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MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD

MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-016

ESTUARINE SURVEYS

August 1998

DHV CONSULTANTS BV

in association with

KAMPSAX INTERNATIONAL
DANISH HYDRAULIC INSTITUTE

DEVELOPMENT DESIGN CONSULTANTS
SURFACE WATER MODELLING CENTRE
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Technical Note on:

ESTUARINE SURVEYS AND DATA PROCESSING
BATHYMETRY, CURRENT PROFILING, SEDIMENT SAMPLING

Dhaka, June 1998

Project Name	:	Meghna Estuary Study (MES)
Location	:	Meghna Estuary
Key words	:	Instrumentation, survey procedures, training Data analysis and storage, data quality management Reference points, water level, waves, bathymetry Flow and sediment transport transects, bed sediments, salinity

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Acronyms and abbreviations

ACQ	:	Name of a computer system for data acquisition
ADCP	:	Acoustic Doppler Current Profiler
BIWTA	:	Bangladesh Inland Water Transport Authority
BTM	:	Bangladesh Transverse Mercator
BWDB	:	Bangladesh Water Development Board
CDSP	:	Char Development and Settlement Project
CSPS	:	Cyclone Shelter Preparatory Study
DGPS	:	Differential GPS
E	:	Easting (east coordinate in the BTM grid)
EGIS	:	Environmental and Geographic Information System
FAP	:	Flood Action Plan
GPS	:	Global Positioning System
HYDRO	:	Name of a computer system for data acquisition
JICA	:	Japan International Cooperation Agency
KMS	:	Kort- og Matrikelstyrelsen (name of a geoid model)
LGED	:	Local Government Engineering Department
LRP	:	Land Reclamation Project
PWD	:	Public Works Department (also name of a reference level)
MERIS	:	Meghna Estuary Resource Information System
MES	:	Meghna Estuary Study (= FAP5B)
N	:	Northing (north coordinate in the BTM grid)
RSP	:	The River Survey Project (= FAP24)
RTK	:	Real-time kinematic (GPS)
SoB	:	Survey of Bangladesh
SSD	:	Survey and Study Division (of BWDB)
S/T	:	Salinity/temperature (of sea water)
SWMC	:	Surface Water Modelling Centre
S4	:	(Name of a self-recording current meter)
WGS84	:	World Geodetic System 1984 (a geodetic model of the Earth)

Annotation: In this report, ± indicates one standard deviation. References are indexed by /slashes/. The glossary (Appendix F) explains some terms used in the report or related to its contents

Summary

The estuarine surveys of MES comprised instrumentation of BWDB/SSD's *'Anwesha'*, field work, laboratory analysis of sediments, and data processing. These activities spanned the entire project period from November 1995 to September 1998. The data collection in the field began in August 1996 and ended in January 1998.

The marine surveys comprised 18 cruises, totalling 260 net operation days of *'Anwesha'*. The following activities were completed:

- Establishment of 35 elevated reference points with accurate positions and elevations, and consistency validation of 15 BIWTA water-level gauge bench marks;
- 13 station-months of water-level gauging at 7 locations;
- bathymetric surveys covering 10,376 km², or 10,095 km line;
- 405 ADCP flow measurements in 19 cross-sections;
- collection and analysis of 1,200 suspended sediment samples from 827 profiles in the same 19 cross-sections;
- 342 temperature/salinity profiles; and
- collection and analysis of 450 bed samples.

The field work and the sediment analyses were made by BWDB/SSD with participation by SWMC, and with support and backstopping by specialists from the MES project team. The data analysis was made by the MES project team.

The following major accomplishments may be mentioned:

- Upgrading of *'Anwesha'* with state-of-the-art equipment for accurate, 3-dimensional RTK positioning and high-capacity ADCP current profiling, a spread which is particularly suited for morphological monitoring, and for flow measurements in the tidal-influenced channels of the estuary;
- training of professional staff from BWDB/SSD in the related techniques and procedures;
- establishment in the field of a grid of geodetic reference points, linked with the Survey of Bangladesh grid, which covers the rest of the country (but not the Meghna Estuary); and
- production of a set of data that provides a consistent description of the physical state of the estuary, as well as an important part of the basis for a quantification of the governing hydraulic processes.

The present report describes how the measurements were made, and when and where. Also, some comments and suggestions are made on continued monitoring.

Results of the measurements are stored in the MERIS data base and are discussed in separate MES reports.

1 Introduction

Meghna Estuary Study (MES) started on November 1, 1995, and is scheduled for completion in September 1998. The Study is a component (FAP5B) of the Flood Action Plan. It is executed by Government of Bangladesh, Ministry of Water Resources, represented by BWDB, with financial support from the governments of The Netherlands and Denmark. The Consultant was DHV, The Netherlands, with associates. The Study builds comprehensively on results of the Land Reclamation Project, which took place from 1977 to 1991.

The development objectives of MES are to increase the physical safety and social security of the some two million inhabitants of the study area, and to promote sustainable development in the coastal areas and on the islands. The immediate objectives are (i) to enhance and strengthen operational knowledge of hydraulic and morphological processes in the Meghna Estuary; (ii) to find suitable land reclamation and bank protection methods; (iii) to increase the capacity of BWDB to reclaim new land and protect the eroding river banks; and (iv) to prepare a plan with priority projects and programmes for flood protection, agricultural and socio-economic development for early implementation.

The present report presents the MES surveys 'as made'. It describes procedures and programme and gives an outline of the data collection. Also, a summary is made of experience gained during the work, together with observations on continued monitoring.

The objective of the MES estuarine surveys was to supply a part of the basis for assessment of the physical behaviour of the estuary. The produced data serve as a supplement to results and data from other sources, such as ongoing routine monitoring by BWDB, BIWTA, and Department of Meteorology, as well as satellite imagery, and historical data, notably from the Land Reclamation Project and the Cyclone Shelter Preparatory Study, executed by LGED in 1995-98.

Recommendations on survey instrumentation were presented to BWDB in the MES Interim Inception Report (December 1995), together with an outline of the planned survey activities. In the meantime, the survey programme has been modified, as a consequence of the improved understanding of the data requirements. Particularly, the need of bathymetric data was more urgent than anticipated at the beginning of the project, where a substantial volume of such data was available, but turned out to be partly obsolete due to rapid changes of planform and channel structure.

The field work was carried out in a close collaboration between the MES project organization and two permanent national institutions: BWDB/SSD and SWMC. BWDB/SSD, as owner of the survey vessel *'Anwesha'*, carried out the field data collection, and undertook the sediment analyses in the SSD laboratory in Chittagong. SWMC established the network of geodetic reference points and participated in the vessel surveys. The MES project organisation refurbished *'Anwesha'*, carried out the survey planning, supplied supervision and backstopping, and undertook the data analysis.

The closely related analysis of satellite imagery was made by EGIS, while the numerical hydraulic modelling was carried out by SWMC in collaboration with the MES project organization.

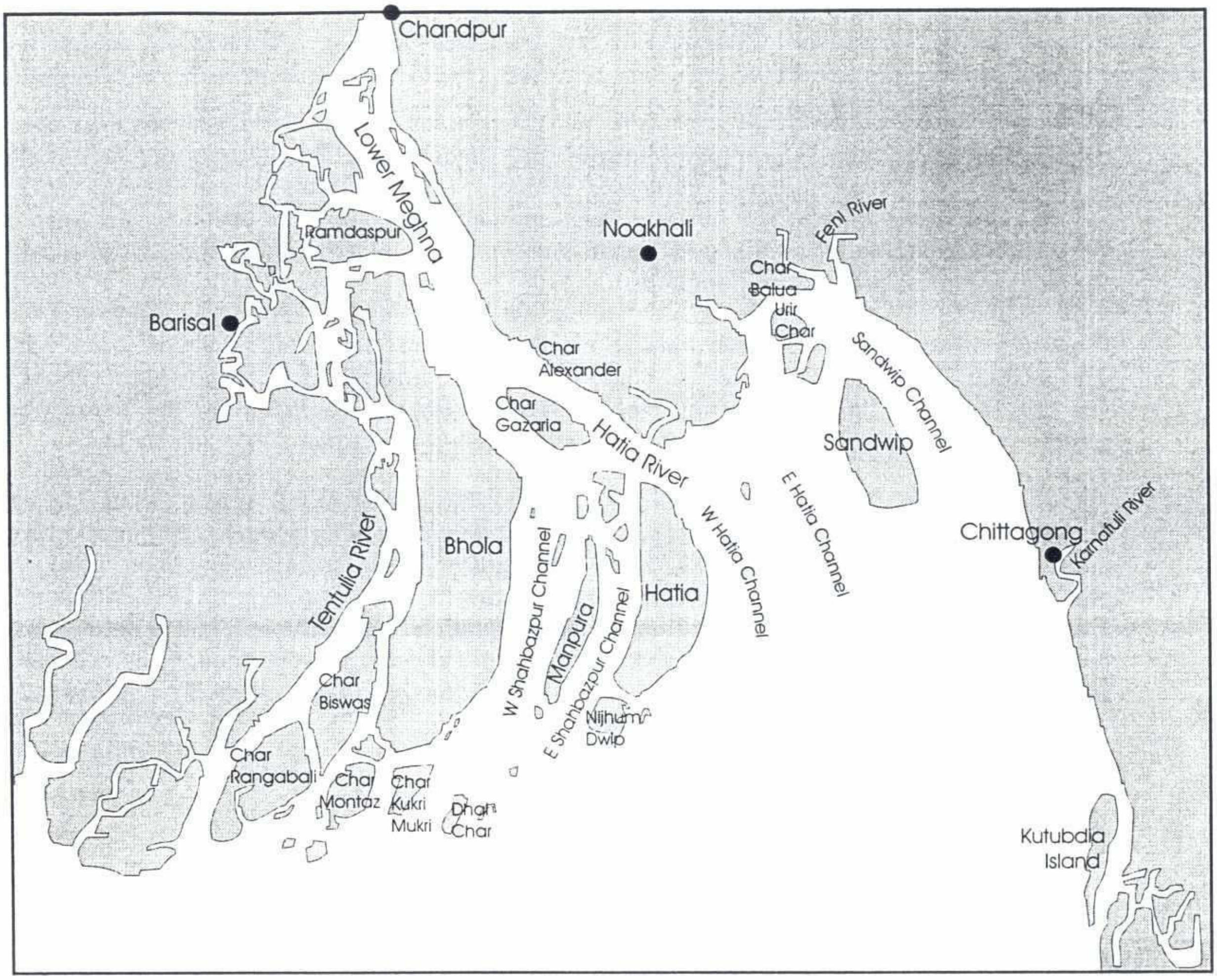

Figure 1.1: Meghna Estuary, key map

2 Background and context

2.1 Physical setting

Meghna Estuary is the easternmost sector of the Ganges delta. The Estuary conveys the joint discharge of the Ganges/Padma, Jamuna/Brahmaputra, and Meghna Rivers. Hereby, large volumes of water (some 1,200 km³ per year) and sediment (some 1,100 mio. t per year) pass the area. The catchment area is 1,520,000 km². It covers parts of India and China, all of Nepal and Bhutan, and almost all of Bangladesh.

There is a pronounced seasonal variation of wind, river discharge, and sediment supply from the river system. The highest discharges occur in August-September and the lowest in February. The 10-years peak flow at Chandpur has been estimated at 123,300 m³/s. The estuary forms a complex network of braided tidal channels with strong tidal streams in many places.

The entire Meghna Estuary (and a part of the upstream river system) is tidal-influenced all year. The BIWTA Tide Tables covers the area well. The tidal range increases in the direction from SW (around 4 m range at S Bhola) towards NE (around 7 m range at Sandwip). There is a pronounced seasonal sea level variation. The sea level is highest during the SW monsoon and lowest in the winter. The range of the seasonal variation is about 0.8 m in the southern part of the MES study area and about 2.7 m at Chandpur (at the northern boundary of the area). Extreme set-ups occur during cyclones, where the storm surge can reach 5 - 7 m (on a 20-100 years basis, in the Chittagong-Bhola sector).

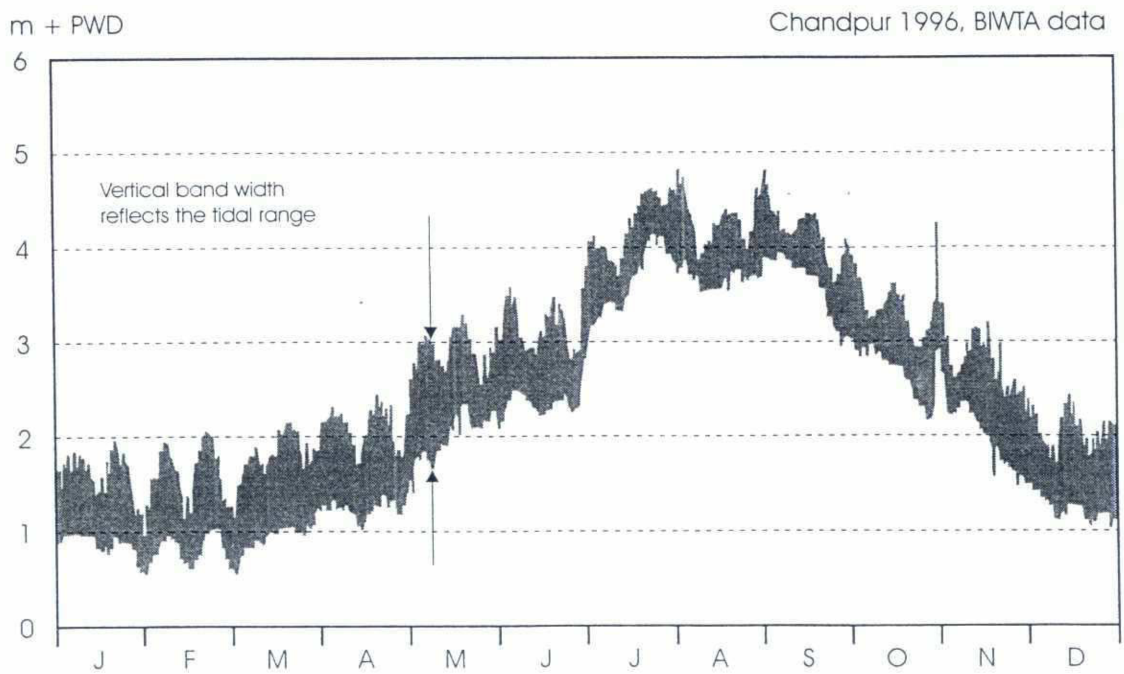

Figure 2.1: The Chandpur hydrograph

In the estuary, fresh water from the rivers meets with saline ocean water from the Bay of Bengal. Due to strong currents and shallow depths, density stratification is not very characteristic. Rather, there are fronts (or transition zones) between the water masses. The location of these transition zones depends on the river discharge and the tide.

The depth of the inner part of the estuary is less than 10 m, except for the thalwegs of the flow channels. Wave heights are generally moderate. In the inner parts of the estuary, and in its extensive shallow areas, the waves are predominantly generated by direct (local) wind action.

Sediments, fine sand and silt, are supplied by the rivers, and are transported within the estuary mainly by the tidal streams. The area is characterized by a highly dynamic morphology, with flow channels shifting their course, and with intermittent erosion and accretion of banks and tidal flats. There is a moderate net accretion, currently estimated by MES at around 10 km² per year (1976-96).

The cause-effect relationships and their interaction can be conceptualized in different ways. One attempt to summarize the most important physical processes is shown in Figure 2.2.

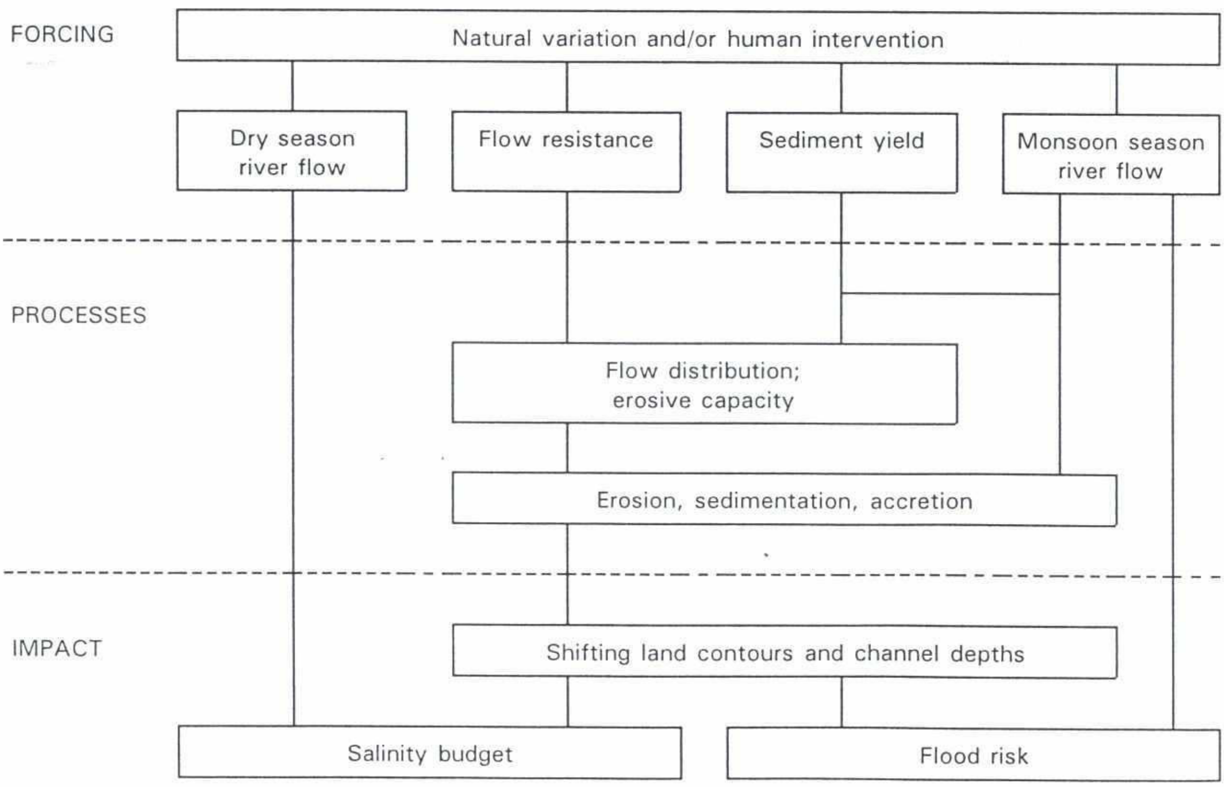

Figure 2.2: Key physical cause-effect relationships in the Meghna Estuary

The variable forcings can be divided into external and local determinants. They comprise:

Dry season conditions (affecting mainly the salinity):

(i) changed flow caused by natural climate fluctuations;
(ii) changed flow caused by upstream irrigation withdrawal or regulation (such as diversion, or large-scale bank protection schemes); and
(iii) long-term sea level changes.

Monsoon season conditions (affecting first the sediment budget, and subsequently the salinity and the flood risk):

(iv) changed flow and sediment yield caused by natural climate fluctuations, earthquakes, etc.; and
(v) changed flow and sediment yield caused by upstream intervention (such as diversion, large-scale bank protection schemes, or deforestation).

Local intervention in the estuary (affecting first the flow distribution, and in turn the sediment budget, the salinity, and the flood risk):

(vi) changed flow resistance caused by natural morphological development;
(vii) changed flow resistance caused by intervention (such as bank protection, cross-dams, etc.);
(viii) changed erosive capacity related to a changed flow resistance (causing a re-distribution of the flow); and
(ix) changed erosive capacity related directly to intervention (such as bank protection, cross-dams, etc).

As clearly illustrated during the morphological studies carried out by MES, the natural planform development is highly dynamic. The development seems to follow a certain pattern over a period of several years, whereafter the pattern shifts to a new one, and the development continues along a different path.

