AN ASSESSMENT OF WATER LEVEL AND BED LEVEL VARIATION IN THE LOWER MEGHNA RIVER

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CERTIFICATE OF APPROVAL

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LIST OF NOTATIONS

A	flow area	(L^2)
g	acceleration due to gravity	(MLT^{-2})
W	river width	(L)
D	depth	(L)
ρ	density of water sediment mixture	(ML^{-3})
μ	apparent dynamic viscosity of the water sediment mixture	(MLT^{-2})
d	grain size of the bed material	(L)
σ	measure of size distribution of bed materials	(L)
ρ_s	density of sediment	(ML^{-3})
S_P	shape factor of particle	(-)
S_R	shape factor of the reach of the stream	(-)
f_s	seepage force in the bed of streams	(MLT^{-2})
C_T	concentration of the bed material discharge	(ML^{-3})
S	slope of the energy line	(-)
U	flow velocity	(LT^{-1})
x	longitudinal coordinates	(L)
y	lateral coordinates	(L)

LIST OF ABBREVIATIONS

ABL	Average Bed Level
AVGD	Average Depth
BWDB	Bangladesh Water Development Board
BIWTA	Bangladesh Inland Water Transport Authority
BUET	Bangladesh University of Engineering & Technology
CD	Chart Datum
CZ	Coastal Zone
FAP	Flood Action Plan
ICZMP	Integrated Coastal Zone Management Program
LWE	Left Water Edge
MES	Meghna Estuary Study
PWD	Public Works Department
RWE	Right Water Edge
SWMC	Surface Water Modeling Center
WARPO	Water Resources Planning Organization
WRE	Water Resources Engineering
DJF	December, January and February
MAM	March, April and May
JJA	June, July and August
SON	September, October and November

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ABSTRACT

This study was conducted to analyze the water level and bed level variation in the Lower Meghna River. Different analysis of cross sectional area, variation of mean bed level, erosion/accretion of the channel and movement of thalweg position were carried out to find the variation of water level and bed level. The assessment was carried out mainly based on the available cross sectional data and water level data from 1985 to 2008 at five different stations along the Lower Meghna River.

It may be seen from the analysis of the cross sectional data that there is no consistency in variation of cross-sections over the years. However, the analysis has shown certain trend in the variation of the different hydro-geometric parameters. The cross sectional area varied rapidly at Chandpur station where as the changes in cross sectional area at Sandwip was steady. The change of cross section at Chitolkhali was very dynamic and a rapid increase followed by decrease in cross sectional area occurred at Chitolkhali.

The variation of water level and bed level followed a typical trend with few exceptions. In most cases the water level dropped as the bed level is lowered or the water level is raised as a consequence of bed level rise. However the change in water level was not very significant as the change in bed level when the data were compared with two selected years. Analysis showed that there were exceptions in the period of 1985 to 1992 where the water level at Chandpur station is raised by 0.48m with a drop in the bed level by 6.58m.

From the analysis of Mean bed level a significant change in the mean bed level of the Lower Meghna River at Chandpur was observed where as the change at Sandwip station was the least. The range of mean bed level rise or fall at Chandpur was from 1.71m to as high as 7.28m over the years.

The shifting of thalweg point was also varied at times at different places. The most frequent movement of thalweg was found at Chandpur.

CHAPTER 1

Introduction

1.1 General

A close relationship always exists between man and rivers since the beginning of civilization, because water has always been an integral part of man's development. Most of the early civilizations were survived as well as developed near the river valleys. The most ancient commercial places have been developed along river banks. Bangladesh is a riverine country with hundreds of rivers overlaying its landscape. Because of its inherent alluvium nature, the rivers of Bangladesh are morphologically dynamic characterized by erosion and sedimentation, which results in changes in hydraulic geometry; plan form and longitudinal profile of the rivers (Habibullah, 1987). Aggradations, degradation or change in plan forms; change in river bed and meandering characteristics are most common features in the rivers of Bangladesh, affecting the major rivers as well as the medium and the minor rivers. When bank erosion of a river takes place the drainage capacity of the river and navigation is hampered and consequently a large number of populations are directly or indirectly affected. Erosion could be mitigated through local protective measures for the time being but properly designed river control and training structures are required to reduce the loss of lands. A detailed study of hydraulic geometry can help controlling rivers in an effective manner.

In many parts of the world, the coastal areas are highly populated and the stretches of coastal land play an important role in respective countries development. It is estimated that 40% of the world population lives within 100 km of a coastline (UNDP, 2000) and expectations are that this figure grows further in the coming half century. Unlike elsewhere in the world, the coastal zone of Bangladesh still reflects a rural setting and extensive urbanization has not happened as yet. Therefore, an extensive study and analysis are required of the coastal rivers, estuaries and coastal zone of Bangladesh. Proper attention to this sector would bring the development of the country as a whole.

In 2001, a total of 35.1 million people lived in the coastal zone of Bangladesh, increasing from only 8.1 million a century earlier, 49% percent of which are female. As large as 41% of the total population is below 15 years of age (IWM, 2005). Agricultural laborer, small farmer, fisher and urban poor make up 70% of the 6.85 million households (PDO-ICZMP, 2003). The coastal population is projected to grow to about 41.8 million in 2015 and 57.9 million in 2050 (IWM, 2005).

Coastal Zone accounts for about 23% of the land area of Bangladesh. Per capita land availability is very low (Singh, 2000). Above this substantial amount of land is lost due to erosion in coastal region. Although land is also accreted in some other locations that land does not become useful and productive immediately. Inhabitants living in areas subjected to erosion become landless. Their sufferings can be minimized by identifying eroded zone and land accretion opportunities. Being a small country, Bangladesh needs to extend land areas which can be done only by accretion in coastal region.

1.2 Background of the Study

Meghna estuary is a very dynamic estuarine system. Meghna Estuary extends from Chandpur to the northern end of the Bay of Bengal which is a coastal plain estuary on the coast of Bangladesh. The coast of Bangladesh is exposed to extreme meteorological and hydrological conditions. Occasional cyclone surges in combination with high tides always have devastating effects on the southern part of Bangladesh, causing loss of human life, crops and livestock as well as the destruction of property (MES, 2001). The lower Meghna River drains the flow from Ganges Valley and the southern part of the Himalayas (Ganges River), the Tibet and the north-eastern part of India (Brahmaputra River) and the north-eastern part of Bangladesh (Lasarte et al., 1991). The discharge varies from 8,000 m^3/s during dry season to 1,20,000 m^3/s during the wet season. The flow starts rising sharply in June, it assumes peak flow sometime in July-September and assumes minimum values in March-May. The total discharge of the lower Meghna River is

diverted through the Tutulia River, the Shahbazpur channel, the Hatia Sandwip cross sections and the Sandwip channel. The main flow is emptied into the sea through the Shahbazpuar channel and part of it is emptied through the south-central region in the Meghna Estuary. The discharges of the Ganges and the Jamuna are collectively known as the Padma River, these three major rivers dominate the river inflow in the Meghna estuary study area. The Meghna Estuary lies between 90°20′0″ to 92°0′0″ Easting and 21°40′0″ to 22°40′0″ Northing (Figure 1.3.2). Sandwip channel in the east is the deepest area in the estuary. The incoming tides from the southern part of the Bay of Bengal are important for the flow features in the Meghna Estuary (Azam, et al., 2000) and they contribute to the residual circulation significantly.

Erosion and accretion rate is very high in Meghna Estuary system. The sediment discharge from the Meghna River is the highest (Coleman, 1969) and water discharge is the third highest of all river system in the world (Milliman, 1991). The river borne sediment load of lower Meghna River amounts to more than a billion tons annually and carried by the combined flows of the Meghna, Brahmaputra and Ganges to the estuary of Bangladesh (Eysink, 1983 and Nishat and Alam, 1987) are deposited in the coastal areas which is dominated by silt to fine sand (Hossain, 1992).

The important driving force for the flow in the Meghna Estuary are the bathymetry, oceanographic conditions outside the estuary (tides), hydrology of the adjacent watershed (river discharge) and meteorological condition (MES, 2001). Considering bathymetrically, the estuary can be considered as a sudden dramatic widening of the Meghna River, which is shallow and followed by a deep land, wide opening towards the Bay of Bengal.

The knowledge about the physical processes and morpho-dynamic behaviour of the lower Meghna Estuary system still creates complex pattern of sediment displacement and erosion in the estuary. The river influence becomes progressively larger in an upstream direction as friction drains tidal energy in the funnel shaped

Meghna Estuary (Akhter and Mahmud, 2007). Tidal influence extends substantially further upstream than salt intrusion and deltaic sedimentation occurs only in sabaquoes environment. Sediment is received from the river and Bay of Bengal, yet most of the sediment received by the river ends up being transported and deposited by tidal currents. It is determined that during the dry flow, the northward flow in the Sandwip Channel is mainly forced by a combination of tide and bathymetry, i.e. it is not greatly influenced by the river discharge (Jakobsen, et al., 2001).

Considering the dynamic situations prevail in the Meghna Estuary a hydrological study has an utmost necessity to identify the impact of water level change, changes in discharge, sediment load and morphological changes. However, an attempt has been taken to assess the variation of water level with bed level changes in the lower Meghna River from Chandpur to Sandwip channel in this study.

1.3 The Meghna River

Meghna River one of the major rivers in Bangladesh, specially famous for its great estuary that discharges the flows of the Ganges-Padma, the Brahmaputra-Jamuna and the Meghna itself. The downstream of Surma River from Ajmiriganj is often referred to as the Meghna. The matter would be simpler but for the fact that from Madna downstream for about 26 km (in a straight line) one of the two Channels of the Surma-Meghna is known as the Dhaleswari. The channel from Ajmiriganj down to the confluence with the Dhanu is referred to as the Surma. This confluence is five kilometers east of Kuliarchar and north of Bhairab Bazar. Downstream from this point, the river is referred to as the Meghna (Figure 1.3.1).

The Meghna has two distinct parts.

The Upper Meghna: Down to Chandpur from Kuliarchar to Shatnol, Meghna is hydrographically referred to as the Upper Meghna

The Lower Meghna: Sixteen kilometres from Shatnol, the combined flow of the Ganges and Brahmaputra-Jamuna, known as the Padma, meets the Meghna at 11 km wide confluence near Chandpur. From this point southwards the Meghna is marked as the Lower Meghna, becoming one of the broadest rivers and largest estuaries in the world. The Lower Meghna is at times treated as a separate river. The Meghna receives the Old Brahmapurta on its right at Bhairab Bazar. A little above the confluence, the Meghna has a railway bridge-'Bhairab Bridge'-and a road bridge-'Bangladesh-UK-Friendship Bridge over it. The width of the river there is around 750m. Several small channels branching off from the Meghna and meandering through the lowland bordering the Tippera Surface receive the flow of a number of hilly streams and rejoin the main river downstream.

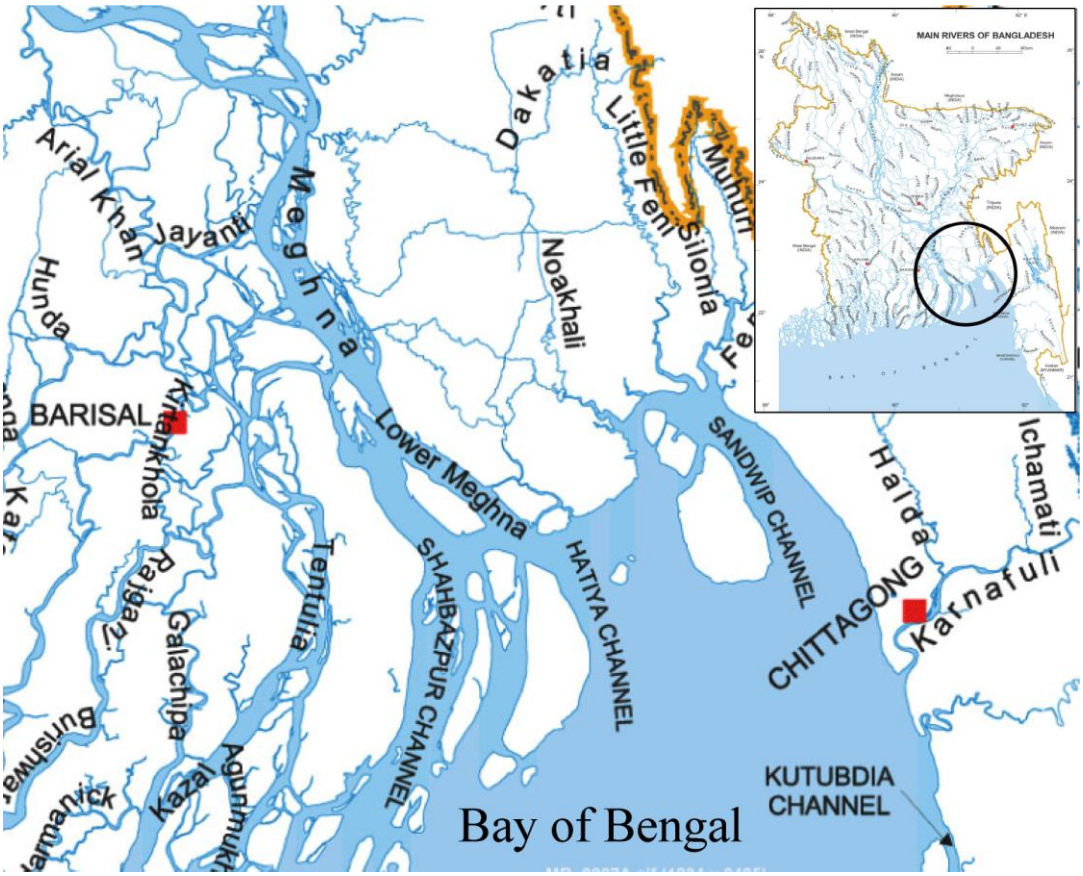

Figure 1.3.1: Lower Meghna River from Chandpur to Swandip Channel

The most important of these offshoots is the Titas, which takes off south of Ghatalpar and after meandering through two long-bends extending over 240 km

rejoins the Meghna through two channels in Nabinagar upazila. Other offshoots of the Meghna are the Pagli, Kathalia, Dhonagoda, Matlab and Udhamdi. The Meghna and these offshoots receive water of a number of hilly streams from the Tripura Hills. The important hill streams are the Gumti, Kakrai, Kagni, Dakatia, Hawrah, Sonaiburi, Harimangal, Pagli, Kurulia, Balujuri, Sonaichhari, Handachora, Jangalia and. All of these are liable to flash floods. The Meghna receives Tippera Surface streams from the east and flows from the enlarged Dhaleshwari from the west.

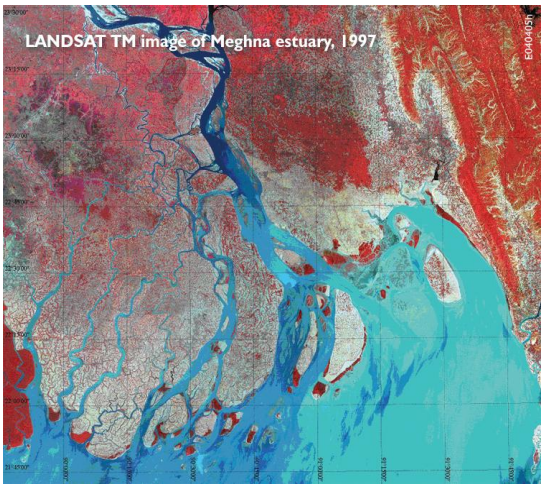

Figure 1.3.2: Satellite image of the Meghna Estuary (Source: LANDSAT, 1997)

At the confluence, just north of Shatnol, the Meghna is about five kilometers wide (Nath, 2004). Dhaleshwari comes down in a brown stream and meets the clear blue-green Meghna. For many kilometers the waters do not seem to mix, for half the river water remains brown and the other half blue-green.

West of the mouth of the Ilsha is the Rabnabad islands. Shahbazpur Channel, 5 to 8 km wide, separates Bhola from Ramgati and Hatiya islands and at its mouth is the Manpura islands. Bamni now is said to be nonexistent. Formerly it used to flow between the islands of Ramgati and Char Lakshmi and the Noakhali mainland, and was at times the main outlet for Meghna. The tides and their bores always affected it considerably, and this channel narrowed or widened in an unpredictable manner. After eroding a considerable part of the mainland in the 1940s, it suddenly shoaled to such an extent, just west of Noakhali town that in winter there was a land bridge

from the mainland to Ramgati Island. To make this a permanent feature, a large earthen cross dam was built. To accelerate the accretion of chars, a second cross dam was built linking Noakhali mainland and Char Jabbar which rapidly built up nearly 260 sq km of land.

The estuary of the Lower Meghna is usually taken to stretch from the Rabnabad islands to the Kumira coast, a distance of 153 km. The water is, however, saline for half of the year as far north, as a line could be drawn from the middle of Bhola to the north of Sandwip. The estuary of the Lower Meghna may be considered as extending between the Ilsha (Tetulia) and Shahbazpur rivers which together have a width of about 40 km at the sea-face. The volume of the estuarine discharge is not known, but at Chandpur the mean discharge from June to October is around 2.5 million cusec. The mean maximum in this period of the year is about four million cusec. The winter flow is about one-eighth of it although the river is even then several kilometers wide. The low flow is due to the stream's sluggishness. In maximum flood, the Lower Meghna's flow is no less than five million cusec. It is also estimated that from May to October its daily load of sediments is nearly four million tons. The annual load of sediments carried by it is about 1,500 million tons and annual water discharge about 875 million acre-feet (MAF). In comparison, the Congo, La Plata and Yangtze rivers have a total annual flow of 1,022, 636 and 559 MAF respectively. The Lower Meghna, as the major outlet of the combined Ganges, Brahmaputra and Meghna has therefore somewhat less outflow than the Congo, which is second only to the Amazon (Milliman, 1991).

The Lower Meghna (160 km) is measured from the south of Chandpur to as far as the Tentulia. The flow is estimated for a point mid-way between Chandpur and Mehendiganj. The total length of the Surma-Meghna is about 670 km. The length of the Upper Meghna is measured up to Chandpur, but the discharge is measured at Bhairab Bazar.

A larger number of settlements, towns, ports and industries have sprung up on both the banks of the Meghna. Narsingdi, Chandpur, Barisal and Bhola are the district towns that stand on the banks of the Meghna. Kuliarchar, Bhairab Bazar, Chandpur

(Puran Bazar), Ramdaspur, Kalupur and Daulatkhan are important riverports and business centers. The Ashuganj thermal power plant and the Fenchuganj fertiliser factory are located on the banks of this river.

The Meghna is a flood-prone river. The Bangladesh Water Development Board (BWDB) has implemented the Meghna Valley Project and constructed embankments along the riverbanks. These embankments are protecting greater Sylhet, Mymensingh and Comilla districts from floods. By constructing dams at different places a total of 180,000 ha of land have been brought under irrigation. About 125 km of dams (*Veri Bandh*) have been constructed in the southern region of Bangladesh under the coastal embankment project. These are helping to control floods and keep salinity off. These *Veri Bandh*s are also playing an important role in land reclamation.

Salient features of Lower Meghna River

Off take:

a) River	: Meghna Upper
b) Location	: Upazila (Sub-District)- Motlob
	: District – Chandpur
River course flow	:Chandpur, Haymchar, Raypur, Laksmipur, Ramgati, Hizla, Mohonganj, Vola, Doulatkhan, Borhanuddin, Tazimuddin, Lalmohon, Charfashion, Monpura.
	: Zilla –Chandpur, Laksmipur, Vola.
Physical Description	: Length- 180 km
	: Width – 13000 meter
	: Depth – 27.00 meter
	: Catchments Area – 1595 sq. km
Flow	:
a) Seasonal/Perennial	: Perennial

b) Month without flow : N/A

c) Low flow (dry season) : February and March

Approx. flow : 10,500 m^3/s

Depth : 20 meter

d) High flow (monsoon) : July and August

Approx. flow : 1,050,000 m^3/s

Depth : 27 meter

e) Influence of low and neap tide: Yes

f) Bank Submergence in flood: Yes

Reference: (BWDB, 2002), Figure 1.3.1

1.4 Objectives of the Study:

The proposed study will be carried out with a view to attain the following objectives

1. To study the water level and bed level of lower Meghna from Chandpur to Sandwip Channel.
2. To identify the possible water level and bed level change by analyzing the hydraulic data over the last 30 years from 1977 to 2007.
3. To draw a conclusion by correlating water level changes with bed level in Lower Meghna River and
4. To increase our knowledge on the mechanics of water level and bed level change in Meghna Estuary.

The study will render comparative information about the hydrologic situation in the Meghna Estuary and the consequences of water level changes in the study area.

The study will depict a clear notion of possible changes in water and bed level in the last three decades. Further study on this basis can be helpful in determining the bank protective measures necessary in the most vulnerable locations. The study can contribute future development of River training and resettlement in the estuarine region of Bangladesh in the context of Global Warming.

1.5 Outline of the project

This research work consists of five chapters. The contents of the chapters are as follows:

Chapter 1 includes general introduction, salient features and objectives of the study. Introductory information is written in this chapter.

Chapter 2 includes literature review and review of previous similar studies. In this Chapter a detailed description of study area is presented with relevant figures. Studies of similar kind by different authors were included at the end of this chapter.

Chapter 3 contains the theory and methodology. The standard procedure that is followed in this work is presented with relevant references here. A brief description of the method of analysis is also included in this chapter.

Chapter 4 includes the analysis of the results and discussion. The major findings of the work are shown in this chapter.

Chapter 5 contains the conclusion of the study and recommendations for future study.

CHAPTER 2

Literature Review

2.1 General

Rivers erode landmasses and carry the water sediment to the ocean. A well-controlled system of physical and hydraulic features is maintained in water and sediment transport processes. The inter relationship between the attributes and their details in this organized system are highly complex and it is hard to visualize many of them simultaneously. However these interrelationships from the typical characteristics of rivers and some knowledge of the basic types of rivers are necessary before complex relationships can be understood.

2.2 Channel Patterns

The pattern of a river is described as the appearance of a reach in a plan view. Observing plan views of most of the major rivers, they can be classified broadly into three major patterns- a) straight, b) meandering and c) braided (Leopold and Wolmen, 1957). Figure 2.2.1 shows the illustrations of the basic type of rivers. Even though the major divisions are represented by these three types, it should be comprehended that a continuous progression is present between on type and another. More than one type of pattern exists along the length of any single river.

The channels are classified in terms of transition pattern by Chital (1970). Single channels are further classified into meandering, straight and transitional between them and multiple channels are classified into braided channels in sub-mountain regions and braiding channels in alluvial fan or deltas near the sea.

Schumm and Meyer (after Schumm, 1977) also classified various types of channels based on pattern and type of sediment load with their relative stability. Channel classified in terms of sediment load refers to wide range of variety. Usually alluvial river carry more sediment down to the sea than the other rivers. The following articles discuss the channel pattern.

Straight Channel

A straight channel is one that does not follow a sinuous course. Straight channels are rare in nature according to Leopold and Wolman (1957). A stream may have moderately straight banks but the thalweg or path of greatest depths along the

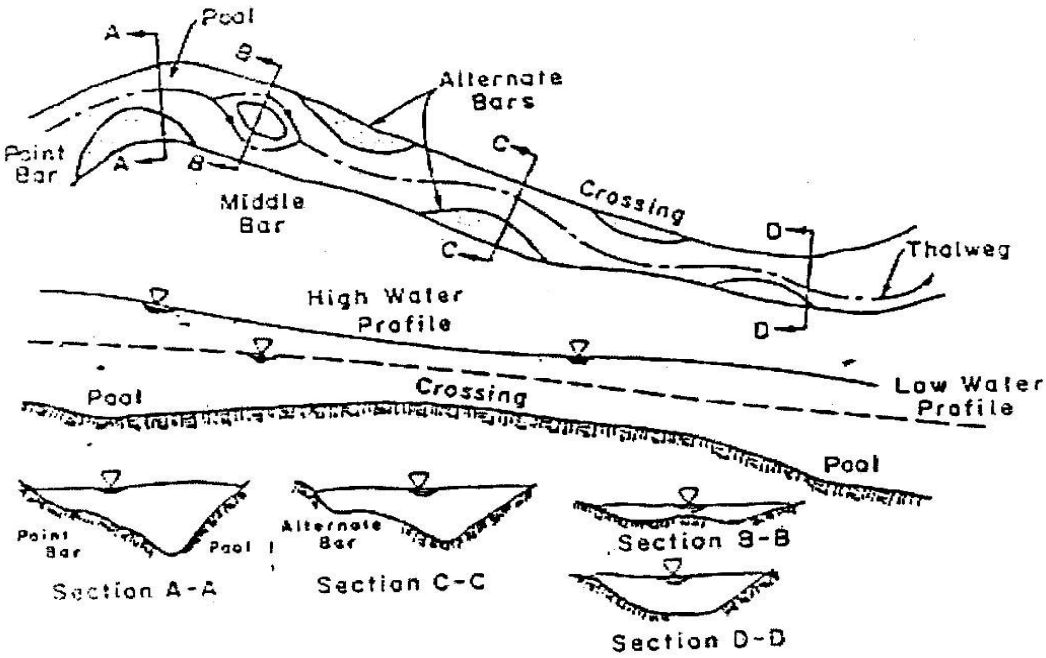

Figure 2.2.1: Channel patterns (Source: Schumm, 1977)

Channel is usually sinuous. Straight channels with prismatic cross-section are not typical in nature. It is only feasible for artificial channel.

To differentiate between straight and meandering channels and sinuosity of a river, the relation between thalweg and length to down valley distance is most frequently used. Sinuosity varies from 1 to 3. Sinuosity of 1.5 is taken as the division between meandering and straight channels by *Leopold et al.*(1964). A series of shallow crossings and deep pools is formed along the channels in a straight channel with a sinuous thalweg developed between alternate bars (Figure 2.2.1).

Unstable reaches are those reaches of a river that are fairly straight over the long distance as are divided flow reaches and those in which bends are migrating rapidly. Naturals or man-made cut-ff of meander loops can create long straight reaches where long reaches of sinuous meandering channels with relatively flat

slopes are converted to shorter reaches with much steeper slopes. Construction works such as dikes and revetment reduce or control sinuosity and induce straight reaches. It is normal for the thalweg to wander back and forth from one bank to the other still where the channel is straight. There is generally a bar or buildup of sediment along the bank opposite to the point of greatest depth and these bars has a tendency to alternate from one side of channel to the other (Figure 2.2.2). The thalweg in a straight reach likely meander within the high-water channel at low stages, forming short pools and relatively long and shallow crossing, normally unsuitable for navigation. Channel pattern is controlled by the alternate bars, so their stability establishes the stability of the reach.

Depending on the regime of the river, the erodibility of the banks, a straight channel can remain as such, if a river is dredged as a straight channel. Seldom only part of a river is straight, typically as stretch of a few miles in between two meander bend.

Meandering River

A meandering channel is one that consists of alternating bends, creating as S-shape to the top-view of the river. In particular Lanne (1957) showed that a meandering channel is one where channel alignment consists mainly of distinct bends, the shape of which have not been established principally by the varying nature of the topography through which the channel flows. The meandering river contains a sequence of deep pools in the bends and shallow crossings in the short straight reach connecting the bends. The thalweg flows from a pool through a crossing to the next pool forming the typical S-curve of a single meander loop.

The plan view and some cross sections of a typical meandering river are illustrated in Figure 2.2.2. Here, one may study the position of thalweg, the location of the point bars, alternate bars and the location of the pools and crossings. It is observed that in the crossing, the channel is shallow compared to pools and the banks may be more exposed to erosion.

Figure 2.2.2 diagrammatically shows that the pools are likely to be triangular in section with point bars located on the inside of the bend. The channel tends to be more rectangular in the crossing and widths are greater and depths are relatively shallow. The local slope is steeper and velocities are larger in the crossing than in the pool at low flows. The thalweg is located very close to the outside of the bend at low stages. The thalweg tends to become straight, more particularly, the thalweg moves away from the outside of the bend intruding on the pint bar to some degree

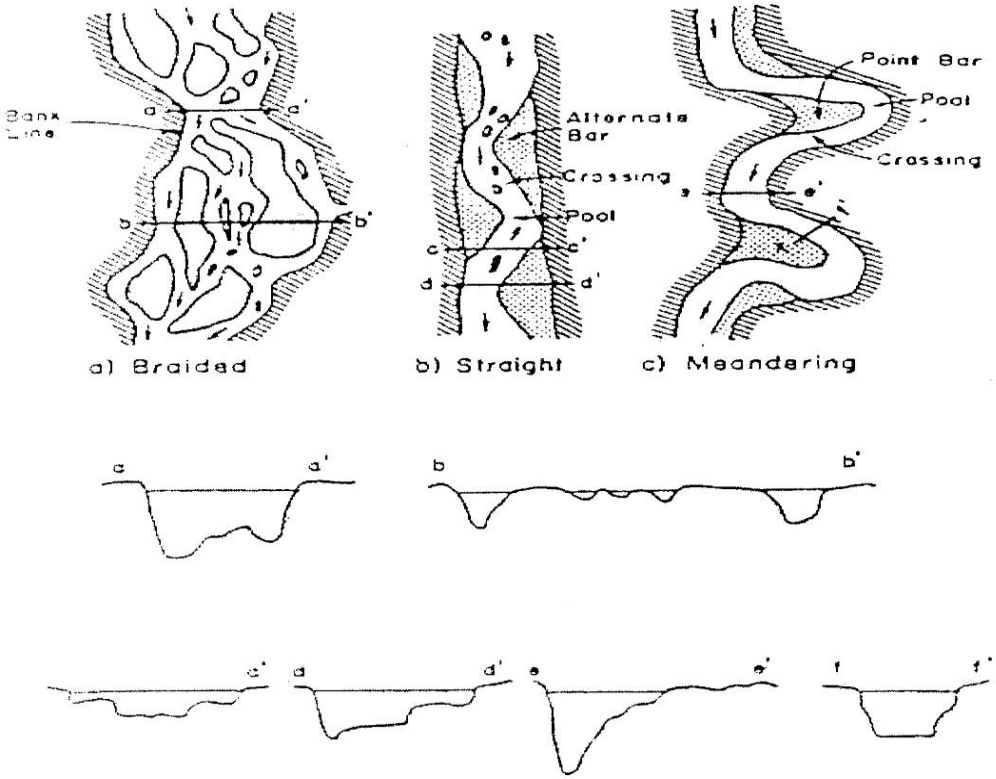

Figure 2.2.2: Various features of channels (Source: Schumm, 1977)

at higher stages. In the severe case, the changing of the flow causes chute channels to develop across the point bar at high stages.

Braided Channel

A braided river is one with generally wide and poorly delineated unstable banks, and is depicted by a steep, shallow route with multiple channel divisions around alluvial islands (Figure 2.2.2 (a)). Leopold and Wolmen (1957) studied braiding in

a laboratory flume. They deduced that braiding is one of many patterns that can maintain quasi-equilibrium among the variables of discharge, sediment load and transporting ability. The two primary reason that may be accountable for the braiding is stated by Lane (1957) as: (1) Overloading, that is the channel may be full with more sediment than it can transport consequently accumulating part of the load, deposition occurs, the bed aggrades and the slope of the channel increases in an effort to maintain a graded condition and (2) steep slopes, which generate high velocity, multiple channels develop resulting the overall channel system to widen with rapidly forming bars and islands. The multiple channels are generally unstable and change position with both time and stage.

Easily eroded banks also cause braiding. The stream widens at high flow and a low flow bars from, which become stabilized, forming island. A braided channel in general has a steep slope, a large bed material load compared to its suspended load, and relatively small amounts of silts and clay n the bed and banks. The braided channel is not easy to control as it is unstable, alters its alignment abruptly, transports heavy loads of sediment, is very wide and shallow even at flood flow and is commonly unpredictable.

2.3 Factors influencing river geometry

Factors governing the geometry and roughness of an alluvial river are numerous and interconnected. Their characteristic is such that it is difficult to single out and study the function of a specific variable. Assessing the consequence of average velocity by increasing channel depth will affect other correlated variables as well. Again, not only will the velocity respond to change in depth, but also the form of bed roughness, the position and shape of alternate, middle and point bars, the shape of cross-section, the magnitude of sediment discharge and so on. Therefore, the study of the mechanics of flow in alluvial channels and the response of channel geometry is incessant.

Variables influencing the geometry of alluvial rivers are numerous and some of the important ones according to Simons (1971) are as follows:

$V, D, S, \rho, \mu, g, d, \sigma, \rho_s, S_P, S_R, f_S, C_T$

Where,

V= Velocity

D= Depth

S= Slope

ρ = Density of water

μ = apparent dynamic viscosity of the water sediment mixture.

g = acceleration due to gravity

d = grain size of the bed materials

σ = measure of size distribution of bed materials

ρ_s = density of sediment

S_P = shape factor of the reach of the stream

S_R = shape factor of the cross-section of the stream

f_S = seepage force in the bed of the streams

C_T = concentration of the bed material discharge

Simons and Richardsen (1962) has described the role of the variables on resistance and bed form. Simons (1971) also partially explained their significance on the channel geometry.

2.4 Aggradation and Degradation of Channels

Aggradation (i.e. rising of the river bed by deposition) occurs in a river if the amount of sediment coming into a given reach of a stream is greater than the amount of sediment going out of the reach. Part of the sediment load must be deposited and hence, the bed level must rise (Ranga Raju, 1980). In alluvial channels or streams bed aggradation evolves primarily form the passage of flood events. The bed profile consequently reduces the section factor of the channel. Sediment deposition along streams or in reservoirs is a complex and troublesome process. It creates a variety of problems such as, rising of river beds and increasing flood heights, meandering and over flow along the banks, chocking up of

navigation and irrigation canals and depletion of the capacity of storage reservoir (Hossain, 1997).

Bed degradation (i.e. lowering of the bed by scouring) occurs when the amount of sediment coming into a given reach of a river is less than the amount of sediment going out of it (Ranga Raju, 1980). The excess sediment required to satisfy the capacity of the river will come from erosion of the bed and there will be lowering of the bed level, which will result in shifting of thalweg line of the river. If the banks are erodible material can be picked up form the banks and widening of the river will also result. Hence the whole process of aggradation and degradation of rivers have potential effects on various hydraulic and geometric features of rivers such as cross-sectional area, section factor, shifting of thalweg line etc.

2.5 Coastal zone of Bangladesh

Coastal zones refer to areas where land and sea meet. The landward and seaward range of the zone, however, varies with the purpose of coastal zone management. The coastal zone in Bangladesh has been delineated previously in various ways (ESCAP/UN, 1987; Danida, 1999; SRDI, 2001; MoWR, 1999; PDO-ICZMP, 2001).

The three basic natural system processes and events that govern opportunities and vulnerabilities of the coastal zone of Bangladesh are: tidal fluctuations; salinities (soil, surface water or groundwater); and cyclone and storm surge risk. By reviewing earlier exercises as well as methodologies from other countries and considering these three criteria, an assessment has been done on the delineation of the coastal zone. For each of these criteria, threshold values have been specified and corresponding impacted areas were determined. Based on these, Coastal Zone Policy 2005 defines the coastal zone of Bangladesh consists of 19 districts comprising 147 upazilas (sub districts) and the Exclusive Economic Zone (EEZ).

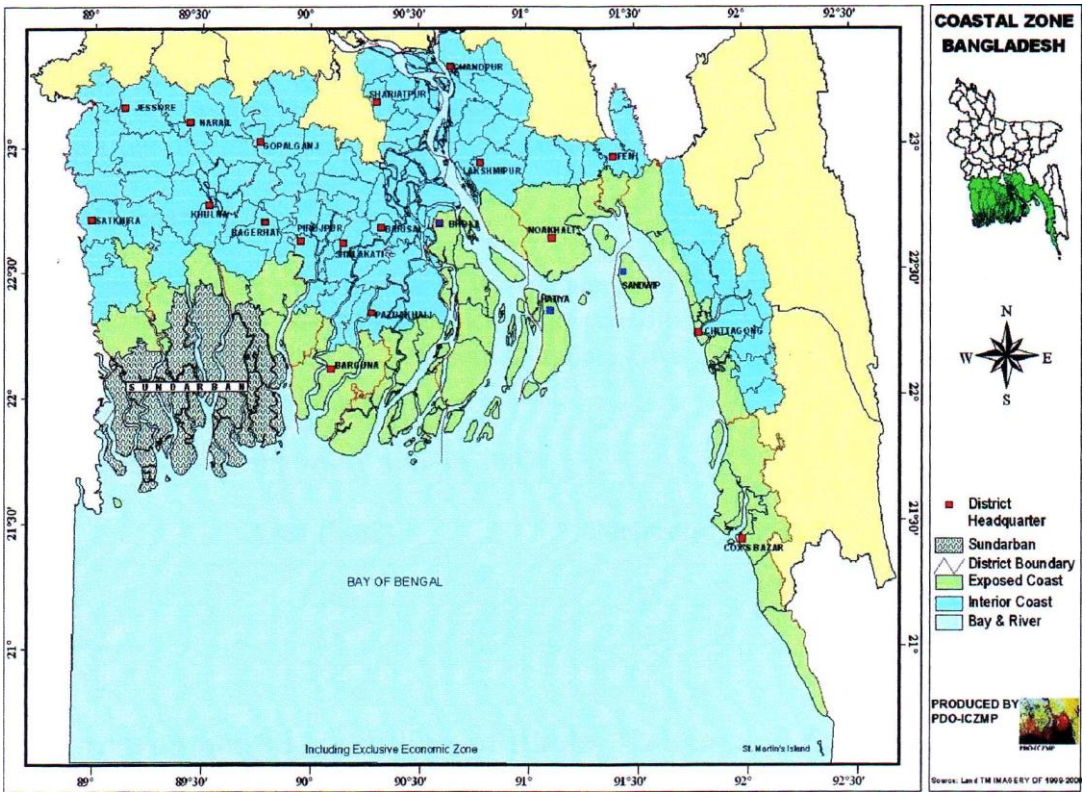

Figure 2.5.1: Coastal zone of Bangladesh

Further, a distinction has been made between upazilas facing the coast or the estuary and the upazilas located behind them. A total of 48 upazilas in 12 districts that are exposed to the sea and/or lower estuaries, are defined as the exposed coast and the remaining 99 upazilas of the districts are termed interior coast shown in Table 2.1 and Figure 2.1.

2.6 Description of the study area

The Main Islands of Meghna Estuary Study area covers the Lower Meghna River from Chandpur town to the Bay of Bengal (Figure 1.3.1). The study area extends from left edge of Haim Char towards the left edge of Char Abdullah and then falls into the Shahbajpur River. The river course from the top of Shahbajpur to the bottleneck of Hatia was taken up to the upper portion of Sandwip through Hatiya River. The river path was followed where there were BIWTA gauge stations. All water level and cross-sectional data were collected primarily from those BIWTA stations.

