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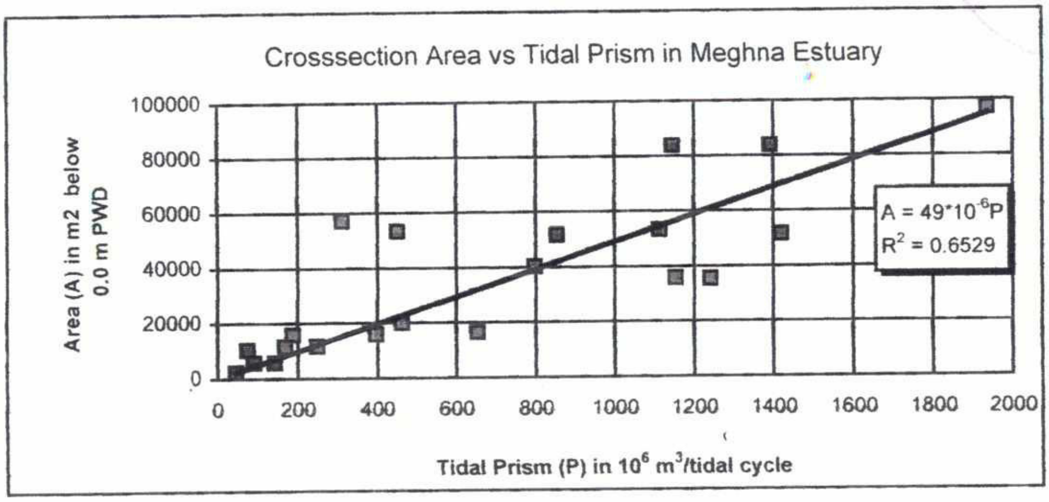
MES II
MEGHNA ESTUARY STUDY



TECHNICAL NOTE MES-034

EMPIRICAL MORPHODYNAMIC RELATIONS TO PREDICT CHANNEL DIMENSIONS IN THE (LOWER) MEGHNA ESTUARY

June 2001

DHV CONSULTANTS BV

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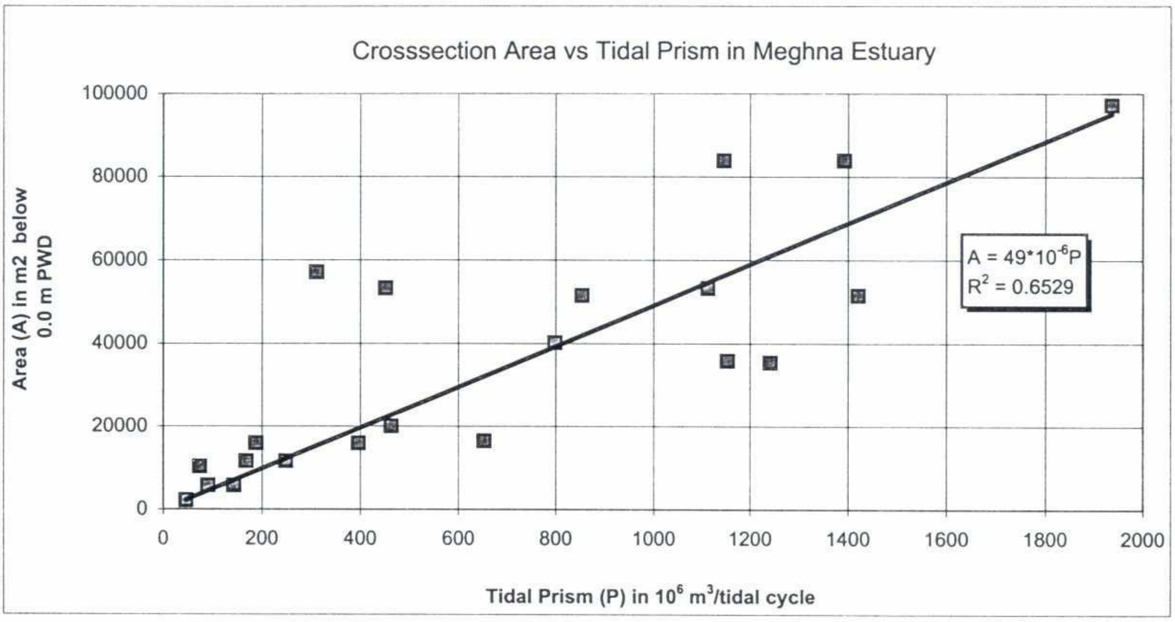

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1. INTRODUCTION

Channel morphology means 'the shape of channel/river' i.e., channel planform characteristics and channel bed configuration. The term 'morphodynamic' is used here to emphasize that channel morphology is a dynamic process. This report describes some empirical morphodynamic relations of most of the tidal channels in the Meghna Estuary (ME) of Bangladesh.

Economic activities in the coastal areas (e.g., fishing, offshore exploration, tourism, settlement of landless poor people in the newly accreted lands, etc.) have increased the migration of people to these areas. As a result, prediction of morphological changes by morphodynamic relations of tidal channels in the fragile coastal ecosystem as a result of natural interactions and human interventions is of paramount importance to minimize their harmful effects.

2. PURPOSE OF THE STUDY

Some stability characteristics (cross-section stability) of tidal channels in the Meghna estuary are analyzed to develop relations among hydraulic and morphologic parameters with the available data. These relations can be used to predict the changes in channel dimensions due to natural and human influences. Forecasting of future morphological changes in the Meghna estuary is very important because the fate of about a few million people living in the coastal areas depend on the resources in the area. Some of these resources are affected by the morphological changes e.g., channel bank erosion displaces people from their homes and causes the loss of valuable and stable agricultural lands. Bank migration and bar development also causes change in spawning and nursery area of fish and shrimps and salt marshes.

3. APPROACH

The morphology of tidal channels is the result of a number of interactive processes. Stability occurs when the sediment transport into a reach of the channel is equal to the transport from that reach. Upstream fresh water flow, tides and waves transport sediments to and from the channels in the ME. The Meghna Estuary (Figure 1) is mainly a meso tidal (tidal range varies between 2 to 4 meters) tide-dominated estuary except the northeastern and the eastern part along the Chittagong coast where the range varies between 3 to 6 meters. The tides are semi-diurnal.

