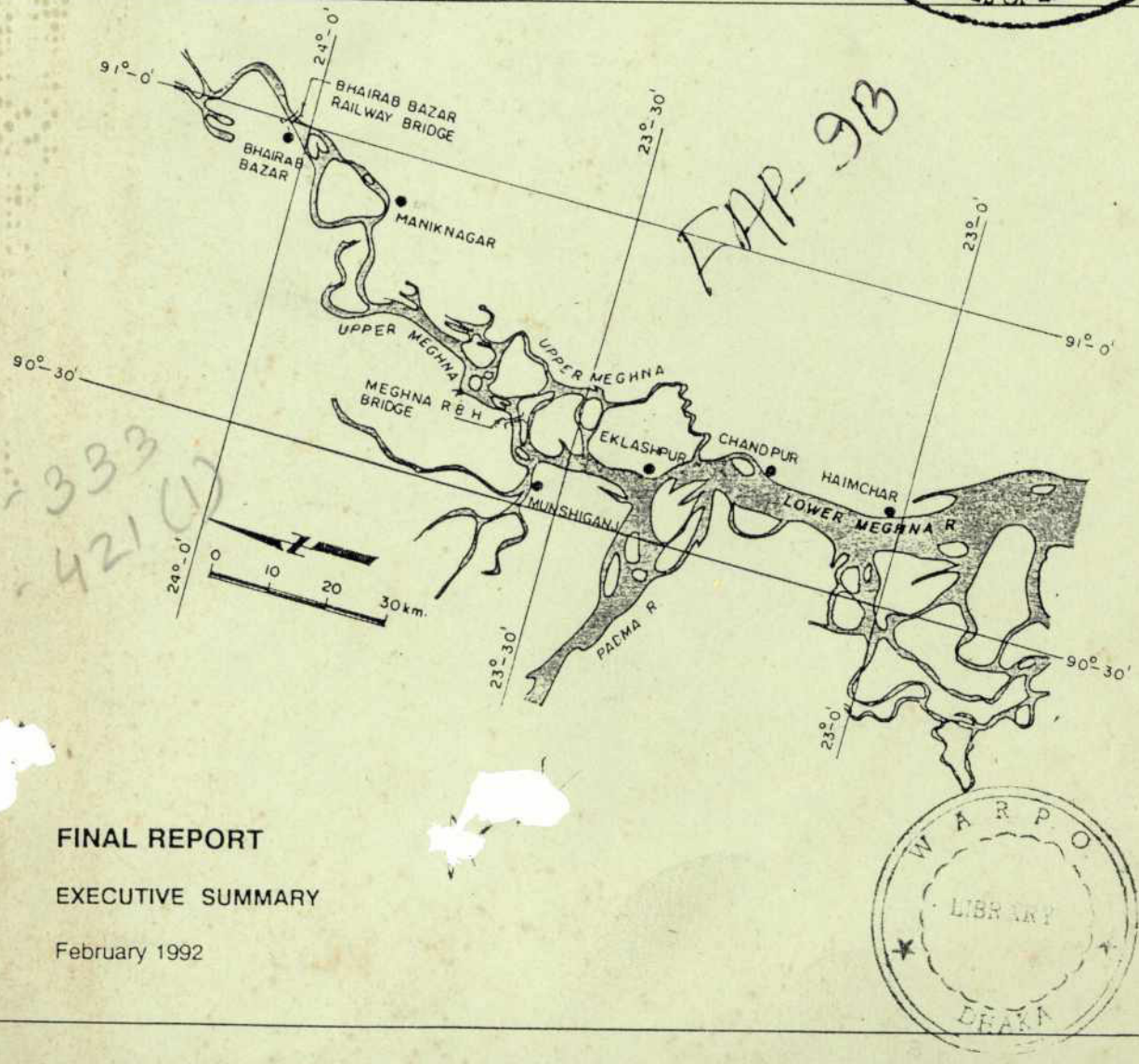
GOVERNMENT OF BANGLADESH

BANGLADESH WATER DEVELOPMENT BOARD

MEGHNA RIVER BANK PROTECTION SHORT TERM STUDY

IDA Credit 1870 BD (Part D), March 1990



FINAL REPORT

EXECUTIVE SUMMARY

February 1992

HASKONING, Royal Dutch Consulting Engineers and Architects

Delft Hydraulics

BETS, Bangladesh Engineering & Technological Services

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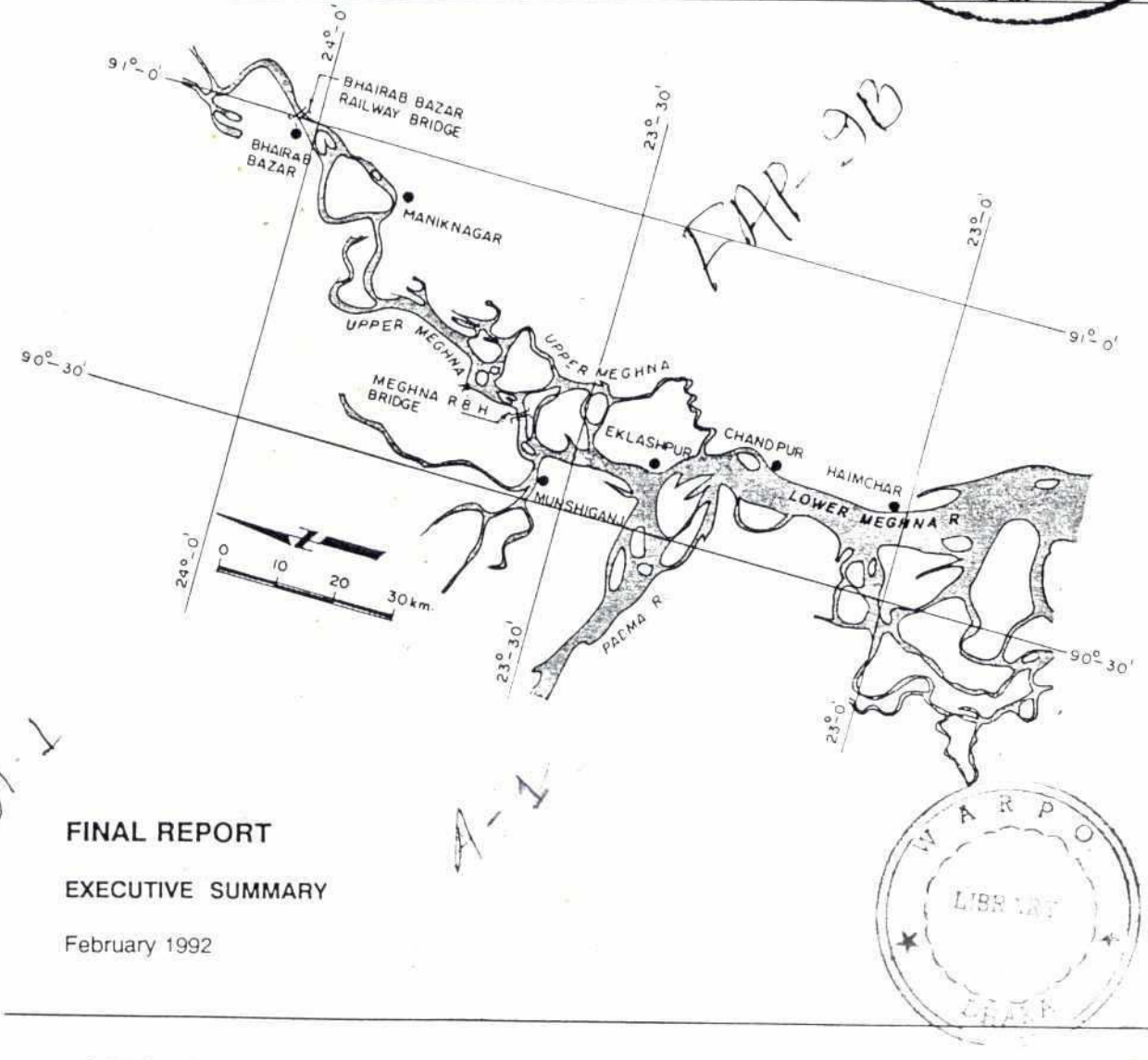

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MEGHNA RIVER BANK PROTECTION

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BACKGROUND

The Meghna, one of Bangladesh's major rivers, flows through the eastern part of Bangladesh and discharges into the Bay of Bengal.
The Meghna River drains an area of 77,000 km^2, of which about 46,500 km^2 is located in Bangladesh. The Ganges joins the Brahmaputra near Aricha and thereafter takes the name of the Padma. The Padma joins the Meghna at Chandpur. The Lower Meghna River conveys the melt and rain water form the Ganges and Jamuna basins, combined in the Padma River, and from the Upper Meghna basin to the sea. The total catchment area is about 1,637,000 Km^2. Maximum flows can be as high as 160,000 m^3/s. The major contribution of the discharge originates from the Jamuna River (annual average 19,642 m^3/s) and the Ganges River (annual average 10,874 m^3/s).

Like other rivers in Bangladesh the Meghna erodes it banks in many points and this erosion has assumed an alarming magnitude since the severe floods of 1987 and 1988. Consequently, a number of locations requires prompt attention to prevent further damage or even events of a catastrophic nature.