Table 2.6.1 Overview of the districts in the coastal zone

Districts	Area (Km^2)	Population (2001)	Salinity	Tidal fluctuation	Cyclone risk
Barguna	1,832	837,955	√	√	√
Barisal	2,791	2,330,960	√	√	√
Bhola	3,403	1,676,600	√	√	√
Bagerhat	3,959	1,515,815	√	√	√
Chittagong	5,283	6,545,078	√	√	√
Chandpur	1,704	2,210,162		√	√
Cox's Bazar	2,492	1,757,321	√	√	√
Feni	928	1,196,219	√	√	
Gopalgonj	1,490	1,132,046	√	√	
Jessore	2,567	2,440,693	√	√	
Jhalokati	758	696,055	√	√	
Khulna	4,395	2,334,285	√	√	
Lakshmipur	1,458	1,479,371	√	√	√
Narail	990	689,021	√	√	
Noakhali	3,601	2,533,394	√	√	√
Patuakhali	3,205	1,444,340	√	√	√
Pirojpur	1,308	1,126,525	√	√	
Satkhira	3,858	1,843,194	√	√	
Shariatpur	1,181	1,057,181		√	
CZ total	47,203	34,846,215			
Bangladesh	147,570	123,151,246			
CZ (%)	32	28			

Source: BBS, PDO-ICZM, 2000

2.6.1 Environmental Condition of the Study area

The process of natural development of the selected islands of Meghna Estuary is governed by the environmental conditions. Rainfall in the catchment is drained by the rivers to the Bay of Bengal. Heavy monsoon rains causes high water levels in the rivers that flood the land, while very high discharge brings enormous amounts of sediments down the rivers to the estuary. The processes of accretion and erosion are strongly influenced by the changes in the river flow, but also by waves. Winds drive the circulation of water in the estuary while cyclones cause high storm surges and (sometimes catastrophic) floods. Tide coming from the Indian Ocean determines the variation in water levels and the flow in the estuary. Saline seawater penetrates through the estuary up to Chandpur during the dry season, while during monsoon the estuary is merely

filled with fresh water. Changes in salinity contribute to flocculation and deposition of silts in the estuary (Ali, 1996).

Knowledge of environmental conditions in the Meghna Estuary is therefore of crucial importance for understanding the morphological processes. These conditions are described in the following chapters.

2.6.2 Precipitation

The climate of Bangladesh is tropical, with a hot, humid summer (March to June), a rainy monsoon (June to September) with predominantly south-westerly monsoon winds, and a dry, relatively cool winter (September to June) with predominantly north-westerly monsoon winds. The catchment of Brahmaputra,

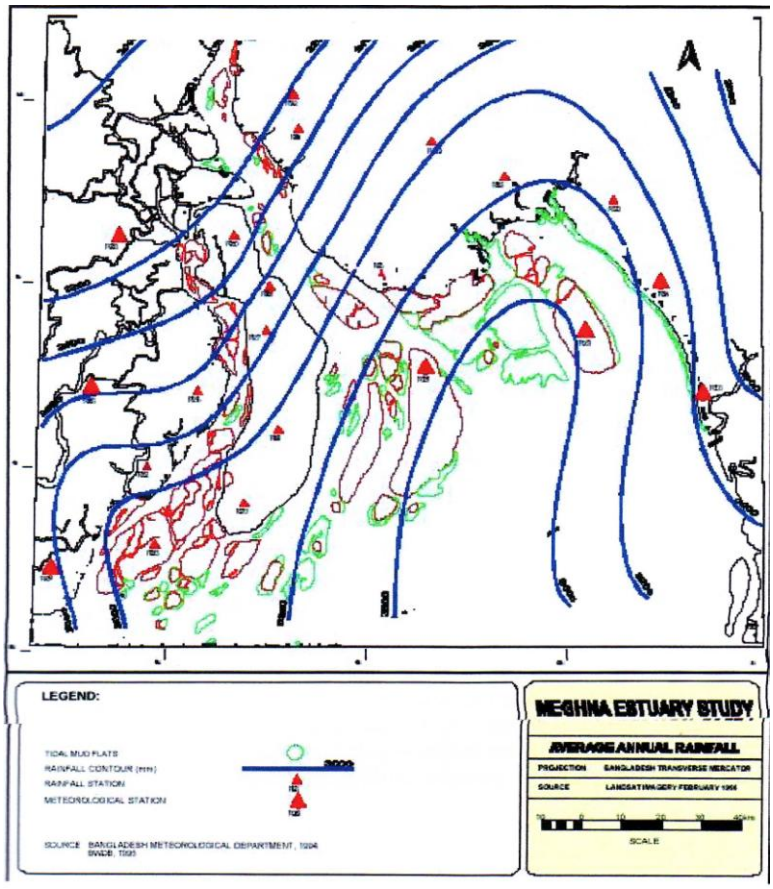

Figure 2.6.1: Average annual rainfall in coastal zone
(Source: BMD, 1994)

Jamuna-Meghna receives annually an average of 1,500 mm of rainfall, most of which falls during the monsoon months but there are great variations in rainfall across the basin. The average rainfall in the coastal area of Bangladesh is about 2000-3600 millimeters per year.

2.6.3 Wind

The wind regime along the Bay of Bengal shows a typically seasonal variation between the dry season (November-March) and the monsoon season (June September). During the dry season the prevailing winds are calm and offshore. The prevailing winds during the monsoon season are from the S-SE direction, with an average velocity of about 8-12 m/s. During severe storms and cyclones, very high wind velocities can occur. The highest wind speed, reported during the April 1991 cyclone (CERP-II, 2000), is 62.5 m/s, corresponding to 225 km/h. Most cyclones occur during April-May and October-November, which are the transitional periods between the dry season and the monsoon season. The highest wind speed recorded in the recently (November 7, 2007) occurred devastating cyclone SIDR was 250 km/h that swept in from the Bay of Bengal.

Monthly average wind speed data as recorded at the study area of Lower Meghna River, the coastal stations are presented in Table 2.6.2

Table 2.6.2 Average monthly wind speed in coastal stations (m/s)

Station	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bhola	0.3	0.4	0.7	1.2	1.0	0.9	0.9	0.8	0.5	0.2	0.2	0.2
Sandwip	0.6	0.9	1.7	2.6	2.3	2.7	2.6	2.4	1.5	0.8	0.5	0.6

(Source: CERP II, 2000)

The tidal wave from the Indian Ocean travels through the deep Bay of Bengal and approaches the coast of Bangladesh approximately from the south. It arrives at Hiron Point and at Cox's Bazar at about the same time. The extensive shallow area in front of the large delta causes some refraction. Also some reflection of the tidal wave occurs contributing to a significant amplification of

the tidal wave in Hatiya and Sandwip Channels. North of Sandwip Island and Urir Char occurrence of tidal bores has been observed (Akhter and Mahmud, 2007).

The water level variation is dominated by a semi-diurnal tide with a considerable variation from neap to spring tides. In the entire coastal area the variation of amplitude from neap to spring is from 0.6 to 1.4 times the average amplitude (FAP 24, 2000).

In the area around Sandwip, the tidal range is significantly higher with an average range of over 4 m. According to the classification of tides proposed by Davies (1964) the tidal range in the study area can be classified as follows and shown in Figure 2.6.2

- Tetulia river - Chandpur : *Micro-tidal* - tidal range 0-2 m
- South bhola - Hatiya North: *Meso-tidal* - tidal range 2-4 m
- East Hatiya-Sandwip: *Macro-tidal* - tidal range >4m.

The maximum high-tide water level is about 6.5 m above PWD and more during cyclone surges. The maximum current velocities vary from approximately 0.1 - 4 m/s in the tidal channels to about 0.2 - 0.5 m/s in the shallow areas on the mud flats and shoals. The amplitude of the tidal velocity shows neap-spring tide characteristics. The tidal characteristics are semi diurnal type in the Bay of Bengal, where there are two peak values of water level and two lowest values in 24 hours. During spring tide the flow velocities are normally higher than during neap conditions. Although velocity measurements during monsoon are rare it can be assumed that the velocities are higher than during the dry season (Islam, 2004).

2.6.4 Waves

No wave heights have been recorded during severe storms until now. In the dry season the waves are generally less than 0.6 m with peak periods of 3 - 4

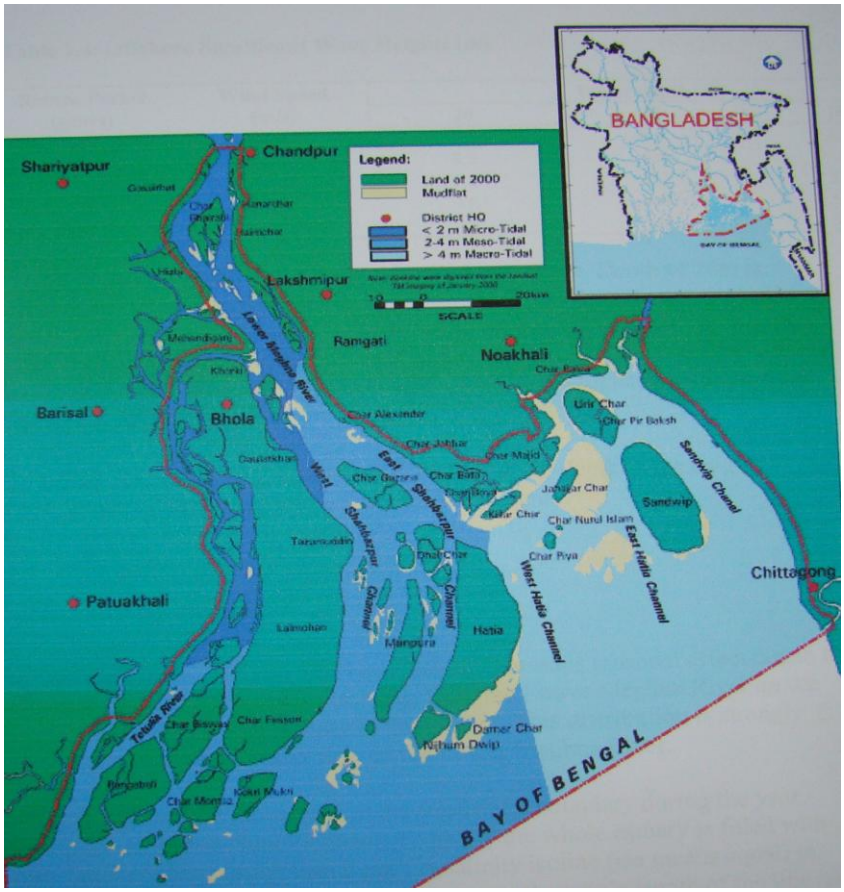

Figure 2.6.2 Mean Tidal Range in the lower Meghna River and Coastal area (BMD, 1994)

seconds. During the monsoon season wave heights exceed 2 m with periods greater than 6 seconds.

Table 2.6.3: Offshore Significant Wave Heights (m)

Return Period (years)	**Wind Speed** (m/s)	**Wave Heights in different Water depth**		
		20(m)	**15(m)**	**10(m)**
5	46.6	7.6	6.1	4.5
10	53.2	8.2	6.6	4.9
25	60.9	9.0	7.2	5.3
70	68.5	9.6	7.8	5.7
100	71.0	9.9	7.9	5.9

The maximum wave height is limited by the water depth. Depth of water is co-related to the wave height. Water depth of 20m is representative for a deeper part of the continental shelf. In the estuary, depths are generally lower than the other

part. The water depth in the estuary is less than 5-l0m when the cyclone surge is taken into account. Waves higher than 0.6-0.8 times of the local water depth will break due to insufficient water depth. Still, waves higher than 5m may be expected in the outer part of the estuary during a cyclone (IWM, 2005).

2.6.5 Salinity intrusion

Salinity data from LRP and MES indicate an enormous seasonal effect due to the influence of huge fresh water discharge from the Lower Meghna River on the horizontal distribution of salinity in the estuary. This distribution is strongly influenced by the fresh water flow in the Lower Meghna River.

During the monsoon (June-September), only in the southeast part of the estuary, south of the Sandwip Channel, higher salinities are found. From about 30-40 km south of the mouth of the Karnafuli River towards the deeper part of the Bay, the estuary remains stratified during monsoon. There, a stratified zone with a width of approximately 100 km developed, with a layer of brackish water moving with the tide over a salt wedge. This zone forms a transition between the fresh water in the estuary and the more saline water coming from the Bay of Bengal, with salinity of approximately 20 ppt. It is expected that during the monsoon, stratification also occurs south and southwest of Hatiya-Bhola, along the boundaries of the estuary where the shallow waters (10 m contour) end. A large portion of the sediment is transported towards this zone by the fresh water flow. During the dry season (October-March) flow in the Meghna River gradually decreases, and saline water penetrates the estuary. The penetration of saline water ends in the river's mouth. The salinities in the main river channels, East and West Shahbazpur Channel, are noticeably lower (between 6 ppt and 8 ppt). Salinity plays an important role in the delta formation process. The spatial distribution and concentrations of salinity in the estuary are important for the deposition of silt and clay. Vertical stratification (vertical variation) of salinity during the wet season may play role in the seasonal storage of sediment at the outskirts of the estuary.

2.6.6 Hydraulic characteristics

The Lower Meghna River conveys the melt and rainwater from the Ganges and the Jamuna basins, combined in the Padma River, and from the Upper Meghna basin to the sea. The discharges of these three major rivers dominate the river inflow in the Meghna Estuary Study Area. Long-term records of discharges and water levels are not available at Chandpur. Therefore, the discharge characteristics of Jamuna, Ganges and Meghna (the three main rivers of Bangladesh) are used here to characterize the river inflow characteristics in the Meghna Estuary Study Area. The river regimes of the Jamuna, Ganges and Meghna are depicted in Figure 2.6.3 and Figure 2.6.4, showing the 90, 50 and 10% exceedance flows for the period 1965-1995 (FAP 24, 2000). Clear differences are observed between the Jamuna and Ganges river regimes: the Jamuna rises on a half to two month earlier than the Ganges, whereas flow recession in the Ganges begins somewhat earlier.

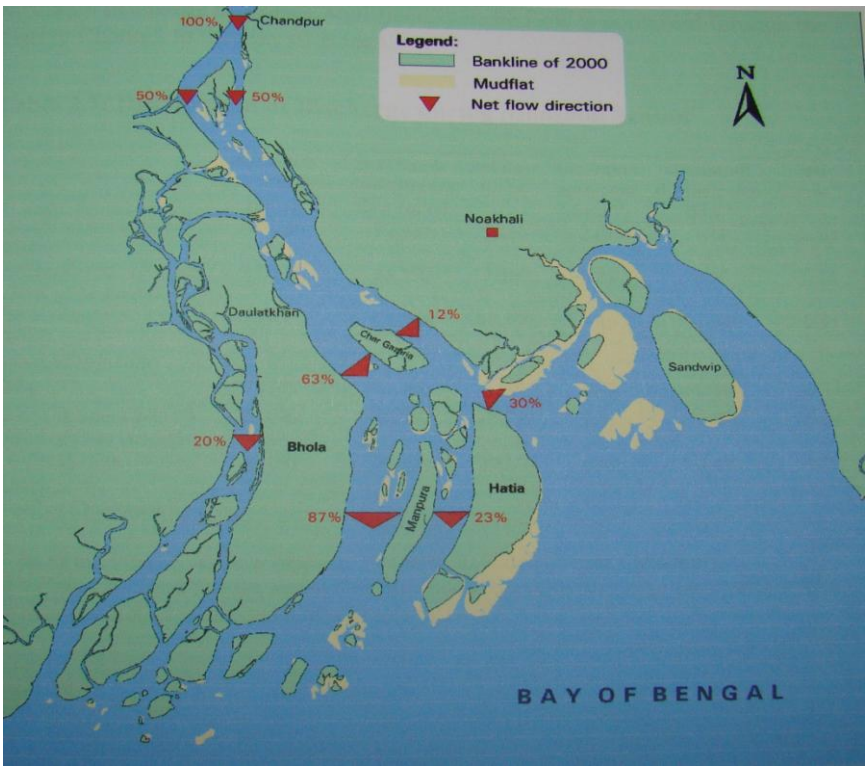

Fig 2.6.3: Net flow distribution in % of flow at Meghna Estuary during dry season (Source: Akhter et al., 2007)

Figure 2.6.4: Net flow distribution in % of flow at Meghna Estuary during monsoon (Source: Akhter et al., 2007)

During August-September the river flows are on average similar. The average discharge of the Jamuna River at Bahadurabad is approximately 21,000 m^3/s. The highest peak flow in Jamuna in the period 1956-2000 occurred in 1998 and amounted to105,000 m^3/s (Akhter et al., 2007).

The average discharge of the Ganges River at Hardinge Bridge of (1966-1995) is about 11,000 m $^3/s$. Since 1934 the highest peak flow amounted to 79,000 m $^3/s$ in 1998. The annual flow volume of the Ganges is about half the Jamuna flow volume. The average discharge of the Meghna River at Bhairab Bazar over the period 1965-1995 is approximately 4,800 m^3/s. Peak values of nearly 20,000 m^3/s have been measured a few times in the past three decades.

The combination of strong river and tidal flow produces a complex flow pattern in the estuary. The Study is validated with the water level and discharge measurements from 1997 monsoon and 1999 dry season. It included both neap and spring tide and was therefore considered to represent characteristic conditions occurring in the Meghna Estuary during the low and the high

discharge conditions. It is noted, however, that the velocities and discharges in the upper part of the river system calculated are significantly lower than the values measured during the 2000 monsoon. Still, it can be assumed that this can fairly well reproduce global flow features in the Meghna Estuary.

2.6.7 Hydrodynamic conditions during dry season

The dry season is the calm period in the estuary. The wind is weak, and the river discharge is much lower than during the monsoon. Water movement in the estuary is mainly forced by the tide entering from the Bay of Bengal.

Hydraulic simulations indicate that during the dry period, the highest flow speeds can be found in the North Hatiya Channel and around Urir Char. The maximum flow speed is about 2.5-3 m/s. Large flats and complicated flow features north and west of Sandwip can be seen, as well as flats south of Hatiya. Rapid changes in the flow direction take place in these areas over very short distance, which is in agreement with the observations. Higher velocities of about 1.5-2.0 m/s are found mainly in the eastern, deeper part of the estuary, and in the Shahbazpur Channel. Lowest speeds of about 0.5-1.0 m/s are found in the upper part of Lower Meghna, where the tidal action is less pronounced (MES, 2001).

The residual flow indicates the transport of water out of the Meghna Estuary, mainly through the West Shahbazpur Channel, and an easterly flow outside the estuary. A prominent counter-clockwise circulation is found around the Sandwip Island, with a northerly current in the Sandwip Channel and southerly current in the southern part of the Hatiya Channel. The anti-clockwise circulation is mainly forced by tides; but influenced by the river discharge. This circulation traps the fresh water from the river in the estuary and thus increases the residence time and may be the reason for the relatively low salinity in the estuary even during the dry season (Jacobsen et al., 2001).

2.6.8 Hydrodynamic conditions during monsoon

Monsoon is the dynamic season in the estuary. The south-westerly monsoon wind is steady, and the river discharge is high. Furthermore, the mean water level is higher than during the dry season The flow and water-level distribution of the estuary are jointly forced by the river discharge, the tide, and the wind. The monsoon season is critical with respect to high water-levels, sedimentation and accretion.

The water from the Lower Meghna is conveyed to the sea through the Shahbazpur Channel and the Hatiya Channel. The residual counter-clockwise circulation around the Sandwip Island indicates that this area is dominated by tides. The net flow and the maximum flow velocities in the Lower Meghna are higher during neap tide than during spring tide, whereas in the Sandwip Channel, due to the domination by tide, maximum velocities are higher during spring tide. Due to higher water level during monsoon, the maximum speeds in the estuary are slightly lower than during the dry period. In the Lower Meghna River, the velocities increase due to increased water flow, with the maximum of 1-2 m/s.

2.6.9 Sediment transport processes

Sediment transport processes form a crucial control in the estuarine processes and evolution of the Meghna Estuary. The estuary is the route by which sediments are transported from the major rivers to the Gulf of Bengal. On their way down the river, continuous deposition, re-erosion and transport alter the composition of sediments. Much of the coarser sediments become trapped on the floodplains of the rivers, only being released at times of flood (Alam et al.,1998). The finer fractions are transported into the estuary. There, the estuarine processes act as a filter on the sediment input, and mixing can take place with sediment brought in from the sea. Additionally, chemical alterations can occur within the estuary that can cause the surface properties of some of the constituent particles to alter, affecting their potential deposition.

2.6.10 Sediment characteristics

Within the Meghna Estuary, concentrations of suspended sediment are generally high, the particles are fine, cohesive, and prone to flocculate, and they are richly organic. To get insight in the sediment characteristics along the study area, more than 450 samples of bed material were collected by MES. The locations of sampling are shown in Figure 2.6.6. The morphological changes derived from the time series of satellite images over the period 1973 to 2000 and the annual sediment discharge indicate qualitatively that the net gain of land is related to the amount of river borne sediment discharge (Hossain, 1992).

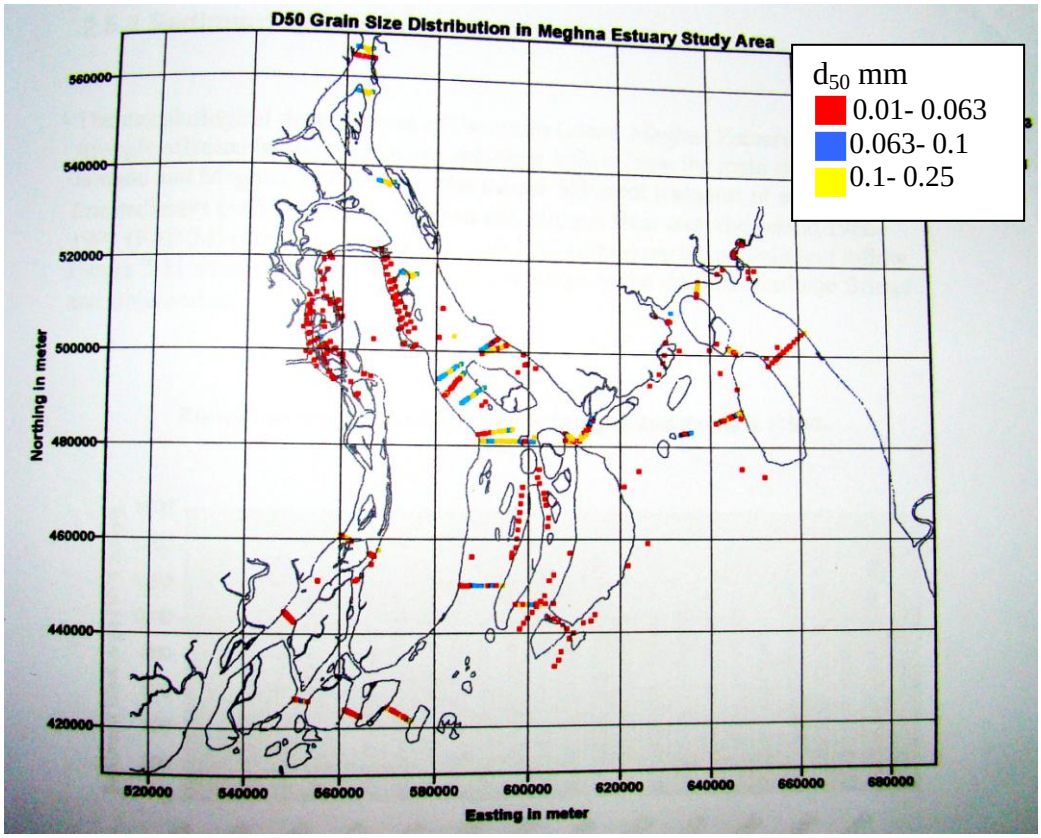

Figure 2.6.6: Spatial Distribution of the d_{50} Grain Size (Source: BWDB, 2002)

Sediment Concentrations

The major part of sediment consists of a mixture of (very) fine sand and silt. It is continuously moved back and forth along the Bangladesh coast and through the

tidal inlets into the system. The relatively coarser material is dominantly moved near the bottom (the bottom-transport). The finer particles of sand and the particles of silt and clay are dominantly moved by current as suspended material. Sediment concentration measurements at different heights in the water column show that the sediment concentration near the bottom is only slightly higher than at the surface. This indicates that the major part of the sediment transport is the transport of vertically well-mixed suspended material.

The maximum depth-averaged sediment concentration varies between 0.5 - 9 gm/liter. Measurements indicate that the maximum concentration can be found near the Urir Char -North Hatiya area (Kamrunnessa, 1994).

The sediment concentration measurements by MES and LRP indicate a variation of the sediment concentration during a fortnightly cycle of the spring and the neap tide. The variation of sediment concentration shows a tendency to increase towards the spring tide. The maximum depth averaged sediment concentration at spring tide is about 2-5 times higher than at neap tide.

Salinity measurements conducted by LRP during low river discharge indicate that the high sediment concentration coincided approximately with the zone of salinity intrusion. The lower limit lies at approximately the 10-20 m depth contour, beyond which a vertical gradient in salinity was measured in the water column (SWMC, 2001). The upper limit of the sediment concentration appears to be associated with density-driven circulation. This means that the zone of turbidity maximum influences almost the entire estuary during dry season.

2.6.11 River profiles, bank erosion and bed material

Materials comprising the beds of alluvial have an important influence on river geometry. Bed slopes at the headwaters of rivers are steep and the bed material is relatively course. In general, both the bed material size and river slope decrease in the downstream direction. Tractive force is not sufficient to move the longer materials down stream, but the smaller material is transported out to the point where hydraulic sorting essentially paves the bed with coarse materials

characteristic of a reach eventually partially decomposed with time due to abrasion and weathering so that, in general, a continuous supply of material capable of being transported is available (Mukherjee, 1995).

The river boundary in a given reach is constantly changing with such interacting flow variables as velocity, depth, slope, density and viscosity of the water-sediment mixture, concentration of bed-load discharge, concentration of suspended load discharge and characteristics of the bed material. River bank stability depends on these interrelated stream variables as well as on channel geometry (Rahman, 1980).

Bank erosion and retrogression or retreat occurs in many ways, primarily as a result of one or a combination of the following:

1. Removal of soil particles from the bank surface either continuously or intermittently over a period of time;
2. Sequential failures of small segments of bank material
3. Failure of a single large segment of bank material

The U.S Army Crops of Engineers (1981) summarized changing conditions that affect bank stability as follows:

1. At the Surface
    (a) Severe surface deterioration that may result in an unstable bank configuration, such as erosion by river flow at the toe of the bank; erosion at the water surface due to waves and erosion along the bank surface due to over bank flows.
    (b) Deep tension cracks due to excessive drying of a cohesive soil or similar structural change that may cause the bank to weaken and become unstable. Crumbling may occur if excessive drying is followed by submergence.

(c) Overburden placed along the top of bank that may cause an otherwise stable bank to become unstable.

2. Moisture Content within the Bank

(a) The slope of cohesion less bank may be temporarily steeper than the angle of repose of the bank material due to capillarity or other temporary stabilizing effect. When the stabilizing effect is removed, the bank becomes unstable.

(b) With piping, cohesion less material is eroded from a location on the bank surface by seepage flow; a cavity develops and extends rapidly into the bank along a dominant seepage path.

(c) Liquefaction of the grained and loosely structured materials subject to rapid increase in pore pressure (as during rapid draw down or earthquake loading) results in a large segment of bank material flowing down slope as a fluid-like mixture.

(d) With a high water table and low stream level, an added hydraulic load is placed on the bank and may result in failure unless relieved by seepage or piping.

(e) Swelling and shrinking during wetting and drying affect the stability of clay soils. Substantial hydraulic pressures may result flow water flowing freely into deep tension cracks and into openings between different bank materials.

(f) The shear strength of clay soils is dependent on pore-pressure and degree of saturation.

3. Miscellaneous Conditions

(a) Artesian or gravity in a cohesion less or porous layer can remove sediment by piping, resulting in shear failure of layers higher in the bank

(b) A thin clay layer that weakens and compresses when saturated can cause shear failure in the upper bank.

(c) Lubrication by water and high hydrostatic pressure along interfaces between bank materials can cause low resistance to sliding, resulting in massive bank failure.

(d) Other site-specific combinations of failure mechanisms.

2.7 Hydro-morphological studies of the rivers of Bangladesh

In Bangladesh there have been many studies done on the hydro-morphological aspects such as hydraulic geometry, erosion/deposition and bed level variations in many rivers. Most of these studies were carried out in the major rivers like the Ganges, the Brahmaputra, the Meghna and the Teesta River.

2.7.1 Hydro-morphological studies carried out in Meghna River and Meghna Estuary

MES, 1999 studied that several interventions were proposed at different locations of the Estuary in order to reduce the loss of valuable existing land and infrastructure from erosion. The interventions proposed for erosion control were made of permeable spurs and bottom screens.

The locations identified for interventions under this study include the northeast coast of Bhola in the Lower Meghna (12 km coastline between the villages of Ilisha in the north and Chowkighata in the south), the east coastline of Bhola (about 50 km between the villages of Chowkighata in the north and Betua in the south), the right bank of the Upper Tetulia River (between Ilisha and Dasmonia), the Mehendigamj-Hizla-Bhedarganj (about 40 km on the right bank of the Lower Meghna), the Lakshmipur-Ramgoti (about 40 km riverbank on the left bank of the Lower Meghna between Haimchar and Char Bouy), the North Hatiya (about 12 km shoreline), and the west coast of Sandwip island (about 15 km in length).

MES-022 studied the long-term hydraulic and morphological process in the Meghna Estuary can be stirred by gravitational circulation due to salinity gradients in the pre-and post monsoon period.

The study estimated the strength of the gravitational circulation for the Shabazpur main channel of the Meghna Estuary. The gravitational circulation was estimated based on LRP measurements of salinity collected during pre-monsoon over the period 1983-1986.

Based on salinity observation and an analytical model, the strength of the gravitational circulation in the main channel (i.e. Shabazpur Channel) of the Meghna Estuary between 15 km and 30 km (from Ramgoti towards sea) was estimated at 0-4 cm/s during pre- and post-monsoon, the exact value depending on freshwater discharge and location. Using crude model it was estimated that even a relatively small residual current of a few cm per period in combination with a tidal current in order of 1 m/s could lead to sediment particle displacements of few hundred meters per tidal cycle. It was also concluded that during monsoon period the strength of the gravitational salinity is negligible in the main channel.

MES-001 determined the tidal flow characteristics and sediment transport patterns during spring and neap tide conditions in the Lower Meghna Estuary that prevailed during Land Reclamation Project (LRP) period.

Following findings were found in this report, which would be useful for the present study:

A tendency of higher sediment concentration during spring tides was observed. Maximum sediment concentration of 9.74 gm/1 at 0.5 m above channel bed during spring tide was recorded at the north of Urir Char. At West Shabazpur Channel the concentration is found between 1.3 gm/1 and 2.2 gm/1.

An important characteristic of tidal flows is that superimposed on the back and forth flow is a net steady circulation, often called the 'residual circulation'. 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, Shabazpur 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.

MES, 2001 The Meghna Estuary Studies (MES I and MES II) were the supporting studies under FAP 5B of the Flood Action Plan (FAP). The FAP was initiated after the disastrous floods in Bangladesh in 1987 and 1988, and it was a co-coordinated action to study the flood problems of Bangladesh.

The main goals of the MES were as follows:

- To collectively gather hydrological and morphological data;
- To increase knowledge of the hydraulic and morphological processes in the Meghna Estuary system;
- To develop appropriate techniques (or efficient land reclamation and effective riverbank protection;
- To provide a Master Plan and Development Plan for the estuarine area
- To enhance the knowledge of the complex morphological process in the Meghna Estuary, a morphological study was carried out within the framework of the Meghna Estuary Studies in the period 1995 to 2001.

Hydraulic simulations under this study indicate that during the dry period, the highest flow speeds can be found in the North Hatiya Channel and around Urir Char.

Simulations also show a net transport of water out of the Meghna Estuary, mainly through the West Shabazpur Channel, and an easterly flow outside the estuary. A prominent counter-clockwise circulation is found around, the Sandwip Island; with a northerly current in the Sandwip Channel and southerly current in the southern part of Hatiya Channel.

2.7.2 Studies on river morphology in Bangladesh

Habibullah (1987) determined the bed level variations and bank line movements between Aricha and Charnatua. According to the study the reach

length between Aricha and charnatura was 211.39 km. He studied 32 stations for the bank line movement and 20 sections for the bed level variations between years 1965-66 and 1983-84. His bank line movement study revealed that the maximum amount of bank line erosion and deposition were 348m/year and 355m/year respectively in 18 years period since 1965-66. His study on mean bed level showed that the mean gradient of the river bed has increased from 6.74m/km in year 1965-66 to 7.99m/km in 1983-84. He also carried out study on the overall erosion and deposition within 210km reach between Aricha and charnatua and concluded that the total volume of material eroded and deposited in 18 years within the study period were $1.22*10^9$ m^3 and $4.443*10^8$ m^3 respectively. He also concluded that the overall net erosion in 18 years since 1965-66 in the 210 km reach was $7.77x\ 10^8$ m^3.

Hossain (1991) carried out studies on the aggradation and degradatin of the Brahmaputra River, the Ganges River and Teesta river. In these studies he had shown the variations of the mean bed levels of the above rivers and also concluded the extent of aggradation and degradations including net sedimentation in different reaches of the river. His study in the case of Ganges the mean bed levels between years 1967-68 and 1985-86. The findings were that aggradation of the bed level between Baghgokulpur and 75 km downstream and degradation in the 75 km reach upstream of Aricha. In the case of Brahmaputra River the study reach extends from Chanrnatua to Aricha (about 230 km reach) and comparison of the mean bed levels were done between years 1965-66 and 1985-86. His study showed that aggradation has taken place in the upper 159 km reach (i.e. between charnatua to 159 km downstream) with a maximum rise of 4.5m and the rest of downstream reach (i.e. 71km) suffered degradation with a maximum fall of bed level by 3.7 m. Hossain's study on the mean bed level variations of the Teesta river was confined within 13 cross-sections for a 10km reach and he compared the mean bed levels between years 1970 and 1987. He concluded that the mean bed levels at various sections showed erratic trend of fall and rise on an average the bed profiles do not show significant trend of change over the study reach. His study revealed highest rise of the bed level by 0.40m and fall by 0.70 m within the study reach.

Klaassen and Masselink (1992) made a first step towards the development of a predictive model for changes and related bank erosion morphological processes in a braided river with fine sand as bed material. The Jamuna river was studied and conclusions from the study on one hand indicate that much more studies are needed to improve the understanding of these different processes and on the other hand that there is a clear limit to the period over which predictions can be made due to the observed chaotic behaviour of the channel changes.

Ashrafuzzaman (1992) carried out an investigation of the geometric aspects of the Arial khan river for a reach length of about 200 km from its off-take. The study included analysis of cross sectional geometry development of non-dimensional co-relations, thalweg and bank line shifting, mean bed level variation, specific gauge analysis and determination of meander parameters.

Hossain (1992) made an analysis of the total sediment load in the lower Ganges and Jamuna. The study revealed that total average sediment flow through the major rivers of Bangladesh was of the order of 1.2 billion tons with a maximum of 1.5 billion tons. The estimated total sediment flow when compared with the finding of previous studies showed good compliance. Moreover, co-relations were developed between water flow and sediment flow for use of in practical design problem.

WARPO (1997) has done investigations on the vertical changes of the Dhaleswari River for their feasibility study of the Kalni-Kushiyara river improvement project. In their feasibility study they have shown the average bed level changes in the 24 km reach from the Issapur bifurcation to the point where the Baisa channel rejoins the Dhaleswari river. The comparison were made using surveys from 1963, 1975,1977 and 1988. WARPO (1997) has also done assessment of aggradation and degradation of the bed level in the lower Kushiyara/Kalni River. In this study they have used BIWTA navigation charts from 1963, 1975, 1977 and 1988. The reach they have studied extended between 50 km upstream of Bhairab Bazar and Fenchuganj (around 225 km upstream of Bhatrab).

1. North west hydraulic consultants Ltd. (1976) reviewed various aspects of the proposals, which were submitted to the Asian Development Bank for funding. This studies essentially involved flood control embankments on both sides of the river from Indian border to some downstream, irrigation aspects.

2. SWMC (2001) studied the morphological behaviour of the river Brahmaputra and some other rivers of Bangladesh with special emphasis on the river Brahmaputra under the project titled "Morphological assessment of the river of Bangladesh". The study revealed that the river was in overall aggradation during the period 1988-89 to 1997-98. The study also aimed at retrieving and archiving historical BWDB cross-section data and development of a morphological data base.

2.7.3 Hydro-morphological studies in the river around the world

Over the past decades several studies have been made to evaluate morphological changes of the major rivers in and outside of Bangladesh. Although the list provided is not exhaustive, yet it provides some information in this respect.

Ranga-Raju (1980) did a study on the practical computation of degradation and aggradation on alluvial river based largely on the works carried out in India. He presented semi-empirical methods for computation of bed and water surface profiles for some of the commonly encountered cases of aggradation.

Soni *et. al* (1980) carried out study on the aggradation caused in an alluvial stream due to increase in sediment supply rate. In such a case the stream bed both upstream and downstream of the section of increased sediment supply shall aggrade. The considered only aggradation in the downstream reaches and assumed that sediment supply to be taking place continuously at a constant rate. Their primary objective has been to predict analytically the transient bed and water surface profiles under such conditions.

Jaramillo and Jam (1984) performed investigations on the aggradation and degradation of alluvial channel bed and introduced a one-dimensional non-linear parabolic model for non-equilibrium processes in the alluvial rivers. Their model can be used as a tool for predicting aggradation-degradation processes in alluvial river.

The factors that determine the channel bed degradation caused by constrictions have been studied by Nat Yanapirut (1985). This investigation is conducted under the static equilibrium theory. He showed that the relative depth of scour caused by channel constriction is not much affected by size of bed material and froud number.

Jain (1989) proposed a guide for estimating river bed degradation. The rate and extent river bed degradation resulting from sediment interruption were determined by means of computer based numerical experiment. He presented the results in the form of algebraic relations that can be easily applied by practicing Engineers to estimate the temporal and optimal river bed degradation during the preliminary phase of the engineering designs. The proposed relationship for the bed degradation has been verified with the field data of Missouri river.

Ramez, P., Paquier, A. and Bonnet, F. (2002) carried out a study on Influence of sediment transport on the computation of water in the river Rhone. The showed that the increase of the head losses due to bed forms is interpreted in the U-curves (ratio of Strickler coefficients versus ratio of bottom shear stresses) and of S-curves (Strickler coefficient versus discharge). This effect is stronger at dominant discharge. It can lead to a rise of water level much higher than the final topographical change. For the presented example of a reach of River Rhône near Bourg lès Valence, this rise is estimated over 1 m for the dominant discharge of about 1200 m^3/s.

2.8 Summary

In this chapter relevant literatures have been included. The meteorological information as well as the environmental condition of the study area has been discussed in this chapter. Also previous studies conducted in Meghna River and other rivers of Bangladesh and around the world have been incorporated.

CHAPTER 3

Theory and Methodology

3.1 General

In Chapter-2 the different methodologies and terminologies that are used in this study have been discussed. In this chapter, the detailed methodology for determining the water level and bed level variation of the selected lower Meghna River under this study will be presented.