Regarding time scales for response to external forcing, it is noted that the hydrodynamic effects (including surface water salinity developments) will be rather immediate (occurring within one season or less), while the general morphological effects will develop unevenly and slowly (over several years or even decades).

2.2 Operating conditions

The best operation conditions occur in BIWTA's period of *'fair weather towage',* which is from November 15 to February 15. In this period, the sea is generally calm. In January and February, fog in the morning hours is expected to be the main obstacle to operation.

The worst weather (frequent and unpredictable storms) occurs from mid April to end of June, before the onset of the SW monsoon. Strong winds and high waves occur during the SW monsoon, for which reason operation in this period should be confined. However, this is also the time of the peak flow in the river system. Therefore, there is a particular need of field work during the monsoon.

Month	Monsoon	River flow	Operating conditions
J			good
F			good
M			medium
A			medium
M			adverse
J	SW		bad
J	SW	high	adverse
A	SW	highest	adverse
S	SW	high	medium
O	SW		medium
N			medium
D			good

Table 2.1: Summary of typical operating conditions

Cyclones can occur all year. They are more frequent in the pre- and post monsoon periods, May, October, and November, and less frequent in January through March. On an average, 0.7 cyclones occur per year somewhere in Bangladesh. Among these, one in four is severe. Ordinary depressions are much more frequent. For example, around 6 ordinary monsoon depressions occur per year in the period from June through September. Such depressions give strong winds and extreme rainfalls.

Thunderstorms are particularly frequent in March, April, May and October (30-40 occurrences per year in this period). They can give strong winds. *Nor'westers,* or *Kal Baisakhi,* occur from March to May, with wind speeds of 75-150 km/hour. Unlike cyclones and other storms related to moving depressions, they nor'westers come suddenly and are difficult to predict.

Operation during the night is regarded as unsafe due to poor charts, and drifting fishing nets and debris, and also considering the rather casual navigation practices that are customary.

2.3 Data sources

MES used hydraulic data from a variety of sources, as listed in Table 2.2.

National agencies	
BWDB	Water-level data, benchmark elevations
BIWTA	Water-level data (including tidal predictions), bathymetric data, benchmark elevations
Survey of Bangladesh	Water-level data, benchmark elevations
Meteorological Department	Wind, air pressure
Other projects (previous and in progress)	
Land Reclamation Project (LRP)	Historical bathymetric data and coastline contours, flow distribution, salinity, sediment concentrations and sediment properties
Cyclone Shelter Preparatory Study	Bathymetric data, benchmark elevations, land elevations
Satellite imagery	
LANDSAT data (processed and interpreted for MES by EGIS)	Coast contours 1995/96 and 1997/98; historical coastline development
MES surveys	
Geodetic surveys (by SWMC)	Reference benchmarks
Vessel surveys (by BWDB/SSD's *'Anwesha'*)	Bathymetry, flow, salinity, sediment transport
Continuous recordings	Water-level and waves

Table 2.2: Primary sources of hydraulic data

Figure 2.3: The BIWTA water-level gauge at Chandpur

2.4 Data applications

The hydraulic survey activities were planned and initiated at a stage where the data demand was known in general terms only. Therefore, the surveys were not (and could not be) targeted towards specific impact studies for the priority schemes that were selected in a later stage of the project. Rather, they aimed at a versatile description of the most important hydraulic states and processes in the area.

Data applications within the framework of MES were:

- Conceptual design for feasibility analysis of planned intervention (for example seabed elevations and sea levels);
- baseline description as a reference for hydraulic, morphological, and general environmental impact assessment (for example flow, sediment transport and salinity); and
- basis for set-up and calibration of the numerical hydraulic model, which is in turn applied for hydraulic feasibility and impact studies of potential intervention.

Data produced by MES were supplied to several other studies, such as:

- Cyclone Shelter Preparatory Studies I & II;
- Coastal Embankment Rehabilitation Project II;
- Flood Forecasting and Warning Centre (FAP10);
- Rural Development Project No. 16 (Pratuakhali); and
- Char Development and Settlement Project.

In general, hydraulic data from the estuary can be applied for a variety of purposes, such as:

- Monitoring of the morphological development, including an improved description of states and processes, as a basis for adjustment of the general physical planning basis and any coastal zone management efforts;
- monitoring of salinity distributions, as an important part of the basis for national management of water resources and water quality;
- hydrodynamic monitoring (of water-levels and flow patterns), in connection with the national flood management and flood forecasting;
- as a part of the basis for environmental feasibility studies, impact prediction, and impact monitoring in relation to the offshore industry; and
- a variety of non-routine purposes, such a specific feasibility, design or impact studies in the downstream river reaches or in the coastal zone (embankments, drainage, irrigation, and other schemes and structures).

3 Instrumentation and survey procedures

The survey methods were identified considering the capacity and quality requirements of the project, and with a view to experience gained and reported by the LRP and the RSP. The methods are summarised in Table 3.1.

Measurement	Method
Positioning	RTK-GPS
Water-level and waves	Pressure gauge
Bathymetry	Echo sounder + RTK
Flow	ADCP
Sediment concentration	Pump sampling, integrating bottle, Owen sampler
Salinity	Direct reading instrument
Bed samples	Van Veen sampler

Table 3.1: Summary of measurements and methods

3.1 Horizontal and vertical control

MES applied a variety of data sources. Therefore, the need of consistency was particular, for example for morphological analysis (involving comparison between recent and past surveys and satellite mappings) and hydrodynamic modelling (involving joint application of bathymetric data and water-level recordings). Also, for design and construction of embankments and drainage systems, it is of decisive importance to establish a link in the field between for example calculated mean sea level and actual land level.

Such circumstances indicated the use of a general and well-defined coordinate system. At the same time, however, the geodetic network in the area was in a state that was less than ideal. Several sets of bench marks had been established by BWDB, BIWTA, and LRP, but several of these were lost due to erosion of embankments, their coordinates were in some cases believed to be uncertain due to the logistic difficulties, and they were not linked with the new Survey of Bangladesh/JICA geodetic grid covering the rest of the country.

An other consideration was that the existing bench marks were located on the ground, whereas elevated reference points were more practical for the purpose of satellite-based position fixing and radio transmission of reference signals as planned for the MES surveys.

For these reasons, it was decided to implement a new network of elevated reference points, mainly located on cyclone shelter roofs, and to establish their coordinates by a new geodetic survey. The rationale is illustrated in Figure 3.1. It is seen that with respect to bathymetric surveying of bed elevations, the approach is basically simpler and more direct than the traditional way, where depths are recorded at the vessel's location and are reduced to the applied datum via water-level recordings at some other location.

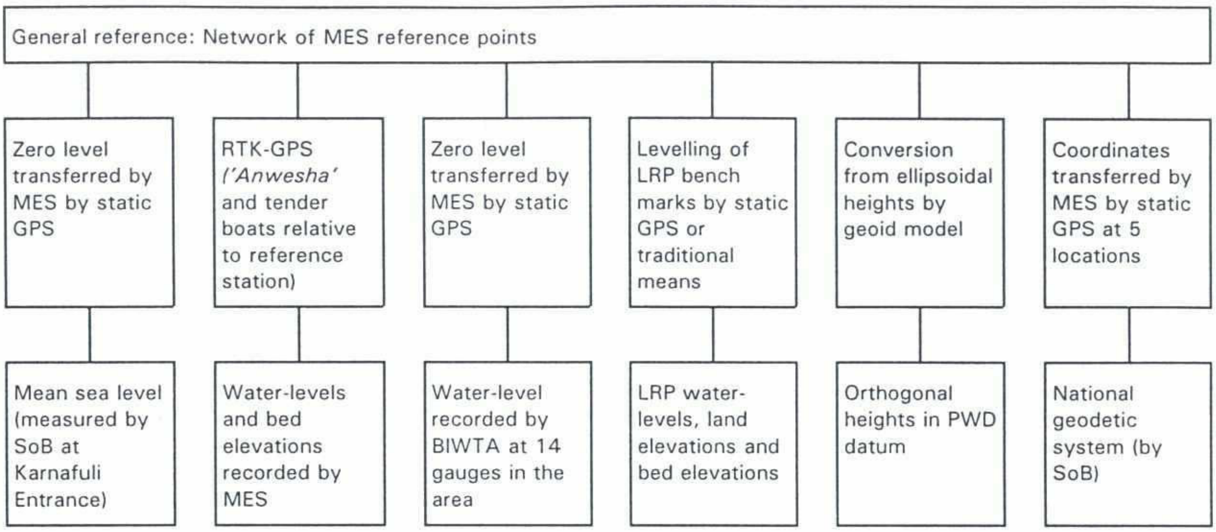

Figure 3.1: Linking of vertical levels

The basic survey was carried out by SWMC in March-April 1996. One Trimble 4000 SE receiver and two Trimble 4000 SSi receivers were applied for the purpose. A supplementary survey was conducted in June 1997. The surveys have been reported separately in /5/ and /9/.

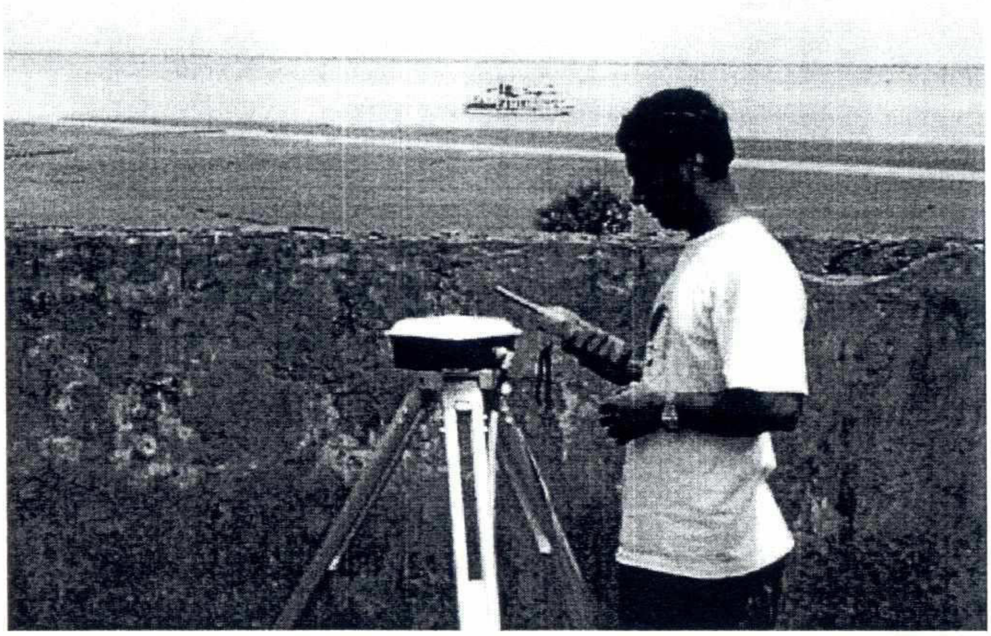

Figure 3.2: View from an elevated reference point

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3.2 Water-level and waves

In order to supplement the data from BIWTA's water-level stations, a number of pressure gauges were deployed by MES. The instrument selected for the purpose was a tide/wave self-recording pressure gauge, which was modified for the purpose of MES. The same instrument was applied for the air pressure recordings that are required for converting the total (water + air) pressure to a water-level.

The pressure gauges were installed on steel pipes that were wash-bored into the seabed.

Zero levels were established by interpolating the MSL relative to PWD at four tidal stations distributed over the entire study area, and comparing with the average level of the recordings. Some corrections to these zero levels were subsequently identified in connection with the hydrodynamic model simulations /13/.

Instrument type:	Van Essen 'Diver' pressure gauge		
Range:	10	m	
Resolution:	0.5	cm	
Recording interval:	120	minutes	
Duration of each recording:	600	seconds	
Sampling interval during recording:	0.5	seconds	
Data storage capacity:	3	months	1)

1): (depending on operation mode)

Table 3.2: Pressure gauge recording cycle

3.3 *'Anwesha'*

The major part of the estuarine surveys was carried out from *'Anwesha'*. The vessel was donated to BWDB by The Netherlands in connection with the LRP. It is stationed in Patenga (Chittagong). The vessel is owned and operated by BWDB/SSD.

Key specifications of the vessel are listed in Table 3.3. As a supplement, a rubber boat (Sillinger 490 RIB PRO) was acquired in 1996. It has a 60 horsepower Mercury water jet engine. Further, one additional minor outboard engine boat called DHE was acquired by MES from FAP24.

Built (Akerboom, Leiden, Holland):	1980
Length:	32 m
Beam:	7 m
Draft (summer mark):	1.9 m
Draft (normal operation):	1.4 m
Speed:	10 knots
Tank capacity, freshwater:	22,000 l
fuel:	36,000 l
Power supply (2x85 kW + 20 kW):	440/220 V AC
2 tender boats, length:	7 m
draft:	1 m
speed:	8 knots

(Partly after *'Holland Shipbuilding', May 1980, pp. 36 - 37)*

Table 3.3: Key specifications of 'Anwesha'

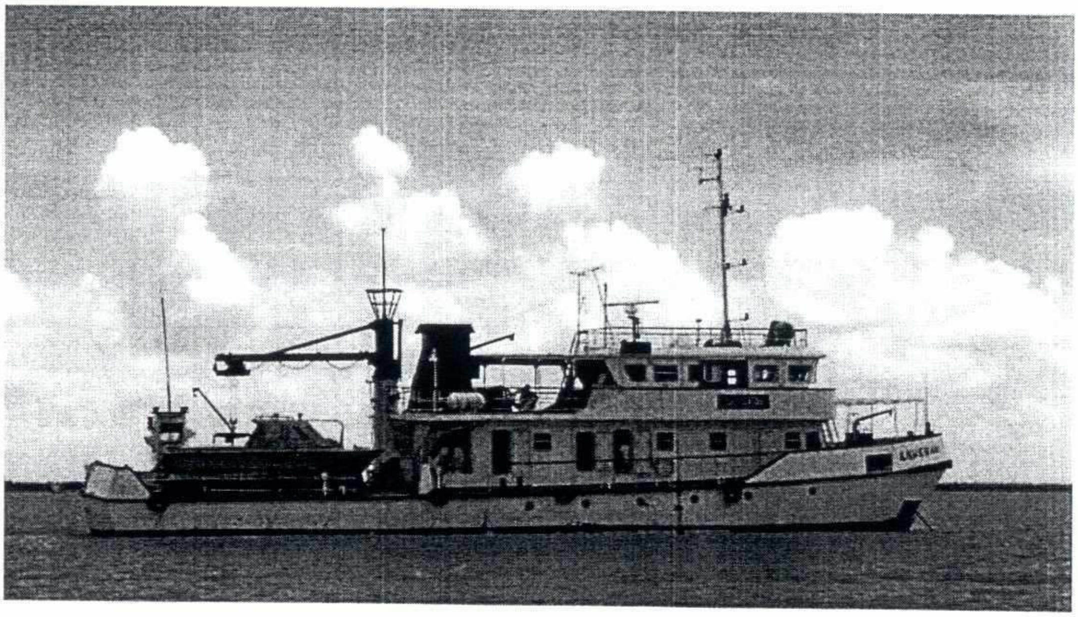

Figure 3.3: BWDB/SSD's survey vessel 'Anwesha'

The instrumentation of the vessel and the tender boats is summarised in Appendix C. In brief, bathymetry surveys with RTK positioning can be made from *'Anwesha'* and the two tender boats at the same time. ADCP flow gauging can be made by either *'Anwesha'* or by one of the tender boats. Sediment sampling by pumping can be made only from *'Anwesha',* while sampling by integrating bottle can be made from both tender boats. S/T profiling, Owen Tube sampling and bed sampling are normally made from a tender boat, but can be made from *'Anwesha'* as well.

Figure 3.4: A tender boat

The applied field sheets are shown in /7/. An outline of the field documentation is shown in Figure 3.5.

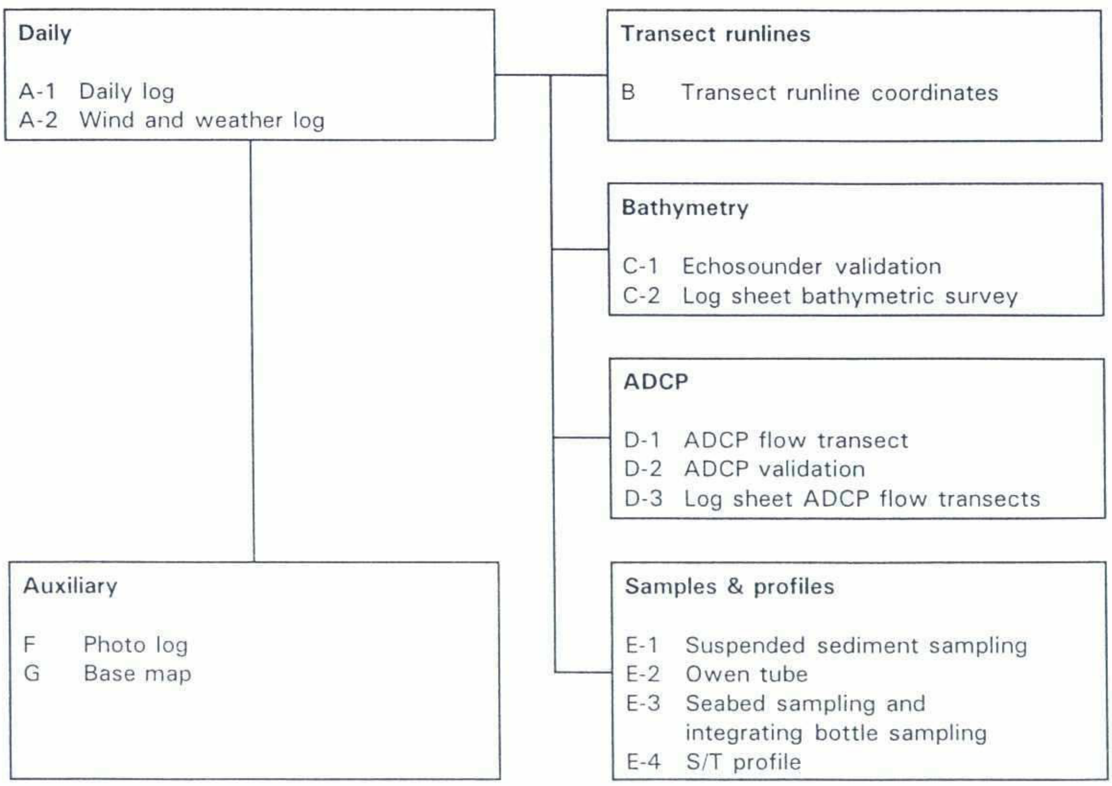

Figure 3.5: Overview of field sheets

3.4 Bathymetry

The bathymetric surveys were made for the following reasons:

- To supply data to be used directly for the morphological studies;
- to supply data and information to support interpretation of satellite photos and old data, also mainly for the sake of the morphological analysis;
- to provide part of the design basis for land development schemes; and
- to provide input data to the hydrodynamic models.

One Knudsen 320 dual frequency echosounder (30/200 kHz) and two DESO 14 echosounder (200 kHz) were applied, the former by *'Anwesha'* and the latter from the tender boats. Their performance is summarised in Table 3.4.

