DGIS/DANIDA GOB

MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD

MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-022

GRAVITATIONAL CIRCULATION SHAHBAZPUR MAIN CHANNEL

September 1998

DHV CONSULTANTS BV

in association with

KAMPSAX INTERNATIONAL
DANISH HYDRAULIC INSTITUTE

DEVELOPMENT DESIGN CONSULTANTS
SURFACE WATER MODELLING CENTRE
AQUA CONSULTANTS AND ASS. LTD.

DGIS/DANIDA GOB

MINISTRY OF WATER RESOURCES

BANGLADESH WATER DEVELOPMENT BOARD

MEGHNA ESTUARY STUDY

TECHNICAL NOTE MES-022

GRAVITATIONAL CIRCULATION SHAHBAZPUR MAIN CHANNEL

September 1998

DHV CONSULTANTS BV

in association with

KAMPSAX INTERNATIONAL
DANISH HYDRAULIC INSTITUTE

DEVELOPMENT DESIGN CONSULTANTS
SURFACE WATER MODELLING CENTRE
AQUA CONSULTANTS AND ASS. LTD.

6

Technical Note on:

GRAVITATIONAL CIRCULATION SHAHBAZPUR MAIN CHANNEL

Dhaka , March 1997

Project Name	:	Meghna Estuary Study (MES)
Location	:	Shahbazpur Main Channel, Meghna Estuary
Key words	:	Gravitational circulation, longitudinal salinity distribution Fine sediment transport

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

An estimate of the Gravitational Circulation in the Shahbazpur main Channel of the Meghna Estuary and its Implications for fine Sediment Transport

1. Objectives

The long-term hydraulic and morphological processes in theMeghna estuary can be stirred by gravitational circulation due to salinity gradients in the pre- and post-monsoon period.
The objectives of this technical note are to estimate the strength of the gravitational circulation for the Shahbazpur main channel of the Meghna Estuary and its importance for the transport of fine sediment. The gravitational circulation will be estimated using LRP measurements of salinity which were collected during the pre-monsoon over the period 1983-1986. For the location of theMeghna estuary and its main channel see Figure 1. For purposes of reference a horizontalcoordinate x, measures along the longitudinal axis of the main channel and positive in the seaward direction, is introduced: $x = 0$ at Ramgati. The area of interest is located betweenRamgati and Hatia-South /Nijhum dwip.
The depth along the thalweg of the main channel decreases from -14m at $x = 0$ to -8m at $x = 65$ km. The maximum tidal velocities in the main channel during pre- and post-monsoon are about 1-2 m/s.