3.2 Theory

Standard procedures were followed to collect the cross-sectional data at different stations in the Lower Meghna River. At the bankfull stage the depth of the rivers were collected using the principle of resonance of sound. A depth reader is dropped from the water surface from the survey vessel and the time required hearing the resonance is recorded. From a known bench mark corresponding depth and distance are measured. The water level was measured by using the auto gauge meter. In every station there is an imaginary reference point called chart datum (CD), the reduced level (RL) of which is known from the nearby PWD bench marks (if available). Then all the depth and water level data were reduced to the chart datum. Where there is no permanent bench mark, the chart datum is taken as the reference level directly from the past history of water level.

3.3 Data Collection

In this study, the hydraulic geometry of the lower Meghna River will be investigated. To study the hydro-geometrical properties of the above river, the water level data measured by BIWTA at different station (Chandpur, Ramdaspur, Chitalkhali, Chowkighata and Sandwip) for different year will be collected for 30 years starting from 1977 to 2007. Cross sectional data at those stations will also be

collected for selected 5 different years (1985, 1992, 1997, 2002 and 2008) from the hydrograpy department of BIWTA.

For the analysis of the cross sectional data and to determine the various hydro-geometrical parameters (cross-sectional area, perimeter, top width, effective width etc.), a computational module has been developed in Microsoft Excel Package. The same calculation procedure will be carried out for each cross section over the selected years. The quantitative change in cross-sectional area at a particular station for different years will be determined. The change in cross sectional shape and size will also be done graphically by superimposing the cross sections at a station for different years using the graphical tool of Microsoft Excel software. Comparing the calculated depth at these cross sections taken from the hydrographic map for different years will produce erosion or accretion of the channel bed for the common section and doing so bed level changes at the certain river reach can be observed.

Combining the bed level and water level data, an analysis will be carried out to identify the impact of bed level change in water level rise or fall. In this study efforts have been made for the assessment of hydraulic geometry of the rivers by several methods. These includes variation of cross-sectional area, area-elevation analysis of cross-sections, analysis and comparison of mean bed level rise or fall and analysis of thalweg profile shifting in horizontal direction along the channel and comparison of mean bed level.

3.4 Methodology

3.4.1 Computational domain of a river cross-section

The raw data comprises the co-ordinates (x_j,y_j) of the river bed levels across the river cross-sections for each station. The total number of x-y co-ordinates to describe one cross-section varies from 25 to 35. The computational domain for a particular station is fixed by the three parameters left water edge (LWD), the right water edge (RWE) and the top water level (TWL) as shown in Fig 3.4.1

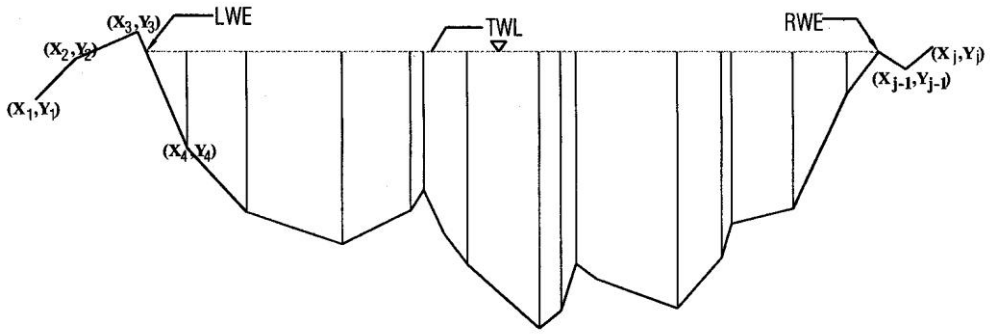

Figure 3.4.1: Definition sketches of x-y co-ordinates of a cross section and computational domain.

For the analysis of raw data of a section, a maximum of 6 water levels with 1 meter interval has been considered. For each of these levels, there are 5 different LWE and RWE which determine the different computational domain at which the different hydro-geometrical parameters have to be computed. The total width will be calculated using the following equation

W= RWE - LWE

The irregular sections will be approximated by equivalent rectangular section to calculate bed level rise and fall. Mean depth of flow will be calculated by averaging the depth measured from the chart datum along the cross section.

3.4.2 Variation of cross-sectional area

The cross-sectional area of a particular section over the years is analyzed both graphically and numerically. In the graphical approach, analysis is done by superimposing the cross-sections at a particular station for different years. At each section, the numerical values of cross-sectional area for different years have been calculated from a fixed datum (bank full stage).

3.4.3 Analysis of mean bed level variation

Analysis of mean bed level variation will be carried out graphically by superimposition of the bed profile for different years at different station. For a particular river it is a very convenient way of assessing the trend in bed topography including erosion and deposition along the course. At the same time it is very useful for checking the consistency of the data of a set of cross-section for the whole river in a particular year as well as from year to year. Moreover, a combination of both superimposition of cross-sections and long bed profiles provide a useful insight into the morphological behaviour of the concerned river. To determine the mean bed level, the irregular cross-sections will be approximated by equivalent rectangular section. The mean bed level may be calculated by the following equation:

MBL= $\frac{1}{n}\sum_{i=1}^{n} y_i$; where n is the number of ordinates and y is the depth of water in meter.

3.4.4 Variation of thalweg Profile

The line joining the deepest points of the cross-sections along the channel is known as thalweg. Slowing the stream bed erosion by taking advantage of a thalweg helps to stabilize running water sources. Placing boulders along the thalweg in a running water source helps to protect the channels sedimentary erosion and deposit balance. Efforts will be made to assess the vertical as well as the horizontal changes by comparing the longitudinal thalweg profile of the different years and by comparing the horizontal shifting of the thalweg line from a reference bank line. During preparation of the thalweg profiles the minimum elevations of across-section with respective chainage will be sorted out and will be plotted as elevations versus chainage. In fact thalweg profile does not give a clear idea about the average bed level positions, but it definitely has impacts on the average bed level. The average variations of the bed levels can be best understood from the comparison of mean bed level profiles for different years.

3.5 Summary

In this chapter the procedure to determine the cross-sectional and cross-sectional area, mean bed level and shifting of thalweg line were discussed. The data collection procedures were also mentioned in this chapter. Standard procedures as described were followed to determine these parameters. The hydro geometric analysis will be done in the following chapter using the procedures mentioned in this chapter.

CHAPATER 4
Results and Discussions

4.1 General

Rivers differ from one another in their characteristics and general behaviour; hardly two can be found alike in nature. The characterizing elements are so unique that it is extremely difficult to describe them independently. Each river is different and each reach of one river is different from all most all other reaches of the same river. The variation in mobility of the river bed together with variation in discharge, results in exceedingly complex phenomena of a progressively changing nature. The different characteristics of the Lower Meghna River like cross-sections, variation of mean bed level, variation of water level with bed level and variation of thalweg profile will be analyzed in this chapter.

4.2 Analysis of variation of cross-sections of the Lower Meghna River

Efforts are made to investigate the changes in river cross-sections due to bank erosion and erosion/deposition of river bed. The analysis is carried out by both graphical and tabular description. Graphical representation is done by plotting a graph with the cross sectional data at each station which is followed by a tabular representation.

4.2.1 Graphical analysis by superimposition of cross-sections

Superimposition of cross-sections at a particular BIWTA station for 5 different selected years (1985, 1992, 1997, 2002 and 2008) reveal the change in geometry of a river along the transverse direction from year to year as a result of erosion and deposition of river bed and shifting in bank line etc. In figure 4.2.2- 4.2.6, the available cross-sectional data (measured from the chart datum) of the Lower Meghna River over the years have been plotted. The various observations that have been conceived from these plotting are discussed below:

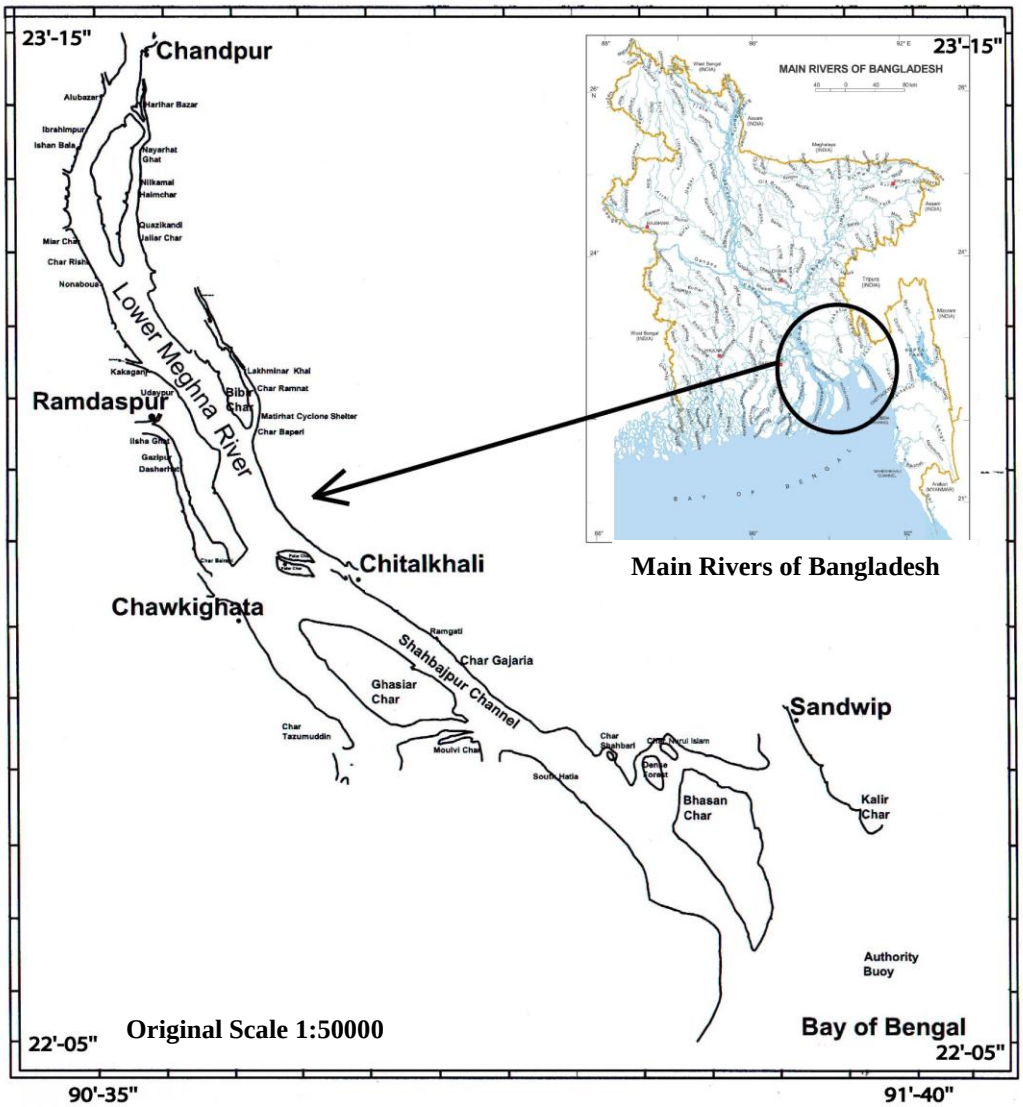

Figure 4.2.1: Location map of different station in Lower Meghna River (Source: BIWTA, 2002)

Cross-section at Chandpur: The variation of cross-sections over the different selected years varies steadily in the vertical direction. There is noticeable erosion towards the left bank in the lateral direction. As a result, the total cross-sectional area at bank full stage over the years is gradually increased at this location (Fig 4.2.2). The variations of cross-section from the year 1985 to 2008 and in the selected intermittent years have been discussed below:

Year 1985 to 1992: There is no significant channel shifting towards the left bank. The right bank has shifted further right to a certain amount. Even though the course of the river is not the same but the cross-sectional area seems to be same. An abrupt change in the depth close to the right bank has been noticed.

Year 1992 to 1997: There is erosion in the left bank and deposition in the right bank. The river bed seems to be eroded at the center of the cross section of the river. The depth has increased to an amount of 20 meters.

Year 1997 to 2002: The right bank seems to be stable during this period but there is considerable erosion at the river bed close to the right bank. An abnormal depth of 50m found at a location near the right bank. Therefore, the cross sectional area seems to have increased during this period of time.

Year 2002 to 2008: There is a noticeable variation in the vertical direction at the left bank. Erosion occurred close to the right bank. The river bed is raised due to the deposition of sediment. Therefore, the cross-sectional area decreased in this six years of time.

Cross-section at Chowkighata: The superimposed cross-section over the years is shown in figure 4.2.3. It was found from the figure that the left bank of the channel at Chowkighata seems to be very stable which indicates that the river system attains its regime condition at this location.

Year 1985 to 1992: The left bank seems to be stable in this station during the period of time but the right bank has a huge shifting. The shifting is almost 4 km. A new channel has been developed during these seven years. Therefore, there is significant change in the channel cross-sectional area. There is no significant variation in the vertical direction of the channel.

Year 1992 to 1997: The right bank shifted further right. The left bank appears stable. There is considerable erosion close to the right bank. The cross-sectional

area increased to a nominal amount. From the figure 4.2.3 it can be seen that there is a noticeable sediment deposition in the river bed in this period of time.

Year 1997 to 1992: During this period of time, it was found that a good amount of sediment is deposited in the right bank. Left bank is almost stable. There is minimum sign of vertical or lateral shifting of the river banks but the cross-sectional area has decreased.

Year 2002 to 2008: An abrupt change in depth near the right bank was found. The difference of depth of that location is almost 8 m. There is no considerable shifting of both the banks. The cross sectional area remains almost same.

Cross-section at Chitolkhali: The cross-section over the years have been plotted and superimposed to determine the variation. It was found that there is a noticeable shifting of the channel towards the left bank. The graphical representation is presented in Figure 4.2.4

Year 1985 to 1992: There is a noticeable change in the lateral direction on the river bank. The left bank has been eroded and there is deposition of sediment in the right bank. There is no significant change in the vertical direction.

Year 1992 to 1997: There is an abrupt shifting of channel towards left bank. The depth seems to be the same. A new channel developed in the year 1992 has disappeared completely.

Year 1997 to 2002: Again the channel shifts towards the left bank significantly and the cross-sectional area of the channel has increase. There is not much variation in vertical direction on an average but abrupt change in depth from 2m to 17m were noticed close to the right bank.

Year 2002 to 2008: There is a change in the vertical direction; the depth of the main channel has increased considerably. Deposition of sediment is noticed near

the right bank. There is no apparent shifting of the channel in the lateral direction. The cross-sectional area remains almost same.

From the year 1985 to 2008 the left bank of the channel at Chitolkhali has a significant shifting to about 4000m towards the left bank.

Cross-section at Ramdaspur: This is the most stable cross section among the other stations which is shown in figure: 4.2.5.

Year 1985 to 1992: The figure 4.4 reveals that there is considerable sediment deposition at the right bank and erosion in the left bank. The right bank of the channel shifted towards the left bank significantly. The cross sectional area decreased in this period. A portion of the channel cross-section close to the right bank has completely disappeared.

Year 1992 to 1997: The variation of cross-sectional area over the years is very much significant in the lateral and vertical direction as well. The cross sectional area decreased in 1997. There is significant shifting of left bank towards the right bank. (i.e. deposition of sediment in right bank).

Year 1997 to 2002: Both the banks have not shifted at all but there is a trace of deposition in the left bank. The depth increased near the right bank. Cross-sectional area seems to be same from the figure 4.2.5.

Year 2002 to 2008: The left bank shifted almost 2000m, which is a significant change. Right bank also shifted to a considerable amount. A new channel developed close to the right bank. Deepest point of this channel is 7 meter.

Cross-section at Sandwip: Sandwip is an Island which lies in the Meghna estuary where a dynamic condition prevails at this location. The average width of the Lower Meghna River at Swandip channel is almost 8 km. Figure 4.2.6 shows the detail of it.

Year 1985 to 1992: Over the seven years, sediment deposited in the left bank. The right bank shifted towards further right. There is significant erosion in the right bank. A sudden change in depth is measured close to the right bank where the depth changes from 5.75m to 9m. The average cross-sectional area is increased in 1992.

Year 1992 to 1997: A peculiar channel pattern in 1997 reveals that during this period there was a large amount of sediment that has been deposited and eroded in different places of the channel bed. There is significant deposition of sediment in the left bank. A new channel has been developed close to the left bank of the channel. However, the cross-sectional area did not vary too much.

Year 1997 to 2002: The new channel that has been developed in 1997 has completely disappeared. A large volume of sediment reduces the cross-sectional area of the channel. The right bank of the channel shifted almost 800m towards further right. A sharp change in depth is observed close to the right bank.

Year 2002 to 2008: Again there is a large sediment deposition in the right bank. From figure 4.2.6 it is also seen that there is deposition in the right bank too. The cross-sectional area decreased to a certain amount. The variation of cross-section in the lateral direction is less than the vertical direction.

As sandwip lies in the center of the estuary, several factors like wind speed; wind direction; salinity intrusion and geographic formation greatly influence the hydro-geometric pattern of the river in this station. Instability in this station is random compared to the other selected station of the Lower Meghna River.

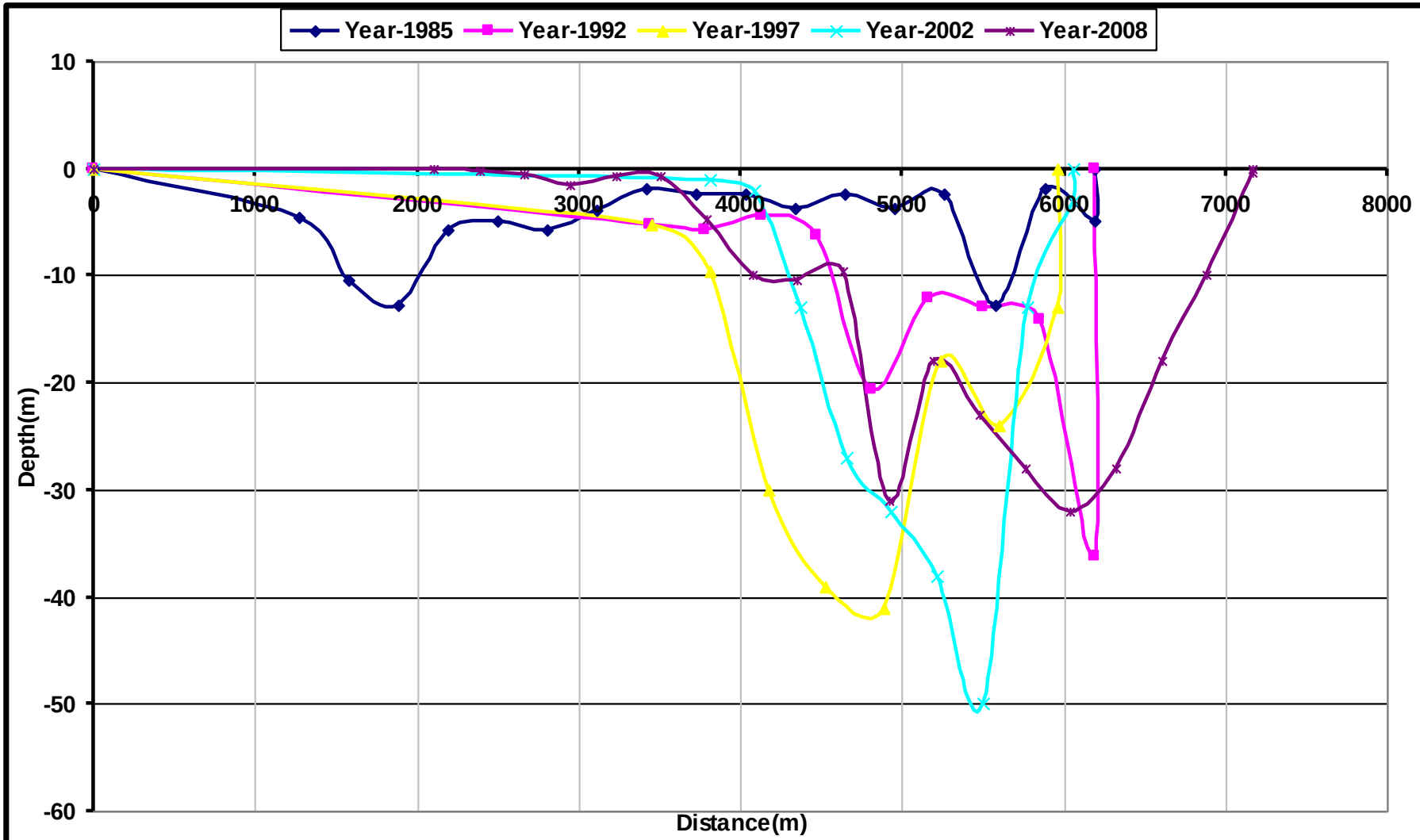

Figure 4.2.2 Cross section of the Lower Meghna River in different years at Chandpur

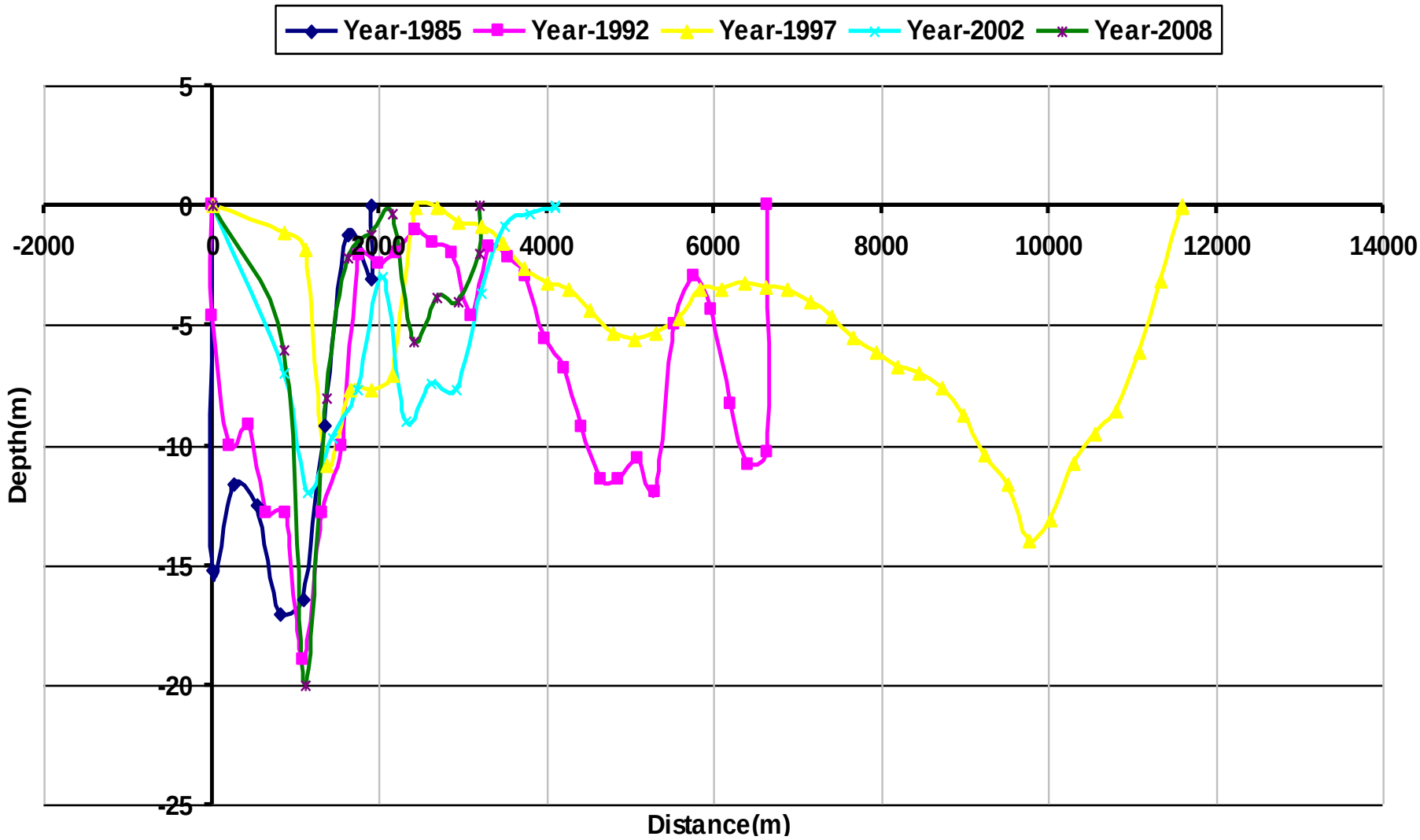

Figure 4.2.3: Cross section of the Lower Meghna River in different years at Chowkighata

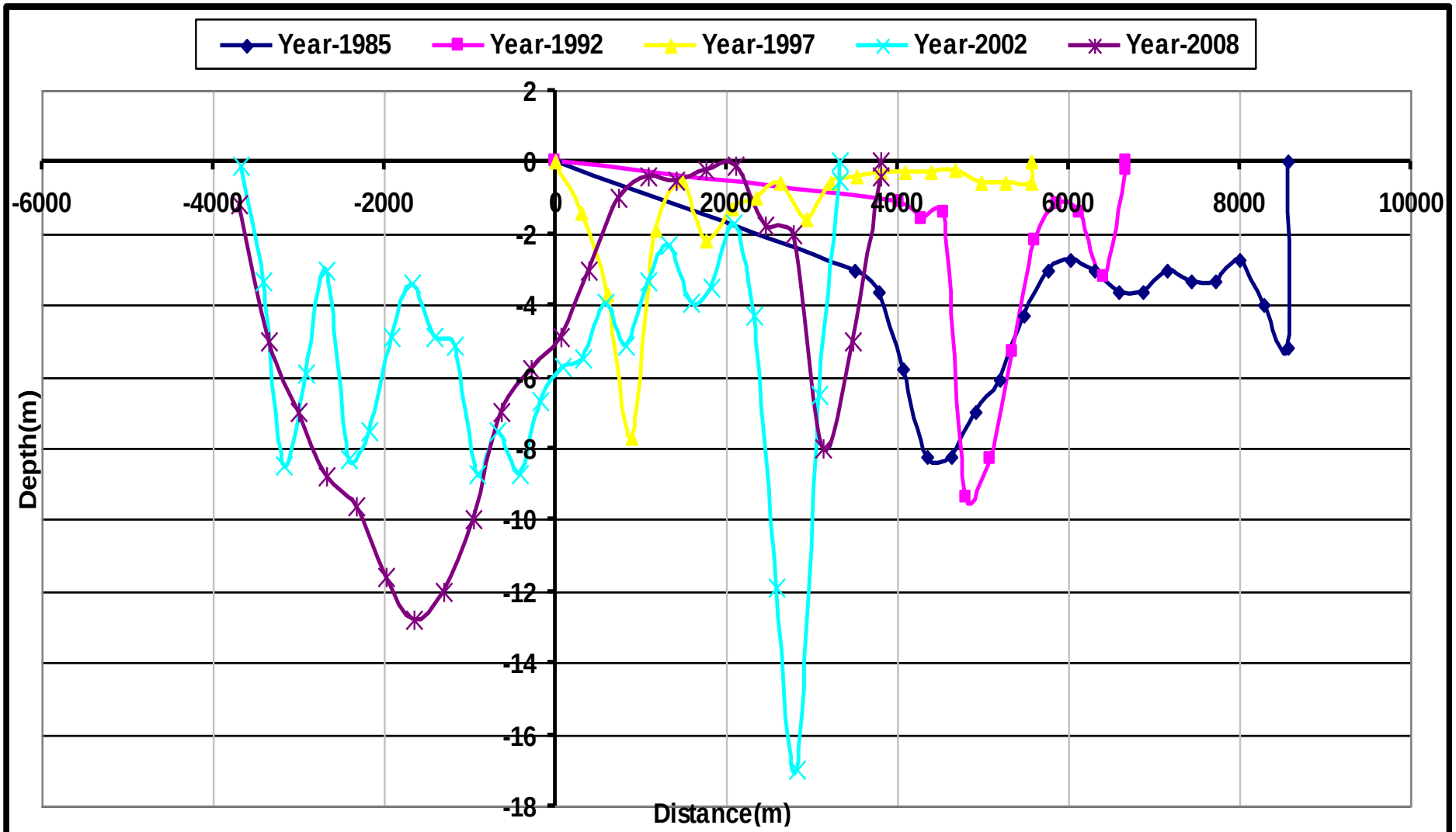

Figure 4.2.4 Cross section of the Lower Meghna River in different years at Chitolkhali

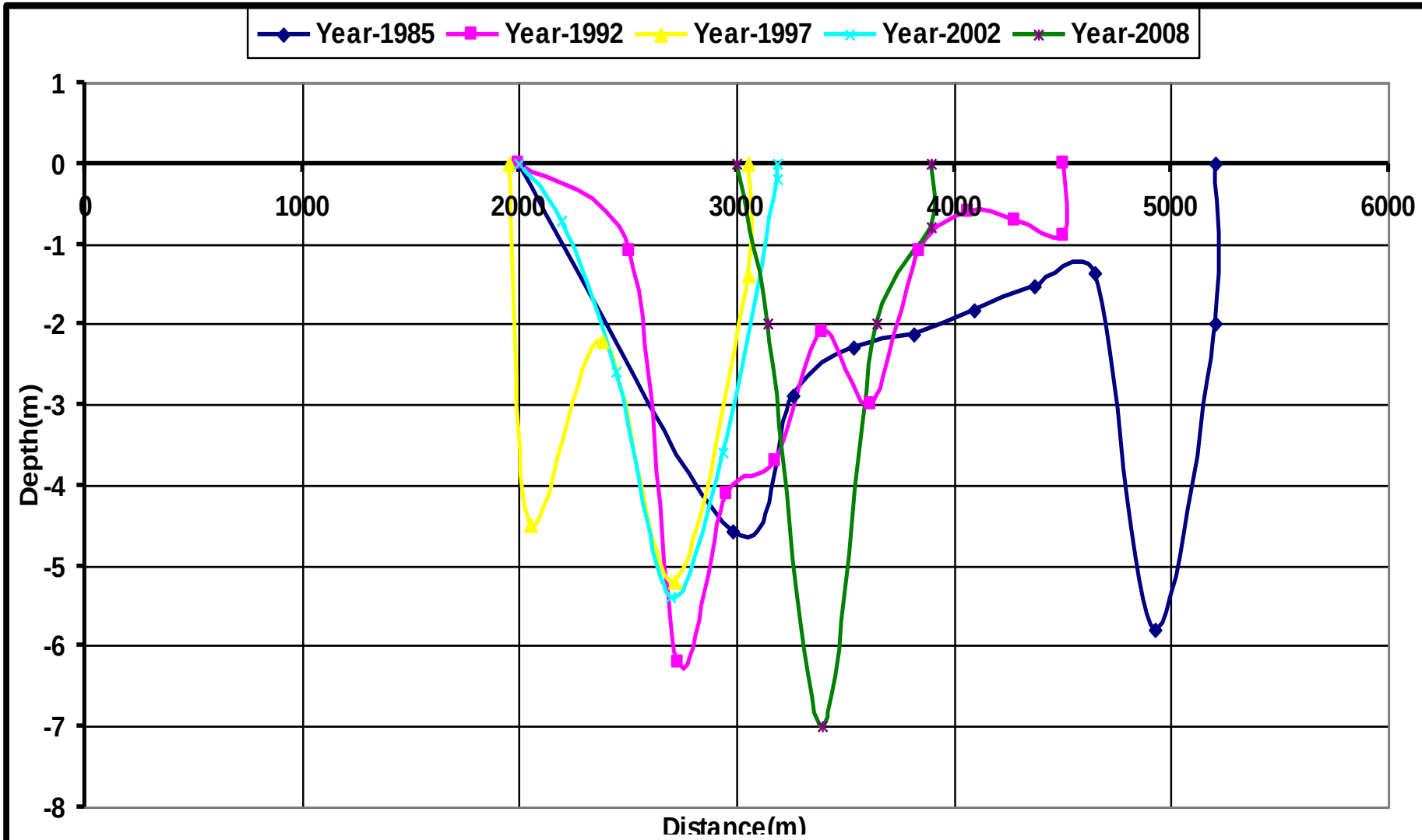

Figure 4.2.5 Cross section of the Lower Meghna River in different years at Ramdaspur

Figure 4.2.6 Cross section of the Lower Meghna River in different years at Sandwip

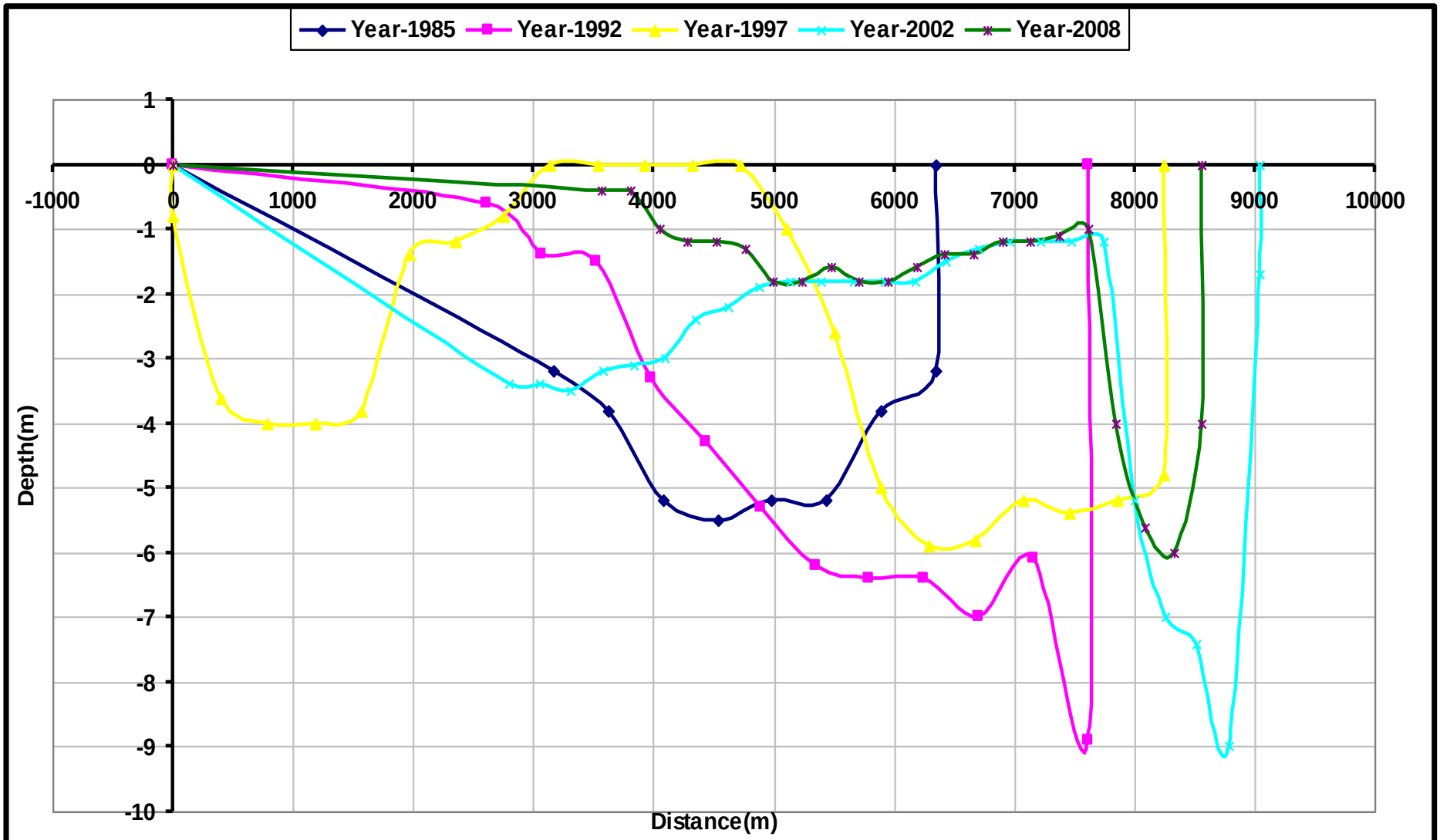

Figure 4.2.6: Cross section of the Lower Meghna River at Sandwip Station

4.2.2 Cross-Sectional Area Calculation

The numerical values of the cross-sectional area are calculated (shown in Table 4.2.1) using the depth data calculated from the chart datum. The areas shown in the table indicates a number of distinct periods of morphological activities. No river section seems to be very stable as there is a significant change in the cross sectional area. The cross-section at the first station Chandpur is gradually eroded

Table 4.2.1 Cross-sectional area of Lower Meghna River in bankfull condition (m^2)

Station	1985	1992	1997	2002	2008
Chandpur	28,727	45,191	66,668	52,125	64,218
Chowkighata	23,858	48,597	59,840	19,588	13,589
Chitolkhali	24,140	8,816	7,719	40,267	40,522
Ramdaspur	6,741	4,824	5,114	3,133	2,633
Sandwip	15,849	24,997	23,361	18,940	10,202

over the years. While the cross section at Ramdaspur slowly aggraded over the years. The cross-section at Chitolkhali is very dynamic i.e. large amount of erosion/deposition occurred most frequently over the years. The period from 1985 to 1997 the section at Chitolkhali is characterized by a noticeable amount of deposition followed by a large amount of erosion during the period 2002 to 2008. There is a certain amount of erosion at Chowkighata station form the year 1985 to 1997 and a huge amount of deposition in the year 2002. The river follows this trend up to 2008. The cross section at Sandwip is characterized by erosion from 1985 to 1997 followed by deposition in the year 2002. A noticeable volume of deposition of sediment occurred from the year 2002 to 2008 at Sandwip. So there were erosion in the only year in 1992, then the river bed experienced deposition in the following selected years. The highest change in the cross sectional area was 13093 m^2 at Chandpur from 2002 to 2008 and the lowest change in cross sectional area was 255 m^2 at Chowkighata form 2002 to 2008.

4.3 Analysis of variation of water level and bed level in the Lower Meghna River at different stations

Attempts were made to find the water level and bed level variation of Lower Meghna River. Analysis was done with the cross-sectional and water level data at five different stations in five selected years (1985, 1992, 1997, 2002 and 2008) based on data availability. As the Meghna River system follows the semi diurnal pattern (Singh et al., 2000) highest and lowest water level data were collected for every month of a year. Based on the rainfall and climate pattern 12 month of a year was divided into following 4 distinct groups:

1. December, January, February (DJF)
2. March, April, May (MAM)
3. June, July, August (JJA)
4. September, October, November (SON)

Then water level data for successive 3 months were averaged for the analysis. Comparison was only made between highest water level to highest water level and with lowest water level to lowest water level data for two different years. Initially the selected years were arranged chronologically starting from the oldest to the most recent years. To make the analysis easier the cross sectional and water level data were reduced to the chart datum (the reference level) of BIWTA for the comparison.

4.3.1 Water level and bed level variation at Chandpur

Analysis was made to find out the water level and bed level variation at Chandpur station for different cross sections in different years. The results are shown graphically in figure 4.3.1 to figure 4.3.8.

