuna, at Bahadurabad, left channel	10 km upstream of Bahadurabad	466678	789365
1	Char Parul		6.5 km upstream of Bahadurabad	468000	786500
1	North Horindhara 4)		1.5 km upstream of Bahadurabad	471652	781069
1	Bahadurabad 5)		0.7 km upstream of Bahadurabad Ghat	471447	780125
1	Belgacha 6)		3.5 km downstream of Bahadurabad	470889	776386
1	Thantania Para		9 km downstream of Bahadurabad	469549	771143
2	Bhuyanpur/ Sirajganj	Jamuna	Left channel, opposite of Sirajganj. Station moved to Sirajganj 1/4 95	479272 471146	702842 706938
3	Aricha (Teota)		2 km upstream of Aricha Ghat	477457	638242
4	Hardinge Bridge	Ganges	At bridge	401066	661668
5	Baruria	Padma	6 km downstream of Aricha	481094	629992
6	Mawa		Near ferry ghat	525840	595937
7	Mymensingh	Old Brahmaputra	At railway bridge	543466	736114
8	Tilly 7)	Dhaleswhari	10 km upstream of bridge	495655	648180
9	Gorai	Gorai	At railway bridge	416646	641622
10	Arial Khan	Arial Khan	Koshabhaya, 3 km downstream of off-take of Arial Khan	507819	590406
11	Bhairab Bazar	Upper Meghna	At railway bridge	601751	658881
12	Mir Char		20 km downstream of Bhairab Bazar, right bank	593839	645104

1) Shifted from 463166 E, 794925 N on 2/5 95
2) Shifted from 462905 E, 782564 N on 9/6 95
3) Shifted from 467071 E, 789615 N on 2/8 95
4) Shifted from 471100 E, 781744 N on 10/11 95
5) Shifted from 471049 E, 779439 N on 30/6 94
6) Shifted from 471021 E, 776497 N on 10/11 95
7) Shifted from 495590 E, 648001 N on 29/5 95

Table 5.3: Location of water-level gauges

Station	River	Operation period	Station-months	Type
1 Kabilpur	Jamuna, at Bahadurabad, right channel	1/6/94 - 3/2/96	20.1	S
1 Shanki Bhangha		1/6/94 - 3/2/96	20.1	S
1 Gobindi		1/11 92 - 30/4/95	30.0	S
1 Gabgachi		15/7/93 - 31/5/96	33.5	A+P
1 Bhagir Char		1/6/94 - 31/12/95	19.0	S
1 North Kathiamari	Jamuna, at Bahadurabad, left channel	21/6/93 - 12/2/94 01/6/94 - 3/2/96	7.7 20.1	S
1 Char Parul		14/6/93 - 12/2/94	8.0	S
1 North Horindhara		1/6/94 - 4/2/96	18.3	S
1 Bahadurabad		6/6/93 -31/5/96	34.3	P
1 Belgacha		1/6/94 - 4/2/96	20.1	S
1 Thantania Para		16/6/93 - 11/2/94	7.9	S
2 Bhuyanpur/ Sirajganj	Jamuna	29/5/94 - 30/4/95 1/4 95 - 26/5 96	11.0 + 13.9	P
3 Aricha (Teota)		13/5/94 - 23/5/96	24.4	P
4 Hardinge Bridge	Ganges	21/7/94 - 31/5/96	22.3	A
5 Baruria	Padma	28/5/94 - 24/5/96	23.9	P
6 Mawa		10/5/94 - 30/5/96	24.7	P
7 Mymensingh	Old Brahmaputra	29/6/94 - 24/5/96	22.8	A
8 Tilly	Dhaleswhari	28/5/94 - 23/5/96	23.8	P
9 Gorai	Gorai	22/7/94 - 31/5/96	22.3	A
10 Arial Khan	Arial Khan	3/6/94 - 31/5/96	23.9	P
11 Bhairab Bazar	Upper Meghna	24/7/94 - 28/5/96	22.1	A
12 Mir Char		31/5/95 - 28/2/96	9.0	S

A: acoustic AWLR + 2 staff gauges, P: pressure cell AWLR + 2 staff gauges, S: staff gauge

Table 5.4: Summary of data collection, water-level gauging

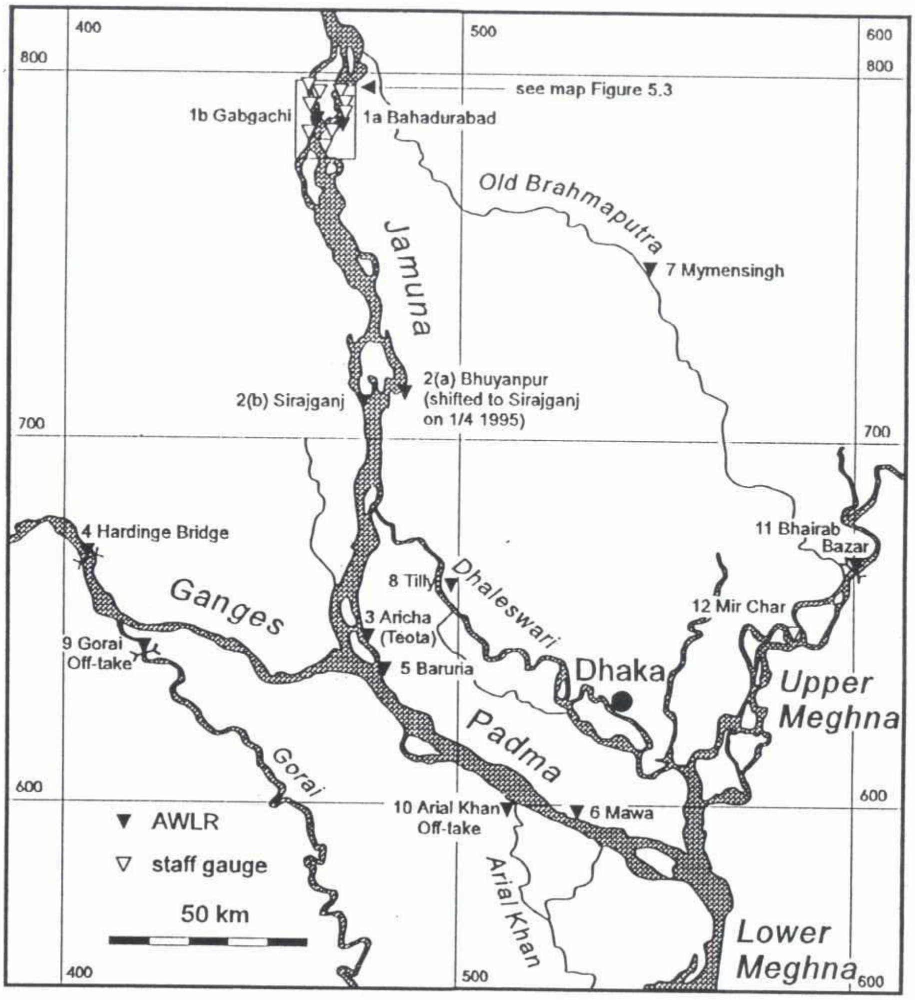


Figure 5.1: Location of water-level gauges

Figure 5.2: An ALWR (Automatic Water Level Recording) platform

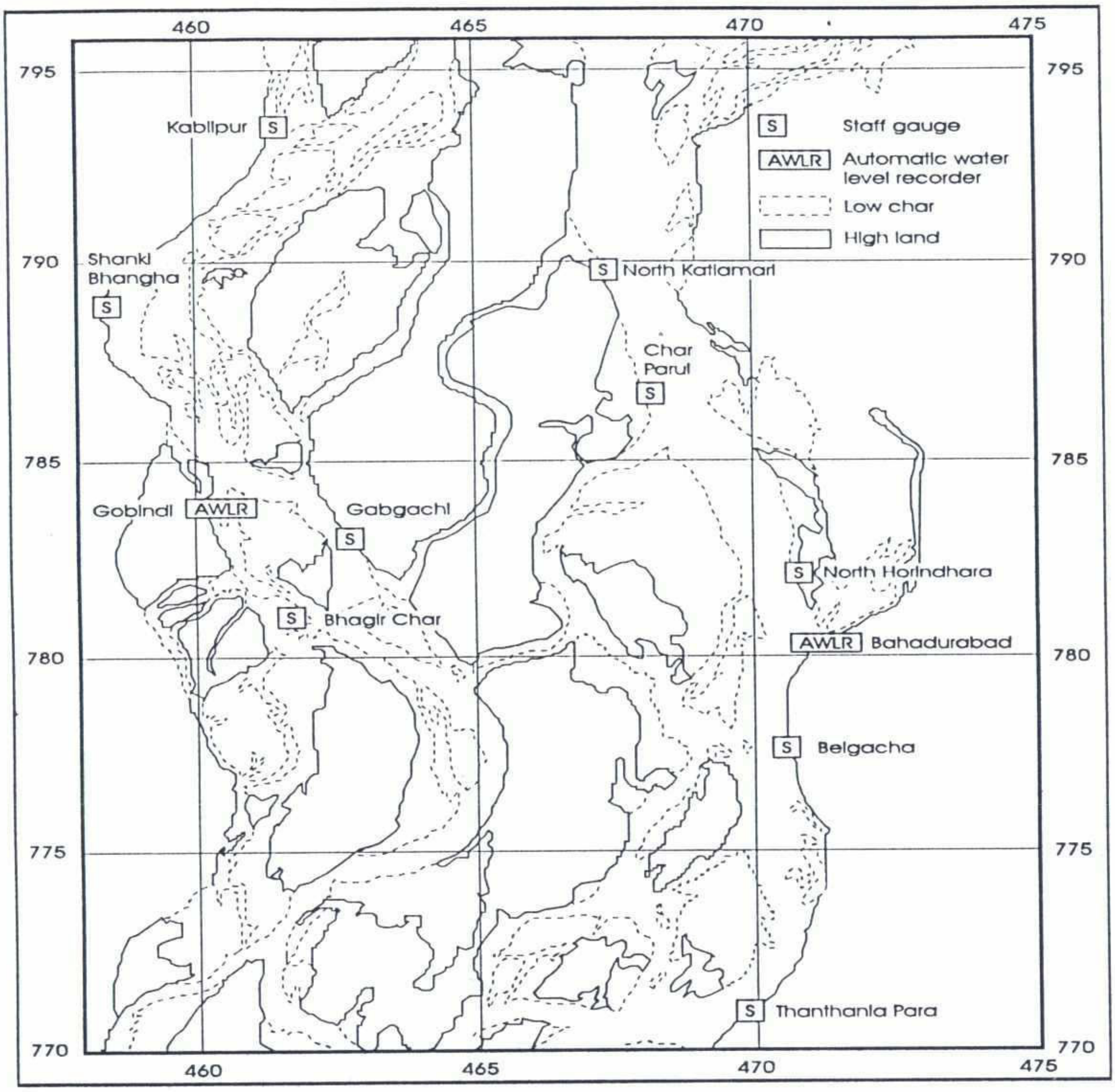


Figure 5.3: Location of water-level gauges, Bahadurabad area

5.4 Routine flow and sediment transport gauging

The locations of the transects for routine gauging of flow and sediment transport are shown in Table 5.5 and in Figure 5.5.

A total of 252 routine flow and sediment transport gaugings were completed in the course of the project. An outline is given in Table 5.6, and a complete inventory with the dates of each survey is attached as Enclosure A.

Transect		River	Easting	Northing
1	Bahadurabad	Jamuna	470	777
2	Sirajganj	Jamuna	477	700
3	Aricha	Jamuna	470	642
4	Hardinge Bridge	Ganges	402	662
5	Baruria	Padma	480	630
6	Mawa	Padma	527	595
7	Mymensingh	Old Brahmaputra	545	735
8	Tilly	Dhaleswari	497	648
9	Gorai Off-take	Gorai	412	645
10	Arial Khan Off-take	Arial Khan	508	594
11	Bhairab Bazar	Meghna	601	659

Table 5.5: Location of transects for routine gauging

Figure 5.4: The Survey Vessel DHC during some profiling

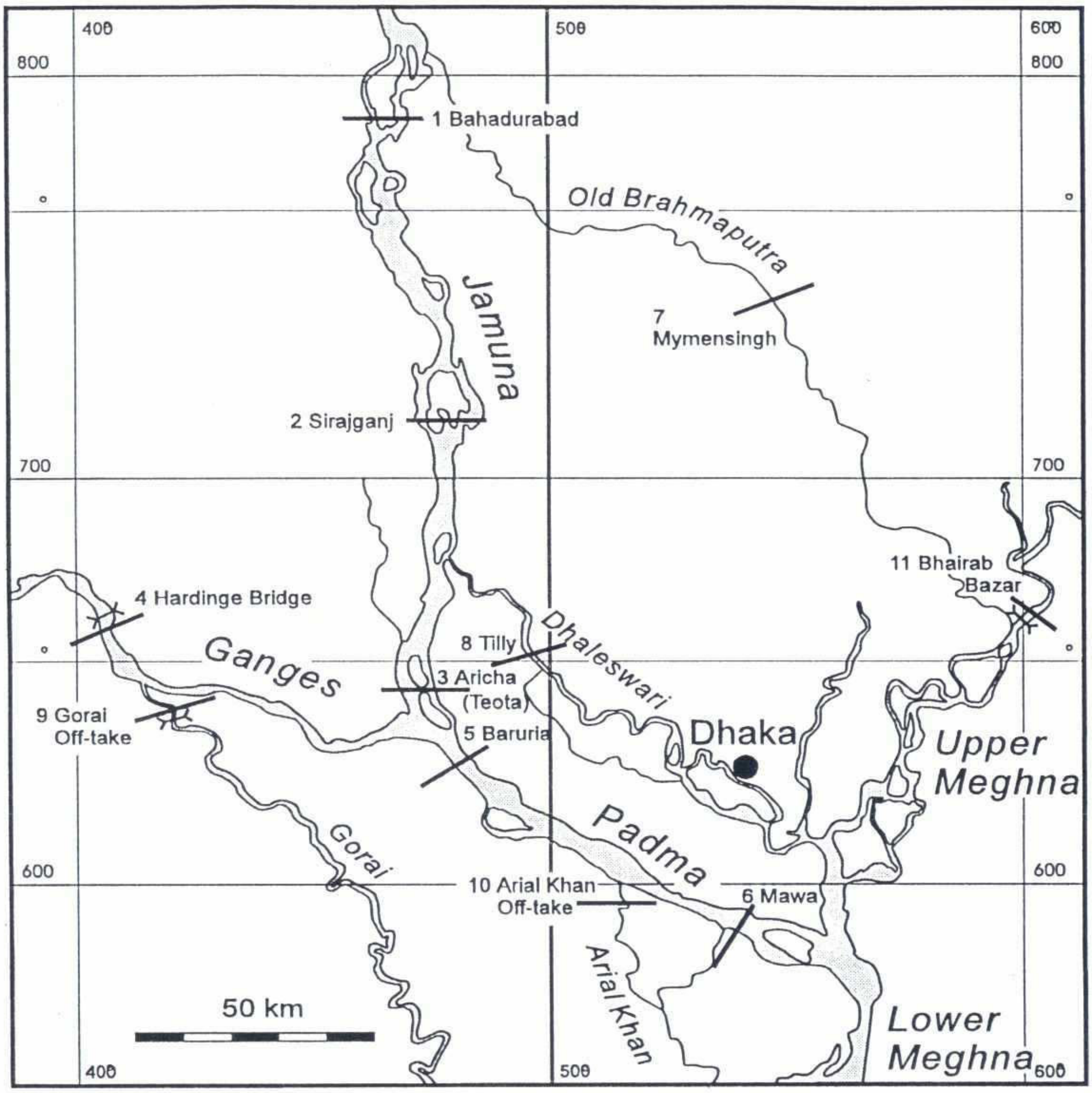


Figure 5.5: Location of transects for routine gauging of flow and sediment transport

In the lean season, the flow through some of the transects are influenced by the tide, particularly around spring tide. This is the case for Baruria, Mawa, Arial Khan, and Bhairab Bazar. In the flood season, tidal effects are insignificant at all transects covered by the project. Please refer to Section 9.1 for a summary of the tidal surveys carried out within the project.

Backwater effects can occur at Aricha during peak flow in the Ganges, and at Bhairab Bazar during peak flow in Padma/Lower Meghna.

Summarised results of the routine flow and sediment transport gauging are given in the RSP Data Books. The complete results are stored in the PSD24 database (see Section 8.4).

	Year	93		94		95		96	Total
	Season	lean	flood	lean	flood	lean	flood	lean	
1	Bahadurabad	3	4	6	7	6	9	8	43
2	Sirajganj		3	5	6	7	7	6	34
3	Aricha		1		2	0	4	0	7
4	Hardinge Bridge		1	5	7	6	7	5	31
5	Baruria		4	5	7	6	7	5	34
6	Mawa		1		2	1	3	2	9
7	Mymensingh			3	4	3	5	3	18
8	Tilly		1	3	4	3	5	3	19
9	Gorai Off-take		1	3	4	3	6	3	20
10	Arial Khan Off-take		1	3	4	3	5	2	18
11	Bhairab Bazar	1	1	3	3	4	4	3	19
	Total	4	18	36	50	42	62	39	252

Table 5.6: Summary of data collection, routine flow and sediment transport gauging

5.5 Bathymetric and topographic surveys

5.5.1 Bathymetric surveys

A programme of bathymetric surveys was carried out as a part of the project. Aiming at providing data for morphological monitoring and for examination of morphological processes, the surveys were done on several occasions in specific areas. These areas are shown in Figure 5.6, and described in Table 5.7.

The survey programme is outlined in Table 5.8. An inventory of the programme, with dates of each survey, is given in Enclosure A, Section A.2.

The line spacing during such surveys is always a compromise between survey area coverage and resolution of details. More irregular bedforms require a closer line spacing for an appropriate resolution. In 1993, the PA initiated a comparison between different line spacings, in order to optimize the survey procedure. On this basis, it was decided to apply a line spacing of 100 m at Bahadurabad, and 200 m elsewhere. On certain occasions, a line spacing of 100 m was applied for other areas than Bahadurabad.

Banklines for the bathymetry maps were established by observing the distance from the bank to each end of each survey line. Here, the required consistency was maintained with respect to coordinate system and its reference.

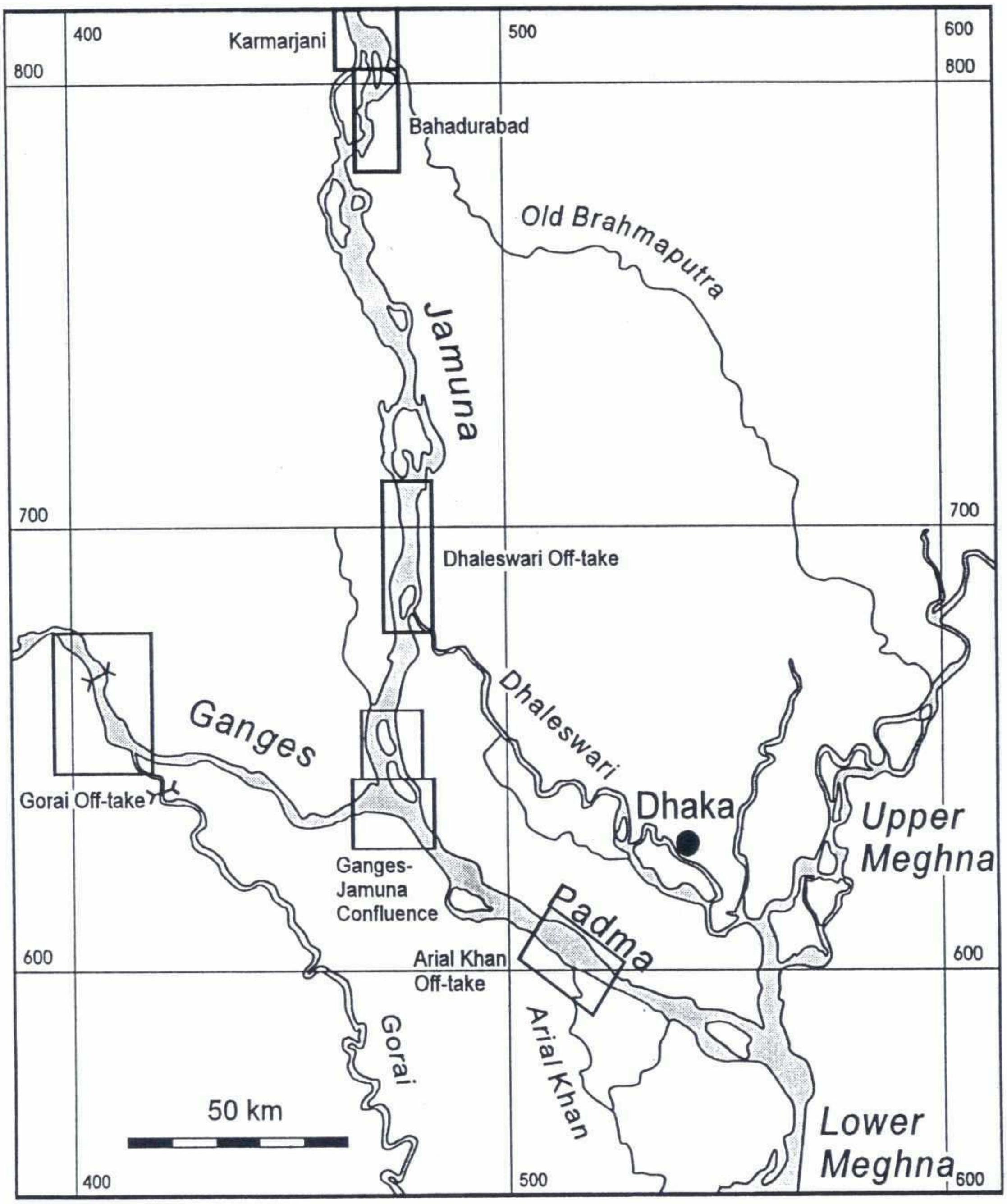


Figure 5.6: Location of bathymetric survey areas

	Location	Area 1)	Line spacing
1	Bahadurabad	29 - 91 km²	100 m
2	Karmajani	50 - 160 km²	100 m or 200 m
3	Dhaleswari Off-take	60 - 85 km²	200 m
4	Hurasagar Outlet	15 - 21 km²	100 m or 200 m
5	Gorai Off-take	4 - 107 km²	100 m or 200 m
6	Jamuna/Ganges Confluence	73 - 107 km²	200 m
7	Arial Khan Off-take	79 -99 km²	200 m
1): The actual net area varies from one survey to another			

Table 5.7: Description of bathymetric survey areas

	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 5.8: Summary of data collection, bathymetric surveys

Charts for morphological studies were made to the following scales:

- interdistance of survey lines: 200 m → scale 1 : 20.000
- interdistance of survey lines: 100 m → scale 1 : 10.000

5.5.2 Char topography

Traditional monitoring of morphological developments implies successive mappings of elevation contours, to be analyzed for level differences caused by accretion and erosion in the period between the surveys.

For routine purposes, these surveys can best be undertaken in the dry season, when the morphological developments proceed slowly or not at all. In case of surveys in the flood season (which may be justified by several good purposes), the data interpretation is more difficult, because the surveys are rather time-consuming, so the time scale of a mapping becomes comparable with the time scale of significant morphological changes.

In the dry season, however, the stage is low, so a substantial part of the river sediment volume exposed to morphological change appears as dry land. Therefore, the mapping must, in some way, cover both the dry and the submerged part of the riverbed. This requires a combination of bathymetric and topographic surveys.

A programme of char topography mapping was carried out in the final stage of the project. An outline of this programme is given in Table 5.9. The extent of the data collection and presentations of the results are given in *RSP Special Report 3: 'Bathymetric Surveys'*. The findings are elaborated in *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data'*.

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 500 m. The point increment along the line was 100-200 m 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. From 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 3 m (horizontally) and 2-3 cm (vertically).

The surveys included a mapping of topographic features, as a support to the interpretation of satellite imagery by EGIS in connection with a joint EGIS/RSP study on *'Spatial representation and analysis of hydraulic and morphological data'*. For this purpose, features were classified as indicated in Table 5.10. For a presentation of results, please refer to *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data'*, jointly prepared by EGIS and RSP.