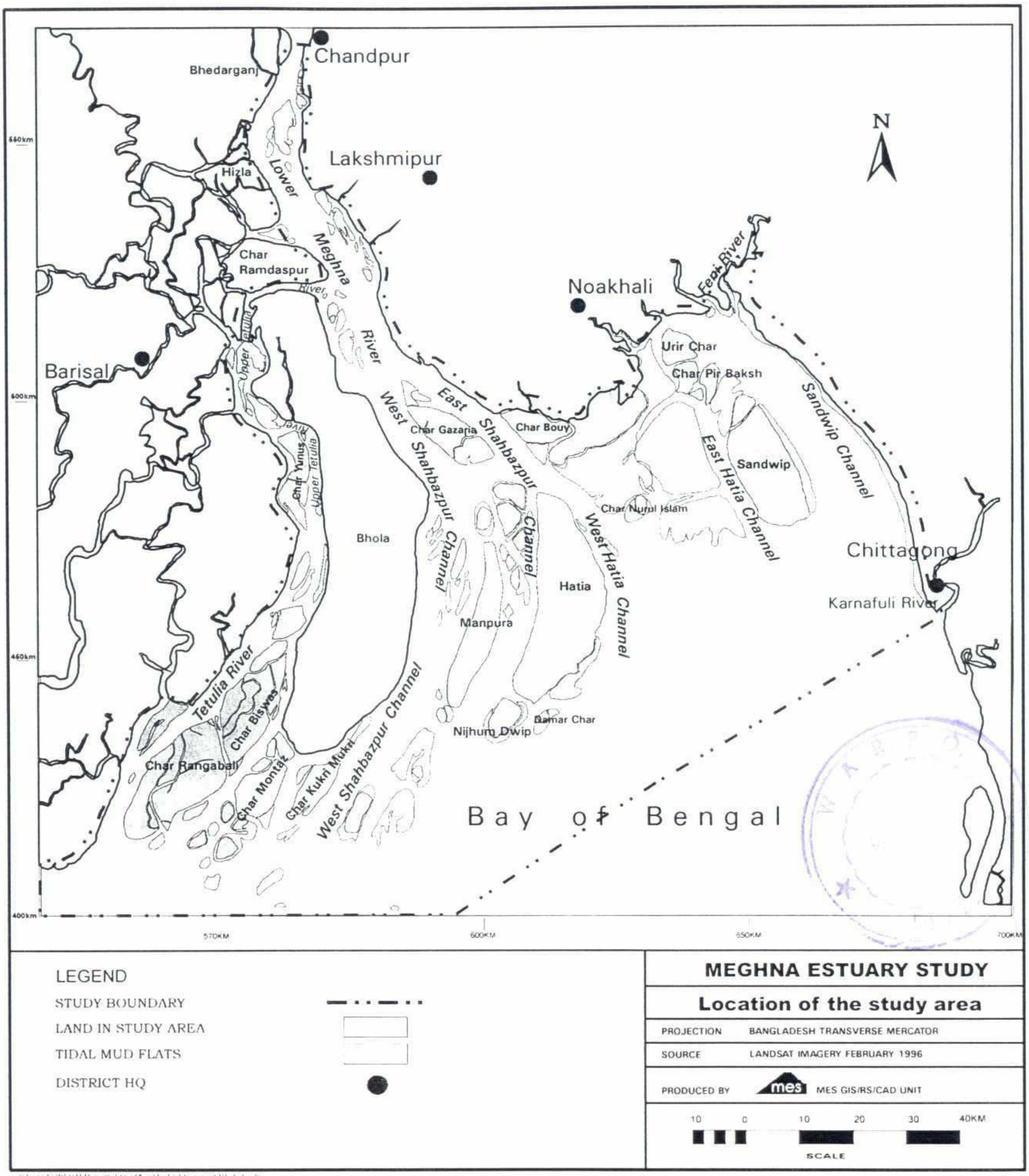
Empirical relation between cross-sectional area and a characteristic hydraulic parameter will be developed to study the morphological behaviour of tidal channels in the ME. To understand this morphological behaviour of channels, islands and tidal flats in the Meghna Estuary for improving the safety of the people living in this area, it is necessary to study the hydraulic parameters such as tidal velocity, and tidal volume and morphologic parameters such as cross-sectional area and depth.

Hydraulic parameters represent the hydraulic energy that shape morphologic parameters and the morphologic parameters are related to the sediment transport. In tidal areas, such a hydraulic parameter can be a characteristic tidal volume, discharge rate and velocity. A combination of two or more such parameters is possible also.

4. EMPIRICAL RELATIONS OF CHANNEL PROFILES

The hydraulic conditions in tidal channels/inlets are important as these are dominant energy sources causing sediment transport, erosion and sedimentation, and grain sorting. Together, these

Figure 1 : Location map of Meghna Estuary



phenomena form the basis of complex geomorphodynamic system. Till now, it is not possible to simulate these complex processes with sufficient accuracy. However, despite the complex and dynamic character of these areas, some system can be recognized in nature if we look in a broad way neglecting details such as migration of channels and shoals (i.e., location stability). It is possible to express certain characteristics in empirical relations that are useful tools for engineers and geomorphologists.

4.1 Historical Perspective

Literature survey shows that some relation between the size of a tidal inlet and the volume passing through it exists (Le Conte, 1905; Brown, 1928; O'Brien 1931 & 1969).

O'Brien (1931) published findings of a study regarding the relationship between the cross-sectional area of a tidal inlet at the gorge and the corresponding tidal prism for a number of sandy tidal inlets protected by two jetties along the Pacific west coast of USA. The following relation existed between the cross-sectional area at mean sea level (Amsl) at the gorge and the tidal prism (P) between MHHW and MLLW of the inlets that were studied by O'Brien

$$\text{Amsl} = \text{coefficient} * P^{0.85}$$

The value of the coefficient depends on the definition and power (in this case 0.85) of P, and the selected reference level (in this case MSL). The numerical co-efficient was $9.02*10^{-4}$.

O'Brien (1969) published the same data and a lot of additional data on inlets with only one jetty or no jetty at all situated along the Pacific, Gulf and Atlantic coasts of USA. The tidal prisms were based on spring tide or diurnal tidal range. His relation can be approximated by

$$\text{Amsl} = 181*10^{-6} * P^{0.94} \quad (\text{Amsl varies between } 43 \text{ m}^2 \text{ to } 232\,000 \text{ m}^2)$$

Other investigators have found similar relationships for different tidal channels/inlets mainly in sandy environment in different parts of the globe which can be generalized in the form :

$$\text{Amsl} = \text{Ca}\, P^n + K \qquad (1)$$

where:

Amsl	= flow area at mean sea level at the throat of the inlet
P	= representative tidal prism
n	= empirical co-efficient
Ca & K	= empirical coefficients depending on the definition of P, the value of n and the selected reference level