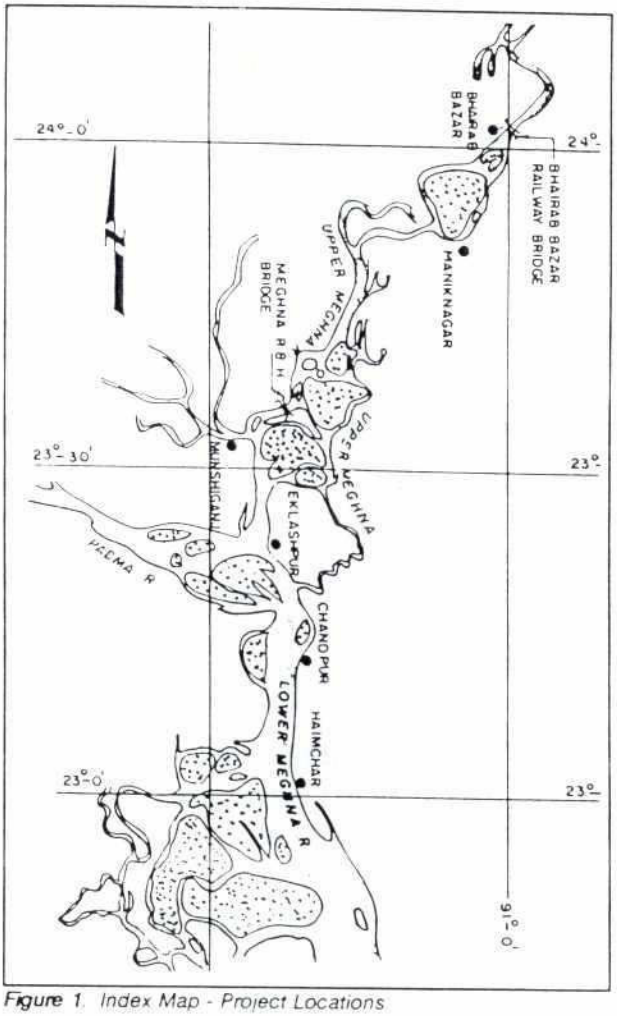

Figure 1. Index Map - Project Locations

SCOPE OF CONSULTING ACTIVITIES

The original Terms of Reference for this project, were prepared in September 1989. On 5th of September 1990 a Contract for Consulting Services was signed between the Bangladesh Water Development Board and HASKONING, Royal Dutch Consulting Engineers and Architects in association with DELFT HYDRAULICS and BETS, Bangladesh Engineering and Technological Services for carrying out the Meghna River Bank Protection Short-Term Study, financed under the Credit IDA BD-1870, Part D.

The Meghna River Bank Protection Short-Term Study, is now one of the main components of the Flood Action Plan for Bangladesh (FAP-9B. MEGHNA LB PROTECTION PROJECT), as included in the Review Report FPCO, December, 1990.

The BWDB, in the meeting held on April 14th and later in May 29th, 1991, in a meeting between the BWDB, FPCO, World Bank and Consultants, agreed an extension of the Consulting Services until March, 1992. It was agreed that the initial Terms of Reference (TOR) for Consulting Services would be revised to conform the revised work programme. ,These Revised Terms of Reference (TOR) contain the consequential revisions incorporated into the standard format for TOR adopted by the Flood Plan Co-ordination Organization (FPCO) for all FAP studies.

PROJECT SITES

The reach of the Meghna River from Bhairab Bazar to Haimchar is about 160 km in length. Width of the river varies from 1 km to more than 10 km. The river channel is more or less well defined upstream of its confluence with the Padma and is braided in the reach downstream of Chandpur. The river is rather deep all along and the depth ranges to 35 m in the bends. The river bed and banks consist mainly of fine sand and silt which are often loosely packed and susceptible to liquefaction at some places. Of the three major rivers, the Meghna carries relatively less sediment. The velocity of flow of the river is high during monsoon. The river banks are also subjected to substantial wave attack at some points.

In view of the river bank erosion problems (disruption of economic activities and dislocation of thousands of people every year), the Government of Bangladesh (GOB) and BWDB, in coordination with FPCO planned to make a comprehensive study on the Meghna River (LB) with a view to devising ways and means for preventing erosion and improvement of the existing protections at the following locations which require prompt attention:

- The Railway bridge at Bhairab Bazar;
- Bhairab Bazar Township along the right bank;
- Maniknagar; along the left bank, falling within the proposed Gumti; Phase II Project;
- Meghna R & H Bridge;
- Eklashpur (near Meghna-Dhonagoda irrigation Project);
- Chandpur Town;
- Haimchar (adjacent to Chandpur Irrigation Project); and
- Munshiganj Town; along the right bank of the Dhaleswari river.

The sites to be considered in the Short-Term Study were divided into two different groups: the sites along the Upper Meghna and the Dhaleswari River (Bhairab Bazar, Maniknagar, Meghna Road and Highway Bridge and Munshiganj) and the sites along the Lower Meghna (Eklashpur, Chandpur and Haimchar).

STUDY OBJECTIVES

The objectives of the short term study are:

- to provide short term measures for protection against erosion for 7 locations on the Meghna river and one location on the Dhaleswari;
- to define a coherent and phased programme of works, aiming at the control of erosion on the defined stretches of the rivers Meghna and Dhaleswari. The protection of the locations indicated above should logically fit in this programme.

PRIORITY SITES

Bhairab Bazar (Town and Railway Bridge).

Bhairab Bazar, a major inland port in Bangladesh, is located upstream of the confluence of Meghna River and the old Brahmaputra River. The historical township is a centre of commercial and industrial activity with a strategic location at the hub of vital rail, road and water routes.

The present and future position of the township is threatened by the eroding force of the Meghna. The river not only threatens commercial and industrial buildings along its waterfront, but also the railway bridge located on the northern fringe of the town and two power towers in the downstream part, close to the confluence with the Old Brahmaputra River. The bridge is vital in the network of Bangladesh Railways as it is the only means of crossing the Meghna in the railway network linking Chittagong and Sylhet to the western part of the country.

Munshiganj Town.

Munshiganj, the centre of potato growing in Bangladesh is located on the Dhaleswari River. As a result of the importance of potato growing in the region, the town harbours a large number of cool stores where the product is kept in store. In addition to this cold storages, industrial activity, comprising of many twining and spinning works and rice mills, is also important in Munshiganj.

The present and future position of the township is nevertheless constantly threatened by the eroding force of the Dhaleswari River. The river not only threatens commercial and industrial buildings along its waterfront, but also the road along the riverbank and the ferry ghat upstream. Until this moment actions taken to counter the erosion of the riverbank have been few. Some effort to protect the ferry ghat were made by the Roads and Highway Department, while the Municipality and private entreprises undertook actions to protection the waterfront.

Chandpur Town

Chandpur is an important inland harbour on the Lower Meghna. Its location on one of the waterways leading to Dhaka and India has made Chandpur a strategic centre of commercial and industrial activity. In the old days the town played an important role as the point where railway and river transport met. Although the importance of railway transport has declined, Chandpur is at present, and will remain so in the future, beyond any doubt an important trading and industrial centre in the national economy of Bangladesh.

The present and future position of the township is nevertheless constantly threatened by the eroding force of the Lower Meghna River. The river not only threatens public assets and private commercial and industrial buildings along its waterfront, but could make Chandpur into an isolated island, completely surrounded by the waters of the Meghna. The serious threat by the ever active and unpredictable river has been for years the focus of studies and research.

Much effort has been made to protect Chandpur against the Lower Meghna currents. As a result of the protection works executed by the Railway and later the BWDB, the rate of migration of the riverbank has considerably been reduced, contributing also to the protection of the Meghna-Dhonagoda and Chandpur Irrigation projects, situated north and south of the town respectively. However, in spite of all the (temporary and emergency) bank protection works carried out so far, the left bank of the Meghna, both upstream and downstream of Chandpur town has shown considerable migration. Without proper action and permanent river bank protection works, this will eventually lead to the outflanking of the town.

THE FINAL FEASIBILITY REPORT

The Report comprises the Consultants' work in response of the revised Terms of Reference which require Consultants to submit:

- feasibility studies, detailed designs and tender documents for the priority sites:
  - Bhairab Bazar and Railway Bridge,
  - Munshiganj,
  - Chandpur,
  - feasibility studies and tender documents for erosion protection at the sites:
  - Chandpur (Emergency protection works),
  - Eklashpur, and
  - Haimchar.

- pre-feasibility studies for erosion protection at the sites:
  - Maniknagar,
  - Roads & Highways Bridge.
- tender documents for the Meghna Lower Long-Term Strategic Plan.

The documents presented include:

- A main Report and eight Annexes (A to G and I), comprising the (pre-) feasibility studies and detailed designs,
- Tender documents for the aforementioned sites in five contract packages:
  - Package I: Chandpur Town.
  - Package II: Bhairab Bazar and Munshiganj.
  - Package III: Chandpur Town, Nutan Bazar, emergency works.
  - Package IV: Eklashpur.
  - Package V: Haimchar.

The Report consists of seven volumes comprising a Main Report and eight Annexes A to G and I. Some Annexes are accompanied by a series of APPENDICES containing detailed information or supporting data relevant to them.

Vol I			Main Report
Vol II	Annex	A :	Hydrology
		B :	River Morphology and Geomorphology
Vol III	Annex	C :	Geotechnical Investigations
Vol IV	Annex	D :	Scale Model Studies
		E :	Mathematical Model Studies
Vol V	Annex	G :	River Bank Protection
Vol VI	Annex	F :	Economics of Protection Works
Vol VII	Annex	H :	(not used)
		I :	Environmental Impact Assessment.