From the comparison of water level and bed level between 1985 and 1992, it may be seen that the cross section of the river at Chandpur changed significantly in 1992. The main channel shifted towards the right bank but there were no significant change in lowest water level as it appears from the figure 4.3.1. The

highest water level raised by 0.70 m in DJF where as the mean bed level change was 6.58 m. The change of percentage of lowest water level was 20% in the year 1992 which is very low if it is compared with the 160% change of bed level. The difference of changes reflects that there were degradation in the river bed but as the water level remained close, the volume of water increased in the same period of time. The same trend was continued in the month of MAM. In JJA as the monsoon set in water level rose. The difference of water level from the year 1985 to 1992 was least with respect to the significant change in mean bed level. So it was clear from the study that there was water from other sources. The variation of highest water level with the bed level was the same as it was for the lowest water level. The same trend of water level change with respect to a high bed level change was followed by the comparison in year 1992 to 1997 and from 2002 to 2008. But from the year 1997 to 2002, there was no significant bed level change with a low water level variation.

4.3.2 Water level and bed level variation at Chowkighata

From the analysis of water level and bed level variation at Chowkighata station for different cross sections in different years, it was found that the river showed significant changes in the bed level and water level as well. A large aggradation in that cross section from 1985 to 1992 is followed by successive aggradation in 1997, 2002 and 2008. The results are shown graphically in figure 4.3.9 to figure 4.3.16.

From the comparison of water level and bed level variation between 1985 and 1992, it may be seen that the cross section of the river at Chowkighata increased significantly in 1992. The right bank of the main channel shifted towards further right and a new channel was developed during these years. As it appears from the figure 4.3.9 due to the decrease in cross section, there was no noticeable variation in highest water level in DJF from 1997 to 2002. The water level remained close in all the other months of 1997. The mean bed level in 1992 was 6.75 m (with respect to CD) where as the mean bed level in 1997 was 5.20m. The water level

It is found form the figure that during the month of MAM in 2002 the water level dropped even though the mean bed level is raised. From the analysis of year 1997 to 2002, it was found that there was a significant decrease in cross sectional area but the water level change was very close. A decrease in the cross sectional area from 2002 to 2008 results an increase in highest water level in the month of September, October and November (SON). Comparing the highest water level and bed level variation, a trend of increased water level in SON was observed from the year 2002 to 2008.

4.3.3 Water level and bed level variation at Chitolkhali

From the analysis of water level and bed level variation at Chitolkhali station for different cross sections in different years, it was found that the river showed very dynamic behaviour at Chitolkhali. A decrease in the cross section in the initial year was followed by rapid increase in the recent most years. The results are shown graphically in figure 4.3.17 to figure 4.3.24.

From the comparison of water level and bed level variation between 1985 and 1992, it may be seen that the cross section of the river at Chitolkhali decrease significantly in 1992. The left bank of the main channel shifted towards further left. As it appears from the figure 4.3.17 due to the decrease in cross section the lowest water level in MAM and SON raised from the year 1985 to 1992. The water level raised by 0.65 m in SON where as the mean bed level change was 1.42 m. The change of percentage of lowest water level was 12% in the year 1992 which is close to the 15% decrease in bed level. The difference of changes reflects that there was aggradation in the river bed and the water level was raised consequently, which is very normal condition. The same trend was continued in the month of MAM. A reverse condition was found when comparison was made with the highest water level and bed level, as the water level dropped with a decrease in the bed level from 1985 to 1992. From the analysis of year 1992 to 1997, it was found that there was no significant change in the cross sectional area or in the water level. An increase in the cross sectional area from 1997 to 2002

resulted a decrease in water level in the month of March, April, May (MAM). But in SON the water level is raised again. Comparing the highest water level and bed level variation, a trend of increased water level was observed in MAM and JJA was followed by decrease in water level in SON and DJF. From the year 2002 to 2008, a slight decrease in the cross sectional area made a reverse change in the water level. The water level in 2008 showed a decreasing trend round the year. That occurrence indicates that the flow of water was very low in 2008 in comparison to the earlier years at Chitolkhali.

4.3.4 Water level and bed level variation at Ramdaspur

The Ramdaspur station did not fall in the braided main channel of Lower Meghna River. However, there are some significant variations in water level and bed level in different years. The results are presented graphically in figure 4.3.25 to figure 4.3.32.

From the figure 4.3.25 it may be seen that the cross sectional area decreased in 1992 from what was in 1985. Subsequently the bed level rose by a significant height. The bed level decreased 0.62 m comparing to the initial bed level of 3.03m from the chart datum. That occurrence of bed level rise was accompanied by an increase in water level in the month of JJA and SON in 1992. But when the highest water level was considered the water level raised significantly by 1.07m in 1992 in DJF. So an interesting condition prevailed at Ramdaspur in 1992 where the water level change was higher than the bed level change. Rather dramatically the cross section decreased in 1997 from 1992 but the water level was raised in 1997 in the month of SON. So it may be assumed that additional water from other outside sources took place. From the figure 4.3.30 it can be seen that the highest water level in DJF, 2002 dropped significantly with a decrease in mean bed level. The change of water level was 1.23m where the mean bed level change was 1.98m. From figure 4.2.5 it can be seen that within 5 years of time the old channel in 1997 is completely disappeared and a new channel was

developed just right to it with a higher thalweg value. This act could have brought a significant change in channel behaviour.

4.3.5 Water level and bed level variation at Sandwip

As stated earlier the tidal influence comes into account at the Sandwip station. The water level and bed level is prone to the effects of sea tidal action rather than the river tides. The analysis is presented in Figure 4.3.33 to 4.3.40. From the figure 4.3.33 it is observed that lowest water level in 1992 is raised with an increased cross section. This unusual condition is a clear indication of water coming from an external source. As we did not consider all the other effects (i.e influence of wind, tide, rainfall) we can not conclude that the unusual water level rise is due to the global sea level rise.

From the figure 4.3.34 it may be seen that the cross sectional area decreased slightly in 1997 from what was in 1992. Subsequently the bed level was raised by an insignificant height. That occurrence of bed level rise was accompanied by a decrease in water level in the month of DJF in 1997. The water level remained close in all other months in 1997. From the figure 4.3.37 it is seen that the cross sectional area in 2002 is decreased by almost 25% but the mean bed level is raised by 0.2m. The unusual condition could have happened due to the fact that the water level data and the depth were not measured in the same month of 2002. However, the water level dropped in DJF and MAM in 2002 even after the bed level rise. The trend of decreased cross section is also followed in the year 2008 as it can be seen from the figure 4.3.39 and 4.3.40. The cross sectional area reduced to 10,202 m^2 from 18,940 m^2.. Consequently the water level is raised in MAM, but remained close in all the other month in 2008. When the highest water level in the month of SON of 2002 was plotted against the highest water level in 2008 with corresponding cross sections in the figure 4.3.40 it was observed that the level of water dropped in 2008 even after the decrease in the cross sectional area. The deposition of mean bed level was 0.99 m where as the water level change was only 0.54 m in 2008.

4.4 Analysis of mean bed level variation

A study of erosion/deposition has been carried out for the Lower Meghna River by comparing the mean bed level profiles over the selected years at different cross-sections. The computation of the mean bed level has been carried out from the chart datum level. The results of mean bed level variation at different cross-sections of the river is shown in table 4.4.1 and followed by another table 4.4.2 that includes the erosion/deposition of the mean bed level where the initial year 1985 was taken as base year. From the tables it is seen that the mean bed

Table 4.4.1 Variation of Mean bed level in the Lower Meghna River at different stations (m, CD)

Stations	1985	1992	1997	2002	2008
Chandpur	4.12	10.7	17.98	16.27	10.81
Chowkighata	8.63	6.75	5.20	4.89	4.43
Chitolkhali	4.01	2.72	1.23	5.21	4.72
Ramdaspur	2.21	1.96	2.22	1.79	1.97
Sandwip	3.51	4.10	2.52	2.70	1.78

level of the Lower Meghna River is very dynamic. i.e it varies significantly over the years. The amount of erosion and/or deposition is significant at Chandpur.

Table 4.4.2 Erosion/Deposition of mean bed level of Lower Meghna River (m)

Stations	Year 1985-92	Year 1992-97	Year 1997-02	Year 2002-08
Chandpur	-6.58	-7.1	1.53	5.46
Chowkighata	1.88	1.55	0.31	0.46
Chitolkhali	1.29	1.49	-3.98	0.49
Ramdaspur	0.25	-0.26	0.43	-0.18
Sandwip	-0.6	1.59	-0.19	0.93

negative sign indicates erosion, positive sign indicates deposition.

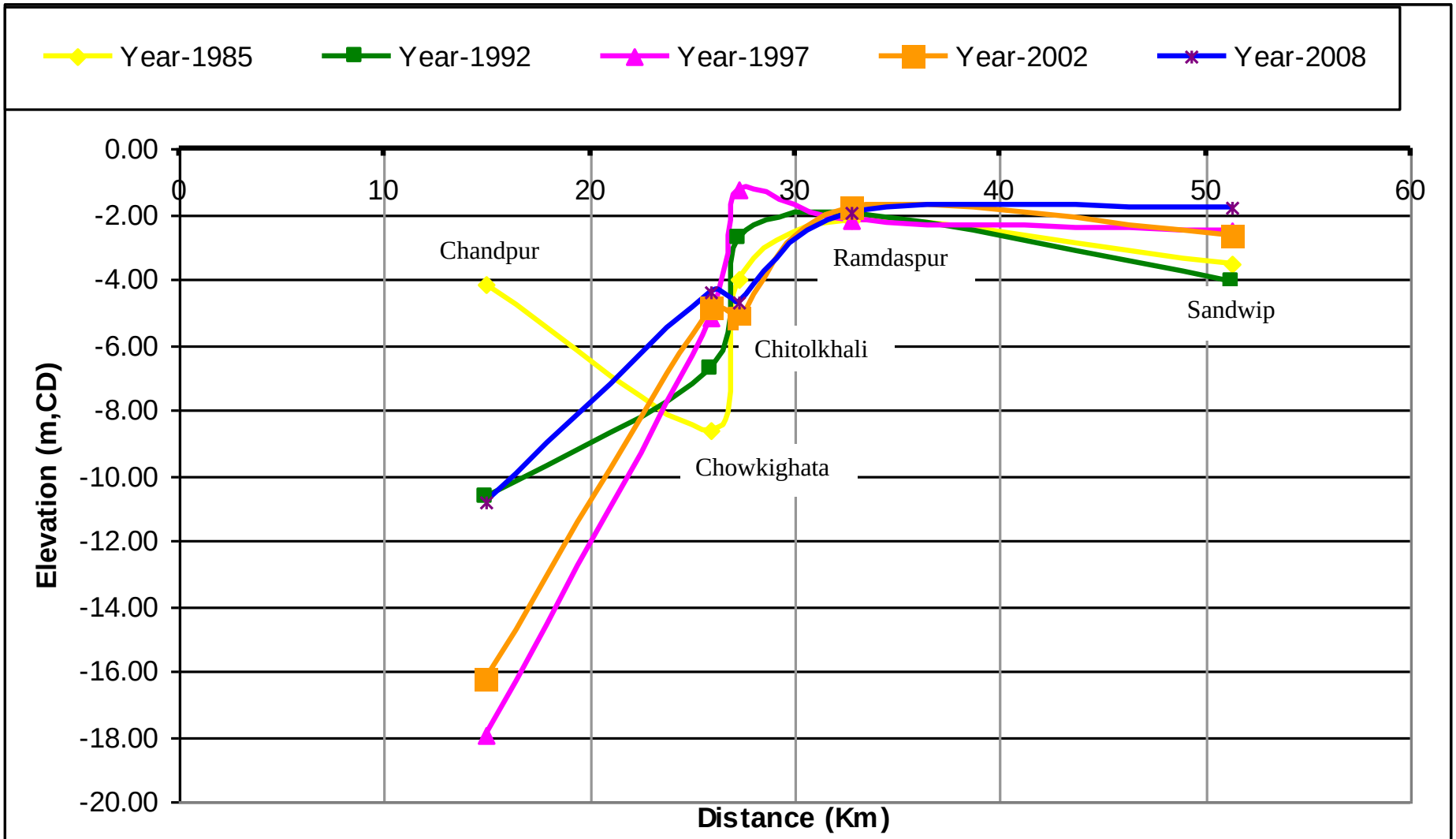

Figure 4.4.1: Variation of Mean Bed Level along the river

From the Figure 4.4.1 this is apparent that all the mean bed level raised sharply from the first station (i.e. Chandpur) to the second station at Chowkighata which is downstream of the river . The erosion/deposition at different is shown in the following figures from figure no 4.4.2 to figure no 4.4.6

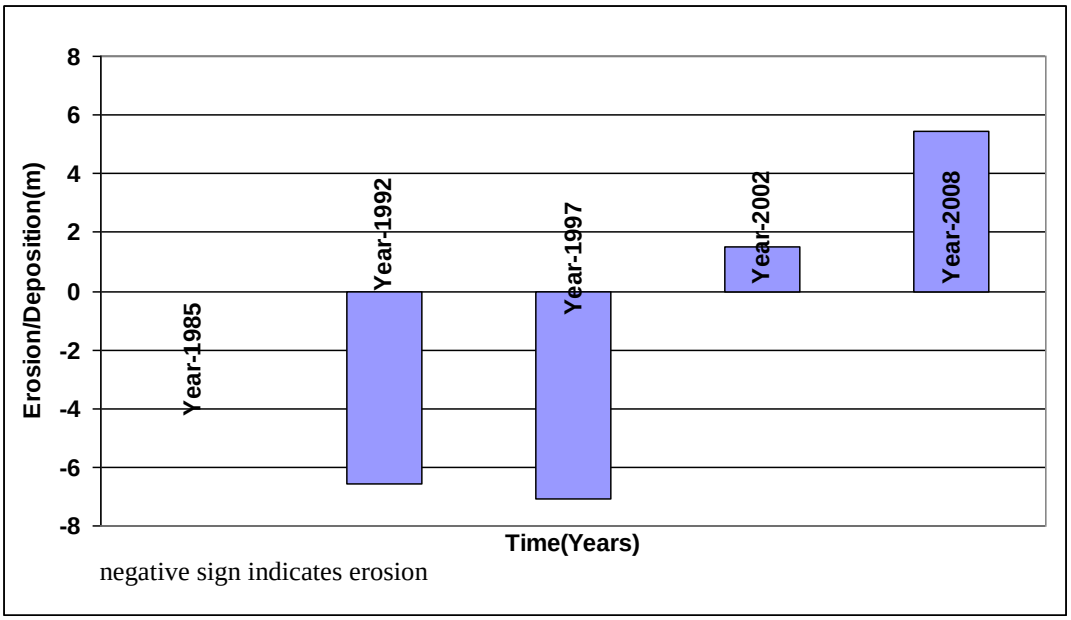

Figure 4.4.2: Study of erosion/deposition of the Lower Meghna River at Chandpur

The change of bed level form Chowkighata to Chitolkhali is not so significant except the year 2002 where there was a significant erosion in the river bed.

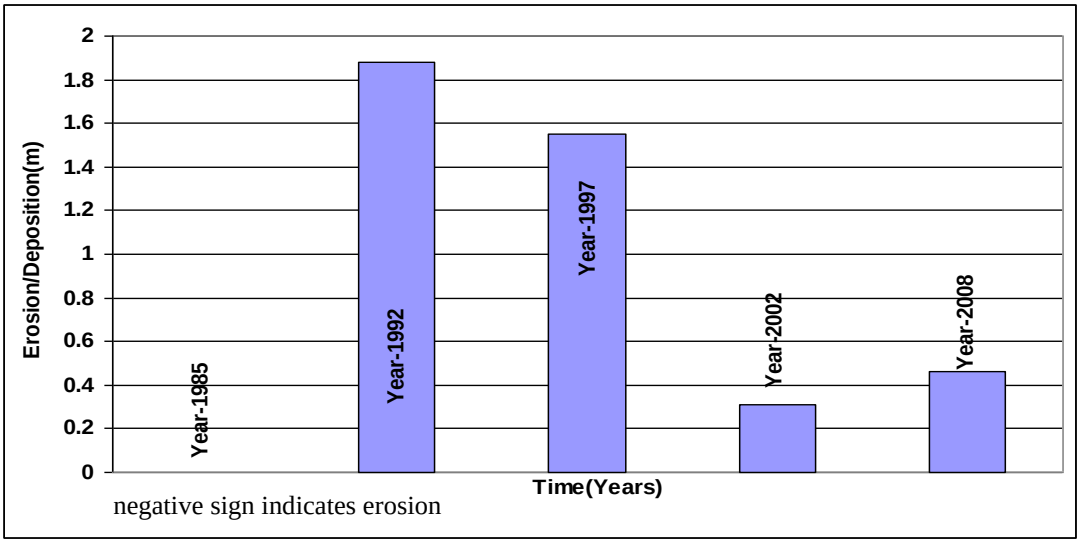

Figure4.4.3: Study of erosion/deposition of the Lower Meghna River at Chowkighata

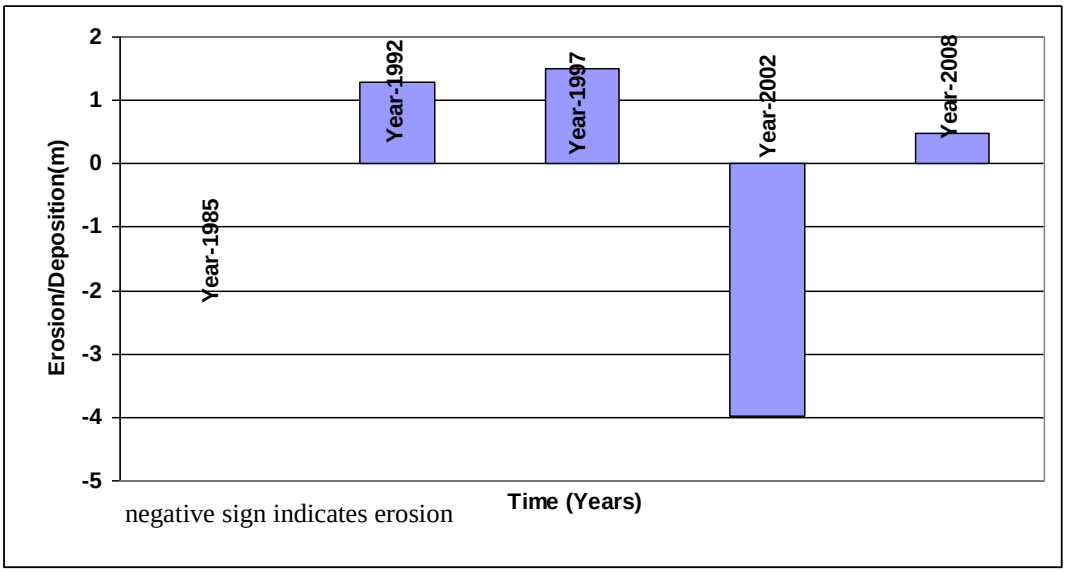

Figure 4.4.4: Study of erosion/deposition of the Lower Meghna River at Chitolkhali

From the cross section 4.2.5 at Ramdaspur it is seen that the top width of the cross-section is relatively small than the other cross-sections and it remained almost same over the years which reflects that there were limited bank erosion. However cross section in this station experiences successive deposition and erosion in alternative selected years. The deposition in the year 2002 was the most among the other years.

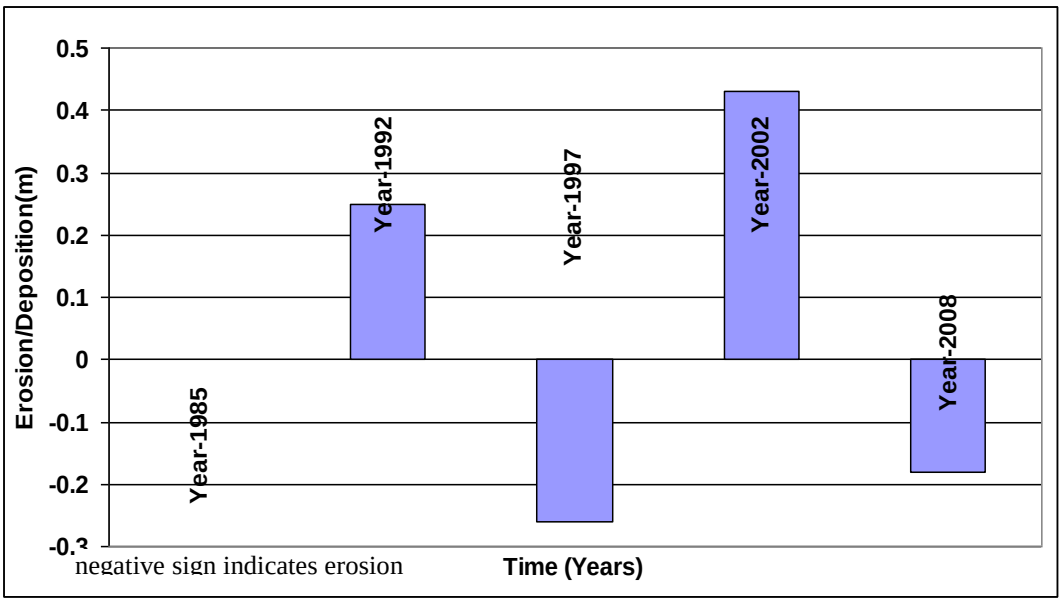

Figure 4.4.5: Study of erosion/deposition of the Lower Meghna River at Ramdaspur

From Ramdaspur to Sandwip the river enters to the estuary and all the tidal effects comes into action. The mean bed level has not change at all from the year 1985 to 1992. But deposition takes place from 1992 to 1997, which is followed by 0.18 m erosion from 1997 to 2002 and again the bed level is raised by 0.92 m from 2002 to 2008.

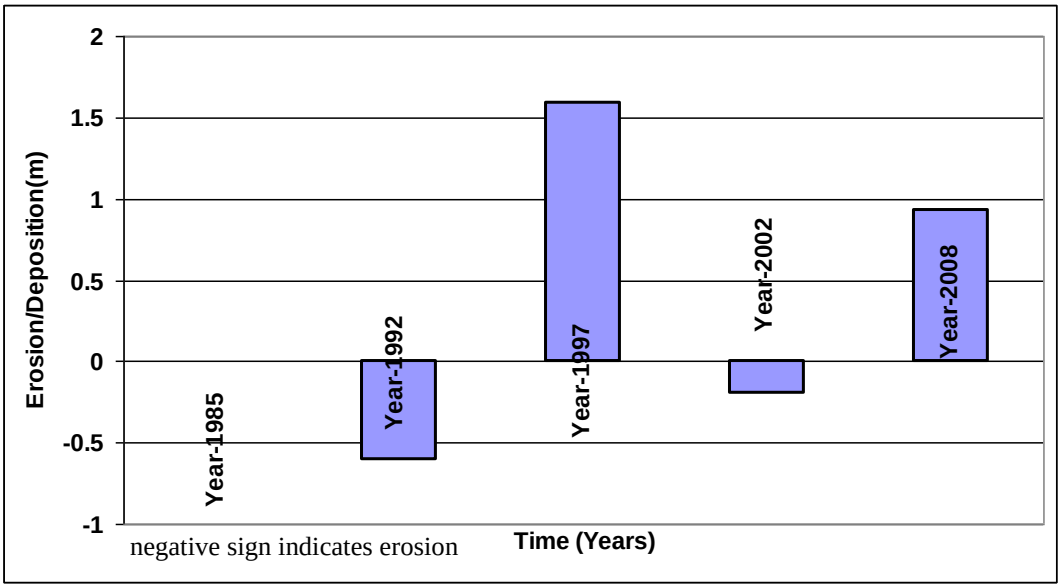

Figure 4.4.6: Study of erosion/deposition of the Lower Meghna River at Sandwip

From the figure 4.4.1 it is apparent that the bed slope is very steep at the upstream reach of the Lower Meghna River, the slope is moderately flat at the middle reach and the slope is relatively flat at the downstream reach of the river. From the analysis it is seen that the river at the extreme downstream reach seems to be more stable than the other section of the river.

4.5 Correlation between mean bed level and water level variations

The result from the analysis of the variation of water level and bed level (BL) may be presented in a tabular form. By a basic notion it may be assumed that when the bed level is dropped from the reference line (CD), consequently the water level would also drop and when the bed level is raised the water level would be raised when compared with two different years. But there were few

deviations from that assumption. The results are shown in the following table (table 4.5.1 to 4.5.4). The Chart Datum (CD) was taken as the reference for the analysis. Where a negative sign in change will indicate drop in bed level (i.e erosion) and positive sign indicates accretion. Subsequently negative sign indicates drop of lowest water level (LWL) and highest water level (HWL). Positive sign for both the water level stand for a rise.

From table 4.5.1 is seen when the water level raised as a result of bed level rise at Chowkighata and Ramdaspur station. But at Chandpur the water level is raised even though there was significant erosion in bed. This unusual phenomenon reflects that the flow has increased at Chandpur from 1985 to 1992.

Table 4.5.1: Water level and bed level variation for the year 1985 and 1992

Location	**1985**			**1992**			**BL Change (m)**	**LWL Change (m)**	**HWL Change (m)**
	LWL	**HWL**	**BL**	**LWL**	**HWL**	**BL**			
Chandpur	0.12	3.42	4.12	0.49	3.9	10.7	-6.58	0.37	0.48
Chowkighata	0.02	4.34	8.63	0.21	4.95	6.75	1.88	0.19	0.61
Chitolkhali	0.7	5.31	4	0.75	5.29	2.72	1.28	0.05	-0.02
Ramdaspur	0.46	4.3	2.21	0.65	4.37	1.96	0.25	0.19	0.07
Sandwip	0.19	6.77	3.5	0.49	3.9	4.1	-0.6	0.3	-2.87

From the table 4.5.2 it can be seen that there are differences in sign of Bed level and water level in each of the station. The difference in sign in bed level and water level for the Chandpur indicates that the increased trend of flow continues in 1997.

Table 4.5.2: Water level and bed level variation for the year 1992 and 1997

Location	**1992**			**1997**			**BL Change (m)**	**LWL Change (m)**	**HWL Change (m)**
	LWL	**HWL**	**BL**	**LWL**	**HWL**	**BL**			
Chandpur	0.49	3.9	10.7	0.53	4.07	17.98	-7.28	0.04	0.17
Chowkighata	0.21	4.95	2.72	0.23	4.67	1.23	1.49	0.02	-0.28
Chitolkhali	0.75	5.29	3.33	0.62	5.09	1.47	1.86	-0.13	-0.2
Ramdaspur	0.65	4.37	1.96	0.57	4.54	2.22	-0.26	-0.08	0.17
Sandwip	0.49	3.9	4.1	0.05	6.94	2.52	1.58	-0.44	3.04

From the analysis of table 4.5.3 it is seen that a consistent trend is followed by the cross section at Chowkighata, Chitolkhali and Sandwip station. But at the Ramdaspur station a rise in bed level is followed by a drop in the in the water level.

Table 4.5.3: Water level and bed level variation for the year 1997 and 2002

Location	1997			2002			BL Change (m)	LWL Change (m)	HWL Change (m)
	LWL	HWL	BL	LWL	HWL	BL			
Chandpur	0.53	4.07	17.98	0.46	4.42	16.27	1.71	-0.07	0.35
Chowkighata	0.23	4.67	1.23	0.32	4.88	4.89	-3.66	0.09	0.21
Chitolkhali	0.62	5.09	1.47	1.12	5.26	5.21	-3.74	0.5	0.17
Ramdaspur	0.57	4.54	2.22	0.42	4.48	1.79	0.43	-0.15	-0.06
Sandwip	0.05	6.94	2.52	0.43	7.02	2.7	-0.18	0.38	0.08

From the table 4.5.4 a contrasting behaviour may be seen at Chowkighata station. In this station the highest water level is dropped even though there was aggradation in the river bed. Chandpur station looks rather steady in 2008 then the previous years. However the cross section at Ramdaspur is eroded by 0.18 m and the lowest water level rise was 0.28 m (LWL) in the year 2008. The occurrence of bed level erosion or deposition is the minimum in 2008 among the other selected years.

Table 4.5.4: Water level and bed level variation for the year 2002 and 2008

Location	2002			2008			BL Change (m)	LWL Change (m)	HWL Change (m)
	LWL	HWL	BL	LWL	HWL	BL			
Chandpur	0.46	4.42	16.27	0.46	4.54	10.81	5.46	0	0.12
Chowkighata	0.32	4.88	4.89	0.77	4.76	4.43	0.46	0.45	-0.12
Chitolkhali	1.12	5.26	5.21	1.33	5.77	4.72	0.49	0.21	0.51
Ramdaspur	0.42	4.48	1.79	0.7	4.35	1.97	-0.18	0.28	-0.13
Sandwip	0.43	7.02	2.7	0.57	7.13	1.78	0.92	0.14	0.11

4.6 Analysis of variation of Thalweg Profile

The variation of the thalweg in the vertical direction over the years is significant. From the analysis it is found that at some cross-sections the elevation is rising and at some locations it is lowering over the years. The results are shown in Table 4.6.1 and figure 4.6.1. From the figure it is seen that elevation of thalweg point at Chandpur cross-section changes rapidly over the years. From the year 1985 to 2002 the deepest point of the cross-section at Chandpur increased successively. But from the year 2002 to 2008 the thalweg point decreased sharply form 50 to 10 m. So there is an indirect indication of sediment deposition from 2002 to 2008 at Chandpur cross-section which is related to the analysis of this study.

Table 4.6.1: Variation of thalweg elevation of the Lower Meghna River over the years (m, CD)

Location of the Station	Distance form Chandpur (Km)	Year-1985	Year-1992	Year-1997	Year-2002	Year-2008
Chandpur	0	12.80	36.30	41.00	50.00	10.50
Chowkighata	26	17.07	12.80	13.10	12.00	20.00
Chitolkhali	27	8.23	9.40	7.70	11.90	12.80
Ramdaspur	33	5.79	6.20	5.20	5.40	7.00
Sandwip	51	5.48	8.90	5.90	9.00	6.00

At Chitolkhali Station the range of thalweg point variation was 7.70 m to 12.80 m. The average change from the intermittent year was almost equal. The thalweg profile was also stable at the Chitolkhali station. There were no significant changes.

Taking the left bank at each station the variation of thalweg line over the years in the lateral direction is shown in Table 4.6.2 and Figure 4.6.2. Form the figure it is seen that the thalweg line is gradually shifting towards the right bank at Chandpur station then it suddenly came back to the initial position in the year 2008. The range of thalweg point at Chowkighata station was between 12 m to 20m. The change in the river width was significant over the change in thalweg

profile at Chowkighata. The deepest point at Ramdaspur in different years was not as deep as compared to the other stations. The thalweg point at Sandwip ranged as low as 5.48m to 9.0m. The thalweg point increased in 1992 followed by a decrease in 1997 and again increased in 2002. The deepest point had a sharp rise in 2008 at Ramdaspur Station.

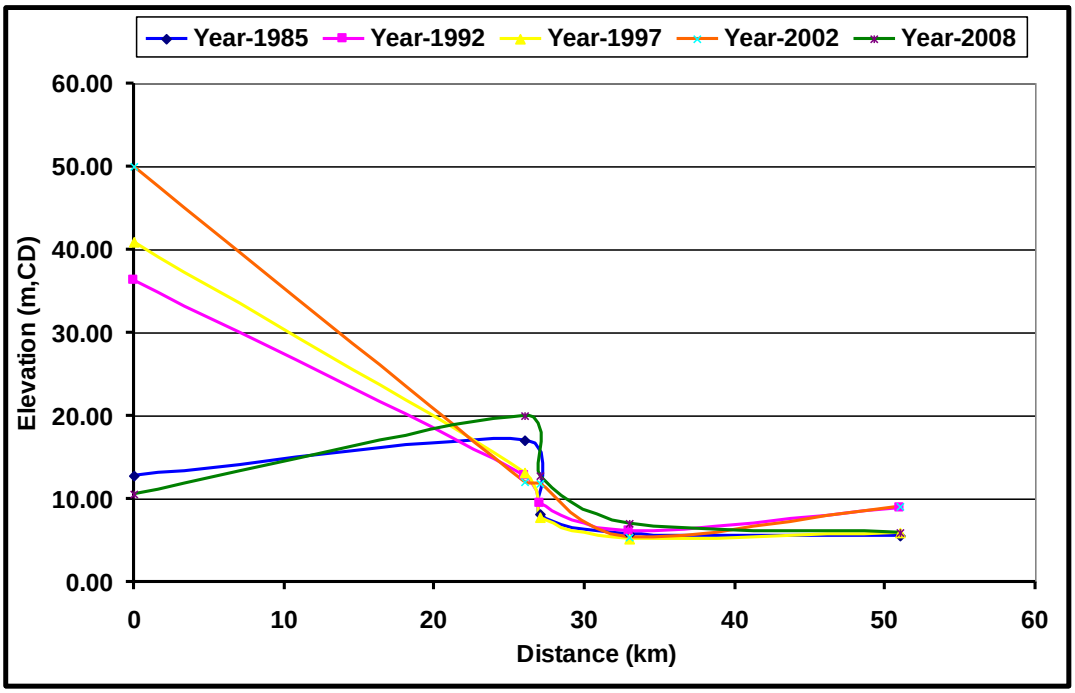

Figure 4.6.1: Variation of Thalweg elevation of Lower Meghna River along the Channel over the years

Table 4.6.2: Shifting of thalweg line of the Lower Meghna River from the Left Bank over the years (m)

Location of the Station	Distance (m)				
	1985	1992	1997	2002	2008
Chandpur	614.7	2750	1428.6	1687.5	2250
Chowkighata	543.6	1329	2500	295	261
Chitolkhali	846.6	795	583.3	2583.75	2045.4
Ramdaspur	1943.55	1998	667	500	250
Sandwip	1360.5	5000	5892.75	5989.2	4760

The position of thalweg line in the interim river reaches seems to be more stable than Chandpur. At the Ramdaspur station the thalweg line shifted towards the left bank gradually.

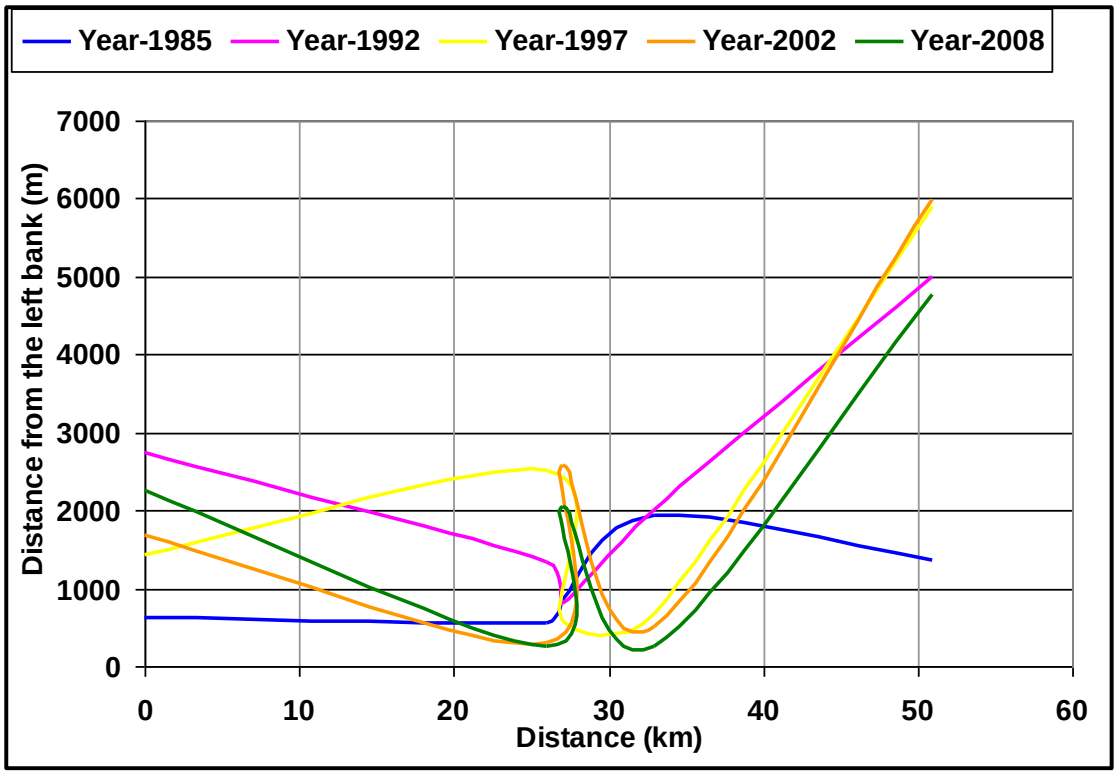

Figure 4.6.2 Thalweg line variation of the Lower Meghna River with respect to the Left bank line over the years along the river reaches.

4.7 Summary

In this chapter water level and bed level variation, cross-sectional area, mean bed level variation and shifting of thalweg line were analyzed and discussed. All the analysis was presented with relevant figures and graphs. The analysis of water level and bed level variation was done by selecting some intermittent years from 1985 to 2008 and comparison was made with every successive years. Efforts were made to find out the deposition or erosion in mean bed level. The shifting of the deepest point (thalweg) was determined to find the main course of the river in this chapter.

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusion

This study highlights on the water level and bed level variation in the Lower Meghna River. The results presented in this study are based on the water level and cross sectional data collected from BIWTA. From the analysis of cross sectional data of Lower Meghna River it can be stated that there were significant changes in the cross section in 5 to 7 years span of time. However, the water level and cross sectional area analysis has shown certain trend in the variations. The following conclusion may be drawn from the study

1. The variation of cross sectional area in the Lower Meghna River is high at different sections and even in a same section over a period of 23 years. The river shows a dynamic behaviour at Chandpur as the ratio of lowest and highest cross sectional area was 1:2.24. The same rising trend of cross sectional area was observed in case of Chowkighata and Chitolkhali station. But the cross sectional area at Ramdaspur decreased over the years. The increase of cross sectional area at sandwip was very small compared to the other stations. The cross section at Sandwip is characterized by erosion from 1985 to 1997 followed by deposition in the year 2002. A large volume of deposition of sediment occurred from the year 2002 to 2008 at Sandwip.
2. The variation of water level and bed level followed a typical trend with some deviations. In most cases the water level dropped as the bed level declined or the water level is raised as a consequence of bed level rise. However the change in water level was not very significant as the change in bed level. Analysis showed that there were exceptions in the period of 1992 to 1997 where the water level at Chandpur station is raised with a drop in the bed level. It indicates the flattening of the bed level. As we did not consider tidal effect, wind speed and bed material characteristics etc.

in our study we cannot conclude from the analysis that excess water at Sandwip station was due to the sea level rise.

3. From the analysis of Mean bed level a significant change in the mean bed level of the Lower Meghna River at Chandpur was observed where as the change at Ramdaspur and Sandwip station were the least. The range of mean bed level rise or fall at Chandpur was from 1.53 m to as high as 7.28m over the years.
4. The movement of the thalweg of the Lower Meghna River in the vertical direction is very dynamic. Again the movement of thalweg at Chandpur was the most. The shifting of thalweg at Chitolkhali, Ramdaspur and Sandwip was very consistent. The thalweg movement from the left bank also varied at different locations with a wide range.

