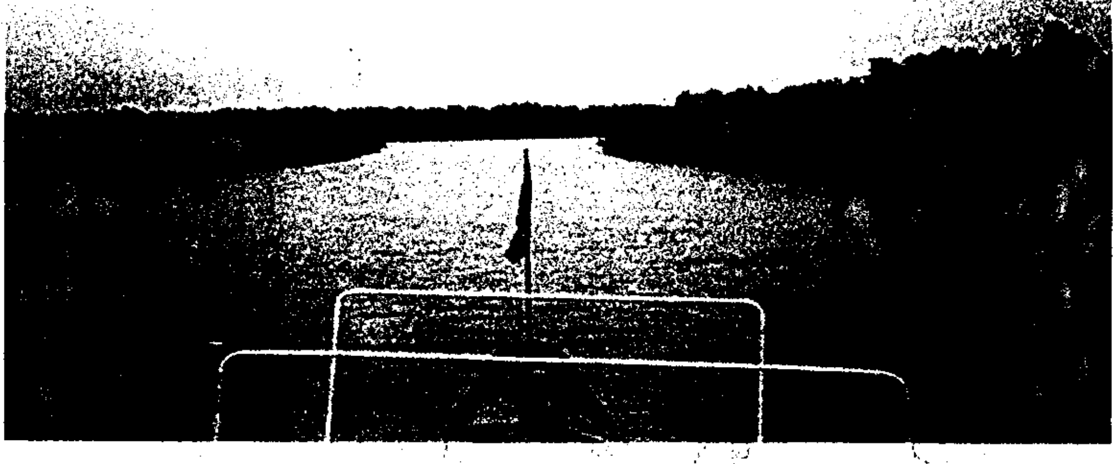
Government of the People's Republic of Bangladesh
Ministry of Environment and Forest
Department of Forest

SUNDARBAN BIODIVERSITY CONSERVATION PROJECT
SURFACE WATER MODELLING
TA NO. 3158-BAN (Contract COCS/00-696)



FINAL REPORT

VOLUME 1

MAIN REPORT

AUGUST 2003

INSTITUTE OF WATER MODELLING
(erstwhile Surface Water Modelling Centre)

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VOLUME 1

MAIN REPORT

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IWM
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Structure of Final Report

Volume 1	Main Report	
Volume 2	Annexure A	: Salinity Maps
	Annexure B	: Water Quality Plots and Tables
Volume 3	Annexure C	: Results of Intensive Monitoring on Pilot Areas
Volume 4	Annexure D	: Flow, Sediment and Morphological Observations
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EXECUTIVE SUMMARY

1. Background

The Sundarbans Reserve Forest (SRF) is a complex ecosystem comprising the largest diversified mangrove forest of the world. Located in the southwest region of Bangladesh, the area in general is coastal flood plain and crisscrossed by numerous rivers, creeks and depressions. The SRF provides habitat for a large number of flora and fauna, including various endangered species of mammals, reptiles, birds and fish. The sustainability of the Mangrove Forest and survival of the ecosystem largely depends upon the circulation of fresh water from the upland. But it is endangered with the increase of salinity and other harmful ingredients including organic and inorganic pollutants. A number of studies were carried out on the area in the past. Most of them were short-term basis and conducted as a part of other projects. The inherent inaccessibility and high cost involvement restricted consistent and systematic data collection activities to a minimum. Only significant data collection programme was taken under Integrated Resources Development Programme of SRF in 1994-95. Those were also limited to hydrological parameters and salinity at selected locations.

The technique of mathematical modelling has been established as an effective tool for generating data at ungauged locations of the complex river system. Once developed and calibrated with the observed hydrological and topographic data, the model is capable to replicate for other hydrological situations at the ungauged locations under known boundary conditions. Thus the need for intensive data collection and monitoring in the inaccessible part of the project could be greatly reduced. The model is also useful in predicting the impact of adverse hydrological and water quality situations in the surrounding areas and helps the decision makers to take adequate measures to prevent or minimise the adversity. In connection with SBCP, the Surface Water Modelling Study was conceived to understand the complex water ecosystem of the SRF area, so that the planners and decision makers including the relevant agencies for forest, ecology and wild life may get sufficient information out of it. Institute of Water Modelling (IWM) having experience in conducting similar studies through field survey, data collection and mathematical modelling was identified by the ADB for conducting a research-oriented study in this connection.

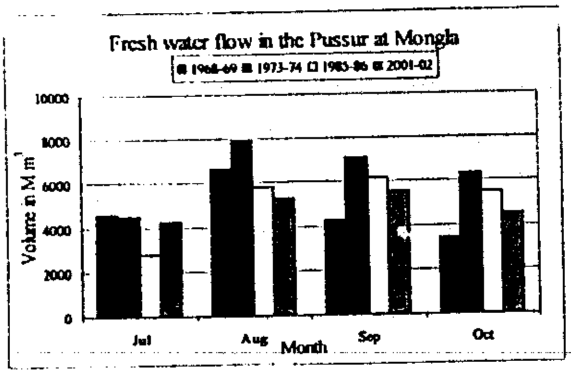
During the initiation phase, IWM proposed four years data collection with four months break each year during high monsoon seasons of difficult accessibility. One additional year was proposed for analysing the data by applying mathematical modelling. Due to limitation of resources, the study period was reduced with a provision of 8 months data collection during 2 wet and 2 dry seasons. Accordingly, a contract between ADB and IWM was made in October 2000 for a period of two and half years (October 2000 – February 03) for the entire study (Appendix A). However, due to delay in commencement of the study, the 1st year wet season data could not be collected. Instead, 12 months data collection (October 2000 – March 2002) with four months break from April to July was taken up. In March 2002, the Mid-term Review Mission of the ADB and IWM agreed on few modifications in the study approach considering the practical situations and additional requirements for the project (Appendix B). In the modified approach the idea of large-scale study on inundation and topographic changes (item 3e & 3f of the ToR) was found non feasible and shifted to comprehensive study on three pilot areas. ADB Review