Chapter 2 of the Main Report sets out the approach to the study; Chapter 3 deals with engineering investigations, and site assessments which have been carried out to arrive at optimum bank protection designs; Chapter 4 discusses project designs. Chapters 5 and 6 deal with risk analysis, probabilistic design, construction methods and programmes all having a direct bearing on the Project Designs. Chapter 7 presents the environmental impact assessment made. Monitoring and maintenance for the various projects proposed are considered in Chapter 9. These projects are costed in Chapter 8. Finally, their economic feasibility has been evaluated (Chapter 10).

PROJECT DESIGNS

The general design approach was elaborated upon in the Interim Report. As part of this approach alternative solutions for bank protection works at the various sites were generated, evaluated and a preliminary selection made. Subsequently, the selected alternatives have been considered in greater detail and dimensioned on the basis of known constraints (boundary limits), design loading, construction materials etc.

Three design loads have been used for testing (by means of the probabilistic method) the probability of failure of the protective layer designed earlier These are:

- scour depth
- current attack
- wave attack

GEOTECHNICAL DATA

The site investigation comprised sinking of 8 bore holes (2 bore holes per site, depths of 20 - 30 m). in conjunction with sampling and Standard Penetration Testing. Extracted undisturbed and disturbed samples were tested in the laboratory for strength properties, classification, granulometry and chemical composition.

The overall assessment and choice of design parameters, to allow slope stability analyses to be carried out, was supplemented by data concerning the geological features and earthquake criteria attributed to the project area. Consequently, the following shear parameters have been chosen to define effective stress conditions:

GEOTECHNICAL DESIGN PARAMETERS FOR SLOPE STABILITY ANALYSIS

Layer	Description	Density [kN/m^3]		Long term stability	
		dry	saturated.	ø'(°)	c'[kN/m^2]
I	FINE SAND, with silt	15.5	19	27	-
II	SILT, with sand & some clay	14.4	19	25	-
III	SILT, with clay some sand	15.2	18	20	10

SLOPE STABILITY CONSIDERATIONS

It has been recognized that exposed slopes, mainly developed at the outer bends of the river bed, are most prone to the effects of the erosive action of currents. Wave attack may further aggravate the erosion of surface layers. The visible effects of receding river banks, however, mainly originate in the events taking place below water level.

Slope protection works would serve to control the effects of currents, wave attack and alternating flow patterns, to ensure that an initially overall stable slope angle will remain intact. This slope stability condition is being referred to as micro slope stability.

Detailed numerical analyses show that without exception a slope gradient of 1:3.5 (vertical : horizontal) will be required to meet the safety factors for macro-stability, whether or not some layering can be expected. It then follows that:

(i) The governing loading condition will develop when combining static load with the effect of an piezometric head difference.

(ii) A slope gradient of 1:3.5 will result in $n > 1.1$ when introducing earthquake loading.

HYDROLOGY AND RIVER MORPHOLOGY

The available ("historical") data were collected and some surveys were done to do additional measurements. The collected data consisted of maps, satellite images, soundings, sediment transport data in addition to the hydrological data. Additional measurements were done during river surveys in February and September of 1991. During these river surveys mainly soundings were made for use for the mathematical modelling, but these data were also useful for the present study as they provided quite detailed information. In addition bed samples were taken during these surveys and these samples were subsequently analyzed at RRI (River Research Institute) in Faridpur. Due to a number of reasons this data collection phase was extended to September 1991.

Knowledge of the hydrology of the Meghna River and its catchment is essential for the development of designs. Parameters like :

- Flood levels having return periods upto 100 years;
- water level range;
- hydraulic head difference across the bank protection; and
- maximum flow velocities near the bank protection;

were determined for each of the selected sites.

These parameters in turn are used to calculate :

- scour depths in front of the bank protection works;
- size of units to be used for revetments or groynes;
- flood levels and duration curves for water levels and discharges in relation to construction periods;
- top level of bank protection works.

Flood levels at the protection sites for 50 and 100 years return periods are given herein below.

FLOOD LEVELS AT THE PROTECTION SITES FOR 50 AND 100 YEARS RETURN PERIODS

SITE	Chainage Km	Return period			
		50 Years		100 years	
		u/s	d/s	u/s	d/s
Bhairab Bazar	7.5 - 9.0	7.66	7.62	7.83	7.89
Maniknagar	31.0 - 37.0	7.22	7.1	7.39	7.27
R & H Bridge	88.0 - 88.0	6.42	6.42	6.59	6.59
Munshiganj(Dhaleswari)	8.0 - 4.0	6.41	6.32	6.60	6.51
Eklashpur	114.0 - 123.0	5.80	5.58	5.93	5.69
Chandpur	134.0 - 137.0	5.31	5.25	5.40	5.32
Hairnchar	147.0 - 154.5	5.02	4.86	5.09	4.91

All levels are in m+PWD

In the past (i.e. before 1780) the Brahmaputra River joined the Meghna at Bhairab Bazar, so the Meghna carried also the discharge of the Brahmaputra. The actual discharge is therefore less than before the major avulsion of the Brahmaputra.

In this respect it should be pointed out that the Upper and the Lower Meghna river are two completely different rivers. Nowadays, however, the Upper Meghna is just a smaller tributary to the Ganges/Jamuna-Padma-Lower Meghna Rivers system. Hence, very often in the Report, the Upper and

the Lower Meghna have been treated separately. Even more, for an understanding of the processes in the Lower Meghna one should include an analysis of the river processes in the Padma River, rather than consider the Upper Meghna in this respect. This explains why often the lower reach of the Padma River has been included in the analysis too.

The Lower Meghna is, in fact, the continuation of the Padma River with peak discharges of the order of 150.000 m3/s. The river system is characterized by a wide river bed of several kilometres in which various channels develop in combination with large propagating sand bars (locally called chars).

The technical study of the river morphology was required to improve the understanding of riverine processes in Bangladesh' major rivers in general and in the Meghna River in particular.

Two main issues have a direct bearing on the design of the proposed bank protection projects :

- future plan form development of the river at and near the various bank protection sites.
- maximum scour that may occur at the foundation level of the bank protection works.

For easy reference some significant conclusions are repeated here:

- Plan form characteristics of the Upper Meghna have remained essentially the same over the last decades. Special mention should be made of the confluence of Dhaleswari and Upper Meghna. Here the Dhaleswari shows a tendency of gradual widening during the last 15 years.

  In the Lower Meghna the situation is more complex in the sense that this river at the confluence of Upper Meghna and Padma shows a cyclic pattern (some 15 years) of two major channels which each in turn grow and deteriorate again. Two processes are going on: The Padma is moving to the east and the channels in the Flood Plain migrate and change in number locally causing erosion.

- Local scour is the scour caused by man-made structures. In bank protection works local scour near groynes, guide bunds, protrusions and along revetments is of interest.

Presently the conditions at Bhairab Bazar are characterized by a fairly straight flow downstream of the bridge. The thalweg of the river is approximately in the middle of the river.

As far as the maximum scour during the passage of Q_{100} = 22,000 m^3/s is concerned. The total scour at Bhairab Bazar will consist of:

- constriction scour,
- bend scour,
- local scour

The total scourdepth becomes 41 m. This scour depth is referenced to the water level of 7.79 (m +PWD), thus the scour depth below PWD to be expected is 33 (m +PWD).

Consultants made an extensive study of the scour pattern at Chandpur as presented on the BIWTA sounding maps (BIWTA) over the period 1964 until 1991. It can be observed that initially the scour depths at Puran Bazar were larger than in Nutan Bazar, but especially in the last years the latter scour has substantially increased. It appears that especially the effect of the protrusion scour has increased recently. Furthermore it can be observed that presently the scour depth are in the same order of magnitude as in the mid seventies.

So finally a scour depth of slightly more than 66 m is found at Chandpur. This scour is referenced to the water level during the 1:100 year flood (about 5.5 m + PWD), hence the scour depth will be about 60 m - PWD.

MODELLING

Apart from site investigations and assessment and design data the various alternative solutions for different locations as formulated in the report must be based on results of mathematical and/or physical (scale) model testing.

The mathematical modelling carried out within the context of this Study (reported upon in Annex E) provided the boundary limits for the scale modelling. The results of scale modelling, combined with other insights gained from the geomorphological studies and mathematical models, should provide the following key data for the design of the protective structures:

- magnitude of local scour due to the presence of a hydraulic structure (revetment, groynes, guide bund);
- maximum current velocities near the structure;
- technical feasibility of a proposed solution as well as its morphological consequences (if any).

SHORT-TERM PROTECTION WORKS

After studying various alternative designs a selection was made for designs to be studied in greater detail. The selection was based on various factors including the impact of the protection works on the flow pattern, the area required to construct and maintain the protection works and cost involved.

Bank protection works to be constructed along the Upper Meghna are in principle not different from works constructed elsewhere in the world along meandering rivers of comparable magnitude.

Bank protection works to be constructed along the Lower Meghna and more specifically at Chandpur are unique in view of the expected depth of scour holes (> 60m) and current velocities (up to 4 m/s) in this large river. On all three sites bank protection in principle will consist of a revetment placed onto a geotechnically stable slope.

The slopes will be formed by placing (hydraulic) fill followed by slope trimming by dredgers.
The revetment will consist of:

- above water of open stone asphalt on a geotextile;
- under water of a fascine mattress ballasted with rock or boulders depending on the site;
- at the toe of a falling apron of rock or boulders without a geotextile underneath.

Bhairab Bazar Town and Railway Bridge

At Bhairab Bazar protection works are required for Bhairab Bazar Town (right bank) and for the Railway Bridge which crosses the Upper Meghna at this location, just upstream of the Town. Deep scouring near the right bank both upstream and downstream of the Railway Bridge has resulted in steep (unstable) underwater slopes and bank slides. Recently, Bangladesh Railways has carried out protection works to prevent development of unacceptable scour holes near the bridge piers.