Depth range:	0 - 100 m
Depth resolution:	0.07 m (30 kHz), 0.01 m (210 kHz)
Sampling frequency:	4 per s
Logging frequency:	1 per s
Typical operational speed:	4 - 6 knots (2 - 3 m/s)
(This gives a sounding value for appr. every 2 - 3 m)	

Table 3.4: Echosounder performance and operational speed

The standard deviation of the WGS84 -> PWD conversion (estimated at ± 0.3 m) is the predominant contribution to the (single registration) accuracy of the bathymetry data, which is as follows:

	Accuracy	Resolution
Echo sounder, instrument performance:	± 0.1 m	± 3 cm
WGS84 elevation by RTK (depending on range):	± 0.2 m	± 5 cm
Estimated combined standard deviation, seabed elevations in WGS84:	± 0.2 m	± 6 cm
WGS84 -> PWD conversion:	± 0.3 m	(nil)
Estimated combined standard deviation, seabed elevations in PWD:	± 0.4 m	± 6 cm

It is seen that the (relative) resolution is much better than the (absolute) accuracy. A part of the WGS84 error is systematic, as well as the entire WGS84 -> PWD conversion error. The effect of these errors can largely be eliminated by maintaining the same procedure (and the same reference point) for successive surveys. The random parts of the echo sounder and the RTK errors are highly reduced by smoothing over a large number of single registrations. Thus, it is estimated that the technique can identify seabed level variations (due to erosion or sedimentation) of a few cm only, and that an erosion/accretion rate can be determined with an error of around 12 cm (= two standard deviations) per time span between successive surveys in case of a flat seabed. If the seabed is not flat there will be an additional error, because the survey lines are not exactly in the same place, but may be dislocated by a some m. The error induced in this way depends on the depth (because the bed area covered by the echo sounder ray increases with the depth), the bed level gradient, and the applied smoothing routine. The error contribution would typically be a few cm.

The daily routine for bathymetric survey work comprised:

a. Check of echosounders and S/T profiles;
b. reconnaissance lines, as appropriate;
c. measurements as per work plan;
d. longshore lines at high tide;
e. coastline observations; and
f. occasional photo documentation.

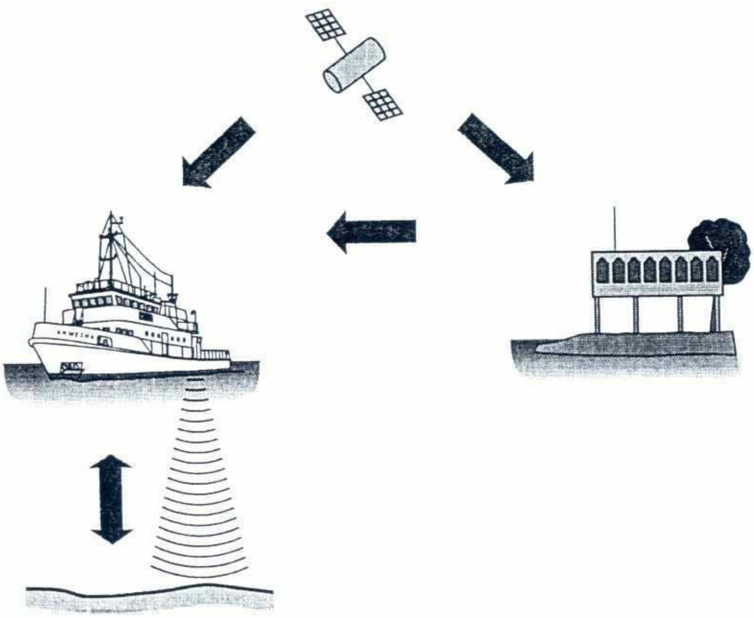

Figure 3.6: Vertical control during bathymetric survey

3.5 Flow and sediment transport transects

Flow gauging was made by a 600 kHz ADCP from RD Instruments. The settings listed in Table 3.5 were applied.

Bin height (depth resolution):	0.5 m
Sampling frequency:	1 per 0.7 - 0.9 s
Frequency of ADCP signal:	600 kHz
Current velocity range:	0 - 10 m/s
Current velocity resolution (1):	0.01 m/s
Averaging period (2):	25 s
Typical operational speed (2):	4 knots (2 m/s)

(1) The resolution depends on bin height and averaging period
(2) This gives a profile for appr. every 50 m

Table 3.5: Applied ADCP settings and operational speed

Figure 3.7: The ADCP lifted from its tubewell onboard 'Anwesha'

Positioning was done by RTK.

According to the planned standard procedure, a fixed self-recording electromagnetic current meter (InterOcean S4) was to be deployed in order to measure the tidal stream. It could either be placed in a traditional mooring, or suspended from a fishing vessel, anchored in the same flow channel as the transect, and as close as possible to it. For 'composite' transects (that are groups of transects in a braided channel), it should be located in the main flow channel. In order to cover the full tidal cycle, it should be deployed for at least 25 hours at each location. Settings are listed in Table 3.6.

However, it turned out that there were so many drifting fishing nets on the transect location that deployment of the S4 was not attempted. Instead, the ADCP transects were repeated, and supplemented with ADCP logging at a fixed location when the vessel was not operating, for example during the night.

The transect measurements comprised a combination of flow gauging and sediment transport measurements. Suspended sediment samples were taken

(i) in order to characterise the sediment with respect to settling velocity and other properties; and
(ii) to estimate the sediment transport.

The samples were taken either (1) as vertically integrated samples (from the tender boats), (2) as vertical profiles of pump samples (from *'Anwesha')*, or (3) by Owen tube (from the tender boats or from *'Anwesha')*.

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Current speed range (1):	0 - 3.5 m/s
Current speed resolution (2):	0.002 m/s
Temperature range:	-5 - 45 °C
Temperature resolution:	0.05 °C
Sampling frequency:	2 per s
Sampling cycle duration:	1 minute (120 samples)
Sampling cycle frequency:	every 15 minutes
Data storage capacity (3):	35 days

(1) Can be selected from 0.5 m/s to 6 m/s
(2) Depends on the selected range and operation mode
(3) Assuming one registration every 15 minutes. The storage capacity is 64 kB or 3449 data records; the period depends on the operation mode

Table 3.6: Applied S4 settings

The pump samples and the Owen tube samples were always accompanied by an S/T profile. The pump sample profiles were always accompanied by a current profile, either by ADCP, or by S4, when the S4 was not deployed for continuous registration. Positioning was made by RTK.

The Owen tube was used instead of pump sample profiling, as necessitated for practical reasons (typical due to draft constraints or logistical constraints).

The sampling profiles were located along the flow transect runline, with a spacing as follows:

- Integrated samples: Every 500 m across the transect, but maximum 5 and minimum 3 locations in each channel;
- pump samples: 1 in each channel, in its deepest part;
- Owen tube samples: As pump samples.

Pump capacity (adjustable):		2 l/minute
Sampling height above seabed (for near-bed samples):		appr. 0.5 m
Flushing of umbilical:		2 minutes
Sample volume: standard:		1 l
	settling tube samples:	25 l
Sampling duration,	standard	60 s
	settling tube samples:	750 s

Table 3.7: Suspended sediment sampling by pumping

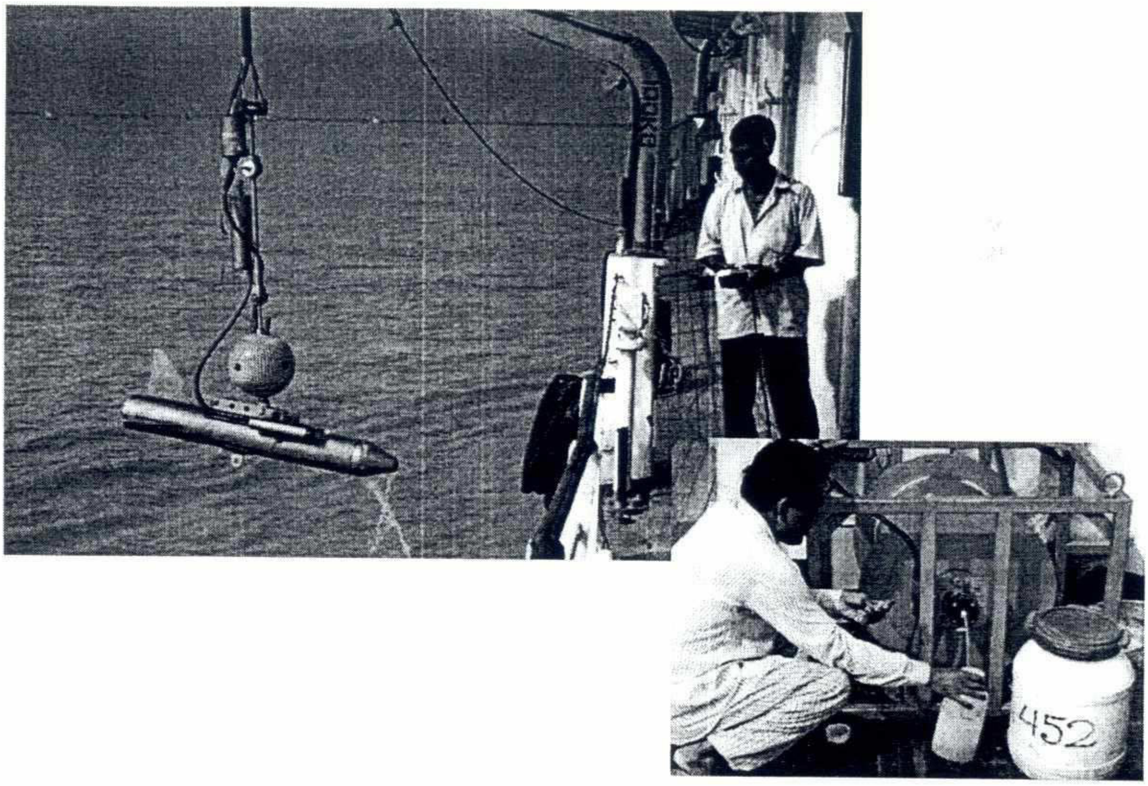

Figure 3.8: The pumping arrangement with umbilical and S4 current meter

The procedure for sampling by Owen tube is indicated in Table 3.8.

Depth	Suspended sediment concentration	Settling tube tests
0.2 D	+	+
0.4 D	+	
0.6 D	+	
0.8 D	+	+
0.5 m above the river bed	+	
Total per vertical	5	2

Table 3.8: Depths of suspended sediment samples

Samples are taken at mid-depth.

Withdraw the tube as soon as it has been closed. Don't shake it or anything, simply raise it to vertical position and start time-counting at the same time. (Time counting starts before it has been placed in its rack).

T = 0 is the time when the tube is raised and the time counting starts.

Take 10 samples (0.2 l each) at the following target times (which cover appr. 8-125 microns):
1 - 2 - 4 - 8 - 16 - 24 - 32 - 48 - 64 - 64 minutes after T = 0

Write down both the target times and the actual sampling times (in Form E-2), they can be different.

If experience shows that there is no sediment in the last 2 or 3 samples, the samples should be taken a little faster:
1 - 2 - 4 - 8 - 12 - 16 - 24 - 32 - 48 - 48 minutes after T = 0, or
1 - 2 - 4 - 8 - 12 - 16 - 20 - 24 - 32 - 32 minutes after T = 0.

Table 3.9: Owen tube sampling

The combined transect measurements of flow, sediment transport and S/T are summarised in Tables 3.9 and 3.10. The minimum net duration of the routine was 25 hours.

To be done the first time at each transect:

1	General reconnaissance
2	Some bathymetry lines at 200-500 m line spacing
3	Selection of a regular transect, definition of runline

Table 3.10: Preparation of transect gauging

1	Installations	
	1.1	Installation of reference station
	1.2	Deployment of self-recording current meter, normally from a fishing boat
	1.3	Installation of temporary staff gauge (arbitrary zero level)
2	Supplementary current measurements Surface current speed and direction (including slack water) to be measured by ADCP every 30 minutes throughout the programme. Readings to be entered into a table	
3	ADCP measurements	
	3.1	1 two-way crossing targeted at maximum ebb current (outflow)
	3.2	1 two-way crossing targeted at maximum flood current (inflow)
4	Sediment sampling and S/T profiles	
	4.1	1 pump profile targeted at maximum ebb current (outflow)
	4.2	1 pump profile targeted at maximum flood current (inflow)
	4.3	Around 4 integrated bottle samples targeted at maximum ebb current (outflow)
	4.4	Around 4 integrated bottle samples targeted at slack water
	4.5	Around 4 integrated bottle samples targeted at maximum flood current (inflow)
	4.6	1 S/T profile for every pump profile and every integrated bottle sample
	4.7	2 more S/T profiles targeted at high tide and low tide (slack water)
5	Seabed sampling 6 - 14 bed samples along the transect runline	
6	Bathymetry profiles Bathymetry profiles to be made (a) in the transect runline, (b) 500 m upstream, and (c) 500 m downstream (total: 3 lines)	
7	Withdrawal of instruments	
	7.1	Withdrawal of reference station
	7.2	Withdrawal of self-recording current meter
	7.3	Withdrawal of temporary staff gauge
	7.4	Daily data back-up, check of field report
Note:	If the self-recording current meter cannot be deployed (due to fishing nets or waves), the number of ADCP transects must be increased to cover the entire tidal cycle by hourly crossings for a whole day	

Table 3.11: Summary of transect routine

3.6 Bed sediments

Sea bed samples were collected in connection with the suspended sediment sampling. Normally, the samples were taken along a runline across a flow channel, aiming at covering the entire channel between the two high water lines, and including the deepest part of the channel. Between 10 and 15 samples were collected along such a transect, approximately as indicated on Figure 3.9.

Positioning was done by RTK from the vessel, and by RTK or GPS on land. In connection with their collection, the samples were visually classified.

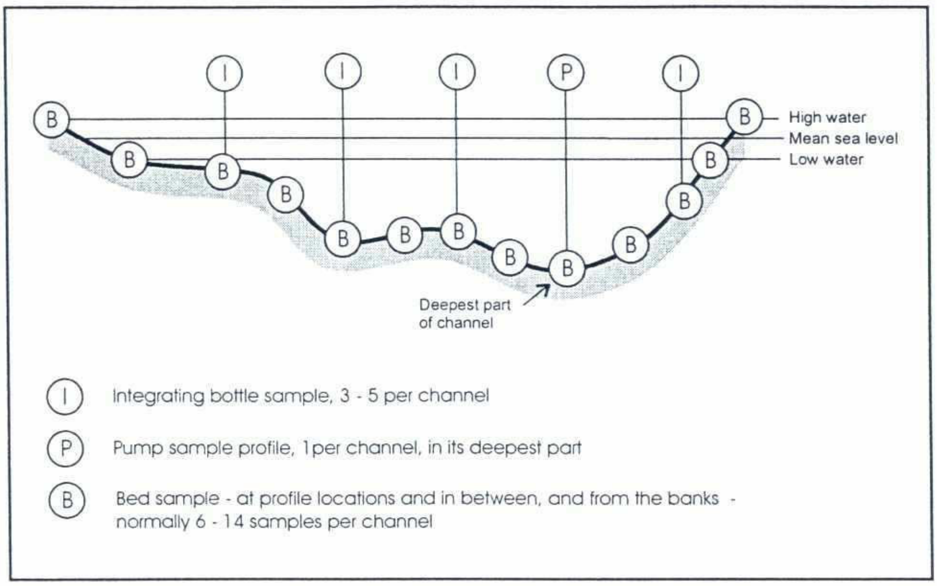

Figure 3.9: Location of profiles and sea bed samples

3.7 Salinity

The Meghna Estuary is a zone of transition between the fresh-water river discharge and the saline sea water of the Bay of Bengal. Mapping of the S/T distribution in the estuary is of a considerable importance, for the following reasons:

- Salinity and temperature variations can affect the echosoundings, and thereby the comparison of depth contours measured on different occasions;
- salinity gradients can generate density-driven flows, for example a flow near the sea bed in the opposite direction of the net current. Such a reverse near-bed flow can highly influence the mode of sediment transport, because high concentrations of coarse sediments occur near the sea bed;
- an enhanced sedimentation can occur in zones of mixing between fresh and saline water, due to flocculation of fine river sediments; and, last but not least,
- the salinity is an important water quality determinant.

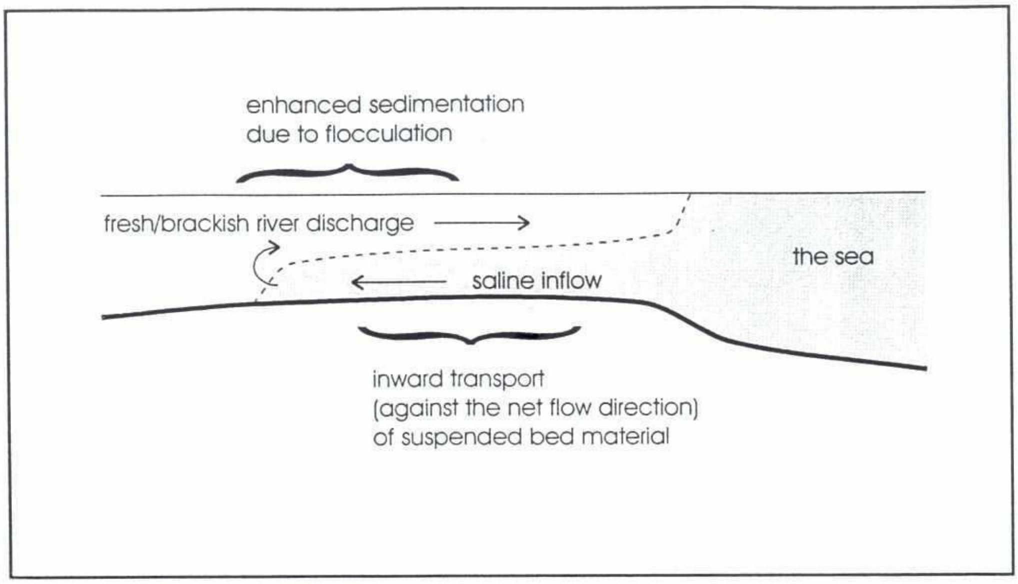

Figure 3.10: Significance of S/T mapping

2 portable S/T profilers, type LF325, were applied. Profiles were made

- (i) before and after each daywork of bathymetry;
- (ii) in connection with flow transect measurements; and
- (iii) otherwise according to the work programme.

4 Data analysis and storage

4.1 Horizontal and vertical control

In the inception phase of MES, the following coordinate system was selected in accordance with established good practice in Bangladesh:

Horizontal coordinates: Bangladesh Transverse Mercator (BTM) grid
Elevations: Public Works Department (PWD) datum

This coordinate system has been retained for all applications within MES, such as field surveys, analysis of historical data, satellite imagery, numerical modelling, and design.

The BTM grid is based on the Everest 1830 ellipsoid. In the past, several variants of this ellipsoid have been applied for different purposes. The one adopted by MES is the 'original' one, selected in accordance with SoB practice. It is described in Table 4.1.

Specifications:		
Semi-major axis a	:	6,377,276.345 m
Semi-minor axis b	:	6,356,075.413 m
Inverse flattening 1/f	:	300.8017
Datum shift from WGS84 to Everest 1830:		
Rotation x	:	0
Rotation y	:	0
Rotation z	:	0
Translation x	:	-283.729 m
Translation y	:	-735.942 m
Translation z	:	-261.143 m
Scale	:	0 ppm

Table 4.1: The Everest 1830 ellipsoid

As the estuarine surveys would largely be based on GPS positioning, the direct recordings of position and elevation would be made within the WGS84 coordinate system. This necessitates two conversions: (i) a horizontal coordinate transformation, and (ii) an elevation shift.

The conversion of horizontal coordinates from WGS84 to BTM is exact. The applied conversion routine (established by SoB) is included in Table 4.1. The BTM projection itself is described in Table 4.2.

Scale factor	:	0.9996
Central meridian	:	90° E
False easting	:	500,000 m
False northing 1)	:	0 m
Latitude of origin	:	0° (Equator)

1) Sometimes, a false northing of -2000,000 m is applied

Table 4.2: The BTM projection

The conversion from ellipsoidal height in WGS84 to orthometric height in PWD is not exact, but is based on empirical observations. For this conversion, a geoid model was applied. A comparison was made between the so-called JICA model (applied by SoB) and the so-called KMS model, supplied by the Danish Geodetic Survey Agency. It was found that the two models performed equally well /5/, and the latter was selected, because it was available as a computer programme, which facilitated the data processing. (The basic conversion algorithms, however, are not available).