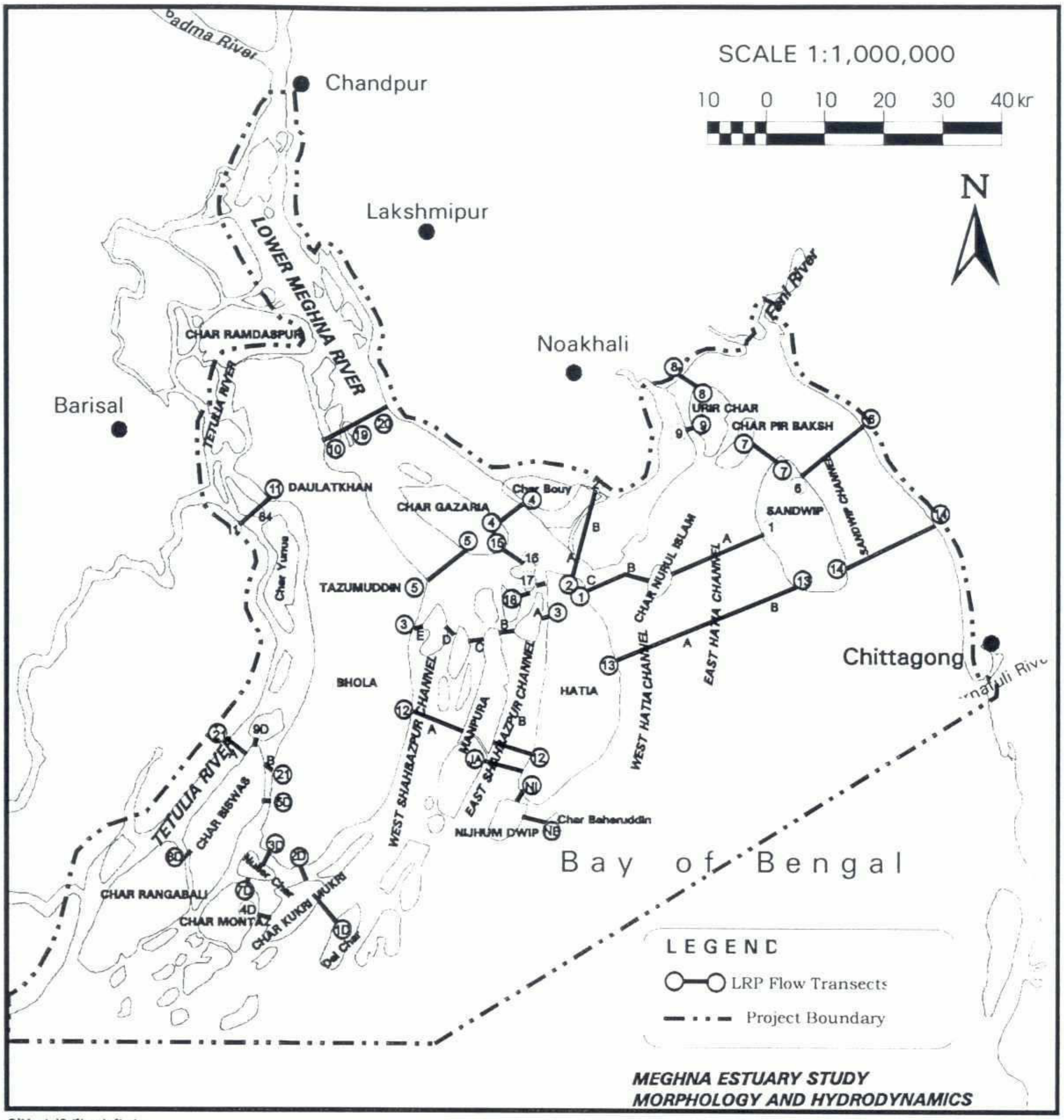
The empirical co-efficients n, K and Ca depend on local conditions such as :

- type of tide (semi-diurnal, diurnal or mixed)
- wave climate (calm, moderate, rough)
- size of inlet
- influence of upstream fresh water flow
- presence of jetties, and possibly
- type of bed material load, upland sediment transport rate, littoral drift and/or salinity effects on flow profiles

4.2 Correlations of Channel Profiles with Other Parameters

A group of empirical morphodynamic relations will be examined here for their suitability in the ME environment. The analysis will be applied both to the channels which are influenced either by fresh water flow and by tidal flow.

Figure 2 : Location of standard flow cross-sections



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The locations of cross-sections in the ME where flow and cross-sectional data were collected are shown in figure 2. To derive a practical and reliable empirical relation on channel profiles in the ME, many cross-sections and measurements in these cross-sections have been selected to correlate different hydraulic parameters with morphologic parameter. Basically, each hydraulic parameter is correlated with the cross-sectional area at a reference level (PWD, whose zero is 0.46 m below the MSL in Bangladesh). It is noted that the different hydraulic parameters are interrelated and generally incorporate minor differences. For example, a relation of maximum discharge rate Qmax with A_{PWD} means a relation of Qmax with maximum flow velocity u_{max} through :

$$Q_{max} = u_{max} A_{PWD}$$

4.2.1 Relation between Tidal Prism, Flow Rate and Cross-sectional Area

The tidal prism is a characteristic hydraulic parameter which represents the integrated hydraulic energy that is present in the everlasting tidal flow passing a tidal channel or inlet (Eysink and Biegel, 1992). In this analysis, a distinction is made between flood volume (FV), ebb volume (EV), tidal volume (TV), dominant tidal volume (DV) and tidal prism (P). These are related parameters but the use of one parameter over the other may be justified in specific cases.

The flood volume (ebb volume) is defined as the total amount of water that flows into (out of) a tidal inlet/channel between two successive slack waters.

The tidal volume is the sum of the flood volume and the ebb volume. Tidal prism is defined as the half of the tidal volume. Dominant tidal volume is the larger of the FV and EV. These quantities were calculated from hourly velocity measurements in very very wide cross-sections (sections 1A and 6) and most of the time, there were 1 to 2 verticals per cross-section to measure the vertical velocity profiles.

To derive a relation between cross-sectional area (A) below 0.0 m PWD level (the zero of national datum i.e., 0.0 m PWD is 0.46 m below MSL in Bangladesh) and tidal volumes during a tidal cycle in the Meghna Estuary, 21 sparse data sets of the period 1985-94 for the cross-sections 1A, 2, 3A, 3C, 4, 5, 6, 7, 8, 9, & 12A (figure 2) has been selected. No human interventions were executed in or around the cross-sections. Sections 2, 3A, 3C, 4, 5 & 12A remain fresh water flow (ebb) dominated during most of the time of the year, even during dry season. The influence of upland fresh water flow is very negligible on sections 1A, 6, 7, 8, 9 & 12A for practical purposes. Spring and neap tidal flow and mean data (mean in the sense that the date of some of the flow measurements fall just at the middle of the period between spring and neap tide) used. In cross-sections 1A, 2, 4, 6, & 8, it is concluded from calculations that the direction of residual tidal flow is opposite to the direction of residual sediment transport. One of the probable reasons is that there may be significant long shore and/or wave driven transport through these cross-sections in addition to the suspended sediment carried by the flow (Ahmed, et al., 1999).

