MEGHNA ESTUARY STUDY

Bangladesh Water Development Board

Technical Note :

Residual Tidal Volume and Sediment Transport Patterns in the Lower Meghna Estuary During Premonsoon and Postmonsoon - An Analysis of Available LRP Data Collected During 1986-94

Draft Final

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LIST OF CONTENTS

	PAGE
LIST OF CONTENTS	2
LIST OF TABLES AND FIGURES	3
ABBREVIATIONS	4
1. INTRODUCTION	5
1.1 Project Area	5
1.2 Objective and Outline of Report	5
2. COMPUTATIONAL METHODS AND ANALYSIS	7
2.1 Computation of Outgoing and Incoming Tidal Volume and Sediment Transport	7
2.1.1 Tidal Volume During Outflow (Ebb Tide) and Inflow (Flood Tide)	7
2.1.2 Quantity of Sediment Transport During Outflow and Inflow	7
2.2 Analysis of Data	8
2.2.1 LRP Tidal Discharge and Sediment Transport Measurements	8
2.2.2 Tidal Environment	10
3. FINDINGS	12
3.1 Introduction	12
3.2 Tidal Velocity	12
3.3 Sediment Concentration	13
3.4 Residual (i.e., Net) Circulation of Water and Sediment	14
4. REFERENCES	16

LIST OF TABLES AND FIGURES

LIST OF TABLES

Table 1 : Summary of Available LRP Discharge and Sediment Measurements of the Period 1986-1994

Table 2 : Mean Spring Tidal Ranges in Meter at Different Locations Along Bangladesh Coast

LIST OF FIGURES

Fig. 1 Location of LRP Flow Transects (i.e., Cross-sections)

Fig. 2 Direction of Residual Tidal Volume During Pre-monsoon and Post-monsoon

Fig. 3 Direction of Residual Sediment Volume During Pre-monsoon and Post-monsoon

ABBREVIATIONS

BWDB	Bangladesh Water Development Board
BIWTA	Bangladesh Inland Water Transport Authority
GBM	Ganges Brahmaputra Meghna
LME	Lower Meghna Estuary
LRP	Land Reclamation Project
MES	Meghna Estuary Study Project
SSC	Suspended Sediment Concentration
SSD	Survey and Study Division

1. INTRODUCTION

1.1 Project Area

The Survey and Study Division (SSD) of Land Reclamation Project (LRP) collected hydrometric, bathymetric, and sedimentological data with a view to reclaiming agricultural land by stimulating natural accretion process in the Lower Meghna Estuary (LME).

The LRP area covered the estuary of the Ganges-Brahmaputra-Meghna (GBM) river system. This estuary is also known as the Lower Meghna Estuary. The Meghna Estuary Study (MES) project covers the same area as that was covered by the LRP. The combined flow of the GBM is drained through the Lower Meghna river into the Bay of Bengal via the estuary. Among the big rivers in the world, the combined flow of the Ganges-Brahmaputra-Meghna rivers ranks third in terms of river flow and first in terms of total sediment discharge (Milliman, 1991). The project area is bounded at the eastern side by Chittagong main land, at the north by Noakhali main land, and at the west by the Tetulia river (located at the west of Bhola island). Based on interactions between the river discharge and tidal volume moving through the channels during the **pre-monsoon and post-monsoon period** in LME, the estuary can be divided into 3 sub-units (fig. 1) : the Tetulia and the west Shahbazpur channel can be termed as **'fluvial** (in the sense that river outflow dominates over the tidal inflow)'; the east Shahbazpur and the west Hatia channels can be termed as **'fluvio-tidal'**, and the east Hatia and the Sandwip channels can be termed as **'tidal'**. Monpura island and Char Faizuddin divides the Shahbazpur channel into east and west. Char Nurul Islam divides the Hatia channel into east and west.

The major rivers that drain into the project area are the Lower Meghna and the Feni. Major channels in the LME distributary system are the Tetulia, east and west Shahbazpur, east and west Hatia and the Sandwip channel. The Sandwip channel carries negligible amount of fresh water flow when compared with tide-induced flow in this channel.

There are many islands and chars in the project area. Notable ones are the Bhola, Hatia, Sandwip, Gazaria, Char Pir Baksh and Urir Char, Manpura and the Nijhum Dwip.

The 'fluvial' and the 'fluvio-tidal' sub-units as described above act as a **tidal river** with very high river discharges in the monsoon whereas the 'tidal' unit behaves as a **tidal estuary** without significant fresh water discharge from the Feni river. The tide is semidiurnal in nature with two tidal cycles per lunar day of 24 hours 50 minutes duration - each cycle having a period of 12 hours 25 minutes. The interaction between the tidal river and the tidal estuary is induced by the open sea connection with the Bay of Bengal south of the Sandwip island and by the two channels between the north of Sandwip island and the Noakhali main land. The flow in these two channels is induced by the tide level and phase difference between tidal river and tidal estuary as mentioned above.

Elevations of channel bottoms in the estuary indicate a pronounced pattern of channels and tidal flats. Due to sedimentation and erosion induced by tidal flow, and river discharge, the location and geometry of channels strongly change even within a few years. Comparison of satellite images taken during several years available at MES support this argument. Tidal flats (land which emerge around low tide when a relatively small part of tidal area is covered with water) are concentrated in the Shahbazpur and in the west Hatia channels indicating interaction of river sediment and the sediments brought in by tidal currents from the Bay of Bengal.

1.2 Objective and Outline of the Report

Tidal velocity and sediment concentrations measured by SSD of LRP in about 33 flow transects i.e., cross-sections located at different parts (fig. 1) of the project area mostly during pre-monsoon and post-monsoon seasons over the period 1986 to 1994 were analyzed and findings were recorded.

The objectives of this technical note are :

- to determine the tidal flow characteristics and sediment transport patterns during spring and neap tide conditions in the Lower Meghna Estuary that prevalied during LRP period and to compare this with the results of data that are being collected by MES. This comparison will help us to identify whether there is any change in distribution of flow and sediment in different parts of the estuary.

- to compare these findings with results of the hydraulic and morphological model of the entire Lower Meghna Estuary

This technical note is divided into 4 sections. In section 1, a general description of the Lower Meghna Estuary and objective and outline of this note are narrated.

In section 2, methods of calculating and analysing outgoing and incoming tidal and sediment volume during spring and neap tides over a tidal cycle of 12 hours and 25 minutes are described. A summary of computation and analysis of available relevant LRP data is given in table 1. Table 1 is appended at the end of this technical note. The findings in section 3 are based on data as discussed in section 2. Section 3 throws valuable insight into the dominant flow and sediment transport patterns under different hydrodynamic conditions during premonsoon and postmonsoon seasons in the estuary of the Lower Meghna. Finally, the sources of quoted statements in this report are referenced in section 4.

This technical note was written jointly by Saifuddin Ahmed and Teunis Louters of the Meghna Estuary Study.

2. COMPUTATIONAL METHODS AND ANALYSIS

2.1 Computation of Outgoing and Incoming Tidal Volume and Sediment Transport

The interaction of a turbulent and oscillating unsteady tidal flow, the characteristics of which are empirical, and a boundary consisting of loose sediments is not very easy to perceive. This is because the combined transport of water and sediment is a 3 dimensional time dependent phenomena and the relationship between water movement and sediment transport is strongly non-linear. The result is complex. However, the observed data, i.e., velocity and sediment concentration in a vertical was depth averaged to make our analysis simple and practical without loosing accuracy.

In this section, some simple relations for computing flow and sediment transport are mentioned.

2.1.1 Tidal Volume During Outflow (Ebb Tide) and Inflow (Flood Tide)

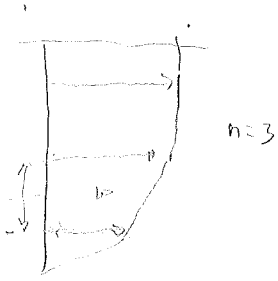
Did you make the computation or was this done by B&K? why absence reference?

Computation of tidal discharge is made by using the velocity area method as described by Barua and Koch (1986). In this method, the total cross-sectional area is divided into representative subareas. In each of these subareas current velocity is measured or is estimated from data of the adjacent vertical. The total discharge is found by the summation of all these subareas according to:

$$Q = \Sigma_{i=1}^{i=n} (b_i * d_i * V_i * \sin\phi_i)_t$$

Where

i	=	subscript representing subarea, total number of subarea being 'n'.
Q	=	total discharge representing the total cross-sectional area [m3/sec]
V	=	depth averaged velocity over a vertical representing a subarea [m/s]
b	=	width of a representing subarea[m]
d	=	water depth of a representing subarea[m]
ϕ	=	angle between the current direction and cross-sectional direction in a vertical representing a subarea.



Depth averaged velocity is computed from individual velocity sampled at 'n' number of points in the vertical, according to;

$$V_i = \frac{1}{d_j} \sum_{j=1}^{j=n} (d_j - d_{j-1}) \frac{(V_j - V_{j-1})}{2}$$

kom niet !!

Where

j	=	subscript representing measuring location in a vertical
V_j	=	measured current velocity at depth d_j ([m/s]
d_j	=	sampling depth [m]

Inflowing and outflowing tidal volume are calculated by integrating hourly discharges computed from depth-averaged hourly velocity measurements over a tidal cycle of 12 hours 25 minutes. Tidal volumes are given in columns 10 & 11 of table 1.

2.1.2 Quantity of Sediment Transport During Outflow And Inflow

The main objectives of sediment transport computations in the large area of turbidity maxima (entrapment of suspended sediment at the mouth of the Lower Meghna river along with fine sediments brought by tide from the Bay of Bengal result in formation of more turbid areas i.e., areas of turbidity maxima) in the LME are

1.- whether an equilibrium condition, erosion, or deposition exist and
2.- to determine the quantities of tidal water and sediment.

Achievement of these objectives is important in designing river training and bank protection works, enhancing accretion for land reclamation (the direction of residual (i.e., net) flow and sediment transport over a tidal cycle at locations of interest will help in designing layout of cost-effective sand catching curtains with an opening towards the tidal current transporting the largest quantities of sediment for making sills for cross-dams), etc.

During current velocity measurements in different cross-sections, water samples were collected usually from three different depths - 0.5 meter below surface, mid-depth and 0.5 meter above bottom, to measure suspended sediment concentration.