Any solution considered should basically satisfy two criteria:

- to prevent geotechnical instability of land areas near Bhairab Bazar Town and Railway Bridge;
- to prevent development of scour holes near the piers of the Railway Bridge.

Consequently, seven alternative solutions were formulated which can be summarized as follows:

(1) maintain present conditions;
(2) overall revetment along existing (right) bank and between piers;
(3) ditto but along an advanced right bank and between piers;

(4) groy
(5) serie
(6) shor
(7) bed

Figure 2. Ba

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(4) groyne u/s Railway Bridge;
(5) series of groynes u/s Railway Bridge;
(6) short groyne u/s Railway Bridge, sill between piers, guide bund along bank u/s of bridge;
(7) bed protection at Railway Bridge, sill between piers and guide bund as (6).

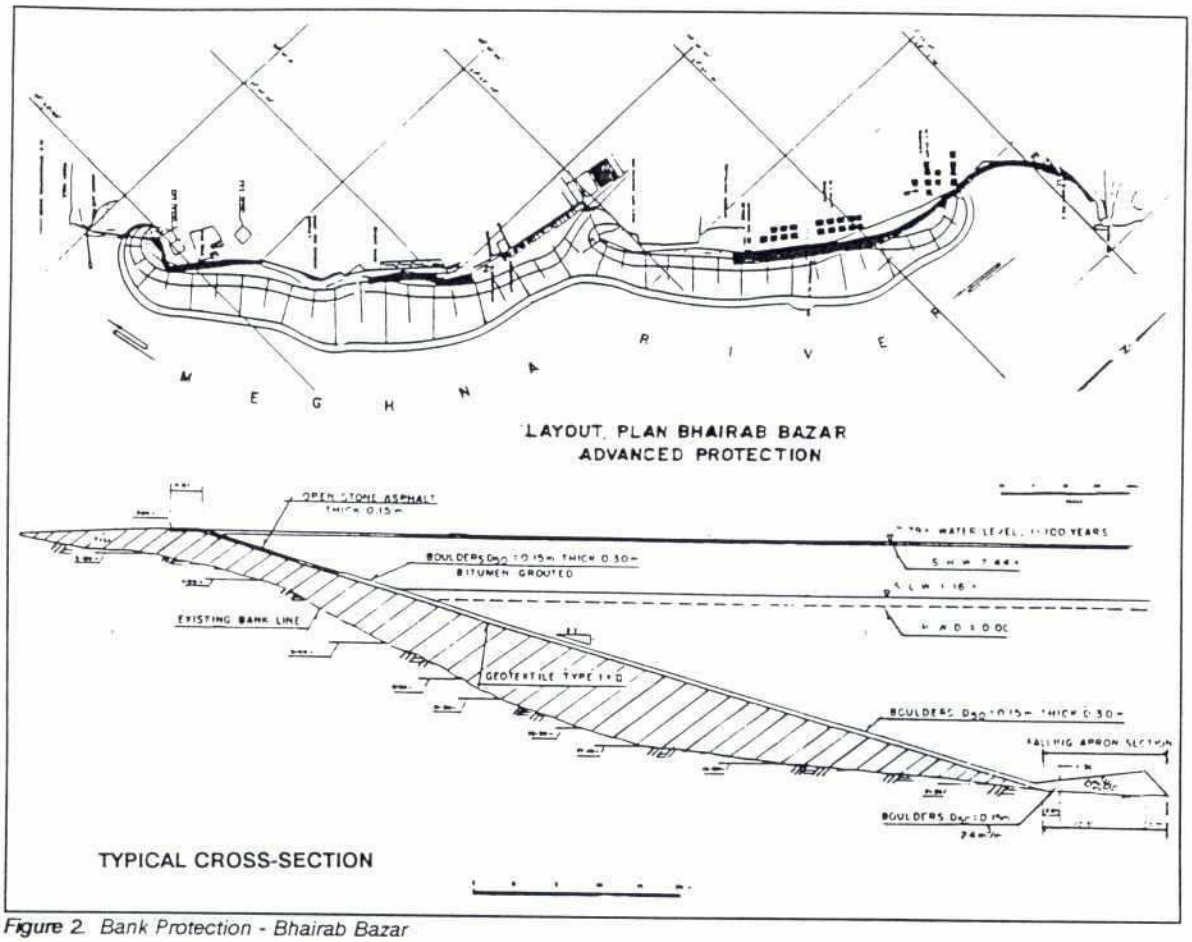

Figure 2. Bank Protection - Bhairab Bazar

The basic difference between a revetment (alternatives 1, 2, 3) and groynes is that by constructing a revetment one accepts scour and high current velocities immediately in front of the revetment at the right bank while a groyne or groynes will divert the flow from the attacked bank and thus preclude erosion due to high currents and scour. However, a groyne (or groynes) create a problem somewhere else (here at the piers of the Railway Bridge and at the left bank) which in turn requires new protection measures (bank protection, sill).

After due consideration it was decided to select alternative (3) for further elaboration.

Munshiganj Town

The situation is in so far different from sites discussed in the preceding sections. At Munshiganj erosion occurs at both banks and this erosion is due to wave attack during high river stages and not due to bank parts sliding into deeply scoured river channels. There is in fact a foreshore in front of the river bank. Consequently, for any proposed protection measures the purpose should be:

- to prevent development of scour in front of foreshore,
- to prevent erosion due to wave attack.

Based on the principle of an overall revetment three alternative solutions were formulated:

(1) a design based on BWDB designs;
(2) protection of foreshore at existing bank line;
(3) protection on re-constructed embankment.

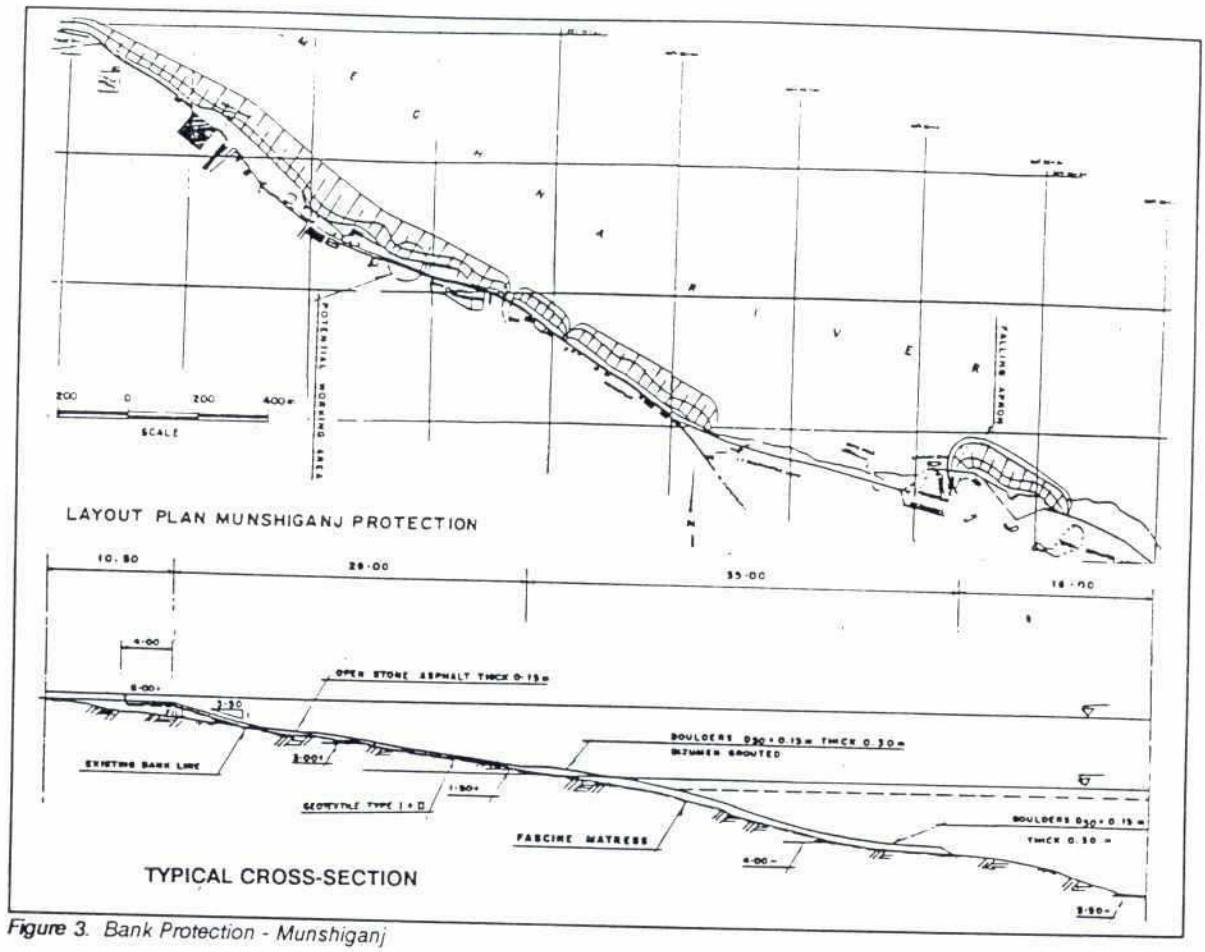

Figure 3. Bank Protection - Munshiganj

Finally, a combination of alternatives (2) and (3) was selected for the final design. As much as possible the existing embankment is used and by means of cut and fill a suitable slope is created on to which the revetment can be made.