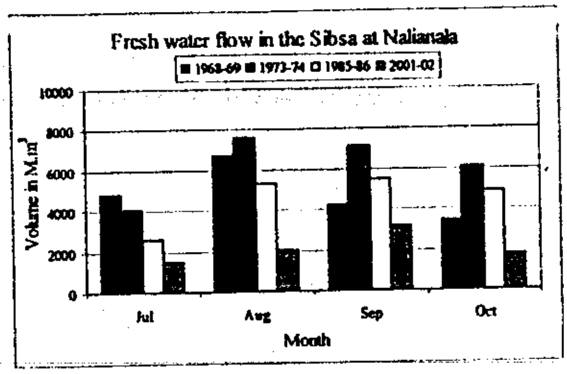
Mission also recognised the need for longer time of data collection and monitoring for better understanding of the water eco-system of the Sundarban. It was agreed to continue the data collection for additional two years up to March 2004. Considering the importance of round the year data IWM agreed to continue the monitoring during the difficult seasons as well. The data collection was further intensified to cover more stations for water quality and salinity. Towards the end of 2002, ADB informed uncertainty of the extension of IWM contract as GoB and ADB had been in the process of negotiation for an overall reformulation of the project. Ultimately, in February 2003, ADB mission during their visit instructed IWM to stop all field activities by February 2003 and submit the Final Report by March 2003. Accordingly, IWM submitted the Final Report in the shortest possible time. At that time it was not possible to make a comprehensive analysis of the data to address all the issues mentioned in the ToR. After receiving the report, ADB and FD made some valuable comments for further improvement. Though it has been beyond the limitation of the allocated time and resources, as a national institution IWM carried out a detailed analysis and review of the data and prepared this Revised Final Report.

During this time, we have tried to address most of the comments and suggestions from ADB and FD. It is expected that the report will be useful to the users and stakeholders to develop a basis for further understanding and monitoring of the complex water ecosystem of the SRF area. The highlights of the report have been presented in the following sections while further details could be available in the main report and the relevant Annexure.

2. Study on the Severe in Decline of Fresh water flow

Mathematical model has been applied to generate wet season flow for the year 1968, 1973 and 1985 for the Pussur and Sibsa systems. Current fresh water flow has been generated from the hydrodynamic model updated during the study period. Results have been used to compare the flow of these rivers. In the Sibsa system, it appears that the freshwater flow has been significantly declined since 1973 (Figure below). The possible reason could be the reduction of fresh water from the upstream channels. It may be mentioned here that after the construction of the Farkka Barrage in the neighbouring country most of its southbound distributaries have been silted up. As a result the dry season as well as the wet season flow in many of those rivers has either been cut off or reduced.





In the Pussur, the model results show less reduction of freshwater flow compared to the Sibsa. This may be because the coastal polders in the Bagerhat area has sealed most of the southbound arteries through the east Sundarban and pushed a significant portion of the Gorai flow towards the Pussur.

It is to be noted here that due to non-availability of historical data the actual topography of the rivers could not be used in the model; the historical flow may vary because of possible change in the conveyance of the rivers.

3. Impact of Tidal Variation on Seasonal Forest Inundation Zones

Analysis of tidal data shows that the tidal ranges in the rivers in the area increase from east to west. It has been observed from the available data that the annual maximum tidal ranges at Khulna, Mongla, Nalianala and Kaikhali vary around 3.25m, 3.90m, 4.30m and 5.0m respectively. It has been observed that recorded annual maximum tidal range at Kaikhali in the western part of the SRF remains unchanged for the last 40 years while significant increase of annual maximum tidal range has occurred at Khulna, Mongla and Nalianala. It is also observed that the maximum tidal range at Mongla (Pussur) and Nalianala (Sibsa) during late sixties was quite close while sharp increase in tidal range at Nalianala occurred after 1973. Tidal range close to coastal places has also been increased during the past decades. One of the reasons for faster increase rate at the Sibsa may be due to the siltation of the upstream channels. Historical changes in tidal conditions occur due to natural processes as well as human interventions. Increase in tidal range may also affect inundation pattern in future as well as topography within the forest.

During the study comprehensive monitoring and data collection including land level survey has been conducted in three pilot areas. Based on the surveyed data inundation pattern has been assessed on those pilot areas by superimposing the results of MIKE11 Hydrodynamic model on the land level. It has been observed that the forestland in the selected sites are rarely inundated during the month of December to February while partial inundation has been observed during the month of March to May at spring tide and higher depth of inundation with longer duration at all sites during June to October at spring tides (Reference Inundation Maps, Annexure C, Volume 3).

Soil salinity and other chemical properties have also been tested for three seasonal cycles on the said pilot areas. It may not be wise to draw any conclusion on the soil salinity with this limited data.

4. Impact of Sea Level Rise on Inundation

The hydrodynamic model has been used to simulate the impact of sea level rise on inundation. Model runs have been carried out with sea level rise of 20cm and 50cm. It has been shown that for 50cm rise in sea level there will be an increase of 45cm in the water level of the Pussur at Mongla. A proportionate increase will occur at other places with respect to distance from the sea. An inundation map showing the depth and extent of flooding in the SRF area for 50cm sea level rise has been presented in Section 8.1 of the main report. The results should be used as indicative only because the model did not consider the possible morphological changes in the rivers. Moreover, the land level of the SRF area is not in the same vertical reference with that of the national datum.

5. Salinity Pattern inside the SRF

The salinity data has been presented in the form of coloured map to show spatial distribution of salinity at different seasons (Annexure A, Volume 2). It has been observed that the Salinity in the SRF area increases from northeast to southwest. Eastern part of the Sundarbans (Supati, Shwarankhola) remains saline free (less than 1 ppt) during monsoon season and at low salinity level (up to 5ppt) during the dry season. While the salinity level at the northern part of the Sundarbans adjacent to Pussur and Sibsa remain close to 5 ppt at the time of monsoon, during the dry period the salinity in that area goes above 15 ppt. The salinity level across the coast also increases from east to west round the year due to the westward circulation of fresh water. All stations on the western part shows a steady increase of salinity from the late monsoon season and reduces only after onset of the monsoon.

Elaborate analysis of salinity data has also been carried out to identify salinity stress area in different period. The results of the salinity for different duration in isohaline maps have also been prepared (Annexure A, Volume 2). **Table 1** shows the areas under different level of salinity stress. It is seen from the table that about 60% of the SRF area already suffers from a high salinity stress of more than 20 ppt for a minimum period of 45 days. The salinity stress of more than 15 ppt for a period of 45 days and 60 days exist in the area of 75% and 65% respectively. Thus only a smaller part of the Sundarbans remains low to medium salinity zone during the dry season. The spatial distribution maps and isohaline maps should be highly useful for the forest department to manage SRF area for vegetation and wildlife. Consideration should be given to the fact that the analysis is based on the data of only one year.