Figure 3 : Cross-sectional area vs flood volume in the Meghna Estuary

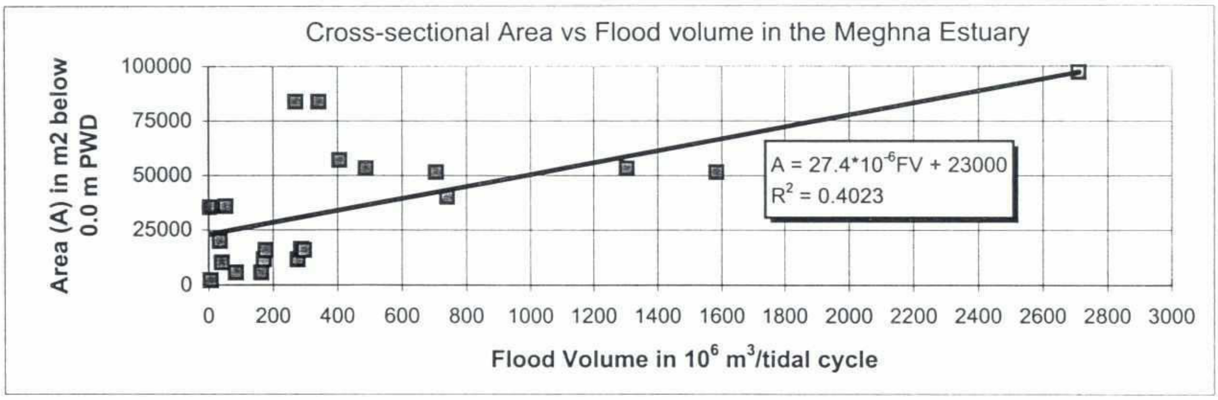


Figure 4 : Cross-sectional area vs ebb volume in the Meghna Estuary

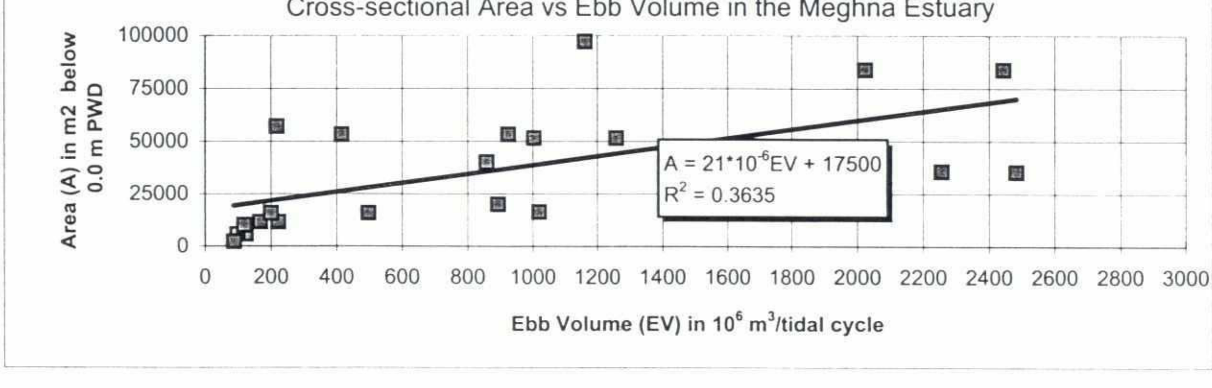


Figure 5 : Cross-sectional area vs dominant tidal volume in Meghna Estuary

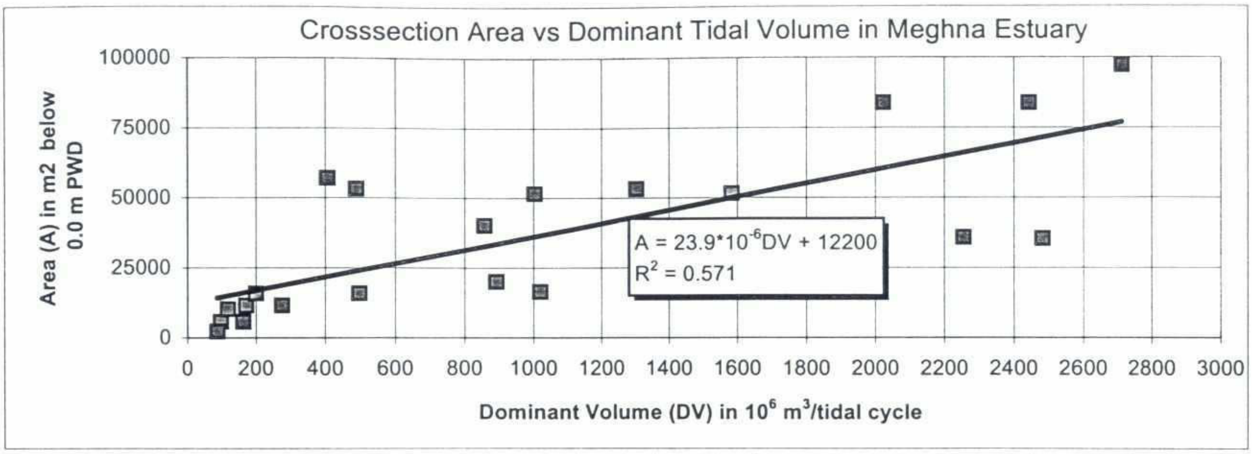
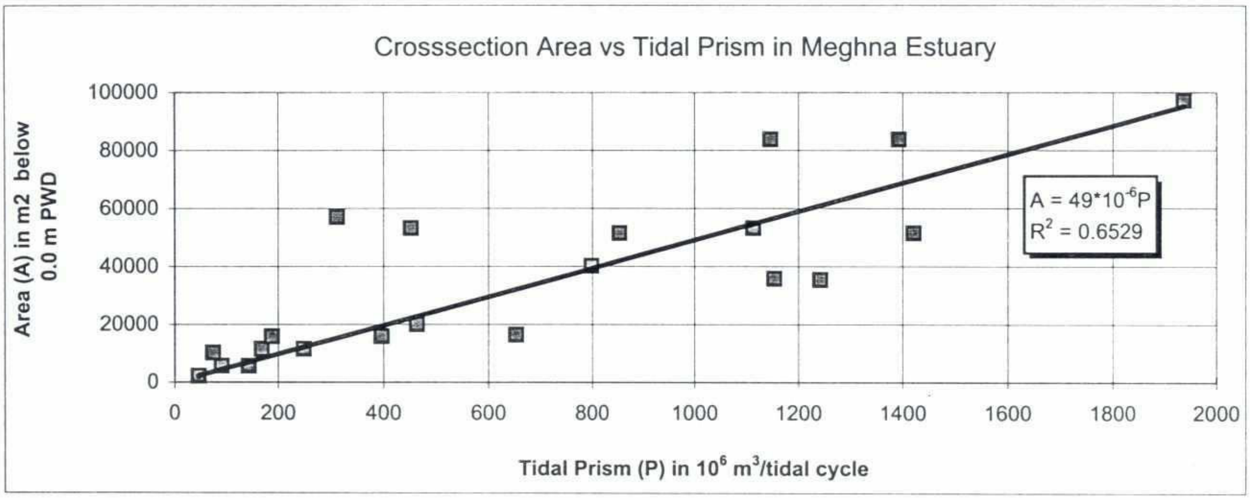