Chandpur Town

The Chandpur Town consisting of Puran Bazar and Nutan Bazar is located at the left bank of the Lower Meghna. The town is bisected by the Dakatia river. The left bank of the Meghna u/s and d/s of Chandpur has been eroding continuously for the past 20 years
Emergency works have been carried out in the past and are being carried out today to protect Chandpur against the erosive forces of the Lower Meghna.

These emergency works had three things in common:

- the designs were not to the standard required for this very difficult situation;
- construction was not carried out in such to manner that the under water protection could fulfil its task;
- construction elements were placed on eroding oversteep and thus unstable slopes.

The conclusions as well as the reasons behind it are presented in greater detail in Annex G of the Interim Report. Here it suffices to state that the emergency measures so far have had a very limited life time.

As specified in the TOR, consultants have identified the causes of erosion and the short term protection measures to be taken immediately have been designed based on a proper study. Any design and construction concept for a durable protection of Chandpur Town should be based on the following principles:

- slopes must be stable under various conditions;
- protective elements and corresponding filter layers must be able to withstand erosive forces of currents and, to a lesser degree, wave attack;
- provision must be made for scour depths in excess of river depth prevailing at the time of construction;
- construction must be according to the designs made by using the right kind of equipment, approved and suitable working methods and quality control.

The oversteep underwater slopes, the remains of various protective layers placed haphazardly in the past as well as the expected future increase in scour depth preclude the implementation of a simple cheap solution.

These considerations as well as many others (see Annex G) have led the Consultants to analyze the following alternative solutions for a durable protection of Chandpur Town:

(1) protective layers on existing slopes improving on present slope angles by cut and fill;
(2) advanced protection at Nutan Bazar, or Puran Bazar or both;
(3) series of 2 groynes in front of Nutan Bazar;
(4) groyne u/s of Chandpur;
(5) submerged sand sausages placed in upstream direction u/s of Chandpur.

Some of these solutions (e.g. (4), (5)) can be considered as long-term solutions (river training) having a "regional" effect. The other solutions are of a local nature, do not require additional comprehensive river studies and can be implemented in the near future. As it was felt that Chandpur is most benefitted by a quick solution alternative (2) i.e. advanced protection of Nutan Bazar and Puran was selected for detailed design. In addition at Puran Bazar in any case measures have to be taken against wave attack.

Eklashpur (Meghna Dhonagoda Irrigation Project)

Eklashpur is situated on the left bank of the Lower Meghna River, near the confluence of the Padma and the Meghna rivers. Erosion has attacked the river bank for more than a decade and is the result of both current and wave action. Agriculture is the main economic activity in the area. However, erosion threatens the embankment around the Meghna-Dhonagoda irrigation project.

The FAP12's rapid rural appraisal (1990) carried out a post-evaluation of the Meghna-Dhonagoda irrigation project four years after its completion. Data on economic indicators for this project can also be found in Thompson's study on the impact of flood control on agriculture (1990).
If the embankment of the Meghna-Dhonagoda project is breached, the whole benefit of flood control for the area would be lost. The project's pump station is located very near to the border of the river. Without any river training works or any other sort of bank protection this will be destroyed.

The area of influence of the proposed works reaches from the point where the Padma and the Meghna join the Dhonagoda River and end some two kilometres south of it. The area protected covers lands outside the existing embankment bordering the river and parts of the Meghna-Dhonagoda irrigation project located inside the embankment.

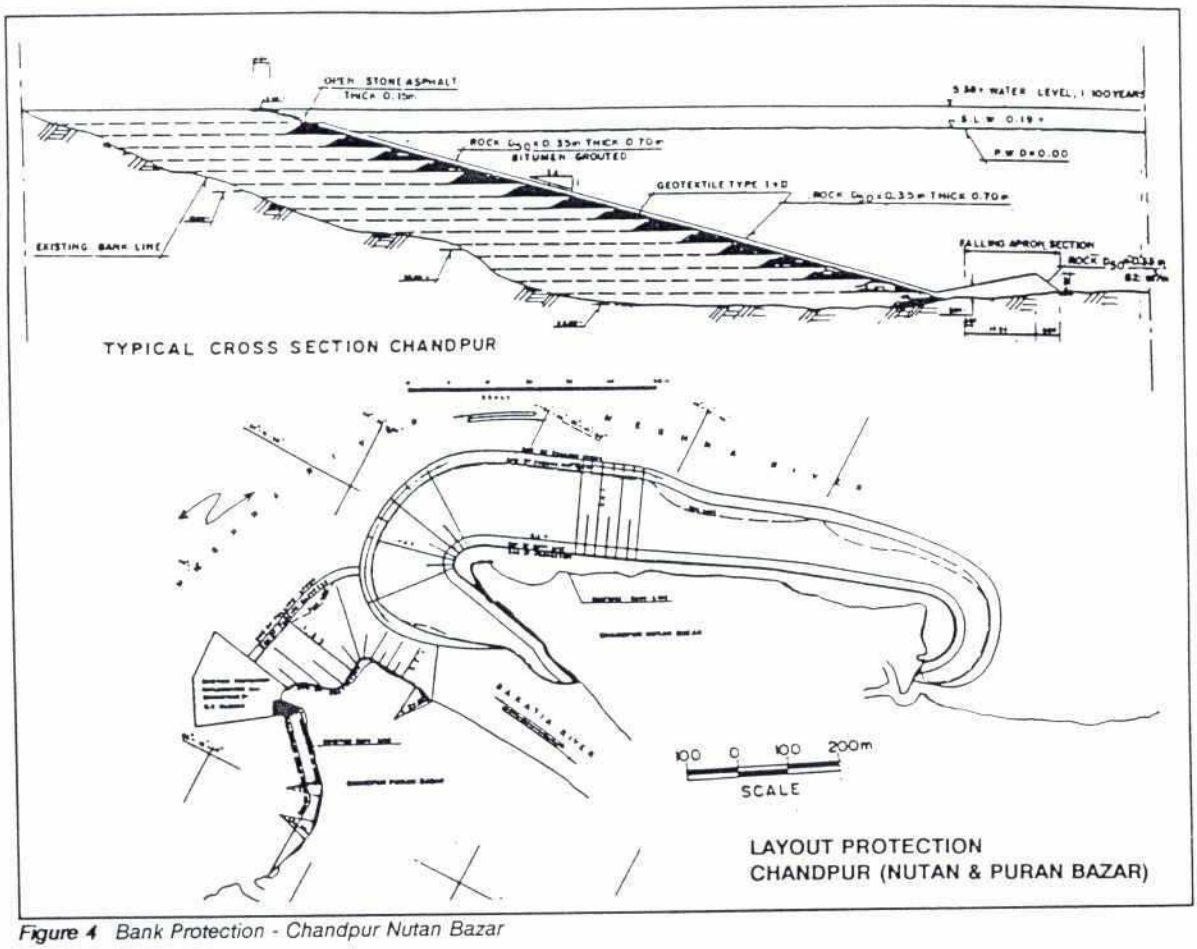

Figure 4 Bank Protection - Chandpur Nutan Bazar

Design of river training and bank protection works are undertaken by the Meghna River Bank Short Term Study, which envisages the protection of:

- the river bank and the embankment in Eklashpur,
- the existing embankment and the irrigation pump station;
- habitations and small commercial enterprises, along the shore of the Lower Meghna.

The progress of bank erosion in the without-scenario situation can be estimated from the results of the geo-morphological study (see Annex B). This progress is expected to be important in the coming 30 years; without any protection works large parts of the existing embankment and land of the MDIP will disappear.

Haimchar (Chandpur Irrigation Project)

Haimchar is situated on the left bank of the Lower Meghna River, about 20 km south of the town of Chandpur. Erosion has attacked the river bank for more than a decade and is the result of both current and wave action. In 1989 the village was retired more inland after the floods. Agriculture is the main economic activity in the area.

If the embankment of the Chandpur project is breached, the whole benefit of flood control for the area would be lost. Without any river training works or any other form of protection, the embankment is likely to be engulfed and irrigation infra-structure will be destroyed.

The area of influence of the proposed works reaches from a point some 3 km north of Haimchar and goes as far as 7 km south of the village. The area to be protected covers land outside the existing embankment bordering the river as well as parts of the Chandpur irrigation project located inside the embankment. Without any protection works large parts of the existing embankment and land of the irrigation project will disappear. Hence, it is more than likely that retired embankments will be constructed at regular intervals. Such as is the case in Eklashpur, it is emphasized that the complete loss of the Chandpur Irrigation Project has not been taken as the without-scenario, since that is not likely to occur. As a result of the sustainable short-term bank protection works executed, less agricultural land will disappear, fewer structures lost and agricultural produce higher.

Meghna Roads and Highways Bridge

Crossing the Meghna by bridge has only been possible by rail for a long time. The railway bridge in Bhairab Bazar exists already 50 years, but all other traffic used to cross the river by ferry. In 1990 the Meghna R&H Bridge was opened and it forms the first chain of bridges in the road network linking Dhaka and Chittagong.

Construction of the bridge was finished in 1990. Local protection works (mainly gabions) to safeguard the engulfment of abutments and the approach roads were included in the construction of the bridge. However, at this date large parts of these protections for the left abutment present structural damage.

Protection works considered by the Meghna River Bank Protection Short-Term Study concentrate on structures to train the river at a point some 2 kilometres upstream of the bridge and/or protecting the old ferry ghat and the vortex area downstream this point. Five alternatives have been studied (pre-feasibility level) for the protection of the bridge, of which four include protection of the ferry ghat and vortex area.