5.2 Recommendations

The following recommendations may be drawn for further study:

1. In this study only the cross sectional and water level data are analyzed to compare the bed level changes with respect to the water level rise or fall for the Lower Meghna River. A further study may be taken considering sediment transport data.

2. This study is carried out based on the bathymetric data, which is surveyed mostly after the flood season. A further study may be carried out with flood season.

3. As the Lower Meghna River falls into the estuary to meet the Bay of Bengal, therefore the influence of tidal and wind data could also be considered in future study.

4. A further study may be taken using the GIS (Geographic Information System) technology with detailed plan, sufficient data and satellite images.

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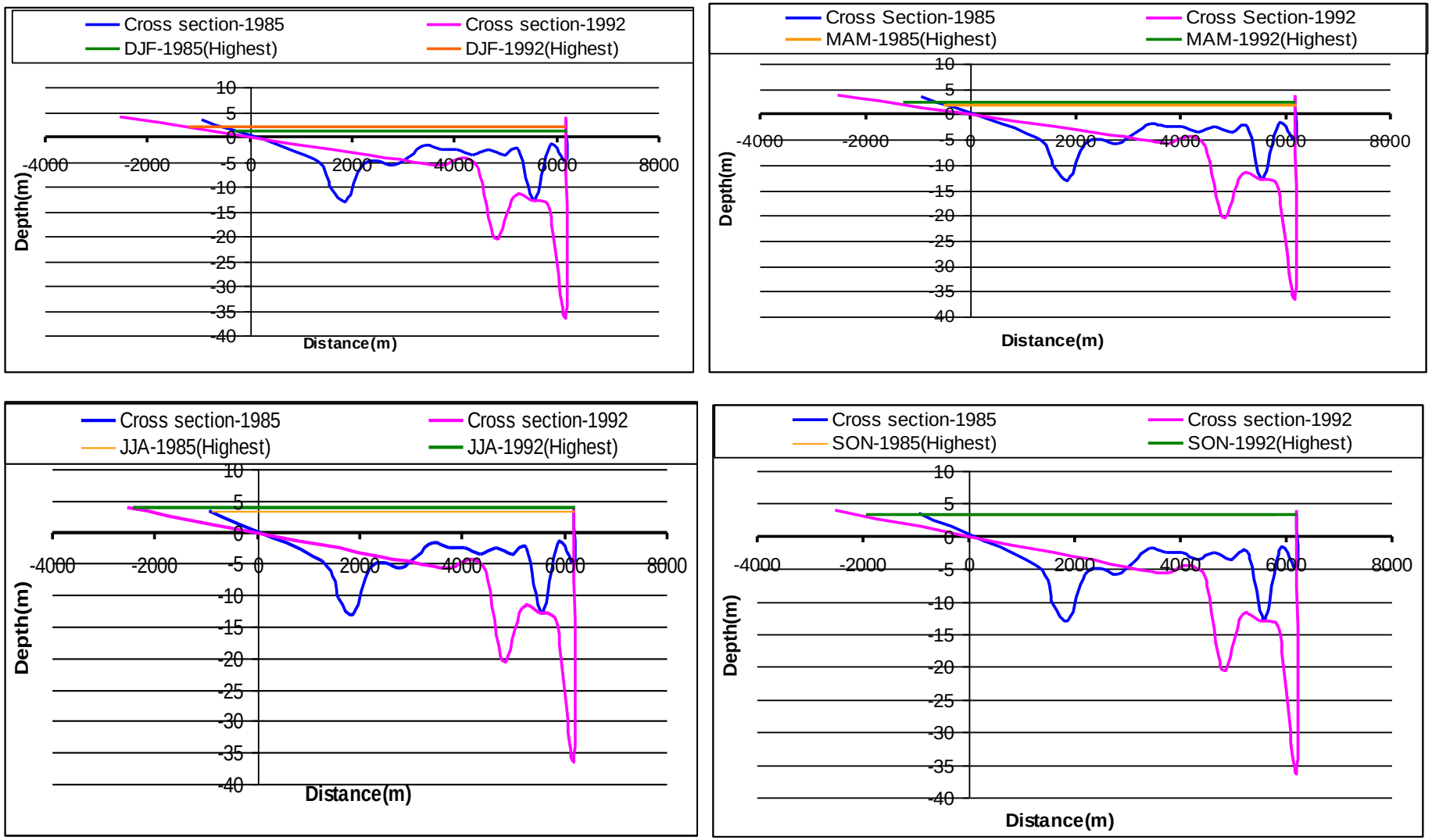


Figure 4.3.1 Comparison of Highest Water Level with corresponding cross section for the years 1985 and 1992 at Chandpur

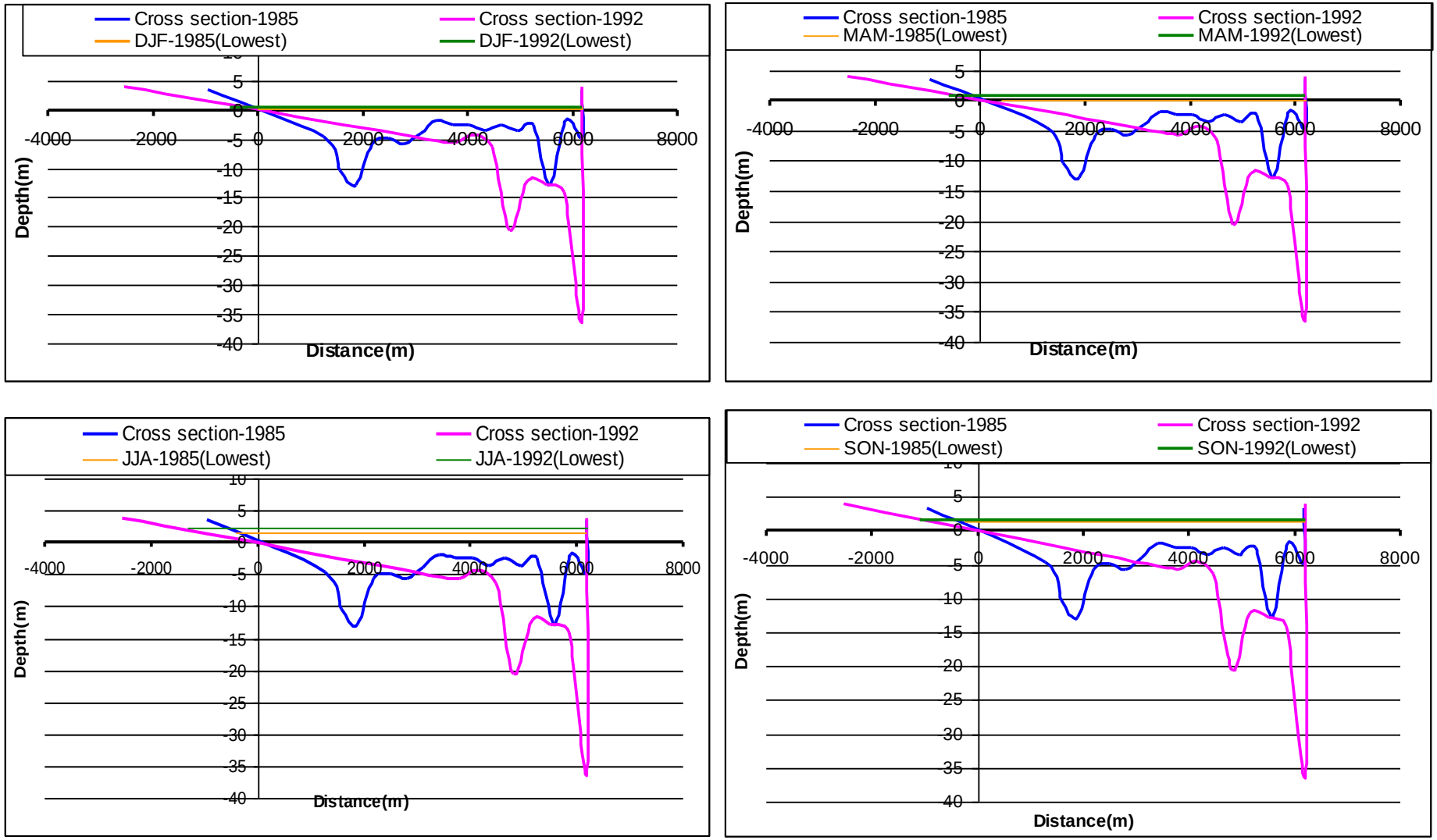


Figure 4.3.2 Comparison of Lowest Water Level with corresponding cross section for the years 1985 and 1992 at Chandpur

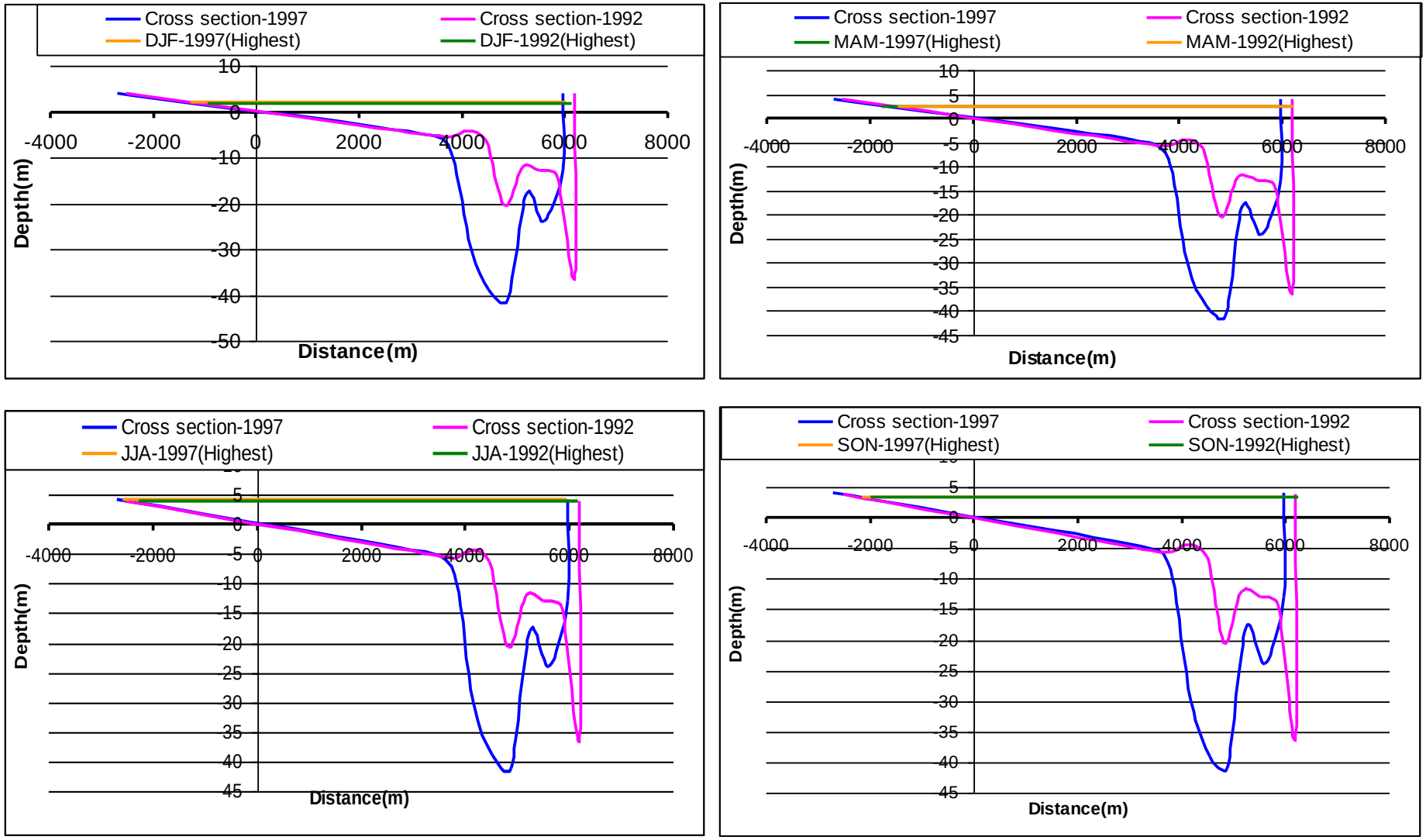


Figure 4.3.3 Comparison of Highest Water Level with corresponding cross section for the years 1992 and 1997 at Chandpur

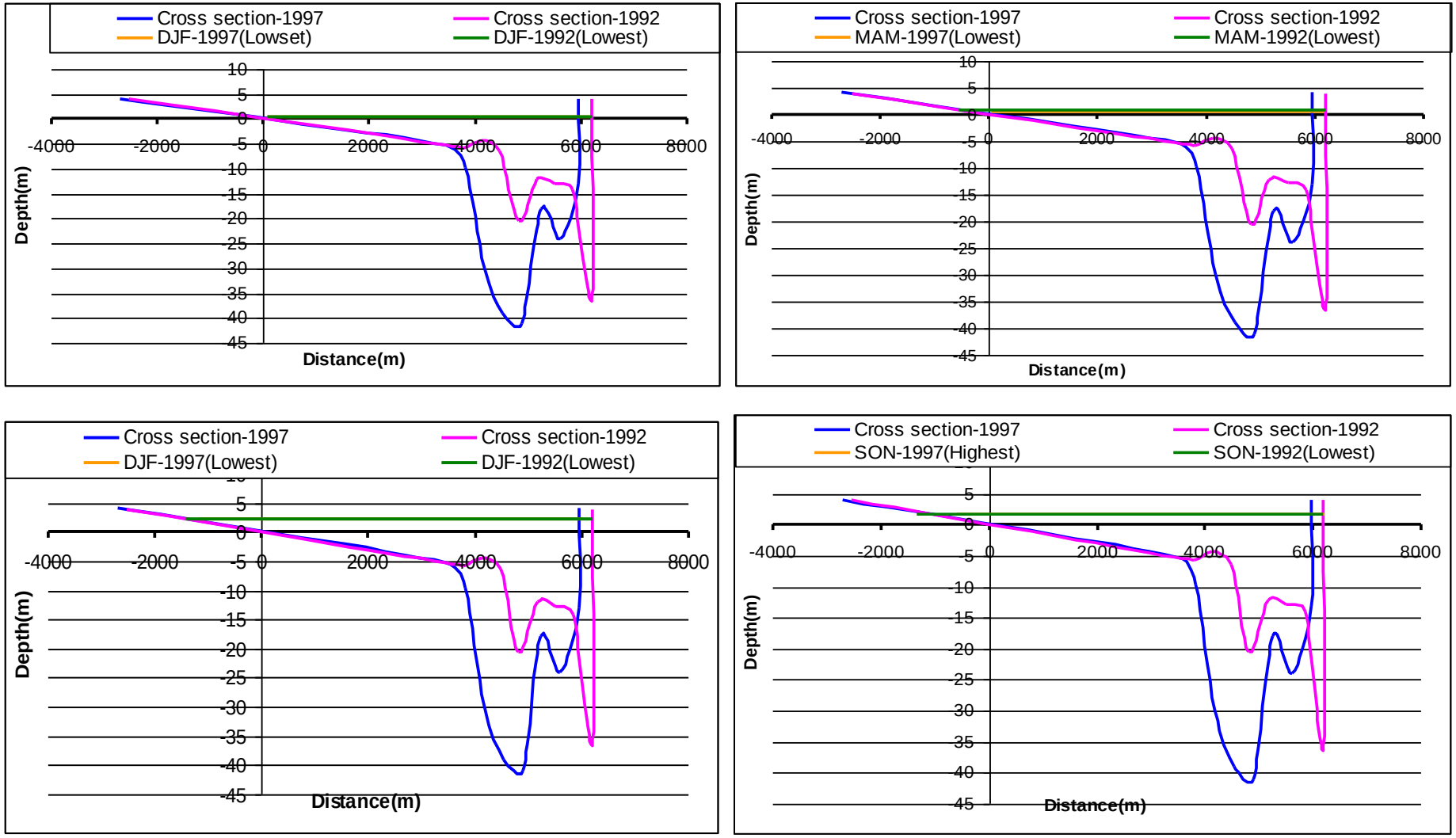


Figure 4.3.4 Comparison of Lowest Water Level with corresponding cross section for the years 1992 and 1997 at Chandpur

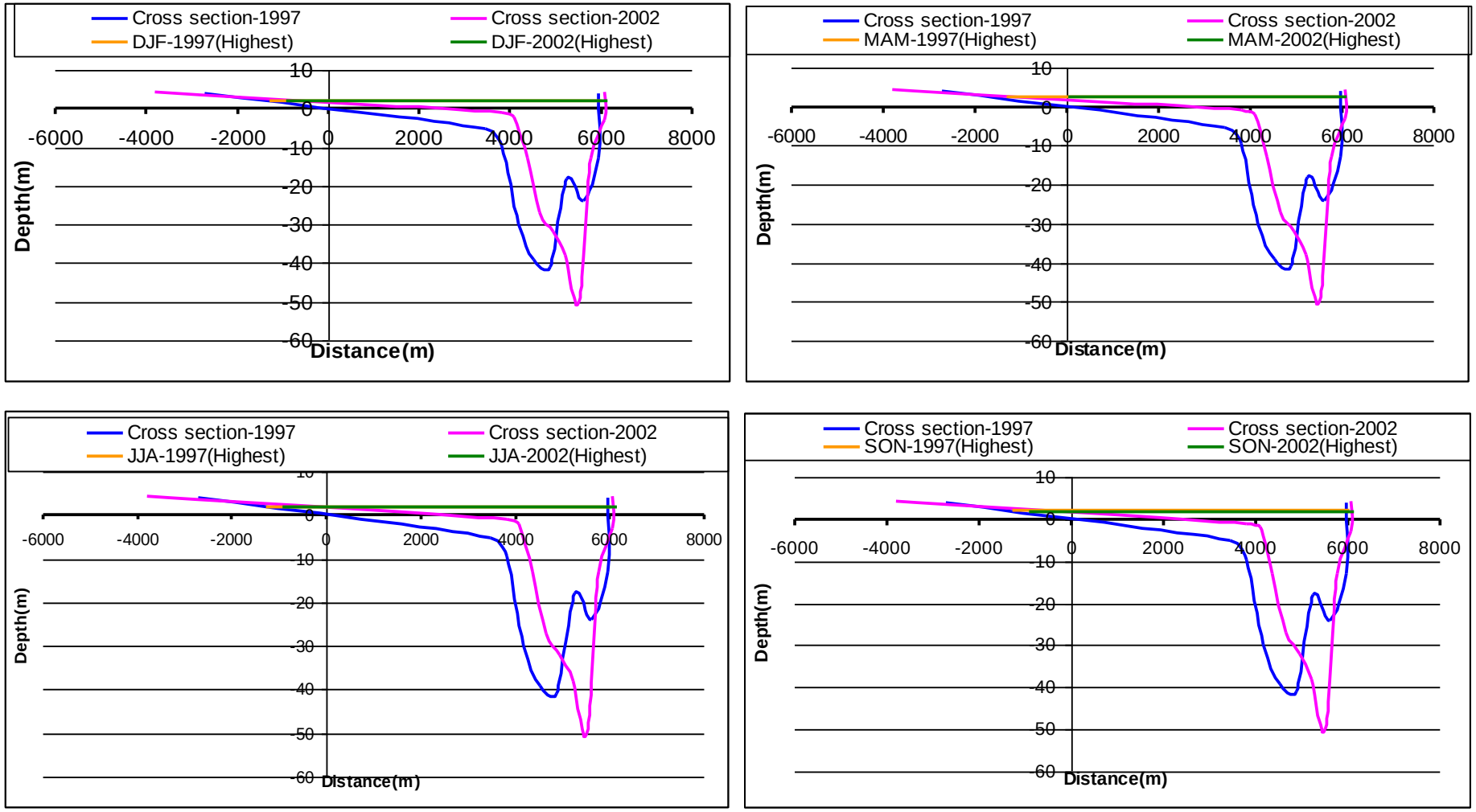


Figure 4.3.5 Comparison of Highest Water Level with corresponding cross section for the years 1997 and 2002 at Chandpur

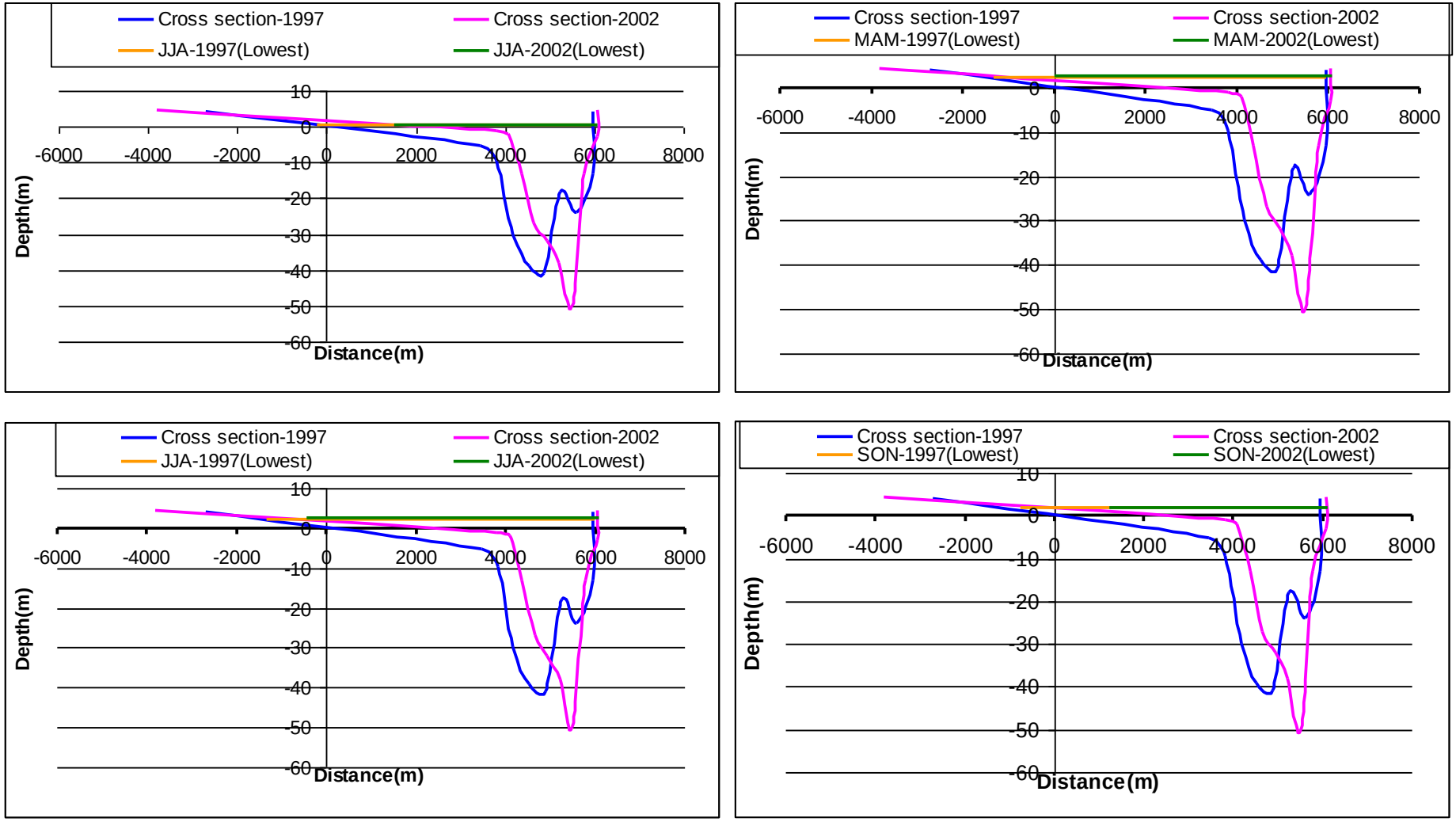


Figure 4.3.6 Comparison of Lowest Water Level with corresponding cross section for the years 1997 and 2002 at Chandpur

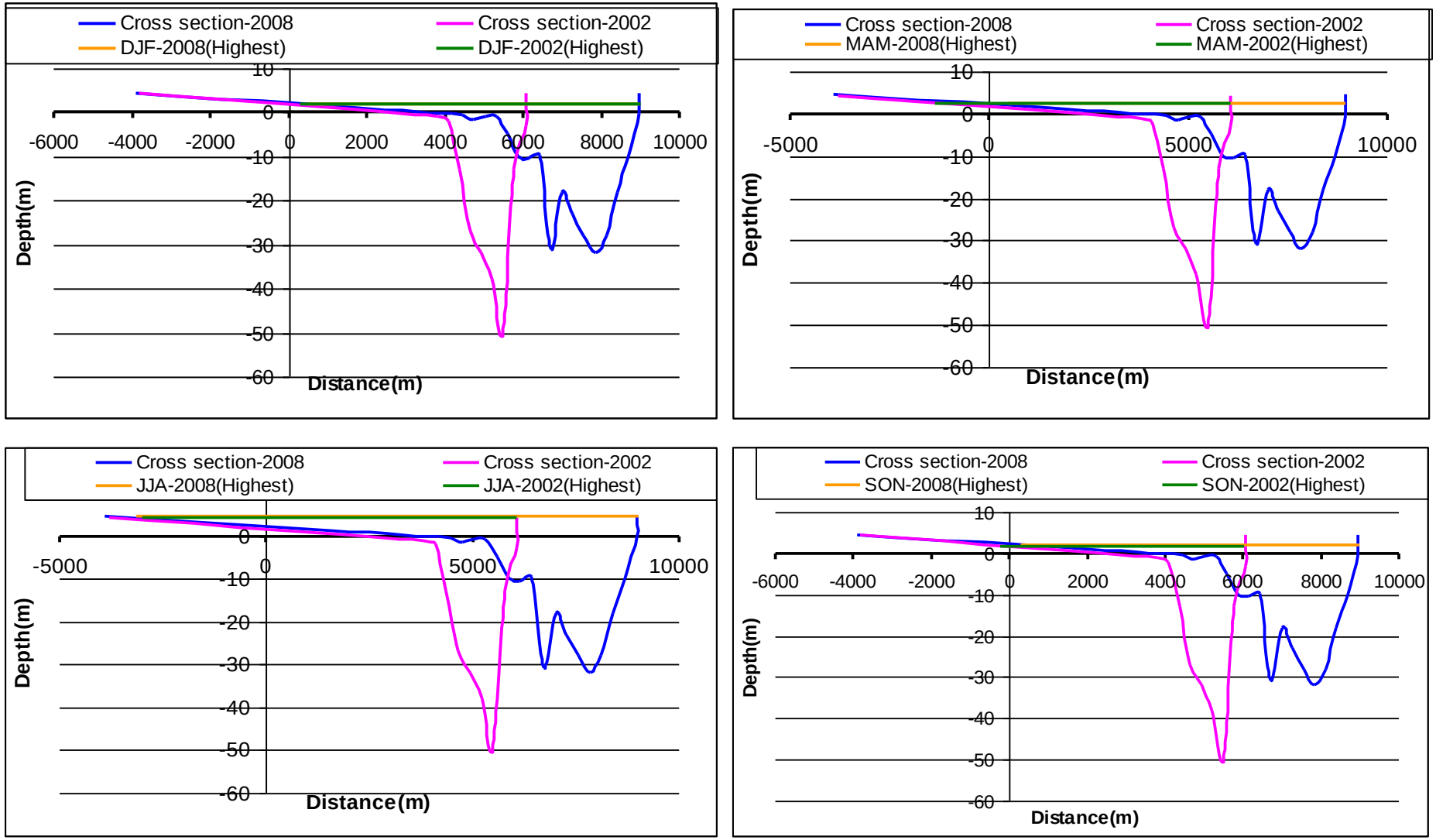


Figure 4.3.7 Comparison of Highest Water Level with corresponding cross section for the years 2002 and 2008 at Chandpur

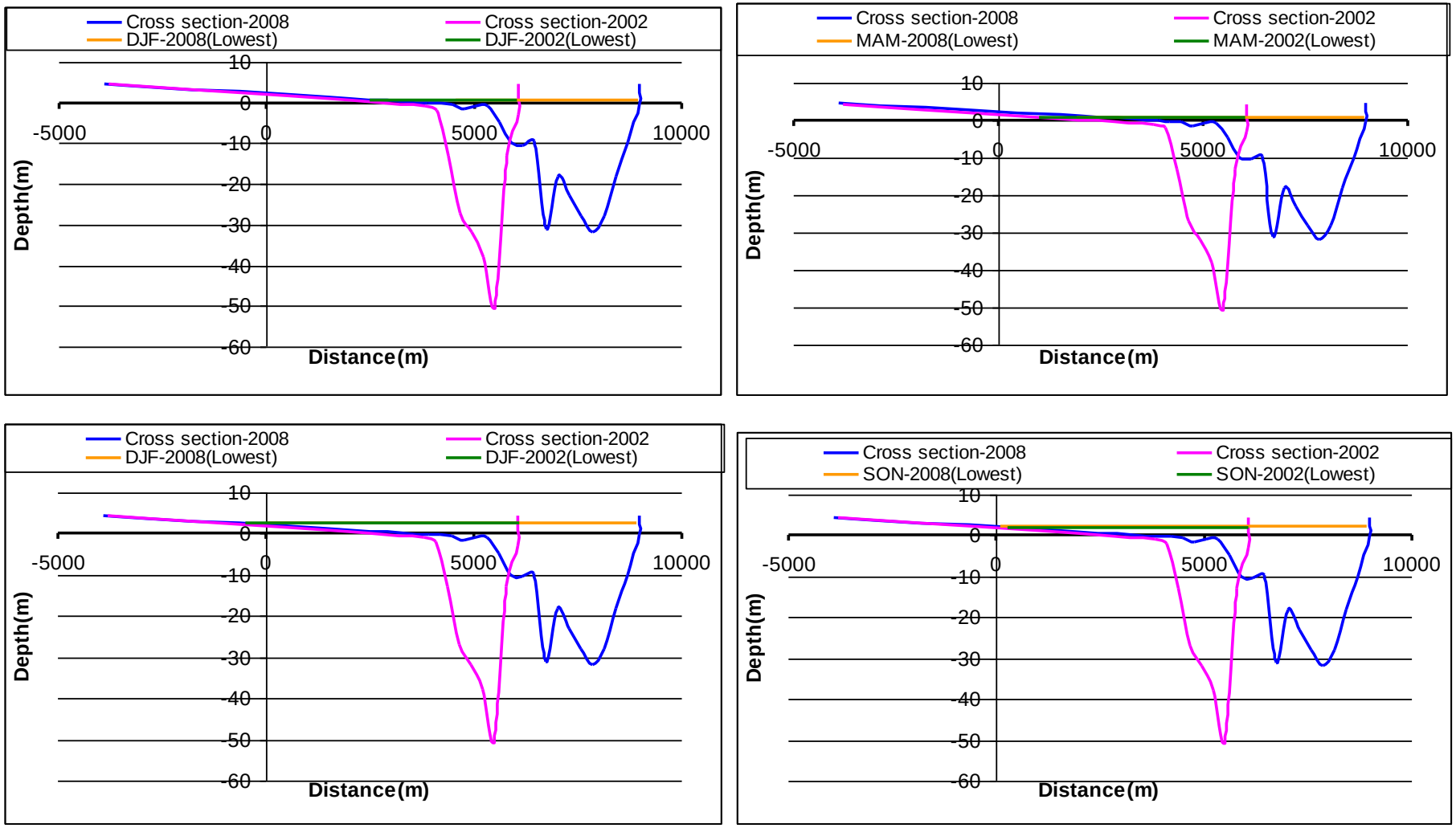


Figure 4.3.8 Comparison of Lowest Water Level with corresponding cross section for the years 2002 and 2008 at Chandpur

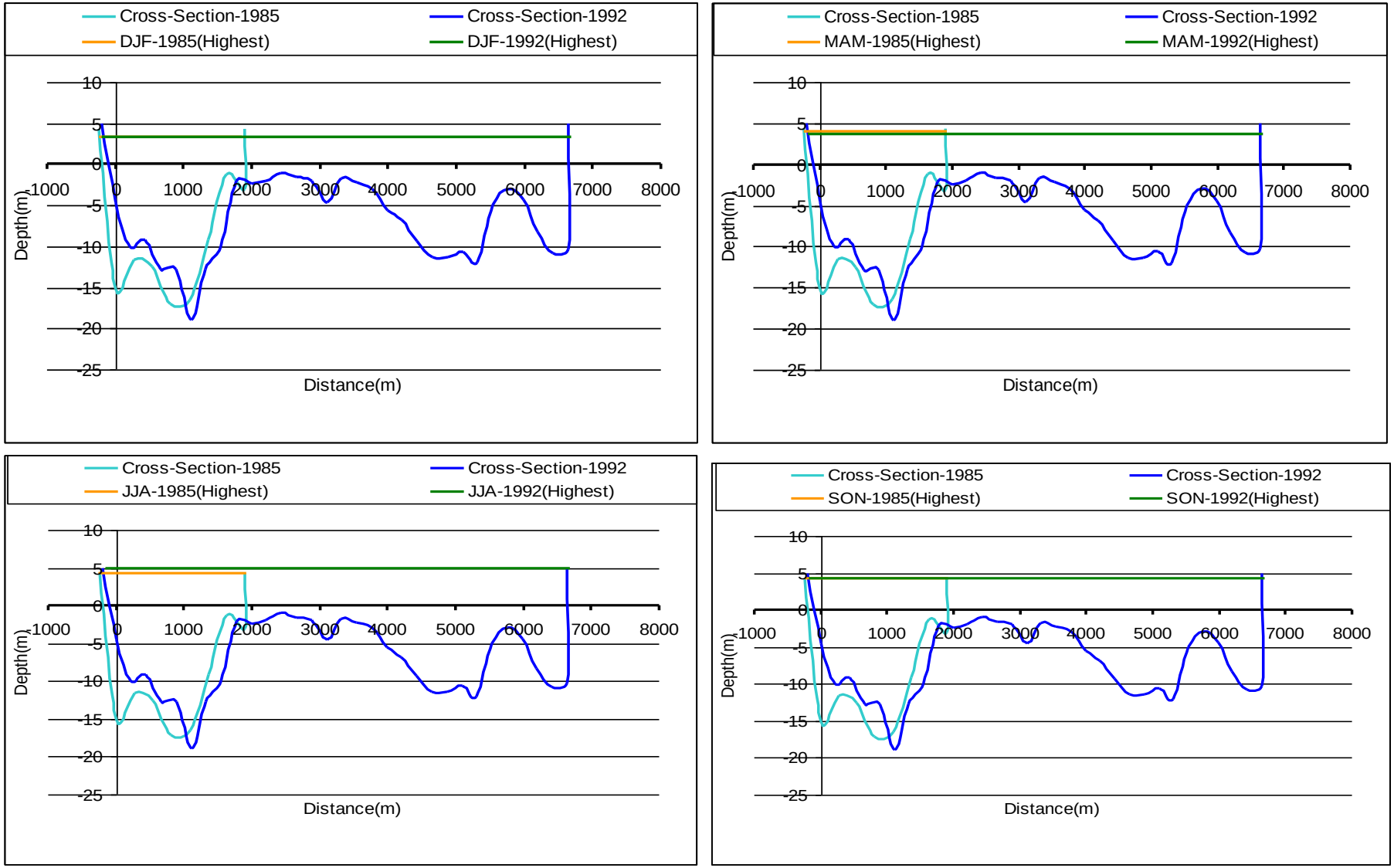


Figure 4.3.9 Comparison of Highest Water Level with corresponding cross section for the years 1985 and 1992 at Chowkighata

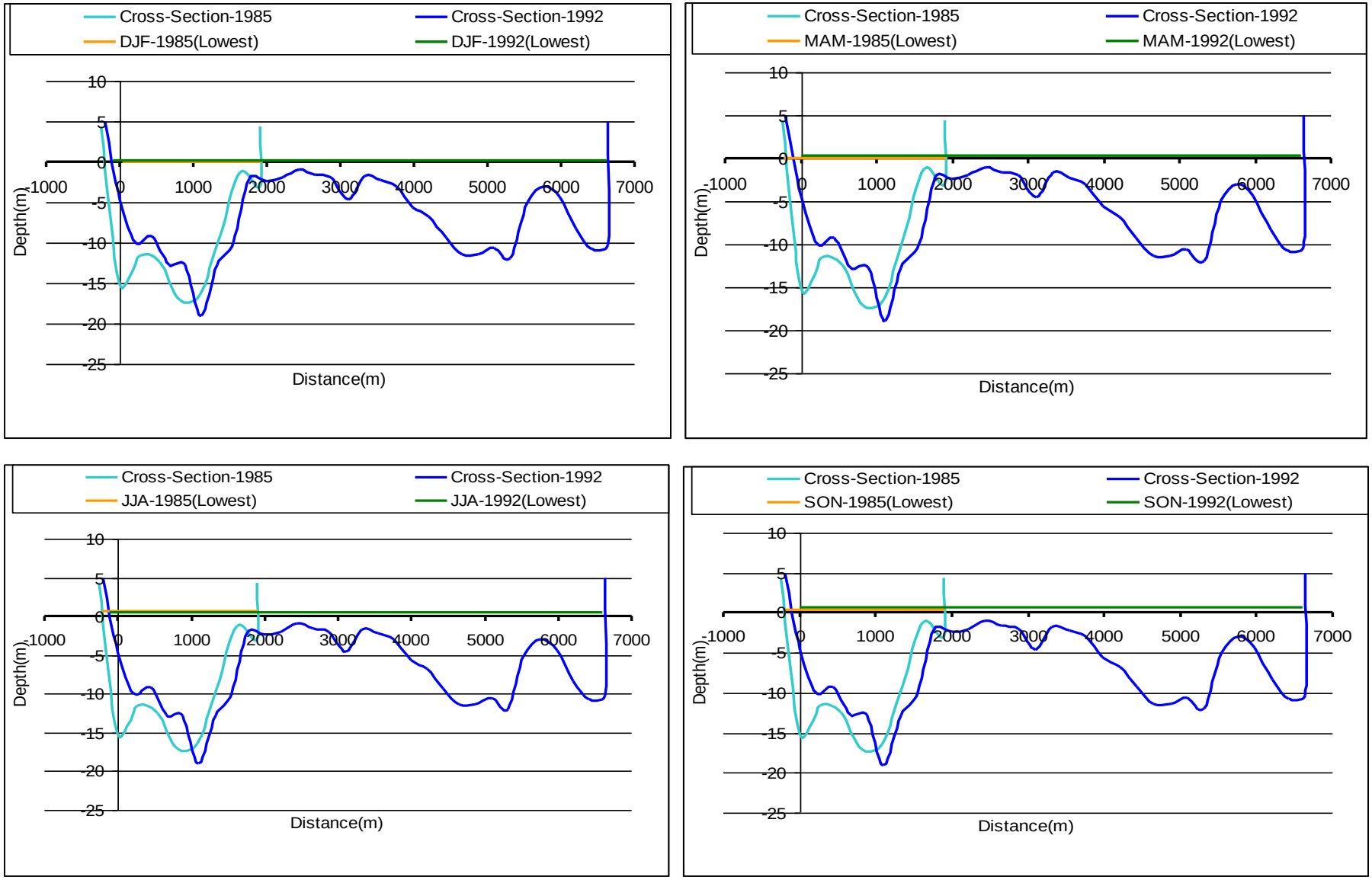


Figure 4.3.10 Comparison of Lowest Water Level with corresponding cross section for the years 1985 and 1992 at Chowkighata