Total sediment transport during outflow and inflow is calculated for each of the divided representative subareas by multiplying the depth averaged sediment concentration with the depth averaged current velocity. The total sediment transport volume is found by the summation of all these subareas according to:

$$Sed_t = \sum_{i=1}^{i=n} (b_i * d_i * C_i * V_i * \sin\phi_i)_t$$

where

i	=	subscript representing subareas, total number of subareas being 'n'
Sed	=	Sediment transport representing the total cross-sectional area ($kg/m^2/sec$)
C	=	depth averaged sediment concentration in a vertical representing a subarea [kg/m^3]
V	=	depth averaged velocity in a vertical representing a subarea[m/s]
b	=	width of a subarea[m]
d	=	water depth of a subarea[m]
ϕ	=	angle between the current direction and cross-sectional direction in a vertical representing a subarea.

Depth averaged sediment concentration is computed from individual sediment concentration sampled at 3 points in a vertical, as per

formula rearranged

$$C_i = \frac{1}{3} \sum_{j=1}^{j=n} (C_{0.5m\ below\ surface} + C_{0.5d} + C_{0.5m\ above\ bottom})$$

where C_i = measured sediment concentration at 0.5m below water surface, and 0.5 m above the bottom, and mean water depth d_j [m/s]

Inflowing and outflowing sediment transport are calculated by integrating the individual discharges over a tidal cycle (12 hours 25 min) which are given in columns 14 & 15 of table 1 as per :

$$Sed_{outflow} = \sum_{t=0}^{t=Toutflow} Sed_t * \blacktriangle t$$

$$Sed_{inflow} = \sum_{t=Toutflow}^{t=Tinflow} Sed_t * \blacktriangle t$$

$$Sed_{tot} = Sed_{outflow} + Sed_{inflow}$$

2.2 Analysis of Data

2.2.1 LRP Tidal Discharge and Sediment Transport Measurements

Tidal volume calculated from hourly discharges and sediment volume and their residual direction in the Lower Meghna Estuary have been studied based upon an analysis of tidal velocity and sediment concentration measurements by the survey vessel 'Anwesha' during full tidal cycles in about 33 flow transects i.e., cross sections (fig 1) mostly at the time of premonsoon and

postmonsoon for the period 1986-1994. Velocity and concentrations were measured in one vertical and at many points in a vertical in a flow transect during the 'influence periods' of spring and neap tides.

LRP usually measured the cross sections with the help of echosounder before the measurement of tidal velocity and sediment concentration in vertical(s) of the cross sections. Available widest cross section among regular LRP flow transacts which do not contain any island or tidal flat between its two banks is cross section no. 14 located between Chittagong coast and south-east Sandwip. Its width and maximum depth were 17.4 km and 12.5 m respectively on 01.11.1987. The total width of the widest cross section which has small island (Char Nurul Islam) and tidal mud-flats between its main two banks is cross section number 1 (including sub-sections 1A, 1B, & 1C). This cross section number 1 is situated in the Hatia channel and its width was about 20.5 km.

Dates of most of LRP tidal velocity and sediment concentration measurements in cross sections located at different parts of the estuary fall in the 'influence period' of spring and neap tides (influence period has a duration of 7 days and this duration is counted from the 3rd day before up to the 3rd day after the occurrence of spring and neap tides) and not exactly on the date of occurrence of spring and neap tides. Locations of these cross-sections give a good coverage of the estuary, at least the areas close to tidal flats and islands were covered. Dates of remaining few measurements coincide with the occurrence of spring and neap tides as published in BIWTA Tide Table.

Some anomalies were observed in assigning 'spring and neap tides' on original LRP discharge computation sheets e.g. 'spring tide' was assigned to the measurement carried out at cross section 1D on 15.10.89 whereas 'neap tide' was attributed to the same cross section after 14 days on 29.10.89. The same is true for cross section 1D. These anomalies were corrected. BIWTA tide prediction tables were used to find the dates of occurrence of spring and neap tides.

Simultaneous tidal flow measurements were not possible in more than one vertical (the reference vertical) in a cross-section during a tidal cycle due to the non-availability of more than one sea-worthy measurement vessel. To compute the missing flow data in the remaining vertical(s) of a cross-section where measurements of flow parameters were not possible on the same day, LRP referenced (Barua and Koch, 1986) the unmeasured vertical(s) to the measured vertical by using Chezy's roughness equation (valid for steady flow) and assuming that water surface across a cross-section is horizontal. As flow in the Lower Meghna Estuary is never in steady state, specially there are wind, wave, transitional shelf width, and tidal effects in addition to the riverine flow, this method of computing missing flow data has drawbacks. Probably LRP used this due to the non-availability of more sophisticated instruments like ADCP (Acoustic Doppler Current Profiler) and GPS (Global Positioning System) and methods of measurement during LRP period.

In LRP measurements, there were combined effects of river outflow, tide, wave, and wind although it is not yet known to what extent these parameters dominate the circulation process and drive sediment dispersal mechanisms. Moreover, the main cause may change from season to season and in a few cases from measurement to measurement. In the Lower Meghna Estuary, usually the measurements are related to a set of hydromorphologic conditions. So, an analysis that is suitable for one season or for a specific set of hydromorphologic conditions, may not be suitable in another season or for another set of conditions. Again, the Lower Meghna Estuary is hardly ever in steady state. Despite that, it is helpful and essential to at least conceptualize the dominant tidal flow and sediment transport mechanisms and trends.

Analysis of LRP tidal flow and sediment transport measurements are summarized in table 1. Some interesting generalizations can be made from most of the numerical figures in columns 12 & 13 and 16 & 17 of table 1. A few numerical figures for the same cross section do not show the same trend as the rest (most of the numerals) do. From table 1, it can be inferred that ratio between outflow and the total tidal volume during a tidal cycle remains considerably more than 50% through cross sections (cross sections 11, 21A, & 21B, 10,19, & 20, 5, and 12A) in fluvial channels except in a few cases which means that river outflow dominates over the tidal inflow from the Bay of Bengal, more but close to 50% through cross sections (3A, 3B, 12B, JA, 2A, 1B,

1C, & 13A) in fluvio-tidal channels and remain always less than 50% through cross sections (1A, 13B, 6 & 14) in tidal channels which means that tidal inflow from the Bay of Bengal dominates over the river outflow. It is to be noted that flow data of 1987 only is available for cross sections 3A, 3B, 3C, & 3D which are comparatively old and seems to be inconsistent also. The sub-division of distributary channels in the estuary into three sub-units as narrated in section 1.1 of this report is also supported by bed material distribution, which is fine sand in fluvial channels, becomes gradually finer as tide becomes significant, and in tidal channels in the east the median diameter (D_{50}) represents fine to medium silt. The subdivision is also an indication of the horizontal stratification of distributary channels and has been recognized by Barua and Koch (1986) and Barua (1990). Some conclusions presented by Barua(1990) are :

1.- Suspended Sediment Concentration (SSC) is lower in fluvial channels and higher in tidal channels, and increases as tidal influences increase.

2.- SSC is independent of river discharge in tidal channels

3.- Spring tidal SSC is about twice the magnitude of neap tidal SSC. The average SSC measured in 1985 and 1986 near the north-west coast of Sandwip is about 4225 mg/l, while near the south-west coast of Hatia measured in 1984 and 1985 it is 1230 mg/l. Tidal average SSC measured on October 15, 1990 - four days before spring tide in the west Shahbazpur channel, was 265 mg/l at surface and 430 mg/l at 1 m above bottom. The median grain size (D_{50}) found at this location was 120 micrometer. Full tidal cycle measurements of horizontal and vertical tides show a long ebb period and a short flood period. In the Shahbazpur channel, the maximum ebb current is higher than the maximum flood current which shows seaward residual transport of sediments

2.2.2 Tidal Environment

Tidal waves approaching the coastal belt and coastal islands of Bangladesh are affected at least by four factors causing amplification and deformation of the waves. They are the Coriolis acceleration, the width of the transitional continental shelf, the coastal geometry (e.g., the funnelling shape of coastline around north of Sandwip island) and the frictional effects due to fresh water flow and bottom topography. Table 2 shows the mean spring tidal ranges at different locations along the coast in 1990 (Barua 1991).

Table 2 : Mean Spring Tidal Ranges in Meter at Different Locations Along Bangladesh Coast in 1990 (Barua 1991)

Name of Location	Mean Tidal Range in Meter
Hiron Point	2.95
Tiger Point	3.15
Khepupara	2.28
Galachipa	2.96
Char Chenga	3.56
Sandwip	6.01
Chittagong Khal No 10	4.81
Cox's Bazar	3.58
Shahpuri Island	3.37

The tidal range at Cox's Bazar is higher than that at Hiron Point partly due to the changes in the transitional shelf width and partly due to Coriolis acceleration which provides higher tidal ranges along the eastern coast than along the western coast in the northern hemisphere. LRP study (Barua and Koch, 1987) shows that the mean tidal range increases up to Sandwip (amplification) after which it gradually gets damped up the estuary along the west Hatia and Shahbazpur channels towards the Lower Meghna river with friction from river flow and bed topography. Available data shows that the recorded maximum tidal range was 9 m during a spring tide on 31.03.94 at Urir Char (West). Water level observations of May 1983, February 1984, and of March and July 1985 in the estuary and around the east and west coasts of Sandwip island in the Sandwip and Hatia channels show that some reflection of the tidal wave occurs contributing to the increase of tidal range around the northeast and northwest of Sandwip island. This means that if any human

intervention is planned or implemented in this area like Noakhali-Sandwip cross-dam, the tidal range will increase as a result and this should be kept in mind. The deformation of the tidal wave with short flooding period and extended ebbing period is also responsible for residual landward transport of fine sediments along the Sandwip and the east Hatia channel (Barua and Koch, 1987 and Barua 1990).

In the estuary, M2 & S2 constituents of tide are dominant. Char Chenga tidal water water level gauge is located few kilometers north of south-west coast of the Hatia island in the east Hatia channel. Analysis of January through July,'86 water level data of Char Chenga shows that M2 & S2 are 1.0103 m & 0.4127 m respectively. The magnitudes of these constituents show seasonal variation also, e.g., monsoon values of M2 & S2 are greater than premonsoon values.

Table 2 shows that the tidal environment of Bangladesh along its coastline is mostly mesotidal (tidal range varies between 1 to 3.5 meters) although around northeast and northwest of Sandwip, it is macrotidal (tidal range is greater than 3.5 meters).

The tide originates in the Indian Ocean and propagates faster along the eastern side than along the western side of the Bay of Bengal. In general, the tidal range decreases gradually going from east to west in the estuary.

Hiron Point is situated at the entrance of the Pussur river and Cox's Bazaar is situated at the south of Chittagong coast along Bangladesh coastline. Hiron Point and Cox's Bazaar are located at about the same latitude. BIWTA water level data of January and August, 1996 for these two stations show that the tide reaches at these two places generally at about the same time although the tide reaches at Cox's Bazaar earlier than it reaches at Hiron Point and the time lag varies between 0 minutes to about 30 minutes.