Table 1: Salinity Stress during 2001-2002 inside the SRF

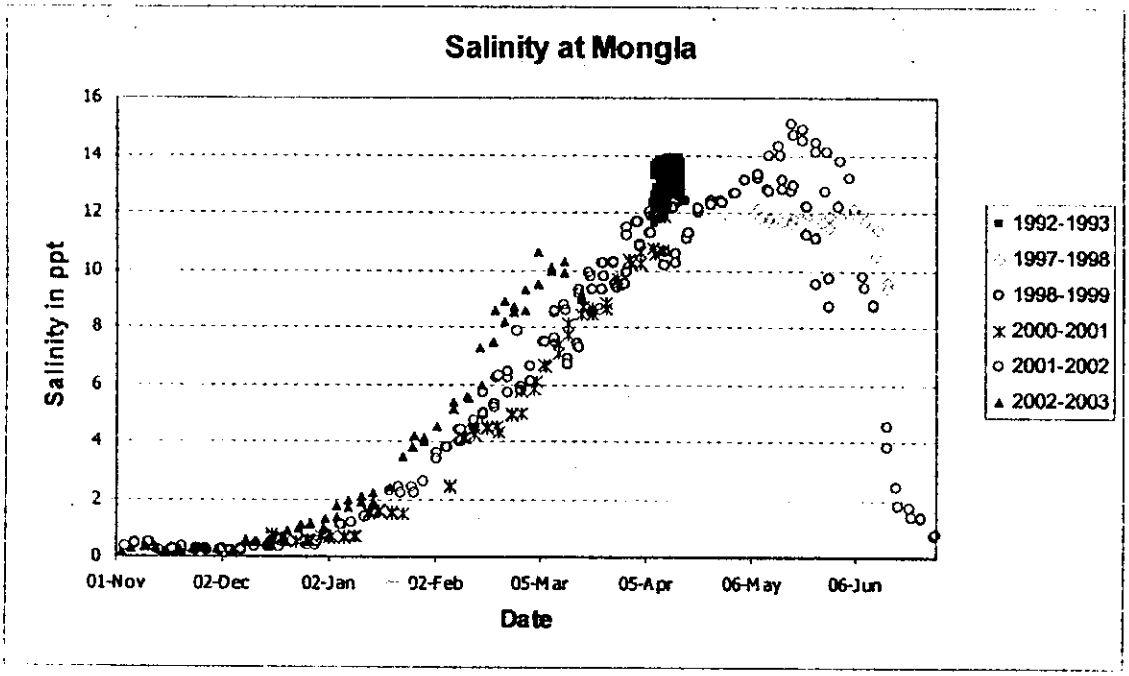
Duration in day	Percentage Area at different Salinity Level					
	>25 ppt	20-25ppt	15-20ppt	10-15ppt	5-10ppt	<5ppt
120	0	25	28	19	15	13
90	6	31	28	15	14	6
60	6	31	28	15	15	5
45	28	30	17	11	10	4
30	29	30	17	11	9	4
15	29	30	17	11	9	4

6. Impact of Freshwater Flow on Salinity

a) From Observed Data

During the study period salinity monitoring has been conducted at 26 stations. Besides, the available data from various sources for the period up to 1993 have also been collected and compiled. The available data has been presented in the form of time series graphs to assess the variation of salinity in different seasons during the recent years.

- It is observed that the salinity in the eastern and central of the Sundarbans gives sharp response to the fresh water flows from the upstream.
- Increase in the duration of fresh water flows may Lead to a longer duration of reduced salinity. An example is the reduction of salinity in the dry period of 2001 at Basantapur, Kaikhali and Kobadak due to unusual flood in the area in September 2000.
- After the pilot dredging in the Gorai mouth in 1999 – 2000 a significant increase in fresh water flow was achieved, though it has not been possible to locate any consistent monitoring data for the SRF area during the said period, it could be visualised from the chart of Mongla that there had been a visible decrease in salinity along the Gorai Corridor. IWM data collection shows a gradual increase of salinity at Mongla, Nandabala, Herbaria, Mrigamari, and Nalianala from 2000 to 2003. It may be because, the dredging effect of the Gorai in 1999-2000 has been gradually diminished during the subsequent years.



It is to be remembered here that major changes in the fresh water flow due to upstream withdrawal at Farakka and polder embankments in the coastal area of Bangladesh took place in the seventies. As the data during this period is not available, it is difficult to make any definite comment on the changes

b) Mathematical Modelling Study

A salinity model incorporating the data of SRF has been developed and calibrated with the observed data of 2001 and 2002. The model has been applied to study the impact of fresh water flow on the salinity level. In this connection a number of options with different combination of flow rates from the upstream have been simulated in the model. The results of option model have been compared with that of the base model under 2001 wet season and 2002 dry season. Findings of the comparisons for few options are presented below, while more detailed has been presented in the main report:

Development option	Findings
Option 1: Minimum discharge at Gorai is 100 m^3/s without changing other existing condition.	The boundary of salinity zone (min 1ppt.) is shifted from Baradia towards Khulna by 25km. The reduction of salinity during March at Mongla is about 1 ppt. The impact reduces towards the sea and western part of the Sundarbans.
Option 2: Minimum discharge at Gorai is 200 m^3/s without changing other existing condition.	The boundary of salinity zone (min 1ppt.) is shifted from Baradia towards Khulna by 45km. The salinity at Mongla reduces by more than 1.5 ppt and at Nalianala by 1 ppt.
Option 3: Minimum of 200 m^3/s into the Kobadak – Betna systems in addition to the Option 2.	Significant improvement on the upstream of the western part of the Sundarbans is observed but not much improvement with respect to option 2 in the Sundarbans area.
Option 4: A Minimum of 300 m^3/s in the Kobadak - Betna system during monsoon period season	Significant improvement at the upstream of the Sundarbans observed, little change inside the Sundarbans

7. Impact of Sea Level Rise on salinity

The salinity model mentioned above has been applied to study the impact of sea level rise on salinity. The results have been presented in Section 8 of the main report. It has been observed that for a sea level rise of 50cm, salinity at Mongla and Nalianala increases by 12ppt and 8ppt respectively as compared with the base condition of 2002 dry season. Under such situation the minimum salinity level in the SRF area would reach 15ppt. It will also intrude approximately 40 km upstream from its present position. A similar option has been tested for the sea level rise of 20cm.

8. Assessment of Water Quality

During the study period comprehensive water quality data collection has been carried out at 16 locations of the SRF area to assess the health status of the waterways. The data has been analysed to assess the spatial and temporal variation for 2001 – 2002. Due to the non-availability of historical data it has not been possible to analyse long-term trend. Summary findings in respect of different water quality parameters have been presented below.

Organic Pollution

The Sundarbans waterways contain high volume of sediments and wastes from the forest. Presence of organic pollution is observed from the high values of BOD and COD of the water samples. It has been observed that the extent of pollution is higher in the western part than the eastern part. The average pollution level inside the SRF area is more than the areas near to the boundary. Thus, it may be said that significant level of organic pollution originates inside the Sundarbans.