Maniknagar (Gumti Phase II Project)

Maniknagar is situated on the left bank of the Meghna, south of Bhairab Bazar. Erosion has attacked the river bank for more than a decade and is the result of both current and wave action. Agriculture is the main economic activity in the area. The area is the location for the future Gumti phase II project and erosion could very well threaten this irrigation project in the future.

The feasibility of the Gumti II project was studied in 1990. The aim of the project is to increase agricultural production. For protection against floods a new embankment at some distance of the river was planned. However, the scope was not on river training works to avert erosion of the proposed embankment. Without adequate protection the outer bend of the Meghna could migrate some 700 m inland in the coming 30 years and destroy the bazar. A substantial area of agricultural land would be engulfed as well. Hence, benefits of river training and bank protection works relate to a reduction of agriculture and urban losses.

The economic pre-feasibility analysis covers four alternatives, notably (a) protection through groynes, (b) overall bank protection works over a length of 5,000 m, (c) a series of sand-sausages and (d) closure of the river arm at the bifurcation upstream of Maniknagar. A comparison is made between a future scenario with river training or protection works (with-scenario) and without any works being implemented (without-scenario).

RISK ANALYSIS AND PROBABILISTIC DESIGN

Until recently civil and hydraulic engineering projects were designed on a purely deterministic basis. This meant that a certain safety factor was applied, a design load selected without regard to the economic consequences of these choices or to the possibilities of failure which existed. In many cases this meant that a structure was over-designed in one aspect and was therefore too costly but also that it had a good chance to collapse because another aspect (e.g. lack of maintenance) was neglected.

The procedures and calculation methods developed in the Netherlands for risk analysis and probabilistic design of large hydraulic engineering projects (Delta Project) were for the first time applied at a large scale in Bangladesh for the design of the river training works for the Jamuna Multipurpose Bridge. Also for the bank protection works at three priority sites along the Meghna River a risk analysis and multicriteria analysis have been carried out.

Probabilistic design implies that for instance for calculating resistance against current attack input parameters were: discharge, Chezy coefficient, Shields constant, stone diameter, specific density of protective elements, slope of the protection, angle of internal friction of protection layer, waterdepth. The mean values and standard deviation of each of the parameters were used in a probabilistic calculation (level III-AFDA with HASKONING software package HASPROB) to determine the risk of failure (which risks of course shall be sufficiently small).

An important side effect of this risk analysis is the saving in the overall construction cost obtained by using probabilistic design methods. This in turn makes it easier to demonstrate the economic viability of the works.

From the failure probability for the top event failure probabilities for the individual elements of the works were determined. Details of this exercise can be found in Annex G.

An acceptable probability of failure for bank protection works is determined on the basis of Fig. 5. The graph displayed in this figure shows generally accepted risk levels for various structures and activities.

In view of the type of protection, magnitude of loads, cost of repair works and commercial interests involved an acceptable failure probability for the top event has been determined:

- for bank protection works at both Bhairab Bazar and Munshiganj: 0.5×10^{-3};
- for bank protection works at Chandpur: 0.25×10^{-3}.

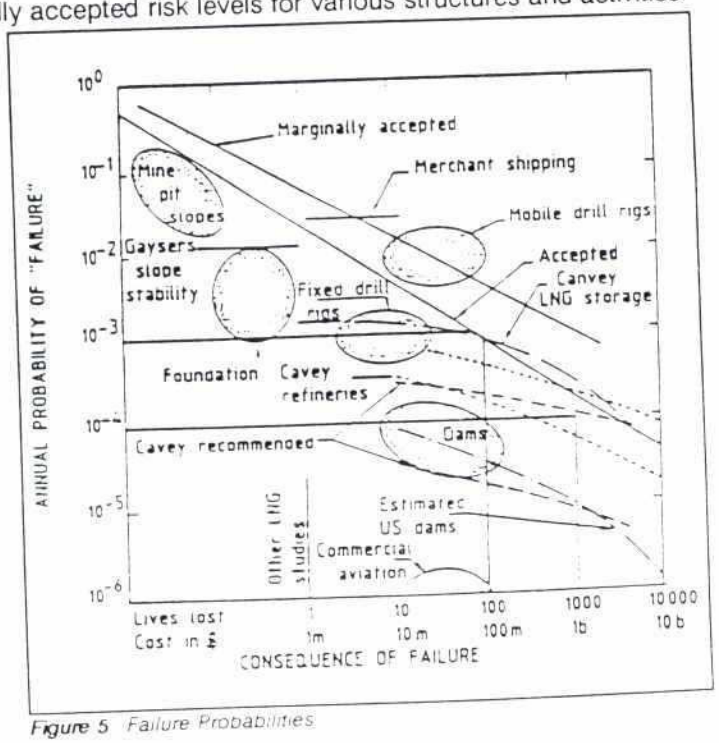

Figure 5 Failure Probabilities

PROJECT COSTS AND BENEFITS

In order to streamline techniques, bring consistency into the appraisals and facilitate comparison of potential investment opportunities, the Flood Plan Coordination Organization of the Ministry of Irrigation, Water Development and Flood Control has prepared standard procedures.

In agreement with the FPCO-guidelines for project assessment, in the present economic feasibility analysis of the short term bank protection works a comparison is made between two future scenarios, (i) the scenario with permanent river bank protection works (with-scenario) and (ii) the scenario without such protection works (without-scenario).

In the without-scenario situation the present day practice regarding river bank repair and maintenance activities is continued. However, it must be noted that the without-scenario is not equal to the present situation, but represents an extension of the present situation into the future.

The most likely future situation without the project is surely not the situation in which all interests along the river bank (urban area, irrigation districts, etc.) will be completely abandoned. If such would be the case the whole economic added value of e.g. the Bhairab Bazar Bridge, Meghna-Dhonagoda and Chandpur Irrigation Projects could be taken into account as benefits to the bank protection projects. Experience from the past, however, indicate that the most probable future scenario without the bank protection projects considered in this study is described by continuous efforts of the authorities to protect the interests along the river banks in a non-sustainable way by either bank protection works, haphazardly designed and carried out, or by regular withdrawing of embankments.

This has, in general, the following consequences:

(i) Experience from Chandpur Town protection measures in the past decades, where expenses for repair and maintenance showed an average growth rate of over 60% over the last 10 years, and the repair measures in Bhairab Bazar, where the annual growth rate for these expenses was over 25% in the past five years, show that expenses needed to repair and maintain the present river bank protection at isolated locations along the water front in the non-sustainable present practice are likely to increase dramatically in the future. Based on that experience it has been estimated that such expenses in the without-scenario will increase by an annual ten percent.

(ii) Experience from Chandpur Irrigation Project shows that the embankments will be retired to the extent bank erosion cannot be stopped by non-sustainable bank protection works, carried out in an ad-hoc way. For the Meghna-Dhonagoda and the Chandpur Irrigation Districts (Eklashpur and Haimchar), the without-scenario is therefore characterized by the extrapolation of this present day practice.

The guidelines for project assessment indicate that for FAP project planning a discounting period of 30 years from the start of project construction must be used. No reason has been identified to change this period for the economic feasibility analysis of river bank protection.

Benefits from River Bank Protection Works

When comparing the with- and without-project case, the benefits from the river bank protection project are related to (i) savings and reduction of costs associated with the present day practice of protecting the interests along the river bank and (ii) damage occurring due to the erosion of the river banks. Therefore benefits from the river bank protection works are related to the following aspects:

- Cutbacks in maintenance and repair cost.
- Reduction of loss and damage in town areas affected by erosion.
- Reduced disruption of economic activities area.
- Reduced disruption of cross river traffic.
- Reduced damage to the agricultural sector.
- Social benefits (population displacement).
- Environmental benefits.
- Secondary benefits.

Some of the benefits are associated with population growth or economic growth rate. They will, therefore, increase annually. The FPCO-guidelines give a 3% to 4% growth rate. For the feasibility studies a growth rate of 3% has been used, as it reflects the economic growth for Bangladesh over the period

1985 to 1990. However, no information is available for economic growth for each of the project sites individually. A 10% annual growth factor has been applied to the annual expected value of repair and maintenance when extrapolating the present day practice. Concerning loss and damage to private and public infra-structure and loss of profit, the annual increase is 3% reflecting the growth and increase of economic activity in the affected area.

Cost of Protection Works

The cost of the river bank protection works relate to construction and engineering cost. As a result of the complexity of the river conditions (high water depths and strong current) and the high level of skill needed for river bank protection works to be carried out under such conditions, it is envisaged that qualified contractors with the required construction capacity and equipment are not available in Bangladesh and that (i) international competitive bidding by pre-qualified contractors and (ii) supervision by a qualified engineer with experience in this type of work are conditions for their proper implementation.

In addition to the construction cost more cost components have to be considered in the economic analysis, notably monitoring and maintenance cost. Monitoring cost have been based on survey cost experienced during the execution of this short term river bank study; an acceptable estimate for survey cost and other monitoring expenses is Tk. 2.0 million (mid-1991 economic prices) per site. Annual maintenance expenses of protection works have been estimated at 4% of the cost of surface protection; e.g. open stone asphalt, fascine mattress, boulders in falling apron and grouting of boulders.

At the later stage, **a contractor's approach** was applied to determine the definitive cost estimate of the works designed. All cost items have been subdivided into local and foreign components.

The cost of each of the project designs has been estimated independently, except for Bhairab Bazar and Munshiganj which are propose to be combined in one contract package. The construction schedules for the Works at each of these sites have been derived taking account of the interdependence of the various activities.

The US dollar was adopted as the base currency for the cost estimates. During the period when the cost estimates were prepared, there were only small fluctuation in its exchange rate with other currencies.