Location	Start date	End date	Survey	
Gorai Off-take	15-Jan-95	14-Feb-95	9044	
Bahadurabad	25-Nov-95	20-Dec-95	8032	F)
Bahadurabad	25-Dec-95	06-Jan-96	8032	F)
Bahadurabad	09-Mar-96	14-Mar-96	8032	F)
Kamarjani	07-Jan-96	16-Jan-96	8034	F)
Kamarjani	15-Mar-96	18-Mar-96	8034	F)
Ganges/Jamuna Confluence	22-Mar-96	31-Mar-96	8037	F)

F): Feature classification was included in this survey

Table 5.9: Topographic mapping of chars

- Crop type: Paddy (species), wheat, jute, sugar cane, firewood (species), tobacco, spices (species), pulse, mustard, others
- Crop height (cm) and area
- Soil type: Silt or sand, dry or moist
- Structures: Buildings, roads, dikes, ditches, embankments, etc.
- Scour holes

Table 5.10: Feature classification

5.6 Geodetic surveys

5.6.1 Zero level validation of BWDB water-level gauges

One of the tasks of the RSP was to verify the zero levels of 47 BWDB water-level gauges by second order levelling.

The stations are listed in Table 5.11, and their locations are shown in Figure 5.7.

Brahmaputra/Jamuna			Easting	Northing
1	45	Noonkhawa	476500	838500
2	45.5	Chilmari	468100	825600
3	46	Kamarjani	479800	814600
4	46.9L	Bahadurabad	471000	777800
5	46.9R	Fulcharighat	460400	782600
6	48	Jagannathganj	481400	725900
7	49.A	Kazipur	470800	726100
8	49	Sirajganj	474600	702000
9	50	Porabari	481300	672400
10	50.3	Mathura	567800	646700
11	50.6	Mathurapara	464400	648600
Ganges				
1	88	Rampur Boalia	356300	695300
2	89	Sardah	372100	678400
3	90	Hardinge Bridge	403400	661700
4	91	Talbaria	408400	648700
5	91.1	Sengram	437200	641200
6	92.1	Mahendrapur	457500	631900
Padma				
1	1.9L	Baruria	478500	632200
2	91.9R	Goalunda	477900	633700
3	93.42	Bhagyakul	510300	608800
4	93.5L	Mawa	522100	602300
5	94	Tarpasha	549300	589500
6	95	Sureshwar	542600	576500

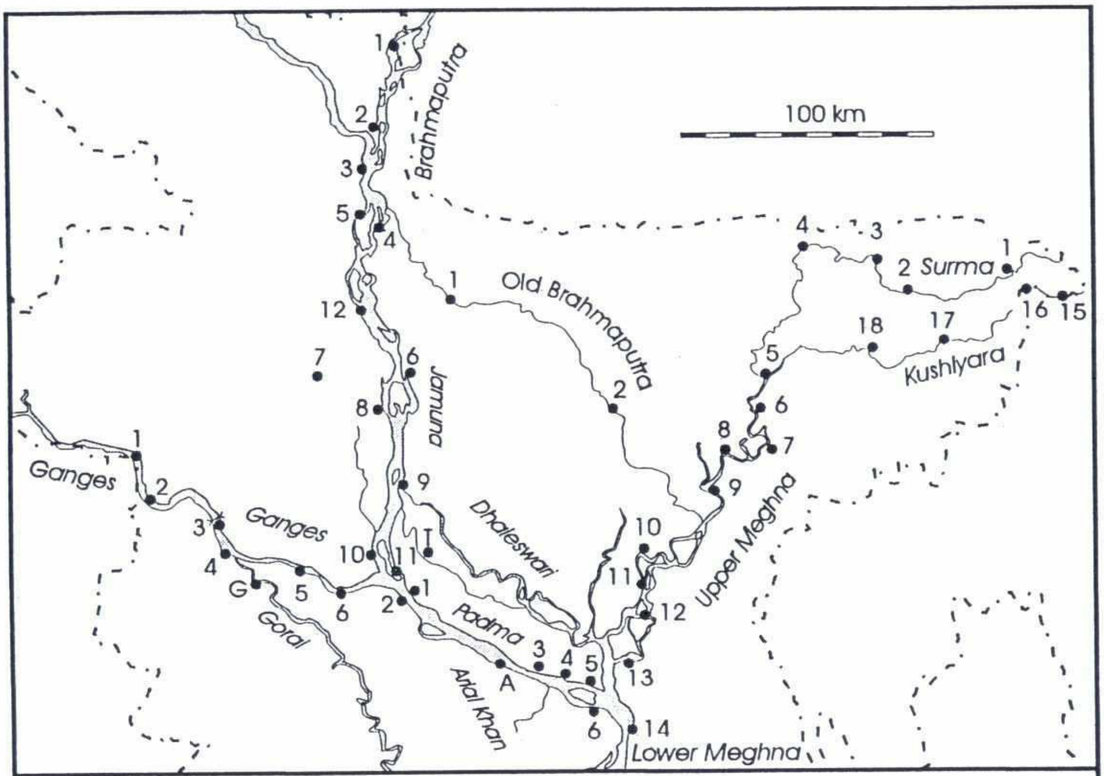
Note: First number or letter is map reference for Figure 5.7
Second number is BWDB reference number
Positions are converted from BIWTA (1990)

Table 5.11: BWDB water-level gauges selected for zero level verification (continued)

Dhaleswhari			**Easting**	**Northing**
T	68	Tilly	498300	654000
Old Brahmaputra				
1	225	Jamalpur	498300	759100
2	228.5	Mymensingh	543800	738900
Arial Khan				
A	9A	Arial Khan Off-take	508500	595000
Gorai				
G	99	Gorai Railway Bridge	418500	639400
Upper Meghna including Surma and Kushiyara				
1	266	Kanairghat	725300	768400
2	267	Sylhet	678400	751100
3	268	Chattak	662600	658600
4	269	Sunamganj	639400	774600
5	270	Markuli	638200	732200
6	271	Ajmiriganj	668700	717700
7	272	Madna	626700	691400
8	272.1	Austagram	609900	685800
9	273	Bhairab Bazar	601600	659900
10	274	Narsingdi	571200	643100
11	275	Baidder Bazar	569600	622800
12	275.5	Meghna Ferry Ghat	562900	609800
13	276	Satnal	561200	593200
14	277	Chandpur	568200	567400
15	172	Amalshid	744000	755800
16	173	Sheola	717100	757200
17	174	Fenchuganj	692100	732800
18	175.5	Sherpur	671700	722200

Note: First number or letter is map reference for Figure 5.7
Second number is BWDB reference number
Positions are converted from BIWTA (1990)

Table 5.11 (continued): BWDB water-level gauges selected for zero level verification



Brahmaputra/Jamuna

1	45	Noonkhawa
2	45.5	Chilmari
3	46	Kamarjani
4	46.9L	Bahadurabad
5	46.9R	Fulcharighat
6	48	Jagannathganj
7	49.A	Kazipur
8	49	Sirajganj
9	50	Porabari
10	50.3	Mathura
11	50.6	Mathurapara

Ganges

1	88	Rampur Boalia
2	89	Sardah
3	90	Hardinge Bridge
4	91	Talbaria
5	91.1	Sengram
6	92.1	Mahendrapur

Padma

1	1.9L	Baruria
2	91.9R	Goalunda
3	93.42	Bhagyakul
4	93.5L	Mawa
5	94	Tarpasha
6	95	Sureshwar

Dhaleswhari

T	68	Tilly

Old Brahmaputra

1	225	Jamapur
2	228.5	Mymensingh

Arial Khan

A	9A	Arial Khan Off-take

Gorai

G	99	Gorai Railway Bridge

Upper Meghna including Kushiyara

1	266	Kanairghat
2	267	Sylhet
3	268	Chattak
4	269	Sunamganj
5	270	Markuli
6	271	Ajmiriganj
7	272	Madna
8	272.1	Austagram
9	273	Bhairab Bazar
10	274	Narsingdi
11	275	Baidder Bazar
12	275.5	Meghna Ferryghat
13	276	Satnal
14	277	Chandpur
15	172	Amalshid
16	173	Sheola
17	174	Fenchuganj
18	175.5	Sherpur

Note: First number or letter is map reference - second number is BWDB reference number

Figure 5.7: Location of BWDB water-level gauges listed in Table 5.11

The verification of the zero levels of the gauges was done by levelling between the station and a nearby BWDB bench mark with a known level. The work was done in the first half of 1993 and comprised four steps:

- First, an inspection visit was paid to the station. Detailed location sketches were made of the bench mark and the water-level station;
- Inspection reports were produced with indications of the conditions of bench marks and gauges, and suggestions for improvement as prompted. A summary was submitted to FPCO;
- Thirdly, a second order levelling was carried out from the BWDB bench-mark to the staff gauge. When practical, nearby FINMAP bench marks were included in the levelling;
- Finally, the results were reported in *RSP Special Report 1: 'Validation of staff gauge bench marks'*. This report gives a table comparing the applied zero levels of the gauges with the levelling results of the River Survey Project, and another table with information about differences between the BWDB and the FINMAP bench mark networks.

5.6.2 Datum transfer across Jamuna

In December, 1992, a levelling across the Jamuna at Bahadurabad was carried out with the objective to examine certain inconsistencies between water levels measured at staff gauges that had been levelled relative to existing bench marks on the left and the right bank of the river, respectively. Three different methods were applied and compared:

- Traditional second order levelling;
- Levelling by staff gauges;
- Datum transfer by GPS.

The traditional second-order levelling was possible because of an unusually low stage at the time.

The exercise identified a gap of 29 cm between the zero levels of BWDB bench marks on each side of the river (FINMAP BM 5244 on the left bank and BM GPS 7 on the right bank). This gap tallied well with the observed water-level discrepancies that had induced the survey, although the value was questioned by the RSPMU. The following observations were made in connection with the survey:

- Among the compared methods, only the traditional levelling complied with the desired second-order accuracy;
- It is questionable whether staff gauge levelling is relevant at all across wide and braided rivers like the Jamuna;
- In 1992, the GPS technology was under a rapid development (as it is today), and should be kept in mind as a potential alternative method.

For details about the datum transfer, please refer to *RSP Survey and Study Report 7: 'Transfer of bench-mark levels across Jamuna River at Bahadurabad'*.

5.7 Special surveys

The special surveys were not specifically included in the ToR, but were an adaption of the programme recommended and approved by the RSPMU. They served a variety of demands of specific river data that were identified in connection with the study activities. They can be divided into three categories:

- additional flow measurements at Bahadurabad (carried out on 28 occasions);
- a so-called bedform inventory programme, comprising repeated recordings of longitudinal depth contour profiles (carried out on 28 occasions);
- a variety of other purposes (carried out on 43 occasions).

Many of the special surveys supported several study activities at the same time, while most of the study activities were based not only on the special surveys, but also on the results of the routine gauging programme (as well as on data produced by BWDB).

Results of the special surveys are reported in the RSP Data Books (RSP Special Reports 22 and 23)

5.7.1 Flow measurements at Bahadurabad

The objective of the additional flow measurements at Bahadurabad was to improve the data coverage of the routine gauging, for several good reasons, one being to allow for a detailed inter-calibration and a mutual validation of the BWDB and the RSP rating curves at that key location.

These flow recordings were made by the same procedure as that of the routine gauging, except that sediment transport measurements were omitted. The surveys were scheduled so that they, together with the routine gauging, provided a good coverage of the hydrograph.

The extent of these recordings is indicated in Table 5.12. Please refer to Enclosure A for a complete inventory. Results of the recordings are reported in the RSP Data Books.

Year	94	95		96	Total
Season	flood	lean	flood	lean	
Number of surveys	16	7	5		28

Table 5.12: Additional flow measurements at Bahadurabad

5.7.2 Bedform inventory programme

The bedform inventory programme supplied data to the studies of bars and bedforms. Like the other special surveys, this activity was not included in the ToR, but was recommended by the PA, and was subsequently formally approved. It comprised repeated recordings of longitudinal depth contour profiles in the Jamuna River between Aricha, Sirajganj, and Bahadurabad. Hereby, a supplement was provided to the information about the time and space variation of bedforms that was produced by the bathymetry surveys, and by a number of special surveys at Bahadurabad. As compared to these surveys, the bedform inventory programme covered the entire downstream reach from Bahadurabad to Aricha, hereby highly extending the spatial coverage of the detailed measurements at Bahadurabad with respect to frequency of occurrence, spatial variability and geometry of bars and dunes.

The measurements were more frequent than the ones at Bahadurabad, but only one longitudinal line was recorded, and the positioning (by ordinary, or 'non-differential' GPS) was less accurate than for the bathymetric surveys. Therefore, and also due to the shifting positions of channel and bars, the transect direction was not always aligned with the main bar and dune axes, and the transects were not the same during successive mappings. The recordings were made while transferring between routine gauging transects.

An outline of the data collection is given in Table 5.13, and a complete inventory is included in Enclosure A. Results of the programme are presented in the related study reports, particularly in *RSP Special Report 9: 'Bars and dunes in Jamuna River'*.

Year	94		95	96	Total
Season	flood	lean	flood	lean	
Number of surveys	11	10	7		28

Table 5.13: Bedform inventory programme

5.7.3 Other special surveys

These surveys were targeted at specific analyses and were in many cases carried out by adaption of elements of the routine procedures. In other cases, measurements were carried out by methods that were selected for the purpose. For example, geological investigations of river deposits were made by vibro-coring, seismic surveying, and by ground penetrating radar. The equipment for this work was supplied and applied by the research institutions involved in the study component of the project. The scope of this category of non-routine surveys covered a variety of subjects, such as for example:

- surface slope mapping;
- flow dynamics at constrictions, off-takes, bifurcations, and confluences;
- hydrodynamic effects of planforms and bedforms;
- examination of survey techniques (hydraulics and sediment transport);
- bed material characteristics;
- comparative measurements with BWDB (hydrology and morphology);
- length and time scales of flow and sediment transport;
- geological mapping of river deposits.

The extent of this activity is indicated in Table 5.14. Please refer to Enclosure A for a complete inventory. Results of the programme are presented in the related study reports.

Year	94		95	96	Total
Season	flood	lean	flood	lean	
Number of surveys	15	6	16	6	43

Table 5.14: Other special surveys

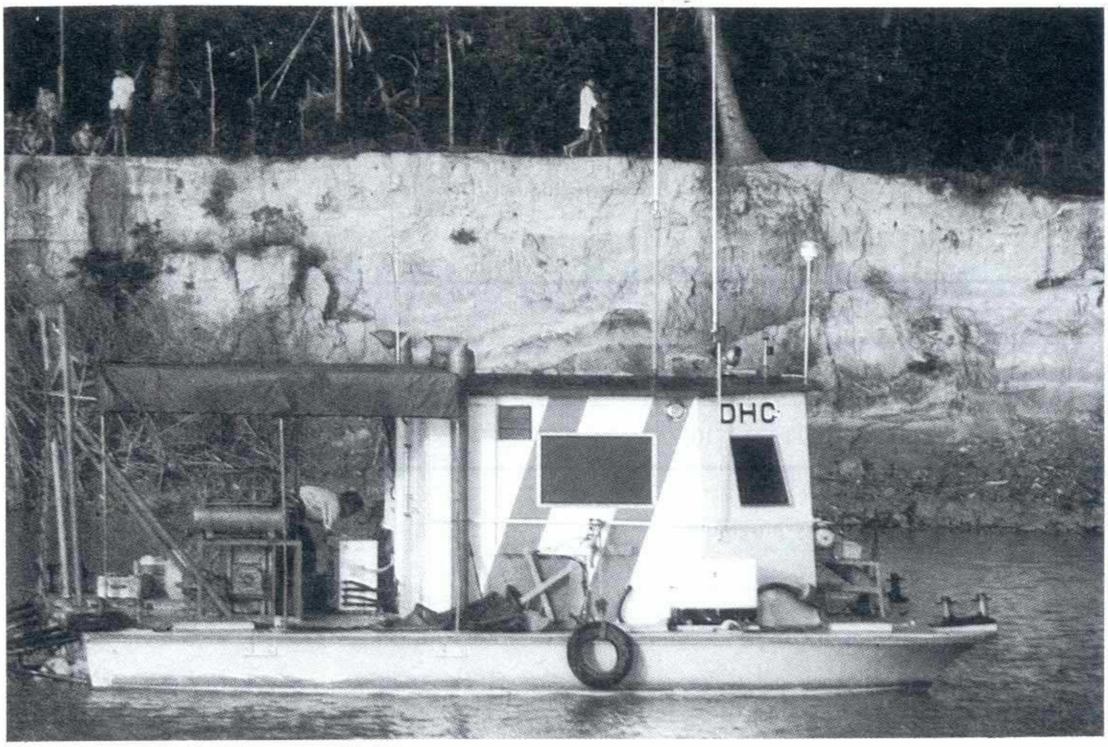


Figure 5.8: The Survey Vessel DHC in the Ganges River

6 The sediment laboratory

6.1 Facilities and procedures

In addition to the flow recordings, the routine gauging 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, as described in Chapter 5, Section 5.4. The analyses included in the routine monitoring are listed in Table 6.1.

Sampling	Method	Analysis			
		Silt concentration	Sand concentration	Grain-size/ settling velocity distribution 1)	Transport rate
Suspended sediment	Collapsible bag, integrating 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
S: By dry sieving (or wet sieving for cohesive sediments)

Table 6.1: Sediment analyses for routine gauging

The various types of samples were analyzed in the sediment laboratory of the River Survey Project. This laboratory 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).

In the laboratory, the concentration samples were separated by an elutriator into grain-size fractions above and below 0.05 mm. The mass of each fraction is determined by micro-filtering using 0.45 μm Millipore filters.

Samples for settling velocity/grain-size analysis were separated by sieving through a 0.063 mm sieve. The portion above 63 microns was analyzed by dry sieving (occasionally by wet sieving), whereas the portion below 63 microns was analyzed by Andreasen settling tube test.

6.2 Concentration and settling velocity analyses

Samples were collected as a part of the routine gauging, as well as during several of the special surveys. In the course of the project, a total of 16209 samples was analysed:

9850 concentration analyses of suspended sediments;
668 grain-size distribution tests of suspended sediments;
4886 grain-size distribution tests of near-bed sediments (by Helley-Smith sampler or Delft bottle);
805 grain-size distribution tests of riverbed sediments.

The results are presented in the RSP Data Books in different ways: (1) As direct results in the form of concentrations and grain-size distributions, (2) as sediment transport rates determined by the transport method (by Delft bottle), and (3) as sediment transport rates (and

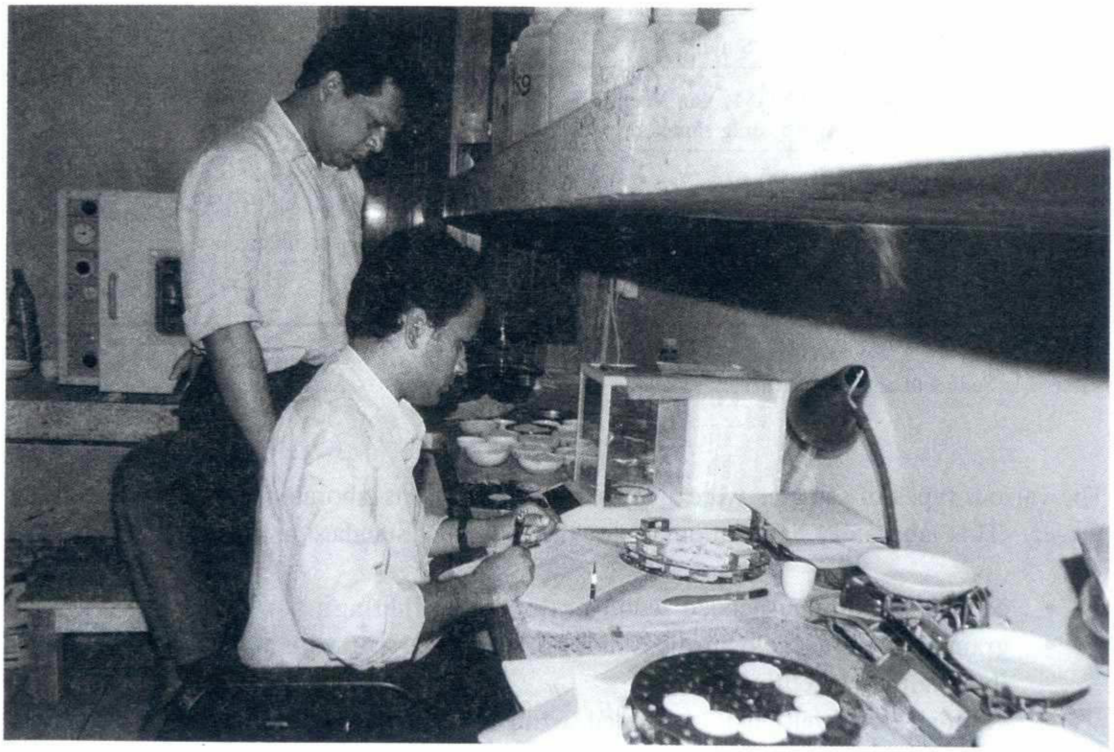


Figure 6.1: Staff at work in the sediment laboratory

cross-sectional distributions) determined by the concentration-velocity method, where the results have been combined with the current-velocity measurements. Also, the results are stored in the RSP database, see Section 8.4.

6.3 Mineralogical composition and physical properties

In close coordination with RSPMU, a programme was framed and executed for determination of the mineralogical composition and physical properties of river sediments. This activity was of a particular interest, since beforehand only scarce information was available for the Bangladeshi rivers.

Samples from Teesta, Brahmaputra, Upper and Lower Jamuna, Gorai, Meghna, and two locations in Padma River were collected for the purpose. Also, some samples were collected on the flood plain. A total of 170 river samples were collected on two occasions, before and after the 1995 flood season, and 33 flood plain samples (including vibro-core samples) were collected after the 1995 flood. Some samples were subjected to a 'full analysis', and some to a 'limited analysis' as shown in Table 6.2.

The grain-size analyses were carried out at the RSP laboratory, whereas the other analyses were made at the laboratories of Geology and Soil Science Department, Dhaka University. Approach and results are described in *RSP Special Report 14: 'Mineralogical and physical properties of river sediments'*.

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

Table 6.2: Analysis of mineralogical composition and physical properties of sediments

7 Data flow and data processing

This chapter gives an outline of the data flow and data transformation from the sensors of the different instruments to the storage of the data files.

7.1 Rationale

7.1.1 General

With the set-up chosen, most of the RSP field measurements generated electronically digitized (computer) data, which were called 'raw data', and which needed supplementary (and comprehensive) off-line data-processing prior to their use for the different intended purposes.

The following types of survey activities produced data to the RSP data processing office:

- Water-level recordings (Section 5.3);
- Flow recordings for routine gauging (Section 5.4);
- Sediment sampling for routine gauging (Section 5.4);
- Bathymetric surveys (Section 5.5.1);
- Char topography (Section 5.5.2);
- Special (non-routine) surveys (Section 5.7).

During the processing, around 14 gigabytes per year of raw data were converted into around 3 gigabyte per year of processed data.

The on-line data processing took place onboard each survey vessel. It comprised logging of signals from the positioning system and from the various sensors, on-line monitoring of the data collection, and generation of composite data files.

The off-line data processing took place in the River Survey Project's office in Dhaka. It comprised data conversion and compression, calculation of flow and sediment transport rates and distributions etc., plotting for preliminary quality check, subsequent data reporting, and listing of files in the data catalogue. After processing, the water-level data were stored within the framework of the HYMOS software system, whereas all other data were stored in a database called PSD24 (Processed Survey Data of FAP24). (Please refer to Section 8.4 for a brief description of the data storage).

The processing of each type of data was carried out by a dedicated combination of standard methods and techniques, developed for the specific purpose as a part of the River Survey Project. An outline of the overall data flow is presented in Figure 7.1.