Dissolve oxygen inside the Sundarbans has been observed within the EQS limit. Dissolved oxygen at places was found to decrease with the increase of sediment concentration. The average of all the values observed from the profiling is 5.99 mg/l, which represents healthy environment of SRF at present. A coarse water quality model to assess the spatial trend of Dissolve Oxygen (DO) has also been developed. In the model it has been observed that with an artificial increase of pollution load by 100% in the water the DO level reduces significantly. This provides a warning that the Sundarbans waterway is vulnerable despite the vastness of the water body.

Nutrient Level

Presence of nutrient in the water is very essential for the aquatic life. Testing of water samples has shown the presence of nutrients like Total Ammonia (NH_4-N), Nitrate (NO_3-N) and Phosphate (PO_4-P) in sufficient quantity but within EQS Limit. Presence of NH3-N was observed in insignificant quantity and does not posses any threat to the aquatic system. The presence of total ammonia is higher in the western part of the Sundarbans. Ammonia increases during dry season and remains at low level during monsoon. Unlike ammonia, Phosphate and Nitrate does not follow any definite seasonal pattern.

Presence of Heavy Metals

Presence of Lead and Chromium has been detected all through the Sundarbans. High values of Lead were observed in the month of March and April during 2001. It was relatively lower in the remaining samples. In general, it varies between 0.02 mg/l to 0.04 mg/l. Chromium exceeded the limit once at four occasions (Nalianala, Kobadak Malancha and Arpangasia) in the samples of March 2002. Both Nalianala and Kobadak on the International route for barges while Malancha & Arpangasia is in the downstream of the Kobadak. Thus there is possibility of pollution coming from the vessels in these cases. But, the sources can be confirmed by long term monitoring at the locations of higher values of Lead and Chromium.

Presence of mercury has been detected in only 5% of samples at very low level (maximum 0.32 ppb). Thus it does not shows any threat to the ecosystem at present.

Presence of Oil & Grease

Presence of Oil & Grease has been detected at about 4 % of samples (eight events) only. The locations are Harbaria, Mrigamari, Harintana, Dingimari, Malancha, Arpangasia and Koikhali. These seem to have originated from point sources, which may be dredgers/ships in the Pussur River and Barges/fishing boats at Koikhali, Dingimari, Malancha and Arpangasia.

Course of Pollutant within the Forest

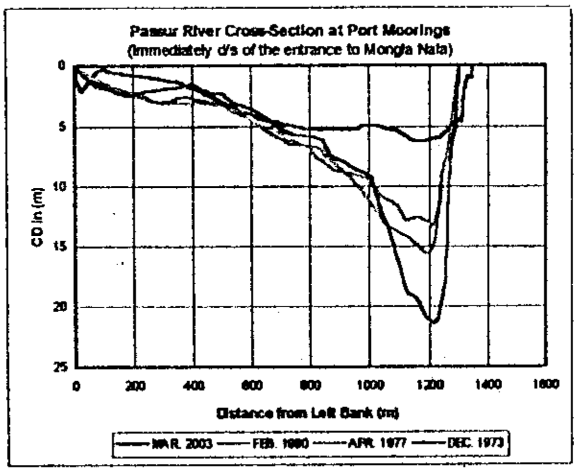
Soil samples collected from the selected pilot areas have been tested for Lead. Observed amount of Lead ranges from 14.19 ppm to 22.29 ppm. This might have been due to accumulation from the Sundarbans water through inundation. However, the samples were tested for one seasonal cycle at 3 areas and needs further data collection for assessment of spatial variation and severity.

8. Impact of Shrimp Farming on Water Quality

Detail investigation of water quality inside the shrimp farms and extent of shrimp farming requires huge resources, which is beyond the scope of the present study. Data on shrimp farming ponds with respect to non-shrimp areas shows that ammonia (NH_3-N) and Dissolved Oxygen (DO) is higher in the shrimp farm area as compared to the non-shrimp farm areas. The higher value of DO indicates less organic pollution in the shrimp farm area. Ammonia content has been detected at a very low level in the Sundarbans Waterways. Thus ammonia released from the shrimp farms seems to have negligible impact on the water quality of the Sundarbans.

9. Siltation of the Rivers

Sundarbans waterways cover about one-third of the gross area and play important role on the mangrove ecosystem. Condition of the rivers has been analyzed by applying the available data of river cross-section and sediment. Except for the Pussur and the Sibsa from Mongla Port Authority it has not been possible to find data of other rivers beyond 1994.



It has been observed that Mrigamari an important artery from the Pussur towards the Selagang shows alarming rate of reduction in conveyance due to siltation during the recent years. Though, it is difficult to make any concluding remarks with the data of only few years it should be treated with cautions. The model results also indicate the possibility of gradual dying up of the river if similar reduction in the channel conveyance continues. It may be mentioned here that Kharma Khal on the left bank of Mrigamari, has already been silted up disconnecting a large areas in the northeastern part of the SRF out of tidal circulation.

In general, the rivers in the west and southwest Sundarban appear less vulnerable to siltation.

10. Topographic Changes on the Forestland

The level of forestland was surveyed at three pilot areas (Jongra, Patkusta & Kaikhali). The spot levels from the survey were compared with those obtained from FINNMAP's survey. It has been observed that the FINNMAP data is generally 0.5m – 1.5m erroneous, though they have declared an error range of 1m – 2m. From the survey data of three pilot areas and those from FINNMAP it appears that the level of forestland in the western part is relatively higher than that of the eastern part. Comparison shows that the land level inside the Sundarbans is around one meter higher than that of the polders in the adjacent areas. This is quite reasonable, because due to the construction of embankments the rate of siltation on the countryside has significantly reduced during the recent years. The after effect is visible from the drainage congestion in the Khulna Jessore Drainage Rehabilitation Project areas.

Monitoring of siltation on the above three pilot areas gives a general indication of the siltation process on the forestland. Minor creeks carry water from the river towards the central part of forest saucers. While travelling along the shallow creeks most of the sediment is dropped due to low velocity at short distance form the rivers. It is therefore reasonable to understand the reasons for denser plantation rate and higher siltation on the forest edge than in the central part. The trend analysis of the three pilot areas shows that the sedimentation rate in the Jongra area (on the Pussur) is higher than that on the Kaikhali area (on the west) while at Patkusta there is a tendency of erosion on the forestland. However, because of short duration data the above remarks should be considered, as indicative for future monitoring programme.

11. Impact of Human Intervention

In the late sixties and seventies huge numbers of polders have been constructed in the coastal areas to protect the area from cyclone surge and salinity intrusion. The polder embankments were highly effective against cyclone and tidal bore but blocked most of the tidal creeks contributing to drainage and flushing in the area. Moreover, with the security from cyclone and tidal surges enhanced development took place in the area through construction of communication networks in the area, resulting in further obstruction to drainage routes. In the ultimate situation tidal fringe has been reduced and tidal circulation interrupted causing siltation in the channels outside the polders. The best example is the closure of Kharma-Bhola system. It may be futile exercise to try to go back to the original situation of the sixties, but monitoring to prevent further degradation of the natural system is a must.