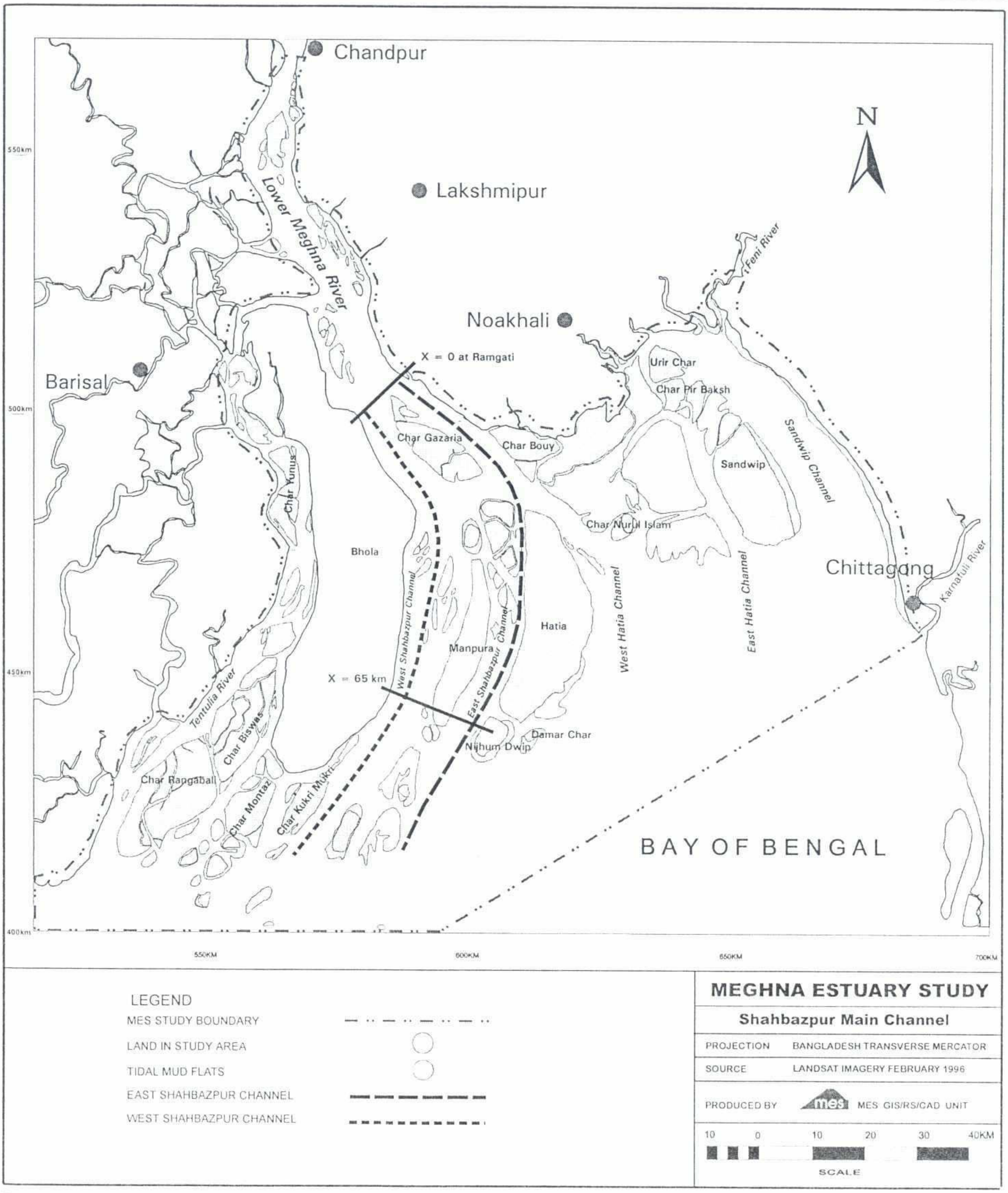
Table 1. Average monthly discharge ratesof the Ganges, Brahmaputra and Meghna rivers

[after Coleman, J.M., Brahmaputra River: Channel processes and sedimentation. Sediment Geol., 3, 1969, pp 129-239]

in 1000 m^3/s

River station period	Ganges, Hardinge Bridge (1934-1963)			Brahmaputra Bahadurabad (1956-1962)			Megna, Bhairab Bazar (1957-1962)			Total
Month	mean	min	max	mean	min	max	mean	min	max	mean
Jan.	3.1	2.3	5.1	5.2	4.4	6.6	0.6	0.5	0.7	8.9
Feb.	2.7	1.9	4.8	4.3	3.4	5.0	0.5	0.4	0.5	7.6
March.	2.4	1.6	3.6	4.7	3.8	6.0	0.6	0.5	1.1	7.6
April	2.0	1.2	3.0	7.1	5.2	8.6	0.9	0.7	1.1	10.1
May	2.1	1.4	3.1	17.8	8.0	24.0	1.9	14	2.5	21.8
June	4.4	2.4	9.7	32.2	26.5	38.7	4.2	3.4	5.4	40.8
July	18.1	10.8	29.6	40.2	33.6	45.4	7.3	5.7	9.1	65.5
August	39.4	23.6	52.6	44.0	30.7	55.5	7.8	6.7	9.1	91.2
Sept.	36.6	25.0	56.0	35.3	24.2	48.5	7.7	6.4	9.5	79.7
Oct.	17.7	8.4	42.3	21.5	14.1	32.0	6.7	5.3	8.1	45.9
Nov.	7.2	4.4	16.5	10.6	8.5	15.0	2.8	1.8	5.0	20.6
Dec.	4.2	2.9	6.7	6.7	5.7	9.4	1.0	0.8	1.3	11.8
Annual mean	11.7	7.8	16.4	19.2	18.0	21.7	3.5	3.0	3.9	34.4