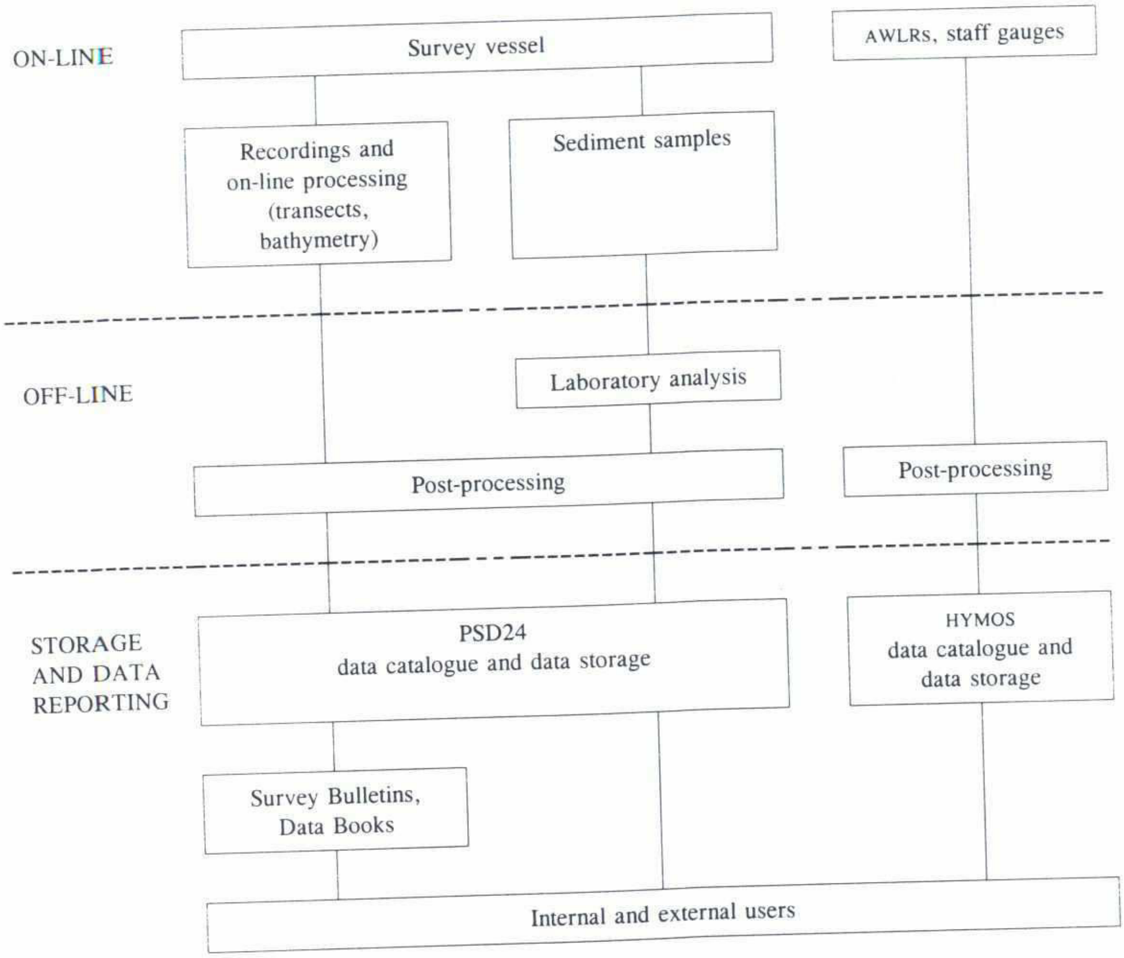


Figure 7.1: Data flow summary

Activity	Typical raw data volume
One vertical profile, routine gauging	0.1 Mb
One flow transect, routine gauging	1 Mb
One entire routine gauging	10-15 Mb
1 km of bathy survey line	3 Mb
Entire RSP	28 Gb

Table 7.1: Raw data volumes

7.2 Data flow summaries

7.2.1 On-line processing

The framework for the primary data logging and the on-line data processing is shown in Figure 7.2. In brief, the system was formed by the following components:

- The HYDRO system, which had three functions: Position control (by DGPS, and relative to pre-defined survey runlines), position data logging, and bathymetry (echo sounder) logging. Results were stored in HYDRO data files. These results were the 'final' raw data for bathymetric surveys, while they were transferred as intermediate results to the ACQ system during routine flow and sediment transport gauging;
- The ADCP system, which executed ADCP data logging. Results were transferred to the ACQ system;
- The S4 system, which executed S4 (and turbidity sensor) data logging. Results were transferred to the ACQ system;
- The ACQ (data ***acq***uisition) system, which received data from the HYDRO, ADCP, and S4 systems, and which generated composite flow transect data files.

Both the 'final' and the intermediate data files were stored on tape for subsequent postprocessing.

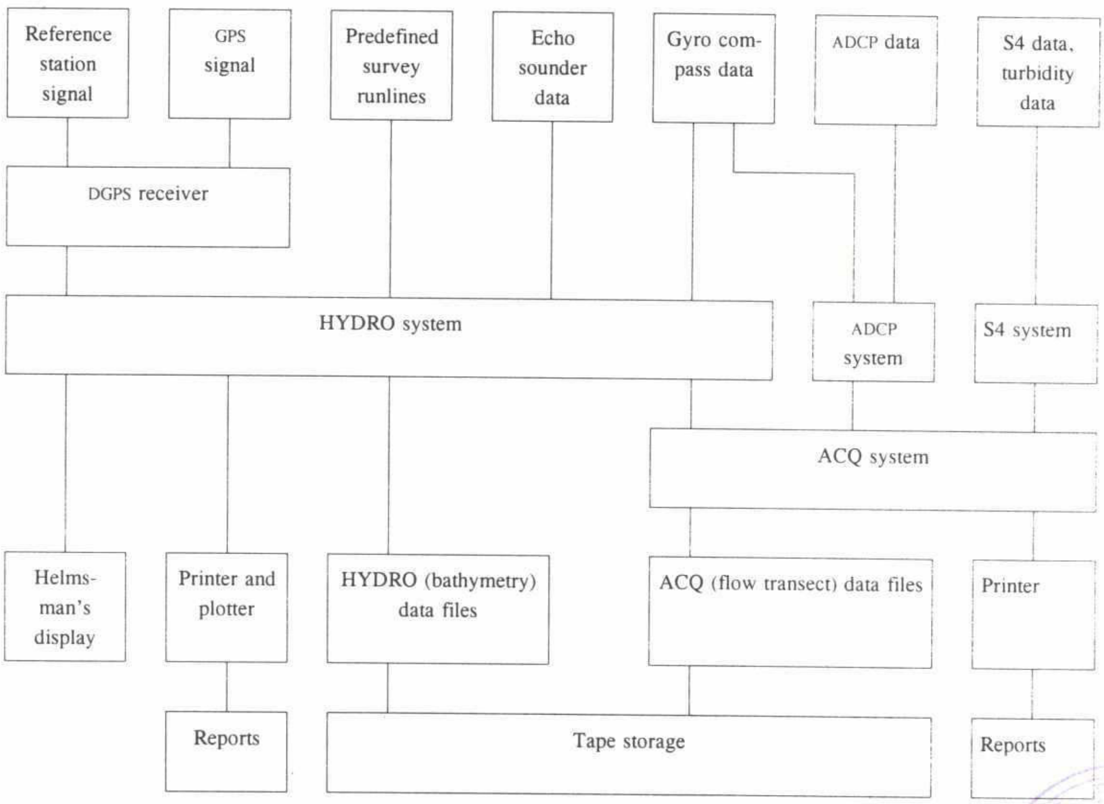


Figure 7.2: On-line data flow

7.2.2 Water-level recordings

The processing of the water-level data is illustrated in Figure 7.3.

Routine quality check of AWLR data comprised three steps:

- automatic control of the physical limits of the data;
- automatic control of the time window of the data;
- examination of difference between AWLR data and staff gauge readings, plotted as a time series: Spikes, steps, trends.

If there were discrepancies, it was sometimes possible to make a correction, or the AWLR data might be replaced by staff gauge readings for some time.

Following conversion and initial processing, the data were further validated by consistency analysis, which involved examination of hydrographs, stage-discharge relationships and inter-station comparison.

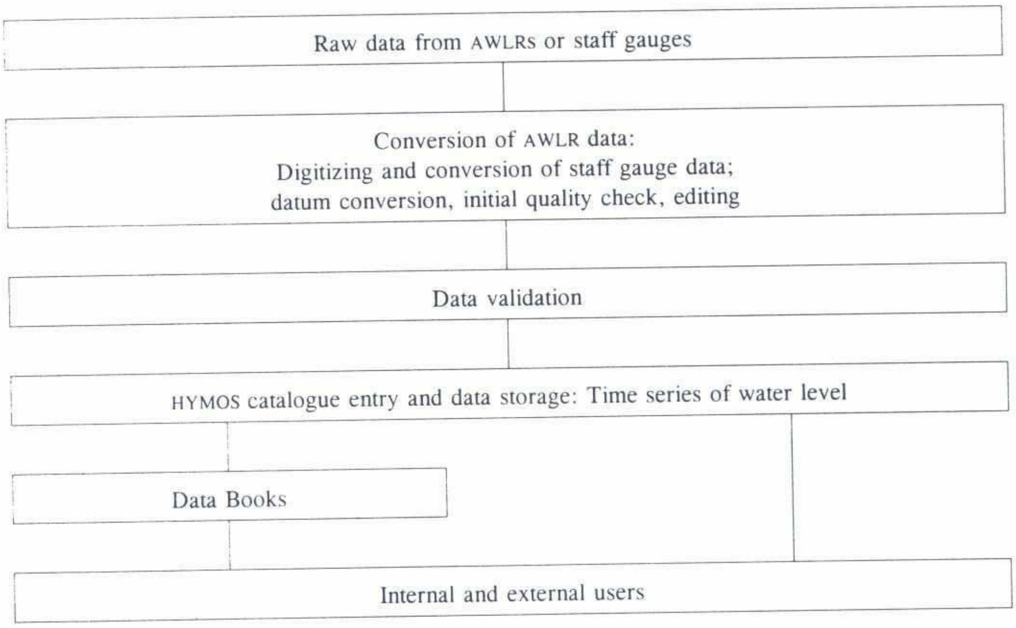


Figure 7.3: Processing of water-level data

7.2.3 Routine flow gauging

The routine gauging comprised measurements of flow and sediment transport. These recordings formed an integrated activity, but the data processing procedures were different. Each single transect produced around 1 Mb of raw data, and each individual vertical profile produced around 0.1 Mb of raw data. Hence, a typical routine gauging would produce somewhere around 10-15 Mb of raw data for each survey at each location, and sometimes more. (This may be compared with the data generation of a traditional velocity-area flow gauging, which, in case of 20 verticals and 2 current recordings per vertical, will produce around 1 kB of data).

All raw data were catalogued and stored at the data processing office.

The processing of the raw data from the field comprised file conversion and a drastic data reduction. Selected cross-section transects and all individual profiles were plotted for quality check and subsequent data reporting. All processed data were entered into the PSD24.

An outline of the entire processing of the flow recordings for the routine flow and sediment transport gauging is given in Figure 7.4.

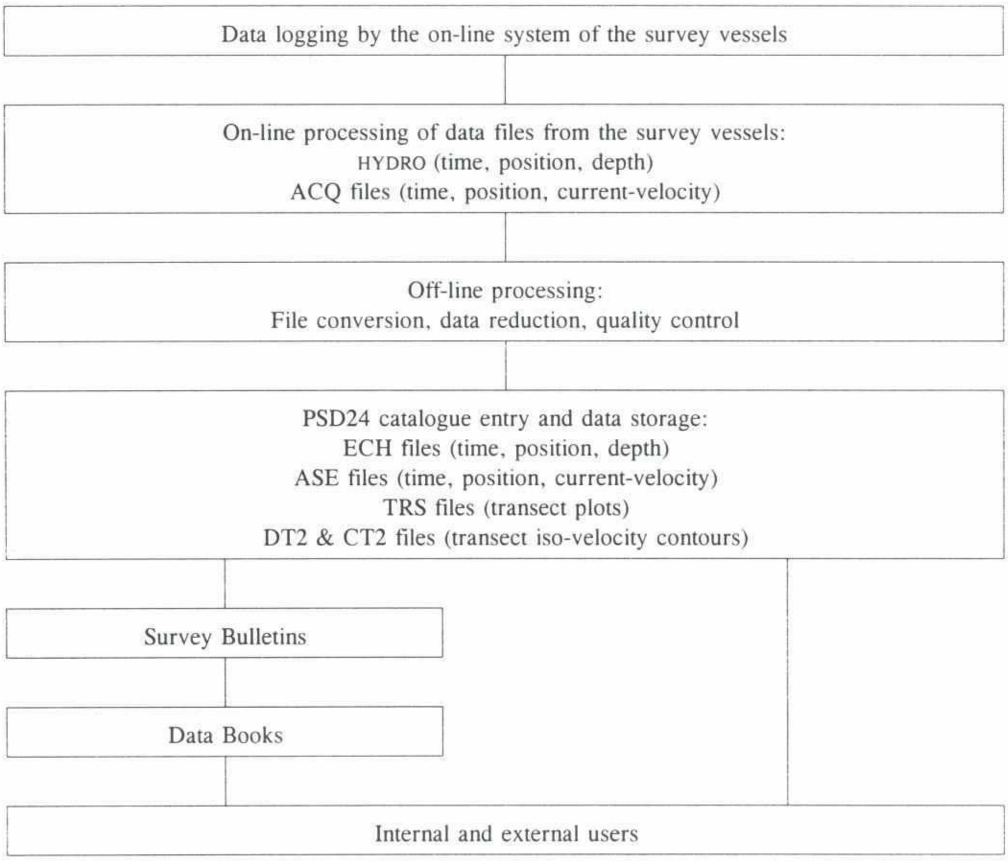


Figure 7.4: Processing of flow data of routine gauging

7.2.4 Sediment sampling for routine gauging

In addition to the flow recordings, the routine surveys 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.

For these purposes, the routine gauging comprised collection of a variety of sediment samples, as described in Chapter 4, Section 4.4. The samples were analyzed as described in Chapter 6, and results of the analyses were used for calculating the transport rates, hereby also using the simultaneous current-velocity recordings. The processing of the sediment data of the routine surveys is shown in Figure 7.5.

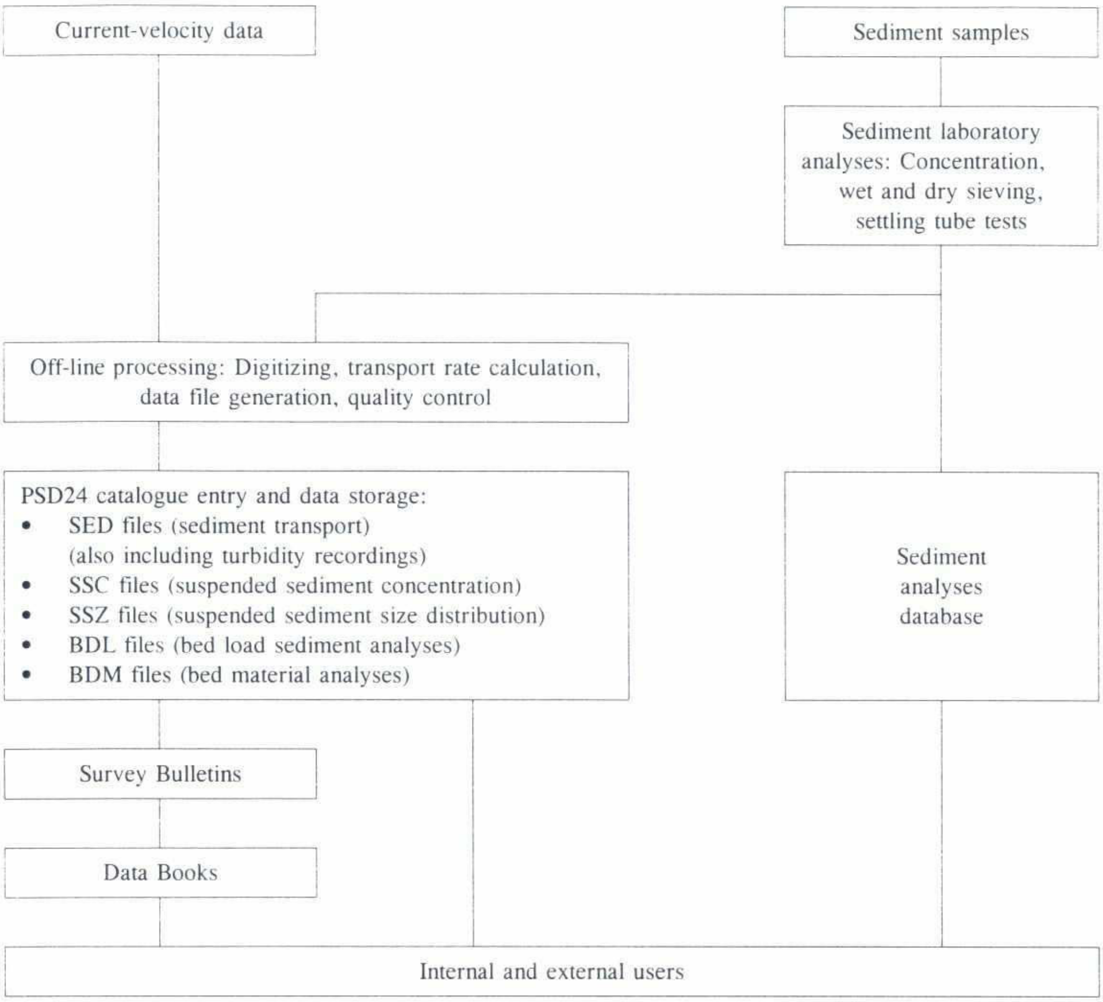


Figure 7.5: Processing of sediment data of routine gauging

7.2.5 Bathymetric surveys

The bathymetric surveys produced as much as up to 30 Mb of raw data per km² of survey (which is 10 km survey line at a line spacing of 100 m).

In the field, the measurements were controlled with respect to position and area coverage (by plotting and monitoring the survey lines). Occasional DGPS instabilities, which might result in an apparent abrupt position shift, were labelled for correction later on. Also, the depth recordings was monitored on-line, and irregularities, if any, were identified and labelled.

The raw data were prepared for interpolation by applying error checking and datum reference conversion procedures. Error checking was done partly automatically and partly manually. Error checking software routines, developed by the project, were used to locate data spikes and other suspicious data, characterised by for example abrupt depth changes or completely constant depths. While some data items could be automatically discarded or edited, or at least automatically identified and labelled for subsequent manual checking, other data must be visually inspected to determine whether they made sense or not.

In some cases, discontinuities remained that were not caused by errors, but which reflected a rapid change of the riverbed level in the course of the survey. This type of discontinuities occurred in connection with high flows, when the field work had, for some reason, to be discontinued for a while, or at interfaces between results from different river sections or channels that had, for practical reasons, to be surveyed with a certain time interval.

The raw data files were converted into processed data files at the data processing office. Hereby, the recorded depths were converted into riverbed levels relative to the applied datum (which is SLW = Standard Low Water). The conversion was a function of time and space, as determined by water-level recordings from the survey area relative to a position where the datum is known.

The bank line was specified, and the data were inspected once again for position and riverbed level irregularities by plots or on the computer screen.
The results were presented as follows:

- Bathymetry charts, which show survey lines and soundings along the lines to the extent possible at the selected scale
- contour plots, based on interpolated arrays of riverbed levels, by application of a smoothing of the contours

The two types of presentations are exemplified in Figure 7.7.

The processed bathymetry data were stored in two types of data files: One file type, the so-called SLW file, contains xyz-sets of position and riverbed level along the survey lines. Another file type contains riverbed levels for the entire survey area in a fixed (50 m by 50 m) grid, which is established by bilinear interpolation of the measured values. The former file type is big, and one survey area will normally comprise a large number of files. The latter file type is convenient for certain types of analyses, such as contour plots, 3-D plots, and calculation of volumetric differences between successive soundings.

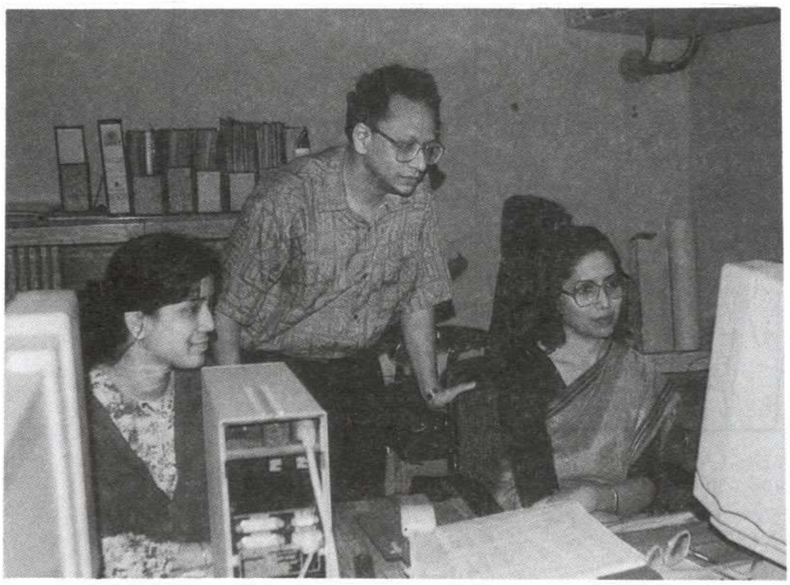


Figure 7.6: Staff at work in the data processing office

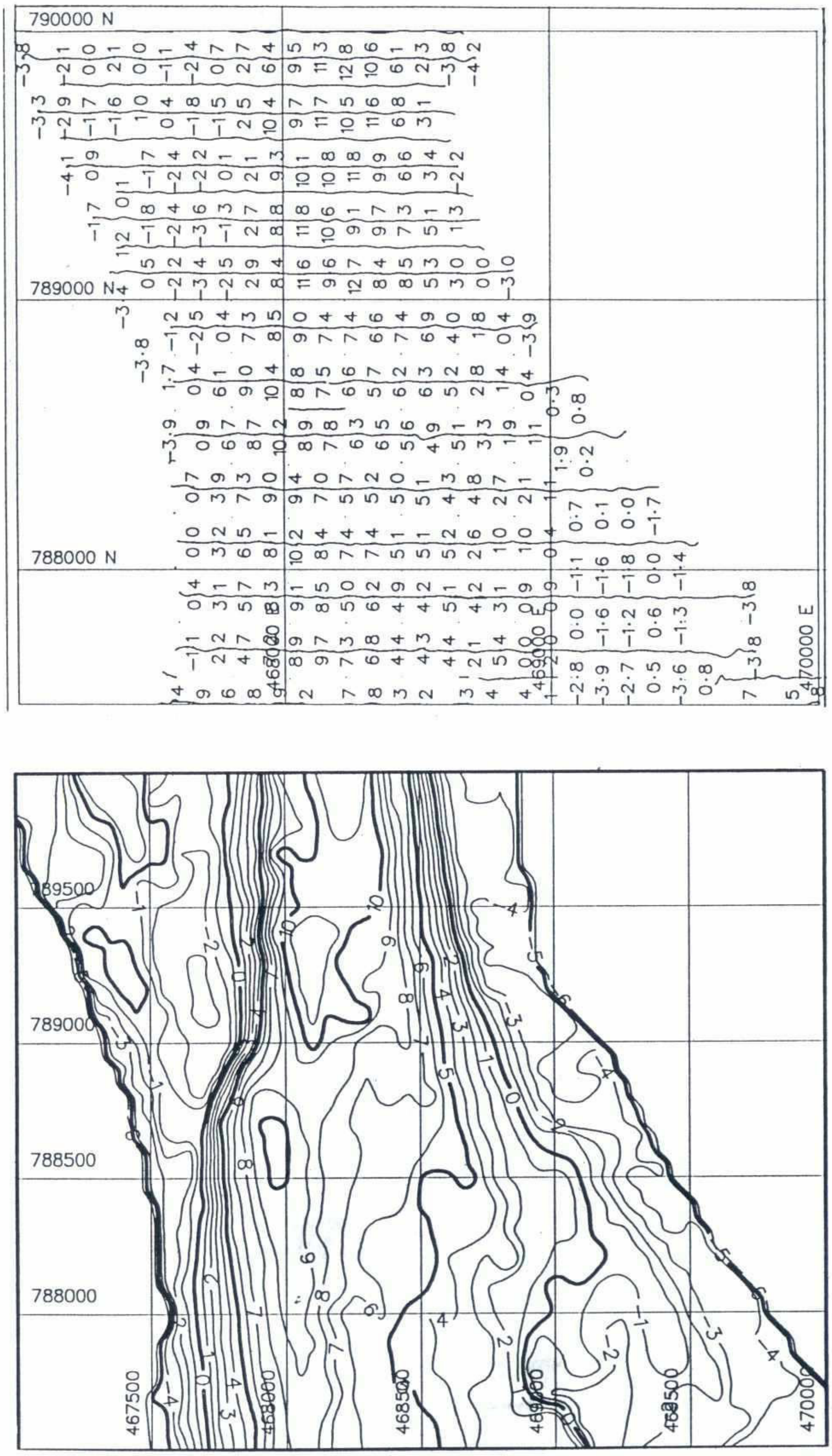


Figure 7.7: Bathymetry chart and contour plot (example, Bahadurabad, flood season 1993)

The processing of bathymetry data is illustrated in Figure 7.8. For details about the processing routines, please refer to *Survey and Study Report 9: 'Bathymetric pilot surveys on Jamuna River at Bahadurabad'*.