Kharma Khal one of the important routes of tidal circulation has gradually silted up. Possibly because of its disconnection with the Pussur system, the Bhola Khal is also getting dead at the upstream. Considering the importance of the Kharma – Bhola system also to address the need from the FD a mathematical modelling study for the system was conducted to identify possible measures for mitigation. From the result of hydrodynamic model it appears that a dredging option might improve the situation. But, the sustainability of the dredged channel has to be confirmed through a dedicated cohesive sediment model and morphological study. The cohesive sediment model requires intensive data collection covering dry and wet period on water and sediment, which was not possible at this stage.

12. Database development

A GIS based interactive database system "Sundarbans Water Information Management System (SWIMS)" has been developed during the study and handed over to MIS Unit of SBCP. Collected data from the study, developed map, historical data and model output has been stored in the database. The database can be used to plot charts, generate reports and exchange data.

13. Training and Technology Transfer

The staffs of the FD have been trained on the monitoring of water level, salinity, water quality and sedimentation in the river and on the forestland. Few key staffs have been trained on the processing and analysing of the data including operating of the database.

14. Findings of the Study

The findings of this study could be summarised in the following:

- Eastern boundary of the SRF has been connected with the national datum (vertical reference) which has improved the model results in the Pussur system significantly;
- Salinity and water quality data collection have been conducted for the entire Sundarban area for a continuous period of more than one and a half year, which was never possible earlier;
- A Sundarban Water Information Management Systems (SWIMS) database has been developed. The data collected during this study and those from earlier studies has been accumulated in the same database and assessed in a comprehensive way to develop a historical trend for different indicators especially for salinity and sedimentation in the rivers;
- An assessment of the temporal and seasonal variation of tidal range has been made and a significant increase in the tidal range has been observed in the Pussur, Sibsa and Kobadak during the last decade;
- Fresh water flow in the Sibsa during the wet season has generally decreased after 1960; dredging in the Gorai offtake during 1999 – 2000 has been found effective to restore the flow for a short period;
- Assessments of sedimentation with the available cross section data shows that the rivers in the east are more vulnerable to sedimentation than those in the west; the data also shows that Mrigamari the connecting channel between the Pussur and Selagang is threatened with siltation; The results of option model shows that if the present trend of siltation in the Mrigamari continues there is a possibility of disconnection of the same from the Pussur which may ultimately lead to the dying up of the upper part of the Selagang.
- Assessment of the salinity for temporal and spatial variation has been made with a comprehensive set of primary data; the data collected in connection with the other studies have also been considered. However, most of those data covers only short period mostly in the dry seasons, in no way they covers round the year. It has been observed that the salinity in the eastern part is significantly less than that of the west. The rate of reduction with the onset of monsoon is also fast in the eastern part. While in the southwestern corner near Notabaki the response is insignificant.
- Augmentation in the Gorai flow reduces the salinity in the Passur and Sibsa, but has got minimum effect on the channels in the west.
- The model results show that increase of flow in the western rivers may reduce the salinity in the western part (Kobadak – Betna system) of Sundarbans. Even increase in wet season flow through the said system reduces salinity in the impact zone.
- Hydrodynamic computation of option models indicate prospect for improvement of the conveyance of Kharma-Bhola system. However, before going for any

implementation measure dedicated cohesive sediment modelling study should be carried out in this respect.

- Organic pollution observed in the SRF waterways do not seem threatening at the moment, however, further monitoring should be continued to avoid any harmful occurrences;
- In few occasions Chromium pollutant has been found to exceed EQS limit in the western part (Kobadak, Nalianala, Arpangasia and Malancha) of the SRF;
- The topographic data of FINNMAP and the land level surveyed on the pilot areas show that land level inside the SRF area is higher than that inside the coastal polders in the vicinity; that indicates increasing threat of drainage congestion in the polder areas.
- Relevant staffs of the Forest Department have been trained in the hydrological and salinity monitoring. The MIS staffs of SBCP have been also trained in the operation and maintenance of the SWIMS database.

The data collection and analysis so far made provides an improve basis for understanding of the complex water eco systems of the SRF area. However, to be able to support the relevant user groups with a desirable level of confidence the monitoring and study should be continued for another two to three years.

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LIST OF ACRONYMS AND ABBREVIATION

AEC	Atomic Energy Commission
ADB	Asian Development Bank
BAU	Bangladesh Agricultural University
BDT	Bangladeshi Taka
BINA	Bangladesh Institute of Nuclear Agriculture
BIWTA	Bangladesh Inland Water Transport Authority
BoBM	Bay of Bengal Model
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering & Technology
CERP	Coastal Embankment Rehabilitation Project
CF	Conservator of Forest
CTP	Conductivity, Temperature, Pressure (sensor)
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DHI	Danish Hydraulic Institute
DOE	Department of Environment
EQS	Environmental Quality Standards
FAO	Food and Agriculture Organization
FD	Forest Department
GEF	Global Environment Facility
GIS	Geographic Information System
GoB	Government of Bangladesh
GoN	Government of Netherlands
GPS	Global Positioning System
GRRP	Gorai River Restoration Project
HD	Hydrodynamic
ICZM	Integrated Coastal Zone Management
IRMP	Integrated Resource Management Plan
IUCN	International Union for the Conservation of Nature
IWM	Institute of Water Modelling
JICA	Japan International Co-operation Agency
KJDRP	Khulna-Jessore Drainage Rehabilitation Project
MIKE11	Modelling Software Developed by DHI
MIKE21	Modelling Software Developed by DHI
MoEF	Ministry of Environment and Forest
MPA	Mongla Port Authority
MPO	Master Plan Organization
PCA	Port of Chalna Authority
PD	Project Director

PP	Project Proforma (GoB)
PPT	Parts per Thousand
PPM	Parts per Million
PPB	Parts per Billion
PWD	Public Works Department
SBCP	Sundarbans Biodiversity Conservation Project
SOB	Survey of Bangladesh
SRF	Sundarbans Reserve Forest
SWMC	Surface Water Modelling Centre
TAG	Technical Advisory Group
TBM	Temporary Bench Mark
UHF	Ultra-high Frequency
UNDP	United Nations Development Program
WaRPO	Water Resources Planning Organization
WQ	Water Quality

1 INTRODUCTION

1.1 Background

The Sundarbans Reserve Forest (SRF) is a complex ecosystem comprising the largest diversified mangrove forest of the world. Located at the southwest region of Bangladesh, the area in general is coastal flood plain and crisscrossed by numerous rivers, creeks and depressions. The SRF provides habitat for a large number of flora and fauna, including various endangered species of mammals, reptiles, birds and fish. The growth and survival of the ecosystem largely depends upon the circulation of fresh water from the upland. On the contrary it is endangered with the increase of salinity and other harmful ingredients including organic and inorganic pollutants. During recent years the biodiversity health in the Sundarbans have been severely affected by the adverse effect of salinity, pollution and siltation in the water and soil. Many of those adverse situations are said to be due to the impact of man-made interventions in the surrounding areas. Long time effect of global warming and sea-level rise could be other reasons.