- Base date : mid-1991
- U.S.$ 1.00 : 36.00 Taka

The financial construction cost of the works designed for the eight priority sites is as follows:

		US $ million
-	Bhairab Bazar and Railway Bridge	15.3
-	Munshiganj	7.7
-	Chandpur:	
	(a) Short-Term	71.2
	(b) Emergency	37.9
-	Roads & Highways Bridge	5.2
-	Maniknagar	20.5
-	Eklashpur	26.5
-	Haimchar	29.3

These costs do not include customs duties or levies and no allowance for escalation in prices.

ECONOMIC EVALUATION

The economic feasibility (and pre-feasibility) analysis showed the following results:

	EIRR %	NPV at 12% in million Tk.
Bhairab Bazar Town and Railway Bridge	20.6	446.4
Bhairab Bazar Town only	19.9	369.7
Munshiganj Town	16.1	76.1
Chandpur Emergency Works	7.3	-992
Chandpur Town	6.1	-983
Eklashpur	2.8	-293.0
Haimchar	1.7	-215.9
Maniknagar	0.2	-190.6
Roads & Highways Bridge	189.9	2074.1

For locations like Chandpur, is however, doubtful whether the presumed economic opportunity cost of capital is the appropriate criterion for an investment decision in an infrastructure of this kind.

Chandpur has derived its importance from its strategic location along the major river Lower Meghna. Many of its activities are related to its location near the river. Therefore, Chandpur should not be considered as an isolated threatened location, but rather as a first fixed point along a more or less fixed alignment of the Lower Padma and Lower Meghna. without Chandpur, or any other fortified (hard point) location along the Lower Meghna, it is difficult to see which mechanism would stop the historical shift of the Lower Meghna in eastward direction Any existing infrastructure would be destroyed in the process of shifting of the river. Apart from the associated financial and economic losses, there would also be grave social consequences: many people loosing their land would not be able to acquire new land and would be bound to become landless and destitute.

Sensitivity Analysis

The most detrimental effect occurs when benefits decrease by 50%. In that case the EIRR decreases to 3.7% (Chandpur). The project is also sensitive to an increase in construction cost: by a 50% increase the EIRR decreases to 4.6%.

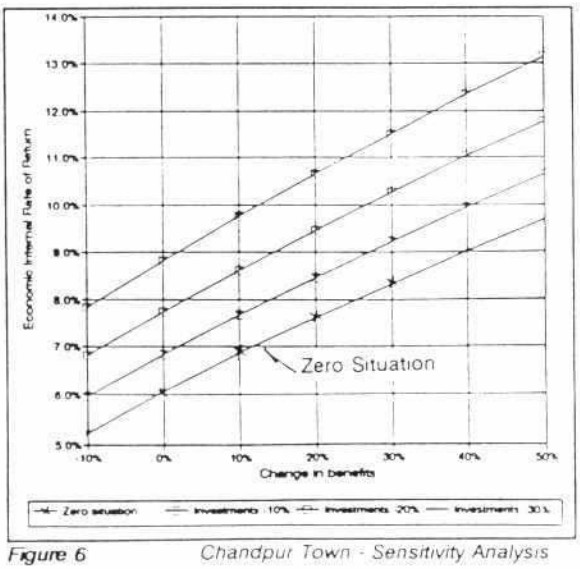

Figure 6 *Chandpur Town - Sensitivity Analysis*

ENVIRONMENTAL IMPACT ASSESSMENT

For each phase of the project, all possible negative environmental impacts have been identified for the various project activities. Most activities associated with river-bank protection have only **temporary, short-term or small-scale impacts**. This is due to the relatively limited area concerned. Furthermore, most impacts are associated with construction activities and not with the constructed works. The effects are therefore also limited in time. River-bank protection does not have a very intrusive nature: it strives to maintain a steady state at a certain location but does not significantly alter the riverine and estuarine ecosystems.

The Lower Meghna has one of the highest rural population densities in the world, and nearly all cultivable land in Bangladesh is farmed. Agriculture is the backbone of the economy. Agricultural practices are adapted to flooding: as the floods recede, submerged areas become productive land, especially for rice.

The socio-economic impact of infrastructure displacement depends on the attitude of the affected population. Information on this issue is not available, but it is expected that minimization of the inconvenience is advisable. The provision of pontoons as temporary landing facilities, and the reorganization of market facilities in the vicinity, will compensate the temporary loss of landing and market facilities at Bhairab Bazar, Munshiganj and Chandpur. It is recommended to develop a relocation scenario in cooperation with the local authorities.

The nature of the protection works is such, that the contractor will minimize dredging activities. The effect on flora and fauna at the dredging site can further be reduced by avoiding heavily polluted sites. If dredging elsewhere is too costly, the effects on water quality and aquatic life should be monitored.

It has been recommended that a long-term strategic plan be prepared for future development in the areas protected. Ideally, a monitoring programme should study the changes in water and soil quality, including the effect on aquatic organisms and fish, before the proposed works are carried out (assessment of existing situation), directly after project implementation (assessment of short-term impact), and after one year (assessment of long-term impact). The monitoring programme should run for at least a year to detect seasonal variations, and preferably several years to detect annual changes.

TENDER DOCUMENTS

The tender documents for bank protection works to be carried out at the three priority sites have been drawn up on the basis of ICB (international competitive bidding) as laid down by the World Bank in its Guidelines for Procurement and in its Sample Bidding Documents for Procurement of Works (September 1985).

The Consultants were recently (1989-90) involved in the drafting of tender documents for the river training works for the Jamuna Bridge. This has enabled them to prepare the tender documents the Meghna bank protection works in an efficient way. Especially the Specification and Bill of Quantities have been drawn up bearing in mind the nature and magnitude of the river engineering works concerned. Departure point has been the construction of these works by large international contractors specialized in hydraulic engineering and marine works.

IMPLEMENTATION

Two vital elements in the construction of new embankments or revetments at these sites are: dredging and protection of slopes under water. The works have more in common: both should be carried out in a relatively short time, mainly around the dry season. Preparations should be made in the time preceding the dry season.

There are no contractors in Bangladesh who have all the resources and experience to complete the works on their own, even when they would join forces. It is therefore inevitable that the works will be executed under the responsibility and control of a foreign contractor with ample working experience in similar works and with adequate equipment at hand or at his disposal.

The construction period for the project has been assessed as:

Package I:	Chandpur Town Protection (Nutan and Puran Bazar)	27	months
Package II:	Bhairab Bazar and Railway Bridge Munshiganj Town	15	months
Package III:	Chandpur Town, Nutan Bazar, Emergency Works	13	months

MONITORING AND MAINTENANCE

It is a known fact in Bangladesh that maintenance of hydraulic engineering structures (like for instance slope protection works) in most cases either is not carried out at all or, if done, is carried out in a haphazard way on an ad-hoc basis. Many reasons can be given for this situation: lack of inspection, lack of interest from the side of the owner, lack of funds, bureaucratic procedures, etc.

Now it must be emphasized first of all that such a situation is not only found in Bangladesh. All over the world infrastructure whether it concerns earthworks or structures is in many cases not maintained as it should be. Exceptions are for instance roads (where a lack of maintenance is immediately felt and seen by owners and users) and bridges (where easy jobs like periodic painting can be done on a routine basis).

This all implies that a great effort has to be made by the local governmental organization which is responsible to have maintenance carried out before it is too late. The (invisible) damage has to be measured first by third parties (which may involve costs), it has to be reported and cost of repairs estimated, it then has to go through all the bureaucratic procedures before a budget is approved. Subsequently, the maintenance will be tendered, a contractor appointed and finally the repair work is carried out.

It therefore is suggested to consider the possibility of for instance a locally based (i.e. in Chandpur or Bhairab Bazar) Meghna River authority which is responsible for, inter alia, maintenance of all river bank protection works:

Such a river authority would be founded by GOB through an ordinance and it could for instance be based on the following:

- power to enter into contracts;
- maintenance only by experienced contractors, possibly using the authority's special equipment;
- regular monitoring especially of underwater works according to a fool proof method;
- maintenance fund to be created by receiving annual contributions from GOB which can be deposited in a bank and be used as required;
- small efficient staff which dares to take decisions and which is technically capable to make these;
- periodic assistance by expatriate consultants for carrying out inspections, to specify repairs required and to inspect repair work done.

It should be made clear that this does not mean that the Authority must be responsible for all aspects of maintenance of the river bank protection works, but merely that ultimately a single body must be responsible to GoB for the safety of the protection works. Obviously, these ideas need further elaboration and discussion with GOB and IDA.

Preferably the set-up and functioning of a special monitoring and maintenance organization should be part of the loan agreement for the construction of the bank protection works described in this Report.

Finally, it is noted that under FPCO a FAP-component, FAP-13 and FAP-26, exist which are called "O and M Study" and "Institutional Development Programme". It would appear that such a study should also make recommendations on the future maintenance of projects following from FPCO sponsored studies like the Meghna Short Term Study (FAP-9B).

Allowances for maintenance of the bank protection works include for a stockpile of repair material to be stored at a depot, for regular studies by consultants to forecast river movements, and sums for periodic contracts for remedial works. Annual maintenance is estimated at 4.0% of the investment cost of all the revetment components and falling apron at Bhairab Bazar, Munshiganj and Chandpur.