3. FINDINGS

3.1 Introduction

To understand the morphological behaviour of channels, islands and tidal flats in the Lower Meghna Estuary for improving the safety situation, it is necessary to study the hydraulic parameters such as tidal velocity and morphologic parameters such as x-sectional area. Hydraulic parameters represent the hydraulic energy that shape morphologic parameters and the morphologic parameters are related to the sediment transport. Also the directions of residual tidal volume and sediment volume (calculated from sediment transport) at different parts of the estuary are important because these give the overall circulation pattern of water and sediment. Tidal velocity and sediment concentrations were measured mostly during post-monsoon and pre-monsoon seasons (October to April) in the course of LRP. Monsoon data (May to September) are few except some measurements conducted in September, 1990 in sections 1, 2, 4, 5 & 6 (fig 1) and also in September,'87 in the channel between South Hatia and Nijhum Dwip and a few in July and August.

3.2 Tidal Velocity

The Lower Meghna River

X-sections 10, 19 & 20 are parts one x-section. X-sections 4 & 5 are the other available x-sections located in this river with Char Gazaria in between them.

Recorded maximum velocity through x-sections 10, 19 & 20 is 1.14 m/sec (outflow). Recorded maximum velocity at x-sections 4 & 5 were 2.3 m/sec (outflow) and 3.2 m/sec (outflow) respectively.

The Tetulia River

In the Tetulia river, through cross section 11 at Dhulia-Gangapur, the recorded maximum velocity varied between 1.07 m/sec (outflow) and 1.42 m/sec (outflow).

Only one measurement is available for x-section 21A and the maximum velocity was 1.57 m/sec (outflow). No data for x-section 21B is available.

Also the x-sections 9D, 5D, and 8D are situated in the Tetulia river. Maximum velocities in x-sections 9D, 5D, and 8D were 1.09 m/sec (outflow), 1.54 m/sec (outflow), and 1.18 m/sec (outflow).

The Shahbazpur Channel

There are three x-sections in the east Shahbazpur river, namely 3A & 3B (part of x-section 3), 12B & JA. Three x-sections are available in the west Shahbazpur river, namely, 3C, 3D & 3E (all are part of x-section 3), 12B & JA. No measurements are available for x-section 3E & 12B.

At x-sections 3C & 3D, and 12A, maximum recorded velocities were 1.74 m/s (inflow), 1.62 m/sec (inflow), 2.66 m/sec (outflow) respectively.

Maximum recorded velocities at x-sections 3A, 3B, and JA were 2.33 m/sec (inflow), 1.4 m/sec (outflow), and 1.38 m/sec (inflow) respectively.

Measurements for x-sections 3A, 3B, 3C & 3E are available for March, 1987 only which are old in the context of MES.

The Hatia Channel

There are 3 x-sections in the west Hatia channel, namely, 2 (2A & 2B), 1B & 1C (parts of x-section 1) and 13A. The x-sections 13A, 1A & 9 are located in the east Hatia channel.

Recorded maximum velocities through x-sections 2A & 2B were 3.13 m/sec (inflow) and 2.55 m/sec (outflow) respectively. **Maximum velocity in x-sections 1B** & 1C were **3.6 m/sec** (outflow) and 1.94 m/sec (outflow) respectively.

Recorded maximum velocities through x-sections 9, 1A & 13B were 1.73 m/sec (inflow), 3.23 m/sec (inflow) and 1.63 m/sec (outflow) respectively.

The Sandwip Channel

X-sections 6 & 14 fall in the Sandwip channel. X-sections 7 & 8 can also be assigned to the Sandwip Channel.

Maximum velocities through x-sections 14, 6, 7 & 8 were 1.13 m/sec (inflow), 1.79 m/sec (inflow), 1.82 m/sec (north-eastward), and 2.07 m/sec (south-westward) respectively.

South and Southeast Bhola Area

Maximum recorded velocities through x-sections 1D, 2D, 3D, 4D, and 7D which are located in this area were 2.41 m/sec (inflow), 1.82 m/sec (inflow), 0.96 m/sec (outflow), 2.59 m/sec (inflow), and 1.12 m/sec respectively. All these velocities were measured in September, 1989.

Nijhum Dwip Area

There are 2 x-sections in this area, namely, NI and NB. Maximum velocities in NI and NB were 2.1 m/sec (inflow) and 2.2 m/sec (outflow) respectively.

3.3 Sediment Concentrations

Concentration of materials held in water in suspension by turbulence (suspended sediment) is measured with a view to computing the amount of sediment present in water column at a particular moment. Sediment is eroded, transported, and deposited by water. This erosion, transportation, and deposition of sediment by flowing water is important on both long and short term time scale in terms of land form development and also on shorter engineering time scale because of its impact on, e.g., navigation channels, on hydraulic structures and, on agricultural resources.

Depth-mean suspended sediment concentrations averaged over whole tidal cycles during discharge measurements in cross sections located at different parts of the estuary are given in column 5 of table 1.

Concentration was measured in a cross section simultaneously with the measurement of discharge. LRP measured concentration of sediments usually at 3 points in a measurement vertical in a cross section - at 0.5 m below water surface, at mid depth and at 0.5 m above bed level. Sometimes, concentration was measured at 2 points only - 0.5 m above bed and 0.5 m below water surface.

LRP data shows that in general, concentration of sediment at 0.5 m above the channel bed is slightly higher than that at 0.5 m below surface.

Except in a few cases, concentration at the surface was close to that at the bottom.

Also, suspended sediment concentrations are higher where tidal ranges are higher. Maximum tidal range of 9 m was recorded around Urir Char on 31.03.94.

A tendency of higher sediment concentrations during spring tides was observed. Maximum sediment concentration of 9.74 gm/l at 0.5 meter above channel bed during spring tide was recorded at the north of Urir Char. Data shows that the area of recorded maximum concentration in the whole project area is the Urir Char area.

3.4 Residual (i.e., Net) Circulation of Water and Sediment

An important characteristics of tidal flows is that superimposed on the back-and-forth flow is a net steady circulation, often called the 'residual circulation'. The residual circulation is generally said to be the velocity field obtained by integrating the velocity at measurement vertical(s) taking into account the flow direction in cross section(s) in the estuary over the tidal cycle.

In large estuaries like the Lower Meghna estuary, one cause of the residual circulation is the earth's rotation which deflects currents to the right in the northern hemisphere and to the left in the southern hemisphere. Therefore, in the northern hemisphere flood tide currents are deflected towards the left bank (looking seaward) and ebb tide currents toward the right bank, resulting in net counter-clockwise circulation. A second cause of this residual circulation is interaction of tidal flow with the irregular bathymetry found in the estuary. This residual circulation is additional to, and superimposed on, circulations driven by wind and the river.

Data was collected mostly during dry season (October to April) and some data were also collected during monsoon.

At the time of calculation of residual water and sediment volume during a tidal cycle of 12 hours and 25 minutes, it was found that river flow dominates over the tidal inflow from the Bay of Bengal during **monsoon** in the Lower Meghna, Shahbazpur and the Tetulia rivers irrespective of the effects of spring and neap tides, i.e., in monsoon, the direction of residual water and sediment volume during a tidal cycle is towards the sea in these rivers.

In figures 2 & 3, two symbols were used - the arrow was used to denote the direction of residual water and sediment volume and '●' was used when ratio of inflow and outflow as a function of total volume of water and sediment integrated over a tidal cycle varies between 47% to 54%. The band of 47% to 54% was chosen arbitrarily to account for errors in calculation and measurements. From the analysis of available data, '●' means that the tidal volume during outflow and inflow counteract.

In general, from figure 3, it is concluded that there is a residual circulation of water in the counter-clockwise direction in the Sandwip, east and west Hatia channels. The same can be concluded for the net circulation of sediment in the same area per tidal cycle except for the cross sections 8 & 13(B) during neap tides.

The direction of residual water and sediment volume per tidal cycle through x-sections 1D, 2D, 4D & 7D is towards southwest during both spring and neap tides. The same through x-sections 5D & 3D is towards southeast during spring and neap tides.

During **neap** tidal cycles, the direction of residual water and sediment volume through the x-sections 4, 5, 2A, 2B, 1B, 1C, and 13A is towards the sea when integrated over a tidal cycle.

The direction of residual water and sediment volume per tidal cycle in the channel between south Hatia and Nijhum Dwip is towards south-east during spring and neap tides and the same for the channel between eastern Nijhum Dwip and Char Baheruddin (i.e., Damar Char) is towards south i.e., seaward.

Barua (1990) tried to define dominant flood and ebb channels in cross sections separated by islands in the Lower Meghna river, and the Shahbazpur and Hatia channels. Based on data of spring and neap tides of the high and low river discharges between 1983 and 1985, Barua (1990) concluded that cross sections 1A, 2B, and 4 had net landward water flow and cross sections 5, 2A, 1B, and 1C had net seaward water flow.

This paragraph pertains to the analysis of 1990 & 1994 LRP tidal and sediment volume data (most recent available LRP data). The authors of this note after analysing data for the cross sections 1A, 2B, & 4 could not conclude the same what Barua (1990) concluded (as mentioned in the previous paragraph) for these same cross sections. This is evident from fig. 2. This disagreement is most

probably due to the morphological changes (e.g., sedimentation) that took place around these cross sections between the years 1983-85 to 1994. Comparison of satellite images of 1984 & 1993 support this conclusion. For neap tidal cycles only, the residual direction of tidal volume for the cross sections 5, 2A, 1B, & 1C is seaward. This agrees with Barua's (1990) conclusion for these cross sections. For spring tidal cycles, tidal volume during outflow and inflow for cross sections 1B, 1C, 2A, & 5 counteract which again does not agree with Barua's (1990) conclusions. Cross section 2B showed net landward flow during spring tides but net seaward flow during a neap tide (24.09.90). Barua (1990) did not report such notable features in flow data of 1983, 1984, & 1985. One of the reasons of such features is that the flows were not measured simultaneously on the same date at all these cross sections due to the availability of only one sea-worthy measurement vessel which means that during a tidal cycle, flow was measured in one vertical only in a cross section. Then the vessel was moved to other cross sections and it took several days to complete the measurements.

Another salient feature of some of the data analyzed by the authors is that the direction of residual tidal volume is opposite to the direction of residual sediment volume. This was spotted in cross sections 1A, 2A, 4, 6 & 8. Barua (1990) did not report such events. Incidentally, all these cross sections are located in and around the Sandwip channel except cross section 4. One of the probable reasons is that there may be significant long shore and/or wave driven transport through cross sections 4, 6 & 8 in addition to the suspended sediment carried by the flow. 2D model studies by LRP showed that tides coming from the sea through the Hatia and Sandwip channels meet somewhere around the northern edge of Sandwip island. The location of this point may vary by few kilometers due to the effects of seasonal climatic events and hydraulic factors. This may be another reason.