1.2 Development of the Project

The SRF has been recently declared as one of the world heritage site. Accordingly, the international organisations like ADB, GEF and others have come forward to support the Department of Forest in developing a sustainable management tools for the Sundarbans. Understanding of the water eco system is an important factor in the context of conservation of biodiversity. Considering the fact that the Institute of Water Modelling (IWM), erstwhile SWMC has got the experience with the hydrological system in the area has been engaged for conducting studies related with the surface water of the Sundarbans and the surroundings since October 2000. The study comprises field survey, monitoring and analysis of the data related with the water eco systems. IWM would conduct a mathematical modelling study to generate water related data at ungauged locations and develop various options to study the impact of man-made intervention and natural changes in the water eco system in the area.

In the original proposal the field data collection was planned to cover four seasons, two monsoon and two dry periods of three months each. This intermittent data collection scheduled to be completed in March 2002. The first year data collection started in October 2000 and continued upto March 2001. The second year campaign started in August 2001 and was planned to continue upto March 2002. However, the contract would continue till mid-February 2003 to conduct analytical studies including mathematical modelling. During subsequent interactions with the ADB and the stakeholders in the SBCP it has been realised that an intensive long-term monitoring and data collection is essential. Accordingly, some immediate actions were taken. The issue was further discussed with the ADB mid-term Review Mission in February 2002. In consultation with the ADB team a detailed work plan with inclusion of additional monitoring locations for different parameters and pilot areas for detailed study were developed. Accordingly, a revised work plan was prepared to cover data collection up to March 2004 with another three months for analysis and review of the data. The progress of achievement up to December 2002 was submitted in Annual Report, February 2003. During the visit of ADB Mission in February-March 2003, it was informed that due to uncertainty in the overall project the Surface Water Modelling activity should be limited within the contract period and the final report be submitted within that time.

1.3 Review of Earlier Studies

The Sundarbans Reserve Forest declared, as a site of world heritage is one of the most remote and inaccessible areas of Bangladesh. As such it is really difficult to find sufficient number of dependable report on the water eco-system of the area.

The relevant highlights of those studies are summarised below:

Halcrow-Mott Macdonald & Associates, 2001, *Options for the Ganges Dependent Area, Final Report, Volume I, Volume 5 and Volume 7,* Ministry of Water Resources, Government of Bangladesh

Water Resources Planning Organization (WARPO) conducted the study in 2001 with expert support of Halcrow, Mott MacDonald and associates. The objective of the study was to test several options for the Ganges dependent area including the Sundarbans to see the impact of increasing the flow of Gorai, Mathabhanga and other spill channels after implementation of the Ganges Barrage. The existing model with the IWM was applied for the purpose. The study quantified the salinity of the Sundarbans and upstream areas by applying mathematical models for different development options related to the implementation of the Ganges Barrage. Due to the limitation of data the results of the model is said to provide qualitative assessment than quantitative. The report mentioned "Lack of basic data on many of the environmental concerns means that much of the impact assessment in this report can be broadly qualitative". The study findings & recommendations for monitoring of the following key environmental parameters for any future study in the area.

- water flows and surface water salinities in key areas, notably at several sites covering the different water and vegetation conditions in the Sundarbans, in order to allow more accurate model simulation in the future;
- hydrological and morphological condition on the Ganges and the Gorai with particular attention to quantifying sedimentation, flooding and river erosion and the areas affected;
- ecological conditions-including the prior identification of suitable impact indicators and threshold values for fish and shrimp (and other aquatic species);
- parallel studies of conditions favourable/essential for survival and –where possible-enhancement of the Sundari dominated mangrove association.

CEGIS, 2001, *Gorai River Restoration Project, Environmental and Social Impact Assessment, Main Report and Annexes,* Ministry of Water Resources, Government of Bangladesh

The river Gorai is said to be the only source of freshwater flow for the eastern half of the Sundarbans. The overall objective of the Gorai River Restoration Project (GRRP) was to prevent environmental degradation in the South West Region, specifically around Khulna, the coastal belt and in the Sundarbans, by ensuring fresh water flows. CEGIS was entrusted for the overall Environmental Impact Assessment (EIA) of the project. SWMC (now IWM) was engaged by the CEGIS to conduct mathematical modelling study to provide hydrological and salinity parameters for the EIA. The IWM modelling team maintained several gauging stations in the entire impact area. However, the time and resources was not sufficient to provide connection of vertical datum for the forest area and the bay line.

Moreover, the main objective of this study was to study the impact of GRRP in Gorai Corridor, the western part of the Sundarbans got less priority. The model came up with the impact of implementing several options in the Gorai offtake to prevent environmental degradation in the Gorai Corridor. The results of the options appear sufficiently useful for the purpose, though the study did not consider the water quality parameters except salinity.

SWMC, 1995, *Integrated Resource development of the Sundarbans Reserved Forest* – FAO/UNDP BGD/84/056, Hydraulic Modelling Study, River Research Institute, Ministry of Water Resources, Government of Bangladesh.

The study was conducted by Surface water modelling Centre under Integrated Resource Development Programme of the Sundarbans Reserved Forest funded by FAO/UNDP. The study commenced in September 1994 and completed in June 1995. The South West Regional Model developed earlier during surface Water Simulation Programme was extended to cover the river systems inside the Sundarbans. The model was used to develop some methodology to provide a qualitative assessment of the hydraulic parameters like tidal circulation, tidal range and salinity distribution in the rivers. The study also tested few options like the impact of Gorai discharge and Sea Level Rise inside the Sundarbans Reserved Forest. However, the duration of the study was too small to come up with dependable series of data to understand the complex system of the SBCP area. The most difficult part of the study was the non-existence of datum connection with the gauging stations in the forest area and the bay line. Such connections are essential for generating a realistic pattern of tidal circulation in the model.