Table 4.3 shows a comparison between nominal and calculated PWD levels at 27 points where information (from different sources) have been available about the nominal PWD height, and where the WGS84 ellipsoidal height has been measured by MES.

Some bench marks deviate from the general pattern and are for that reason considered as being doubtful. For example, MES points 1105 and 1106, located some 30 km apart on the mainland between Dhaka and Chittagong, were validated by a land survey by MES in November 1997. According to this survey, point 1105 was 0.8 m higher than estimated by the KMS model, while point 1106 was 1.1 m lower. Such a large difference is a surprise, considering the applied survey procedures, and indicates a local inconsistency within the PWD datum.

Comparison between PWD and KMS	All points	Excluding 'doubtful' points
Range of difference (highest minus lowest difference)	556 cm	102 cm
Average difference (PWD minus KMS)	32 cm	12 cm
Standard deviation	102 cm	28 cm
Number of points	27	21
PWD: Nominal PWD level KMS: PWD level calculated by the KMS model on the basis of the WGS84 level		

Table 4.3: Comparison between nominal and calculated PWD

The difference between the orthometric height and the ellipsoidal height is called the geoid height. Geoid heights estimated by the KMS model are listed in Table 4.4, which shows that the datum conversion is far from uniform within the MES study area. Please refer to Figure 4.1 for the relative location of the reference levels.

	E = 500	E = 550	E = 600	E = 650	E = 700
N = 2600	54.41	54.04	53.54	52.90	52.63
N = 2550	54.67	54.24	53.76	53.09	52.70
N = 2500	54.87	54.38	54.22	53.70	52.98
N = 2450	55.47	55.04	54.87	54.36	53.30
N = 2400	56.33	56.14	55.71	55.14	53.86

Numbers indicate the elevation difference (in m): PWD minus WGS84, where
PWD is the estimated orthometric height relative to PWD
WGS84 is the measured ellipsoidal height relative to WGS84
E is easting, and
N is northing in the BTM coordinate system

Table 4.4: Geoid heights within the MES area

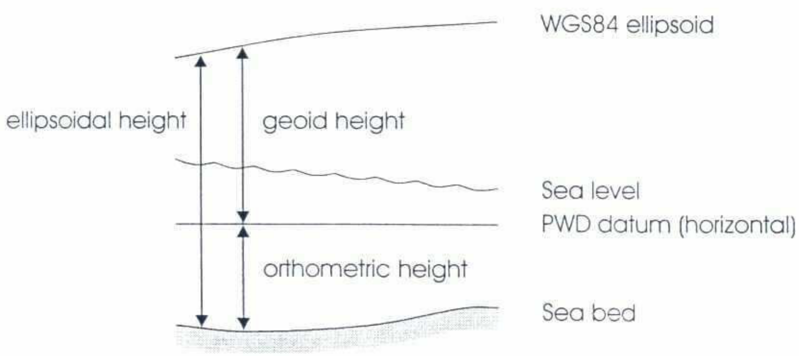

Figure 4.1: Relative location of reference levels

4.2 Water-level and waves

The pressure gauge readings were analyzed by subtracting the atmospheric pressure from the recorded total pressure in order to derive the pressure of the water column above the sensor. This was in turn converted to a water surface height by dividing by the gravity acceleration and the density of sea water, as determined by its temperature and salinity. The height was converted to PWD datum by RTK observations of the sea surface elevation in connection with installation and servicing.

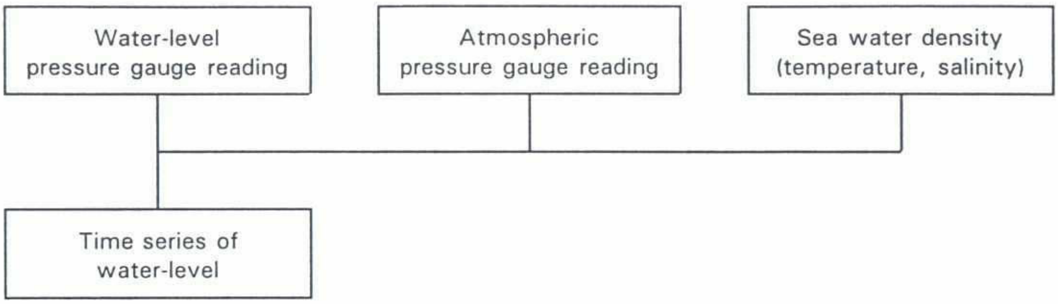

Figure 4.2: Data flow, water-level from pressure gauges

4.3 On-line processing facilities

The self-recording data collection system installed onboard *'Anwesha'* consists of three integrated components:

- A positioning and navigation system (by RTK);
- a depth-recording system (by echosounder); and
- a flow profile recording system (by ADCP).

The data flow from the two former components is managed by the so-called HYDRO system. The data flow from the entity of all three components are managed by the so-called ACQ system, which receives signals from the HYDRO system and from a separate ADCP system.

An outline of the on-line data flow is given in Figure 4.3.

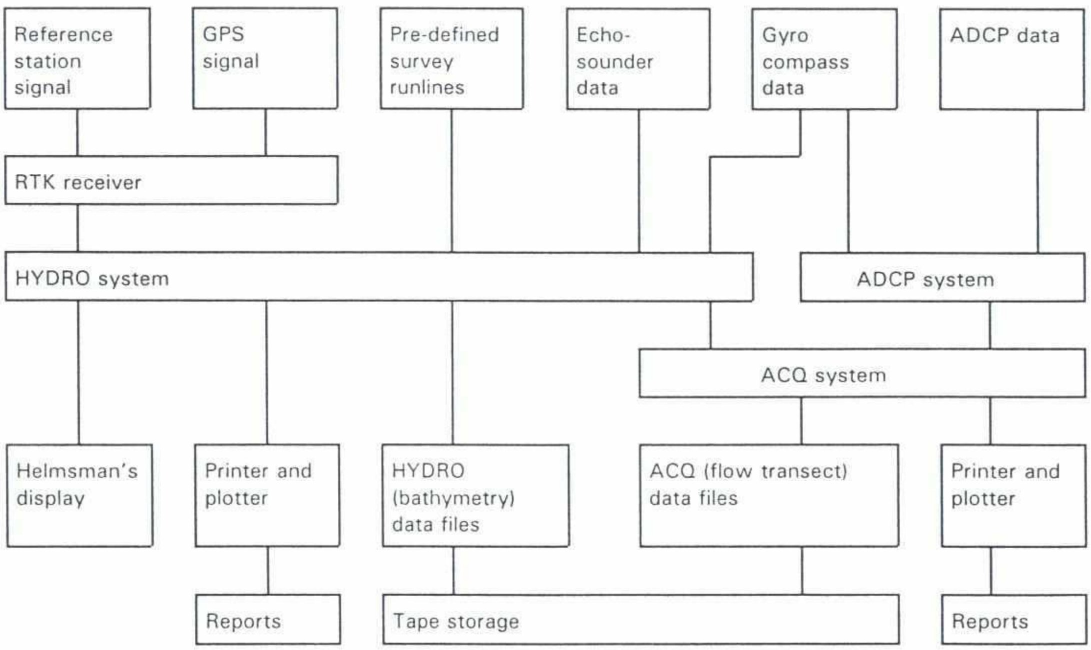

Figure 4.3: On-line data flow

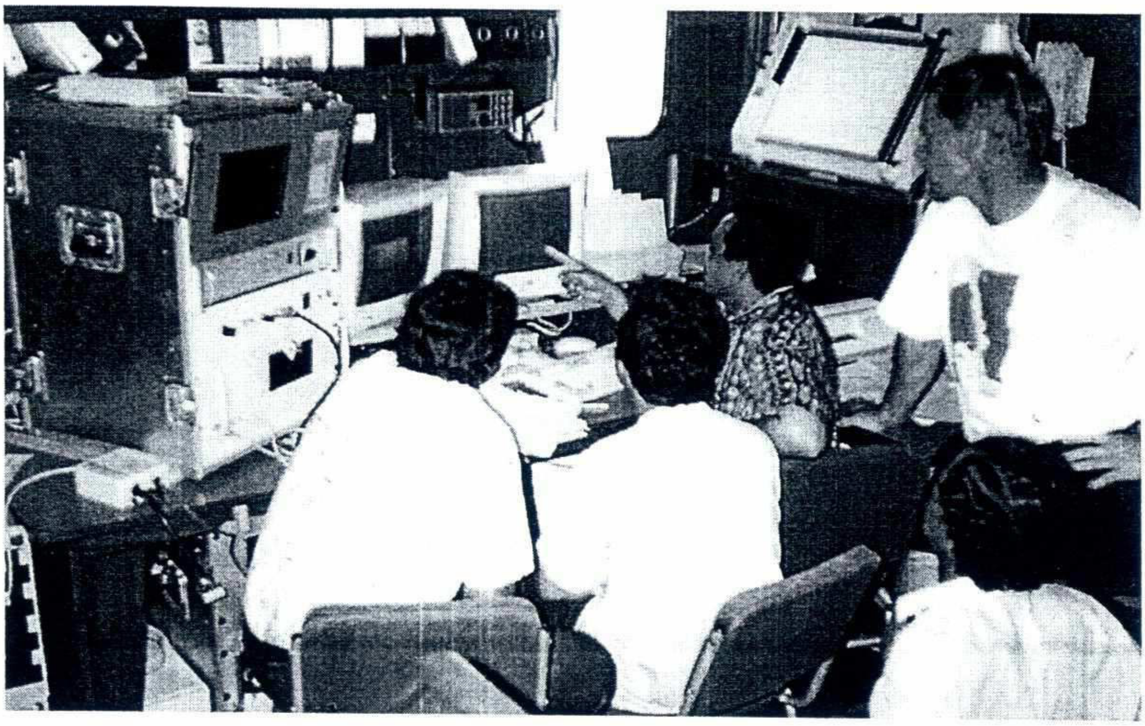

Figure 4.4: 'Anwesha's survey room

4.4 Positioning

Positioning of *'Anwesha'* and the tender boats was done by RTK relative to the network of reference benchmarks. The coordinates were produced as follows:

a. The coordinates of the reference benchmark are regarded as 'correct';
b. the RTK reference station measures the coordinates of the reference benchmark. These coordinates are compared with the 'correct' ones, and the pseudo range corrections for each satellite are calculated and transmitted by UHF radio to *'Anwesha'*;
c. the RTK receiver onboard *'Anwesha'* measures the coordinates of its position. The pseudo range corrections received from the reference station are applied to obtain the 'correct' coordinates.

Datum conversion from WGS84 (applied by the GPS satellites) to BTM grid and PWD datum (applied by MES) took place during the post-processing. All registrations in the field were made in WGS84.

The position was given for *'Anwesha's* GPS antenna. During the measurements, the coordinate differences (or the off-set) between the antenna and each instrument was taken into account in order to obtain the correct position of the instrument. This is particularly important for the bathymetric surveys and for the ADCP measurements. While the antenna and the instruments are fixed relative to each other, the coordinate off-set depends on the orientation of the vessel, which changes all the time. A gyro compass was used for monitoring the orientation of the vessel, so that the correct eastings and northings can be obtained. These corrections were made by the HYDRO on-line data processing system.

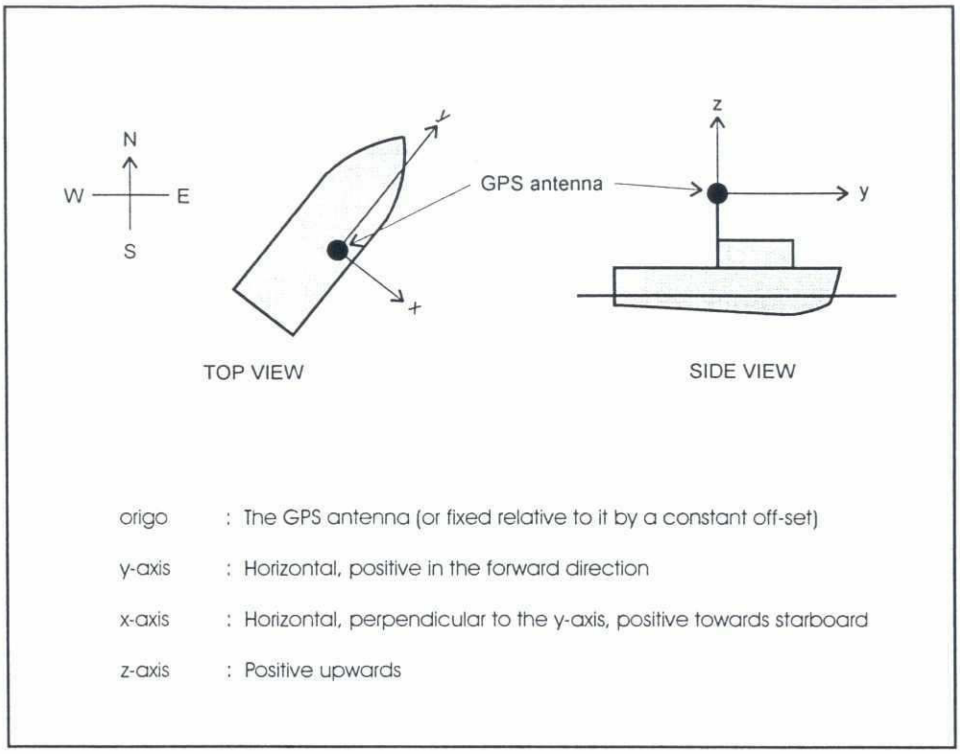

Figure 4.5: The ship's coordinate system

Also, the sea level can vary relative to the GPS antenna, depending on the draft of the vessel. The draft will change

- When loading and unloading one or both tender boats;
- due to consumption of water and fuel, and when bunkering; and
- when relocating between freshwater and saline areas.

When using RTK, the draft changes are not so important for the bathymetric surveys, but they can have some significance during the flow measurements. The actual draft was registered during the work (on field sheets C-1 and D-1).

4.5 Bathymetry

The data processing comprised

- removal of spikes and steps in the field data records;
- linking of files;
- datum conversion; and
- generation of x-y-z files.

Results were organized as data files in x-y-z format, suitable as input to for example the MIKE model system, or standard graphic packages like *'Surfer'*.

4.6 Flow and sediment transport transects

The transect measurements produce information about

- morphological development (by repeating the measurements from one year to another)
- flow distribution and net flow through the cross-section (by correlating with the tide)
- sediment transport through the cross-section

In accordance with the first-mentioned objective, successive measurements should be done in exactly the same place. Also the data processing should aim at a direct compatibility.

Each ADCP flow recording contains a lot of information, but is, in principle, merely an example of the cross-sectional flow distribution and of the total flow through the cross-section. Both these values vary while the measurements are made, and also from day to day, depending on the varying river discharge and the neap-spring fortnightly tidal variation. Therefore, the flow recordings must be adjusted to enhance their validity.

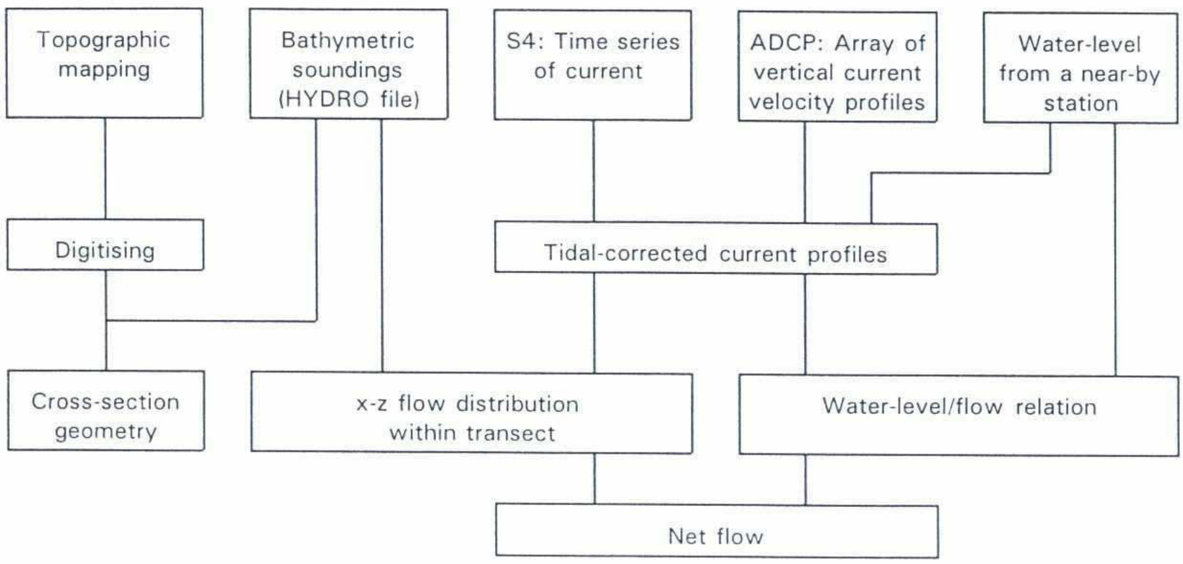

Figure 4.6: Data flow, transect gauging

A full tidal correction of the ADCP measurements is required when the measuring time is large as compared with the tidal variation. (For practical purposes, a measuring time of around 1 hour is regarded as 'large'). The full tidal correction comprises:

(1) The S4 current registration is projected into its main direction, whereby a simple time series is obtained;
(2) this time series is normalised by dividing by its maximum value in each direction;
(3) the ADCP flow transect is schematized into instantaneous cross-sectional velocity at a 100 m length increment and a 2 m depth increment;
(4) each length increment is normalised by dividing by the normalised S4 time series. Hereby is obtained the normalized flow velocity distribution over the transect;
(5) the corresponding flood and ebb flow volumes are calculated by integrating the velocity over (1) the entire cross-section and (2) half a tidal period, hereby considering the tidal sea level (and flow area) variation;

(6) the sea level/S4-current relationship is described as a basis for subsequent estimates of the long-term variation of the flow.

The coordinate transformation of the velocity measured by ADCP while sailing is illustrated in Figure 4.7.

Depending on the intended application, results can be presented as

- schematized sea bed levels;
- schematized cross-sectional distribution of tidal-corrected current velocity, (1) at ebb flow and (2) at flood flow;
- relationship between cross-section area and water-level;
- relationship between total flow and water-level at the selected station;
- time series of total flow over a tidal period; and/or
- ebb flow volume, flood flow volume, and net flow and -direction.

Subsequent analysis can from case to case comprise calculation of transect accretion and erosion, or generation of long time series of flow.

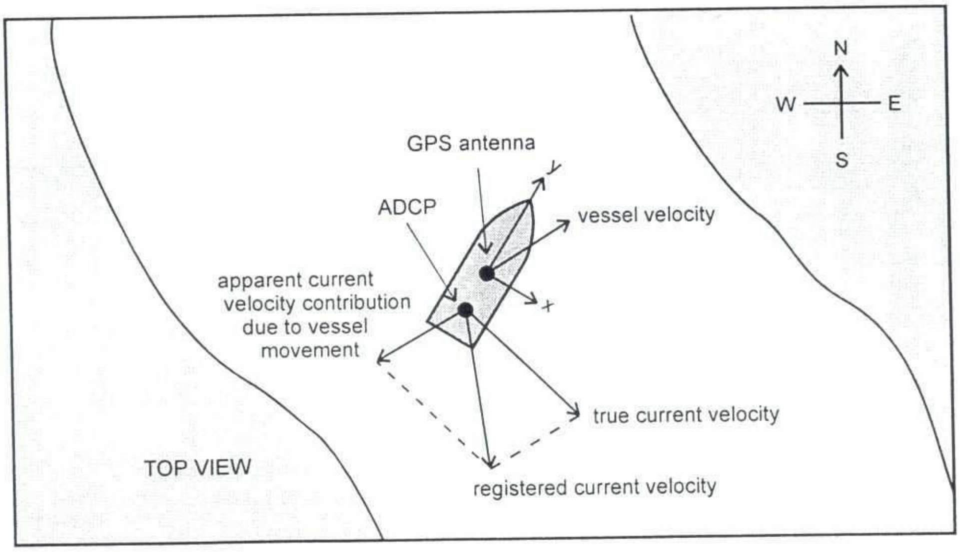

Figure 4.7: ADCP velocity vector transformation

4.7 Sediment analysis

In the field, sediment samples were collected in the following ways:

- 1 l suspended sediment samples by pumping;
- 1 l suspended sediment samples by integrating bottle;
- 25 l suspended sediment samples by pumping (bulk samples);
- settling velocity samples by Owen tube; and
- bed samples by Van Veen (grab) sampler.