4. REFERENCES

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TABLE 1 : SUMMARY OF AVAILABLE LRP TIDAL FLOW AND SEDIMENT VOLUME MEASUREMENTS OF THE PERIOD 1986-1994

Cross Section No.	Date	Tidal Condition	Tidal Range	Average Sediment Content	Vmax-Inflow	Average Direction Inflow	Vmax-Outflow	Average Direction Outflow	Tidal Volume Inflow	Tidal Volume Outflow	Volume-Inflow/Total Volume	Volume Outflow/Total Volume	Tidal Sediment Inflow	Tidal Sediment Outflow	Sediment-Inflow/Total Sediment	Sediment-Outflow/Total Sediment
			m	gm/l	m/s	degree	m/s	degree	10^6m3/cycle	10^6m3/cycle	%	%	10^6kg/cycle	10^6kg/cycle	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1A	17.09.90	Neap	4.62	0.77	3.23	333	2.26	151	1492.2	1371.3	52.1	47.9	808.0	1332.1	37.8	62.2
1A	18.09.90	Spring	5.89	1.09	3.14	349	2.40	167	1683.6	1528.5	52.4	47.6	1602.7	1800.0	47.1	52.9
1B	16.09.90	Neap	4.95	0.53	1.42	318	2.65	148	945.1	1783.3	34.6	65.4	449.5	1056.6	29.8	70.2
1B	19.09.90	Spring	6.01	0.63	1.54	325	3.60	143	1282.3	2129.2	37.6	62.4	1111.0	1142.8	49.3	50.7
1C	15.09.90	Neap	3.25	0.50	1.09	335	1.45	155	281.7	393.2	41.7	58.3	120.5	213.6	36.1	63.9
1C	20.09.90	Spring	4.51	0.91	1.64	327	1.94	163	301.0	319.7	48.5	51.5	238.3	334.1	41.6	58.4
2	06.03.89	Spring	2.88	0.46	1.22	287	1.54	121	740.6	573.3	56.4	43.6	454.0	229.8	66.4	33.6
2A	03.01.87	Neap	2.36		1.15	288	1.90	128	4.5	18.7	19.4	80.6	1.9	10.1	15.8	84.2
2A	25.09.90	Neap	3.10	0.55	1.30	278	3.15	129	322.7	1534.0	17.4	82.6	147.8	926.3	13.8	86.2
2A	03.10.87	Neap	2.36	0.56	1.15	290	1.89	120	4.5	18.7	19.3	80.7	1.9	10.1	15.9	84.1
Mean			2.61		1.20	285	2.31	126	110.6	523.8	18.7	81.3	50.5	315.5	15.2	84.8
Std.dev.			0.43		0.09	6	0.72	5	183.7	874.8	1.1	1.1	84.2	529.0	1.2	1.2
2A	26.09.87	Spring	3.88	0.87	1.66	314	2.21	121	290.0	879.1	24.8	75.2	174.2	647.3	21.2	78.8
2A	27.09.87	Spring	3.69	0.60	1.63	294	2.84	125	807.8	2163.4	27.2	72.8	589.6	1292.3	31.3	68.7
2A	21.09.90	Spring	4.06	0.60	3.13	276	2.98	120	1556.3	1518.4	50.6	49.4	882.5	958.8	47.9	52.1
Mean			3.88		2.14	295	2.68	122	884.7	1520.3	34.2	65.8	548.8	966.1	33.5	66.5
Std.dev.			0.19		0.86	19	0.41	3	636.6	642.2	14.3	14.3	355.9	322.6	13.5	13.5
2B	24.09.90	Neap	3.06	1.90	2.35	290	1.12	126	25.1	39.3	39.0	61.0	52.5	93.2	36.0	64.0
2B	05.10.87	Spring	3.41	0.34	2.35	306	1.18	135	279.8	152.9	64.7	35.3	87.6	149.5	36.9	63.1
2B	23.09.90	Spring	3.45	1.75	2.55	298	1.33	121	28.8	11.9	70.8	29.2	72.5	15.2	82.7	17.3
2B	28.09.87	Spring	3.41	0.75	1.88	319	1.60	138	233.4	191.8	54.9	45.1	191.8	161.9	54.2	45.8
Mean			3.42		2.26	308	1.37	131	180.7	118.9	63.4	36.6	117.3	108.9	57.9	42.1
Std.dev.			0.02		0.34	11	0.21	9	133.6	94.7	8.0	8.0	65.0	81.4	23.1	23.1
3A	26.03.87	Neap	2.77	0.40	1.47	354	1.87	194	83.7	96.9	46.3	53.7	16.0	28.9	35.6	64.4
3A	20.03.87	Spring	2.77	1.31	2.33	358	1.58	177	162.4	122.8	56.9	43.1	258.2	151.8	63.0	37.0
3B	25.03.87	Neap	3.11	0.50	0.43	290	1.05	122	32.3	58.1	35.7	64.3	11.2	27.4	29.0	71.0
3B	19.03.87	Spring	3.11	2.17	1.36	326	1.40	124	246.6	153.3	61.7	38.3	574.1	342.9	62.6	37.4
3C	24.03.87	Neap	3.13	0.40	1.11	18	1.25	185	170.2	166.1	50.6	49.4	93.4	41.7	69.1	30.9
3C	18.03.87	Spring	3.13	1.87	1.74	17	1.64	186	275.3	221.7	55.4	44.6	491.2	412.5	54.4	45.6
3D	23.03.87	Neap	3.13	0.44	0.98	18	1.04	197	211.4	184.2	53.4	46.6	119.1	52.9	69.2	30.8
3D	17.03.87	Spring	3.13	1.32	1.62	352	1.12	183	214.2	253.9	45.8	54.2	233.8	371.5	38.6	61.4

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Cross Section No.	Date	Tidal Condition	Tidal Range	Average Sediment Content	Vmax-Inflow	Average Direction Inflow	Vmax-Outflow	Average Direction Outflow	Tidal Volume Inflow	Tidal Volume Outflow	Volume-Inflow/Total Volume	Volume Outflow/Total Volume	Tidal Sediment Inflow	Tidal Sediment Outflow	Sediment-Inflow/Total Sediment	Sediment-Outflow/Total Sediment
			m	gm/l	m/s	degree	m/s	degree	10^6m3/cycle	10^6m3/cycle	%	%	10^6kg/cycle	10^6kg/cycle	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
4	02.08.90	Neap	1.57	1.29	0.41	347	2.10	135	33.9	891.5	3.7	96.3	64.3	1091.8	5.6	94.4
4	01.03.90	Spring	3.00	0.72	1.31	298	1.14	124	316.9	336.2	48.5	51.5	495.4	114.1	81.3	18.7
4	07.10.87	Spring	3.74	0.56	1.04	316	2.30	111	286.5	1018.8	21.9	78.1	177.6	506.7	26.0	74.0
Mean			3.37		1.18	307	1.72	118	301.7	677.5	35.2	64.8	336.5	310.4	53.6	46.4
Std.dev.			0.52		0.19	13	0.82	9	21.5	482.7	18.8	18.8	224.7	277.6	39.1	39.1
5	01.08.90	Neap	1.45	0.62	0.00		2.76	139	0.0	2482.4	0.0	100.0	0.0	1396.1	0.0	100.0
5	30.03.91	Spring	2.76	0.50	1.49	336	2.05	149	307.4	447.9	40.7	59.3				
5	27.02.90	Spring	2.66	0.34	1.51	306	1.56	131	739.2	856.6	46.3	53.7	170.0	382.8	30.8	69.2
5	09.10.87	Spring	2.81	0.31	0.19	298	3.20	165	51.5	2255.2	2.2	97.8	12.8	779.8	1.6	98.4
Mean			2.74		1.06	313	2.27	148	366.0	1186.6	29.8	70.2	91.4	581.3	16.2	83.8
Std.dev.			0.08		0.76	20	0.84	17	347.6	947.8	24.0	24.0	111.2	280.7	20.6	20.6
6	27.09.90	Neap	3.04	0.28	1.79	351	1.53	117	2711.0	1161.4	70.0	30.0	621.4	428.0	59.2	40.8
7	03.03.89	Neap	2.64	0.69	0.56	54	0.74	208	24.2	154.6	13.5	86.5	6.8	126.4	5.1	94.9
7A	21.02.94	Neap	2.40	0.46	0.32	63	0.48	213	0.4	2.3	14.8	85.2	0.1	1.1	8.3	91.7
Mean			2.52		0.44	59	0.61	211	12.3	78.5	14.2	85.8	3.5	63.8	6.7	93.3
Std.dev.			0.17		0.17	6	0.18	4	16.8	107.7	0.9	0.9	4.7	88.6	2.3	2.3
7B	20.02.94	Neap	2.62		0.62	39	0.87	216	40.2	117.6	25.5	74.5	29.8	83.4	26.3	73.7
7B	14.02.94	Spring	5.08		1.82	34	2.06	199	44.6	393.3	10.2	89.8	160.2	1098.1	12.7	87.3
8	04.04.94	Neap	4.21	0.23	1.11	53	0.84	226	176.1	199.3	46.9	53.1	51.6	38.4	57.3	42.7
8	31.03.94	Spring	9.00	3.26	1.91	50	2.07	216	294.8	497.1	37.2	62.8	587.4	2669.3	18.0	82.0
9	19.02.94	Neap	3.90	1.06	1.08	64	1.49	221	5.5	86.7	6.0	94.0	3.4	137.4	2.4	97.6
9	02.03.89	Spring	3.02	0.63	0.63	36	1.03	229	9.7	29.2	24.9	75.1	5.8	21.1	21.6	78.4
9	27.02.94	Spring	6.30	2.23	1.73	34	1.30	213	36.7	246.6	13.0	87.0	110.4	973.1	10.2	89.8
Mean			4.66		1.18	35	1.17	221	23.2	137.9	18.9	81.1	58.1	497.1	15.9	84.1
Std.dev.			2.32		0.78	1	0.19	11	19.1	153.7	8.5	8.5	74.0	673.2	8.0	8.0