SWMC, 1993, *Surface Water Simulation Modelling Programme, Phase-II,* Ministry of Irrigation Flood Control & Drainage, Government of Bangladesh

Surface Water Modelling Centre conducted the study during 1990-93. The aim of the study was to develop a mathematical model for the South West Regional of Bangladesh. The study included data collection in the entire southwest region including the Sundarbans. The model developed at that stage underwent improvement during the subsequent phases.

DHI-BUET-BETS, 1993, *Pussur Sibsa Study,* Ministry of Irrigation Flood Control & Drainage, Government of Bangladesh

The study was conducted by DHI, BUET and BETS during 1990-93 aimed at the siltation problem of the Pussur-Sibsa system. Recommendation of the study was to collect Sediment, Water Level and Discharge Data for calibration of Sediment Transport Model.

Farleigh.D.R.P.1984, *Pussur River Study, Phase-II,* Final Report, Port of Chalna Authority

DRP Farleigh, Consultant to Port of Chalna Authority the study during 1980 - 1984. The aim of the study was to find a solution for the navigability in the Chalna Port (Mongla Port) area. The study comprised of water level and discharge observation in the Pussur, the Sibsa and the inter-connecting river. As a part of the study Hydraulic Research Ltd. of UK was engaged for mathematical study. The developed model was applied for different schemes (like closure of channels) with a view to insure higher discharge through the Pussur River and improve the navigation condition. The study provides very comprehensive analysis on the development of bed topography of the Pussur River and its impact on tidal range, tidal discharge and sediment concentration. As concerned with the hydraulic aspect of the Pussur-Sibsa system due to the implementation of the coastal embankment projects and the establishment of Mongla Port itself this report could be milestone. But issues relating to the water and environment were beyond the scope of this study.

1.4 Structure of the Report

This main volume of the Revised Final Report of the "Surface Water Modelling" component of the Sundarban Bio-diversity Conservation Project has got 12 chapters. This Chapter -1 provides the background of conceiving the Surface Water Modelling Study. It also includes a review of the earlier studies in this context. Chapter 2 presents the achievements made in connection with field monitoring and data collection. Analysis and assessment of the data has been provided in Chapter 3. Chapter 4 presents methodology followed in the development and updating of the South West Regional Hydrodynamic Model to study the SRF areas. The type of data including the boundary conditions and model parameters and the status of calibration of the model has also been presented in this chapter. Chapter 5 presents the methodology followed for the development and calibration of a salinity model for the SRF area. Sample salinity distribution maps developed here demonstrates good prospect of using mathematical model for understanding the ecosystem of the SRF area. Chapter 6 & 7 presents the efforts for preliminary stage development of a Water Quality and a Sediment Transport Model. The said models could not progress well due to limitation of data and time. Different options for improvement of freshwater flow and channel navigability in the SRF area has been presented in Chapter 8. The chapter also addressed the impact of freshwater flow on salinity and impact of sea level rise on salinity and inundation. Chapter 9 provides the facilities available with the Sundarban Water Information Management System (SWIMS) database developed in connection with the study. Chapter 10 provides an overview of the training and interaction with the Forest Department staff during the study period. Chapter 11 is the schedule of reporting and Chapter 12 is a brief recommendation from the study.

The report has got 8 numbers of Annexes organised in 5 volumes. The main report is contained in Volume 1. Annexure A & B are in the volume 2 having all salinity maps in the Annexure-A and all charts & Tables related with the water quality data in Annexure B. Volume 3 contains Annexure C having shown the results of intensive monitoring on the three pilot areas. Volume 4 contains Annexure D having the results of flow velocity and sediment observations. Volume 5 contains the Annexure E to Annexure I having the results of hydrodynamic model calibration in Annexure E, salinity model calibration in Annexure F, pollution model 'Load' calibration in Annexure G and option model study in Annexure H. The user manual of the SWIMS database has been provided in Annexure I.

2 DATA COLLECTION

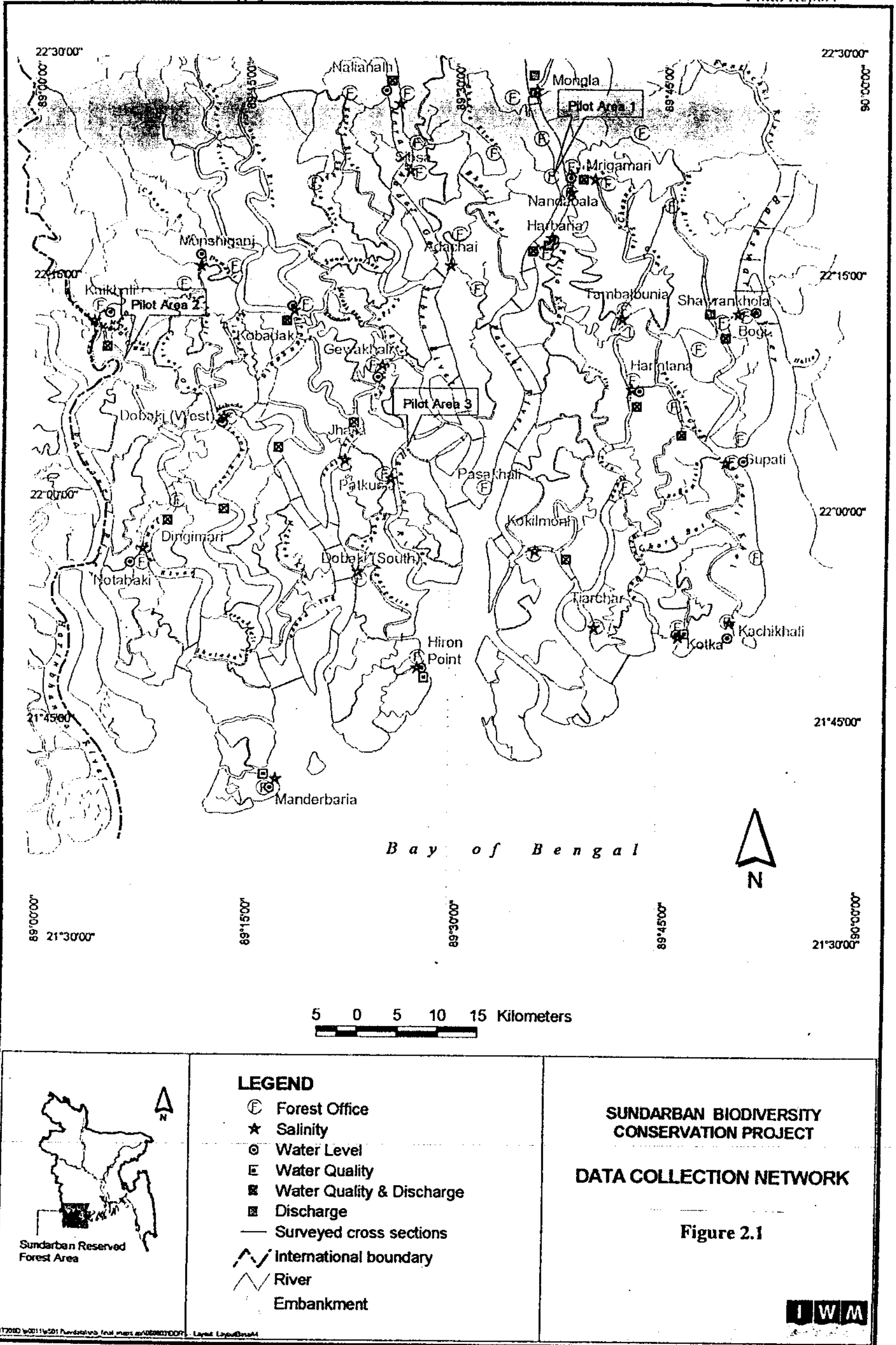
Primary data acquired in connection with this study comprised water level, discharge, salinity, sediment concentration, settling velocity of sediment, river cross-section and water quality. The locations of the stations are shown in Figure 2.1 and the summary status has been presented in Table 2.1.