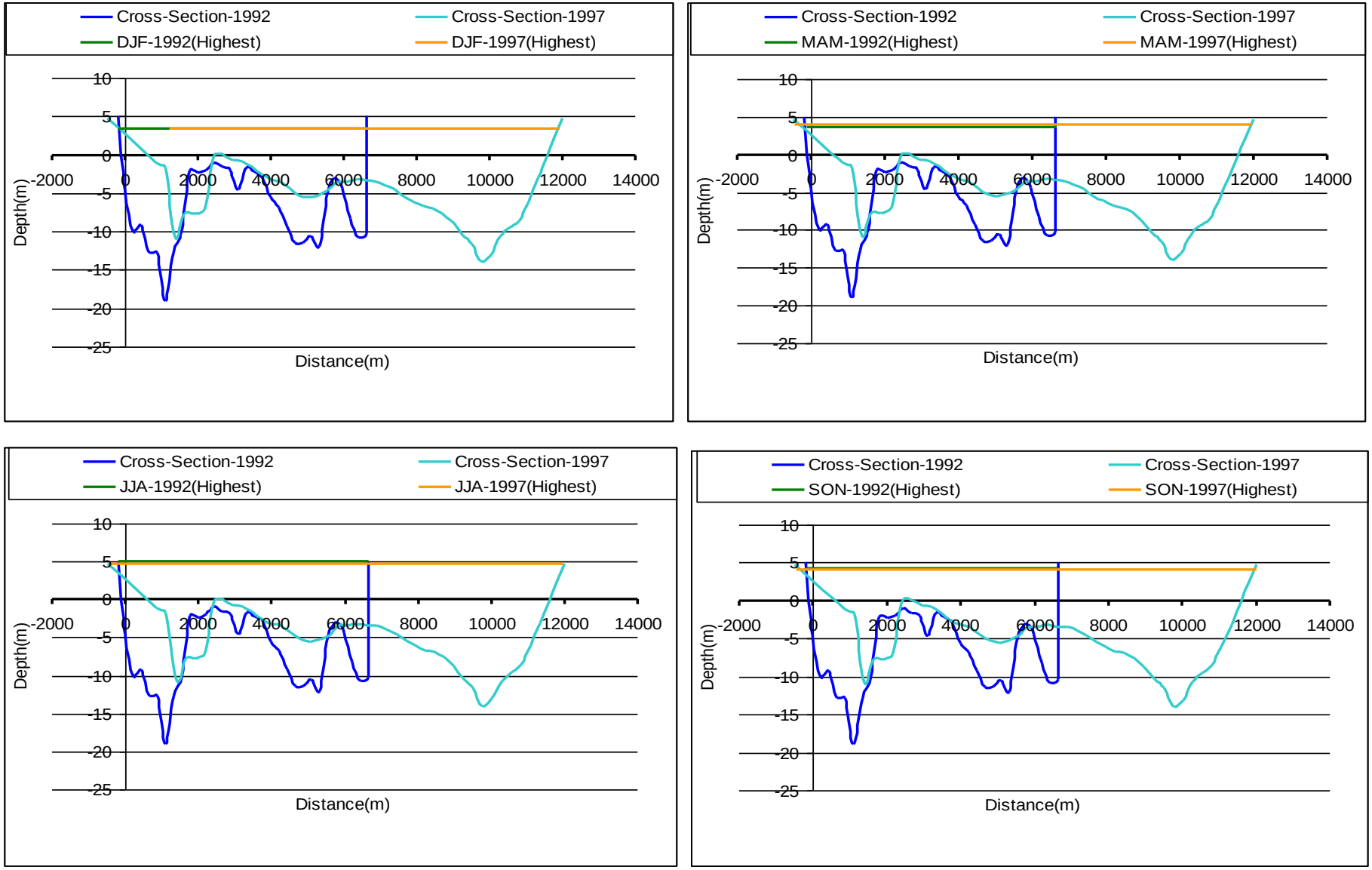
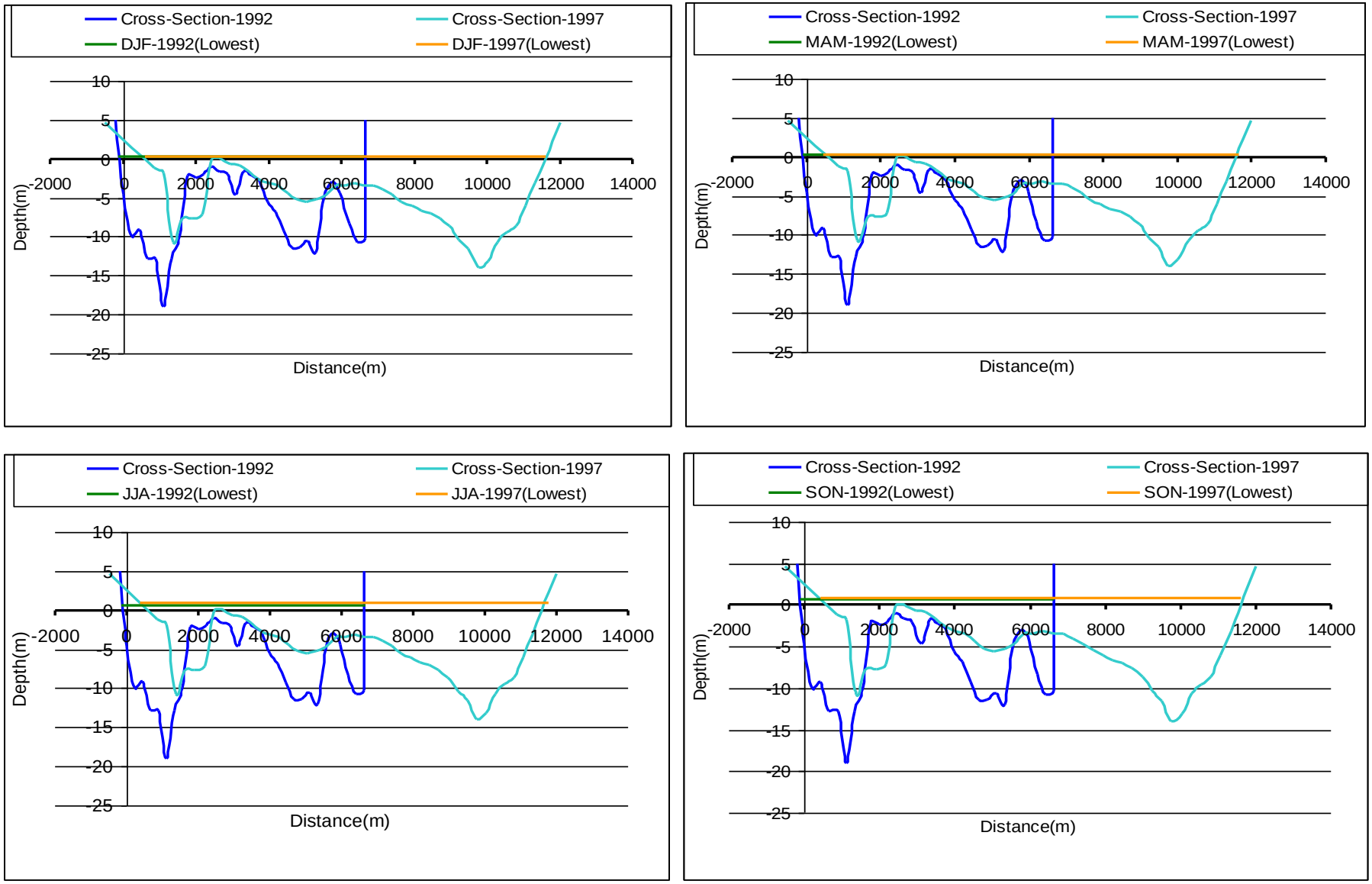


Figure 4.3.11 Comparison of Highest Water Level with corresponding cross section for the years 1992 and 1997 at Chowkighata



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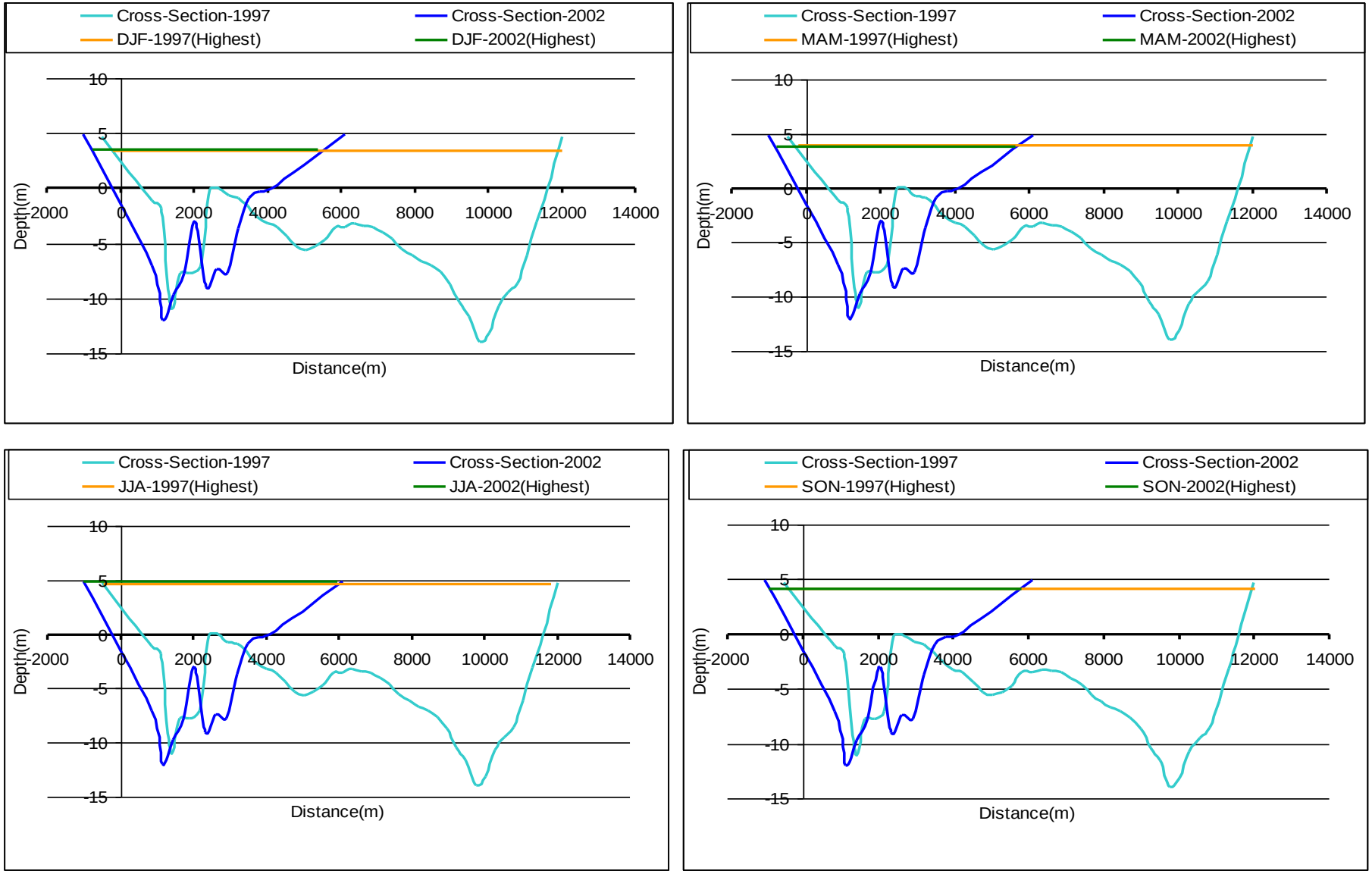
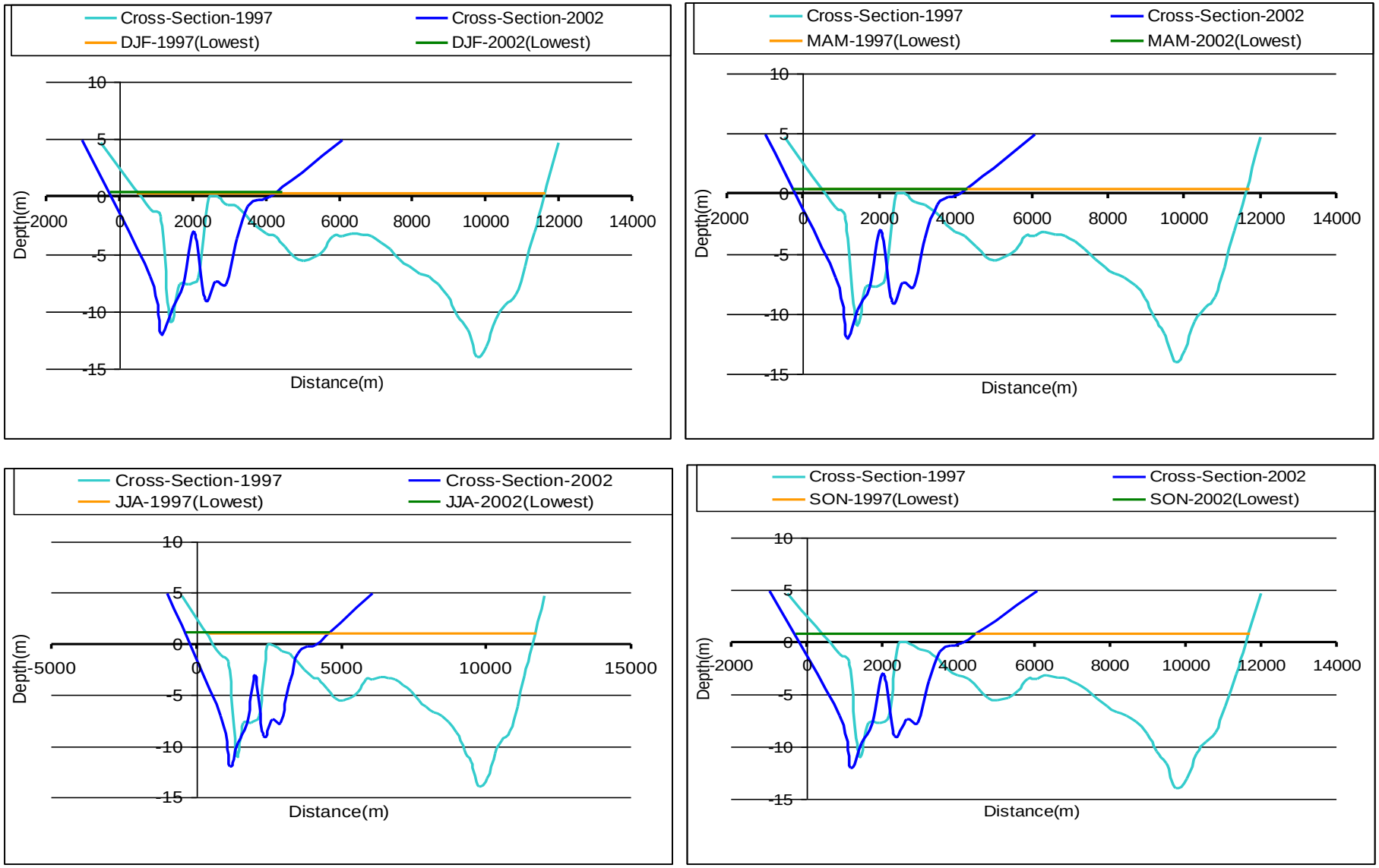


Figure 4.3.13 Comparison of Highest Water Level with corresponding cross section for the years 1997 and 2002 at Chowkighata



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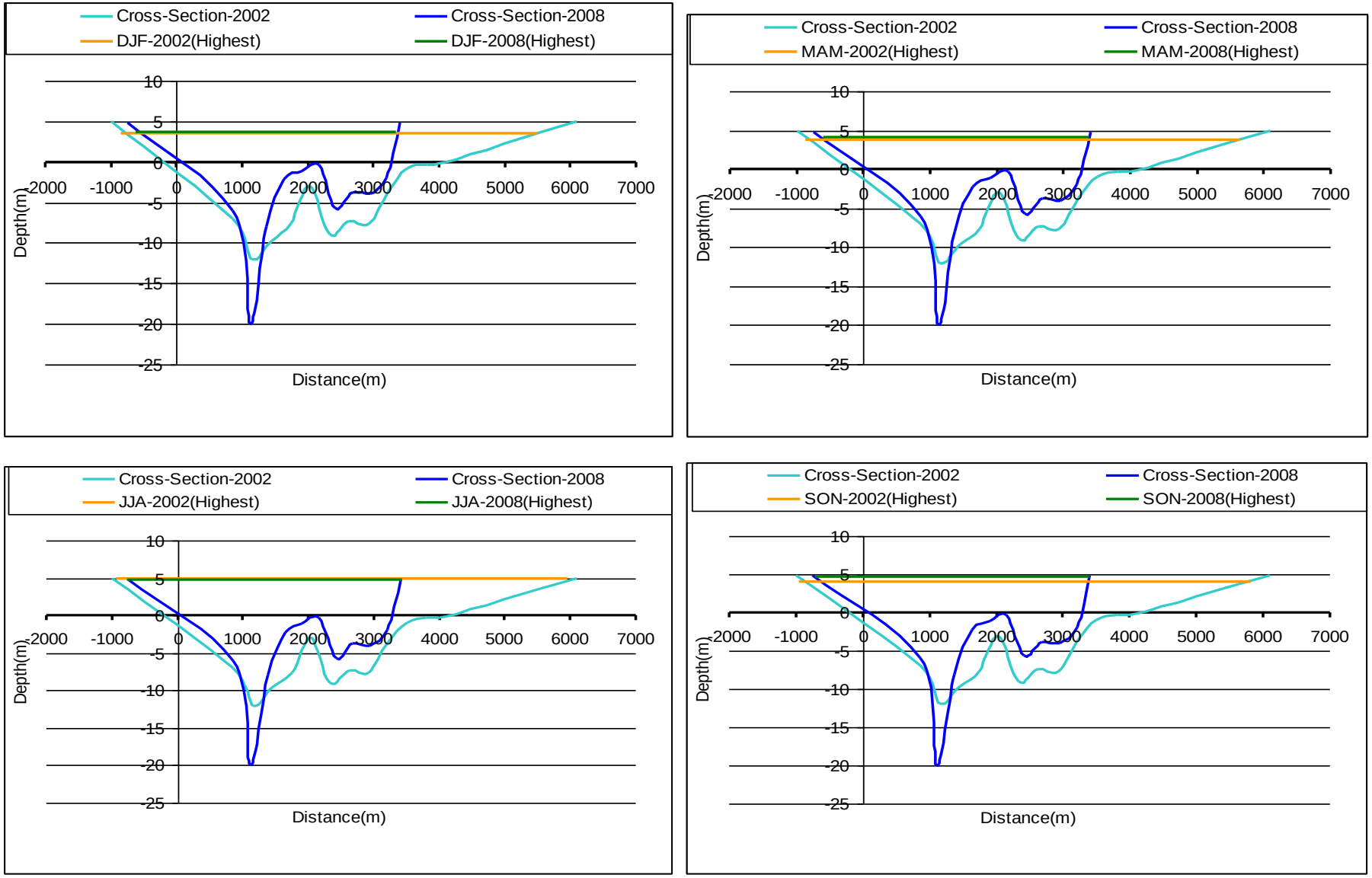
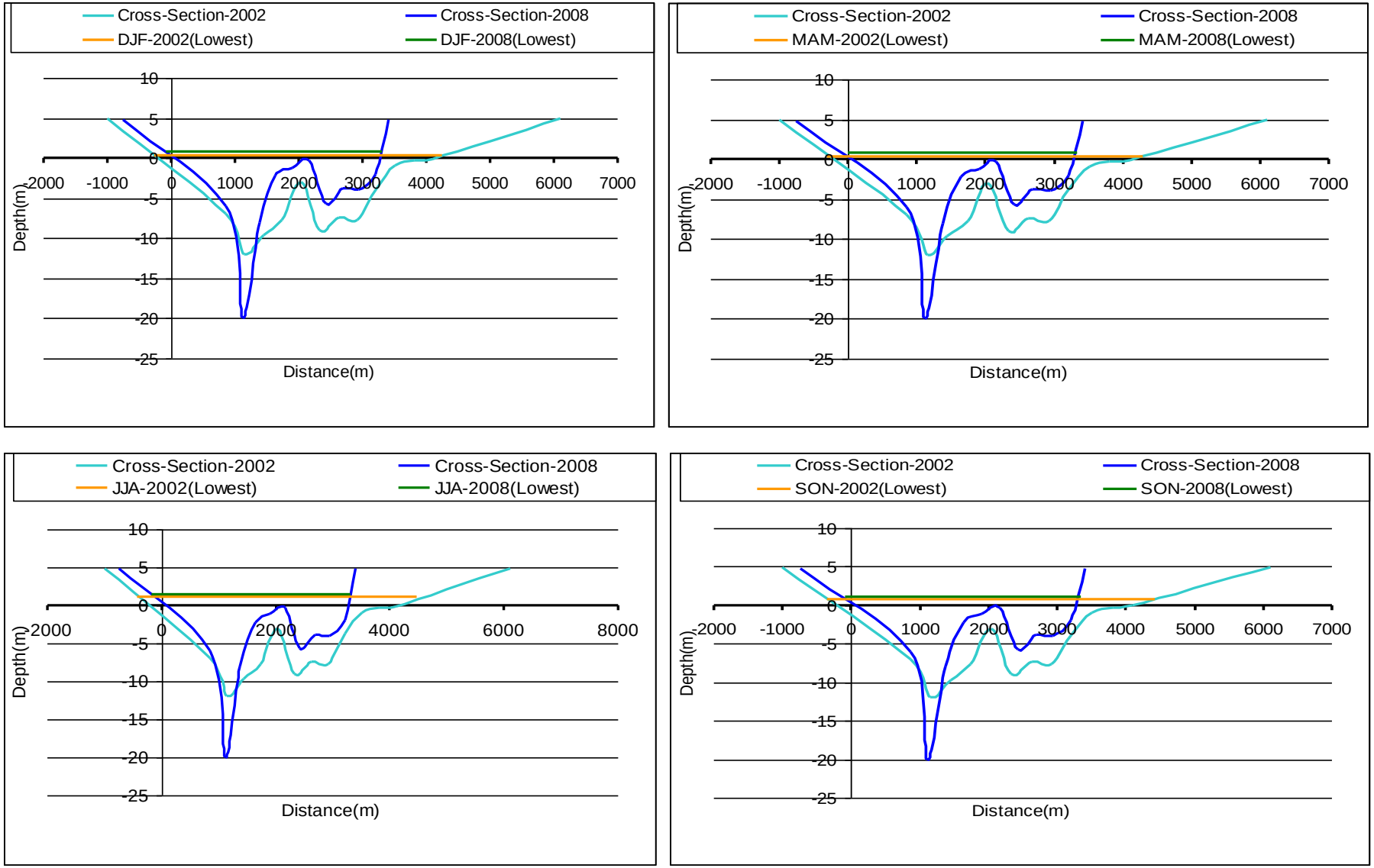


Figure 4.3.15 Comparison of Highest Water Level with corresponding cross section for the years 2002 and 2008 at Chowkighata



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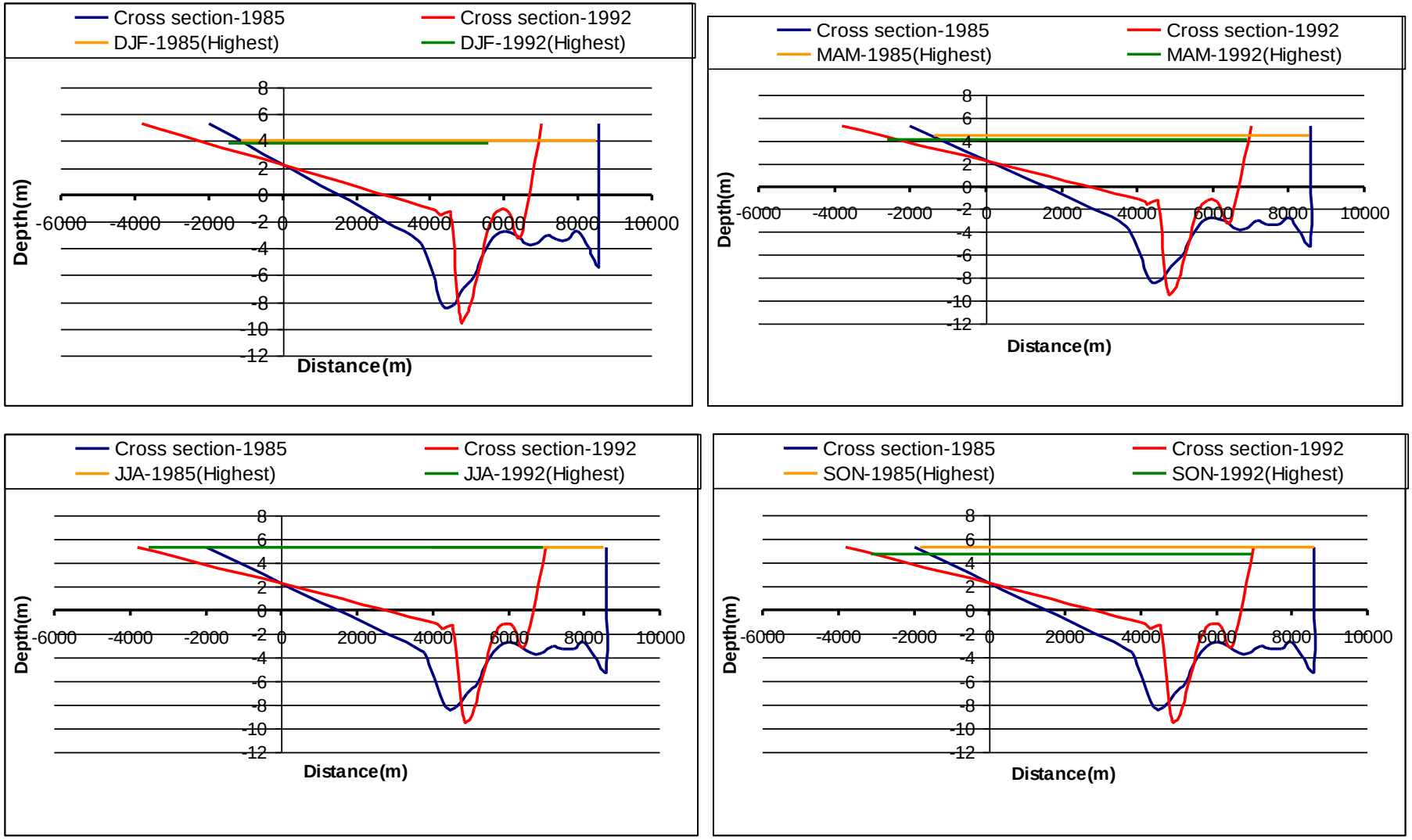
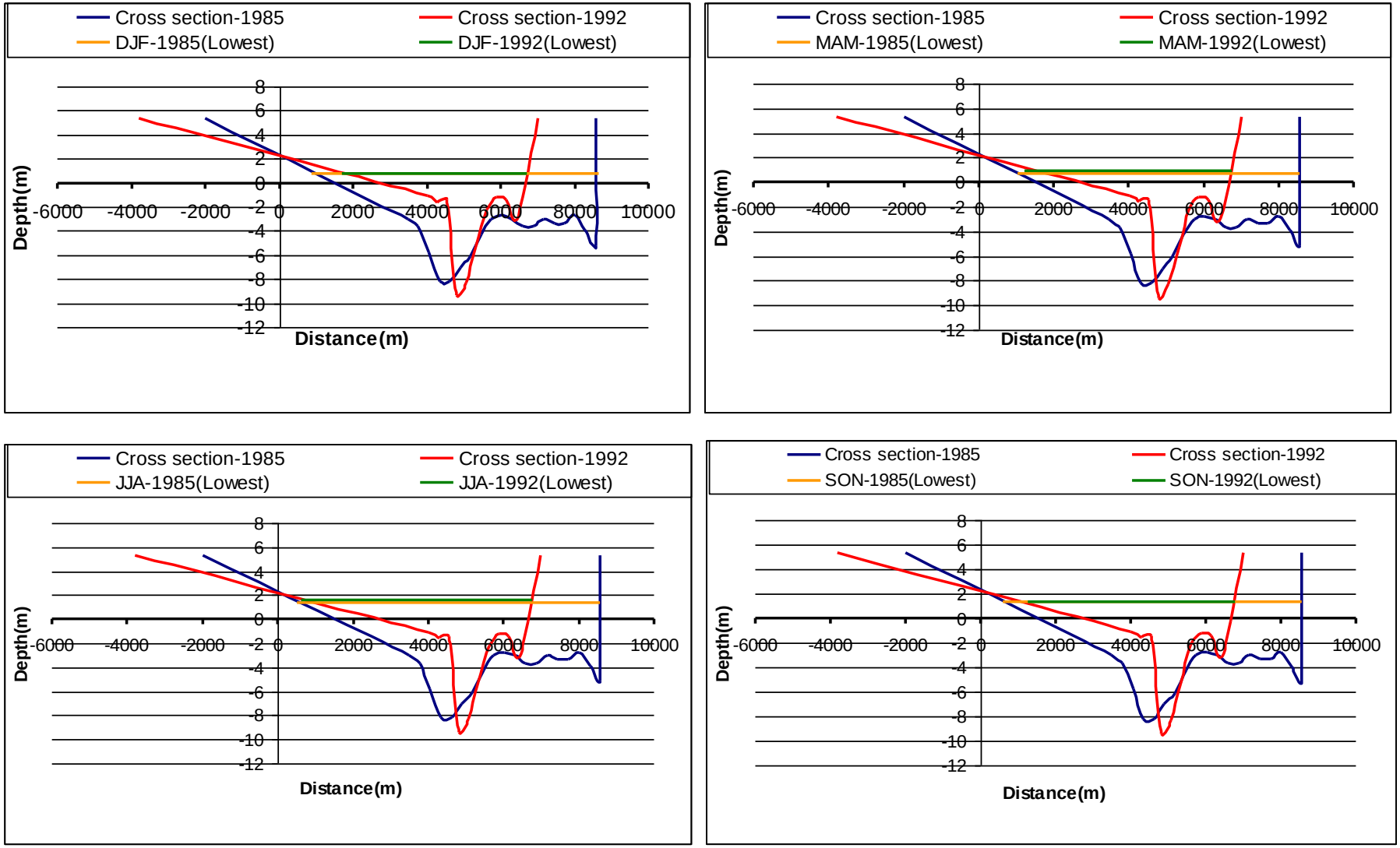


Figure 4.3.17 Comparison of Highest Water Level with corresponding cross section for the years 1985 and 1992 at Chitolkhali



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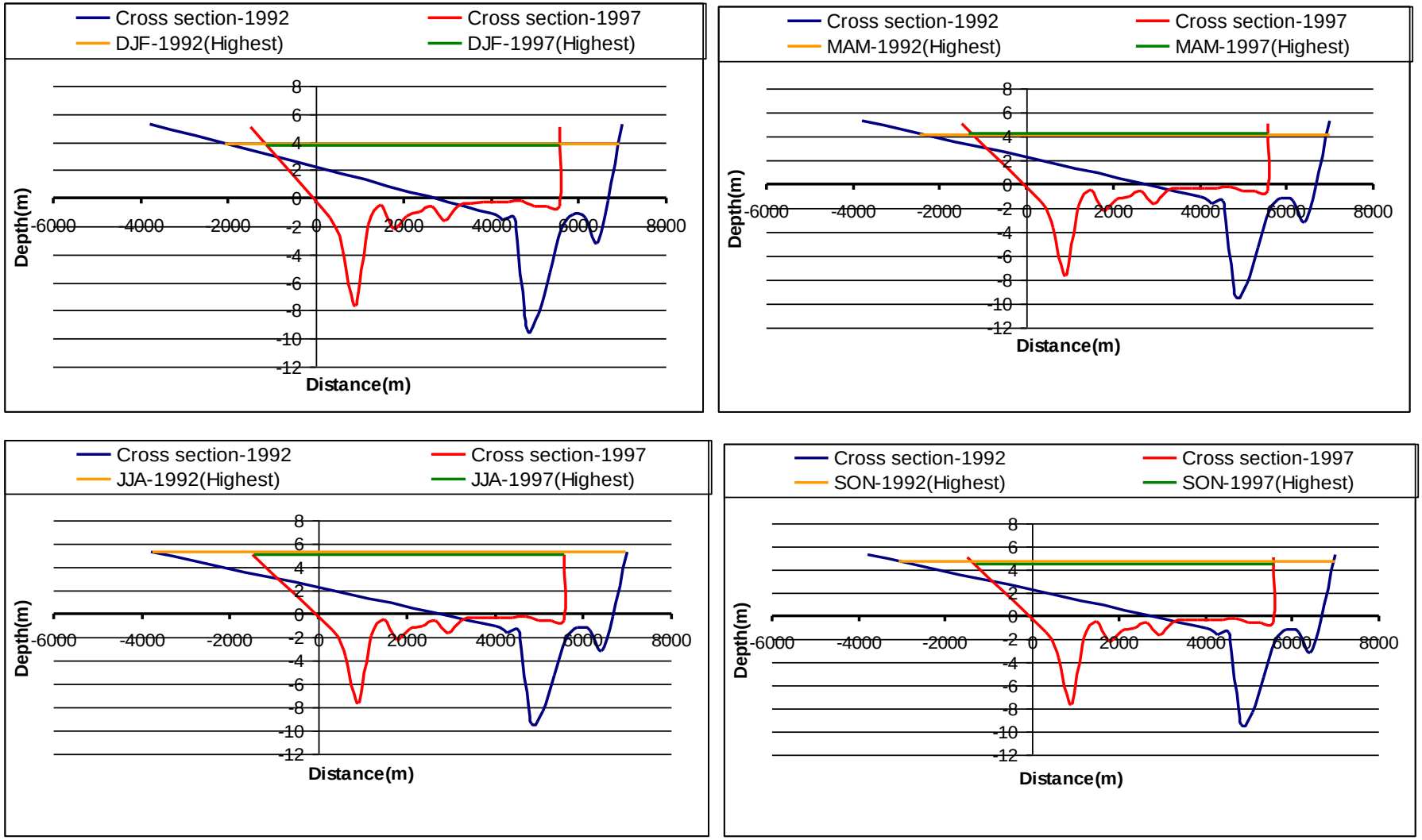

Figure 4.3.19 Comparison of Highest Water Level with corresponding cross section for the years 1992 and 1997 at Chitolkhali

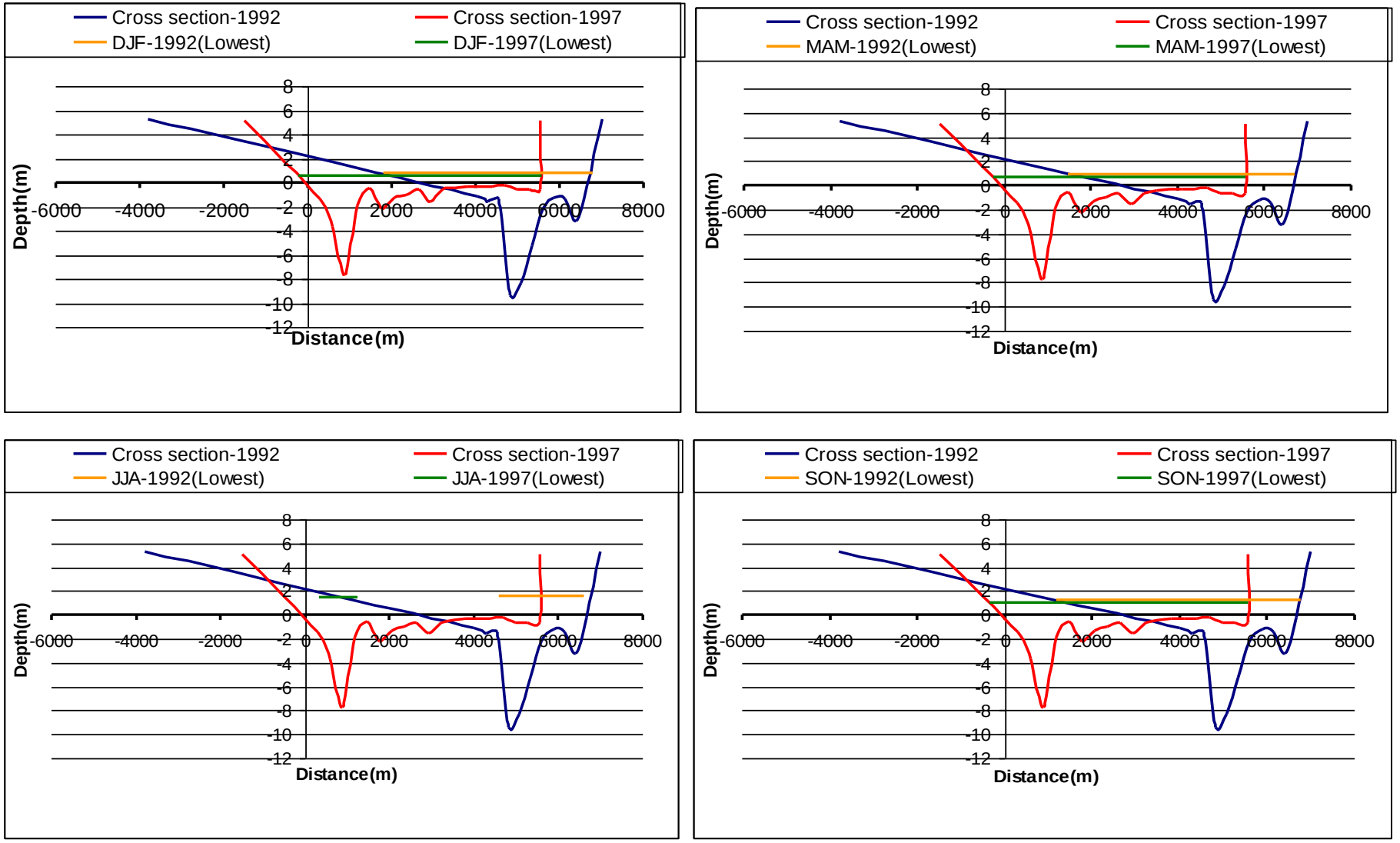

Figure 4.3.20 Comparison of Lowest Water Level with corresponding cross section for the years 1992 and 1997 at Chitolkhali