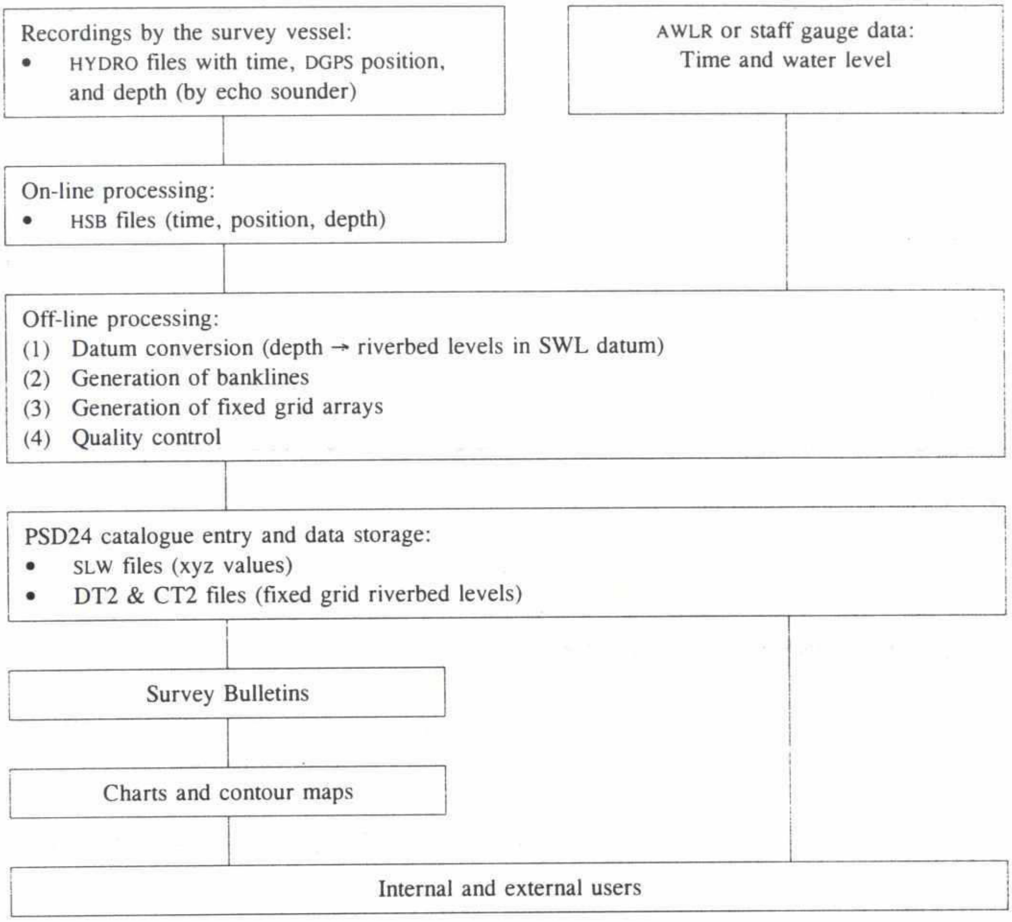


Figure 7.8: Processing of bathymetry data

7.2.6 Special (non-routine) surveys

Many of the special surveys consisted of elements of the routine gauging. This was for example the case with the additional flow measurements at Bahadurabad, which were carried out in exactly the same way as the flow measurements of the routine gauging. In such cases, the data processing followed the routine procedures as described above.

When a special survey comprised activities that were different from the ones of the routine gauging, dedicated procedures for the data processing were established in a dialogue with the study team and the PA, and were applied in accordance with the objective of that survey.

7.3 Data processing facilities

The data processing office of the River Survey Project undertook off-line data processing, production of Survey Bulletins, and operation of the PSD24 database and the LAN network. Hardware facilities for data processing are listed in Table 7.2. All internal users were connected with the HYMOS package and the PSD24 by the LAN network for convenient downloading of data for secondary analysis in connection with the different study activities.

Off-line data processing and survey bulletins

- 1 UNIX server, 33 MHz, 16 Mb RAM, 1 Gb harddisk, 1 DAT tape drive, and 1 external CD ROM drive
- 1 UNIX work station, 33 MHz, 16 Mb RAM, 200 Mb harddisk
- 2 486 PCs, 16 Mb RAM, 200 MB harddisk, and 1 486 notebook PC
- 2 DOS tape stations
- 1 A3 digitizing table
- 1 A0 plotter, 1 A3 plotter, and 1 laser printer

PSD24 operation

- 1 UNIX server, 66 MHz, 16 Mb RAM, 2x1 Gb harddisk
- 3 486 PCs

Table 7.2: Hardware for data processing

7.4 Data processing software

Water-level data were processed, analyzed, presented, and stored using the HYMOS software package for data administration of hydrological time series (see Section 8.4).

Post-processing of data from the routine flow and sediment transport gauging took place in two steps:

(1) primary data processing and presentation;
(2) generation of composite data summary files for the PSD24 database.

Following primary file conversion, with calculation of distributions of flow and sediment transport, compilation and datum conversion of bathymetry files, etc., presentations were made by a standard (Quattro Pro) spreadsheet programme and by modules from the MIKE21 Pre- and Post-processing software package, which were used for presentation of contour plots (of cross-sectional flow distributions and bathymetries).

The PSD24 data files were produced by various utility programmes. The files were presented and stored using a standard (Quattro Pro) spreadsheet. Also, sediment data were processed, presented and stored in a standard (Quattro Pro) spreadsheet.

Bathymetric plots were produced by three software routines within the UNIX environment:

- The Consultant's utility program SCAN was used to produce maps of the echo-soundings. This program served a dual purpose: It was used for the visual inspection of the data for the sake of quality checking, and it also produced the sounding charts;
- M21DIGI (from the MIKE21 software package) was used for schematization of the prepared raw data into a fixed grid;
- T2PLOT (also from the MIKE21 software package) was used for contour plots based on the fixed grid data.

7.5 Quality control

The data quality control comprised (1) on-line control, (2) off-line control, and (3) user control.

In the three stages, various types of errors and deficiencies were monitored, according to the increased aggregation of information from different periods of time or from different sources.

The on-line control was an integrated part of the survey procedure. It comprised the survey documentation, the basic data coverage, the immediate data consistency, and obvious measurement errors. Errors and deficiencies to be detected included for example improper performance of instruments or of the on-line data processing system; inconsistent recordings, such as for example instantaneous position shifts; or identification of unusual recordings, where values were beyond an expected range. The on-line control resulted in reporting of actual or potential deviations, and could prompt an immediate decision to repeat a suspect measurement.

The off-line control was an in-depth examination of the results, which normally involved examination of a graphic presentation of data from one or more sources. Inter-station comparison was a common tool, where it for example was checked whether some unusual stage fluctuation occured at one station only, or whether the pattern appeared in several independent records.

This exercise could be quite time-consuming. For example, a bathymetric survey may display an unusual steep slope between two successive soundings. This may be due to either an error, or due to a true, but extreme bed level variation. An evaluation could involve an examination of the specific survey line, whereby erroneous spikes could be identified, or adjacent survey lines had to be compared in order to find out whether an unusual feature was reflected in independent recordings. This is illustrated in Figure 7.9, which shows a plot of depth differences as determined by two succesive bathymetric surveys. Certain types of errors (if any) will appear clearly on this type of plot, but will be less evident when one mapping is scrutinized independently.

The final routine data validation took place during the associated activities of preparation of the Survey Bullletins and the PSD24 data files. Here, the contents of the data files and their labelling and documentation were checked for consistency and completeness, against the Survey Reports prepared in the field, and against SPOT images and previous surveys at the same location. The validation was carried out according to a check list which is summarised in Table 7.3.

Similarly, certain errors became visible during comparison between hydrographs from adjacent stations, or during derivation of a stage-discharge rating curve.

The data quality control is a process that continues for as long as the data are being used, and some errors or deficiencies will inevitably remain after post-processing and data reporting. For example, during a calibration of a hydrodynamic model, small errors within stage levels or phase lags can be detected that could not have been identified in any other way.

During the project, to make sure that no data was lost, all data was stored on DAT tapes. Raw data was stored in duplicate, whereas of the processed data one copy was stored (this information could be re-established, if the need would arise).

General:	• Completeness; missing pages, x- and y-axes of graphs, captions • Consistency of filenames • Consistency of cross-section areas, water levels, flow, suspended sediment transport, bed load transport • Total number of measurements indicated in Summary Table • $D_{35} < D_{50} < D_{65}$
Location map:	• Date of map versus date of survey • Scale bar • RSP and BWDB staff gauge locations • Position of all transects • Width(s) of transect(s)
Cross-section:	• Width(s) of transect(s) • Depths (as compared with echo sounder plots in Survey Reports) • Consistency of depth indications • Left bank $<>$ right bank
Key figures:	• Check extent against field sheets • Check water levels
Horizontal distributions:	• Transect azimuth/definition sketch • Whole graph reversed? • Left bank and right bank distances • General flow direction, versus (1) river planform, (2) definition sketch, (3) echo sounder plots from Survey Report • Consistency with (1) SPOT image, (2) previous survey at same location • Spikes • Unmeasured parts (versus PSD24 information) • General sediment transport pattern versus general flow pattern • Are high sediment cathes reflected? • $S_{total} = S_{wash\ load} + S_{suspended\ bed\ load} + S_{bed\ load}$? • Measurement locations verus vertical locations • Consistency of D_{50} values
ADCP/iso-velocity plots:	• Readability of contours and numbers • Contours touching the bottom or crossing each other • Unmeasured parts • Consistency with (1) SPOT image, (2) previous survey at same location
Sediment data:	• Sampling times and depths (against field sheets)
ADCP transects:	• Selection and indication of transect for PSD24 • Times and file names (against field sheets) • Miscellaneous notes under each table
PSD24 file list:	• Completeness • File type

Table 7.3: Data validation check list (simplified)

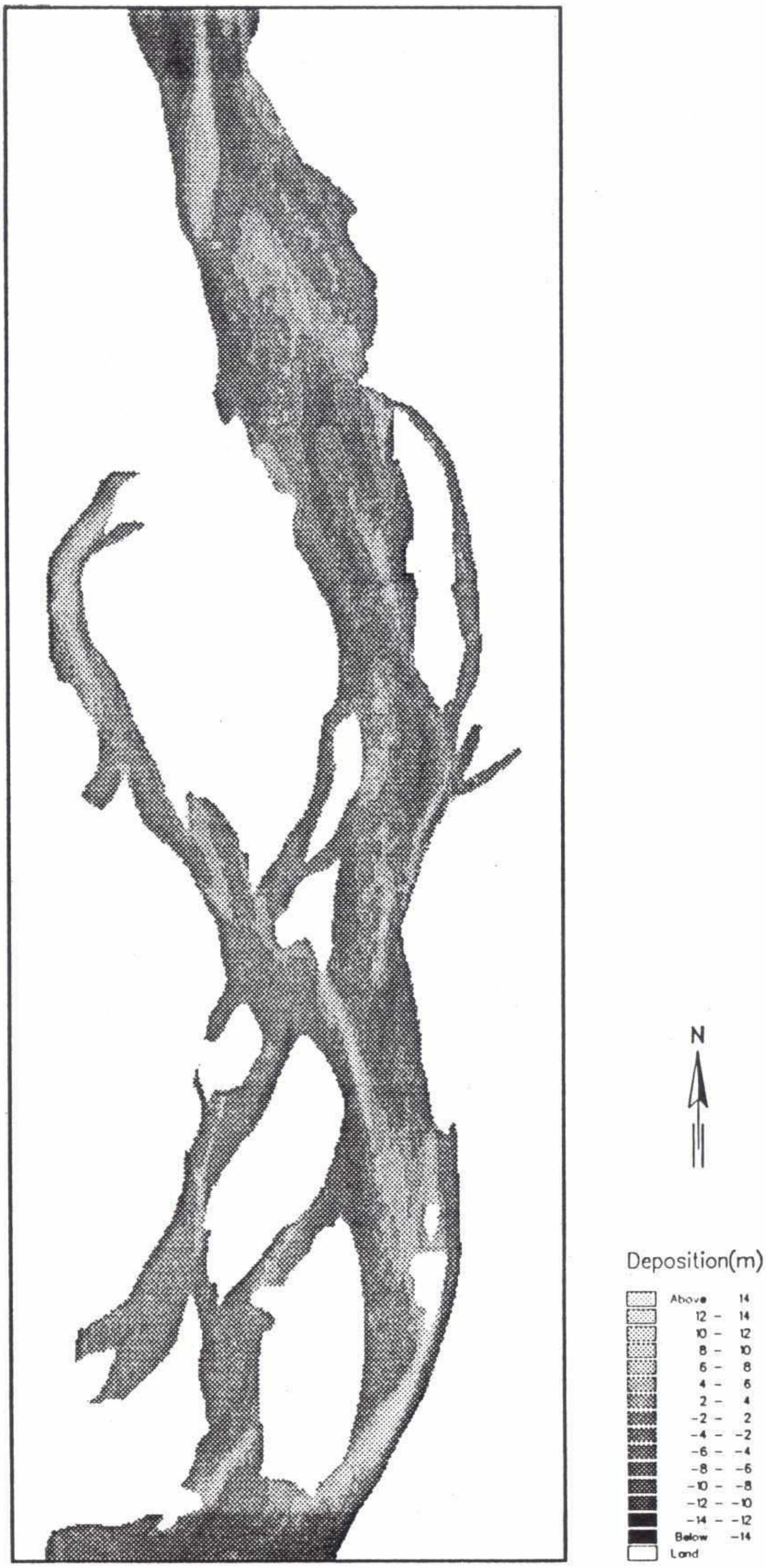


Figure 7.9: Plot of difference between riverbed levels
(example, Bahadurabad, August and November, 1993)

8 Reporting and data storage

8.1 Rationale

The final reporting of the River Survey Project was arranged in two main sections:

- General project reporting
- Data reporting

Each of these lines is formed by a hierarchy of reports, reflecting an increasing degree of synthesis.

This chapter gives an outline of the reporting structure and of the documentation of the findings of the survey component of the RSP, both with respect to the experience gained and the data produced.

8.2 General reporting

The structure of the general reporting of the RSP survey component is illustrated in Figure 8.1.

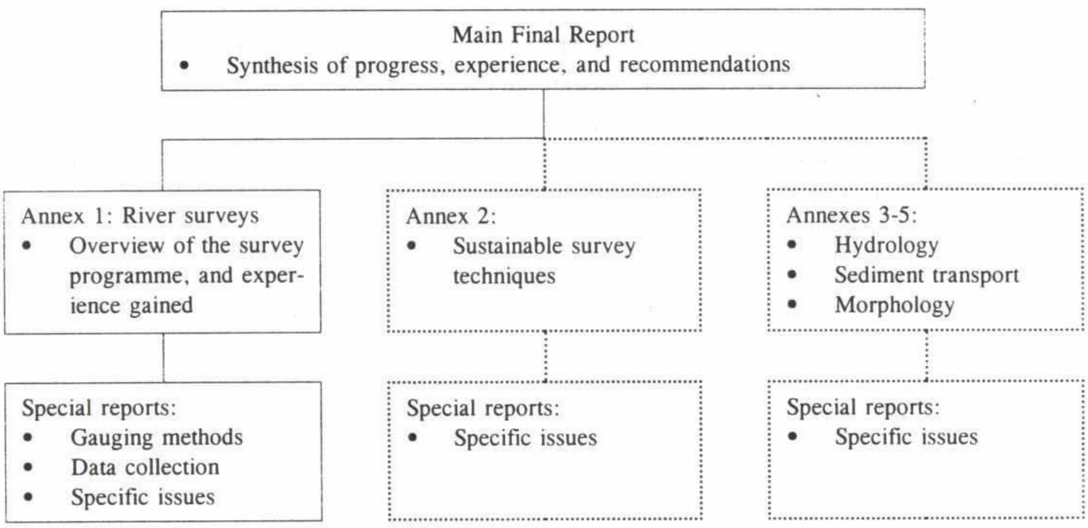


Figure 8.1: General reporting of the RSP survey component

From one point of view, all reports of the project are in some way related to its survey component. Notably, as indicated by the references given throughout this report, several study activities have directly addressed (and reported on) specific survey or monitoring aspects, data analysis procedures, and recommendations on optimization of field data collection. The ones that are most directly related to the field surveys are included in the reference list of the present report.

8.3 Data reporting

The structure of the data reporting of the RSP is shown in Figure 4.2.

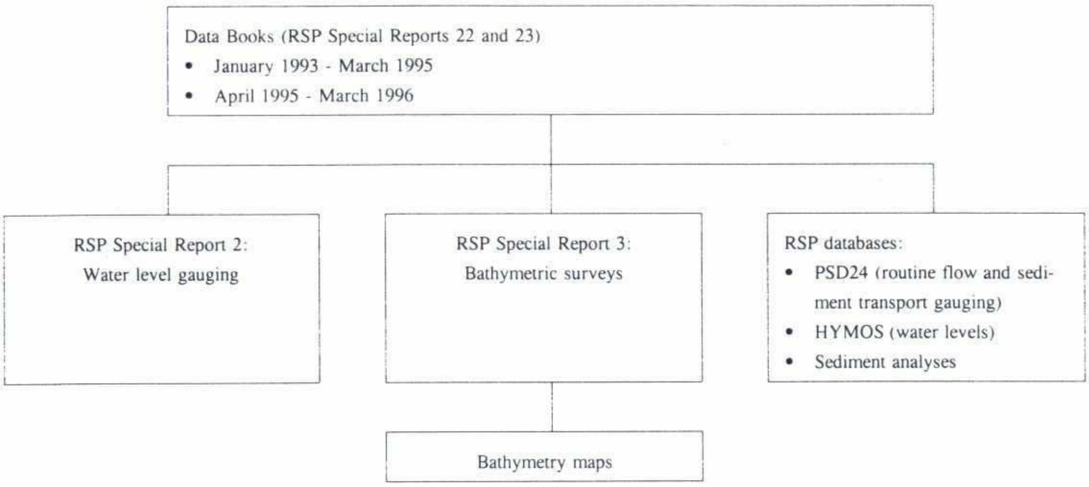


Figure 8.2: Data reporting of the RSP

The ordinary data reporting comprises the following:

- Data Books (water-level data and extracts of routine flow and sediment transport gauging)
- Survey Bulletins, basic series (routine flow and sediment transport gauging)
- Survey Bulletins, 9000-series (special surveys)

One Survey Bulletin was issued for each survey. They served the temporary purpose of progress reporting, and were subsequently fully incorporated into the Data Books.

At the initiative of the PA, the format of the basic series of Survey Bulletins was changed by the end of March 1994, Survey Bulletin 48 being the first one in the new format. The reason was that the bulletins had become too bulky. At the same time, the new format was made compatible with the PSD24. The new bulletins provide an outlook of the gauging conditions, provide an extract of the findings, and supply a catalogue reference to the data files, rather than presenting the detailed results in their entirity.

All data, excluding part of the special surveys, have been published in two RSP Data Books: One covering the period from January 1, 1993 to March 31, 1995, and the other one the period from April 1, 1995 to March 31, 1996. These Data Books with their annexes describe:

- The overall approach and progress, at an introductory level;
- Where and when the measurements were carried out;
- A brief extract of the findings, as a documentation of the prevailing conditions, rather than intended for direct use. An example of a part of this extract is given in Figures 8.3 and 8.4 (which origin from one of the Survey Bulletins);
- Full data file catalogue listings.

In general, the person who would like to use the data for some purpose would need (1) the Data Books, and (2) access to the database. The database is largely self-explanatory, so for many purposes, it can be used also without cross-reference to the Data Books.

Type of measurement	Method	No. of measurements in channel 1	2	3	4
Discharge	ADCP transect	7	4	4	-
	EMF transect	-	-	-	-
	Echo-Sounding	-	-	-	-
Vertical current profile	No.of verticals in channel	10	3	8	-
	ADCP	10	3	8	-
	S4 current meter	1	1	1	-
	Ott current meter	-	-	-	-
Vertical sediment profile	Pump bottle sampling	6	6	6	-
	Andreasen settling tube	-	-	-	-
	MEX turbidity meter	-	-	-	-
	Integrated bottle sampling	10	3	8	-
	Collapsible bag	-	-	-	-
Bed load	Dune tracking	-	-	-	-
	Helley-Smith sampler	2	2	2	-
	Delft Bottle	19	6	15	-
Bed material	US BM-54 bed sampler	-	-	-	-
	Van Veen bed sampler	-	-	-	-

Table 2.1: Survey programme as made

Channel	Width (m)	Area (m^2)	Stage h (m+PWD)	Discharge Q (m^3/s)	Bed load transport Sb (kg/s)	Suspended Sedimen transport Ss total (kg/s)
Channel 1	3774	20804	19.15	36675	3468 *	32265
Channel 2	770	1968	18.89	2465	357 *	1780
Channel 3	2552	11983	19.02	10038	712 *	6388

Table 2.2: Key figures

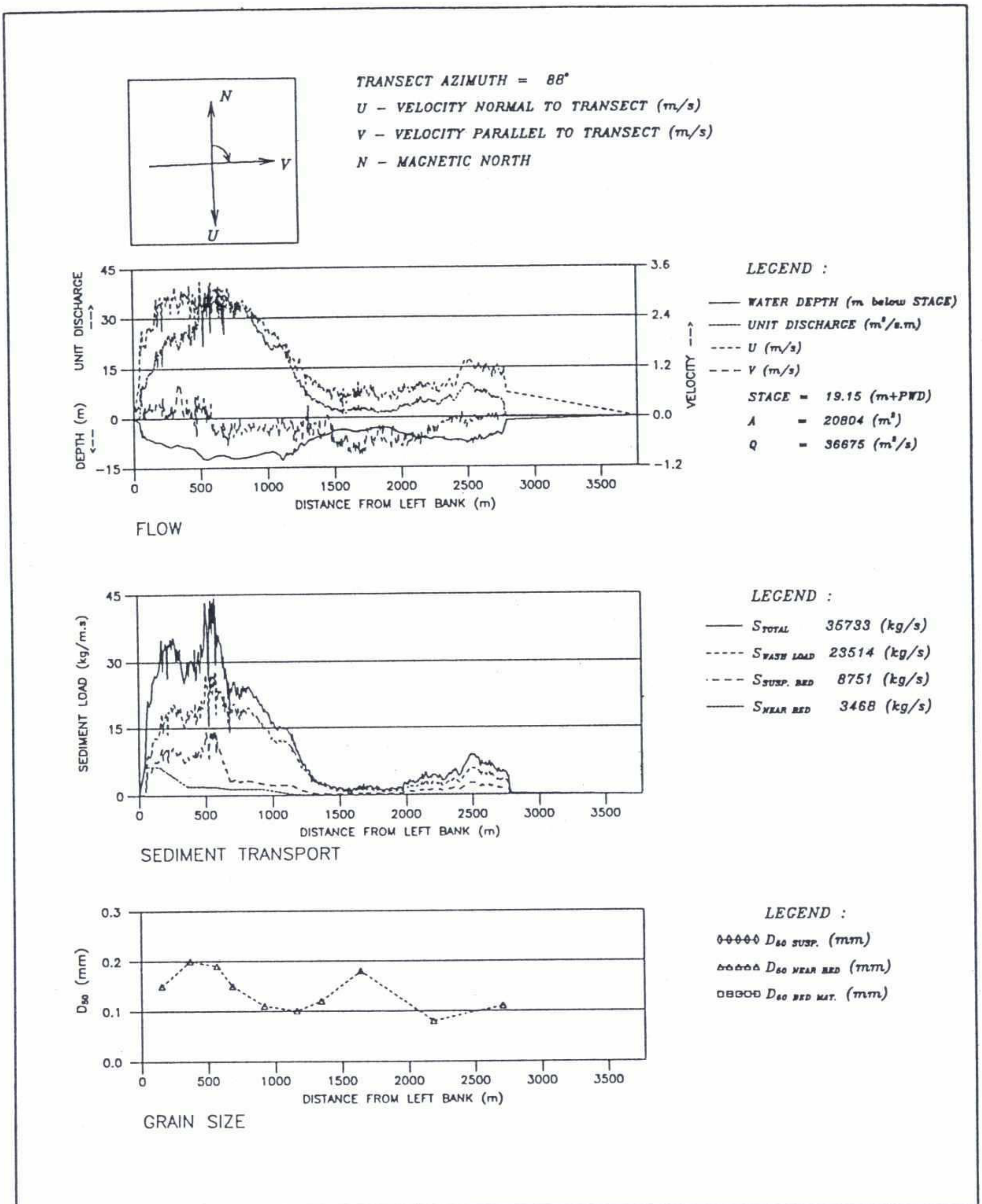
* based on Delft bottle measurements

Gauge Location	Channel	Date	Water level (Daily average) (m+PWD)	Gauge
Bahadurabad	Channel 1	21 Jul 95	19.15	FAP 24
		23 Jul 95	19.09	
	Channel 2	25 Jul 95	18.89	
	Channel 3	24 Jul 95	19.02	

Table 2.3: Water-Levels

FAP 24 DELFT · DHI — RIVER SURVEY PROJECT	Survey Bulletin 174 : 21 - 25 July, 1995	
	Location 1 : Jamuna River, Bahadurabad	
File : B57L1T03 B57P1T01 B57O1T02 — Date : 16 Nov 1995 — Init : mzh/sjr	Survey programme as made and key figures	page 2.1

Figure 8.3: Summary of data collection for a routine flow and sediment transport gauging (example)



FAP 24 RIVER SURVEY PROJECT Flood Plan Coordination Organization Commission of the European Communities		Survey Bulletin 174 : 21 - 25 July, 1995	
		Location 1 : Jamuna River, Bahadurabad	
File : B57L1T03	Date : 16 Nov 1995	Horizontal distribution of flow and sediments	page
	Init : sjr/mzh	Channel 1	3.1

Figure 8.4: Summary of data presentation for a routine flow and sediment transport gauging (example)

8.4 The River Survey Project database

8.4.1 Rationale

The RSP database comprises three components:

- HYMOS: Water-level data;
- PSD24 (= Processed Survey Data of FAP24): Results of the routine flow and sediment transport gauging;
- Primary sediment analysis data. Although incorporated in an aggregate form in the PSD24, the individual analyses contain much information that may well be of interest for certain applications.