The sediment analyses of MES were made by SSD's sediment laboratory (in Chittagong), which was partly refurbished for that purpose. The following analyses were applied:

- Grain size distribution by dry sieving
- Grain size distribution by wet sieving
- Separation by elutriator
- Volume adjustment (if necessary)
- Concentration analysis by microfiltering
- Grain size (settling velocity) distribution by Andreasen settling tube

The application of the different analyses is shown in Table 4.5. The sediment analyses closely resembled the ones applied by the River Survey Project (FAP24). They were particularly well suited for quantification of the fine portion of the sediments, hereby allowing for a distinction between wash load and suspended bed load. Please refer to /8/ for details about the applied procedures.

Analysis	Sample type			
	Pump samples (1 l)	Integr. bottle (1 l)	Bulk samples (25 l)	Bed samples
Dry sieving			4)	6)
Wet sieving			1)	7)
Elutriator separation	1)	1)		
Volume adjustment	2)	2)		
Settling tube			5)	8)
Microfiltering	3)	3)		

Notes:

1): For separation of coarse and fine fraction
2): If sample volume differs from 1 l
3): A volume of 60-80 ml of the fines is filtered
4): Coarse fraction
5): Fine fraction
6): In case of coarse samples (predominantly sand)
7): In case of fine samples (predominantly clay)
8): Fine fraction, and only if sample contains more than 10 percent of material less than 63 micron

Table 4.5: Summary of sediment analysis procedures

4.8 Sediment transport

Calculation of sediment transport is made on the basis of (1) the flow data; and (2) the sediment concentration data. An outline of the procedure is given in Figure 4.8.

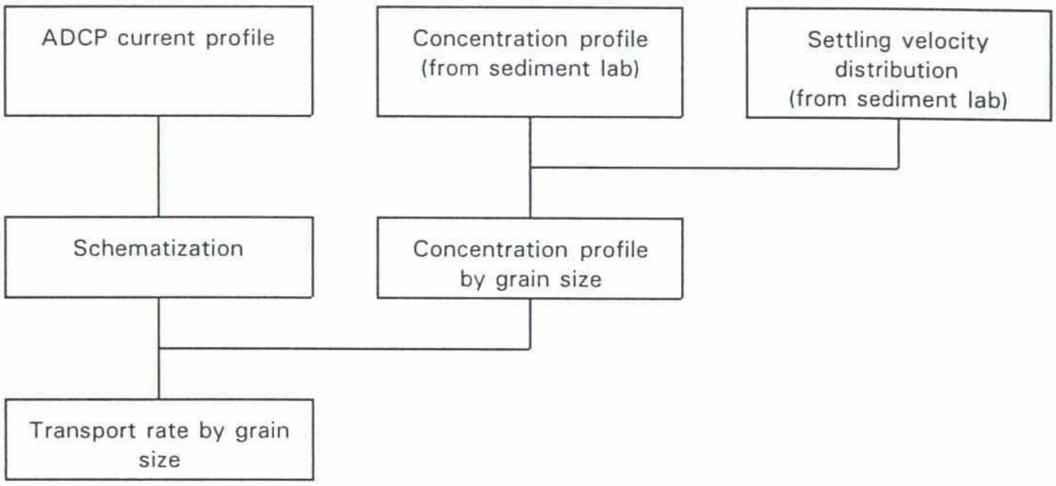

Figure 4.8: Data flow, sediment transport

Results can be presented as

- schematized vertical current profile (data tables + plots);
- settling velocity distribution (data tables + plots);
- grain size distribution (data tables + plots);
- concentration profile by grain size category (data tables + plots); and
- schematized sediment transport profile, by grain size category (data tables + plots).

Often, a distinction is made between sediments above and below 0.063 mm (sometimes referred to as 'suspended bed material load' and 'wash load', respectively). For many purposes, the former category is the more interesting one.

Subsequent analysis can comprise for example estimates of daily average and long-term cross-section transport, and further segregation into grain size categories.

4.9 Salinity

No post-processing was required for salinity data, since these were produced by direct reading instruments.

4.10 Data storage

After post-processing, data were stored in Excel format in the MERIS (Meghna Estuary Resource Information System) database, together with LRP data /12/.

5 Summary of data collection

5.1 Reference points

As shown in Table 5.1, MES established 35 reference points, most of which are located on cyclone shelter roofs. At the same time, for the sake of consistency, 15 BIWTA water-level gauge bench marks were linked to the applied coordinate system.

Survey	Reference points	BIWTA water-level gauges	Auxiliary points	Report
29/2 - 27/4 96	14	15	4	/5/
7/6 - 26/6 97	21		1	/9/
Total	35	15	5	

Table 5.1: MES reference points

The network of reference points has been linked with the geodetic grid established by Survey of Bangladesh, as described in /5/. Further, it has been linked with PWD datum as established in the field at certain points within the study area, and with Mean Sea Level as established in Karnafuli Entrance by Survey of Bangladesh.

In the basic survey of March-April 1996, the relative closing error of the survey varied from 0.28 PPM to 0.94 PPM. The horizontal accuracy of the reference point coordinates is estimated at ±10-40 mm. The vertical accuracy (of the ellipsoidal heights) is estimated at better than ±70 mm.

An additional uncertainty is introduced by the conversion from WGS84 to PWD. This contribution has been estimated at ±15-30 cm, depending on the data set applied for the analysis. As this contribution is significant as compared with the resolution of the method, all heights are stored both in WGS84 and in (estimated) PWD.

The reference points are shown in Appendix B, together with a listing of their coordinates. Field sheets for all points are included in /5/ and /9/, which also contain journals of the field work and details about the applied procedures for data analysis and interpretation.

5.2 Water-level and waves

Gauge locations are shown in Figure 5.1, while the data coverage is summarised in Table 5.2. The total data production was 13 station-months.

Air pressure was recorded at the Feni Regulator (for correction of data from MES-4, 5, and 6), and at Nijum Dwip (for correction of data from MES-1, 2, 3, and SE).

A sample presentation of water-level recordings is shown in Figure 5.2. No waves of any practical significance were recorded, as the wave heights remained below 10 cm in the recording period.

The recordings were discontinued because of the logistical implications, and as it was found that the data coverage from BIWTA's water-level gauges was good. The data quality as such was satisfactory. Results are stored in the MERIS database.

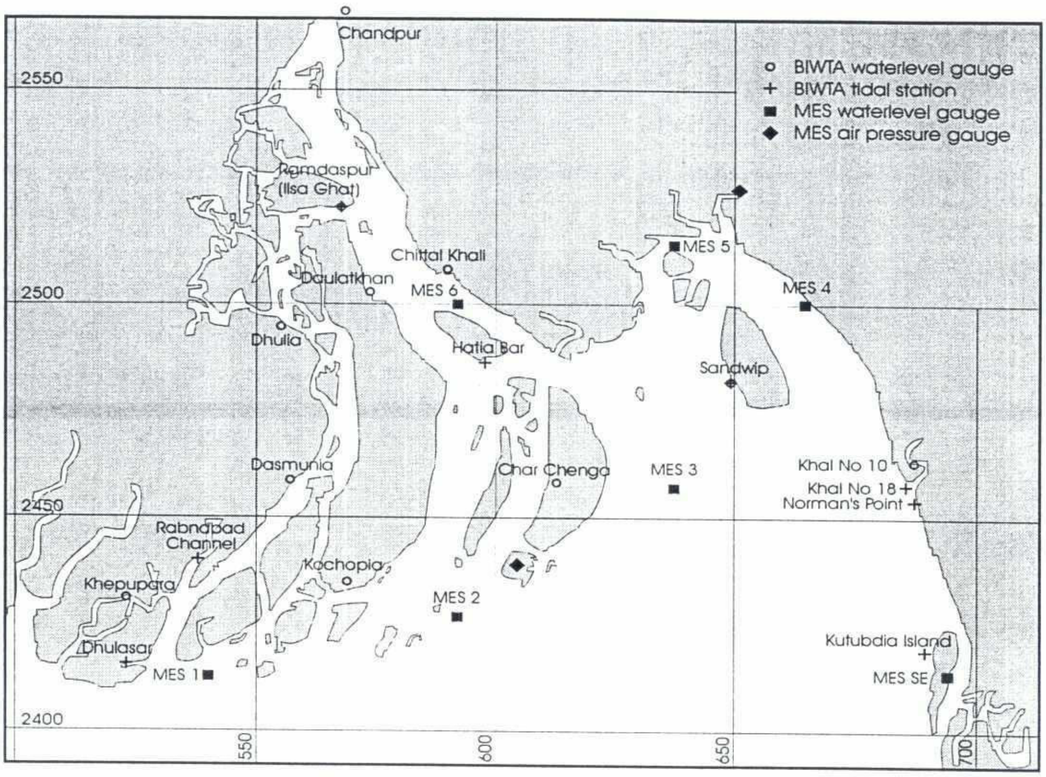

Figure 5.1: Map of MES and BIWTA water-level gauges

Station	E	N	Registration period
MES-1	540014	2412723	11/12 96 - 8/2 97
MES-2	591974	2426766	12/12 96 - 31/1 97
MES-3	637387	2457130	18/12 - 29/12 96
MES-4	664455	2500204	17/12 96 - 17/2 97, 21/2 - 24/4 97
MES-5	637347	2513778	16/12 96 - 15/2 97
MES-6	592000	2500000	19/12 96 - 18/2 97
MES-SE	694105	2413510	1/1 - 19/1 97

Table 5.2: Data coverage, water-level gauges

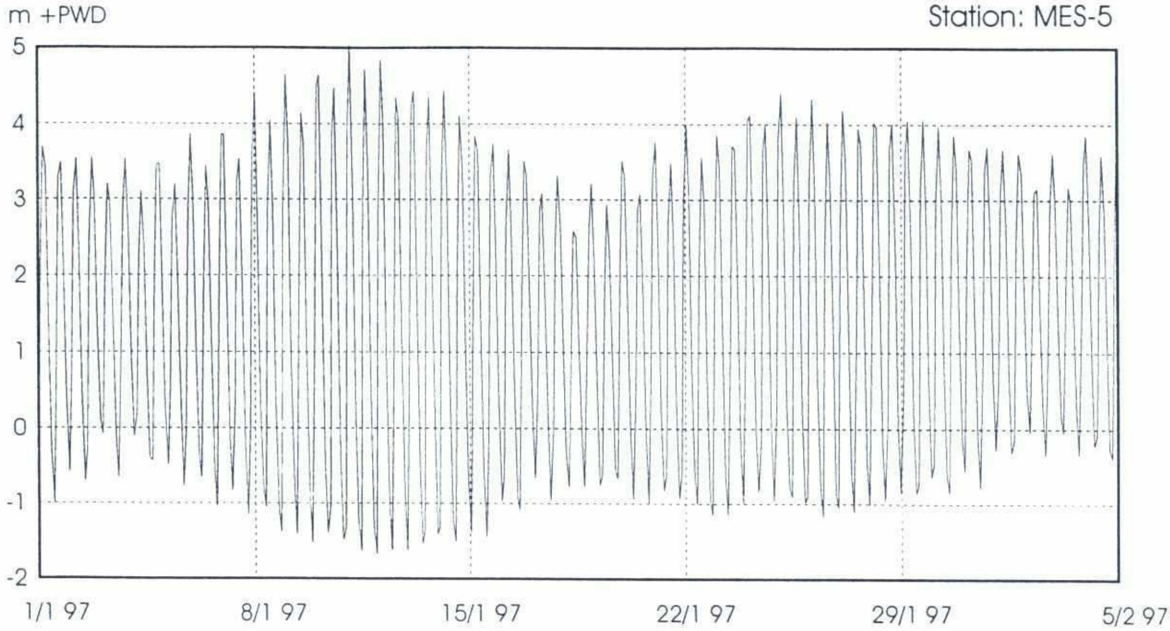

Figure 5.2: Water-level recording at MES-5 (example)

5.3 Bathymetry

Bathymetric surveys were carried out between cruise 3 and 18, over a period of 13 months from January 1997 through January 1998. RTK positioning was applied everywhere except during cruise 3, which covered the open, southern part of the study area, which was out of reach of the reference stations. The line spacing varied from 2600 m to 250 m. In total, 10,376 km² were surveyed. A minor part of the area (the one covered by cruise 18) was surveyed twice. This was because the first line spacing (of 2500 m) was found to be inadequate for describing the flow channels, so the area was covered once again, with a line spacing of 600 m.

The coverage is shown in Figure 5.3 and Table 5.3, while a summary presentation of the bathymetry of the Estuary is given in Figure 5.4.

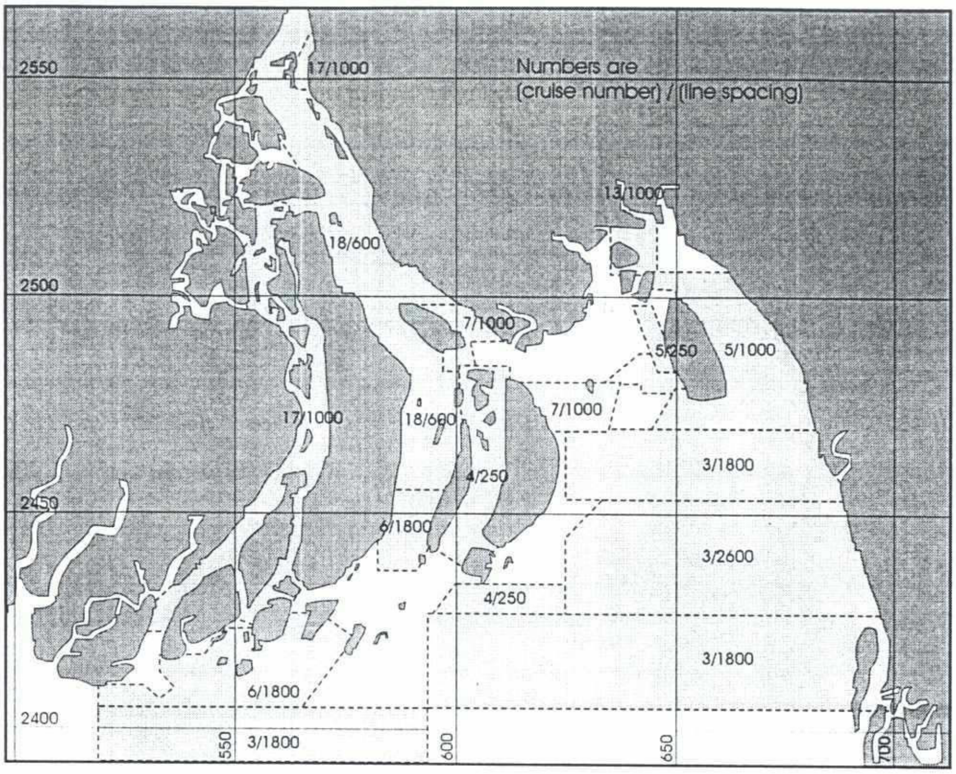

Figure 5.3: Mosaic of bathymetry surveys

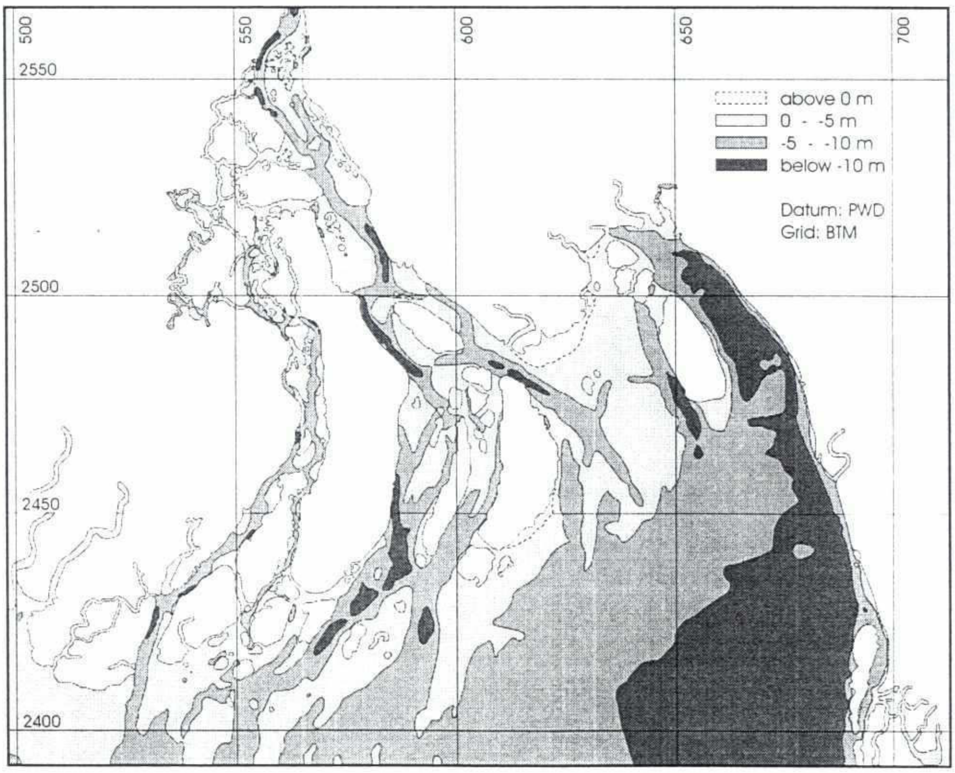

Figure 5.4: Bathymetry map

Cruise	Location	Time	Area km²	Line spacing m
3	SE quarter of MES study area	Jan 97	5166	1800, 2600
4	Hatia, Nijhum Dwip, Ramcharan, Nalchira	Jan-Feb 97	675	250
5	Sitakunda, Pahartali, Sandwip	Feb-Mar 97	854	250, 1000
6	Nijhum Dwip, Under Char	Mar 97	1005	1800
7	Char Mujib, Sandwip, Nalchira	Apr 97	555	250, 1000
11-13	Chandpur, Char Alexander, Ramdaspur, Hazimara, Char Gagaria, Hatia, Sitakunda, Sandwip, Urir Char	Jul-Sep 97	800	1000, 2500
17	Dasmina, Khepupara, Char Biswas, Debir Char	Nov-Dec 97	521	1000
18	Chandpur, Hazimara, Ramdaspur, Khorki, Bhola East, Shashiganj, Burir Doun (Bhola)	Jan 98	800	600
Note: There is an overlap between areas covered by cruises 11-13 and 18				

Table 5.3: Data coverage, bathymetric surveys

Cruise	Area km²	Line km	Time days	Progress km/day	Comments
3	5166	2576	14	184	RTK not used
4	675	2700	19	142	
5	854	1174	14	84	
6	1005	558	11	51	
7	555	888	8	111	
11-13	800	344	12	29	
17	521	521	18	29	
18	800	1333	15	89	
Total	10376	10095	111		
Average				91 76	(incl. cruise 3) (excl. cruise 3)

Table 5.4: Progress of bathymetric surveys

As an illustration of the actual survey capacity, Table 5.4 shows a summary of the progress made. The length of line per day depends highly on the complexity of the area, and the time needed for installation and withdrawal of RTK reference stations.