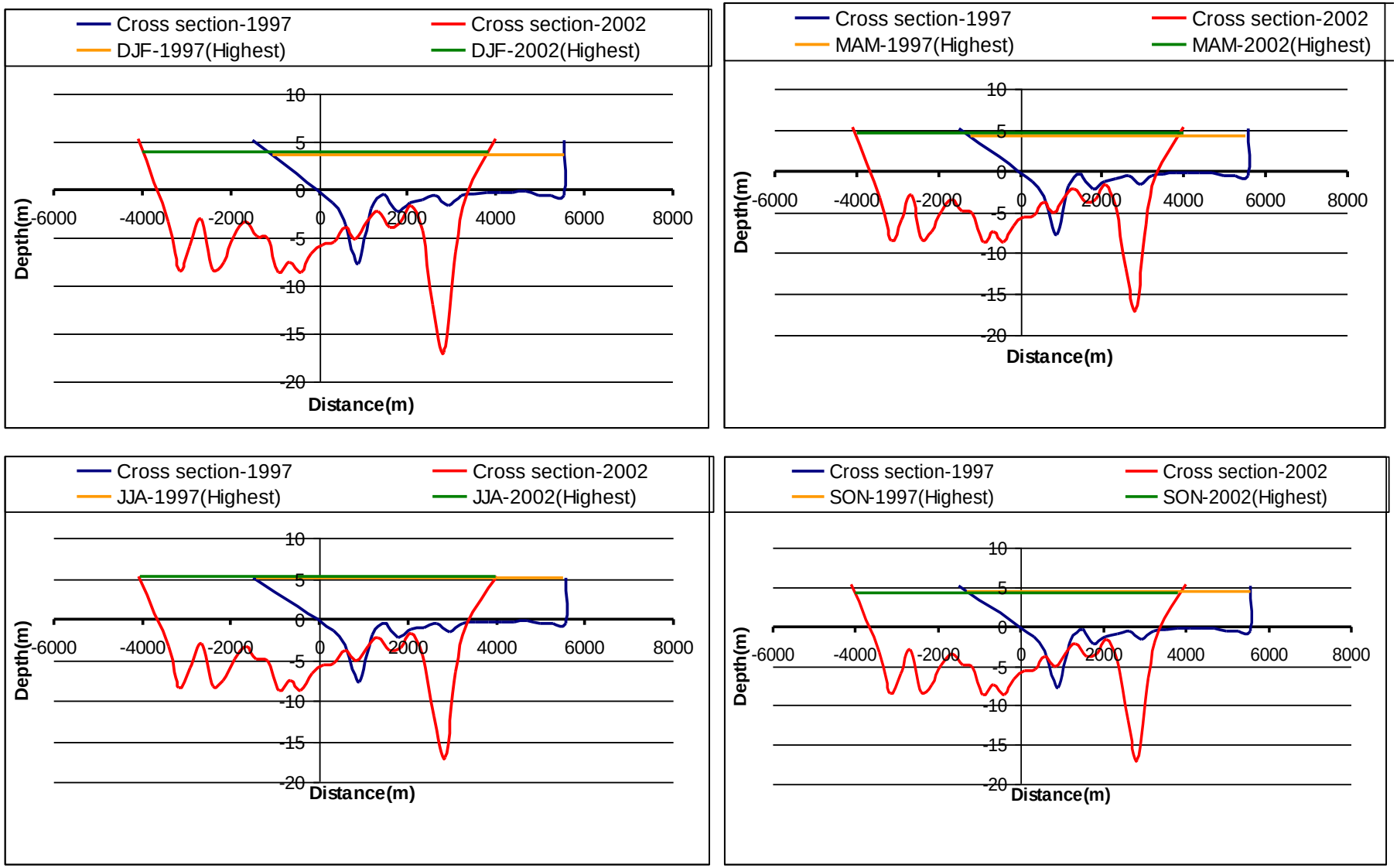

Figure 4.3.21 Comparison of Highest Water Level with corresponding cross section for the years 1997 and 2002 at Chitolkhali

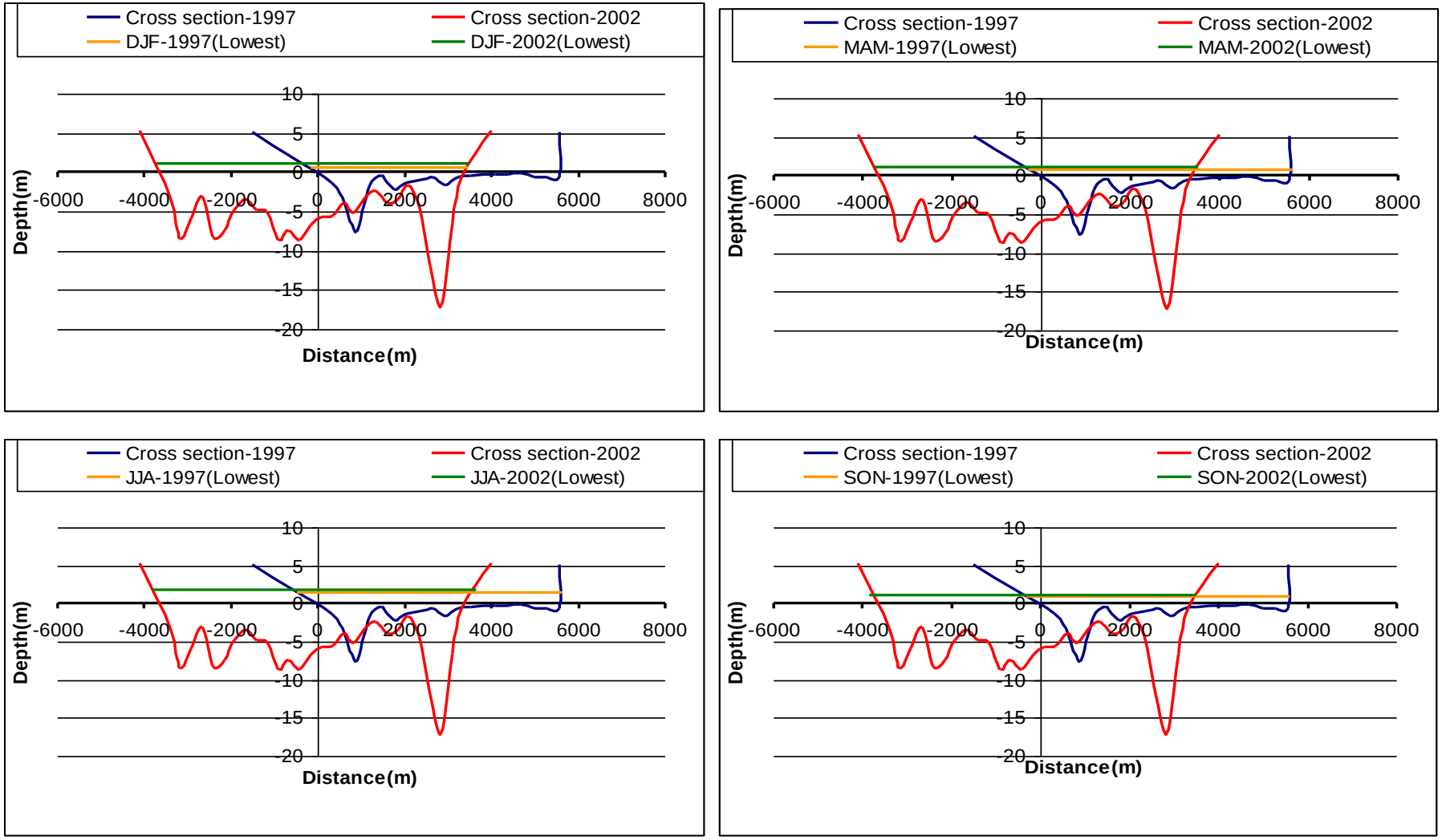

Figure 4.3.22 Comparison of Lowest Water Level with corresponding cross section for the years 1997 and 2002 at Chitolkhali

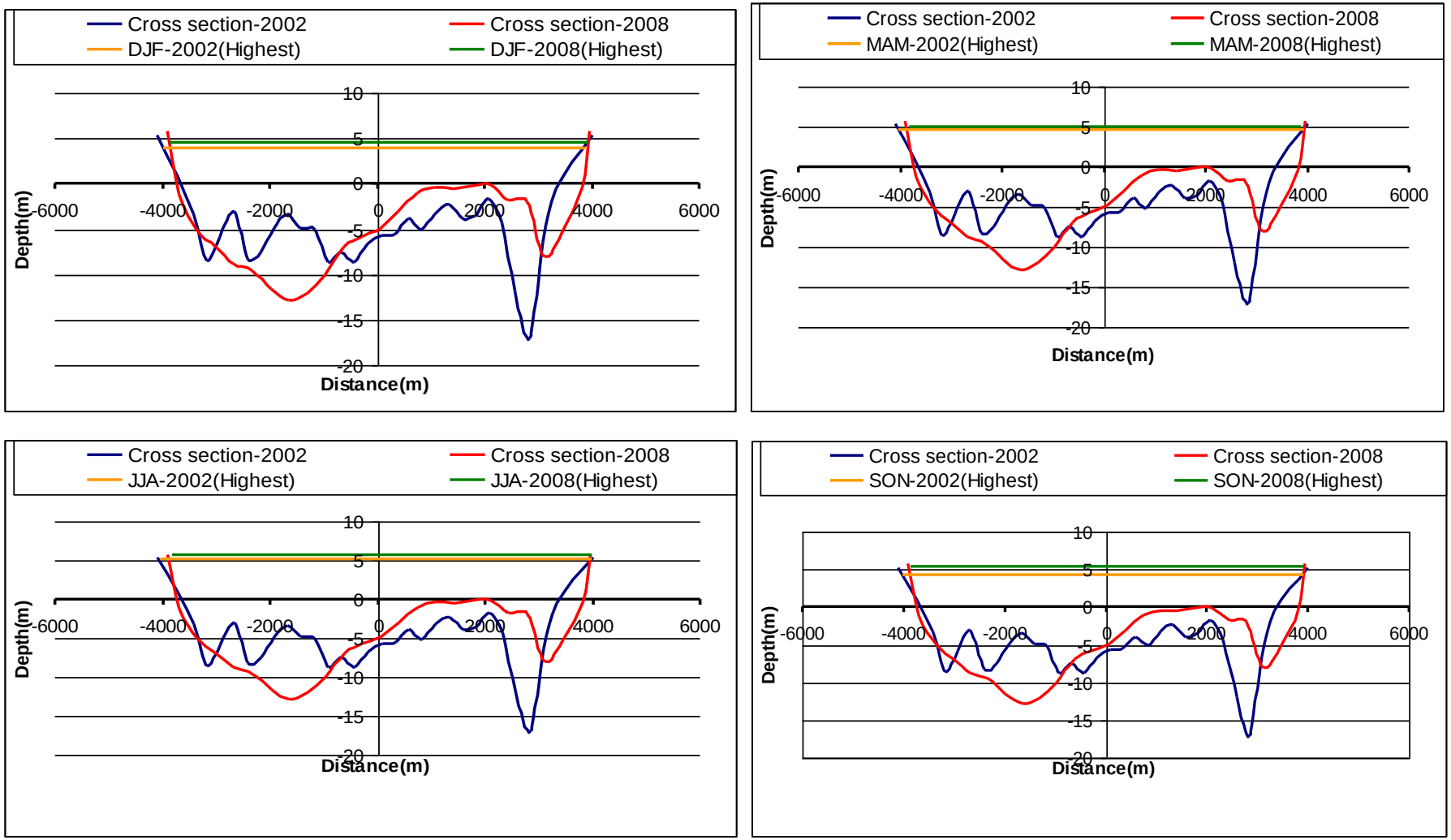

Figure 4.3.23 Comparison of Highest Water Level with corresponding cross section for the years 2002 and 2008 at Chitolkhali

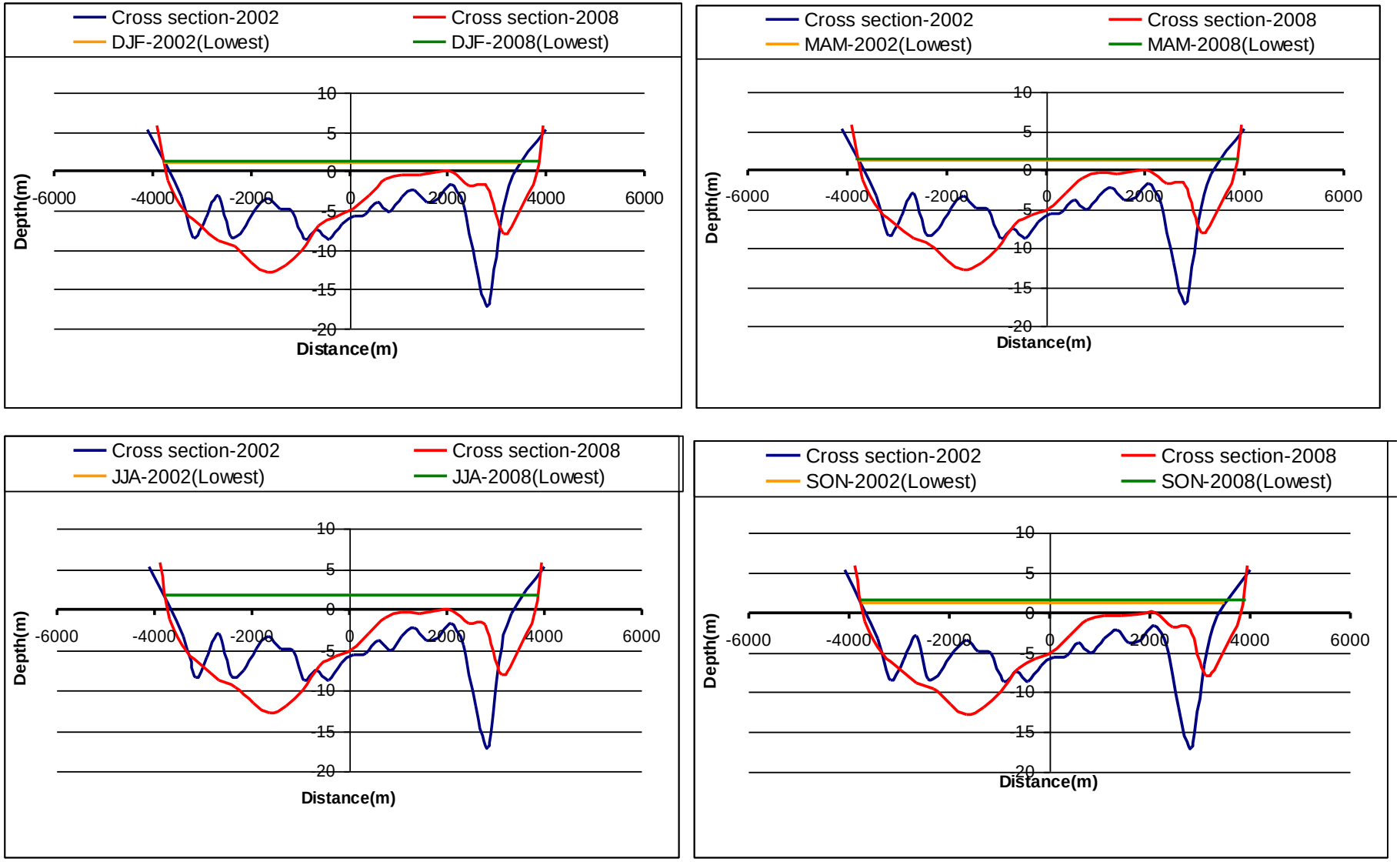

Figure 4.3.24 Comparison of Lowest Water Level with corresponding cross section for the years 2002 and 2008 at Chitolkhali

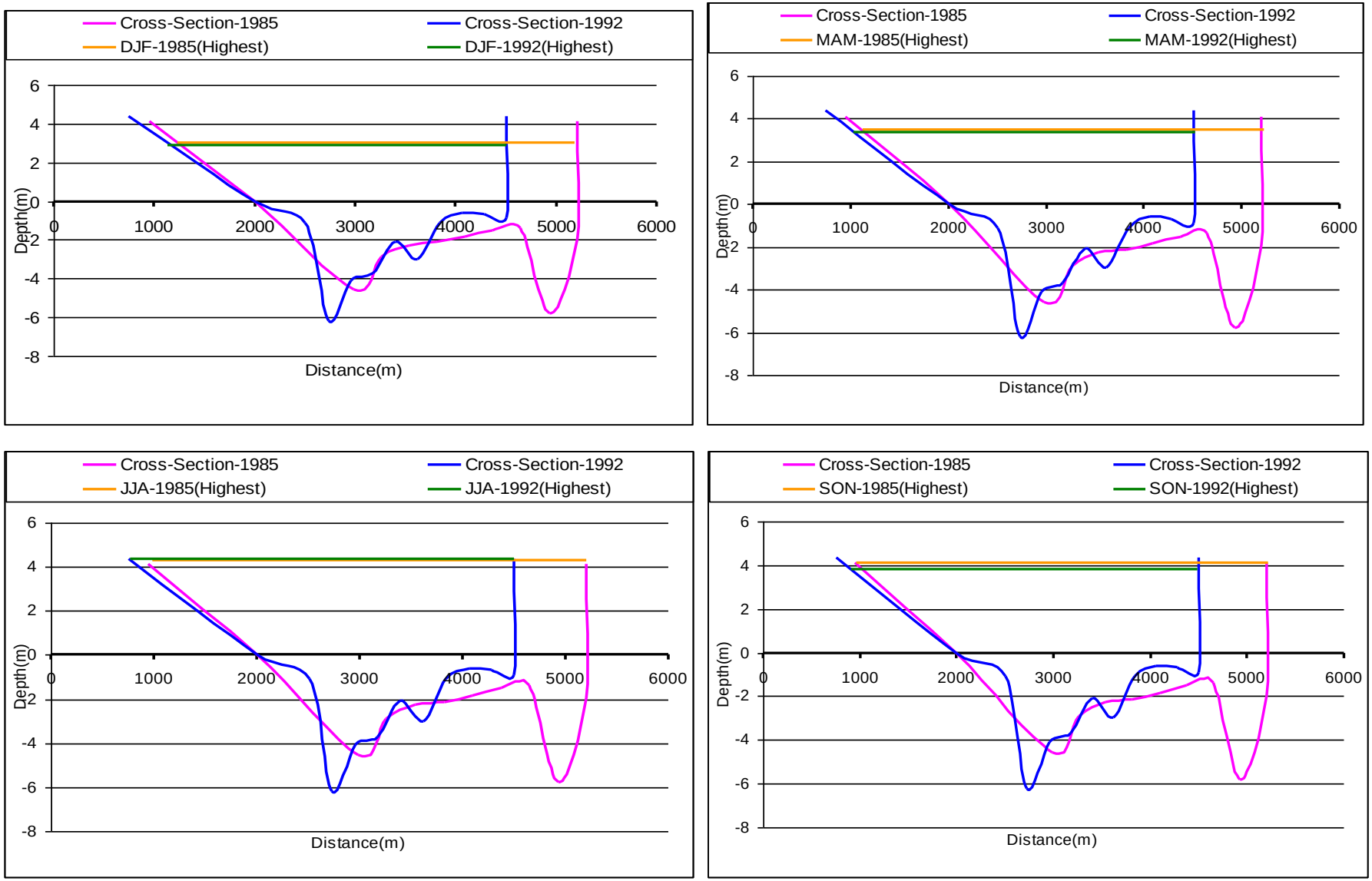

Figure 4.3.25 Comparison of Highest Water Level with corresponding cross section for the years 1985 and 1992 at Ramdaspur

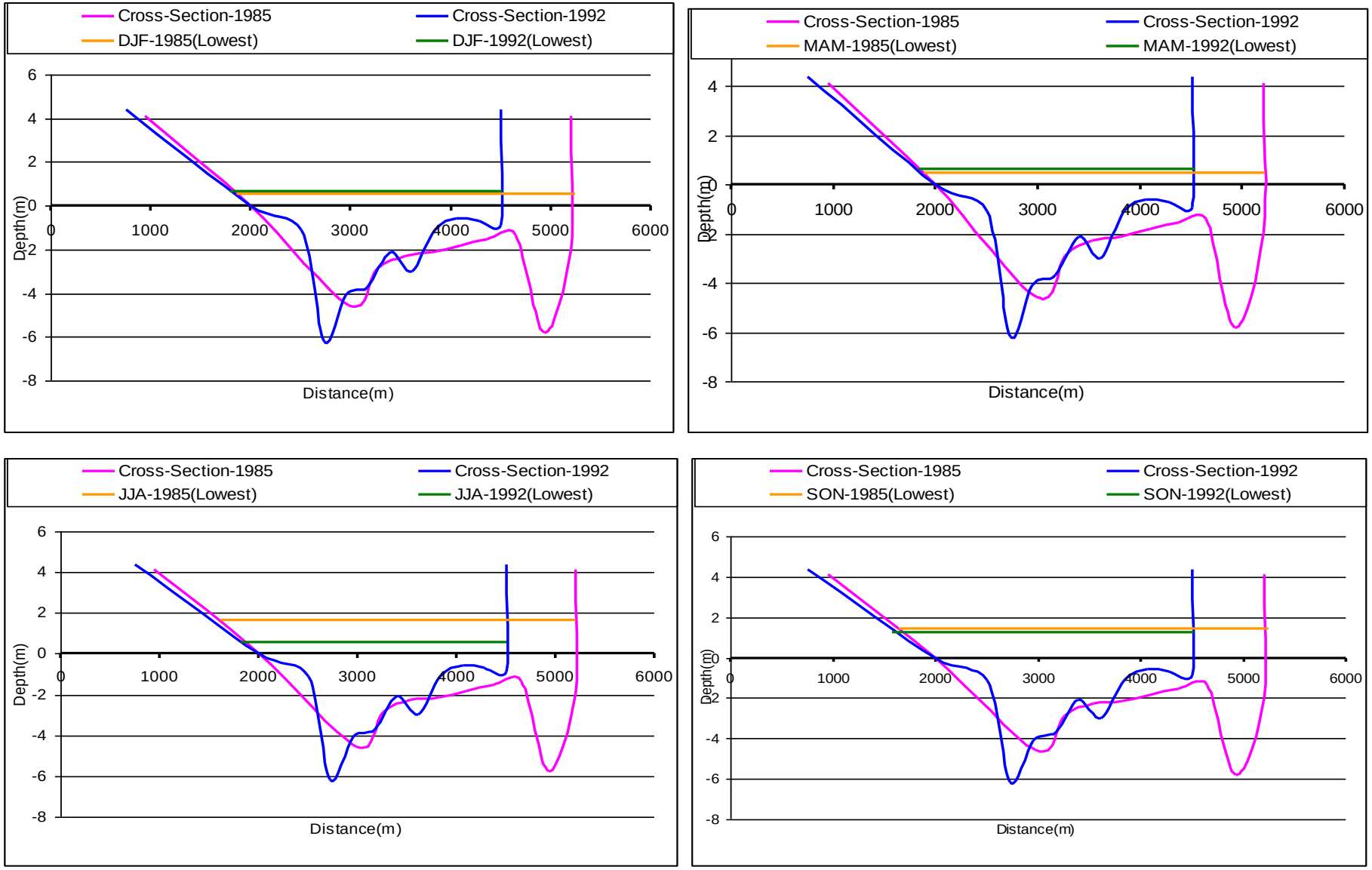

Figure 4.3.26 Comparison of Lowest Water Level with corresponding cross section for the years 1985 and 1992 at Ramdaspur

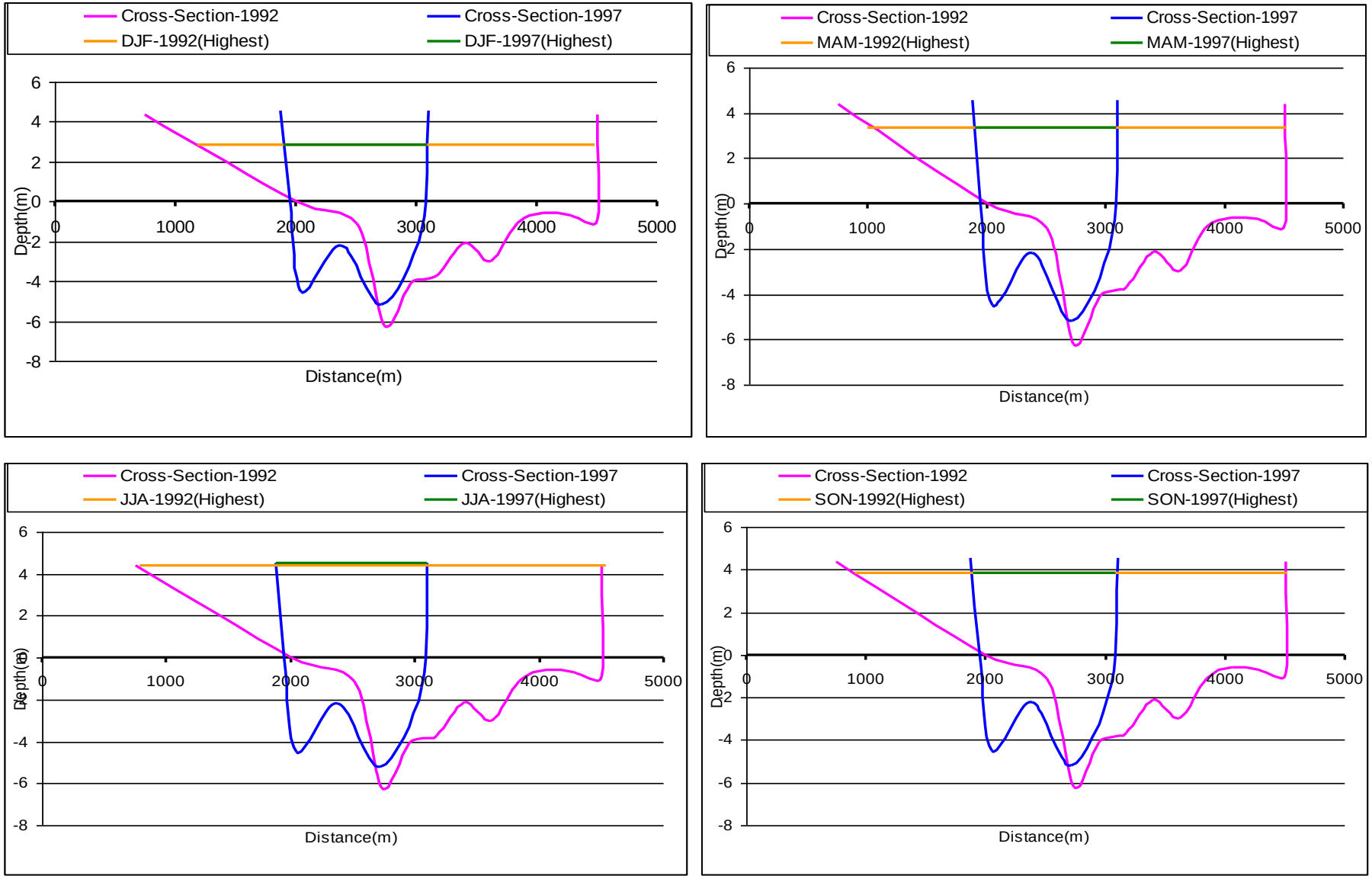

Figure 4.3.27 Comparison of Highest Water Level with corresponding cross section for the years 1992 and 1997 at Ramdaspur

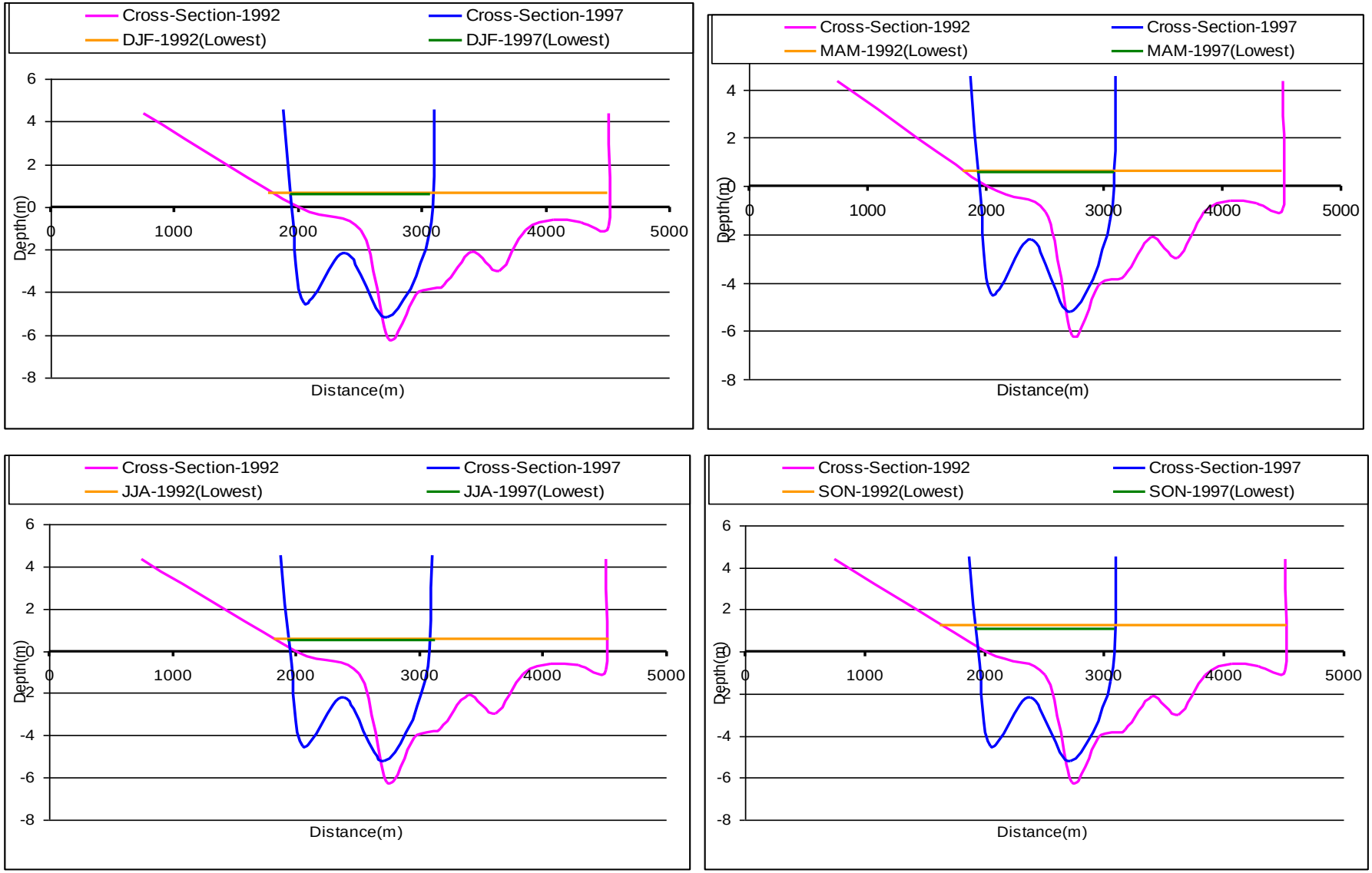

Figure 4.3.28 Comparison of Lowest Water Level with corresponding cross section for the years 1992 and 1997 at Ramdaspur

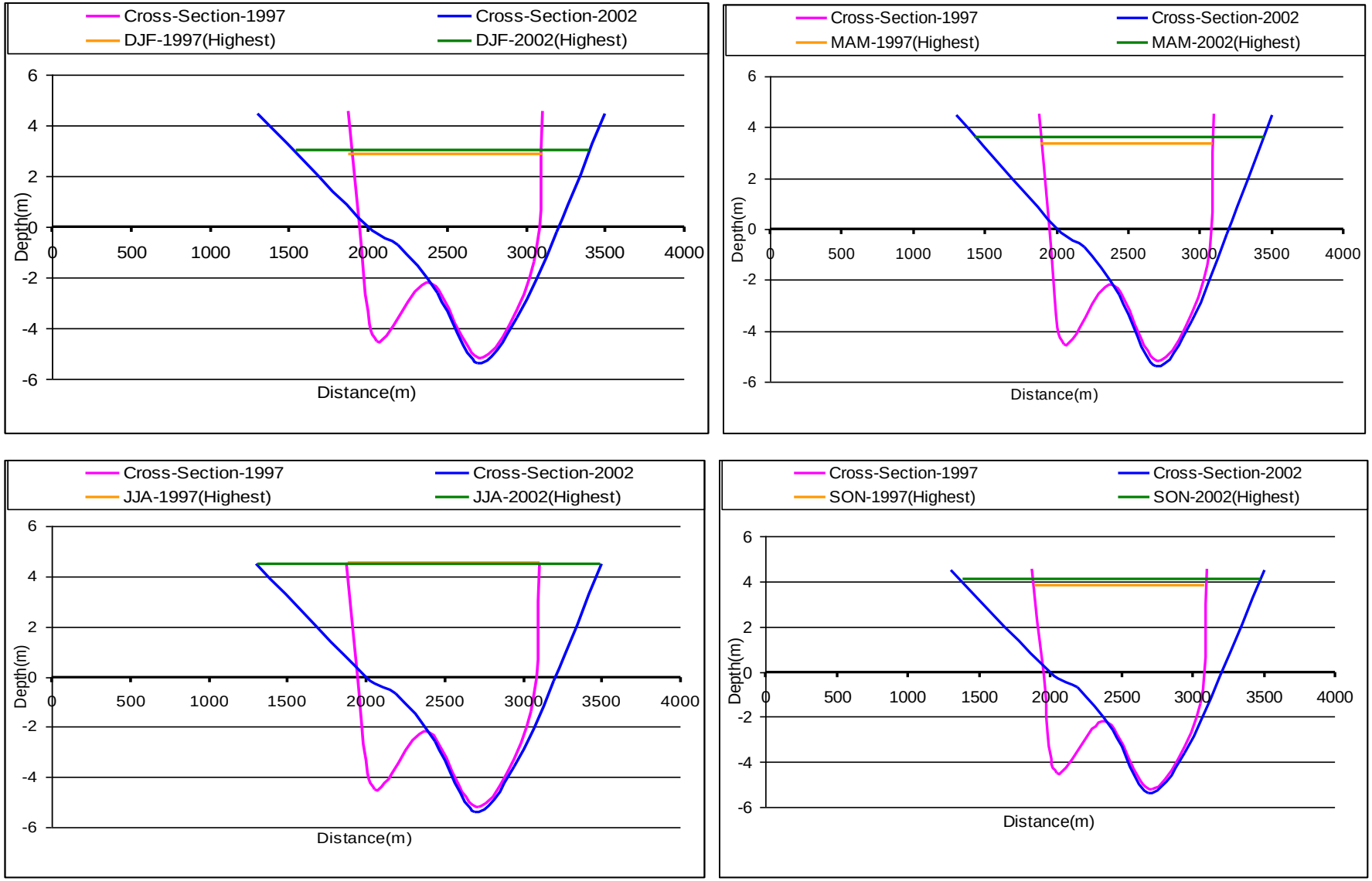

Figure 4.3.29 Comparison of Highest Water Level with corresponding cross section for the years 1997 and 2002 at Ramdaspur

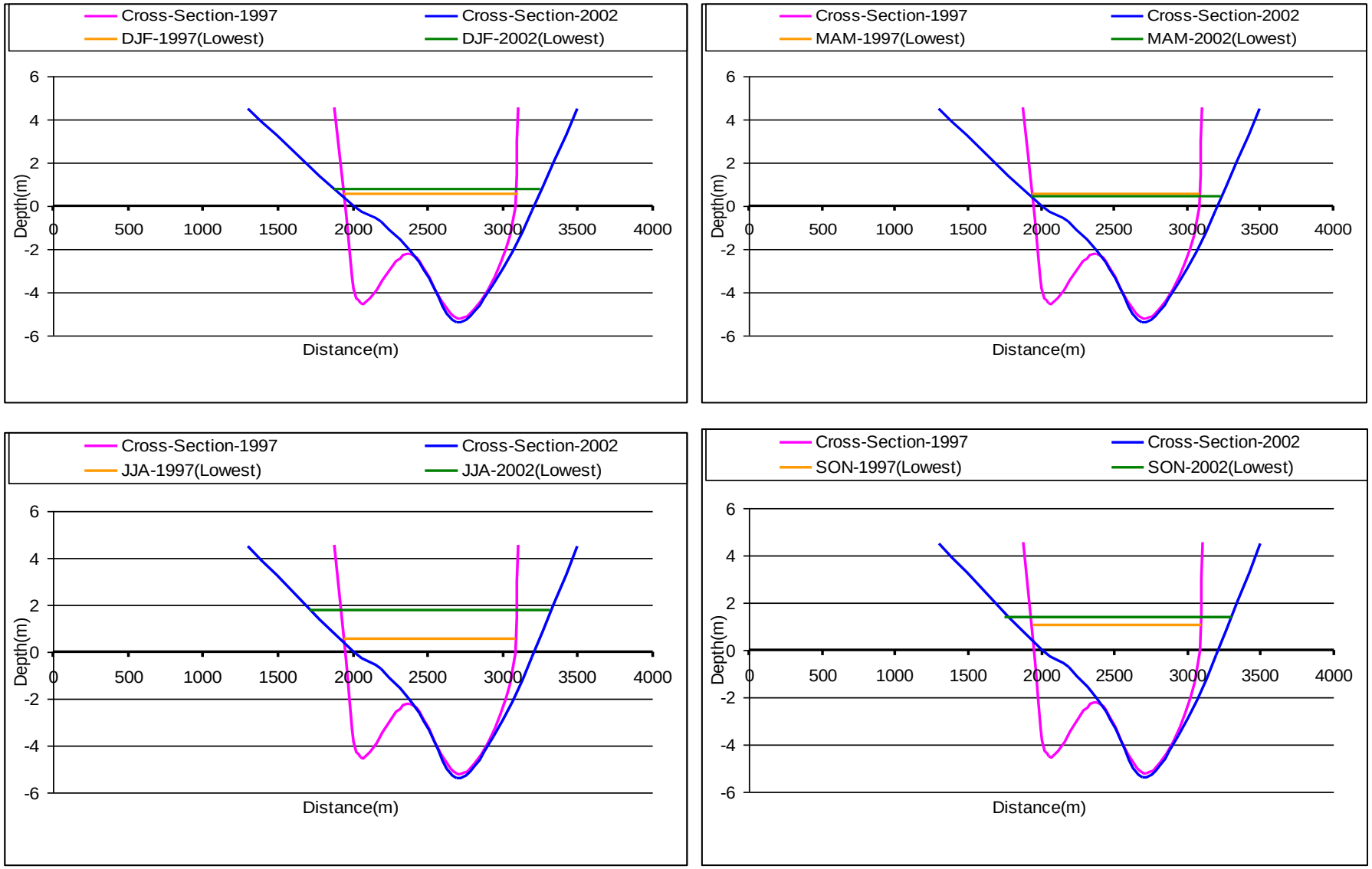

Figure 4.3.30 Comparison of Lowest Water Level with corresponding cross section for the years 1997 and 2002 at Ramdaspur