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			m	gm/l	m/s	degree	m/s	degree	10^6m3/cycle	10^6m3/cycle	%	%	10^6kg/cycle	10^6kg/cycle	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
11(vert-1)	31.07.90	Neap	0.41	0.44			0.65	115	0.0	220.0	0.0	100.0	0.0	88.1	0.0	100.0
11(vert-1)	07.04.91	Neap	0.59	0.50	0.44	308	0.62	99	138.9	85.0	62.0	38.0	67.6	19.0	78.1	21.9
11(vert-1)	03.12.92	Neap	0.76	0.03	0.36	274	0.67	110	44.6	156.6	22.2	77.8	0.9	4.7	16.1	83.9
11(vert-2)	04.12.92	Neap	0.80	0.04			0.54	90	0.0	179.0	0.0	100.0	0.0	8.6	0.0	100.0
Mean			0.64		0.40	291	0.62	104	45.9	160.2	21.1	78.9	17.1	30.1	23.5	76.5
Std.dev.			0.18		0.06	24	0.06	11	65.5	56.6	29.3	29.3	33.7	39.1	37.1	37.1
11(vert-1)	10.01.89	Spring	1.63	0.24	0.73	283	0.65	113	173.4	209.9	45.2	54.8	43.1	53.8	44.5	55.5
11(vert-1)	09.08.90	Spring	1.46	0.74	0.54	323	1.42	109	221.8	553.6	28.6	71.4	113.8	530.0	17.7	82.3
11(vert-1)	31.03.91	Spring	1.46	0.50	1.40	298	1.07	122	594.0	240.6	71.2	28.8	257.9	108.9	70.3	29.7
11(vert-1)	23.11.92	Spring	1.04	0.07	0.66	288	0.91	111	126.5	231.3	35.4	64.6	7.8	17.2	31.2	68.8
11(vert-2)	24.11.92	Spring	1.16	0.05	0.00		0.69	90	0.0	292.9	0.0	100.0	0.0	16.8	0.0	100.0
Mean			1.35		0.67	298	0.95	109	223.1	305.7	36.1	63.9	84.5	145.3	32.7	67.3
Std.dev.			0.24		0.50	18	0.31	12	223.1	141.9	25.9	25.9	106.8	218.3	26.7	26.7
12A	13.08.90	Neap	1.59	0.49	0.80	350	1.75	189	269.6	2022.7	11.8	88.2	109.3	1170.6	8.5	91.5
12A	06.08.90	Spring	2.70		0.82	323	2.66	173	341.0	2443.0	12.2	87.8	200.3	1233.6	14.0	86.0
13A	26.09.90	Neap	3.03	0.62	0.72	16	0.96	182	262.4	535.5	32.9	67.1	253.9	395.9	39.1	60.9
13B	27.09.90	Neap	3.80	1.14	1.15	352	1.63	153	3121.8	3008.8	50.9	49.1	3869.8	2136.7	64.4	35.6
14	28.09.90	Neap	2.19	0.23	1.13	353	0.88	160	817.7	723.0	53.1	46.9	200.7	169.9	54.2	45.8
16	01.10.87	Neap	2.47	0.47	1.06	259	1.46	72	330.4	448.2	42.4	57.6	124.8	228.2	35.4	64.6
17	28.02.87	Spring	3.29		2.51	344	1.26	157	63.9	92.5	40.9	59.1	86.7	127.6	40.5	59.5
18	02.10.87	Neap	2.28	0.38	1.12	359	0.72	195	99.3	151.9	39.5	60.5	40.0	70.4	36.2	63.8
21A	30.07.90	Neap	0.69	0.49	0.30	346	0.96	179	36.1	359.9	9.1	90.9	14.0	214.5	6.1	93.9
21A	05.04.91	Neap	1.34		0.69	333	1.22	171	193.7	314.9	38.1	61.9				
Mean			1.02		0.50	340	1.09	175	114.9	337.4	23.6	76.4				
Std.dev.			0.46		0.28	9	0.18	6	111.4	31.8	20.5	20.5				

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			m	gm/l	m/s	degree	m/s	degree	10^6m3/cycle	10^6m3/cycle	%	%	10^6kg/cycle	10^6kg/cycle	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
21A	02.04.90	Spring	1.85		1.21	19	1.57	165	335.7	388.0	46.4	53.6				
10,19,20 (vert-2)	19.12.92	Neap	1.13	0.06	0.42	350	1.14	191	92.6	470.2	16.5	83.5	2.7	34.4	7.3	92.7
10,19,20 (vert-1)	20.12.92	Neap	1.19	0.04	0.13	324	0.42	164	61.5	140.7	30.4	69.6	2.8	5.6	33.3	66.7
Mean			1.16		0.28	337	0.78	178	77.1	305.5	23.4	76.6	2.8	20.0	20.3	79.7
Std.dev.			0.04		0.21	18	0.51	19	22.0	233.0	9.9	9.9	0.1	20.4	18.4	18.4
10,19,20 (vert-2)	25.12.92	Spring	2.07	0.05	0.75	351	1.02	174	177.5	466.3	27.6	72.4	5.7	29.5	16.2	83.8
Ilisha-Ram-daspur	22.12.92	Neap	1.38		0.38	304	0.27	145	15.0	8.2	64.7	35.3	1.1	0.2	84.6	15.4
Nil	31.12.87	Neap	1.13		0.84	18	0.88	207	329.9	409.7	44.6	55.4	77.0	75.2	50.6	49.4
Nil	06.01.88	Spring	1.77		1.38	24	1.36	203	552.5	681.0	44.8	55.2	763.8	125.6	85.9	14.1
Kukri - Bhola	01.12.86	Spring	1.61	0.69	0.84	240	1.07	96	165.9	210.5	44.1	55.9	101.6	117.3	46.4	53.6
Char Faiz-Goalia	12.09.86	Neap	2.11	0.63	0.64	336	0.75	197	2.6	2.2	54.2	45.8	1.6	1.5	51.6	48.4
Char Faiz-Goalia	13.09.86	Neap	2.00	0.54	0.30	305	0.61	146	3.0	1.4	68.2	31.8	1.8	0.7	72.0	28.0
Char Faiz-Goalia	19.09.86	Neap	3.11	0.69	0.81	355	1.07	91	2.1	7.6	21.6	78.4	1.2	3.4	26.1	73.9
Mean			2.41		0.58	332	0.81	145	2.6	3.7	48.0	52.0	1.5	1.9	49.9	50.1
Std.dev.			0.61		0.26	25	0.24	53	0.5	3.4	23.9	23.9	0.3	1.4	23.0	23.0
Jahajmara-Goalia	31.12.87	Neap	1.13	0.19	0.84	39	0.88	190	330.0	409.7	44.6	55.4	77.0	75.2	50.6	49.4
Jahajmara-Goalia	06.01.88	Spring	1.77	0.18	1.38	32	1.36	198	552.5	681.0	44.8	55.2	76.4	125.5	37.8	62.2

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Cross Section No.	Date	Tidal Condition	Tidal Range	Average Sediment Content	Vmax-Inflow	Average Direction Inflow	Vmax-Outflow	Average Direction Outflow	Tidal Volume Inflow	Tidal Volume Outflow	Volume-Inflow/Total Volume	Volume Outflow/Total Volume	Tidal Sediment Inflow	Tidal Sediment Outflow	Sediment-Inflow/Total Sediment	Sediment-Outflow/Total Sediment
			m	gm/l	m/s	degree	m/s	degree	10^6m3/cycle	10^6m3/cycle	%	%	10^6kg/cycle	10^6kg/cycle	%	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1D	29.10.89	Spring	1.96	0.19	1.52	249	1.14	45	1007.0	856.0	54.1	45.9	232.0	135.0	63.2	36.8
1D	15.10.89	Spring	2.29		2.41	214	1.12	35	1958.0	623.0	75.9	24.1	853.0	177.0	82.8	17.2
2D	27.10.89	Spring	1.78	0.22	1.35	301	0.89	108	125.0	103.0	54.8	45.2	27.0	22.6	54.4	45.6
2D	15.10.89	Spring	2.29	0.62	1.82	255	1.41	79	363.0	119.0	75.3	24.7	228.0	64.0	78.1	21.9
3D	26.10.89	Neap	1.72	0.16	0.18	317	0.70	169	5.7	7.6	42.9	57.1	0.8	1.7	31.7	68.3
3D	16.10.89	Spring	2.16	0.57	0.16	350	0.96	140	2.5	28.0	8.2	91.8	2.1	12.6	14.3	85.7
4D	28.10.89	Spring	1.80	0.29	0.87	357	1.36	227	197.8	296.5	40.0	60.0	64.7	77.9	45.4	54.6
4D	15.10.89	Spring	2.29	0.54	2.59	359	2.15	194	578.0	599.7	49.1	50.9	288.7	370.0	43.8	56.2
5D	24.10.89	Neap	1.25	0.19	0.44	347	0.52	214	19.4	70.1	21.7	78.3	3.2	11.6	21.6	78.4
5D	16.10.89	Spring	2.16	0.51	0.91	20	1.54	212	80.3	164.8	32.8	67.2	26.0	114.2	18.5	81.5
6D	20.10.89	Neap	0.90	0.33	0.19	261	1.20	110	2.9	216.7	1.3	98.7	0.6	82.4	0.7	99.3
7D	23.10.89	Neap	0.59	0.29	0.00		0.45	275	0.0	9.0	0.0	100.0	0.0	3.0	0.0	100.0
7D	17.10.89	Spring	2.28	0.57	1.12	103	1.10	252	10.4	10.0	51.0	49.0	5.7	5.6	50.4	49.6
8D	22.10.89	Neap	0.66	0.24	0.00		0.52	186	0.0	43.0	0.0	100.0	0.0	11.7	0.0	100.0
8D	17.10.89	Spring	2.79	0.58	1.01	311	1.18	164	107.6	70.6	60.4	39.6	76.1	36.2	67.8	32.2
9D	25.10.89	Neap	1.85	0.23	0.68	79	0.85	256	6.1	18.0	25.3	74.7	1.3	4.5	22.4	77.6
9D	16.10.89	Spring	1.72	0.54	0.93	70	1.09	183	11.7	15.6	42.8	57.2	5.9	9.6	38.1	61.9
Jahajmara-Nizumdwip	14.09.86	Neap	2.11	0.54	0.86	318	1.14	141	48.9	63.7	43.4	56.6	22.2	39.0	36.3	63.7
NI	02.09.87	Neap	1.73	0.42	0.94	294	1.25	114	43.7	85.6	33.8	66.2	18.7	44.8	29.4	70.6
NI	29.12.87	Neap	1.17	0.17	0.61	277	0.47	156	32.9	28.8	53.3	46.7	5.8	4.0	59.2	40.8
NI	04.01.88	Neap	1.97	0.23	0.86	319	1.10	133	50.8	57.5	46.9	53.1	11.4	14.7	43.7	56.3
Mean			1.62		0.80	297	0.94	134	42.5	57.3	44.7	55.3	12.0	21.2	44.1	55.9
Std.dev.			0.41		0.17	21	0.41	21	9.0	28.4	9.9	9.9	6.5	21.2	14.9	14.9
Jahajmara-Nizumdwip	18.09.86	Spring	3.17	0.69	1.30	284	1.16	136	41.2	55.2	42.7	57.3	28.8	37.6	43.4	56.6
NI	08.09.87	Spring	3.38	0.92	2.10	322	2.00	115	139.3	130.5	51.6	48.4	78.9	89.4	46.9	53.1
NI	09.03.89	Spring	3.13	1.18	1.20	300	1.20	127	32.9	79.1	29.4	70.6	32.5	123.2	20.9	79.1
Mean			3.26		1.65	311	1.60	121	86.1	104.8	40.5	59.5	55.7	106.3	33.9	66.1
Std.dev.			0.18		0.64	16	0.57	8	75.2	36.3	15.7	15.7	32.8	23.9	18.4	18.4
NB	30.12.87	Neap	1.14	0.26	0.55	7	0.65	218	16.3	31.1	34.4	65.6	3.0	7.9	27.5	72.5
NB	10.03.89	Spring	3.32	1.61	2.00	351	2.20	183	114.3	163.8	41.1	58.9	150.6	324.1	31.7	68.3