5.4 Flow and sediment transport transects

Locations of flow and sediment transport measurements are shown in Figure 5.5. The data collection is summarised in Tables 5.5 and 5.6.

The transects have been named by a letter (C = Chandpur, H = Hatia, S = Sandwip, and T = Tentulia River), followed by a channel number. Divided channels have been given an index (N = north, E = east, S = south, and W = west). After cruise 12 it was decided to shift transect H-2 to a new location, as shown in the map.

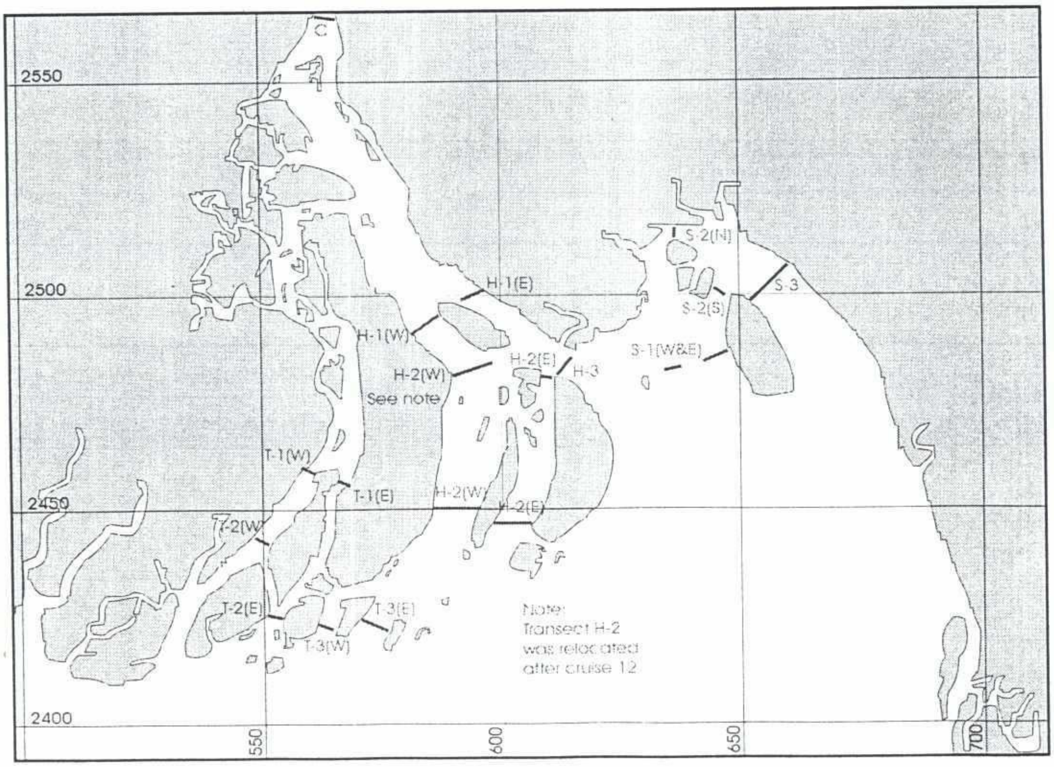

Figure 5.5: Location of flow and sediment transport transects

Transect	Location	Cruise	Date	No. of flow measurements
C	Chandpur	11	27-28/7 97	11
H-1E	Char Alexander-Char Gazaria	11 12	2-3/8 97 13-14/8 97	6 4
H-1W	Bhola-Char Gazaria	12	10-11/8 97	6
H-2E	Maulavirchar-Hatia	12 12	13/8 97 16/8 97	5 17
H-2E, new	Manpura to Jahajmara	14 14	11-12/9 97 20-21/9 97	14 14
H-2W	Bhola-Char Maulavirchar	12	12/8 97	4
H-2W, new	Bhola-Manpura	14 14	13-14/9 97 22-23/9 97	6 15
H-3	Hatia-Noakhali	11 12 14	4/8 97 15/8 97 19-20/9 97	4 4 10
S-1E	Sandwip-Char Nurul Islam, E	13 16	31/8 97 9-10 97	0 21
S-1W	Sandwip-Char Nurul Islam, W	16	11/11 97	15
S-2N	Urir Char-Char Balua	13 16	1-2/9 97 7-8/11 97	0 43
S-2S	Sandwip-Urir Char	16	5-6/11 97	35
S-3	Sandwip-Sitakunda	13 16	27-28/8 97 2/11 97	0 1
T-1E	Char Biswas to Bhola	15	8-9/10 97	38
T-1W	Dasmina-Gosair Hat	15	7-8/10 97	46
T-2E	Char Biswas-Char Montaz	15	12-13/10 97	24
T-2W	Panpatti-Char Biswas	15	10/10 97	26
T-3E	Char Kukrimukri-Dhal Char	15	16-17/10 97	14
T-3W	Char Kukrimukri-Dhal Montaz	15	15-16/10 97	22

Table 5.5: Data coverage, flow and sediment transport

Pump samples	:	338
Bulk samples (for settling tube analysis)	:	70
Integrating bottle samples	:	651
Owen tube samples	:	141

Between them, the samples represent 827 vertical profiles

Table 5.6: Data coverage, suspended sediment samples

As seen in Table 5.5, the ADCP data coverage was nil during Cruise 13. Leaving superstition apart, it is evaluated that this was because the instrument was exposed beyond its ability with respect to silt concentration in the water. During that cruise, concentrations of 2-3 g/l or even more were measured around Sandwip, where the measurements were attempted. During a subsequent cruise (Cruise 16) successful flow measurements were made in the same locations.

5.5 Bed sediments

A total of 450 bed samples were collected along the flow transects during cruise 1-16. An inventory of the samples is given in Table 5.7. The transect locations are shown in Figure 5.5.

Transect	Location	Cruise	No. of bed samples
C	Chandpur	1, 11, 15	32
H-1E 1)	Char Alexander-Char Gazaria	1, 11, 12	31
H-1W 1)	Bhola-Char Gazaria	1, 12, 14	56
H-2E 1)	Maulavirchar-Hatia	1, 12	51
H-2E, new	Manpura to Jahajmara	14	22
H-2W	Bhola-Char Maulavirchar	2	10
H-2W, new	Bhola-Manpura	14	26
H-3 1)	Hatia-Noakhali	1, 11, 12, 14	39
S-1E	Sandwip-Char Nurul Islam, E	16	13
S-1W	Sandwip-Char Nurul Islam, W	16	12
S-2N	Urir Char-Char Balua	13, 16	23
S-2S	Sandwip-Urir Char	16	12
S-3	Sandwip-Sitakunda	13, 16	33
T-1E	Char Biswas to Bhola	15	9
T-1W	Dasmina-Gosair Hat	1, 15	19
T-2E	Char Biswas-Char Montaz	11, 15	15
T-2W	Panpatti-Char Biswas	15	13
T-3E	Char Kukrimukri-Dhal Char	15	14
T-3W	Char Kukrimukri-Dhal Montaz	15	13
-	Nijhum Dwip Channel	5	6
-	Hiamchar	11	1
1): Including some adjacent areas			
Total			450

Table 5.7: Data coverage, bed sediment samples

The samples were consistently fine. Considering the bulk of the samples, and disregarding their detailed validity, their median diameter D_{50} was distributed as follows:

0.23 - 0.2 mm	(2 samples only)
0.063 - 0.2 mm	36 %
0.02 - 0.063 mm	48 %
0.007 - 0.02 mm	16 %

5.6 Salinity

A total of 342 salinity profiles were measured during the programme. With rare exceptions, the water column was well mixed, so that surface and near-bed salinities were identical or nearly so. In many cases, as would be expected, the salinity was nil.

The data collection is summarised in Table 5.8. Results are stored in the MERIS data base.

No.	Period	Place	No. of salinity profiles
4	20/1 - 6/2 97	Around Nijum Dwip	17
5	15/2 - 5/3 97	Sandwip Channel	15
6	21-31/3 97	Nijhum Dwip, Under Char	8
7	5-12/4 97	Char Mujib, Sandwip, Hatia Channel	8
8	29/4 - 13/5 97	Whole MES study area	7
9	18/5 - 3/6 97	Bhadarhat, Char Alexander	17
11	24/7 - 6/8 97	Lower Meghna, Shabazpur Channel	19
12	8-17/8 97	Hazimara, Char Alexander, Char Gagaria, Shabazpur Channel	13
13	27/8 - 3/9 97	Sitakunda, Sandwip Channel, Urir Char	48
14	9-24/9 97	Tentulia River and Shabazpur Channel	146
15	3-18/10 97	Lower Tentulia River	44
Total			342

Table 5.8: Data coverage, salinity profiles

6 Evaluation

In this chapter, some observations are made on the experience gained during the work. Related recommendations are given in Chapter 8.

6.1 Instrumentation and procedures

The surveys comprised two technologies of recent origin. One was RTK-based bathymetric surveys, and one was flow measurements by ADCP.

RTK positioning was developed shortly before the start of the Project, and was applied for the first time in Bangladesh. The expectations were fulfilled with respect to survey capacity and data quality, both of which are considered as superior to traditional surveying, notably with respect to datum reduction. This was demonstrated during the Project by comparison between Cruise 3, which was made by traditional means, and the other cruises, which were made by RTK. This technique does not require a dense network of water-level recordings, and a comprehensive post-processing for datum adjustment. Also, heave and draft compensation are not required, because the recordings are made directly as WGS84 levels, rather that as water depths. The technique is better than any alternative with respect to detection of seabed level variations over large areas.

Flow measurements by ADCP have been made once before in Bangladesh (by the River Survey Project, FAP24, 1992-96), but was implemented within BWDB for the first time in connection with MES. By this technique, each single recording is in fact much less accurate than provided by for example traditional propeller instruments like SSD's Ott recorders. But, as each recording is made in a split of a second (as compered with the 60-90 seconds of a propeller instrument), the accuracy is highly improved by averaging over a number of registrations, hereby reducing the random deviation (by the square root of the number of registrations). The key quality of the technique is its recording capacity, which makes it possible to cover a cross-section while sailing with a cruising speed of 4 knots (as compared with 30 minutes, or more, per vertical for traditional flow measurements). This quality is decisive when operating in a tidal-influenced environment as the Meghna Estuary, where the current speed changes continuously, and the current direction in many cases shifts 4 times per day.

The point has been made that such advanced technology incurs a dependency on foreign, expensive expertise, because repairs can only be made by the manufacturer. This is correct; but the same argument relates to so many other types of modern technology which are now indispensable for a variety of purposes, in Bangladesh as well as worldwide.

One major obstacle during the survey operation was the intense fishing in the area, using drifting nets, which occurred everywhere and all the time. In addition to hampering the cruising (which was planned to be made along straight runlines), it was almost impossible to deploy self-recording instruments, like the S4 current meter, which was intended for registration of the time variation of the flow, as the indispensable supplement to the instantaneous mapping of the flow distribution by ADCP. The adopted contingency measure was to increase the number of ADCP measurements, and to use the ADCP for continuous registration during night stops.

Detailed procedures were defined for the routine execution and documentation of the data collection. Still, for many reasons, deviations from the plans were unavoidable, as it is normal for this type of work. In some cases, particularly in the first part of the programme, the need of documentation was not always fulfilled. One particularly important part of the documentation is the daily field report, which should be made on a routine basis each and every day during the entire cruise (see Table 6.1).

The daily field report must be prepared *every evening during the entire cruise,* also if there seems to be 'no news', for example during weather stand-by. It should contain *keywords only,* describing:

1.	Date, time, initials	1)
2.	Evening position (and destination, if sailing)	1)
3.	Place: Morning, waypoints, evening	1)
4.	Activities of the day	1)
5.	Weather	1)
6.	Staff arrivals and departures	2)
7.	Anything else	2)

1): Always
2): As appropriate

Table 6.1: Daily field report

6.2 Scoping and survey operation

As a consequence of experience gained under way, the MES surveys as made deviated in several ways from what was planned. There were two main reasons for this. First, the need of bathymetric data was larger than anticipated, and a substantial survey capacity had to be transferred for this purpose. Second, certain activities, such as initial mobilisation, testing and reconnaissance, took a longer time than expected. The main deviations were as follows:

- The bathymetry area was extended to (almost) the entire estuary, as compared with selected priority areas only;
- in return, each area was surveyed only once, as compared with twice;
- further, each flow/sediment transport transect was surveyed only once, as compared with 4 times according to original plans.

The actual total number of effective cruise days (of 260, excluding weather downtime) equals the planned number (according to the MES Inception Report, Revised). The capacity was allocated as follows:

Bathymetric surveys:	118 days	(45 percent)
Flow/sediment transport measurements:	36 days	(14 percent)
Non-routine work (see text below):	70 days	(27 percent)
Transfer and onboard mobilisation:	36 days	(14 percent)

Non-routine work comprised reconnaissance, deployment, servicing and withdrawal of water-level recorders, establishment of reference stations that could not be accessed by car, and assistance to installation of bank protection vanes and screens.

Downtime due to routine and non-routine maintenance averaged 18 weeks per year. In contrast with what was anticipated, weather down-time was negligible (only 3 days in all), partly because the activities were planned with due consideration to the operating conditions.

The utilisation of the vessel is summarised in Table 6.2. In addition to what is shown in this table, the vessel spent lengthy periods in dockyard for major overhauls before and after the commissioning period.

Activity		Days	Percent
Mobilisation (at berth):		46	9
Estuarine surveys (cruises 1-18):		260	50
Inspection cruises:	1)	7	1
Weather down-time:		3	1
Unscheduled repairs:	2)	143	27
Scheduled maintenance:		39	7
Stand-by (incl. scheduled holidays):		25	5
Entire commissioning period:	3)	523	100

1): Site visits by BWDB executives and donor representatives
2): More than half of this time was a major overhaul in late 1996
3): 20/8 1996 - 24/1 1998 (17 months)

Table 6.2: Actual utilisation of 'Anwesha'

One or several so-called 'synoptic surveys' were considered, but were not made (due to capacity constraints). The objective was to collect salinity and suspended sediment data from a larger area within a short time, as a supplement to the more detailed measurements that were made in the fixed standard cross-sections. It is still believed that such synoptic data would serve as a valuable extension of the data collection programme. Particularly the discrete salinity data are difficult to interpret (unless extended over a much longer period of time). In general, for the purpose of model calibration, an intensive coverage over a short period of time is particularly valuable (while systematic long-term registrations are equally valuable for a general understanding of states and processes in the estuary).

The salinity measurements do not need to be made from *'Anwesha'*, because the instrument is small and light, and positioning can adequately be made by a hand-held ordinary GPS unit. Therefore, it is possible to carry out the salinity measurements from a small separate vessel.

6.3 Hovercraft surveys

In early 1998, a Hovercraft was acquired in order to facilitate bathymetric surveying on mud flats and in shallow areas that cannot be covered by *'Anwesha'* or its tender boats. Due to late delivery and import it was not commissioned, but it was mobilised and tested in the late stage of the survey period.

The cruising speed of the vessel is 40 knots when unloaded. When loaded with survey equipment (and 2 persons), the cruising speed is reduced to around 12 knots, and the operational speed during survey work is 6-7 knots. Perhaps the speed can be increased by further weight reduction of the equipment and trimming of the transducers.

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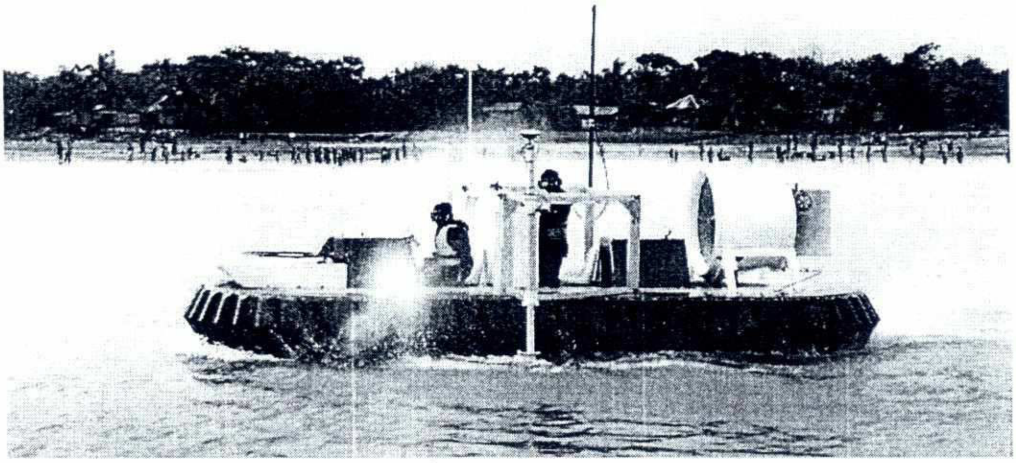

Figure 6.1: The Hovercraft

Preliminary indications are that

- the vessel is suited for perfectly calm weather only;
- it is particularly difficult to navigate;
- it is structurally fragile;
- it requires a support vessel, preferably *'Anwesha',* while operating;
- its potential performance for surveys in shallow areas seems impressive, due to its zero draft.

6.4 Data analysis and storage

Procedures for data management were initially drafted at the start of the programme and were gradually improved during their implementation. At the same time, the data processing capacity was strongly extended. In the last year of the Project, when a suitable volume of processed data was available, and the numerical model was being set up and calibrated, a fruitful interaction took place between the data producers and the data users.

A further development of the routines, possibly a simplification, may be considered in connection with a continuation of the monitoring.

As a subject for future development, the flow and sediment transport data quality may be enhanced by a data assimilation technique, whereby the complex time and space variations during the measurements are jointly referred to a numerical model of the cross-section. Today, such technique is not available as a routine tool, but needs to be developed, possibly as a research project. The data produced by MES can serve as a part of the basis for such development.

6.5 Data coverage

In general, the data coverage complied with expectations.

One major setback was an initial malfunctioning of the ADCP, due to a manufacturing fault, so that the instrument had to be sent back to the manufacturer (in California) for a guarantee repair. This was a disappointment, particularly in view of the experience of the River Survey Project (FAP24), where two similar instruments were applied for 3 and 2 years, respectively, without malfunctioning. (These instruments are still in operation on other projects outside Bangladesh 5 and 4 years after their acquisition). It is hoped that the instrument acquired by MES will prove equally reliable after its initial repair.

The water-level pressure gauges were in operation shorter than expected, and the wave recordings turned out to be of little interest (because there were no waves worth mentioning in the deployment period). The main reason for this was the logistical implications, which tied up sparse cruising days that could be better allocated for other purposes, also as it was confirmed that the BIWTA water-level data had a good quality and coverage.

6.6 Quality management

Within the temporary project organisation, quality management was implemented on an ad hoc basis. Certain shortcomings were identified and were wholly or partly mitigated, such as for example

- the field reporting, and the handling, storage and circulation of the field reports and data tapes;
- the dialogue between the field team, the data processing team and the data users; and
- the development of the routine applied for datum conversion from WGS84 to PWD, and the related aim of data consistency between different cruises.

Many of the tasks of the data production are highly specialised and require a deep insight into details, so that it is not possible for one single person to master the entire data production process. At the same time, however, an outlook of the context is important, and particularly so during the implementation and adjustment of new routines. With this aim, sessions were held between the field team, the data processing team, and the numerical modelling team, in order to facilitate the dialogue and the mutual understanding of demands and constraints.

A number of updates were made of the Survey Guidelines and the Data Processing Guidelines, with an active participation by the involved staff members, but still, a scope remains for improving the concordance between the formal and the real procedures. Hereby, experience gained in the field should be incorporated in the formal documentation of the procedures. This will serve the twin purpose of a good documentation of how the work was done, and a better planning of future surveys.

6.7 Training and capability development

The SSD team has a long-standing experience in execution of field surveys. Supplementary training was provided as a part of the Project in relation to the new techniques that were implemented.