Figure 1: Meghna Estuary and Shahbazpur Main Channel



2. The longitudinal salinity distribution

Gravitational circulation in the estuary depends on the rate of freshwater inflow from the river and the degree of tidal mixing. In particular, the resulting longitudinal salinity gradient is an important parameter; it causes thebaroclinic pressure gradient that forces thegravitional circulation.
The average monthly discharges of the major freshwater source of the GangesBrahmaputra and Meghna rivers are presented in table 1. The average discharge values during monsoon vary between 40,000-90,000 m^3/s. The average discharge values during pre-monsoon are between 7,000-12,000 m^3/s. The salinity during pre-monsoon (December-April) is about 0-1,0ppt at Ramgati and 10,0-16,0 ppt near Nijumdwip (Figure 2).

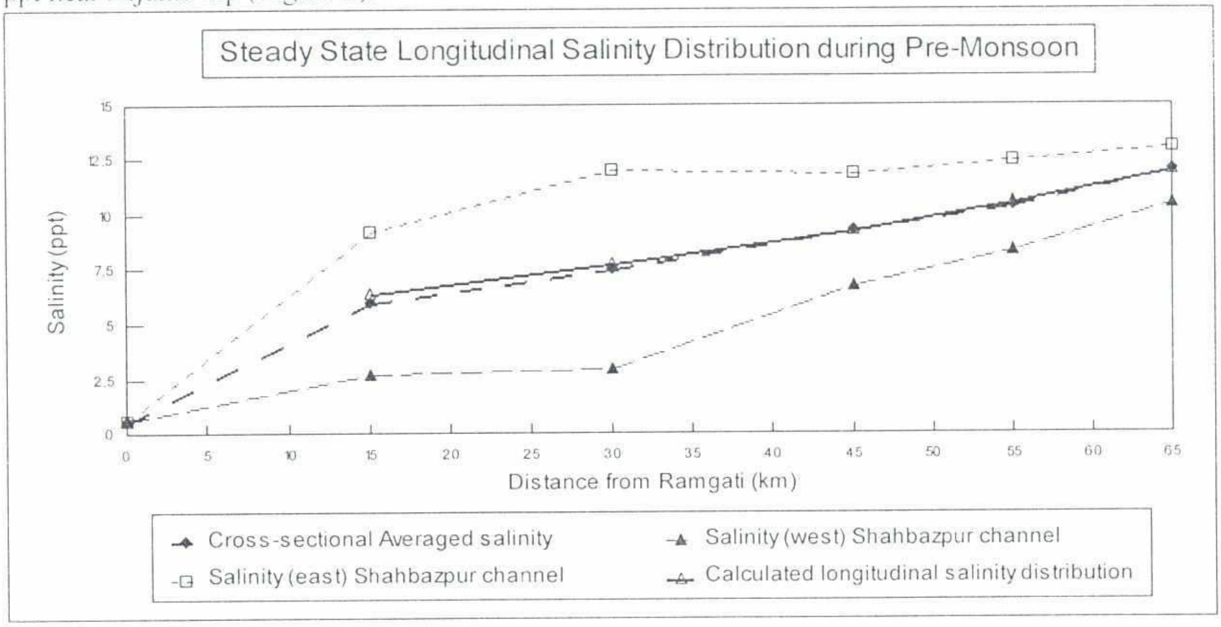


Figure 2. Steady state longitudinal salinity distributions.

In channels with a large freshwater discharge a steady salinity distributions in the main channel can only be obtained using the steady-stateadvection-diffusion equation (Van deKreeke et al., 1990):

$$Q_r s - AD\frac{\delta s}{\delta x} = 0 \qquad (1)$$

in which
Q_r is the river discharge assumed constant; s(x) is the tidally and crosssectionally averaged salinity; A(x) is the tidally averaged cross-sectional area, a typical value (aRamgati) is A=40,000- 60,000 m^2; D(x) is the longitudinal dispersion coefficient (includes effect of tidal shear, trapping, pumping and gravitational circulation). The solution toEq. (1) is

$$s(x) = s(L)e^{-\int_x^L \frac{u_f}{D} d\xi} \qquad (2)$$

in which x = L is the seaward boundary and$u_f(x) = Q_r/A(x)$ is the freshwater velocity (net velocity due to river discharge).