FIG 2 : DIRECTION OF RESIDUAL TIDAL VOLUME DURING PRE-MONSOON AND POST-MONSOON

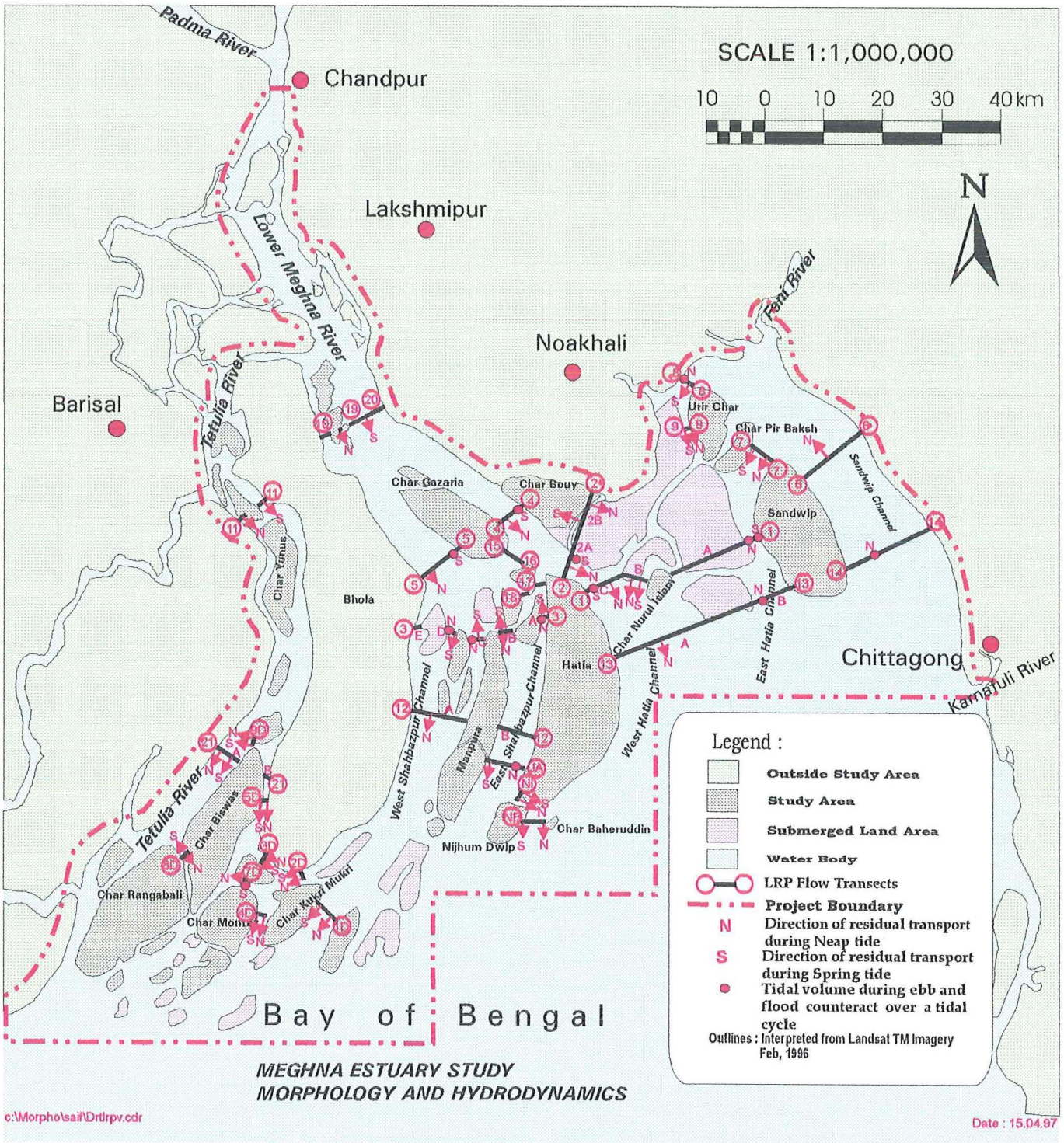
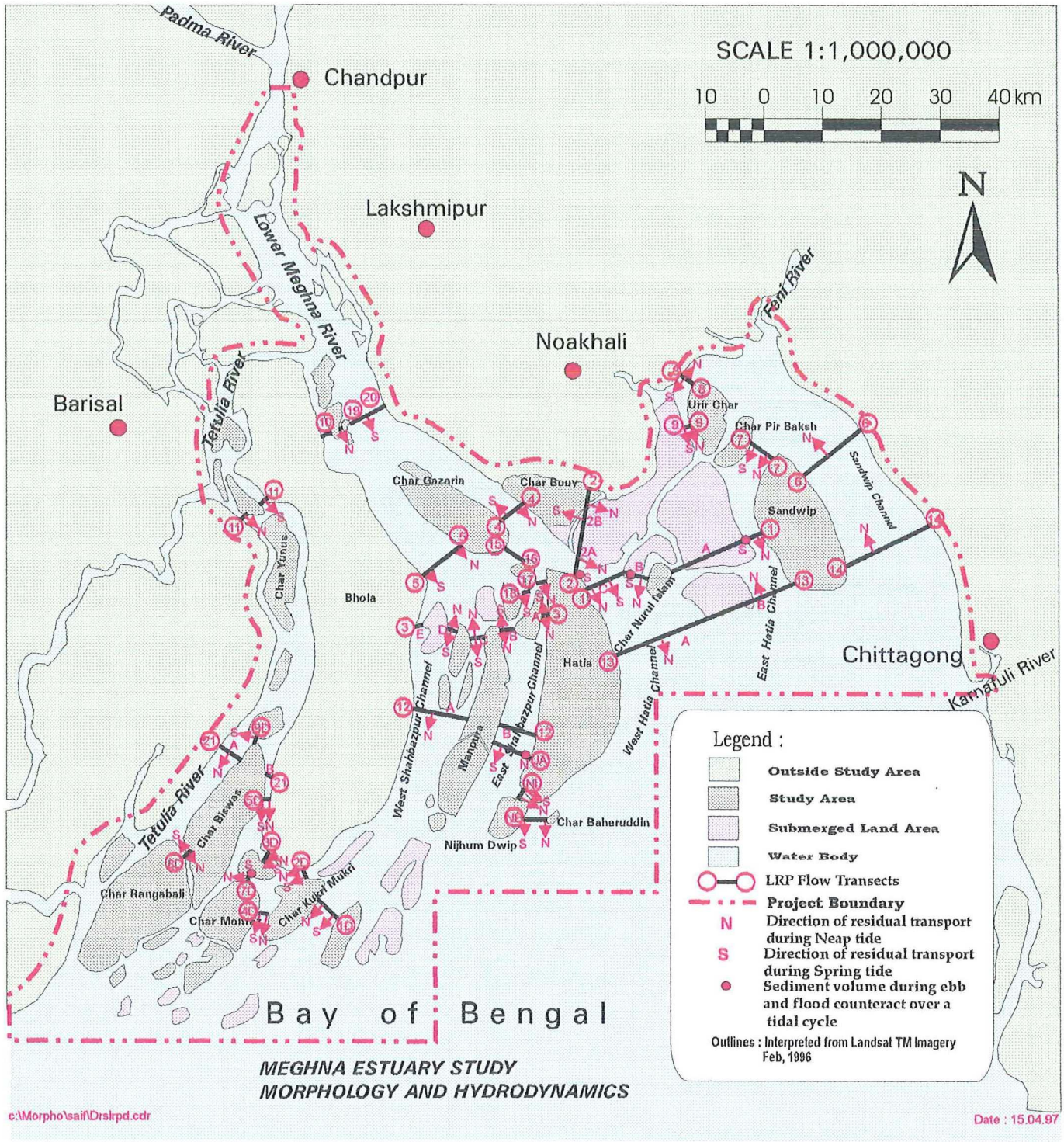
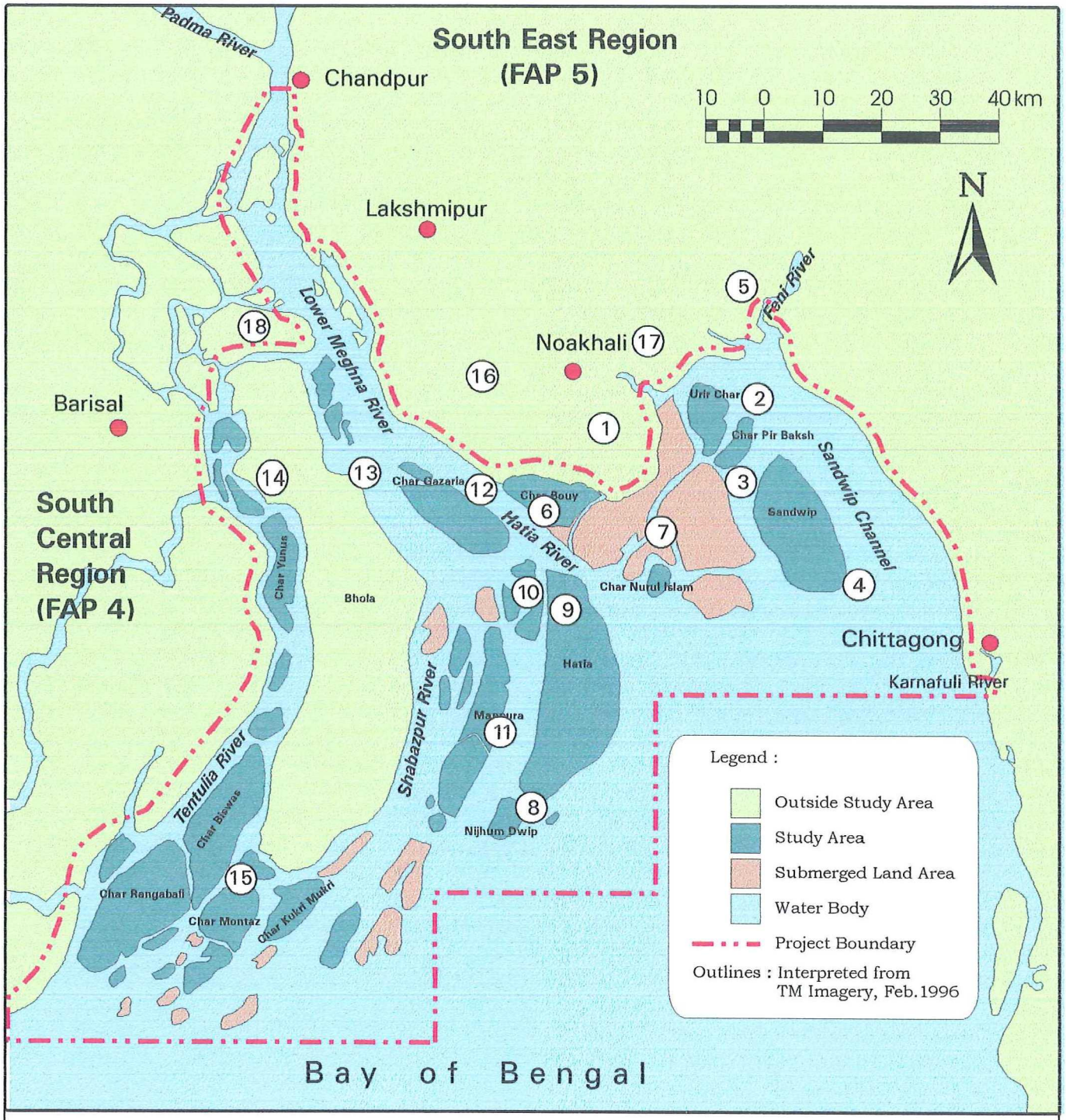