The database has been arranged in three separate databases, rather than implementing one single system, because of the many different short-term and potential requirements of internal and external users. The PSD24 was developed for the purpose of the RSP. It contains highly synthesised data on the one hand, and big primary data files on the other. Here, its direct use is subject to its inherent specific information compression and presentation procedures, whereas its use for non-routine purposes will normally require an alternative, supplementary post-processing, simply because of the large data volumes. Otherwise with the water-level data: These are not excessively voluminous, and most analyses are made by well-established tools. Hence, the HYMOS system, a standard software package of DELFT HYDRAULICS was a good choice for this purpose.

8.4.2 HYMOS

The HYMOS system comprises both the water-level data and the tools for their analysis and administration:

- data files (time series of water level);
- data administration routines: Data entry, validation and de-bugging, editing (merging, interpolation, averaging, transformation), data storage;
- software routines for hydrological calculations: Velocity-area flow calculation, rating curves and rating curve validation;
- software routines for statistical analyses: Correlation analysis, distribution analysis, extreme value analysis;
- data presentation routines: Time series, x-y plots, statistical plots.

Refer to Table 8.1 for an introductory description of the system. For details, please refer to the HYMOS Manual (Version 3.00, DELFT HYDRAULICS 1992).

Operating system:	DOS	
Data file types:	Data catalogue Water-level data files	(file index) (time series)
Facilities:	Analysis:	data debugging and conversion time series analysis correlation analysis distribution analysis extreme value analysis file format conversion
	Data presentation:	time series, x-y plots, statistical plots
Required storage:	Software system: RSP water-level data files:	12 Mb 2 Mb

Table 8.1: The HYMOS database

8.4.3 PSD24

The PSD24 system comprises

- The Paradox data catalogue (primary data files and processed data);
- data files (processed data only);
- a Quattro Pro spreadsheet programme for analysis and presentation of processed files.

Specifications for the PSD24 were drafted in April-May 1994, and in the following months were reviewed in a dialogue with the PA, BWDB, and internal users in the following months. Some consideration was given to the choice of the basic operating system, weighing the performance requirements against the convenience for the users. The UNIX-based (Oracle) database that was established in Phase 1 of the project had performed well, but had never been effectively implemented, because it was not readily accessible by the users; another aspect was the highly increased performance of DOS software that appeared in the period since the planning of the project. On the other hand, certain bulky data processing operations must necessarily be done in a UNIX environment due to capacity requirements.

Hence, it was decided to implement a DOS database, and Paradox 4.5 for Windows was selected for the purpose. Wherever possible, preference was given to an ASCII or a DOS standard spreadsheet file format. At the same time, the Ethernet LAN network of the data processing office was extended to cover all internal data users. Certain processing operations, such as conversion of raw transect data and all bathymetry data processing, remained within the UNIX environment.

The data catalogue comprises all data files of the routine flow and sediment transport gauging of the River Survey Project.

As regards the data files, the processed transect data are directly accessible via the database, while the primary transect data and the bathymetry data are not: These files are too bulky and are therefore not well suited for the DOS environment. The former categories of data are stored in Quattro Pro spreadsheet format, which can easily be converted into ASCII, if so required. These data files can be downloaded from PSD24 directly into a Quattro Pro spreadsheet, in which many types of analyses and presentations can be made.
A summary of PSD24 is given in Table 8.2. For details, please refer to *RSP Special Report 21: 'Guide to FAP24 databases'*, and to the PARADOX and Quattro Pro manuals.

Operating system:	**DOS**	
Data file types:	File catalogue	(PARADOX)
	Transect data files	(x-y data, Quattro Pro)
	Vertical profiles	(x-y data, Quattro Pro)
Facilities:	Analysis:	data file identification and retrieval correlation analysis distribution analysis file format conversion
	Data presentation:	time series, x-y plots
Required storage:	PARADOX:	16 Mb
	Quattro Pro:	13 Mb
	Data catalogue:	2 Mb
	Data files	750 Mb (routine gauging and special sruveys

Table 8.2: The PSD24 database

The catalogue structure and the various software routines were gradually established and implemented in August-September, 1994, and the system became operational in October, 1994. Debugging and adjustments of plotting routines continued until May, 1995. The PSD24 complied well with the requirements of the internal users, and it represents a good practical compromise between performance and accessibility.

8.4.4 Primary sediment analysis data

The results of the sediment analyses are of an intermediate character within the overall data flow, but are potentially of a much wider interest, because, as it is the case with other intermediate results of the field programme, they contain a lot of detailed information which is inevitably dimmed during the synthesization.

The sediment analyses are readily accessible, because they have been catalogued and stored in a standard (Quattro Pro) spreadsheet, from which they can easily be retrieved for various purposes. This set of spreadsheet files can be regarded as an independent part of the RSP database.

The sediment data storage is outlined in Table 8.3. The structure of the database is self-explanatory to the user, and is shown in Figure 8.5. Figure 8.6 presents an example of an analysis sheet from this database.

Operating system:	**DOS**	
Data file types:	File index	
	Data	(Quattro Pro)
Facilities:	Analysis:	data file identification and retrieval correlation analysis distribution analysis file format conversion
	Data presentation:	data listings, x-y plots
Required storage:	Quattro Pro (Windows):	13 Mb
	Data files:	173 Mb

Table 8.3: Storage of sediment analysis data

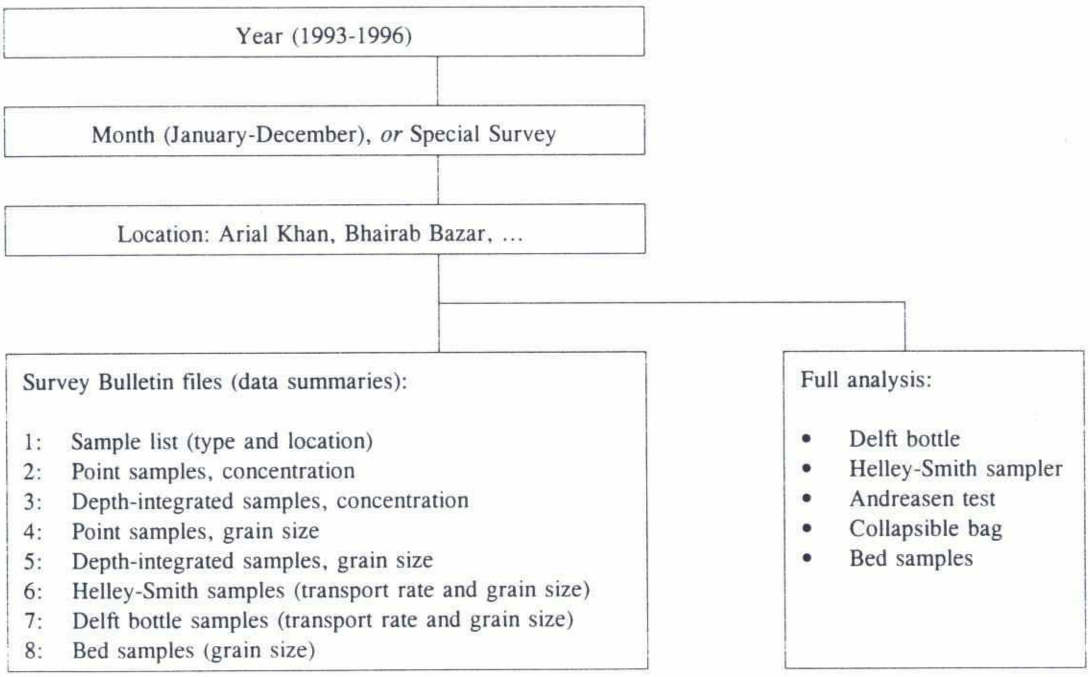


Figure 8.5: The RSP sediment database

RIVER SURVEY PROJECT FAP24 SEDIMENT LABORATORY

Sieve Analysis Of Bed Load

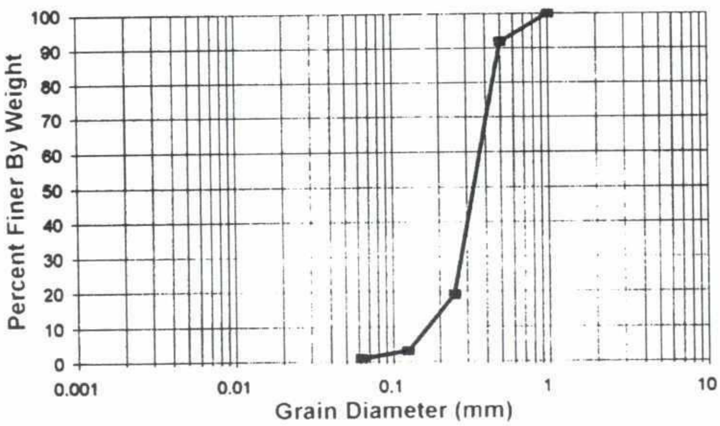
Study Survey

Sample No: A465

Wet/Dry:	Dry	Position:	E:470295;N:777506
River:	Jamuna	Vertical No:	1
Station:	Bahadurabad	Depth (m):	13.90
Collection Date:	30/05/95	Total Weight (g):	1900.0000
Collection Time:	11:35	Before Sieving Wt.(g):	50.5492
Sampler Type:	HELLEY-SMITH	After Sieving Wt.(g):	50.5175
Collection Period(s):	30	Loss(g):	0.0317
		Transport Rate (kg/(m².s)):	10.964912
		Correction Coefficient:	1.00

Sieve Size (mm)	Material (g)	Material (%)	Material <d (%)
1.000	0.0384	0.076	99.924
0.500	4.0353	7.988	91.936
0.250	36.7426	72.732	19.204
0.125	8.1326	16.099	3.105
0.063	1.1428	2.262	0.843
Pan	0.4258	0.843	-0.000

Vertical No.: 1
Sample No. : A465



D35 (mm)	D50 (mm)	D65 (mm)	Geometric Standard Deviation
0.291	**0.335**	**0.387**	**1.461**

D16 (mm)	D84 (mm)	D90 (mm)	D10 (mm)
0.218	**0.464**	**0.491**	**0.168**

ANALYSED BY : MM C:\1995\STUDY\MAY\BAHA\HELY-SMT\A465.WB1

Figure 8.6: Presentation of sediment analysis (example)

9 Specific issues

This chapter provides summarized elaborations of certain specific issues in connection with the river survey component of the Project: (1) tidal surveys, (2) measurements of overland flow, (3) measurements of floodplain sedimentation, and (4) sediment transport measurements by ADCP.

9.1 Tidal surveys

In the dry season, the astronomical tide from the sea can extend up to several of the RSP standard transects: Baruria, Arial Khan Off-take, and Mawa in the Padma River, and Bhairab Bazar Railway Bridge in the Upper Meghna. Dry season flow measurements in tidal reaches are of a considerable practical interest for many purposes, such as water resources planning of irrigation supply, environmental monitoring, and any other purpose that requires information about flow during low stages. These surveys address conditions where a single point stage-discharge relationship is ambiguous or undefined.

A number of pilot surveys of tidal-influenced flow was carried out by the Project, as listed in Table 9.1. The programme was planned in a dialogue with BWDB, and with the PA, who on several occasions discussed the significance and implications of these measurements (see for instance 11th PA Mission Report, Annex 1).

During these surveys, the flow was monitored over periods of 13 or 26 hours. Specific procedures were implemented that aimed at describing the time and space distribution of the flow in more detail than it was done during the routine flow gauging.

The surveys aimed at a providing an appropriate time resolution of the tidal flow and, at the same time, a reasonably detailed resolution of the cross-sectional distribution of flow and sediment transport. Two or three vessels were deployed for the purpose. One vessel was moving doing regular (hourly) flow and depth contour measurements along and across the river, while one or two vessels were anchored doing continuous single point (EMF) current-recordings, and regular (hourly) single vertical current-profiles by ADCP/EMF and S4. Also, the near-bed sediment transport was measured every hour by the anchored vessels, with Helley-Smith sampler and Delft bottle.

Bhairab Bazar (Upper Meghna)	26-28/4 1993 10-12/2 1994 18-19/3 1995
Baruria (Padma)	21/3 1994
Arial Khan Off-take (Padma)	18-19/4 1994
Mawa (Padma)	17-18/2 1995 30-31/1 1996 7-8/2 1996

Table 9.1: Tidal surveys

The latest surveys (in 1996) concentrated on Mawa, because previous measurements at this location were better suited for interpretation and for drawing conclusions regarding appropriate survey methods. In 1996, measurements were carried out both during neap and spring tide, and more emphasis was given to covering the entire cross-section with respect to sediment transport, by adding more verticals. In order to get an improved picture of the flow and sediment transport conditions at the time of the survey, the bathymetry survey area immediately upstream of the transect was extended to about 5 km downstream.

Results of the surveys were analyzed with respect to the time and space variation of the flow, hereby providing a basis for designing an appropriate gauging routine for later surveys, for example by a combination of single point current-measurements, continuous or discrete water-level measurements, and regular flow transect gauging.

Also, the measurements were compared with simultaneous measurements by BWDB. The standard tidal survey routine of BWDB comprises 15-hours measurements every two weeks.

It was concluded that surveys of this type are well suited for good estimates of the net flow, particularly if the data are generalised by hydrodynamic modelling. Estimates of the (net) sediment transport require an additional effort, which may not be justified for the purpose of routine monitoring, considering the relatively low sediment transport prevailing in the dry season.

For information about the measurements and the findings, please refer to *RSP Final Report Annex 2: 'Sustainable survey techniques'* and to *RSP Special Report 24: 'Morphological developments at Bahadurabad'*.

9.2 Overland flow

While the overland flow may represent a small part of the annual river discharge, it can be of a considerable practical interest during events of extremely high flow. Also, knowledge about the overland flow is required for analysis of important processes and effects, such as floodplain development, and hydraulic and environmental impact of human interventions, such as FAP projects.

In the first years of the project, overland flow (excluding flow over low chars) was negligible, due to low flood-season river stages.

A pilot programme of spill and over-bank flow measurements was carried out in the 1995 flood season. The measurements took place on the left bank of Jamuna River, southeast of Bahadurabad, which is also where the simultaneous flood plain sedimentation programme took place (see Section 9.3 below). The area was selected partly because of its elevation and flood pattern, and partly because it is fairly accessible during the period of interest. Floodplain sedimentation in the same area has been investigated by FAP19 (ISPAN/FPCO 1995), see Section 9.3 below.

A total of 11 flow transects were measured in the floodplain rivers, Jhenai and Chatal, from July 12 to August 22, 1995. The measurements comprised culvert flow, flow and depth contours along cross-sections, and suspended sediment sampling. The instrumentation comprised a Valeport (hand-held, propeller type) current-meter, drogues, and a leadline for sounding. The measurements were made from a shallow-draft country boat. Positioning was carried out by a hand-held GPS instrument, a rope, and a meter tape. The measurements also included 22 weekly collections of suspended sediment samples along a 4 km cross-line. Information about water levels was collected from ongoing monitoring programmes.

For information about the measurements and the findings, please refer to *RSP Special Report 15: 'Overland flow and floodplain sedimentation'.*

9.3 Floodplain sedimentation

The low flood season river stages in 1993 and 1994 implied that the floodplain sedimentation was negligible in these years. In 1995, however, a 15-years flood event created large scale inundation of the Jamuna floodplain during four peak flows.

Measurements of floodplain sedimentation took place on a pilot basis in 1995. The measurements were made on the left bank of Jamuna, between the river and the town of Sharishabari, some 30 km southwest of Jamalpur (Figure 9.1). A 5 km long transect over the floodplain was measured west of Sharishabari on August 19-22, 1995. Six sampling plots were established between June 8 and 11, 1995. The higher plots were recovered on September 25-26, 1995, and the lower ones on October 22-23, 1995.

Each plot comprised:

- three permeable mats,
- three sediment traps,
- three brick dust layers.

The layout of the sampling sites is shown in Figure 9.2.

The measurements were coordinated with the overland flow measurements mentioned above. In the sample plots, the inundation depth was measured daily, and on August 10, measurements were made of flow direction and velocity. Weekly samples were taken at the sample plots for determinantion of suspended sediments.

Results were analyzed with respect to sedimentation rate and sediment properties. For information about the measurements and the findings, please refer to *RSP Special Report 14: 'Mineralogical and physical properties of river sediments'*, and *RSP Special Report 15: 'Overland flow and floodplain sedimentation'.*

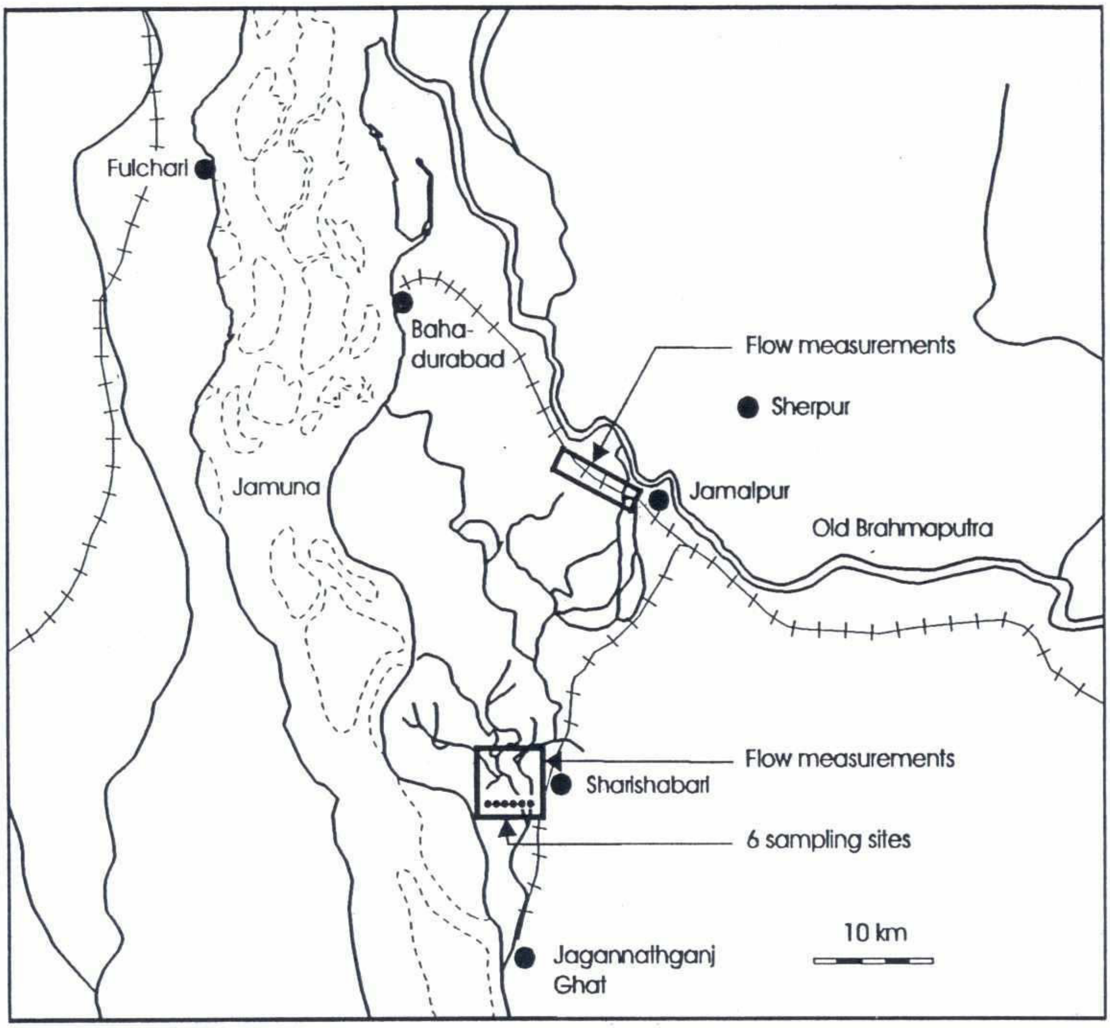


Figure 9.1: Location map, floodplain sedimentation measurements 1995

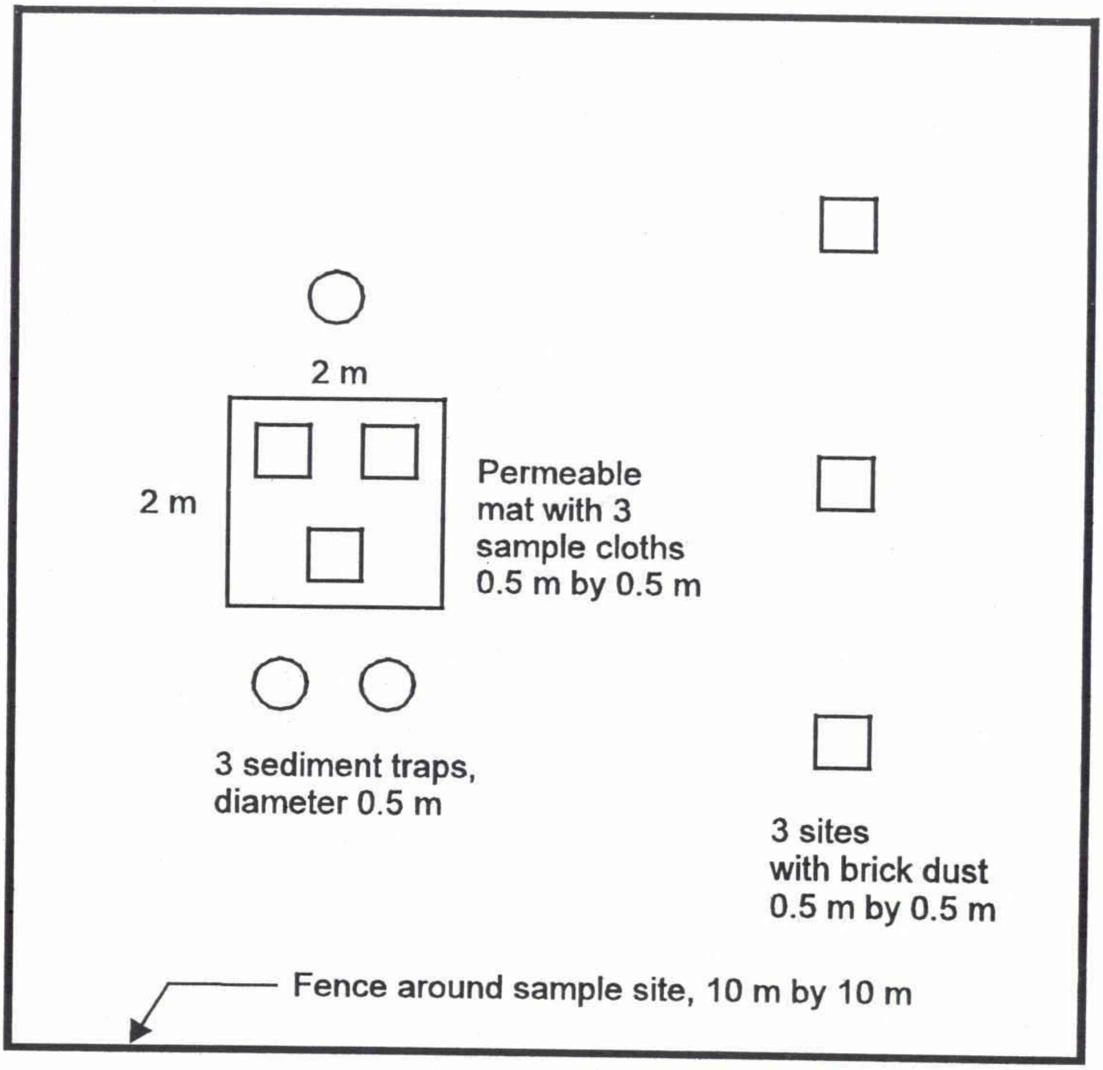


Figure 9.2: Sampling site for floodplain sedimentation

9.4 Sediment transport measurements by ADCP

While the Project implemented an advanced method of moving boat flow gauging (by ADCP), the same was not the case for the sediment transport gauging, which was done by a conventional velocity-concentration-area method.