Figure 6 : Cross-sectional Area vs Tidal Prism in Meghna Estuary



Figures 3, 4, 5 & 6 show the relation between flood volume (FV), ebb volume (EV), dominant tidal volume (DV), tidal prism (P) and the area (A) below 0.0 m PWD respectively. The accuracy of field measurements and calculation of these volumes can be taken as ± 10%. In figures 3 & 4, there are a lot of scatters and the correlation is very weak. Although reasonable, the correlation in figure 6 is better than those in figures 3, 4 & 5. Although not universally equivalent, this correlation is probably the same for areas that form a morphological unit.

$$A = 27.4 * 10^{-6} FV + 23000 \quad (2)$$

$$A = 21 * 10^{-6} EV + 17500 \quad (3)$$

$$A = 23.9 * 10^{-6} DV + 12200 \quad (4)$$

$$A = 49 * 10^{-6} P \quad (5)$$

The larger of the flood (FV) and ebb (EV) volumes that is denoted as DV can be taken as the bed-forming quantity (Gerritsen, 1990). In figures 3, 4, & 5, as a straight line regression is drawn, the lines of best fit do not pass through the origin. The relation between tidal prism and cross-sectional area can be used to forecast the change in the channel regime in future due to human interventions. For example, if the area is changed, a range of change in tidal prism can be estimated. The adaptation of tidal channels to natural and man-made influences is mainly governed by the tidal prism and cross-section relation.

All the scatters which are out of the trend line in fig 6 are from neap tide measurements and 4 scatters are from monsoon and 2 are from dry season measurements. Different authors arrived at different coefficients in the empirical relation between cross-sectional area and tidal prism because of statistical error (partly) and inaccuracies in measurements and tidal prism calculations but the main reason is due to varying physical conditions of different areas.

Sections 2, 3A, 3C, 4, 5, & 12A are located in an area where seasonal variation of mean high water level and mean low water level is about 2.5 m and 1.5 m respectively. Sections 1A, 6, 7, 8, & 9 are located around the Sandwip island where the seasonal variation of mean high water level and mean low water level is about 2.8 m and 2.0 m respectively (based on the analysis of '96 & 97 data).

In the Meghna Estuary, the river discharge varies between 2000 m3/sec approximately in the dry season to about more than 100000 m3/sec during the monsoon. The estuary is shallow and some of the largest tidal channels are very wide and shallow (depth between 10 to 13 m) , e.g., the cross-sectional area and depth of Sandwip Channel around east of Sandwip island is about 100000 m2 and 11-12 m respectively at 0.0 m PWD (the width/depth ratio is roughly 10000). The estuary is mainly meso-tidal (tidal range varies between 2-4 m) but the eastern part of the estuary along the Chittagong coast and around Sandwip is macrotidal (tidal range > 4m). The seasonal variation of mean high water level at Chandpur is about 2.7 m. This variation in the south-western part of the estuary is about 0.7 to 1.7 m. Maximum velocity in the estuary varies between 0.2 to 3 m/sec. During the period between July to October, the water in the estuary is almost fresh i.e., saline-free. The rate of loss of existing stable agricultural land in the areas which are prone to erosion varies between 10 to 200 m/year on average. The median bed material grain size (D_{50}) varies between 0.016 mm to O.2 mm. About 70% of bed material has D_{50} size less than 0.075 mm. The maximum depth averaged suspended sediment concentration varies between 0.5 gm/l to 9 gm/l. During spring tide, the suspended concentration is about 2-5 times higher than that during neap tide.