The training was made on an ad hoc basis, by personal instruction of SSD staff and permanent MES team members by specialists from Bangladesh and abroad. In this way, the required proficiency was developed in instrument handling and on-line processing.

Small training sessions were held occasionally. Field team professionals participated in dedicated presentations about data processing and modelling, and modelling specialists participated in the field work.

The sediment laboratory of SSD was set up in connection with the Land Reclamation Project, but had been idle for a while prior to the start of MES. The laboratory staff was trained in the analyses selected for the purpose of MES (which closely resembled the ones already applied).

A training course in Hovercraft operation was held for SSD staff in France in late 1997.

There is a remaining need of implementation of the off-line data processing routines somewhere outside of the temporary MES project organisation. This is a prerequisite for utilising the acquired field techniques and skills after completion of the project.

A wider capacity upgrading of SSD would require a number of measures, including

- An organisational upgrading (within or outside the mother organisation);
- a capacity expansion in terms of specialist staff and support staff;
- career incentives aimed at retaining specialist staff;
- a provision to operate on a semi-commercial basis, with the generated income (wholly or partly) earmarked for operation of SSD;
- allocation of a certain authority to SSD, in order to meet the requirements imposed by a semi-commercial operation (such as swift decision-making);
- transfer of the entire set of integrated field monitoring and data management routines applied by MES, comprising hardware, software, and training;
- a consolidation period for technology implementation at SSD on a routine basis, with access to backstopping and maintenance.

It has briefly been considered whether an organisational upgrading should take place within or outside BWDB. Several pros and cons relate. BWDB is a large, resourceful and influential organisation, which could give ample support to a separate sub-unit. On the other hand, in concordance with its designation, BWDB has no tradition of semi-commercial operation. The question must depend on the preferences of BWDB, and, in the end, of the Government. Some high-level decisions are in any case required if the status of SSD is to be changed.

7 Future activities

7.1 Future monitoring of Meghna Estuary

Continued bathymetric, hydraulic and morphological monitoring is a necessity for any prudent management of the Meghna Estuary. This is because of the highly dynamic morphology of the area, which renders information about bathymetry and coast contours uncertain or even obsolete within a time scale of a few years.

The information is required for a variety of important purposes, such as general water resources management, rehabilitation of embankments, design and maintenance of drainage and irrigation systems, navigation, and any coastal management in the area. Such monitoring would serve as an important supplement the routine monitoring of river flow, sediment transport and morphology, which has being carried out by BWDB for decades, but which has so far not been extended to cover the downstream, tidal reaches of the main river system. The monitoring can provide data for a variety of purposes of high national importance, as indicated in Table 7.1.

- River basin management: Data from the downstream reaches are important for basin-wide water balances of flow and sediment transport, which in turn are part of the fundament of the national water management
- Flood forecasting: Data from the downstream reaches are important for set-up calculations, as carried out on a routine basis by BWDB's Flood Forecasting and Warning Centre
- Engineering design: Valid, updated design water-levels and morphological stability data for coastal flood protection embankments, cyclone shelters, irrigation and drainage schemes, waterways, marine pipelines, harbours, power plants, offshore structures, and any coastal structures and physical development schemes
- Navigation: Feasibility and impact studies, and non-routine monitoring of waterways
- Water quality monitoring: Salinity and salinity intrusion through the lower part of the river system into agricultural areas and mangrove areas; and management of fish farming

Table 7.1: Application of monitoring data (examples)

A continued monitoring (after completion of MES) could be based on regular, say bi-annual, satellite mappings, and a programme of vessel surveys, for example a monsoon campaign and a dry season campaign. The monsoon campaign could comprise flow and sediment transport measurements during one cruise, and the dry season campaign could comprise bathymetry during 2 cruises, flow and sediment transport during one additional cruise, and salinity during 1 cruise, see Table 7.2. If more practical, the salinity cruise could be made from a small separate launch, doing one tour around Bhola. The programme would leave ample time for non-routine allocation of survey capacity for dedicated purposes.

	Flow, sediment transport	Salinity	Bathymetry
Monsoon season	1 cruise		
Dry season	1 cruise	1 cruise	2 cruises

Table 7.2: Outline of future routine monitoring programme

A continued hydraulic monitoring can conveniently be combined with some suitable programme of extended water quality monitoring (with a scope beyond salinity). Initially, a provision should be made for collecting a limited number of water samples for analysis of pesticides and heavy metals. Also, fish samples should be collected for the same purpose. The programme should cover the dry season, and should distinguish between the fresh water body and the saline water body. Depending on the outcome, a suitable level of continued effort can be established. Further, it is recommended to consider the scope for systematic biological monitoring of fish and fisheries, and, possibly, other biological characteristics and indicators.

7.2 Other future applications

In addition to routine monitoring, *'Anwesha'* will have capacity to spare for non-routine applications, possibly on a commercial or semi-commercial basis. With its up-to-date and highly powerful navigation and data collection systems, its tender boats, and its accommodation facilities, the vessel can contribute effectively to serving the continuous national need of survey capacity.

It is sometimes overlooked that the vessel is well suited for river navigation. Even if it is large, its draft is less than the draft of the *'DHA'*, the main vessel of the River Survey Project (FAP24), which for 4 years covered the main river system upstream of the Padma-Meghna confluence. In 1992, *'Anwesha'* did a survey for FAP24 at Bahadurabad without any problems.

'Anwesha' is mobilised already and can operate independently, without foreign participation. Therefore, it can make god sense to use this vessel for a given specific, temporary purpose, rather than spending time and money on import of instruments and mobilisation of a new survey unit.

8 Recommendations

8.1 Over-all recommendations

Reference benchmarks

The network of reference benchmarks established by MES is believed to be the best one available in the area today. Furthermore, the coordinates are publicly available. The benchmarks are highly valuable in connection with any monitoring or construction activities in the estuary (for example embankments, and irrigation and drainage schemes). It is strongly recommended to retain the network for future applications. This will require merely an annual inspection, freshing up the painting etc., and with an occasional re-establishment of lost benchmarks, if required.

Today, the national geodetic network of Survey of Bangladesh covers almost the entire country except the estuary. Presumably, some time in the future that network will extended to include the estuary as well. In this connection, suitable links should be established to the MES network, in order to facilitate conversion of reference levels for the purpose of historical analyses of land and seabed elevations and water-levels.

Data analysis capability

In the course of the project, the SSD team extended their high degree of proficiency to cover the handling of the new instruments that were implemented. The data analysis, however, was made by the MES project team, which is by its nature a transient being. The efficiency criteria applied, by necessity, by the Project do not in all respects comply with long-term demands. According to the MES routine, the raw data tapes were produced onboard, and were handed over to the project office upon completion of each cruise, together with the field sheets, for post-processing. Once the Project is completed, the SSD team will still be able to produce tapes with highly accurate raw data, but the risk exists that there will be nobody to receive and process these tapes.

Therefore, a provision should be made for building a permanent data processing expertise within SSD, which would in this way become self-contained with respect to the final product of the survey operation.

Data management

The applied data management routines were tailored for the specific needs of MES, and for that particular project organisation, and should be reviewed prior to implementation in a different setting.

The detailed individual routines may be well suited for many purposes, but the general organisation of the data flow must be adapted, particularly with respect to organisation and allocation of competence. The framework should be well defined, so that it is clear who is doing what. The entire data flow should be encompassed, from the sensors on the vessel to the post-processing and the final storage on CD ROMs.

For the sake of long-term data consistency, routines should be changed only with due consideration. Measuring locations and reference stations should be retained as far as practical. The routine for conversion from WGS84 datum to PWD datum should be updated at rare intervals only, and updates should be duly authorised, and clearly announced and reported to the data users. In general, minor improvements should be implemented with caution.

Whenever field or data processing routines are modified, the documentation should be revised. The transparency of the methodology is a cornerstone of the quality of survey data.

Operation of 'Anwesha'

Today, as one achievement of MES, BWDB's *'Anwesha'* is equipped as an advanced survey vessel, which is able to perform survey work with a high quality and capacity. The routines are partly, although perhaps not yet in all respects fully consolidated within BWDB/SSD. Bottlenecks in connection with a full implementation outside the framework of the MES project organization are (i) data processing capabilities (skills and tools); (ii) access to expertise for ordinary and extraordinary maintenance and repair of instruments, particularly electronic instruments; and (iii) funds for operation and maintenance of vessel and equipment.

It is believed that a commercial demand exists which can ensure a financially sustainable operation of the vessel and of SSD, although some institutional implications need to be sorted out. (For the sake of completeness, these are (i) a market-orientation at the management level; (ii) policy formulation and competence allocation for commercial decision-making; (iii) career opportunities and other incentives for specialist staff; and (iv) a provision for part of the generated income being retained for operation and maintenance. Please refer to /11/ for details).

A semi-commercial operation would consolidate the present qualifications of SSD and would enhance the value of a unique national expertise in the field of estuarine surveying.

8.2 Detailed recommendations

- The quality procedures that were implemented during MES should be continuously revised and further developed, so that a suitable concordance is maintained between nominal and actual procedures for field work and data processing. This requires a regular updating of the survey guidelines and the data processing guidelines (while the need to update the sediment analysis guidelines seems less urgent).

- If so desired, it would be a natural thing to extend a continued estuarine monitoring programme with a small pilot programme of water quality monitoring, comprising collection of some water samples and some fish samples for subsequent analysis of (for example) pesticides and heavy metals.

- The liaison between the field staff and the data processing staff should be consolidated, in order to develop en outlook over the context of the field work, and enhance the over-all data quality.

- The original field reports should be kept in a safe place, from where only photo copies are circulated. Raw data tapes should be made in duplicate and stored in different places. One person should be in charge of the data management.

- The SSD team should be extended with an electronic engineer who can maintain the computer hardware and the different electronic instruments and undertake minor repairs.

- In order to maintain the accuracy during future field work, it is important always to use the same reference station for work in a given area. If in the future, for some reason, the 30/200 Mhz transducer of *'Anwesha'* is shifted, its new level should be determined relative to the present one with an accuracy of ± 1 cm, and the difference should be kept in mind when analyzing measurements of bed level changes.

- A permanent coordinate system should be made on *'Anwesha'*. A number of fix points should be marked with bronze nails, with accurate coordinates relative to each other in 3 dimensions. This will facilitate the relative positioning of antenna, transducers and different sensors. At the same time, some draft scales could be painted on the hull near the ADCP and the echo sounder transducers.

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/3/: Danish Hydraulic Institute: Procedures for determination of suspended sediment characteristics in the field. March 1989

/4/ Survey of Bangladesh: The study on the geodetic survey in the People's Republic of Bangladesh. Japan International Cooperation Agency and Survey of Bangladesh, March 1995. In: Seminar on determination of horizontal and vertical datum for Bangladesh. 5th September 1995 at Sonargaon Hotel, organized jointly by Survey of Bangladesh and Japan International Cooperation Agency

/5/ Government of the People's Republic of Bangladesh, Ministry of Water Resources, Bangladesh Water Development Board: Geodetic (BM) survey by RTK-GPS. Final Report submitted to Meghna Estuary Study (FAP5B) by Surface Water Modelling Centre, June 1996

/6/ MES Guidelines on data processing, estuarine surveys. Internal document, Meghna Estuary Study. Revised, February 1997

/7/ MES Guidelines on execution of estuarine surveys. Internal document, Meghna Estuary Study. Revised, February 1997

/8/ Technical Note MES-005: Sediment analysis procedures. Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultants BV and associates, June 1997

/9/ Technical Note MES-008: Static GPS survey. Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultants BV and associates, June 1997

/10/ Technical Note MES-010: Estuarine survey procedures. Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultants BV and associates, June 1997

/11/ Technical Note MES-011: Assessment of marine survey capabilities. Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultants BV and associates, June 1997

/12/: Meghna Estuary Resource Information System (MERIS), morphology and hydrodynamics, Vol. 1: Cross-section data, and Vols. 2-4: Flow, sediment concentration and salinity measurements data, Part 1-3. Meghna Estuary Study, draft, May 1998

/13/: Government of the People's Republic of Bangladesh, Ministry of Water Resources, Bangladesh Water Development Board: Numerical modelling of hydrodynamics, salinity, waves and sediment transport in the Meghna Estuary. DHV Consultants BV and associates, June 1998

Appendix A:

List of cruises

No.	Period	Place	Purpose
1	26/8 - 10/9 96	Whole MES study area	Reconnaissance
2	8-21/12 96	Whole MES study area	Pressure gauge installation
3	1-12/1 97	Southern sector of MES study area	Bathymetry
4	20/1 - 6/2 97	Around Nijum Dwip	Bathymetry
5	15/2 - 5/3 97	Sandwip Channel	Bathymetry
6	21-31/3 97	Nijhum Dwip, Under Char	Bathymetry
7	5-12/4 97	Char Mujib, Sandwip, Hatia Channel	Bathymetry
8	29/4 - 13/5 97	Whole MES study area	Pressure gauge servicing, supplementary reference stations
9	18/5 - 3/6 97	Bhadarhat, Char Alexander	Assistance to bank protection pilot project
10	6-22/6 97	Whole MES study area	Static GPS survey of reference stations
11	24/7 - 6/8 97	Lower Meghna, Shabazpur Channel	Bathymetry, flow/sediment transport
12	8-17/8 97	Hazimara, Char Alexander, Char Gagaria, Shabazpur Channel	Bathymetry, flow/sediment transport
13	27/8 - 3/9 97	Sitakunda, Sandwip Channel, Urir Char	Bathymetry, flow/sediment transport
14	9-24/9 97	Tentulia River and Shabazpur Channel	Bathymetry, flow/sediment transport
15	3-18/10 97	Lower Tentulia River	Flow/sediment transport
16	1-12/11 97	Around Sandwip	Flow/sediment transport
17	18/11 - 8/12 97	Lower Tentulia River, Khorki, Hiamchar	Bathymetry
18	7-24/1 98	Lower Meghna, Shabazpur Channel	Bathymetry

Appendix B:

MES reference points

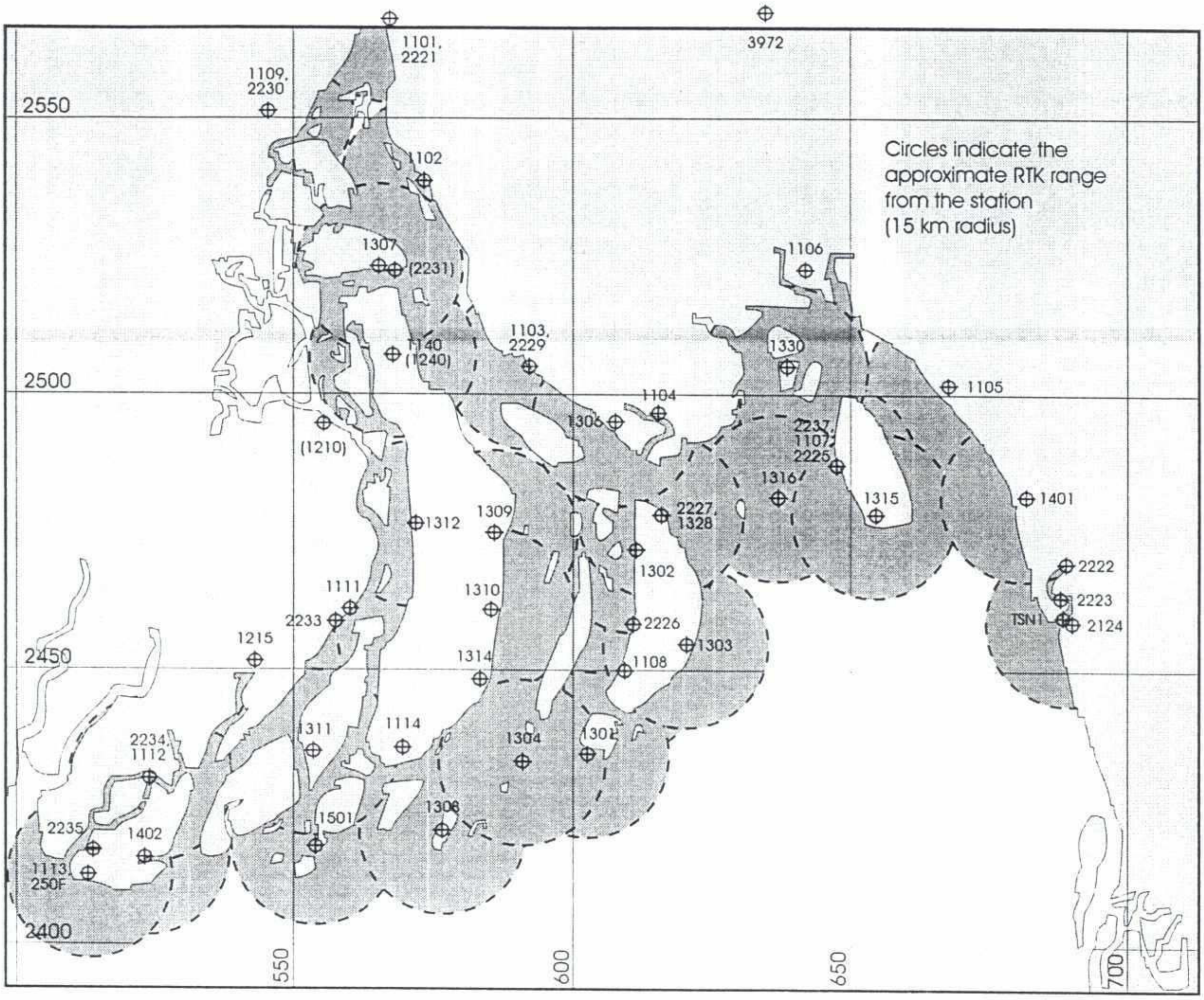

Figure B.1: Map of the MES reference points

No.	Location	Type	Easting BTM (m)	Northing BTM (m)	Ellipsoidal height WGS84 (m)	Estimated level PWD (m)
1101	Chandpur	ERP	566997.6	2568064.1	-37.08	16.98
1102	Hajimara	ERP	573231.5	2538848.5	-40.44	13.65
1103	Char Alexander	ERP	592585.8	2505246.5	-42.95	11.26
1104	Char Mujib	ERP	615305.3	2496728.5	-43.50	10.66
1105	Sitakunda	ERP	667768.8	2501718.9	-38.40	15.05
1106	Sonagazi	ERP	641841.8	2522825.9	-41.87	11.62
1107	Sandwip	ERP	647753.7	2486770.8	-37.87	16.04
1108	Hatia	ERP	609241.3	2449939.2	-45.87	8.94
1109	Gosair Hat	ERP	544465.6	2551291.9	-40.25	14.02
1111	Dasmina	ERP	559998.8	2461075.2	-40.77	14.02
1112	Kepupara	ERP	524487.9	2430175.0	-41.51	14.15
1113	Kuakata	ERP	512757.9	2412568.8	-41.36	14.74
1114	Bhola	ERP	569419.1	2435760.7	-37.68	17.57
1140	Bhola	ERP	567633.7	2507171.9	-40.90	13.38
1210	Dhulia	WLG	555261.7	2494737.5	-51.38	3.02
1215	Galachipa	WLG	543030.3	2451646.5	-52.51	2.54
1240	Bhola	ERP	567633.7	2507171.9	-40.84	13.44
1301	Hatia	ERP	601705.8	2437500.3	-39.24	15.38
1302	Hatia	ERP	611266.1	2472232.5	-41.43	13.06
1303	Burir Char	ERP	620120.1	2455005.7	-45.53	9.13
1304	Char Nijam	ERP	586886.0	2427827.9	-47.21	8.11
1306	Char Alexander	ERP	603177.6	2497314.3	-40.28	13.95
1307	Char Ramdaspur	ERP	565296.9	2522562.1	-44.08	10.13
1308	Char Fasson	ERP	576840.8	2423025.4	-46.64	8.84
1309	Tazimuddin	ERP	587875.9	2478218.3	-41.94	12.57
1310	Lalmohon	ERP	585707.5	2462444.3	-40.70	14.02
1311	Char Biswas	ERP	554619.6	2436953.4	-46.19	9.11
1312	Debir Char	ERP	571218.9	2476528.5	-42.07	12.48
1313	Najirpur	ERP	570668.8	2471388.3	-44.53	9.15
1314	Mofizabad	ERP	584053.0	2449509.5	-42.08	12.85

(table continued ...)