A reliable and practical moving boat registration of sediment transport would be an important development within river survey technology, the advantages being comparable with the ones of ADCP flow gauging relative to velocity-area measurements from an anchored vessel.

If so desired, an ADCP instrument registering a reflected sound wave can provide information about the backscatter capacity of the water column, by the intensity of the reflected signal, in the same way as an echo sounder records (and can register, if so desired) both the delay and the intensity of the reflected sound impulse. Retrieval of the backscatter signal is possible (and straightforward) whenever an ADCP instrument is used for the purpose of flow recording.

For a given ADCP sound signal frequency, the intensity of the reflected signal (called the backscatter) depends on the sediment concentration and on the grain-size distribution, so that, according to theory, one of these magnitudes can be determined, if the other one is known or estimated.

Within the RSP survey programme, the ADCP backscatter signal was registered as a part of the routine gauging and stored in the PSD24 database. On this basis, a separate programme was carried out for analysis of corresponding backscatter data and sediment concentrations.

An example of the relation between backscatter and sediment concentration is shown in Figure 9.3, which indicates a fair correlation, particularly when keeping in mind that the 'measured' sediment concentration in the figure is not the 'true' concentration; part of the scatter in the figure, and perhaps not an insignificant part, is due to practical constraints related to the sediment sample collection in the field. Please note that the validity of the example is in principle confined to the actual measuring conditions, and, particularly, to the actual grain-size distribution.

The findings indicate that continued development of the method can at least highly reduce the required number of sediment samples to be collected for determining the transport with a given accuracy. Like the ADCP flow measurements, the method requires a computerized data processing and storage system.

For information about the theory and the findings, please refer to *RSP Special Report 12: 'Optimization of sediment measurements'* and to *RSP Special Report 24: 'Morphological developments at Bahadurabad'*.

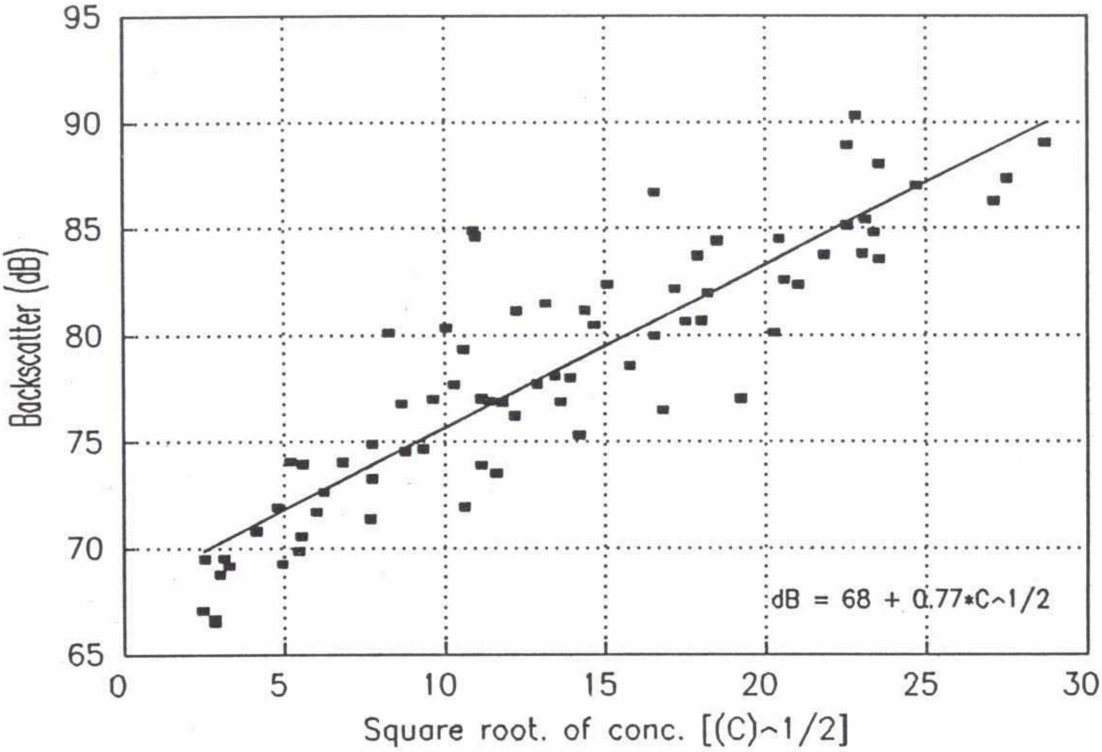


Figure 9.3: Comparison between ADCP backscatter and suspended bed material concentration (example, data from Bahadurabad, July-December 1994)

10 Evaluation and recommendations

This chapter presents some general observations on operational aspects of the river survey activities. Also, occasional references are given to pertinent technological developments that have taken place within river survey technology in the more than 5 years that have gone by since the blueprint of the River Survey Project was finalised.

Hence, unlike the remaining part of this Annex 1, the present chapter extends beyond what was done, and contemplates what could have been done in the past, or what might be done in the future within the scope of the River Survey Project.

Please refer to *RSP Final Report, Annex 2: 'Sustainable survey techniques'* for a more comprehensive discussion and for recommendations on implementation of the experience gained. Specific comments on the river survey routines applied by BWDB are given in *RSP Special Report 19: 'Joint BWDB/FAP24 measurements, hydrology'* and *RSP Special Report 20: 'Joint BWDB/FAP24 measurements, morphology'*.

10.1 The context of the project

The project took place in a period when the capacity for 'supply' of river data was expanding rapidly, due to the general technological developments within field survey techniques, data processing and analysis, data assimilation, and numerical modelling. As one example can be mentioned the availability of the DGPS positioning system, which allows a faster positioning of a moving vessel, retaining the accuracy of the best methods hitherto available, and which facilitates morphological monitoring and other survey operations.

At the same time, the 'demand' for river data has increased. The national infrastructural and economic development implies a more intense interaction with the rivers and an increased need of adaption to and active management of their development. This, in turn, has incurred an extended need of knowledge about the hydrological, morphological and environmental state and processes of the river system.

In accordance with its project blueprint, RSP has applied a combination of well-proven and new technologies. The well-proven, traditional methods (such as staff gauge measurements) resemble the ones applied by BWDB and other national agencies for decades. The new technologies (such as ADCP measurements) were characterised by only a minimum of experience being available, particularly experience relating to the difficult physical operating environment on the Bangladeshi rivers.

By this combination of alternative methods, by pilot applications, and by comparative test gauging, the project inevitably obtained a substantial mass of experience with respect to measuring techniques and survey operation.

10.2 Data demand

There are four categories of national demand for river data:

- for flood management (FPCO/WARPO and others): General planning, selection of mitigation measures, impact assessment, and operational flood forecasting. This demand is the background for the River Survey Project (FAP24);
- for national water resources planning and management, and for specific water supply and irrigation schemes (by Ministry of Water Resources, including BWDB and WARPO, and others): General planning, design, impact assessment, and operation;
- for planning and management of waterways and physical infrastructure (BIWTA, JMBP, and others): Feasibility studies, design, impact assessment, and operation;
- for environmental planning and management (by the Ministry of Environment and Forestry, and Ministry of Water Resources): General planning, selection of mitigation schemes, impact assessment, and monitoring.

These demands have existed for decades, but change and increase in the course of time. Examples of recent developments of demand of information are the need of real-time monitoring for flood forecasting, as implemented by BWDB/FFWC, and supported by FAP10, the need of environmental monitoring (for example in the area south of the Ganges), and the need of detailed morphological data to meet the technological challenge of the Jamuna Multipurpose Bridge Project.

10.3 Evaluation of survey methodology

The present section is a listing of observations made at the final stage of the project in connection with the different survey activities.

For a comprehensive outlook of experience and induced recommendations, please refer to *RSP Final Report Annex 2: 'Sustainable survey techniques'*.

10.3.1 Water-level gauging

The staff gauges were implemented in a way similar to the procedures applied by BWDB, and the Project has little to add to the long-term experience of that organisation. In many cases, the staff gauges functioned well. In some instances, the data quality was poor in general, whereas in other cases occasional errors occurred for example in connection with stage shifts and gauge relocations. A proper bench mark reference is crucial, as well as regular verification of the staff gauge datum level and occasional validation of the bench mark level. Any datum shifts, for whatever reason, must be recorded.

A well-known consideration, which was encountered in connection with the analysis of BWDB data, is the placement of the gauging stations in a river that continuously shifts its course and flow domain. Several BWDB stations are located at places that would not be selected today, but are retained at those places in order to preserve the continuity of the long-term records. Here, a compromise must be pursued between the conflicting requirements of long-term continuity and short-term validity. Please refer to *RSP Final Report, Annex 2: 'Sustainable survey techniques'* for a discussion of this subject.

At locations with a pronounced tidal effect, staff gauge readings made during daytime only are not adequate: At some locations and some periods of the year, staff gauge readings make little sense at all, unless combined with a dense programme of flow recordings. At such locations, a combination of an unvented pressure cell recorder and staff gauge readings may be considered as a viable gauging method, at least for fixed-term measurements. The advantage of an unvented pressure cell is its much easier installation (which also reduces the installation costs). However, this type of instrument is not well suited for routine gauging, and can best serve as a supplement to the staff gauge, where it can close short gaps in the time series, e.g. overnight. The method has not been used by the RSP.

An important future demand of AWLR data (rather than staff gauge readings) is expected in connection with real-time monitoring of flow and water level, for example for operational flood forecasting. Also, any type of river model calibration will benefit from availability of continuous data records rather than discrete observations.

The experience with the AWLRs operated by the Project is somewhat conditional. First, it is noted that an AWLR is much more expensive than a staff gauge with respect to procurement and installation, whereas the operation costs are of the same order of magnitude. Secondly, it was learned that identification of a good location for installation was difficult, and sometimes impossible. Problems encountered were (1) river erosion or siltation, (2) impact of ship collision, and (3) drying up of the river. In order to meet these difficulties, a strategy was conceived of applying the AWLRs for recording during high stages only, when they can be installed in 'safe' places. If so, the measurements at the same location during low stages must be done using staff gauges.

AWLRs require a monthly service check-up by a skilled instrument engineer and are also for that reason more demanding as regards personnel than staff gauges.

Irrespective of whether a suitable location could be identified, a set of two adjacent staff gauges was installed and operated for the reasons of quality checking and data collection security. It is concluded that such a support procedure is essential.

At one location (Hardinge Bridge), where the (acoustic type) recorder was installed on a bridge pier, it was found that the recordings were influenced by local surface irregularities that occurred during extremely high flows.

10.3.2 Flow recordings by DGPS-ADCP

A particular feature of the River Survey Project is the application of the combined DGPS positioning and flow recording by ADCP, which makes it possible to measure flow distribution and integrated flow rates over a cross-section with a better accuracy and in a much shorter time (and hence with a better validity) as compared to traditional velocity-area standard methods. To do a velocity-area flow transect in one of the large rivers requires several days, which is simply too long as compared to the time scale of flow fluctuations not only at the tidal-influenced sections but also in the upstream reaches.

Further, the DGPS-ADCP approach does not require anchoring of the vessel while doing the measurements; on the contrary, the method is intended for flow recordings while transversing the river. This is a particular advantage in the large Bangladeshi rivers, where mooring in the main flow channels is not only risky from a safety point of view, but can also be unpractical, because the anchor can sometimes be buried so deep in the riverbed that it cannot be retrieved. For example, during the initial pilot survey with the *'Anwesha'*, mooring in the main flow channels at Bahadurabad was not practical. Also, it was noted that the routine flow gauging at that location carried out by BWDB (by the velocity-area method using Ott propeller current-meters) has, by necessity, to be made without mooring.

For these reasons, it can be concluded that the DGPS-ADCP technique has distinct advantages, both with respect to quality and capacity, also for the Bangladeshi river environment, as compared to velocity-area flow gauging by propeller instruments.

As pointed out by the PA, a potential remains for further development of the technique and for improving the understanding of its performance. This involves further studies of the accuracy of the single current profile as well as of the entire flow gauging, and also for optimization of deployment, as well as of the entire flow gauging procedure. One example of an open question is the best deployment of the EMF (at 0.5 m below the surface), in order to reduce the influence of the hull of the survey vessel on the flow past the sensor.

Due to the high instrument procurement and maintenance costs, and the need of a fully computerised data processing, the DGPS-ADCP technique is initially best suited for dedicated, fixed-term applications. In the course of time, the technology (in its future state of development) will most likely be implemented for routine monitoring purposes in Bangladesh and elsewhere.

10.3.3 Schedule for routine flow and sediment transport gauging

The scheduling of the routine flow and sediment transport gauging has been a matter of concern throughout the project, and has been continuously reviewed between the project and the Project Advisor. Two main considerations were:

- The measurement programme should address the time scale of stage-discharge variations (rather than the time scale of the flow variation itself)
- For the same reason, the measurement programme should provide an effective coverage of peak flow events

This is because even detailed and accurate measurements of an instantaneous flow rate remain examples, with a low validity, unless supported by related long-term data. The desired knowledge about the flow is inevitably produced on the basis of some type of stage-discharge relationship. The quality of the information about the flow depends not only on the quality of the flow gauging itself, but also on the quality of the water-level monitoring and of the relationship between them.

The significance of the scheduling is enhanced when using a gauging routine like the one of the River Survey Project, which is based on a few high-cost survey units, instead of a dense network of lower-cost units, as applied by BWDB.

Please refer to *RSP Special Report 11: 'Optimization of hydraulic measurements'* for a discussion of this issue.

10.3.4 Flow recordings at tidal-influenced stations

At cross-sections influenced by the tide, the stage-discharge relationship is distorted, or it does not exist at all, so that the stage and the flow through the section become unrelated. This is particularly the case when the tidal flow and the river discharge are of comparable significance (whereas a pure tidal flow is easier to monitor, as is the case with a pure river flow).

The tidal effect on flow gauging has not been considered as crucial in connection with the River Survey Project, because this effect does only occur at the most downstream cross-sections, and only in the lean season. Some dedicated tidal flow gaugings have been made at Mawa and Bhairab Bazar.

It is expected that in the future the demand of flow data from tidal-influenced reaches will increase in Bangladesh in connection with the enhanced utilisation of the lean season water volume and because such data are important in connection with environmental studies. One example would be impact monitoring of the reduced lean-season flow in the Ganges.

Gauging of tidal-influenced reaches is rather more complicated than elsewhere:

- The water level must be registered continuously, and with a time increment that can resolve the (around 12 hours) tidal wave, for instance 30 minutes. This requires either AWLR registration, with the implications mentioned above, or round-the-clock staff gauge readings;
- The flow (or the surface slope) must be registered separately in addition to the stage;
- The data analysis and data interpretation are more complex;
- Real-time flow monitoring is considerably more complex (whereas real-time water-level monitoring at tidal stations does not differ from non-tidal stations).

It is noted that for analyses based on hydrodynamic modelling, water-level monitoring at such stations is of a pronounced practical interest, even in the absence of simultaneous flow monitoring. In cases when routine monitoring of the flow is not practical, a series of dedicated fixed-term tidal surveys can provide a substantial amount of valuable information.

10.3.5 Backwater effects

Within the RSP routine gauging programme, backwater effects were encountered at Aricha during peak flow in the Ganges, and at Bhairab Bazar during peak flow in Lower Meghna. The effect was examined on the basis of water-level slopes along the rivers, and one new water-level gauging station (at Mir Char, 20 km downstream of Bhairab Bazar, on the Upper Megna) was established for the purpose.

The traditional way to avoid backwater effects is simply to locate the gauging stations beyond the affected area, but in the complex river system of Bangladesh this would be a serious trade-off due to the extent of such areas.

Effective flow monitoring during backwater can be made by a combination of measurements and hydrodynamic modelling, either by traditional hindcast simulations, or by an off-line or real-time data assimilation procedure. This, however, was not pursued within the framework of the Project.

10.3.6 Suspended sediment sampling

The physical environment for suspended sediment sampling in the large Bangladeshi rivers is extreme with respect to highly varying current velocities (up to around 4 m/s) and with respect to a highly varying sediment concentration (up to around 5 g/l). This affects not only the sampling and analysis procedure, but also the design of the sampling device, and its handling and operation.

The method originally recommended for the RSP by the Consultant was sampling by a traditional pumping system. The sampler was designed for the purpose of the present project, as it was expected that samplers developed for application elsewhere could not function under the given physical operating conditions. The sampler consisted of a combination of a submerged pump with a variable capacity and an EMF, carried by an umbilical (a single string cable for suspension, flow tube, and power supply). Also, a turbidity meter was attached.

Initially, this device did not perform according to expectations. The system was modified, several alternatives were tested, and a depth-integrating bottle as well as a Delft bottle were implemented as supplements.

It is concluded that the initial inadequate performance of the pumping system was due to poor design (rather than inherent shortcomings of the technique as such). Problems encountered are summarised in Table 10.1.

- electrical interference between the pump and the EMF (resulting in noisy flow velocity registrations)
- accretion of sediments in the pump house (resulting in contamination of the sample)
- inadequate flow velocity in the umbilical (resulting in a sorting of the sediments during sampling)
- practical difficulties with adjusting the intake nozzle flow to the ambient flow (resulting in a sorting of the sediments during sampling)
- flow at intake nozzle disturbed by the presence of the sampler
- vibrations of the umbilical
- the sampler was difficult to handle near the riverbed under high flow velocities
- the sampler could not rest on the riverbed without support by the cable

Table 10.1: Problems encountered during suspended sediment sampling by pumping

The suspended sediment sampling technique will inevitably remain a compromise between given aims and some rather visible limitations. If possible, the method should be targeted towards the specific application of the data (provided that the application is known beforehand). For general purposes, a well designed pumping system is believed to be the most accurate and also the most versatile, although its implementation for routine monitoring can have significant practical limitations with respect to costs, as well as handling of the instrument itself and of the samples.

The experience gained during the RSP indicates that the design criteria summarised in Table 10.2 are relevant in connection with the physical environment of the Bangladeshi rivers.

Please refer to *RSP Special Report 12: 'Optimization of sediment measurements'*, for details about the findings and their implications.

Current force:	• small cross-section area (of the sampler itself and, particularly, the suspension cable) • streamlined shape • prevention of flow separation behind cable (by fairings)
Stability on the riverbed:	• self-supporting • low scour generation (when resting on the riverbed)
Handling control:	• single string (umbilical) • gravity depression (easier to control than dynamic depression in a strongly varying flow) • tilt control
Sensors:	• registration of depth, orientation, and tilt • single point real-time current registration near the intake nozzle • other sensors as required (turbidity sensor, ultra-sonic flow/sediment gauge, echo sounder)
Intake nozzle flow:	• adjustable to ambient velocity (by adjustment of flow rate and/or intake nozzle area) • intake flow undisturbed by the sampler itself
Flow in pump house and tube:	• sufficient for effective flushing and for precluding sorting of the sample

Table 10.2: Design basis for a sediment pump sampler

10.3.7 Bed load and near-bed transport measurements

During the initial planning, it was envisaged to measure the bed load transport by sand dune tracking: Repeated fine-grid depth soundings of a suitable area, followed by a calculation of the transport as represented by the propagating sand dunes.

Pilot surveys in 1992 and 1993 indicated that this procedure was not well suited. Sometimes, sand dunes did not exist, or their propagation could not be resolved in a practical way. Besides, dune tracking is in any case a time-consuming exercise with a not fully reliable outcome. Thus, for the purpose of routine gauging the bed load transport was omitted. Instead, the near-bed transport was measured by a Helley-Smith sampler.

As an alternative, at the initiative of the PA, a Delft bottle was applied on a pilot basis, and it was later included in the routine gauging programme. It was found that certain design adjustments of its frame would be needed before this sampler was fully applicable for this purpose in the Bangladeshi rivers, particularly in strong currents (where also the bed load transport is at its highest). These design modifications were expected to be comprehensive, if all flow conditions shall be accommodated, and a conclusion was not arrived as to whether such design modifications were practical.

Subsequent observations of the occurrence of sand dunes indicated that dune tracking may be more auspicious than was concluded during the initial test gauging programme. Therefore, the method should not be discarded, but kept in mind in connection with similar future measurements.

10.3.8 Sediment analysis

Analysis of suspended sediments and riverbed sediments took place in the in-house sediment laboratory of the project. The analyses were confined to traditional characteristics (concentration, grain-size distribution, and settling velocity distribution), and were carried out by proven techniques (microfiltering, Andreasen settling tube tests, and sieving). Supplementary special analyses were carried out by the laboratories of Geology and Soil Science Department, Dhaka University (see Chapter 6 in this Annex, and *RSP Special Report 14: 'Mineralogical and physical properties of river sediments')*.

As it turned out, the sediment laboratory emerged as an entirely problem-free zone within the project. The data produced reflect the advantage of routine application of proven technology, namely a good data consistency and data transparency.

The information obtained by the 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.

10.3.9 Data analysis, sediment transport

Some open questions occurred in connection with the processing and routine presentation of the sediment transport rates. Calculated transport rates represent a compound of many different data, which can be processed and presented in many different degrees of synthesisation (single point versus depth increment versus vertical profile versus length increment versus entire cross-section, instantaneous versus daily mean versus long-term net transport, total transport versus different grain-size categories). When the purpose of the data compilation is general rather than specific, the choice is in principle open within such a multi-dimensional array of options.