For L>65 km. $A(x) \to \infty$ and $u_f/D \to 0$ and contributions to the integral are negligible. Therefore, selection of the value of L, provided it is larger than 65 km, is not critical. Based LRP salinity measurements during pre-monsoon the salinity at x =65 km is taken equal to 12.0ppt for Q_r = 9,000 m^3/s.

Using (2) and substituting D= 12,000 m^2/s m as value of the longitudinal dispersion coefficients, the longitudinal salinity distribution for Q_r = 9,000 m^3/s can be calculated.

The results are also presented in figure 2. The longitudinal salinity distribution calculated from (Eq.2) is close to the observed distribution.
Due to freshwater dischargessalinities gradually increase when going in a seaward direction. Longitudinal salinity gradients are the largest at thelandward end near Hatia-north (x=30 km). The maximum value for the salinity gradient,ds/dx, is estimated:

Q_r = 9,000 m^3/s ds/dx = $1.0*10^{-4}$ to $4.0*10^{-4}$ ppt/m

3. Estimated strength of the Gravitational Circulation using asimplified analytical expression

A simplified analytical expression for the gravitational circulation and the longitudinal gradient of the vertically averaged salinity,ds/dx, is decribed in Van de Kreeke and Zimmerman (1990).

$$u_{gc} = -0.015\frac{g\beta H^3}{A_z}\frac{ds}{dx} \qquad (3)$$

in which u_{gc} is the strength of the gravitational circulation: g is gravity accelerationβ - $0.78 * 10^{-3}$ ppt^{-1}, relates density and salinity through the equation of state: H is depth andA_z is the turbulent viscosity in z direction. For partially mixed estuaries the value ofA_z ranges between $10\text{-}100.10^{-4}$ m^2/s (Officer 1976, Bowden and Gilligan, 1971 van de Kreeke and Robaczewska 1989).

Gravitational circulation is expected to be maximum at theHatia north, i.e. at x =30 km.
For Q_r = 9,000 m^3/s with ds/dx = $1.0*10^{-4}$ to $4.0*10^{-4}$ ppt/m, H = 10 m and taking A_z= 10-20 cm^2 s, it follows from Eq. (3) u_{gc}= 1- 4 cm/s. A somewhat lower value of A_z is selected because of increased stratification.

4. Gravitational Circulation and Fine Sediment Transport

A crude estimate of the effect of the gravitational circulation on the transport of fine sediment can be made by assuming that all transport takes place in the lower layers and the velocity in the lower layers can be approximated by:

$$u = u_o + u_t \sin\omega t \qquad (4)$$

The first term on the righthand side represents a steadylandward current, the second term represents the tidal velocity. Both u_o and the tidal amplitude u_t are assumed to be independent of space and time. Sediment particles areadvected with the water when the current velocity exceeds the critical erosion velocity u_e. When the current speed decreases below the critical sedimentation velocity, u suspended particles immediately settle to the bottom (zero settling lag).

The net particle displacement follows from:

$$\int_{t_1}^{t_2} u\,dt + \int_{t_3}^{t_4} u\,dt \qquad (5)$$

For definition of t_1 - t_4, see figure 3.
Taking u_t= 1 m/s, u_e= 0.3 m/s, u_s=0.2 m/s and ω= 2π/45,000 rad/s, the resulting net displacement for value of u_o between 0 and 0.1 m/s is indicated in figure 4
The net displacement of a sediment particle is substantial and reaches a value close to 1000 m per tidal cycle for even a relatively small value of the gravitational circulation,u_o, near the bottom of 2 cm/s.