Figure 7 : Qmaxflood vs corresponding area for Meghna Estuary

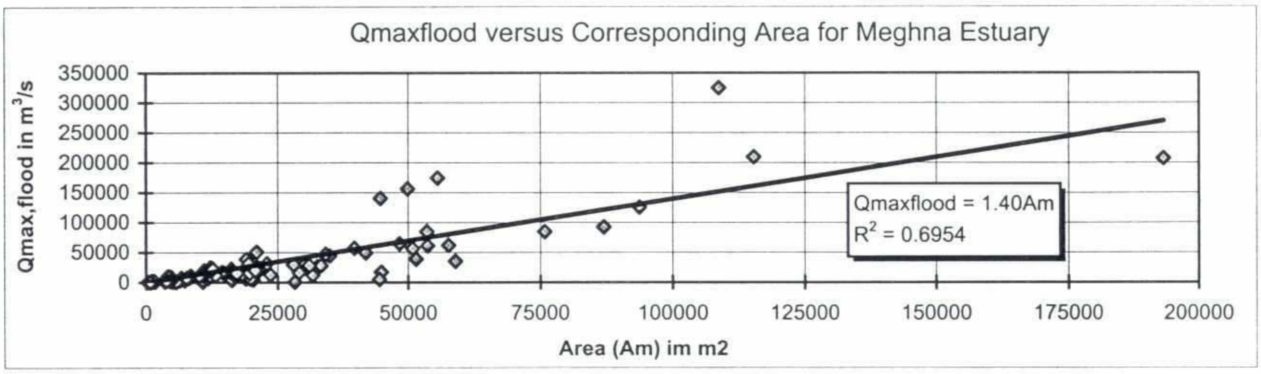


Figure 8 : Qmax ebb versus corresponding area for Meghna Estuary

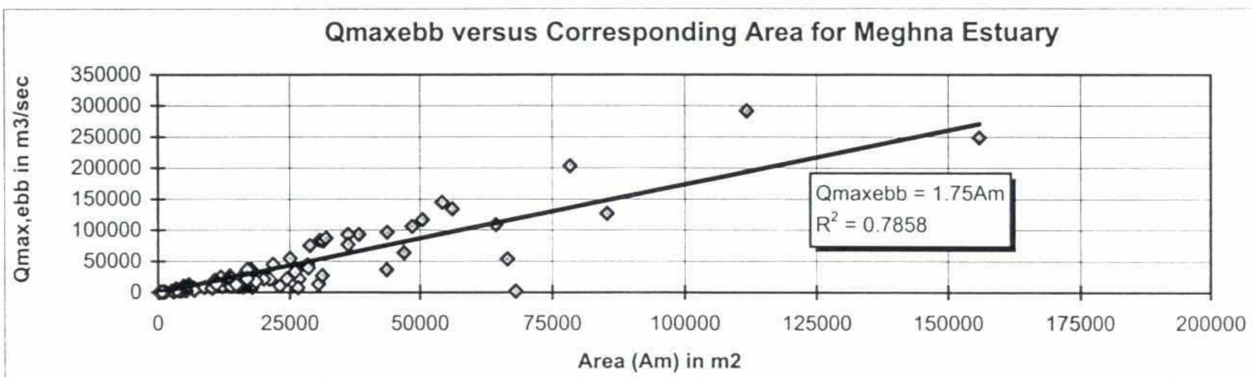
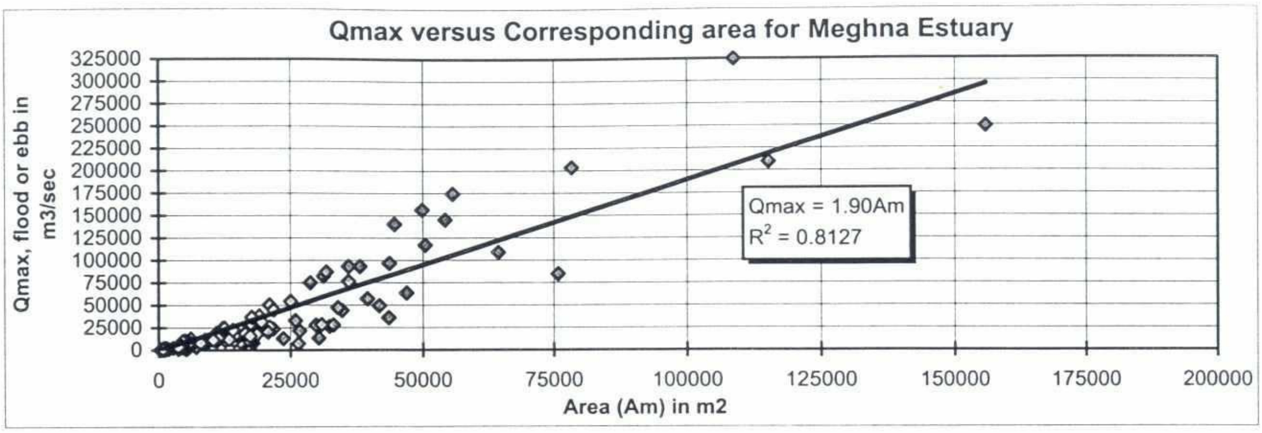


Figure 9 : Qmax versus corresponding area for Meghna Estuary



Figures 7, 8 & 9 show the relations between max flood volume (Qmaxflood), max ebb volume (Qmaxebb), and Qmax (either of food and ebb) and the corresponding cross-sectional areas (Am) at the time of maximum discharges respectively per tidal period for all cross-sections.

$$Q\max flood = 1.40Am \qquad (6)$$

$$Q\max ebb = 1.75Am \qquad (7)$$

$$Q\max = 1.90Am \qquad (8)$$

Equations 7 & 8 are significantly close (relatively speaking, Qmax is about 8.6% more than the Qmaxebb and Qmax is about 36% more than the Qmaxflood) which means that although maximum of the hourly tidal flow per tidal cycle of 12.4 hours was considered to derive equation 8, the influence of ebb flow during neap tide and river flow during monsoon through some cross-sections is quite significant and it is actually the case for the Meghna Estuary. For most part of the monsoon (May to October), some cross-sections remain ebb-dominated and these are sections 2, 3, 4, 5,10,11,12,19, 20 and JA in figure 2.

Data of river dominated and tide dominated parts of the estuary were correlated separately to get better correlation but no improvement in correlation was found. Separate correlations for dry and monsoon data also did not improve the correlation.

In figure 7 for Qmaxflood vs Am except for the cross-sections 1(A), 2(A), 2(B), 5, 6, 12(A), & 13(A) that fall outside the general trend , the correlation is reasonable considering the highly dynamic environment in the Meghna Estuary. The fit of Qmaxebb vs corresponding cross-sectional area is good. The relation between Qmax (maximum of the flood and ebb) per tidal period and corresponding cross-sectional area (Am) is the best among the three correlations. Qmax/Am represents the average maximum velocity through a cross-section. Almost half of the points have average maximum velocity of more than 1m/sec and even some has 2 m/sec or more. The scatter in these plots are due to the large variability of upstream fresh water and tidal flows, the measurement of flows during spring, neap and mean tidal flows, influence of depth and size of channel, seasonal variation in water level and large fine silty sediment transport. The amount of available data is very small and it is firmly believed that if adequate data are available, better correlations can be developed.

4.2.2 Characteristic velocity, cross-sectional area and hydraulic radius

It is clear from section 4.2.1 that the ratios P/A and Qmax/Am are not constant for all cross-sections but vary with the size of the cross-sections. In this section, some characteristic velocities such as the hourly maximum ebb (Umaxebb) and flood (Umaxflood) velocity and the tide averaged velocity (Uavt) are used.