Following an examination of the immediate demands of the internal data users of the project, and after consultations with BWDB and the RSPMU, the project selected the standard presentations included in the Data Books. These comprised (1) horizontal distributions across the river of instantaneous, vertically averaged transport of wash load, suspended bed material load, near-bed load, and total transport; (2) horizontal distributions across the river of instantaneous, vertically averaged transport of D_{50} of wash load, suspended bed material load, and near-bed load; (3) summaries of single (depth-specific) suspended material grain-size analyses: Weight percent above and below 0.063 mm, and D_{10}, D_{50} and D_{90}; and (4) summaries of single bed material grain-size analyses: Weight percent above and below 0.063 mm, and D_{35}, D_{50} and D_{65}.

These presentations aimed at two objectives, one being a documentation of the physical conditions (with respect to flow and sediment transport) prevailing during the specific data collection, and one being a condensed extract of the data, suited for example for gross transport sediment rating curves. Experience indicated that alternative post-processing was required for the purpose of the different analyses and studies. This was well possible, because all individual analyses were stored for this purpose. Still, a more versatile presentation could be conceived, perhaps a computer-based inter-active data catalogue that could extract the desired information.

10.3.10 Topographic and bathymetric surveys

The land surveys were largely carried out by traditional means, with occasional DGPS support, whereas the bathymetric surveys were carried out by traditional echo sounding and with DGPS positioning.

Within the project, relative emphasis was given to the bathymetric surveys as compared to the land surveys, both with respect to capacity and time spent. With the benefit of hindsight, it is concluded that the resource distribution was less than optimal. Due to the stage variation, the effects of the morphological processes can materialise both below the river surface and on chars and banks that are dry land during parts of the year. The mapping of land contours and riverbed contours are complementary, and the data coverage should be harmonized.

The surveys were not only made before and after the monsoon, but also during high flows, when the morphological processes were in rapid progress, in order to examine details of these processes. It appeared that the data analysis of such high-flow surveys was particularly intricate, because not only the stage, but also the bed levels varied during the work. For example, if the measurements for some reason had to be discontinued for a few days, a discontinuity would appear in the recordings, because the bed level had changed in the meantime. Even when the measurements were made continuously from one end of the survey area to the other, so that no discontinuities appeared, the interpretation was difficult, because the data would not yield an instantaneous (and thereby fully consistent) image of the bed forms: The data represented a complex combination of time variations and space variations. (This aspect somewhat resembles the implications of measuring flow by a traditional velocity-area method over a large cross-section over several days, where the flow can change significantly during the work). It is conceivable that the objective of these measurements could have been pursued more effectively within the same resource allocation by covering a selected, smaller area with successive surveys, rather than a big area surveyed once.

During both land surveys and bathymetric surveys, practical and general professional questions emerged with respect to both the horizontal and the vertical control. These matters are briefly elaborated below.

10.3.11 Horizontal control

The horizontal control suffered from the absence of a well-defined, operational geodetic grid. At the start of the project, it was expected that in general a new BTM grid established at that time by FAP18 would be implemented within the FAP programme. Official information about this grid had not been released, and in an attempt to facilitate the data exchange within the FAP programme, the Project tried to re-construct the required ellipsoid transformation and datum shift parameters from field surveys of fixed points with known coordinates.

However, it appeared that the BTM grid established by FAP18 was never implemented. Instead, in the mean time a new BTM grid, the 'Geodetic Control Network in Bangladesh' had been developed by Survey of Bangladesh and Japan International Cooperation Agency. It is tentatively expected that this grid will be commonly used in the future but, for reasons explained above, it is not entirely compatible with the one applied by the RSP. The deviation is tentatively expected to be within 10 m within the operation area of the Project (but could be much more beyond this area).

10.3.12 Vertical control

The vertical control during the bathymetric soundings was done in the traditional way: the actual, instantaneous water depth was recorded from a moving vessel using an echo sounder, and the simultaneous water level was recorded relative to the datum by staff gauges and/or AWLRs (with a known zero level) at certain locations within the survey area. The bed level relative to the datum was calculated as a part of the post-processing.

This procedure requires that the water-level difference between the location of the water-level gauge and of the vessel is known, for example from interpolation of the water level between adjacent gauges. In some cases, however, the vertical control was affected by surface slope irregularities. For example, between Bahadurabad and Baruria, the average surface slope is some 7 cm/km, but as has been demonstrated by RSP measurements, the slope can vary considerably with time and space around this average value. Among the bathymetric survey areas of the RSP, problems in this regard were particularly felt at Bahadurabad (due to braided channels), and at the Jamuna/Ganges confluence, where backwater occurs during peak flow in the Ganges.

The vertical control can be improved within the framework of the applied procedure by the following means:

- applying a fine grid network of water-level gauges, so that the survey vessel remains within, say, 2-3 km from the nearest gauge, and so that the water level is always gauged in the channel where the soundings are made
- interpolating the water level (rather than extrapolating, except over short distances)

However, this is not free of hassles. The data processing becomes more intricate, and, maybe more significant, the transparency of the results is reduced, because the datum cannot be easily traced to bench marks in the field thus contaminating the data become with inherent benchmark datum irregularities.

A recent technological accomplishment offers an alternative way of maintaining the vertical control during this type of work, as the DGPS positioning has been developed to serve the purpose of accurate vertical positioning of a moving boat. This system, the so-called RTK (real-time kinetic) DGPS, seems particularly attractive for bathymetric surveying in areas with a significant, irregular, and, perhaps, not fully known surface slope. This is because the riverbed level is mapped directly relative to the selected (satellite-based) coordinate system, and not indirectly via datum transfer by a simultaneous water level.

The RTK-DGPS tool was not available until late in the project period and was for that reason not applied by the Project.

10.3.13 Satellite imagery

For morphological (and many other) studies, a highly valuable insight can be obtained by combining bathymetric soundings and topographic surveys with satellite mapping. This approach was examined on a pilot basis within the River Survey Project. Findings are reported in *RSP Survey and Study Report 10: 'Morphological studies, Phase 1'* and *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data'*. A substantial additional experience is available with FAP19 (the present EGIS project) and from the GIS implementations at FAP25 (the Flood Management Modelling Project, presently incorporated in SWMC).

The combined mapping by field surveys and remote sensing enhances the need of a common geodetic reference, as briefly explained above. This should be kept in mind in connection with the expected wider implementation of high-accuracy (GPS-based) positioning within river monitoring.

Satellite imagery is freely available from alternative suppliers on a commercial basis, and a processing facility exists in Dhaka (at EGIS). The data are not free of charge, but the costs are fully reasonable as compared to the costs of the field work. The joint study of EGIS and RSP on analysis of morphological data strongly indicates that the advantages of combining traditional mapping with satellite imagery are substantial and will further increase for a long time to come.

10.3.14 Data processing

Whilst the data collection of the RSP was partly based on the most recent technology, the data processing was largely carried out by proven methods.

It is tentatively believed that there is a potential, and perhaps a big potential, of enhancing the quality and the validity of the river data by implementation of new data processing technology, notably by data assimilation into numerical hydrodynamic and morphological models. A circumstance to keep in mind in this context is that field measurements are expensive as compared to numerical modelling, and particularly so when compared to the operating costs of a model once it has been established.

A suitable combination of field measurements and numerical modelling is particularly powerful for description of complex processes, such as flow in backwater and tidal areas, and overland flow phenomena. Here, the modelling can serve two purposes: (1) an integral processing of aggregate information on a well-defined (although simplified) basis, and (2) an extension of the validity of short-term registrations.

Hydrodynamic models are well implemented in Bangladesh, for example for BWDB's operational flood forecasting. Data assimilation techniques exist, but can today hardly be characterised as well-proven, particularly not with respect to sediment transport and morphological processes. Still, there is reason to believe that attempts to improve the accuracy and validity of knowledge about the river processes should consider an upgrading of the data processing. This is particularly the case when keeping the overall cost-effectiveness in mind.

10.4 Summary of observations from the routine gauging

The experience gained within the Project induces the following synthesis in relation to routine monitoring of flow, sediment transport, and morphological processes of the main river system of Bangladesh:

10.4.1 AWLRs

The experience of the project does not justify a general use of AWLRs for routine monitoring in the area covered. This is not only due to the higher costs, as compared to staff gauges, but also because of the difficulties with finding a good permanent location for installation. Subject to proper organisation and execution, the two methods can provide equal data quality (although the time resolution of the staff gauges is less than that of the AWLRs). Within the main part of the river system, where tidal effects are insignificant, staff gauge readings remain a cost-effective method with a suitable potential performance.

In the future, however, AWLRs may be required in Bangladesh for real-time monitoring for operational flood forecasting purposes and at tidal stations.

10.4.2 ADCP flow gauging

The ADCP (moving boat) flow gauging performed well. The method is much more powerful than traditional area-velocity flow gauging with respect to data collection capacity, and in addition with respect to time and space resolution and validity.
These advantages, however, are partly reduced when combined with sediment sampling, where the superior flow recording capacity cannot be fully used. Yet, for sediment transport gauging, a good description of the flow field is a cornerstone of good results.

The ADCP gauging requires DGPS positioning to reach its full performance, and is entirely dependent on such positioning when bottom tracking is not possible. This is the case (1) if the riverbed cannot be detected during extremely high suspended loads, or (2) if the riverbed is fluidised and moving at high flows. During the planning of the RSP, the former difficulty was envisaged (and provided for in the design of the survey spread), while the latter was not. As it turned out, the latter was the main problem, but the effect was the same, and could be mitigated in the same way, namely by substituting the bottom track by the GDPS position.

The penetration of the ADCP depends on its frequency, the penetration being better for low frequencies, but at the cost of a somewhat reduced vertical resolution. Initially, the RSP mobilised a 300 kHz instrument for the DHA vessel, in view of the lack of experience with the instrument under extreme sediment loads. Subsequently, a 600 kHz instrument was selected for Phase 2 for the DHB. Both instruments performed well under the conditions encountered, the 600 kHz one giving the best resolution (0.25 m as compared with 0.5 m for the 300 kHz instrument). Inevitably, both were equally affected by a moving riverbed, when occurring.

The Project encountered quite some difficulties with respect to the processing of ADCP data, which is obviously much more complex than for the area-velocity gauging. It is concluded that these difficulties were caused by the lack of experience with this new technology, and that in the near future, the computerised data processing of ADCP transects will become a matter of routine.

10.4.3 Suspended sediment sampling

Initially, the pumping system implemented by the RSP did not perform according to expectations. This was due to poor design (rather than inherent shortcomings of the technique as such), and quite some effort was made to upgrade and supplement the sampling device. One example was the strong vibrations of the umbilical cable during high current-speeds, which were countered by mounting fairings on the cable.

For general monitoring purposes, the Consultant believes that a pumping system (when properly designed and operated) is the most accurate and, particularly, the most versatile, although its implementation for routine monitoring can have significant practical constraints with respect to costs, as well as handling of the instrument itself and of the samples.

Practical and useful alternatives exist, such as the integrating bottle, but are characterised by certain constraints with respect to time, space and grain-size resolution and validity.

10.4.4 Land surveys

The experience of the Project indicates a need for a higher capacity and resource allocation for this activity, possibly at the cost of a reduced resource allocation for bathymetric surveys, because these two activities are complementary. New land survey instruments have recently been developed, which may well have a large potential for monitoring of morphological processes. The same is the case for the new satellite-based, three-dimensional positioning system (by RTK-DGPS).

10.4.5 Geodetic grid

The implementation by SoB of a well-defined, operational geodetic grid will highly facilitate the exchange of data between the many different data producers and data users in Bangladesh.

10.4.6 Satellite imagery

Satellite mapping technology has already been implemented within the FAP programme, mainly on a pilot basis, and its benefits are convincing. This technology offers a substantial potential for improved insight into the morphological processes and for monitoring of their effects, for example by combined GIS processing and analysis of satellite imagery and standard bathymetric maps.

10.4.7 Data processing

An observation made at an early stage of the survey programme was the size of the volume of the data that could be produced in the field by the high-capacity survey instrument spreads. Initially, the field measurements produced more data than could be processed with any reasonable effort. This high production rate of field data reflected a considerable duplication of measurements for consistency validation and data security, which was not justified once some experience had been developed with the routine gauging. Therefore, in the first half of 1994, the gauging procedures were streamlined, and the data collection and data processing routines and capacities were harmonised, so that in the final year of the survey programme, the routine gauging truly became 'routine'.

Whilst the data collection of the Project was partly based on the most recent technology, the data processing was largely carried out by proven methods, such as simple separate time and space integration procedures for data reduction, and separate analysis and storage of data that describe time and space variations.

There may well exist a considerable potential for enhancing the quality and the validity of the river data by implementation of new data processing technology, notably by data assimilation into numerical hydrodynamic and morphological models. This is particularly the case when keeping the overall cost-effectiveness in mind, since automatic data processing and computer-based data analysis are less costly than field measurements.

11 References

11.1 RSP reports

The following reports among the ones prepared by the River Survey Project describe the progress, interim findings, or results of the survey component. Numbering refers to the implemented numbering of each report series. For a complete list of RSP reports, please refer to the main volume of the Final Report.

Final Reports

RSP Final Report, Main Volume, November 1996
RSP Final Report, Annex 1, Surveys, November 1996
RSP Final Report, Annex 2, Sustainable Survey Techniques, November 1996
RSP Final Report, Annex 3, Hydrology, November 1996
RSP Final Report, Annex 4, Morphology, November 1996
RSP Final Report, Annex 5, Morphological Characteristics, November 1996

Special Reports

1 Validation of staff gauge bench marks
2 Water level gauging stations
3 Bathymetric surveys
4 Stage-discharge relationship for the Jamuna at Bahadurabad
6 Flood plain levels and bankfull discharges
8 Bed material sampling in Ganges, Padma, Old Brahmaputra and Jamuna
11 Optimization of hydraulic measurements
12 Optimization of sediment measurements
14 Mineralogical and physical properties of river sediments
17 EGIS and the River Survey Project, FAP24: Spatial representation and analysis of hydraulic and morphological data
19 Joint measurements BWDB/FAP24, hydrology
20 Joint measurements BWDB/FAP24, morphology
21 Guide to FAP24 databases
22 River Data Book, June 1993 to March 1995
23 River Data Book, April 1995 to May 1996

General Project Reports

1 Inception Report, August 1992, revised October 1992
3 1° Interim Report, Volume I: Main Report, and Volume II: Annexures on survey work, February 1993
7 Final Report Phase 1, August 1994
8 2° Interim Report (1° Interim Report, Phase-2), February 1995
9 Phase-2, 2° Interim Report, September 1995

Survey and Study Reports

1 Additional survey, September 1992, October 1992
3 Test Gauging Report: Survey procedures and data presentation, October 1993
4 Selection of survey techniques, November 1993, revised May 1994
5 Survey Report Phase 1: Dry season 1992/93, December 1993
7 Transfer of bench-mark levels across Jamuna River at Bahadurabad, December 1993
8 Survey Report: Flood season 1993 (3 volumes), July 1994
9 Bathymetric pilot surveys on Jamuna River at Bahadurabad in 1993, August 1994

Survey Notes

2 Anwesha survey, technical guidelines, September 1992
4 Programme outline for test gauging, August 1993
5 Survey procedure for the routine gaugings in the dry season 1993/94, January 1994
6 Survey procedures, routine gaugings, monsoon season 1994, June 1994
7 Survey procedures, routine gaugings, monsoon season 1995, May 1995
8 Determination of physical properties of sediments, June 1994
10 Over-land flow measurements, June 1995

Working papers

1 Technical recommendation and verification of the acoustic sensor type of AWLR, October, 1993
2 Tidal and backwater effects at Bhairab Bazar
4 Optimization of hydraulic measurements: Turbulent flow structure and an optimum averaging time, August 1995
5 Suspended sediment sampling: Selection of instruments and methods, August 1995

Various

7 River bathymetry assessment by radar remote sensing, September 1994
8 Note on discharge and sediment distribution at bifurcations and off-takes, November 1994
11 Remote sensing for morphological assessment and radar remote sensing pilot project, February 1995
16 Spatial analysis with digital bathymetry data (prepared by FAP19 in cooperation with FAP24), August 1995

Workshop contributions 6-8 Nov 1993

3 Mosselman, E., and G. J. Wensink: River bathymetry observation with radar remote sensing
4 Iversen, C.: Survey techniques selected by FAP24

Lecture notes

5 van Groen, Pieter: Advanced river survey techniques

11.2 External references

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FPCO (1995): Bangladesh Flood Action Plan, Progress Report, June 1995. Flood Plan Coordination Organization, Ministry of Water Resources, Government of the People's Republic of Bangladesh.

Hoyer, Hans (1994): Note regarding coordinate systems. Mimeo, FAP24, December 14, 1994.

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Enclosure A

Inventory of executed surveys

A.1 – Routine gauging

Location	Start date	End date	Survey type	Number
Bahadurabad	14-Jan-93	16-Jan-93	routine gauging	1
Bahadurabad	13-Feb-93	15-Feb-93	routine gauging	2
Bahadurabad	13-Mar-93	16-Mar-93	routine gauging	3
Bhairab Bazar	27-Apr-93	28-Apr-93	routine gauging	5
Bahadurabad	06-Jun-93	09-Jun-93	routine gauging	6
Bahadurabad	15-Jul-93	17-Jul-93	routine gauging	7
Sirajganj	23-Jul-93	29-Jul-93	routine gauging	8
Baruria	04-Aug-93	08-Aug-93	routine gauging	9
Bahadurabad	23-Aug-93	24-Aug-93	routine gauging	10
Bahadurabad	11-Sep-93	11-Sep-93	routine gauging	11
Sirajganj	17-Sep-93	17-Sep-93	routine gauging	12
Aricha	19-Sep-93	19-Sep-93	routine gauging	13
Baruria	19-Sep-93	19-Sep-93	routine gauging	14
Hardinge Bridge	26-Sep-93	29-Sep-93	routine gauging	15
Gorai Off-take	29-Sep-93	30-Sep-93	routine gauging	16
Baruria	01-Oct-93	01-Oct-93	routine gauging	17
Mawa	03-Oct-93	07-Oct-93	routine gauging	18
Arial Khan Offtake	08-Oct-93	08-Oct-93	routine gauging	19
Bhairab Bazar	12-Oct-93	12-Oct-93	routine gauging	20
Tilly	16-Oct-93	16-Oct-93	routine gauging	21
Baruria	19-Oct-93	22-Oct-93	routine gauging	22
Sirajganj	24-Oct-93	27-Oct-93	routine gauging	23
Bahadurabad	02-Nov-93	03-Nov-93	routine gauging	24
Baruria	04-Dec-93	05-Dec-93	routine gauging	25
Sirajganj	07-Dec-93	08-Dec-93	routine gauging	26
Bahadurabad	10-Dec-93	12-Dec-93	routine gauging	27
Bahadurabad	29-Jan-94	01-Feb-94	routine gauging	28
Mymensingh	30-Jan-94	31-Jan-94	routine gauging	29
Sirajganj	03-Feb-94	03-Feb-94	routine gauging	30
Baruria	05-Feb-94	06-Feb-94	routine gauging	31
Tilly	05-Feb-94	07-Feb-94	routine gauging	32
Arial Khan Off-take	09-Feb-94	09-Feb-94	routine gauging	33
Bhairab Bazar	10-Feb-94	10-Feb-94	routine gauging	34
Kushtia/Gorai	14-Feb-94	15-Feb-94	routine gauging	35
Hardinge Bridge	16-Feb-94	18-Feb-94	routine gauging	36
Mymensingh	23-Feb-94	23-Feb-94	routine gauging	37
Kushtia/Gorai	05-Mar-94	06-Mar-94	routine gauging	38
Hardinge Bridge	07-Mar-94	07-Mar-94	routine gauging	39
Bahadurabad	15-Mar-94	17-Mar-94	routine gauging	40
Sirajganj	18-Mar-94	19-Mar-94	routine gauging	41
Mymensingh	20-Mar-94	20-Mar-94	routine gauging	42
Baruria	21-Mar-94	21-Mar-94	routine gauging	43
Tilly	21-Mar-94	22-Mar-94	routine gauging	44
Bhairab Bazar	24-Mar-94	24-Mar-94	routine gauging	45
Arial Khan Off-take	24-Mar-94	24-Mar-94	routine gauging	46

Hardinge Bridge	27-Mar-94	29-Mar-94	routine gauging	47
Bahadurabad	02-Apr-94	04-Apr-94	routine gauging	48
Sirajganj	05-Apr-94	07-Apr-94	routine gauging	49
Hardinge Bridge	08-Apr-94	08-Apr-94	routine gauging	50
Baruria	08-Apr-94	10-Apr-94	routine gauging	51
Bhairab Bazar	16-Apr-94	16-Apr-94	routine gauging	52
Arial Khan Off-take	18-Apr-94	19-Apr-94	routine gauging (tidal)	53
Bahadurabad	26-Apr-94	28-Apr-94	routine gauging	54
Sirajganj	29-Apr-94	01-May-94	routine gauging	55
Baruria	03-May-94	05-May-94	routine gauging (tidal)	56
Kushtia/Gorai	11-May-94	11-May-94	routine gauging	57
Hardinge Bridge	12-May-94	12-May-94	routine gauging	58
Tilly	15-May-94	15-May-94	routine gauging	59
Bahadurabad	02-Jun-95	08-Jun-95	routine gauging	60
Hardinge Bridge	05-Jun-94	06-Jun-94	routine gauging	61
Sirajganj	08-Jun-94	12-Jun-94	routine gauging	62
Baruria	12-Jun-94	15-Jun-94	routine gauging	63
Mymensingh	15-Jun-94	15-Jun-94	routine gauging	64
Tilly	16-Jun-94	16-Jun-94	routine gauging	65
Kushtia/Gorai	19-Jun-94	19-Jun-94	routine gauging	66
Hardinge Bridge	20-Jun-94	21-Jun-94	routine gauging	67
Bahadurabad	24-Jun-94	26-Apr-94	routine gauging	69
Sirajganj	01-Jul-94	03-Jul-94	routine gauging	72
Bhairab Bazar	04-Jul-94	05-Jul-94	routine gauging	73
Aricha	06-Jul-94	08-Jul-94	routine gauging	74
Arial Khan	08-Jul-94	08-Jul-94	routine gauging	75
Baruria	09-Jul-94	10-Jul-94	routine gauging	77
Hardinge Bridge	14-Jul-94	15-Jul-94	routine gauging	79
Bahadurabad	14-Jul-94	16-Jul-94	routine gauging	80
Sirajganj	18-Jul-94	20-Jul-94	routine gauging	82
Mymensingh	19-Jul-94	20-Jul-94	routine gauging	83
Mawa	24-Jul-94	25-Jul-94	routine gauging	84
Tilly	25-Jul-94	25-Jul-94	routine gauging	85
Baruria	29-Jul-94	30-Jul-94	routine gauging	86
Hardinge Bridge	31-Jul-94	01-Aug-94	routine gauging	87
Kushtia/Gorai	03-Aug-94	03-Aug-94	routine gauging	88
Bahadurabad	06-Aug-94	09-Aug-94	routine gauging	89
Arial Khan Off-take	10-Aug-94	10-Aug-94	routine gauging	90
Bhairab Bazar	13-Aug-94	13-Aug-94	routine gauging	91
Baruria	21-Aug-94	23-Aug-94	routine gauging	92
Mawa	25-Aug-94	26-Aug-94	routine gauging	93
Sirajganj	25-Aug-94	31-Aug-94	routine gauging	94
Bahadurabad	01-Sep-94	06-Sep-94	routine gauging	95
Baruria	09-Sep-94	10-Sep-94	routine gauging	96
Aricha	11-Sep-94	13-Sep-94	routine gauging	97
Bahadurabad	21-Sep-94	28-Sep-94	routine gauging	98
Sirajganj	02-Oct-94	05-Oct-94	routine gauging	99
Bhairab Bazar	05-Oct-94	05-Oct-94	routine gauging	100
Arial Khan	07-Oct-94	07-Oct-94	routine gauging	101