FIG 3 : DIRECTION OF RESIDUAL SEDIMENT VOLUME DURING PRE-MONSOON AND POST-MONSOON

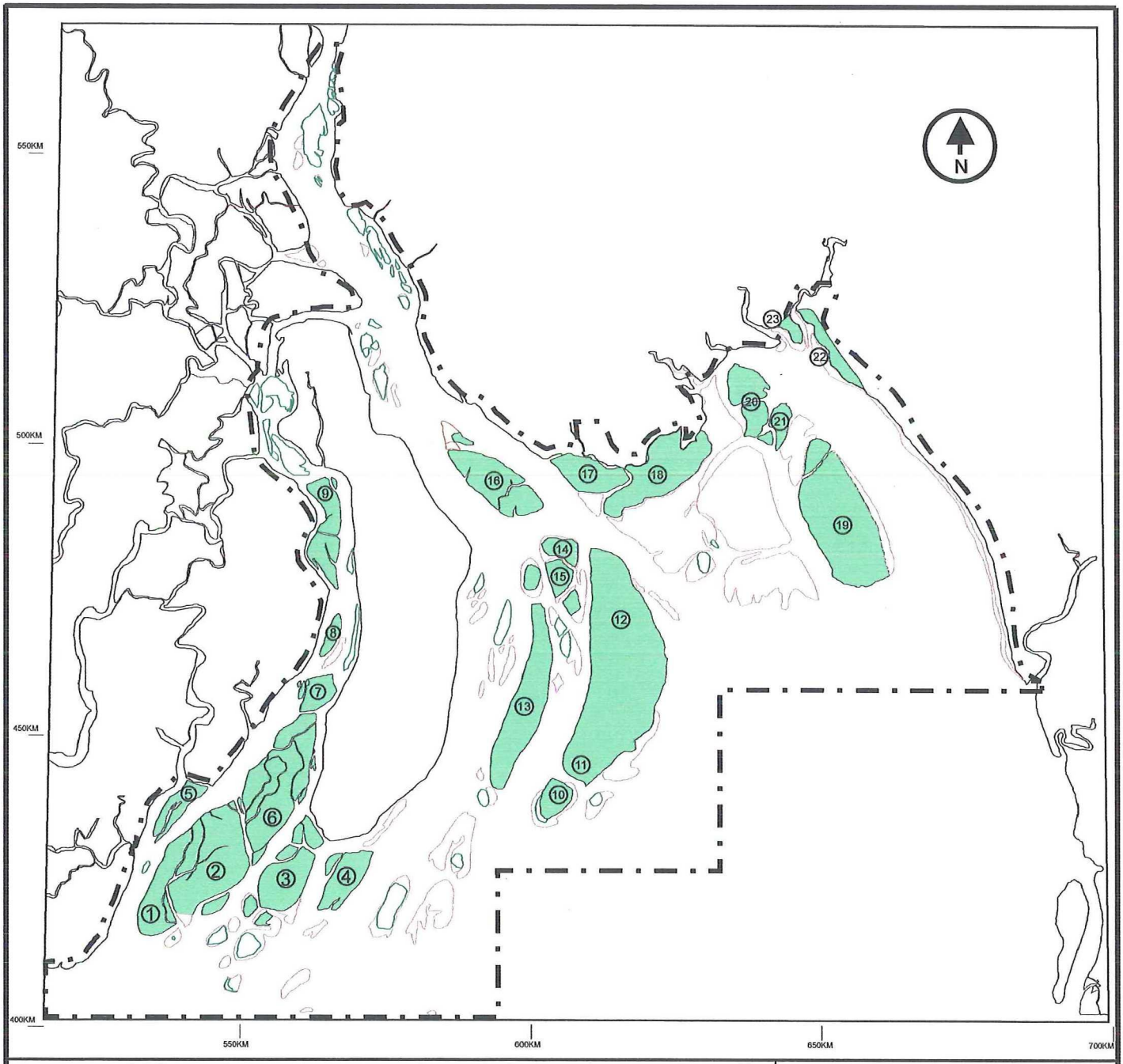


PADMA-JAMUNA-MEGHNA ESTUARY

SCALE 1:1,000,000



1. SIX POLDER SCHEME
2. URIR CHAR POLDER
3. SANDWIP CROSS-DAM
4. SOUTH EAST SANDWIP POLDER
5. FENI POLDER
6. CHAR BOYA CROSS-DAM
7. CHAR NURUL ISLAM POLDER
8. SOUTH HATIA CROSS-DAM
9. HATIA BANK PROTECTION
10. NORTH WEST HATIA CROSS-DAM
11. MANPURA POLDER
12. GAZARIA POLDER
13. NORTH EAST BHOLA BANK PROTECTION
14. WEST BHOLA BANK PROTECTION
15. SOUTH BOLA CROSS-DAMS
16. RAMGATI POLDER
17. SUDHARAM DRAINAGE
18. RAMDAPUR CROSS-DAM