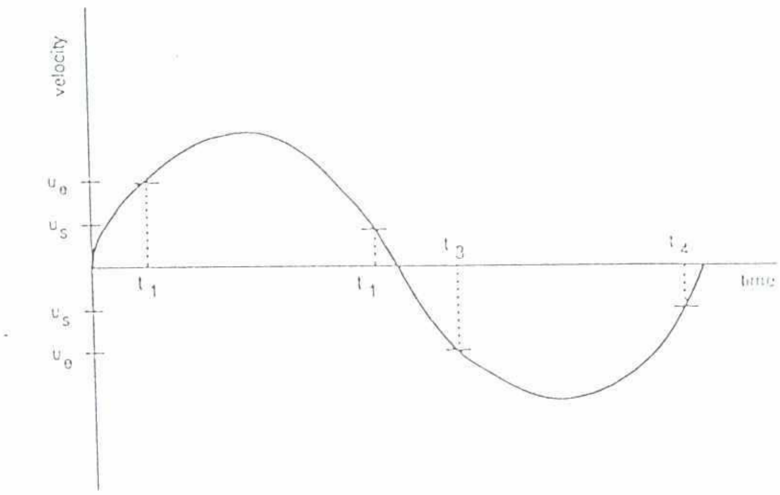


Figure 3. Net particle displacement: definitions

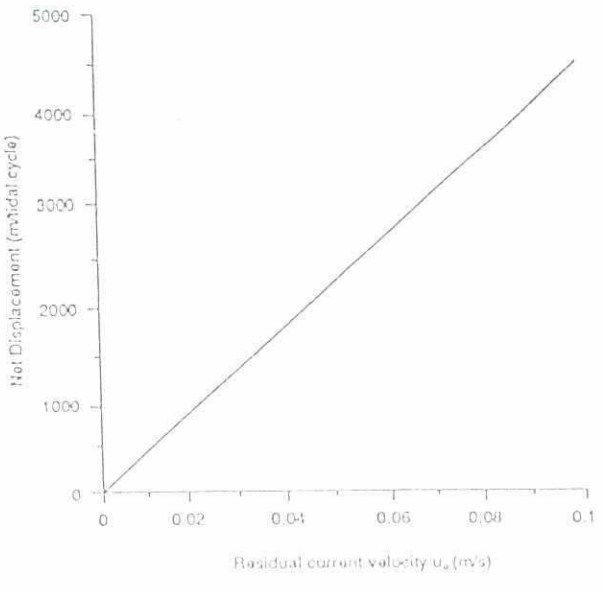


Figure 4. Net particle displacement as a function of residual velocity

5. Conclusions

Based on salinity observations and an analytical model, the strength of the gravitational circulation in the main channel of the Meghna Estuary between 15 km and 30 km is estimated at 0 - 4 cm/s during pre- and postmonsoon, the exact value depending on freshwater discharge and location. Using crude models it is estimated that even a relatively small residual current of a fewcms per period in combination with a tidal current of order one meter per second can lead to sediment particle displacements of few hundreds of meters per tidal cycle.
Furthermore it can be concluded that during monsoon period the strength of the gravitational circulation is negligible in the main channel.
Salinity measurements (LRP) indicate that the salinity gradient in the area near theTentulia river as well as in the Hatia channel is steeper. For these areas the strength of the gravitational circulation might be more than 0 - 4 cm/s.

6. Recommendations

To obtain improved estimates of the strength of the gravitational circulation, it is recommended that monthly measurements of salinity in theMeghna Estuary study area should be carried out.
With respect to hydraulic and sediment transport models it is recommended that the effect of gravitational circulation on the hydraulic and sediment transport processes should be evaluated for pre- and post-monsoon conditions.

7. References

Bowden . K.F.. and R.M. Gilligan 1971. Characteristic features ofEstuarine circulation as Represented in the Mersey Estuary.Limnology and Oceanography, V. 16(3) pp.490-503.

Coleman, J.M., Brahmaputra River: Channel processes and sedimentation. Sediment Geol., 3, 1969, pp 129-239

Officer, C.B. 1976. Physical Oceanography of Estuaries and Associated Coastal Waters). JohnWiley and Sons, p.465.

Van de Kreeke, J and K Robaczewska 1989. Effect of wind on the Vertical Circulation and Stratification in the Volkerak Estuary. Netherlands Journal of Sea Research 23(3), pp.239-253.

Van de Kreeke, J. and J.T.F. Zimmerman 1990. Gravitational Circulation in Well- and Partially-Mixed Estuaries. In: Le Mehaute B. and D.M. Hanes, The Sea, Vol.9, Part A, pp.495-521.