Baruria	08-Oct-94	10-Oct-94	routine gauging	102
Mymensingh	11-Oct-94	11-Oct-94	routine gauging	103
Hardinge Bridge	11-Oct-94	12-Oct-94	routine gauging	104
Tilly	13-Oct-94	13-Oct-94	routine gauging	105
Kushtia/Gorai	16-Oct-94	16-Oct-94	routine gauging	106
Bahadurabad	18-Oct-94	22-Oct-94	routine gauging, with BWDB	107
Hardinge Bridge	20-Oct-94	20-Oct-94	routine gauging	108
Kushtia/Gorai	24-Oct-94	24-Oct-94	routine gauging	109
Arial Khan Off-take	25-Oct-94	25-Oct-94	routine gauging	110
Sirajganj	26-Oct-94	29-Oct-94	routine gauging	111
Mymensingh	27-Oct-94	27-Oct-94	routine gauging	112
Tilly	28-Oct-94	28-Oct-94	routine gauging	113
Baruria	28-Oct-94	28-Oct-94	routine gauging	114
Hardinge Bridge	31-Oct-94	01-Nov-94	routine gauging	115
Bahadurabad	07-Nov-94	08-Nov-94	routine gauging	117
Sirajganj	10-Nov-94	12-Nov-94	routine gauging	118
Baruria	14-Nov-94	15-Nov-94	routine gauging	119
Arial Khan Off-take	17-Nov-94	17-Nov-94	routine gauging	120
Bhairab Bazar	20-Nov-94	20-Nov-94	routine gauging	121
Bahadurabad	26-Nov-94	28-Nov-94	routine gauging	122
Tilly	28-Nov-94	28-Nov-94	routine gauging	123
Mymensingh	30-Nov-94	30-Nov-94	routine gauging	124
Hardinge Bridge	02-Dec-94	04-Dec-94	routine gauging	125
Kushtia/Gorai	05-Dec-94	05-Dec-94	routine gauging	126
Sirajganj	15-Dec-94	16-Dec-94	routine gauging	127
Baruria	18-Dec-94	18-Dec-94	routine gauging	128
Hardinge Bridge	03-Jan-95	04-Jan-95	routine gauging	129
Kushtia/Gorai	05-Jan-95	05-Jan-95	routine gauging	130
Hardinge Bridge	03-Feb-95	04-Feb-95	routine gauging	131
Bahadurabad	08-Feb-95	10-Feb-95	routine gauging	132
Sirajganj	11-Feb-95	13-Feb-95	routine gauging	133
Mawa	17-Feb-95	18-Feb-95	routine gauging (tidal), with BWDB	134
Bhairab Bazar	21-Feb-95	21-Feb-95	routine gauging	135
Arial Khan Off-take	23-Feb-95	23-Feb-95	routine gauging (tidal)	136
Baruria	25-Feb-95	25-Feb-95	routine gauging	137
Bahadurabad	11-Mar-95	12-Mar-95	routine gauging	138
Bhairab Bazar	17-Mar-95	20-Mar-95	routine gauging (tidal), with BWDB	139
Baruria	22-Mar-95	22-Mar-95	routine gauging	140
Tilly	24-Mar-95	24-Mar-95	routine gauging	141
Sirajganj	24-Mar-95	25-Mar-95	routine gauging	142
Hardinge Bridge	27-Mar-95	30-Mar-95	routine gauging	143
Bahadurabad	28-Mar-95	29-Mar-95	routine gauging	144
Mymensingh	03-Apr-95	03-Apr-95	routine gauging	145
Sirajganj	05-Apr-95	06-Apr-95	routine gauging	146
Baruria	14-Apr-95	14-Apr-95	routine gauging	147
Arial Khan Off-take	17-Apr-95	17-Apr-95	routine gauging	148
Bhairab Bazar	20-Apr-95	20-Apr-95	routine gauging	149
Hardinge Bridge	27-Apr-95	30-Apr-95	routine gauging	150
Bahadurabad	29-Apr-95	30-Apr-95	routine gauging	151

Sirajganj	01-May-95	02-May-95	routine gauging	152
Baruria	04-May-95	04-May-95	routine gauging	153
Sirajganj	19-May-95	20-May-95	routine gauging	154
Tilly	19-May-95	19-May-95	routine gauging	155
Mymensingh	20-May-95	20-May-95	routine gauging	156
Hardinge Bridge	25-May-95	26-May-95	routine gauging	157
Kushtia	27-May-95	27-May-95	routine gauging	158
Bahadurabad	02-Jun-95	05-Jun-95	routine gauging	159
Sirajganj	07-Jun-95	08-Jun-95	routine gauging	160
Baruria	10-Jun-95	12-Jun-95	routine gauging	161
Aricha	12-Jun-95	14-Jun-95	routine gauging	162
Mymensingh	14-Jun-95	14-Jun-95	routine gauging	163
Bahadurabad	17-Jun-95	22-Jun-95	routine gauging	164
Tilly	19-Jun-95	19-Jun-95	routine gauging	165
Kushtia/Gorai	21-Jun-95	22-Jun-95	routine gauging	166
Bhairab Bazar	07-Jun-95	07-Jun-95	routine gauging	167
Arial Khan Off-take	10-Jun-95	10-Jun-95	routine gauging	168
Hardinge Bridge	27-Jun-95	29-Jun-95	routine gauging	169
Sirajganj	28-Jun-95	29-Jun-95	routine gauging	170
Baruria	01-Jul-95	05-Jul-95	routine gauging	171
Bahadurabad	11-Jul-95	13-Jul-95	routine gauging	172
Sirajganj	11-Jul-95	13-Jul-95	routine gauging	173
Bahadurabad	21-Jul-95	25-Jul-95	routine gauging	174
Bhairab Bazar	26-Jul-95	26-Jul-95	routine gauging (peak)	175
Mawa	28-Jul-95	29-Jul-95	routine gauging (peak)	176
Mymensingh	30-Jul-95	31-Jul-95	routine gauging	177
Tilly	02-Aug-95	02-Aug-95	routine gauging	178
Baruria	05-Aug-95	06-Aug-95	routine gauging	179
Hardinge Bridge	09-Aug-95	10-Aug-95	routine gauging	180
Kushtia/Gorai	12-Aug-95	12-Aug-95	routine gauging	181
Bahadurabad	19-Aug-95	25-Aug-95	routine gauging	182
Mymensingh	22-Aug-95	23-Aug-95	routine gauging	183
Tilly	27-Aug-95	27-Aug-95	routine gauging	184
Arial Khan Off-take	28-Aug-95	28-Aug-95	routine gauging	185
Baruria	30-Aug-95	31-Aug-95	routine gauging	186
Bahadurabad	27-Aug-95	31-Aug-95	routine gauging	187
Sirajganj	02-Sep-95	04-Sep-95	routine gauging	188
Hardinge Bridge	05-Sep-95	05-Sep-95	routine gauging	189
Gorai/Kushtia	06-Sep-95	06-Sep-95	routine Gauging	190
Aricha	06-Sep-95	09-Sep-95	routine Gauging	191
Bhairab Bazar	14-Sep-95	14-Sep-95	routine Gauging	192
Arial Khan	16-Sep-95	16-Sep-95	routine Gauging	193
Mawa	18-Sep-95	22-Sep-95	routine gauging	194
Bahadurabad	18-Sep-95	21-Sep-95	routine Gauging	195
Sirajganj	24-Sep-95	27-Sep-95	routine Gauging	196
Hardinge Bridge	26-Sep-95	28-Sep-95	routine Gauging	197
Tilly	27-Sep-95	27-Sep-95	routine gauging	198
Mymensingh	26-Sep-95	26-Sep-95	routine gauging	199
Gorai/Kushtia	28-Sep-95	28-Sep-95	routine gauging	200

Dhaleswari	26-Dec-95	09-Jan-96	bathymetry	8031
Bahadurabad	25-Nov-95	20-Dec-95	topography	8032
Bahadurabad	25-Dec-95	06-Jan-96	topography	8032
Bahadurabad	09-Mar-96	14-Mar-96	topography	8032
Ganges-Jamuna Confluence	14-Jan-96	31-Jan-96	bathymetry	8033
Kamarjani	07-Jan-96	16-Jan-96	topography	8034
Kamarjani	15-Mar-96	18-Mar-96	topography	8034
Arial Khan	03-Feb-96	06-Feb-96	bathymetry	8035
Arial Khan	09-Feb-96	14-Feb-96	bathymetry	8035
Hurasagar	02-Mar-96	04-Mar-96	bathymetry	8036
Ganges-Jamuna Confluence	22-Mar-96	31-Mar-96	topography	8037
Gorai Off-take	02-Apr-96	07-Apr-96	bathymetry	8038
Bahadurabad	09-Mar-96	13-Mar-96	bathymetry	8039

A.3 Special surveys

Location	Start date	End date	Survey type	Number
Bahadurabad	31-Mar-94	01-Apr-94	study survey	9000
Baruria	12-Apr-94	13-Apr-94	study survey	9000B
Bahadurabad	18-May-94	19-May-94	bar dynamics	9000C
Bahadurabad	23-Jun-94	23-Jun-94	weekly discharge	9001
Bahadurabad	27-Jun-94	27-Jun-94	slope mapping	9002
Bahadurabad	28-Jun-94	28-Jun-94	weekly discharge	9003
Arial Khan	08-Jui-94	08-Jul-94	study 4.1.b	9004
Aricha → Sirajganj	11-Jul-94	11-Jul-94	bedforms	9005
Bahadurabad	13-Jul-94	13-Jul-94	weekly discharg	9006
Bahadurabad	16-Jul-94	16-Jul-94	weekly discharge	9007
Naryanganj->Aricha	28-Jul-94	28-Jul-94	bedforms	9008
Aricha → Bahadurabad	31-Jul-94	01-Aug-94	bedforms	9009
Hardinge Bridge	02-Aug-94	02-Aug-94	flow-discharge upstream	9010
Bahadurabad	02-Aug-94	02-Aug-94	weekly discharge	9011
Bahadurabad	02-Aug-94	04-Aug-94	near bed measurements	9012
Kushtia/Gorai	04-Aug-94	05-Aug-94	off-take study	9013
Kushtia → Aricha	06-Aug-94	06-Aug-94	bed material sampling	9014
Bahadurabad	05-Aug-94	05-Aug-94	slope mapping	9015
Old Brahmaputra	09-Aug-94	20-Aug-94	bed sampling	9016
Bahadurabad	10-Aug-94	14-Aug-94	bars and dune fields	9017
Bahadurabad	14-Aug-94	18-Aug-94	bar dynamics	9018
Bahadurabad	18-Aug-94	18-Aug-94	weekly discharge	9019
Bahadurabad → Aricha	19-Aug-94	20-Aug-94	bedforms	9020
Aricha → Bahadurabad	28-Aug-94	29-Aug-94	bedforms	9021
Bahadurabad	30-Aug-94	30-Aug-94	weekly discharge	9022
Bahadurabad	31-Aug-94	01-Sep-94	slope mapping	9022B
Bahadurabad	06-Sep-94	06-Sep-94	weekly discharge	9023
Bahadurabad → Aricha	07-Sep-94	08-Sep-94	bedforms	9024
Sirajganj → Bahadurabad	16-Sep-94	16-Sep-94	bedforms	9025
Bahadurabad	17-Sep-94	17-Sep-94	weekly discharge	9026
Bahadurabad	18-Sep-94	18-Sep-94	bar dynamics	9026B

Bahadurabad	19-Sep-94	20-Sep-94	bars and dune fields	9026C
Bahadurabad	28-Sep-94	28-Sep-94	weekly discharge	9027
Bahadurabad	29-Sep-94	30-Sep-94	slope mapping	9028
Bahadurabad → Aricha	01-Oct-94	06-Oct-94	bedforms	9029
Aricha → Sirajganj	15-Oct-94	15-Oct-94	bedforms	9030
Sirajganj → Bahadurabad	16-Oct-94	16-Oct-94	bedforms	9031
Bahadurabad	17-Oct-94	17-Oct-94	weekly discharge	9032
Hardinge Bridge	19-Oct-94	19-Oct-94	study campaign	9033
Hardinge Bridge	21-Oct-94	21-Oct-94	study campaign	9034
Bahadurabad	23-Oct-94	23-Oct-94	weekly discharge	9035
Bahadurabad → Sirajganj	25-Oct-94	25-Oct-94	bedforms	9036
Bahadurabad	04-Nov-94	04-Nov-94	bar dynamics	9037
Bahadurabad	06-Nov-94	06-Nov-94	turbulence study	9037B
Bahadurabad	26-Nov-94	26-Nov-94	weekly discharge	9039
Bahadurabad	04-Dec-94	12-Dec-94	study campaign	9040
Bahadurabad	13-Dec-94	13-Dec-94	weekly discharge	9041
Bahadurabad → Sirajganj	14-Dec-94	14-Dec-94	bedforms	9042
Sirajganj → Aricha	17-Dec-94	17-Dec-94	bedforms	9043
Bahadurabad	08-Feb-95	08-Feb-95	weekly discharge	9045
Bahadurabad → Aricha	11-Feb-95	14-Feb-95	bedforms	9046/47
Bahadurabad	06-Mar-95	10-Mar-95	bar dynamics	9048
Bahadurabad	11-Mar-95	11-Mar-95	weekly discharge	9049
Bahadurabad → Sirajganj	14-Mar-95	14-Mar-95	bedforms	9050
Bahadurabad	24-Mar-95	27-Mar-95	study: Morphology	9051
Bahadurabad	27-Mar-95	27-Mar-95	weekly discharge	9052
Bahadurabad	31-Mar-95	04-Apr-95	optimization survey	9053
Bahadurabad	03-Apr-95	03-Apr-95	weekly discharge	9054
Aricha → Sirajganj	27-Apr-95	27-Apr-95	bedforms	9055
Sirajganj → Bahadurabad	28-Apr-95	28-Apr-95	bedforms	9056
Bahadurabad	30-Apr-95	30-Apr-95	weekly discharge	9057
Bahadurabad → Sirajganj	01-May-95	01-May-95	bedforms	9058
Sirajganj → Aricha	03-May-95	03-May-95	bedforms	9059
Aricha-Sirajganj	18-May-95	18-May-95	bedforms	9060
Sirajganj → Bahadurabad	21-May-95	21-May-95	bedforms	9061
Bahadurabad	22-May-95	01-Jun-95	instrument performance	9062
Bahadurabad	20-Jun-95	20-Jun-95	peak flow gauging	9063
Bahadurabad	25-Jun-95	26-Jun-95	bar dynamics	9064
Hardinge Bridge/Gorai	27-Jun-95	28-Jun-95	off-take study	9065
Sirajganj	07-Jul-95	10-Jul-95	peak flow gauging	9066
Bahadurabad	07-Jul-95	10-Jul-95	peak flow gauging	9067
Bahadurabad	15-Jul-95	15-Jul-95	peak flow gauging	9068
Sirajganj	14-Jul-95	14-Jul-95	peak flow gauging	9069
Bahadurabad	16-Jul-95	20-Jul-95	study - joint BWDB	9070
Bahadurabad	26-Jul-95	31-Jul-95	float tracking	9071
Bahadurabad	26-Jul-95	30-Jul-95	optimization study	9072
Bahadurabad	31-Jul-95	01-Aug-95	Study survey-Leeds	9073
Bahadurabad (North)	02-Aug-95	03-Aug-95	transects etc.	9074
Bahadurabad	14-Aug-95	14-Aug-95	peak flow	9075
Bahadurabad	17-Aug-95	17-Aug-95	peak flow	9076

Baruria	29-Sep-95	30-Sep-95	routine Gauging	201
Aricha	03-Oct-95	05-Oct-95	routine gauging	202
Hardinge Bridge	02-Oct-95	02-Oct-95	routine gauging	203
Mawa	04-Oct-95	06-Oct-95	routine gauging	204
Arial Khan Off-take	06-Oct-95	06-Oct-95	routine gauging	205
Bahadurabad	08-Oct-95	10-Oct-95	routine gauging	206
Baruria	09-Oct-95	10-Oct-95	routine gauging	207
Gorai/Kushtia	12-Oct-95	12-Oct-95	routine gauging	208
Hardinge Bridge	12-Oct-95	13-Oct-95	routine gauging	209
Sirajganj	12-Oct-95	13-Oct-95	routine gauging	210
Aricha	16-Oct-95	17-Oct-95	routine gauging	211
Bhairab Bazar	18-Oct-95	19-Oct-95	routine gauging	212
Arial Khan Off-take	24-Oct-95	24-Oct-95	routine gauging	213
Tilly	25-Oct-95	25-Oct-95	routine gauging	214
Mymensingh	27-Oct-95	27-Oct-95	routine gauging	215
Baruria	26-Oct-95	27-Oct-95	routine gauging	216
Bahadurabad	28-Oct-95	30-Oct-95	routine gauging	217
Hardinge Bridge	29-Oct-95	29-Oct-95	routine gauging	218
Sirajganj	01-Nov-95	03-Nov-95	routine gauging	219
Gorai/Kushtia	29-Oct-95	29-Oct-95	routine gauging	220
Bhairab Bazar	02-Nov-95	02-Nov-95	routine gauging	221
Bahadurabad	09-Nov-95	12-Nov-95	routine gauging	222
Tilly	07-Nov-95	07-Nov-95	routine gauging	223
Gorai/Kushtia	09-Nov-95	09-Nov-95	routine gauging	224
Sirajganj	14-Nov-95	15-Nov-95	routine gauging	225
Baruria	16-Nov-95	18-Nov-95	routine gauging	226
Hardinge Bridge	18-Nov-95	19-Nov-95	routine gauging	227
Bahadurabad	18-Nov-95	19-Nov-95	routine gauging	228
Gorai/Kushtia	20-Nov-95	20-Nov-95	routine gauging	229
Arial Khan Off-take	20-Nov-95	20-Nov-95	routine gauging	230
Bhairab Bazar	23-Nov-95	23-Nov-95	routine gauging	231
Mymensingh	22-Nov-95	22-Nov-95	routine gauging	232
Baruria	28-Nov-95	29-Nov-95	routine gauging	233
Sirajganj	03-Dec-95	05-Dec-95	routine gauging	234
Bahadurabad	07-Dec-95	10-Dec-95	routine gauging	235
Sirajganj	11-Dec-95	12-Dec-95	routine gauging	236
Gorai/Kushtia	12-Dec-95	12-Dec-95	routine gauging	237
Hardinge Bridge	13-Dec-95	13-Dec-95	routine gauging	238
Bahadurabad	17-Dec-95	19-Dec-95	routine gauging	239
Mymensingh	21-Dec-95	21-Dec-95	routine gauging	240
Tilly	18-Dec-95	18-Dec-95	routine gauging	241
Arial Khan Off-take	23-Dec-95	24-Dec-95	routine gauging	242
Hardinge Bridge	26-Dec-95	26-Dec-95	routine gauging	243
Bhairab Bazar	28-Dec-95	28-Dec-95	routine gauging	244
Bahadurabad	07-Jan-96	09-Jan-96	routine gauging	245
Sirajganj	11-Jan-96	12-Jan-96	routine gauging	246
Baruria	14-Jan-96	15-Jan-96	routine gauging	247
Mymensingh	14-Jan-96	14-Jan-96	routine gauging	248
Tilly	16-Jan-96	16-Jan-96	routine gauging	249

Hardinge Bridge	20-Jan-96	20-Jan-96	routine gauging	250
Bahadurabad	22-Jan-96	23-Jan-96	routine gauging	251
Sirajganj	25-Jan-96	26-Jan-96	routine gauging	252
Baruria	27-Jan-96	28-Jan-96	routine gauging	253
Mawa	30-Jan-96	31-Jan-96	tidal survey	254
Baruria	09-Feb-96	10-Feb-96	routine gauging	255
Mawa	07-Feb-96	08-Feb-96	tidal survey	256
Sirajganj	13-Feb-96	14-Feb-96	routine gauging	257
Bahadurabad	16-Feb-96	17-Feb-96	routine gauging	258
Hardinge Bridge	01-Mar-96	02-Mar-96	routine gauging	259
Bahadurabad	29-Feb-96	01-Mar-96	routine gauging	260

A.2 Topographic and bathymetric surveys

Location	Start date	End date	Survey type	Number
Bahadurabad	20-Jun-93	03-Jul-93	bathymetry	8001
Bahadurabad	23-Aug-93	09-Sep-93	bathymetry	8002
Ganges-Jamuna Confluence	15-Oct-93	31-Oct-93	bathymetry	8003
Bahadurabad	10-Nov-93	18-Nov-93	bathymetry	8004
Hurasagar	23-Nov-93	30-Nov-93	bathymetry	8005
Arial Khan Off-take	01-Jan-94	10-Jan-94	bathymetry	8006
Ganges-Jamuna Confluence	19-Apr-94	05-May-94	bathymetry	8007
Kamarjani	01-Sep-94	26-Sep-94	bathymetry (special)	8008
Gorai Off-take	13-Oct-94	23-Oct-94	bathymetry	8009
Bahadurabad	01-Nov-94	11-Nov-94	bathymetry	8010
Kamarjani	10-Nov-94	20-Nov-94	bathymetry (special)	9038
Dhaleswari Off-take	24-Nov-94	11-Dec-94	bathymetry	8011
Ganges-Jamuna Confluence	13-Dec-94	25-Dec-94	bathymetry	8012
Hurasagar	25-Dec-94	29-Dec-94	bathymetry	8013
Gorai Off-take	06-Jan-95	20-Jan-95	bathymetry	8014
Gorai Off-take	15-Jan-95	14-Feb-95	topography	9044
Arial Khan Off-take	04-Feb-95	13-Feb-95	bathymetry	8015
Bahadurabad	24-Feb-95	27-Feb-95	bathymetry	8016
Kamarjani	06-Mar-95	13-Mar-95	bathymetry	8017
Dhaleswari Off-take	29-Mar-95	04-Apr-95	bathymetry	8018
Ganges-Jamuna Confluence	08-Apr-95	15-Apr-95	bathymetry	8019
Hurasagar	18-Apr-95	20-Apr-95	bathymetry	8020
Arial Khan Off-take	27-Apr-95	07-May-95	bathymetry	8021
Kushtia/Gorai	28-May-95	12-Jun-95	bathymetry	8022
Kushtia/Gorai	24-Jun-95	30-Jun-95	bathymetry	8023
Bahadurabad	03-Jul-95	25-Jul-95	bathymetry	8024
Gorai Off-take	08-Aug-95	14-Aug-95	bathymetry	8025
Kamarjani	05-Aug-95	19-Aug-95	bathymetry	8026
Gorai/Kushtia	08-Sep-95	24-Sep-95	bathymetry	8027
Gorai/Kushtia	16-Oct-95	20-Oct-95	bathymetry	8028
Bahadurabad	11-Nov-95	24-Nov-95	bathymetry	8029
Kamarjani	25-Nov-95	13-Dec-95	bathymetry	8030

Gorai Off-take	11-Aug-95	14-Aug-95	transect/floats/sed.etc	9077
Bahadurabad → Sirajganj	01-Sep-95	01-Sep-95	bedforms	9081
Sirajganj → Aricha	05-Sep-95	05-Sep-95	sand dunes	9082
Gorai/Kushtia	07-Sep-95	12-Sep-95	off-take study	9078
Aricha → Bahadurabad	10-Sep-95	11-Sep-95	bedforms	9083
Bahadurabad	12-Sep-95	16-Sep-95	bars and bedforms	9079
Bahadurabad → Sirajganj	22-Sep-95	22-Sep-95	bedforms	9084
Sirajganj → Aricha	28-Sep-95	28-Sep-95	bedforms	9085
Gorai/Kushtia	11-Oct-95	15-Oct-95	float tracking	9080
Hardinge Bridge	03-Oct-95	03-Oct-95	study - joint BWDB	9086
Aricha → Bahadurabad	06-Oct-95	07-Oct-95	bedforms	9087
Gorai/Kushtia	13-Oct-95	16-Oct-95	off-take transects etc	9088
Mawa	19-Oct-95	22-Oct-95	study - joint BWDB	9089
Bahadurabad → Sirajganj → Aricha	11-Oct-95	14-Oct-95	bedform study	9090
Aricha-Bahadurabad	24-Oct-95	25-Oct-95	bedform study	9091
Bahadurabad	07-Nov-95	08-Nov-95	study - joint BWDB	9092
Bahadurabad	05-Nov-95	09-Nov-95	study, UoL	9093
Bahadurabad	18-Nov-95	23-Nov-95	float tracking	9094
Kamarjani	05-Dec-95	19-Dec-95	float tracking	9095
Ganges-Jamuna Confluence	25-Jan-96	04-Feb-96	float tracking	9096
Bahadurabad	24-Feb-96	28-Feb-96	study, UoL	9097