LEGEND

STUDY BOUNDARY

STUDY AREA

SUBMERGED LAND AREA

POSSIBLE AREAS FOR CHAR DEVELOPMENT

REMARK: BHOLA IS EXCLUDED FROM THE STUDY AREA

MEGHNA ESTUARY STUDY

POTENTIAL AREAS FOR CHAR DEVELOPMENT

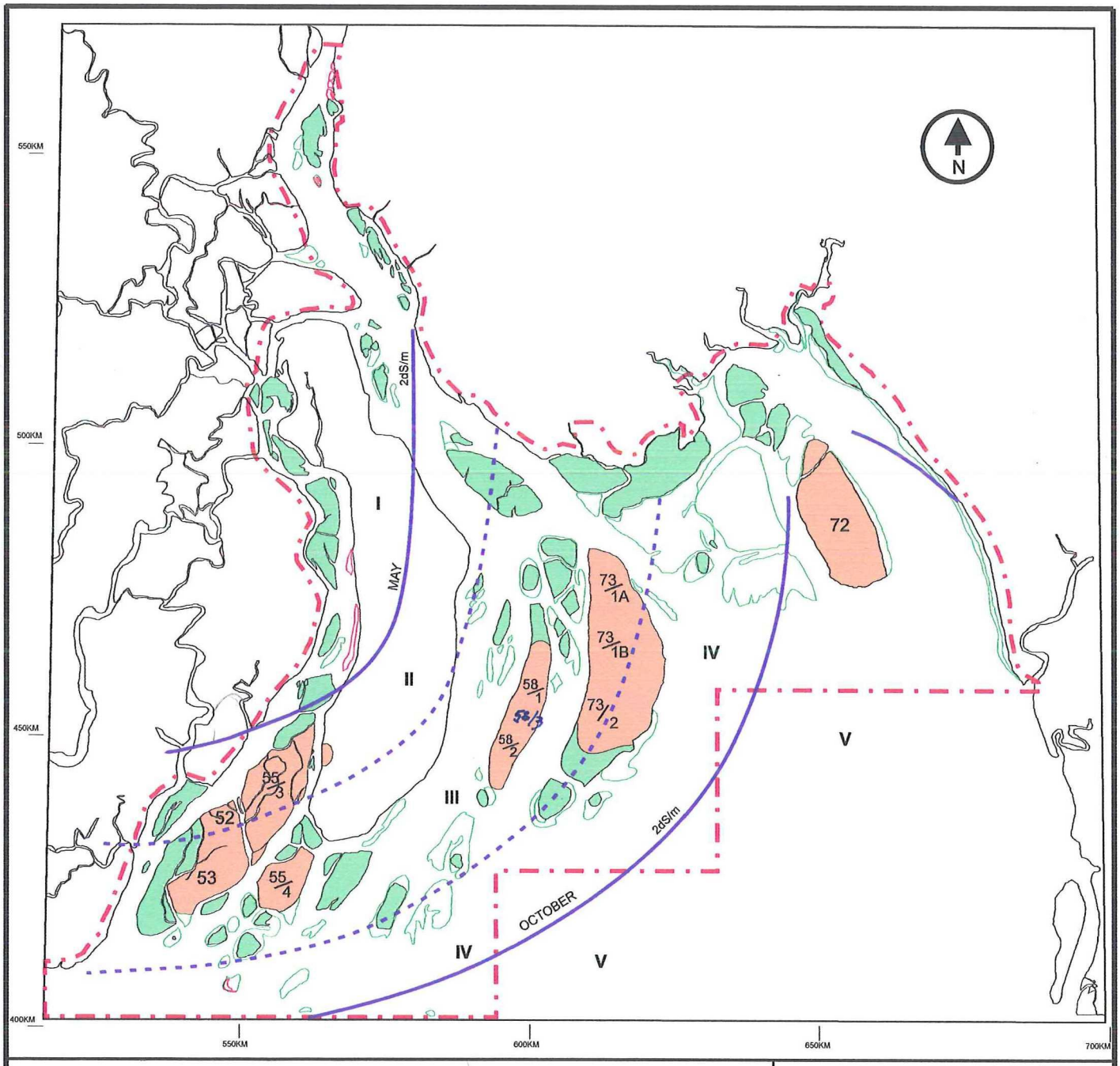
PROJECTION	BANGLADESH TRANSVERSE MERCATOR
SOURCE	LANDSAT IMAGERY FEBRUARY 1996

10 0 10 20 30 40KM

SCALE TO FIT

1 Char Bara Baishdia/Ganga
2 Char Ranga Bali
3 Char Montaz
4 Char Kukri Mukri
5 Char Chalita Bunia
6 Char Biswas
7 Kachur Char
8 Char Kushum
9 Char Yunus
10 Nijhum Dwip
11 South Hatia
12 North Hatia
13 Manpura
14 Moulvir Char
15 Dhal Char
16 Char Gazaria
17 Char Buoya
18 Char Clark Accretion
19 Sandwip
20 Urir Char
21 Char Pir Baks
22 Muhuri Accretion
23 Little Feni Accretion

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LEGEND

STUDY BOUNDARY

STUDY AREA

SUBMERGED LAND AREA

REMARK: BHOLA IS EXCLUDED FROM THE STUDY AREA

MEGHNA ESTUARY STUDY

DRAINAGE AND WATER MANAGEMENT OPTIONS

PROJECTION	BANGLADESH TRANSVERSE MERCATOR
SOURCE	LANDSAT IMAGERY FEBRUARY 1996

10 0 10 20 30 40KM

SCALE TO FIT

EMPOLDERED LAND

UNPROTECTED LAND

2 dS/m SALINITY CONTOUR

AREA BOUNDARY

I Permanent fresh water area, no limitation for surface water irrigation

II Scope for surface water irrigation if empoldered.

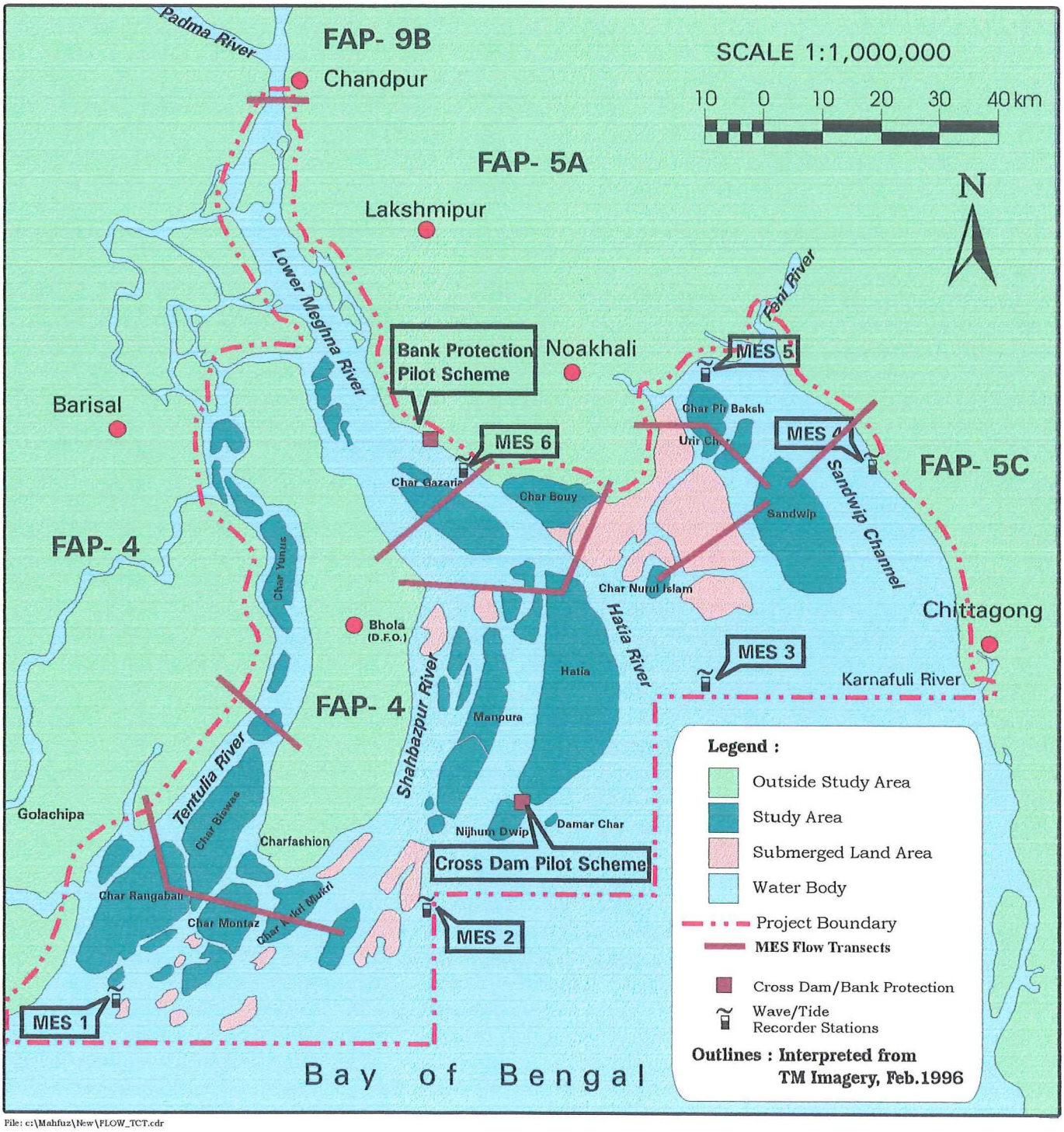
III Scope for marginal embankment against salinity intrusion by tidal floods.

IV Mainly saline water area.

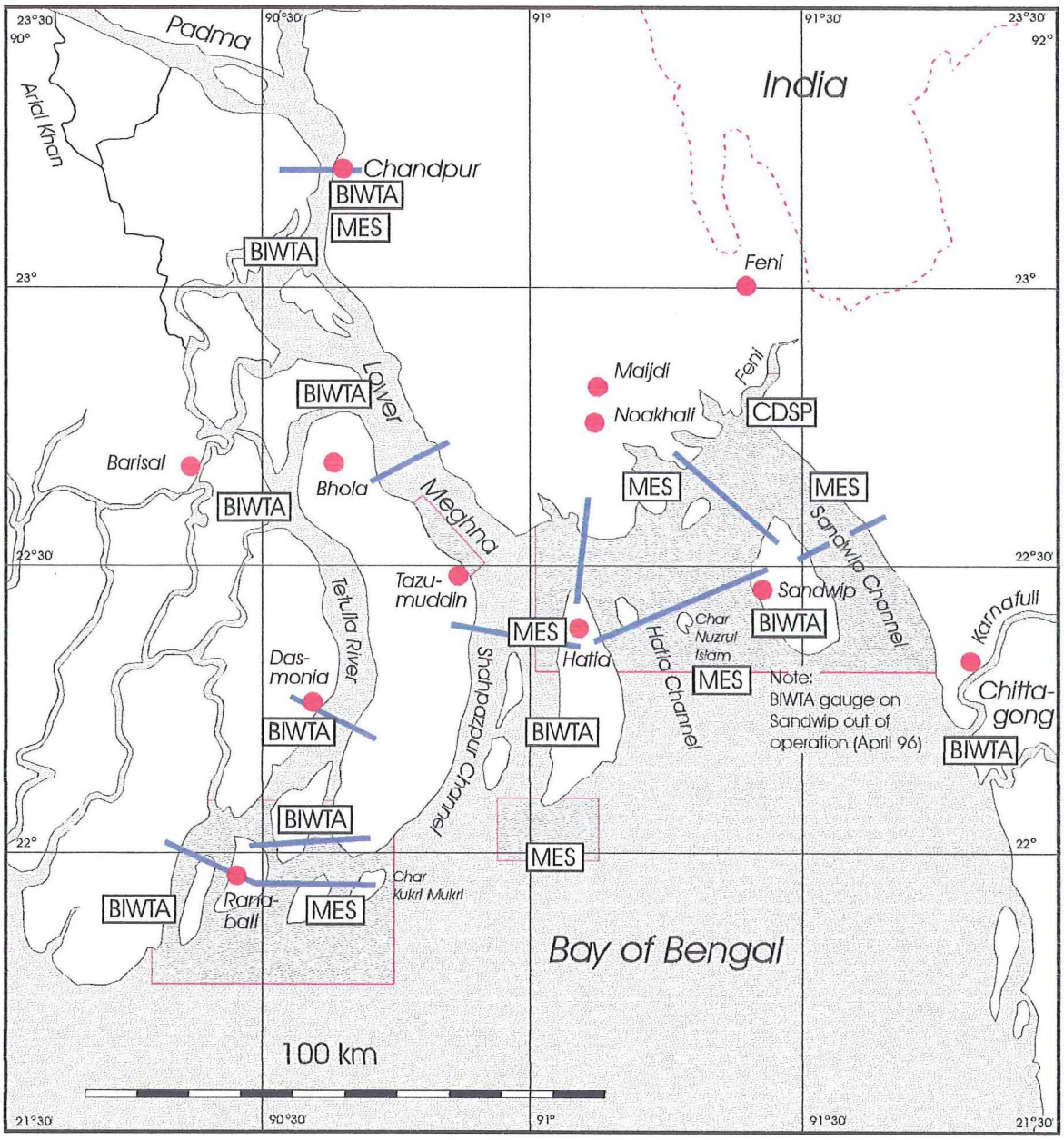
V Permanent saline water area.

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Location Map of MES Flow Transects & MES Pilot Schemes



File: c:\Mahfuz\New\FLOW_TCT.cdr



file: c:\mahfuz\new\ mes-02.cdr

MES bathymetry and flow gauging transect

MES priority study area and bathymetry area

BIWTA — BIWTA water level gauge - location shown in BIWTA Tide Tables

MES — MES wave and water level gauge, to be established

CDSP — CDSP wave and water level gauge, to be established