(... table continued)

No.	Location	Type	Easting BTM (m)	Northing BTM (m)	Ellipsoidal height WGS84 (m)	Estimated level PWD (m)
1315	Sarikait	ERP	652625.4	2478066.5	-41.93	12.02
1316	Char Nurul Islam	ERP	631490.1	2481975.3	-41.20	12.98
1316A	Char Nurul Islam	AUX	631653.1	2482015.2	-50.21	3.97
1328	Nalchira	ERP	614893.3	2478558.3	-40.91	13.48
1330	Urir Char	ERP	638134.4	2504008.6	-40.73	13.07
1401	Pahartali	ERP	681544.6	2475434.3	-35.98	17.53
1501	Under Char	ERP	554060.4	2418174.9	-46.72	9.02
2124	Anuwara	ERP	690008.9	2458812.4	-30.96	22.51
2221	Chandpur	WLG	566907.9	2567853.6	-49.65	4.41
2222	Sadar Ghat	WLG	688904.4	2469641.1	-48.49	4.92
2223	Khal No. 10	WLG	687933.9	2463388.4	-45.78	7.70
2225	Sandwip	WLG	647866.5	2486947.7	-50.35	3.56
2226	Char Chenga	WLG	610686.5	2458357.4	-50.07	4.62
2227	Hatia	WLG	615827.8	2478328.5	-50.43	3.96
2229	Char Alexander	WLG	591664.4	2505141.5	-51.42	2.80
2230	Nalmuri	WLG	546255.0	2551466.9	-51.63	2.63
2231	Char Ramdaspur	WLG	567970.6	2522571.9	-50.63	3.57
2233	Dasmina	WLG	557417.4	2458800.6	-52.96	1.88
2234	Khepupara	WLG	523411.6	2430245.3	-53.15	2.52
2235	Dhulasar	WLG	513673.3	2416962.9	-52.79	3.22
2237	Sandwip	WLG	647237.2	2487741.9	-49.33	4.57
250F	Kuakata	AUX	512794.2	2412558.6	-52.09	4.00

ERP: Elevated reference point, in most cases located on a cyclone shelter roof
WLG: BIWTA or BWDB water-level gauge bench mark
AUX: Auxiliary point

Note: Estimated PWD levels reported in /9/ differ from those listed above. The ones listed above are considered better estimates and were generally applied by MES

'PWD level' is the same as 'orthometric height relative to PWD datum'

Appendix C:

Instrumentation of *'Anwesha'*

Navigation and communication

1	GPS receiver	(for navigation)
1	Gyro compass	(for navigation and survey)
1	Echosounder	(for navigation)
1	Autopilot	
1	Radar	
1	Helmsman's display	(used with HYDRO unit)
2	Helmsman's display (small, portable)	(used with HYDRO unit)
1	SSB radio	
5	Fixed VHF radio 25 W	(2 on *'Anwesha'*, 1 spare)
3	Portable VHF radio 5 W with charger	
2	Safecom unit	(incl. 1 spare)

Survey positioning

4	RTK receiver (Trimble 7400MSi) with Radtel GXi UHF radio for reference signal transmission	(1 is for reference station) (interchangeable)
1	Tripod	(for reference station)
1	UHF antenna	(for reference station)

Survey equipment and sediment samplers

1	ADCP current profiler (RDI 600 kHz)	(interchangeable)
1	Knudsen 320 echosounder (30/200 kHz)	
2	DESO 14 echosounder (200 kHz)	
1	S4 current meter with pressure cell, temperature/salinity sensors, tilt compensation, 64 kB data storage, S110 interface unit	(used for profiling with umbilical system or deployed as a self-recording unit)
2	S/T profiler with battery charger	(portable)
1	Portable GPS receiver	(borrowed from MES)
3	Grab sampler	(portable)
1	Umbilical pumping system, 50 m, with Grundfos pump and McArtney power winch	
3	Integrating bottle	
2	Power winch for integrating bottle	
1	Owen sampler	

Data logging and storage

3	HYDRO racks with RTK receiver, UHF radio, HYDRO PC, display and keyboard	(interchangeable)
1	ACQ rack with ADCP PC, ACQ PC, display and keyboard	(interchangeable)
2	Backpack tape storage units	(portable)
1	SAFECOM PC	(also serving as a spare)
1	Compaq notebook PC with charger	(portable, for reference station set-up)
3	SVGA monitors	
2	OKI Microline 380 matrix printers	
1	HP Laserjet 5L	
1	Roland A3 pen plotter	
1	CD ROM drive	(kept at MES Project Office)

Power supply

2	24 V 12 A power supply	
1	UPS Netpro 220 V 2000 W	
2	12-24 V DC/DC converter	
2	24 V battery unit	(for HYDRO rack, interchangeable)
2	24 V battery unit	(for power winch, interchangeable)
1	24 V battery unit	(for reference station)
2	12 V charger	

Bottles

	1 l bottles	(for suspended sediments)
	25 l bottles	(for settling distribution)
	2 l bottles	(for integrating bottle)
	0.2 l bottles	(for Owen tube)

Miscellaneous

1	Electronic toolbox	
1	Multi-meter	
1	S4 mooring string	(recommended for acquisition)
3	Portable lamp	(recommended for acquisition)
1	Portable lantern (for country boat)	(recommended for acquisition)
2	Light anchors	(recommended for acquisition)
5	Light marker buoys (low-cost)	(recommended for acquisition)
1	Measuring tape	(recommended for acquisition)
2	Staff gauges for temporary deployment	(recommended for acquisition)

Consumables

Paper rolls for Knudsen echosounder
Paper rolls for Deso echosounder
Log sheets
Plastic bags for bed samples
Labels for bottles and bags
Printer paper for OKI Microline
A4 paper for HP Laserjet
Data storage tapes
1.4 Mb floppy diskettes
2 mm nylon rope
4 mm nylon rope
15 mm PE rope
4 mm chain
Assorted shackles

Software

3	HYDRO software, with dongle
1	ACQ software
4	Trimble GPS remote control, with dongle
1	S4 communication and data downloading
1	Transect software (for ADCP)

Manuals etc.

3	Log books
1	BIWTA Tide Tables
1	Geodetic survey report, SWMC June 1996
1	MES survey guidelines
1	Trimble 7400MSi operation manual

1	DESO 14 operator's manual
1	S4 user's manual
1	RDI 'Read this first' (for BB-ADCP)
1	ADCP technical manual (RDI)
1	Transect user's manual (RDI)
1	HYDRO installation guide
1	HYDROedit user's guide
1	HYDROtransfer user's guide
1	HYDROnav user's guide (with addendum)
1	OKI microline 380 printer handbook
1	McArtney electrical/optical slip ring handbook
1	Knudsen 320M marine echosounder operator's manual
1	LF325 (S/T profiler) instruction manual
1	Sailor VHF technical manuals for (1) compact VHF and (2) battery charger
1	Philips message handling software, operator's guide
1	Grundfos installation & operating instructions (for sediment pump)
1	Backpack user's guide
1	Backpack CD-ROM drive system
1	Logitech (PC mouse) user's guide
1	CTC1 trickle charging station info sheet
1	MS-DOS user's guide
1	CXL 2-3 LW antenna specification sheet
1	Ladac battery charger, directions for use
1	Roland XY plotter, user's manual
1	Radtel GXI operations manual
1	Sailor manual for 24/12 V regulator
1	Sailor VHF RT2048 compact programme

Appendix D:

Sediment laboratory equipment

(Inventory as per April 1997)

1	Drying kiln Memmert UM-300	1) 2)
1	Drying kiln Heraus FT 420	
1	Millipore filter manifold for 3 filters	1)
3	Filter funnels Type Millipore XX10 047 04	1)
1	Vacuum pump Vacuubrand	1) 2)
2	Andreasen settling tubes 25 l	1)
1	Retsch sieve shaker AS-200 Basic	1) 2)
1	Old sieve shaker (stand-by, presently not applied)	
1	Set of sieves: 600-300-200-150-125-106-90-75-63 micron	1)
22	Old sieves with different mesh widths (presently not applied)	
1	Mettler balance 0.1 mg	
1	Sartorius balance BP3100 P 10 mg	1) 2)
1	Elutriator (rented from SWMC)	
1	Desiccator	1)
1	Stop watch	1)
1	AC stabiliser Stabila 600	1) 2)
1	Vitatron Universal Photometer Type DCP	
1	Sink	1)
1	Aircon	
	Millipore filters Type HA, 0.45 micron	1)
	0.5 litre plastic bottles	
	Tubes and glassware: Beakers, measuring cylinders, pipettes	

1): Supplied by MES
2): With manual

Appendix E:

Survey and data processing staff

MES Survey Team and specialists:

Carl Henrik Andersen, Chief Hydrographer
Palle Mikkelsen, Instrument Specialist
Ejler Haubirk, Marine Surveyor
Lars Dall, Geodetic Surveyor
Lars Bjoern Andersen, Surveyor
Casper Jepsen, Geodetic Surveyor
Mogens Jonsson, Software Engineer

MES Data Processing Team and specialists:

Z. M. Haque, Data Processing Specialist
Md. Mamun, Sediment Specialist
Shahariar Kabir (sediment laboratory)
Ms. Salma Shaheed (data processing)
Ms. Badrun Nahar Polly (data processing)

BWDB/SSD Team:

Md. Sultan Ahmed, executive engineer (until late 1997)
Khalilur Rahman Bhuiyan, executive engineer (from late 1997)
Md. Nurul Amin, SDE
A. Sattar, SDE, Processing Unit
Khan Md. Mostafa Kamal, JRS
Md. Mosiuzzaman, JRS
P. C. Das, JRS
Ali Ahammed Mozumder, Laboratory Technician
Abdul Latif Khan, Laboratory Technician

SWMC Survey Team:

Mahbubur Rahman (geodetic survey)
Nahid Mostafa Choudhury (geodetic survey)
Shah Mohammad Alamgir (geodetic survey)
Farouque Mohiuddin (geodetic survey)
Mohammad Jahangir Kabir (geodetic survey)
Biswasit K. Kundu, JLC (geodetic and marine survey)
Md. Fakhrul Abuddin, SDE (marine survey)
Sajidul Rahman Sarder, SDE (marine survey)

Complement of 'Anwesha':

Md. Younus, captain
Md. Saifuddin, engineer
Md. Kamrul Islam, sailor
Md. Jamal Hossain, sailor
Md. Sayed Zakir Hossain, sailor
Md. Nur Hossain, greaser
Md. Abul Bashar, greaser
Md. Abdur Rashed, lasker
Md. Abdul Manan, survey kalashi
Md. Sk. Mozibur Rahman, cook
Md. Chan Miah, cook
Md. Akkas Ali, bearer

Appendix F:

Glossary

Accuracy: The compliance between a true and a measured or a calculated value, expressed in the physical unit of the value, and often expressed as the (estimated) standard deviation. The accuracy of a measured value can often be improved by repeating the measurement several times

Analysis (of hydraulic data): Processing, involving a sometimes comprehensive transformation and interpretation, in order to arrive at some desired knowledge. Data analysis is often carried out stage-wise and in different contexts: On-line processing in the field, off-line processing, further synthesisation for model input, etc. 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 in a river can be calculated assuming that the current measurements were made simultaneously, even if they 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

Astronomical tide: Water movement caused by the gravity fields of the sun and the moon, strictly periodic and (in theory) fully predictable. At a given location, the tidal height is the sum of a number of sinusoidal components. The period of each component is universal, while the phase and amplitude can be determined by harmonic analysis of long-term records

Bathymetry: (1) The shape of the seabed, (2) measuring the shape of the seabed

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

BTM (Bangladesh Transverse Mercator) grid: A geodetic grid of the Mercator type, which features a true projection of angles and a slightly distorted projection of distances. 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 on Equator and 500 km east of the central meridian, which is 90 °E. Hereby, all coordinates become positive. Except on the central meridian, the 'north' and 'east' directions of the BTM grid deviate slightly from geographical north and east, and the shortest distance between two points is only approximately a straight line.

Calibration: (1) (of an instrument): A series of measurements where the result is known beforehand, for example by comparison with a more accurate instrument under controlled conditions, in order to determine the systematic deviation of the instrument; (2) (of a hydraulic model): A series of simulations aiming at improving the concordance between measurements and calculated results by adjustment of relevant parameters

Char: A low island formed by river deposits. A tidal bar is submerged at high tide, and has no vegetation; a low char is submerged at high tide and has some vegetation; a high char is flooded only occasionally, has a permanent vegetation cover, perhaps with trees, and can be inhabited and cultivated

Coastline stability: A rough distinction can be made between (i) an accreting coastline, with a low gradient, wide sand bars without vegetation, or with thin, juvenile vegetation (typically grass), and no trees or coastal structures near the coastline; (ii) a stable coastline, with a mean gradient, ordinary vegetation (possibly including trees) extending to the high water line (or even beyond), no sign of erosion, coastal structures being in their proper place; and (iii) an eroding coastline, with a steep gradient, a steep eroding bank, vegetation extending to the edge of the bank, perhaps trees are falling into the water, and coastal structures may be damaged

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

Cohesive sediments: Fine sediments, or a mixture of fine and coarse sediments, where the particles adhere to each other in a way that influences the surface erosion of the bed. To be distinguished from non-cohesive sediments, where the surface erosion of the bed is not influenced by interaction between particles. A minor portion of fine sediments in a mixture can make the mixture cohesive

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. Often, reference is made to depth-averaged current velocity without explicit mention of it

Cyclone: A strong depression, characterised by a wind speed of at least 62 km/hour, while a 'severe cyclone' has a wind speed of at least 89 km/hour. Extreme cyclones can have wind speeds of 200 km/hour (or even more), and a storm surge of 6-10 m. In the Bay of Bengal, cyclones are systematically monitored and can be forecasted within a period of some days, but their route is difficult to predict

Datum: A fixed, well-defined reference level for elevations (such as water-levels and bed levels). A datum does not need to be horizontal. WGS84 (used for GPS positioning) is not horizontal, and neither is the BIWTA Chart Datum (CD) nor the Mean Sea Level (MSL) datum. The Public Works Department datum (PWD) is horizontal

Density: Mass per unit volume. The density of sea water is related to its temperature and salinity

Deviation (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. The deviation is inversely related to accuracy and validity, and can be random (stochastic) or systematic

Discharge: Flow or sediment transport through a fixed cross-section of a river

Elevation (or height): Distance above or below a datum. Wherever an elevation is indicated, the datum should be indicated as well

Ellipsoid (for geodetic mapping): An assumed, simplified, but geometrically well-defined shape of the Earth

Ellipsoidal height: Height relative to an ellipsoid

Error (of a calculation method): (1) same as deviation, (2) a deviation with an unacceptable magnitude

Everest 1830: An ellipsoid applied for the BTM geodetic coordinate system

Fine sediments: Clay and silt, with a grain size below 0.063 mm (cf. cohesive sediments)

Flow: Volume transport per time unit (for example through a cross-section of a river)

Frequency: Number (of cycles, units or events) per unit time

Gauging: Measuring at a fixed point; a gauge is a measuring device (e.g. for water-level or pressure)

Geodetic survey: Mapping of geodetic coordinates (of bench marks, reference stations, etc.)

Geoid model: An empirical routine for conversion between ellipsoidal height and orthometric height (for example from WGS84 to PWD)

Horizontal: A plane (or direction) which is perpendicular to the direction of the gravity force. A horizontal plane can be established by a traditional levelling instrument, or by hydrostatic levelling (by a long tube filled with water), but not (directly) by GPS

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

Khal: Canal or creek

Kharif (or summer season, or wet season): March-October. Rainfall is scarce in the first months of this period

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

Mean Sea Level (MSL): The long-term average sea level, without influence from waves, tide, or any short-term variations, but influenced by average river discharge and salinity, and average wind, air pressure, and current. Therefore, Mean Sea Level is not horizontal

Model: (i) A simplified description of a part of reality, preferably well structured; (ii) a simplified but well-defined description of selected, assumed relations within a part of a system (used for analysis of that system); (iii) a software system for analysis of natural phenomena

Monsoon season (in Bangladesh the same as the southwest monsoon season, or late kharif): July-October

Morphology (of a coast or a river): (1) its shape, (2) the study of states, processes and effects that determine or influence the shape

Nadi: River

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

Net current: A long-term and non-orbital current component (for example an ocean current averaged over at least one tidal period, or a wave particle motion averaged over several wave periods)

On-line data processing: Real-time data processing during the survey, aiming at producing raw data files and monitoring the coverage and quality of the measurements, so that they can be repeated immediately, if need be. To be distinguished from off-line data processing (or post-processing)

Orthometric height: Height relative to a horizontal reference level (such as PWD)

Peak (in a record): A deviation of short duration from previous and subsequent levels of an observed or simulated variable

Period: (Please refer to time scale)

Procedure (for a field survey): A fixed set of routines for instrument handling, data collection and field documentation

PWD: Public Works Department datum, a horizontal reference level widely used in Bangladesh and applied by MES

Quality: The compliance between a desired and an actual property (or set of properties) (for example the actual outcome of a study as compared with the Client's expectations). Within hydraulic surveys, quality characteristics can comprise accuracy, resolution, transparency, validity, costs, delivery time, and several other aspects

Quality management: Management addressing the quality of produced data or services

Rabi (or dry season, or winter season): November-February

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 (for example an ADCP recording)

Reference: A basis for comparison

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

Resolution (of a survey instrument): The smallest increment of the true value that can be registered. The increment 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, except as a limiting factor

Runline: A straight survey line identified by its start and end coordinates, and characterised by its orientation

Salinity (of sea water): Relative mass of the salt contents, given in PPT (parts per thousand) (kg per 1,000 kg), or in PSU (practical salinity units) (which is very nearly the same as PPT)

Scenario: A hypothetical, intendedly consistent, set of conditions, describing a possible future situation

Seiche: Long-periodic wave

Settling (or sedimentation): The downward transport of suspended substance under the influence of gravity

Standard Low Water: The water-level that is exceeded in 90 percent of the time. Used as Chart Datum by BIWTA, as it is well suited for practical navigational applications. It is highly influenced by long-term flow variations, and by the morphology. It is not horizontal, nor (in principle) constant in time

Survey: A specific programme of field measurements

Thalweg: The deepest part of a river or a flow channel; the line connection the point of maximum depth of the cross-sections

Tide: (Please refer to astronomical tide)

Time scale (or period, in statistical terms): A time interval that is characteristic for a specific phenomenon (for example a wave period, or a tidal period). A description of the phenomenon requires a fair number of measurements within one time scale. By averaging a record over several time scales, the phenomenon will become concealed (aliased, in statistical terms)

Topographic survey: Mapping of land elevations

Transparency (of a 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 procedures

Trend (in a record): A gradual change of the general level of values

True value (of a parameter or variable): An ideally correct value, determined without any errors whatsoever, and expressed in a standard unit. 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

Validity (of hydraulic data): The compliance between a pursued and an actual value. Even if a recording is accurate, its validity can sometimes be low, for example due to time and space variations (such as flow determination based on a single-point current recording)

Wave: A (periodic or single) orbital movement of water particles, caused by the wind, the tide, or other external forcing

Wave current (or wave-generated current): Current related to the wave motion, and oscillating with the period of the wave. Close to a coast, the wave current can contain a pronounced net component that can transport pollutants or sediments

WGS84: An ellipsoidal (and hereby geometrically well-defined) geodetic coordinate system applied for GPS positioning