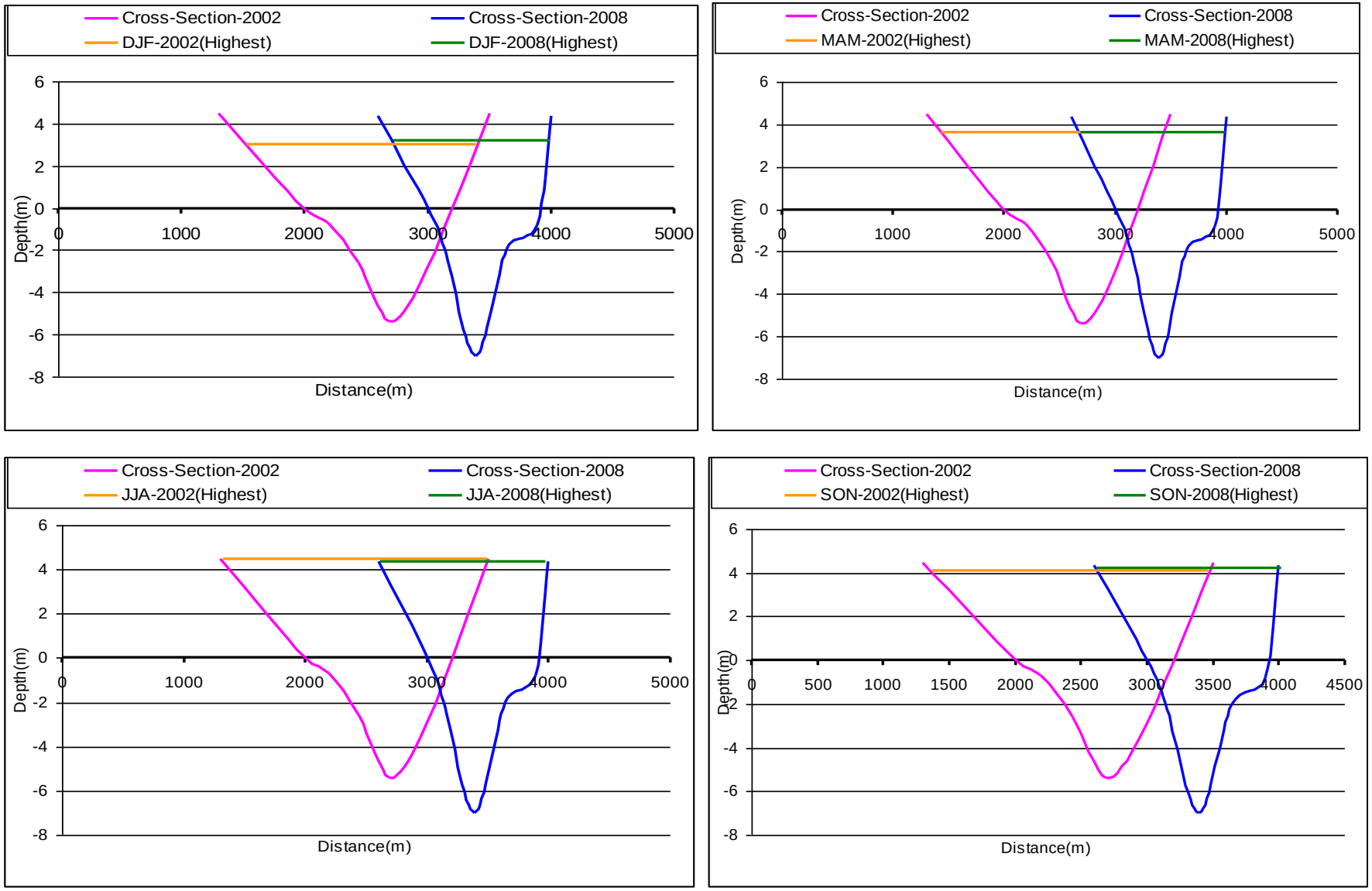

Figure 4.3.31 Comparison of Highest Water Level with corresponding cross section for the years 2002 and 2008 at Ramdaspur

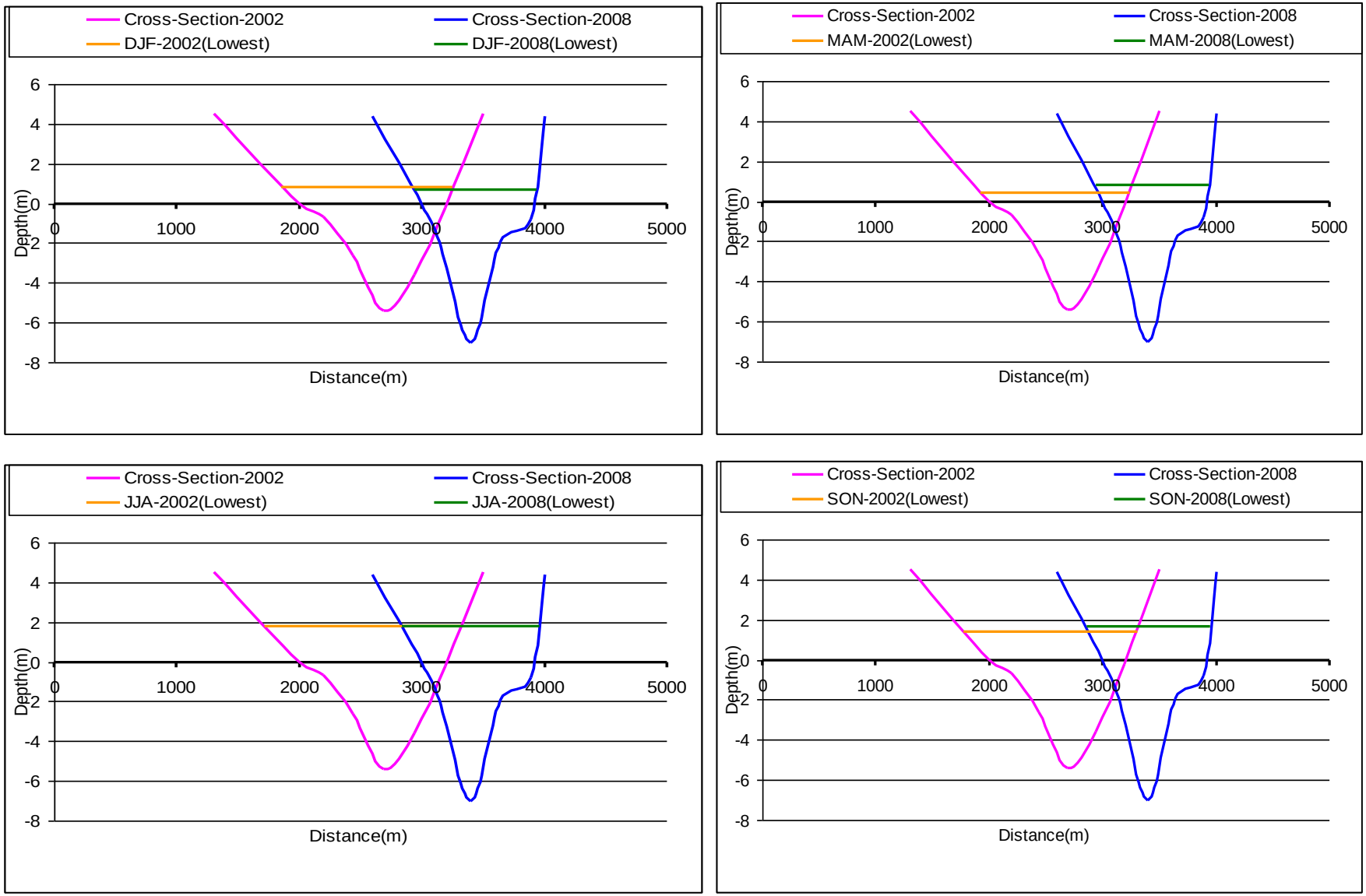

Figure 4.3.32 Comparison of Lowest Water Level with corresponding cross section for the years 2002 and 2008 at Ramdaspur

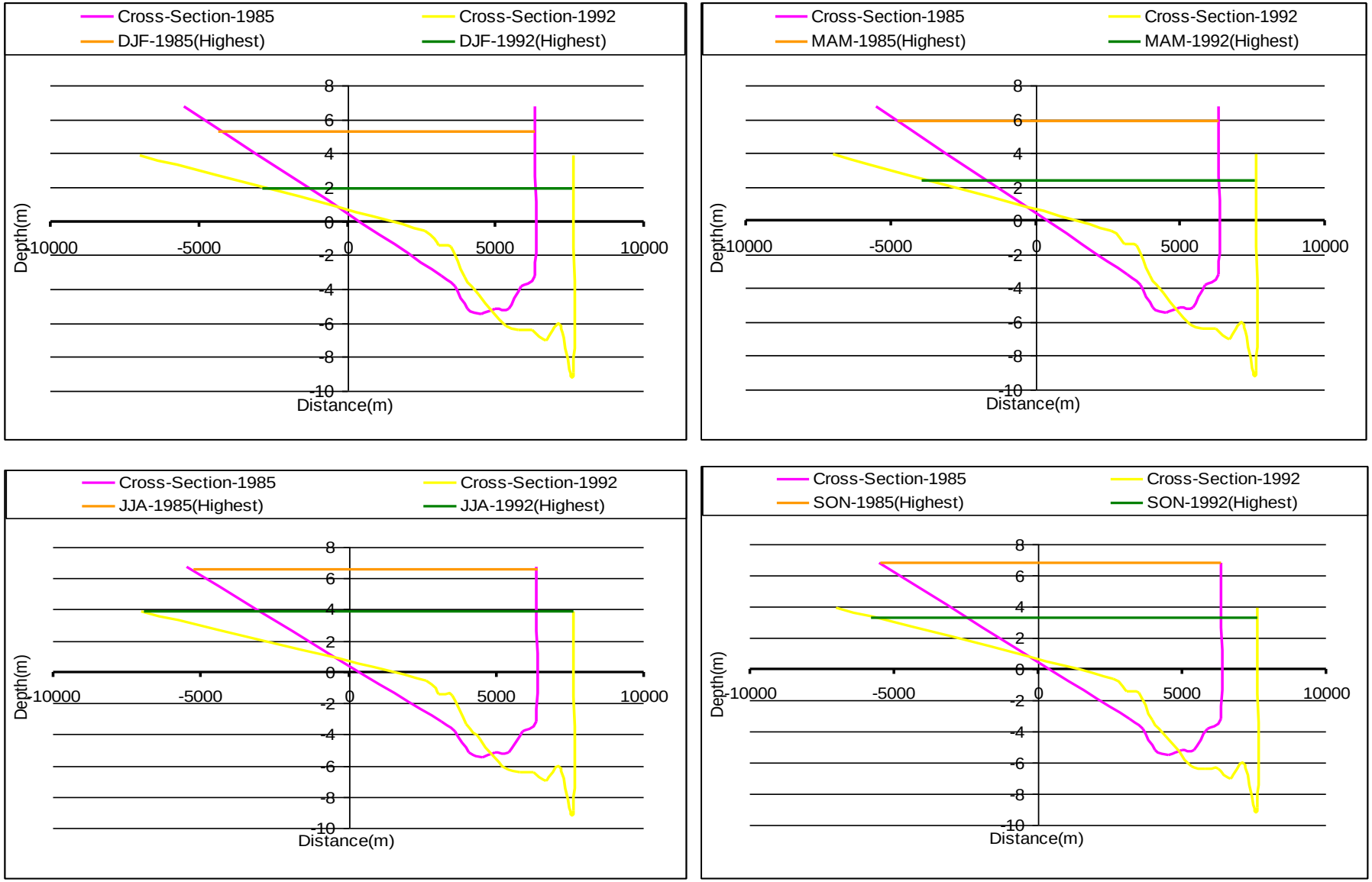

Figure 4.3.33 Comparison of Highest Water Level with corresponding cross section for the years 1985 and 1992 at Sandwip

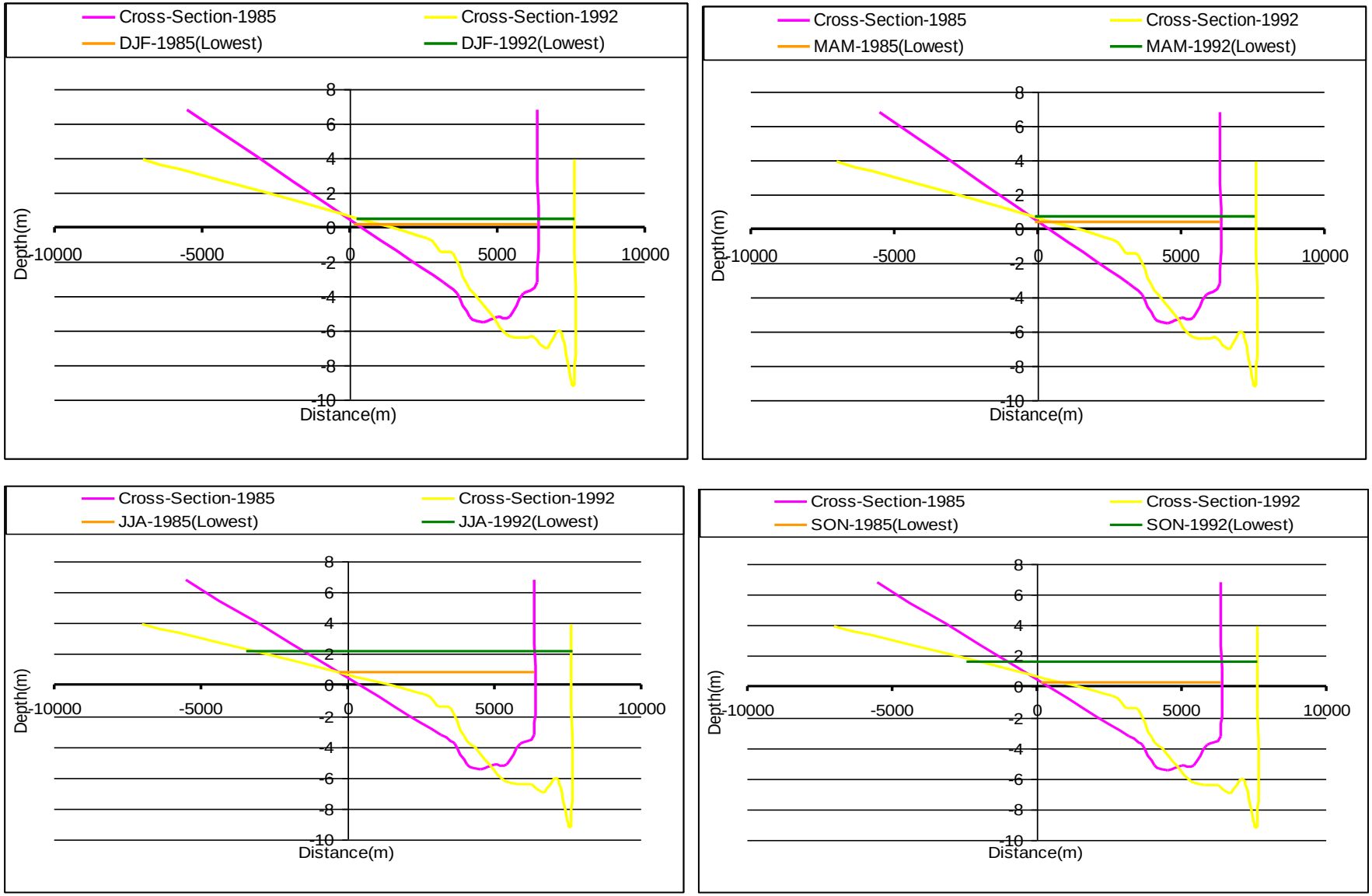

Figure 4.3.34 Comparison of Lowest Water Level with corresponding cross section for the years 1985 and 1992 at Sandwip

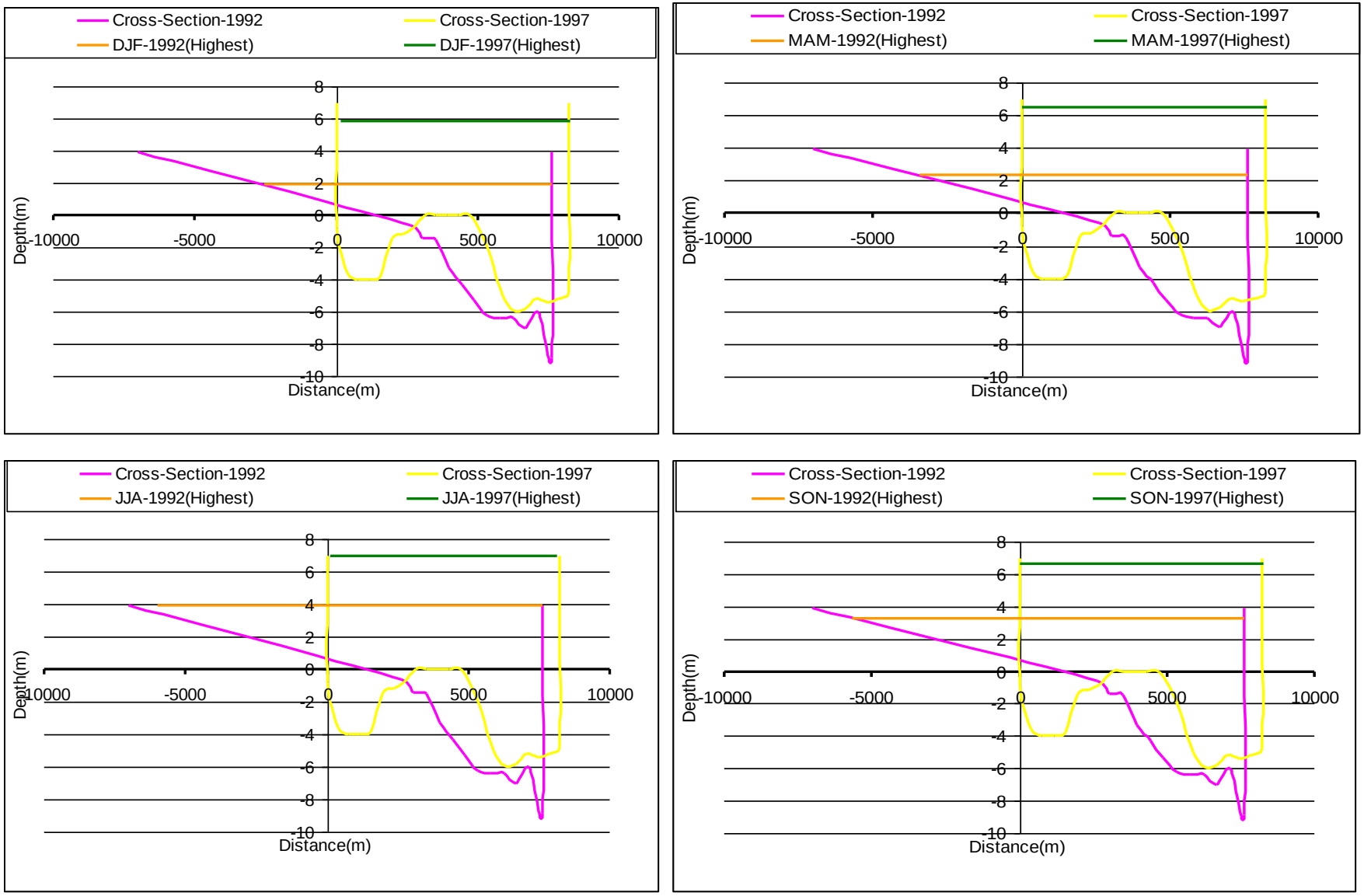

Figure 4.3.35 Comparison of Highest Water Level with corresponding cross section for the years 1992 and 1997 at Sandwip

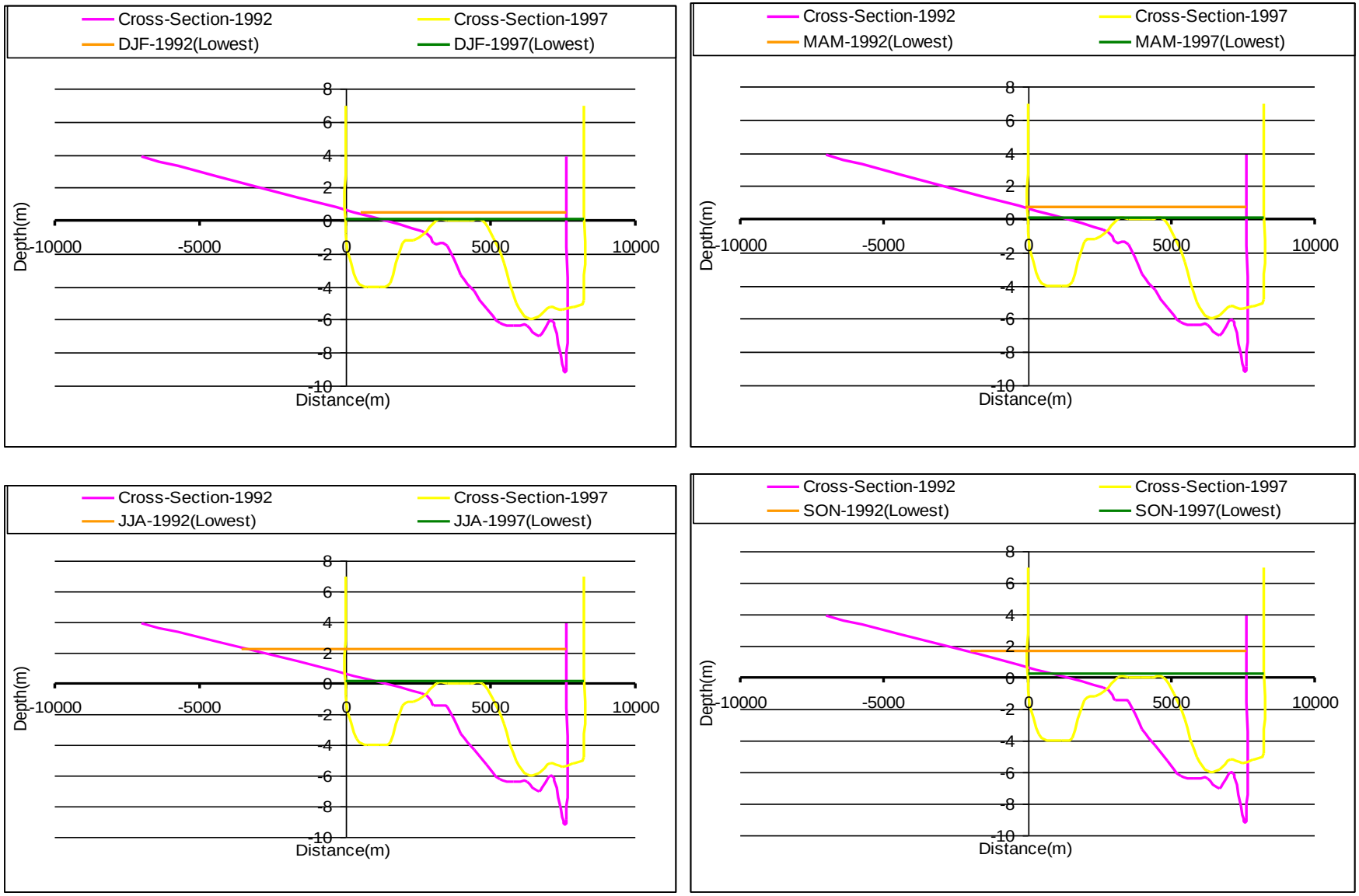

Figure 4.3.36 Comparison of Lowest Water Level with corresponding cross section for the years 1992 and 1997 at Sandwip

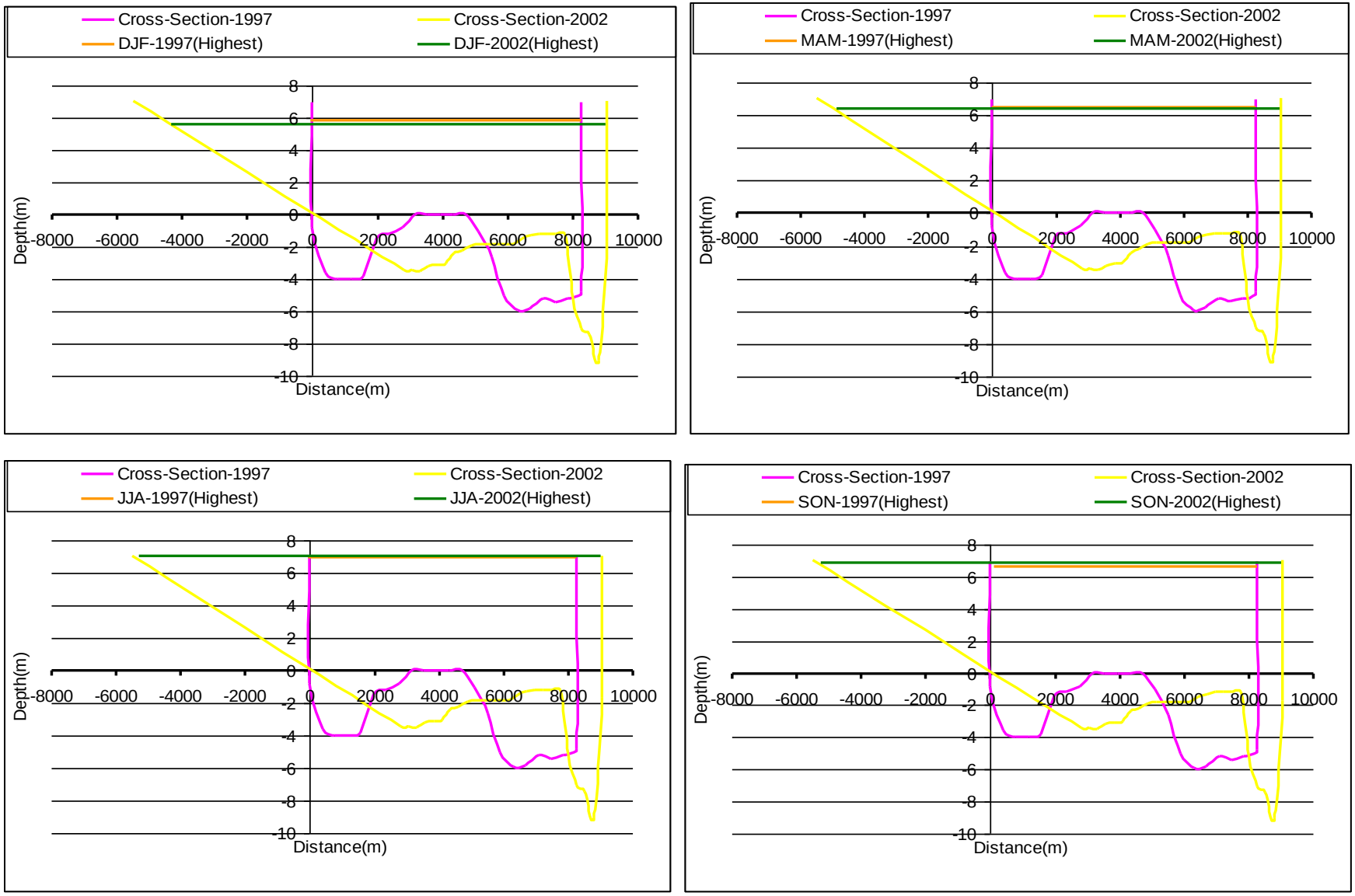

Figure 4.3.37 Comparison of Highest Water Level with corresponding cross section for the years 1997 and 2002 at Sandwip

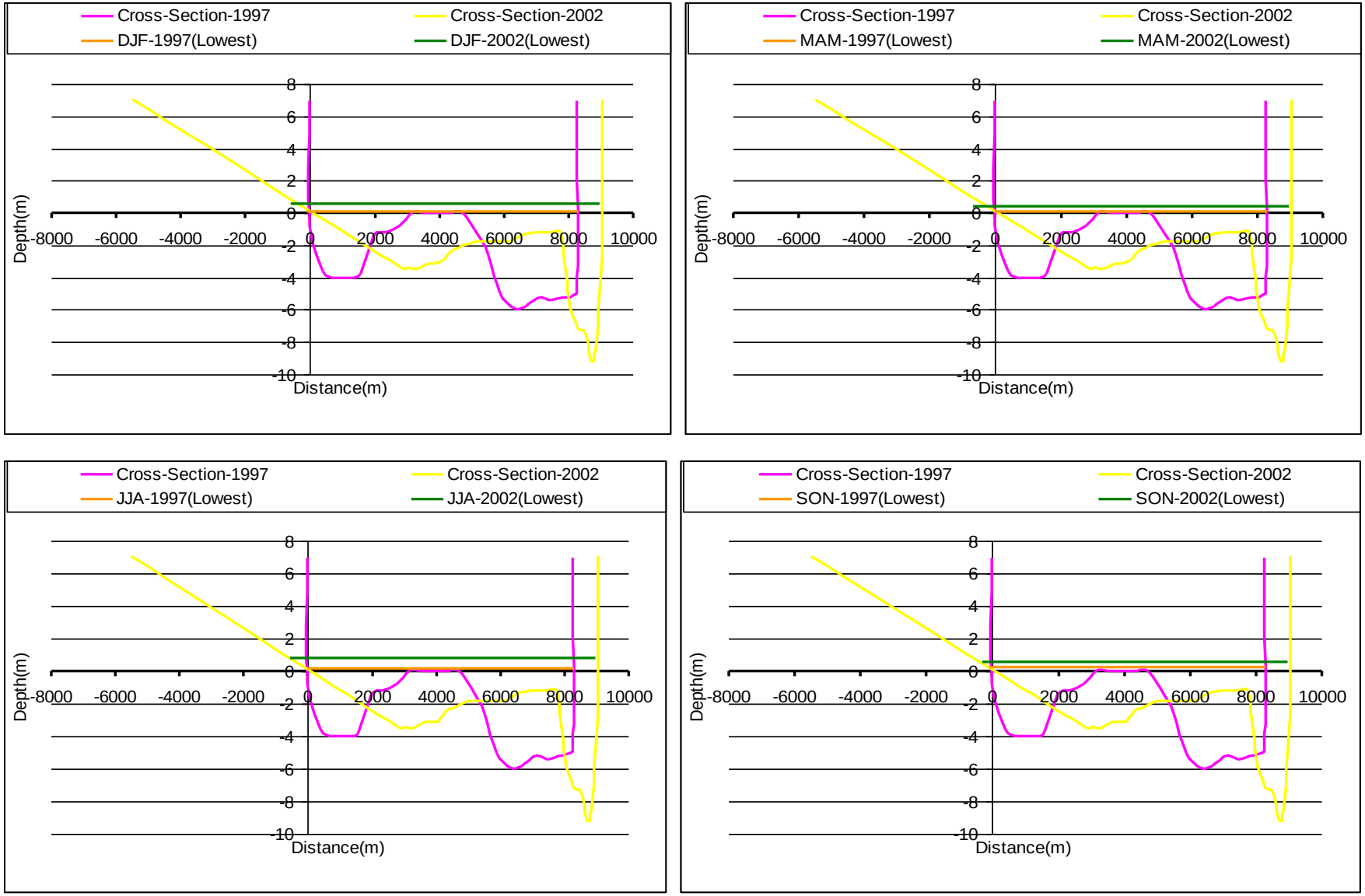

Figure 4.3.38 Comparison of Lowest Water Level with corresponding cross section for the years 1997 and 2002 at Sandwip

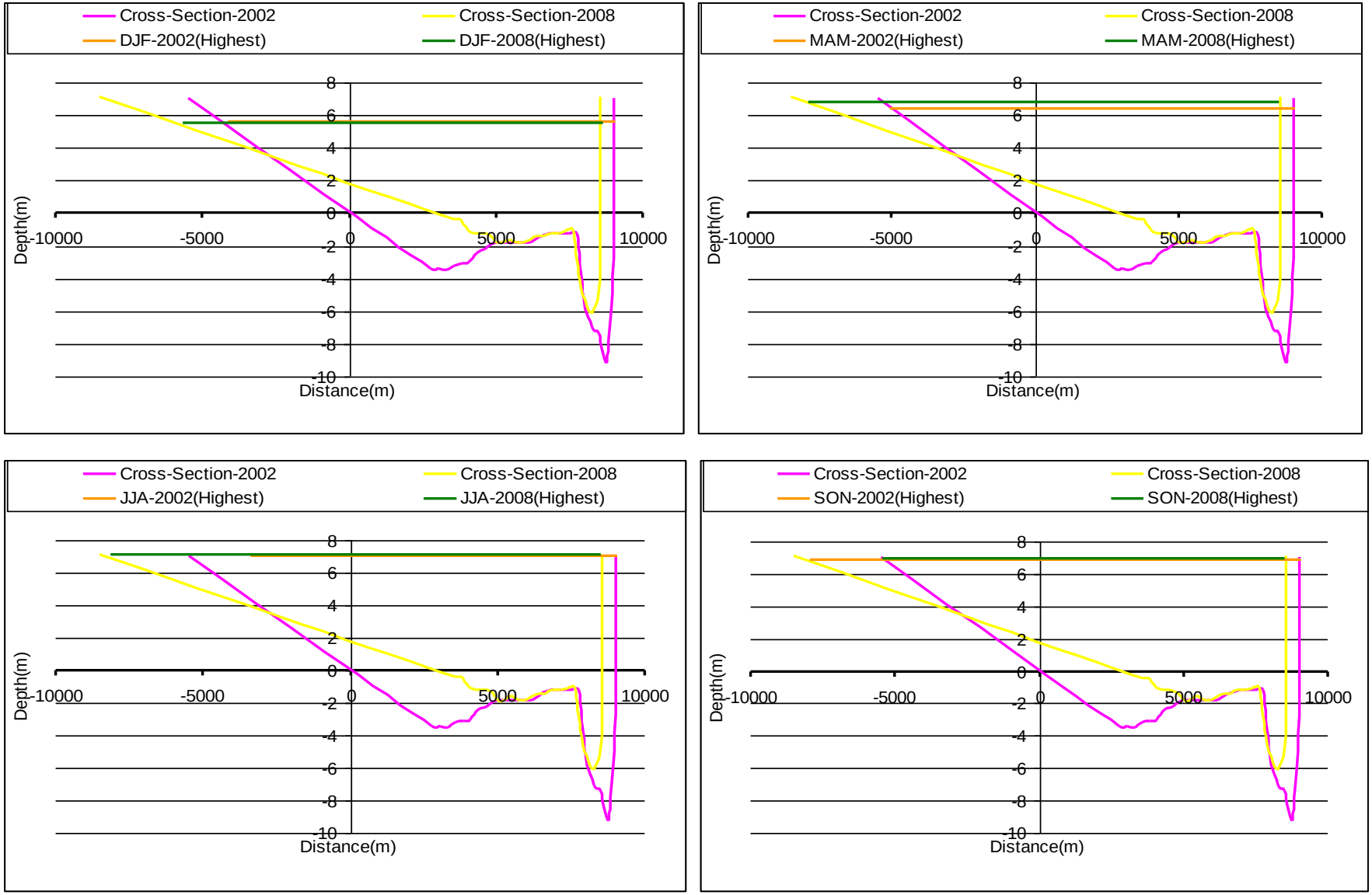

Figure 4.3.39 Comparison of Highest Water Level with corresponding cross section for the years 2002 and 2008 at Sandwip

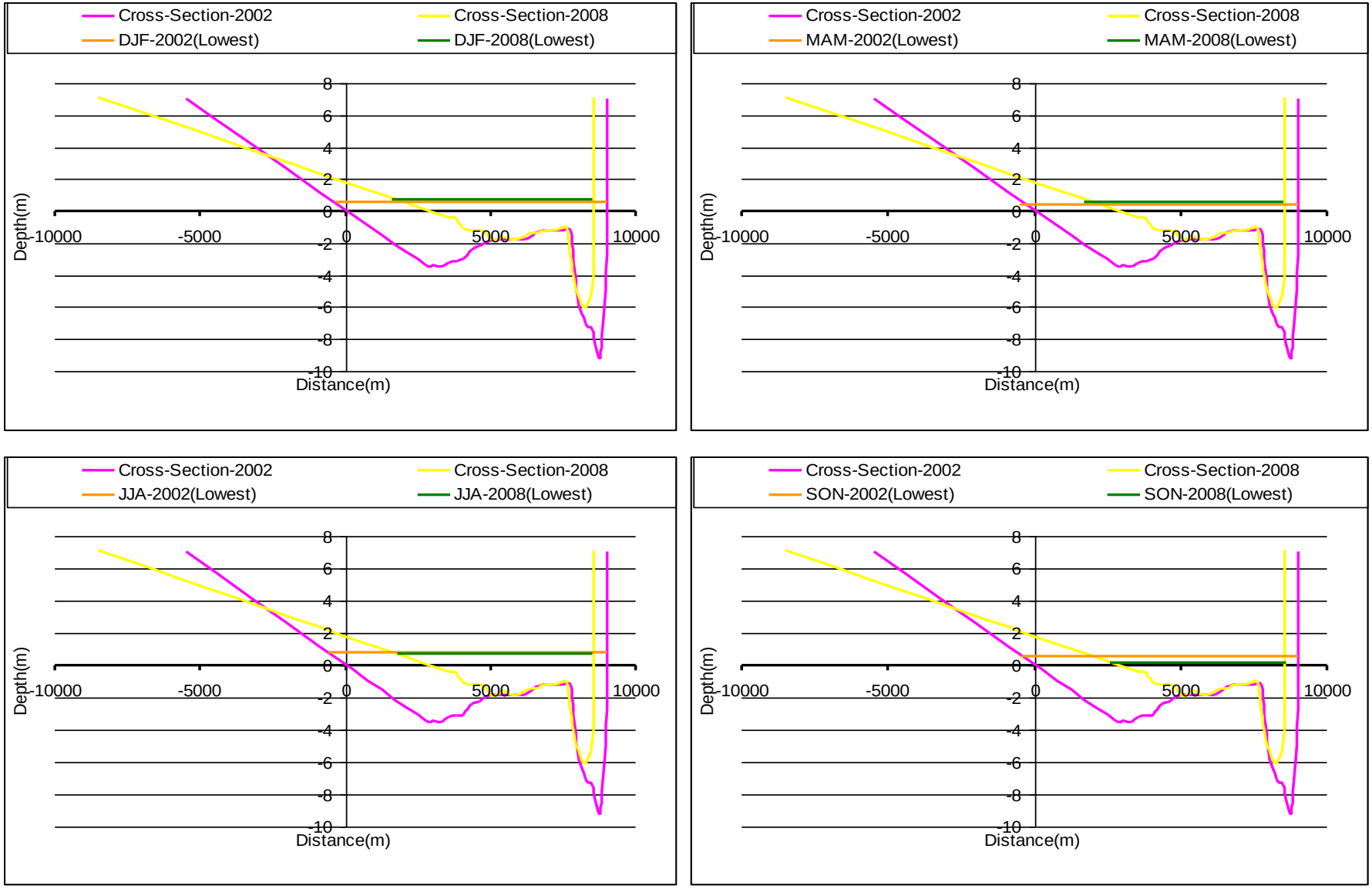

Figure 4.3.40 Comparison of Lowest Water Level with corresponding cross section for the years 2002 and 2008 at Sandwip