LEFT BANK OF THE LOWER MEGHNA

Although, within the scope of the TOR for the Meghna River Bank Protection Short-Term Study assessment of an overall protection of the Lower Meghna was not included, the proposed short-term protections would be sustainable by themselves and also allow being included in a long-term strategic development plan of the Lower Meghna. Therefore, Consultants carried out only a preliminary economic assessment of a possible river training scheme for the Lower Meghna by undertaking the short-term measures designed for Eklashpur, Chandpur and Haimchar taking into account that, these should fit within a long-term protection scheme for the Padma/Lower Meghna. The basis of the assessment is provided by the sustained protection works for Chandpur town in combination with the short term protection works at Eklashpur and Haimchar and completed by protection works in the intermediate zone.

Year after year the course of the Lower Meghna has shifted towards the east despite all efforts made by the authorities. Although, much attention has been paid in the past to protect the town of Chandpur and irrigation projects upstream and downstream of the town, no comprehensive concept has been proposed yet for long term protection.

Given the influence of the various FAP and other previous and future projects along the Upper and Lower Meghna Rivers on the morphological behaviour of these rivers, it is important to recall that this study demonstrates the importance of the morphological processes taken place in the Padma River for bank erosion and scour processes in the Lower Meghna River. It is therefore imperative to include the analysis of morphological processes in the Padma River downstream of Mawa into the long-term strategic plan for the Padma and Lower Meghna. Consultants prepared detailed TOR for such Long-term strategic planning for a phased implementation of protection works aiming to protect the left bank of the Lower Meghna.

The construction of long term protection works for the left bank of the Lower Meghna comprise a series of bank protection and river training structures. As a result of the preliminary nature of the analysis only one alternative was investigated which consists of the following works:

(a) Protection of the existing bank at Eklashpur to be executed in 1993, 1998 and 2005.
(b) Protection works between Eklashpur and Chandpur, envisaged for the year 2002.
(c) Sustainable town protection at Chandpur, first phase in 1993 and additional works to be executed in and 2003 and 2018.
(d) Protection between Chandpur and Haimchar, planned for the year 2002.
(e) Guide bund protection works at Haimchar to be executed in 1993, 1998 and 2008.

For reasons already explained, it has been assumed that the avoidable maintenance and repair expenses increase annually by 10%. This increase is justified by the ever increasing cost of protecting land against the water of the Meghna in the present situation without sustainable river bank protection. Other benefits associated with population growth and increasing economic activities have been assumed to increase by 3% per year. This reflects the economic growth of Bangladesh, which was between 3 and 4% over the last planning period.

INVESTMENT SCHEME LOWER MEGHNA FOR PROTECTION WORKS AT EKLASHPUR, CHANDPUR AND HAIMCHAR

CONSTRUCTION OF PROTECTION WORKS	YEAR OF INVESTMENT	COST IN US$ in million
Chandpur Town	1993	71.215
Haimchar (first part)	1993	10.923
Eklashpur (first part)	1993	10.078
Eklashpur (second part)	1998	8.211
Haimchar (second part)	1998	8.012
Chandpur (length = 400m)	2003	7.500
Eklashpur (third part)	2005	8.211
Haimchar (third part)	2008	10.384
	TOTAL cost in US$	134.538

TERMS OF REFERENCE TO ESTABLISH THE MEGHNA RIVER LONG-TERM STRATEGIC PLAN (MLTSP)

Terms of Reference have been drawn up for the Meghna River Long Term Strategic Plan, aiming at a long-term development plan within which the short-term river bank protection works will fit.

The Terms of Reference have been defined for a study which will:

(1) provide insight in the long-term natural changes in the planform of the Upper and Lower Meghna Rivers;
(2) indicate the influence of the various FAP and other previous and future projects along the Upper and Lower Meghna Rivers on the morphological behaviour of these rivers;
(3) determine the influence of river training works on the natural planform development, allowing to design an appropriate and long-term strategy for sustainable river training of the Upper and Lower Meghna Rivers;
(4) assist in providing boundary conditions for river training works to be designed along the Upper and Lower Meghna Rivers;
(5) generate the boundary conditions for the mathematical and physical model studies to be carried out to generate these and other boundary conditions;
(6) provide the morphological data required for the evaluation of alternative methods for controlling the Upper and Lower Meghna Rivers, like large scale dredging, floating vanes, etc. using the results of FAP 22 as far as available during the period of the assessment;
(7) identify long-term measures against river bank erosion, their relative priority and their technical and economic feasibility;
(8) identify river training schemes suitable for the permanent protection of the river banks;
(9) prepare an implementation schedule for a phased implementation of such training schemes and other measures to be taken;
(10) prepare cost estimates for implementation and maintenance of the long term strategic plan.

As the short-term study has demonstrated the importance of the morphological processes in the Padma River for the bank erosion and scour processes in the Lower Meghna River, it is imperative to include the analysis of the morphological processes in the Padma River downstream of Mawa into the present study. The results of the morphological study will be used for the design of the river training works on a probabilistic basis. Hence the results of the morphological study should reflect the stochastic behaviour of the different phenomena like bank erosion and scour to allow such a probabilistic approach.

The bank protection scheme for the whole Lower Meghna give an EIRR of about 7%%. This means that the benefits are sufficient to offset the cost. The EIRR will reduce to about 6% in case of an additional investment of Tk. 270 million is required in the year 2002 to provide an additional hard point between Eklashpur and Haimchar.

The economic net present value of the bank protection scheme for the Lower Meghna, evaluated at a discount rate of 12%, is negative (Tk. -658 million). The NPVR ratio as required by the FPCO-guidelines can be calculated at -0.17.

Although preliminary assessment of bank protection of the Lower Meghna from Eklashpur to Haimchar gives an EIRR (6.7%) below the opportunity cost of capital, the assessed rate might be considered as acceptable for this type of infra-structural works. A more detail study is required to provide more substantiated conclusions for the river training works in the Lower Meghna.

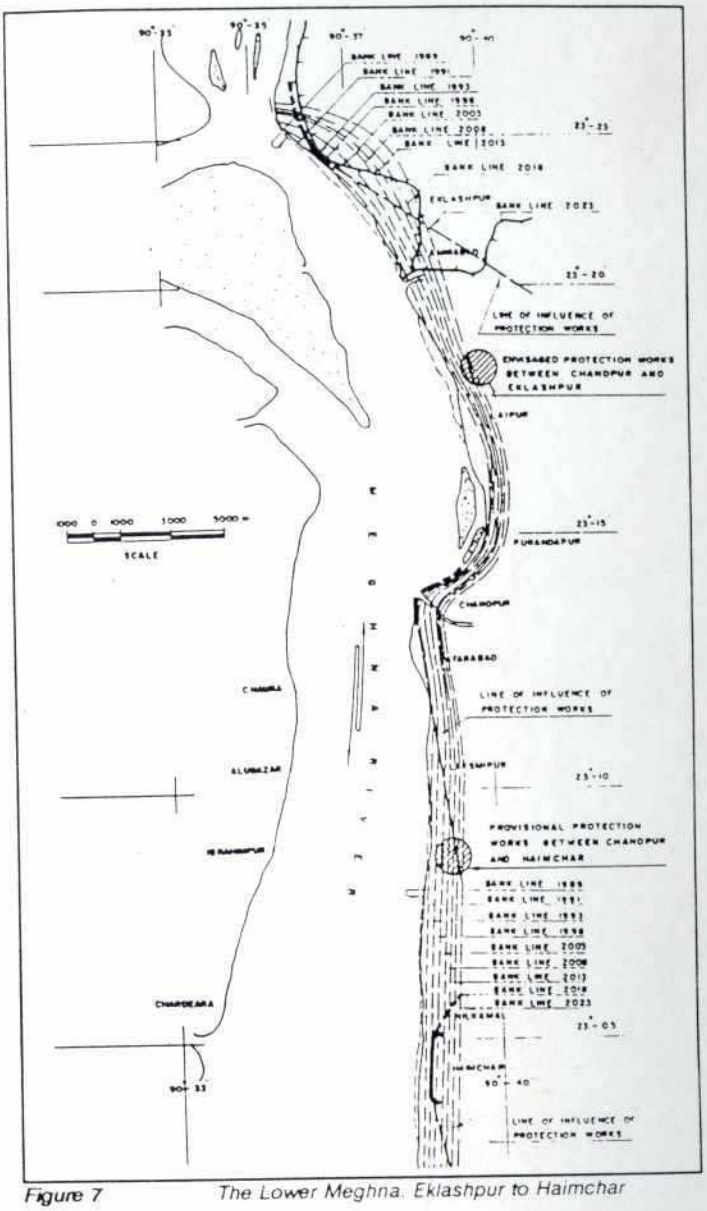

Figure 7 *The Lower Meghna. Eklashpur to Haimchar*

Displacement of Population

The preliminary assessment of the bank protection scheme is based on uncertain future events and imperfect data. Therefore, a sensitivity analysis is presented. This implies an analysis of the economic internal rate of return as function of changes in investment cost, monitoring and maintenance expenditure and estimated value of benefits.

Based on the result of the socio-economic survey and the migration of the bankline in the town area of Chandpur, it has been possible to estimate the number of persons affected by erosion. The area covered by the survey was estimated from the street map as 293,000 m^2 and 2,620 residents in this area were identified. Hence, the population density is 8,940 persons per km^2.

Based on the Statistical Yearbook of Bangladesh for 1991 (table 2.08, page 45), the annual population increase was 2.17% over the last 10 years. Using this factor and the area lost shows that about 17,000 people in Chandpur Town will be affected by erosion in the coming 30 years.

For the rural areas along the Lower Meghna the averaged rural population density is estimated at 400 people per square kilometre. The total rural area likely to be lost along the Lower Meghna in the coming 30 years is estimated at 3,570 ha. It is therefore estimated that about 14,000 people will be affected in the rural areas outside Chandpur Town.