Figure 10 : Maximum ebb velocity and corresponding cross-sectional area

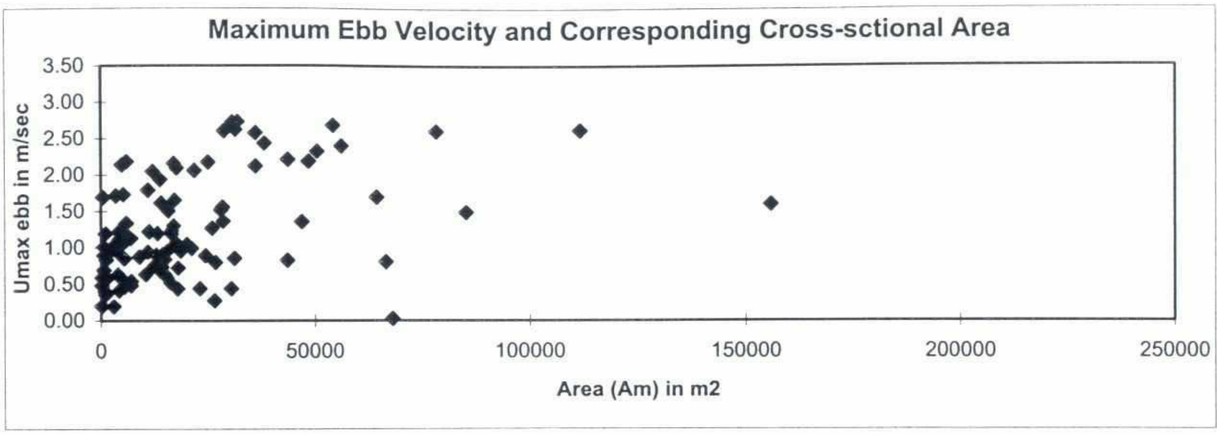
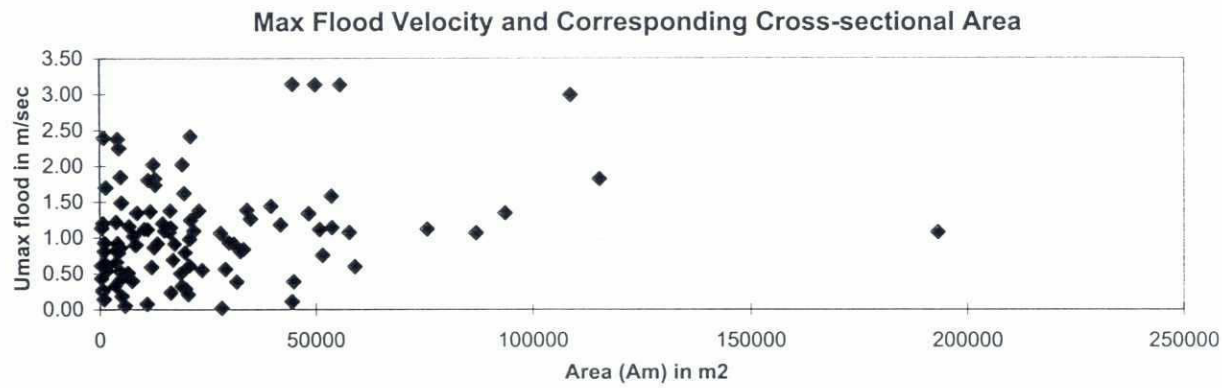


Figure 11 : Maximum flood velocity and corresponding cross-sectional area



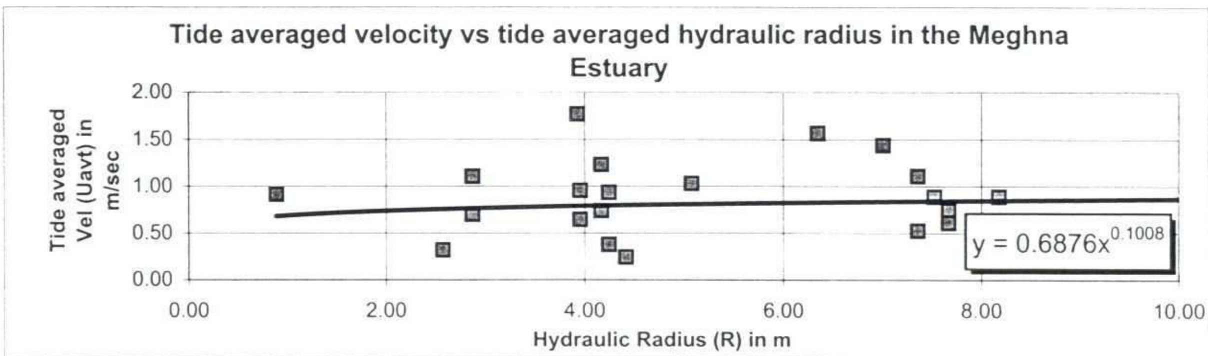
In figures 10 & 11, Umaxebb, Umaxflood and corresponding areas of almost all the cross-sections in figure 2 are plotted where a lot of scatters can be found. No correlation exists.
The tide averaged velocity Uavt is defined by

$$Uavt = \frac{2P}{AT} = \frac{(FV + EV)}{AT} \qquad (9)$$

where :

A is the cross-sectional area and
T is the semidiurnal tidal period (12.416 hours) and other symbols are already defined.

Figure 12 : Tide averaged velocity vs tide averaged hydraulic radius in the Meghna Estuary



In figure 12, tide averaged velocity Uavt versus hydraulic radius R of cross-sections 1(A), 2, 3(A), 3(C), 4, 5, 6, 7, 8, 9, and 12(A) are drawn. There are a lot of scatters and almost no correlation exists.

Figures 10, 11 & 12 show no correlation. In figure 12, in general, for theoretical interest, a power relation of Uavt = 0.687 $R^{0.1}$ can be deduced to examine the effect of R on A-P relation but the correlation is extremely weak. This relation will lead to some other deductions in the next section. For R = 0, Uavt must be zero and that's why a power relation is fitted.

From the definition of Uavt

$$Uavt = 2P/(AT) = 0.687\ R^{0.1} \qquad (10)$$

which gives with tidal period of T = 44700 sec

$$A = 6.50 * 10^{-5} \frac{P}{R^{0.1}} \qquad (11)$$

4.2.3 Effect of depth on A-P relation

For theoretical interest (because correlation between Uavt and R is nil in figure 12), the relation between Uavt and R may be used to modify the relation between A and P to include the effect of channel depth.

In terms of depth in very wide (width > 10*depth) channels where R~d, equation 11 becomes

$$A = 6.50 * 10^{-5} \frac{P}{d^{0.1}} \qquad (12)$$

Eq 12 can be rewritten as $\frac{P}{A} = 1.54 * 10^{4} * d^{0.1}$ (13)

Theoretically, the equations 11 & 12 show that the ratio between A/P decreases with increasing R (i.e., d) and demonstrates that hydraulic radius (or depth) has an effect on the A-P relation. Due to the presence of lot of scatters in data, the effect of depth could not be determined practically.

Figure 13 : Average depth and total tidal volume in Meghna Estuary

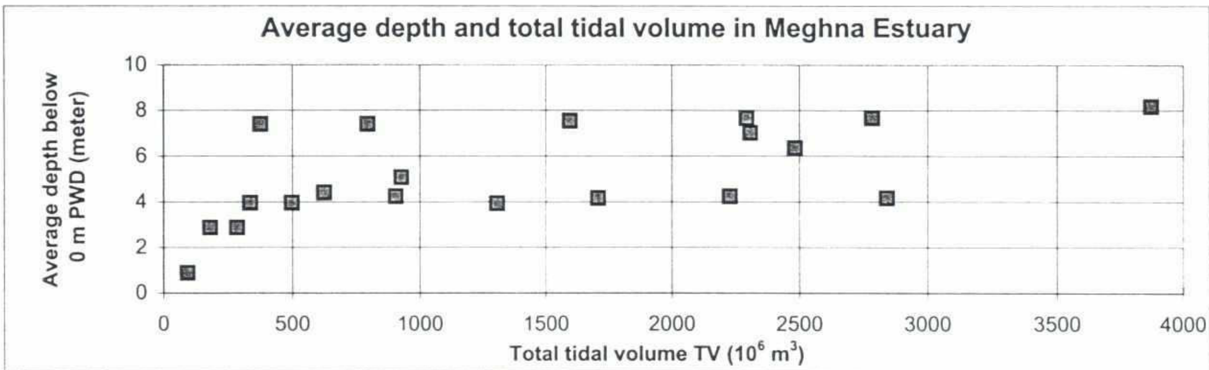


Figure 14 : Average depth and dominant tidal volume in Meghna Estuary

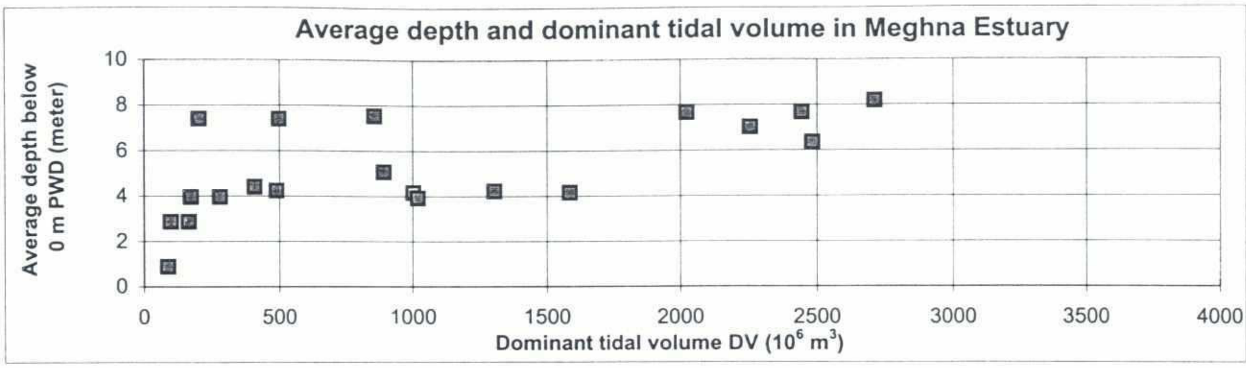
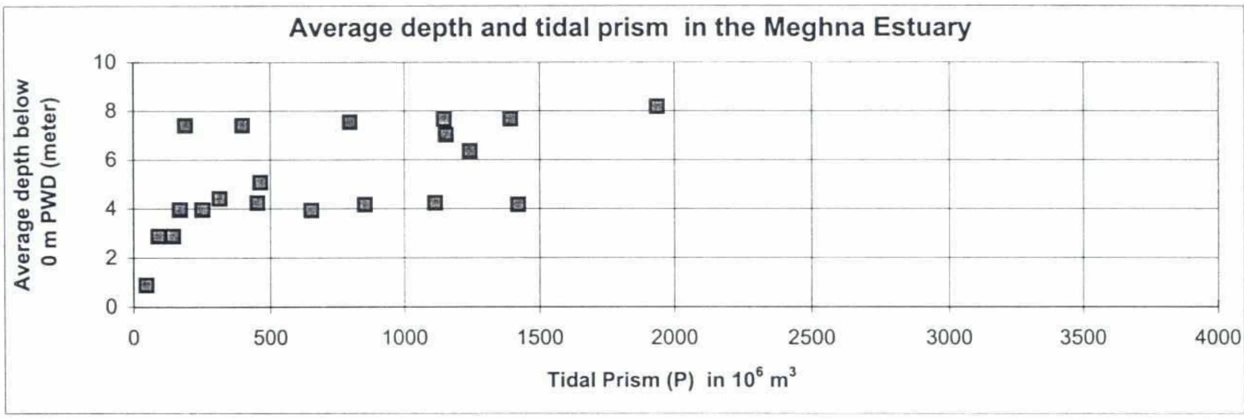


Figure 15 : Average depth and tidal prism in the Meghna Estuary



The available data that are used in this analysis for the Meghna Estuary do not show significant difference in depth and so, the effect of d or R on the A-P relation does not follow the above theoretical trend. In tidal systems where the variation of depth is relatively small, the effect of R on A/P relation will not be pronounced and this is the case for Meghna Estuary. Moreover, it shows for cross-section 4 that the ratio of A/P increases with an increase in average depth of 1.2 m which is contrary to the above theoretical finding. However, the effect of R should be evident if large differences in depth are present.

Figures 13, 14 & 15 show that there are no correlations between depth and tidal volumes. A close look at these three figures reveal that although the tidal volume increases, the depth does not increase significantly which means that the cross-sections must be wide so that despite the increase in tidal volume through the cross-sections, the depth does not increase proportionately. In fact, the cross-sections are very wide, e.g., sections 6 & 14 are more than 12 km wide although the depth varies between 10 to 13 m. The width/depth ratio of cross-sections in the Meghna Estuary is phenomenal.

Theoretical relation can easily be derived through equation 11 to show the effect of channel width 'B' on the area-tidal prism relation.

5. CONCLUSION

Some empirical relations exist between hydraulic and morphologic parameters in the Meghna Estuary. The quality of scatters in the analyzed data sets shows that none of the channels in the estuary is in a state of equilibrium.

Considerable scatters around much of the analyzed data sets in the Meghna Estuary and variety of relations in literature confirm that no reliable correlation exist between channel depth and tidal volumes. These parameters depend on seasonal influences of local flow and bed conditions. They should never be used in combination to derive the cross-sectional area, but only as a secondary relation to get an idea about the shape and size of a cross-section.

Flow measurements during neap tide caused considerable scatter around the best fit line of the area-tidal prism relation than those during spring tide.

From the analyzed data sets in sections 4.2.1, 4.2.2 & 4.2.3, it follows that even if the correlation functions are based on true physics, the fits are not perfect because of large variations in and nonlinear relations between flow parameters in the highly dynamic and complex Meghna Estuary and also because of inaccuracies in data sets.

The derived empirical relations show that they may not be considered as universal relations (in the sense that they cannot be applied to all the coastal channels of Bangladesh).

The empirical relations show that cross-sectional area and depth affect the relations and some of these relations cannot be applied to the available data in the Meghna Estuary.

The best correlations exist for dominant tidal volume (DV) and maximum tidal discharge Qmax i.e., maximum flow gives better fits.

6. RECOMMENDATION

More systematic data collection at the same cross-sections are necessary for arriving at better fits. Inclusion of shear stress velocity or stability shear stress and wave climate in the relations with the availability of improved and sophisticated data are believed to enhance the general validity of the derived relations but it is unclear at this moment how much this inclusion will reduce the scatter of data around the best fit lines. Study of migration characteristic of channels and bars in the channels may throw more insight into the stability phenomena.

The effects of sediment transport, erosion-deposition on the relations are not studied in this analysis for lack of data which may influence the relations.

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