Table 2.1 List of Primary Data Collection

Type	Station	Frequency	Unit	Total Observations	Period From	Period To	Remarks
Rainfall	5	Daily	SM	94	Oct'01	Mar'03	
Water Level	15	Hourly	SM	75	Nov'00	Mar'01	
			SM	300	Aug'01	Mar'03	
Salinity	6	Hourly	SM	30	Nov'00	Mar'01	
			SM	120	Aug'01	Mar'03	
	10	4 times/wk	SM	50	Nov'00	Mar'01	
			SM	200	Aug'01	Mar'03	
	10	4 times/wk	SM	170	Nov'01	Mar'03	Selected as per discussion with FD and TAG
Discharge	15	Seasonal (1 to 2 times)	TC	42	Jan'01	Dec'02	8 additional measurement for Kharma Khal study
Sediment	15		TC	42	Jan'01	Dec'02	Do
River sections	139	Once	Number	178	Dec'00, Aug'02 and Oct'02		Additional 39 sections required by the model
WQ	13	Seasonal	Number	26	Mar'01	Nov'01	Once in each season
WQ	16	Monthly		212	Jan'02	Mar'03	Includes 2 from sea
Salinity/DO Profiling	-	-	Month	14	Feb'02	Mar'03	Data collected during monitoring trips
Velocity Profiling at Sea	1	Once	Number	1	Jan'02		As required by the Fisheries Expert of TAG
Land level survey	4 pilot areas	Once	Number		Jan'02	Apr'02	As per modified approach of study
Hydrological data collection including micro current measurement on forestland	3 pilot areas	Once in a quarter	-	4	Apr'02	Mar'03	As per modified approach of study

Note: SM = Station Month, TC=Tidal Cycle, WK=Week, DO=Dissolved Oxygen

A large amount of data from secondary sources has also been collected. The list of data collection from secondary sources is presented in Table 2.2



SUNDARBAN BIODIVERSITY CONSERVATION PROJECT

DATA COLLECTION NETWORK

Figure 2.1

Table 2.2 Summary of Data Collected from Secondary Sources

Type	No. Of Stations	Observation Frequency	Sources	Period	
				From	To
Rainfall	63	Daily	BWDB	Apr'00	May'02
Evaporation	09	Daily	BWDB	Apr'00	May'02
Groundwater	38	Weekly	BWDB	Apr'00	May'02
Water Level	67	3 hourly	BWDB	Apr'00	May'02
Water Level	18	24 hourly	BIWTA	Apr'00	May'02
Discharge	04	Fortnightly/weekly	BWDB	Apr'00	May'02
Salinity	11	Twice Weekly (High & low)	OGDA/ IWM	Oct'99	Nov'99
Salinity	2	Hourly	OGDA/ IWM	Oct'99	Nov'99
Topographic Map	Entire forest area	Once	BIWTA/FINNMAP		

2.1 Rainfall

Rainfall plays on important role in diluting the salinity level on the forestland. Rainfall Gauges were installed at five locations during monsoon 2001. The locations are at Supati, Jhalia, Notabeki, and Hiron Point inside the Sundarbans Reserved Forest. The other station is located at Mongla. The data collection for 2000 monsoon could not be materialised because of non-availability of a suitable flood free spot for the gauge. After failing several approaches an innovative idea of placing the gauges on wooden posts was found satisfactory. The gauges were installed following standard specifications. The data collection continued from October 2001 to March 2003 in all the stations except Hiron Point, where observation interrupted during dry season of 2002 due to stealing of the rain gauge.

2.2 Water Level

15 manual water level gauges were installed inside and around the forest area. The gauge locations are shown in Drawing 1. Four additional gauges were installed for study related to Kharma Khal re-opening on Kharma-Bhola System during 2002. The gauges were made of 3m long wooden planks and clearly visible from the bank. At each station, two gauges were installed to cover both high and low water level. The gauges were replaced time to time due to deteriorating of the coloured markings. The zero values of the gauges were connected to the mainland datum in mPWD where available while it was connected to arbitrary benchmark inside the forest stations. The connection to these gauges was done later on by using the model results. The gauge connections were checked every month during field visit. To record continuous data

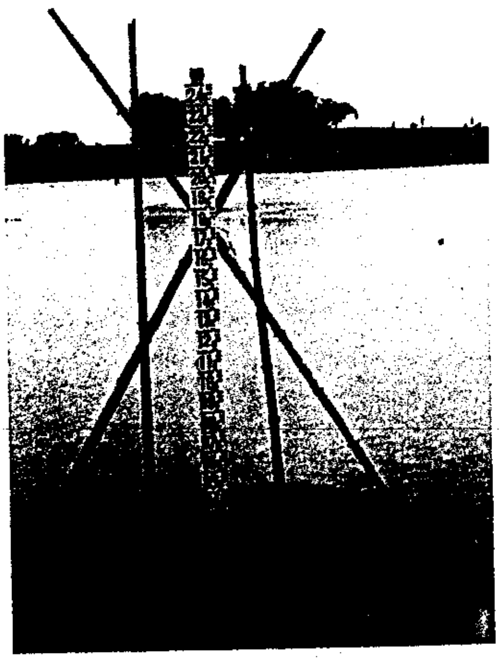


Figure: 2.2 Water Level Gauge

at the remote boundaries, two Automatic Tide Recorders have been procured from the project. These were installed at Hiron Point, Mandarbaria, Kochikhali and Dingimari at different times. Sample water level charts from the Auto Recorder is shown below.

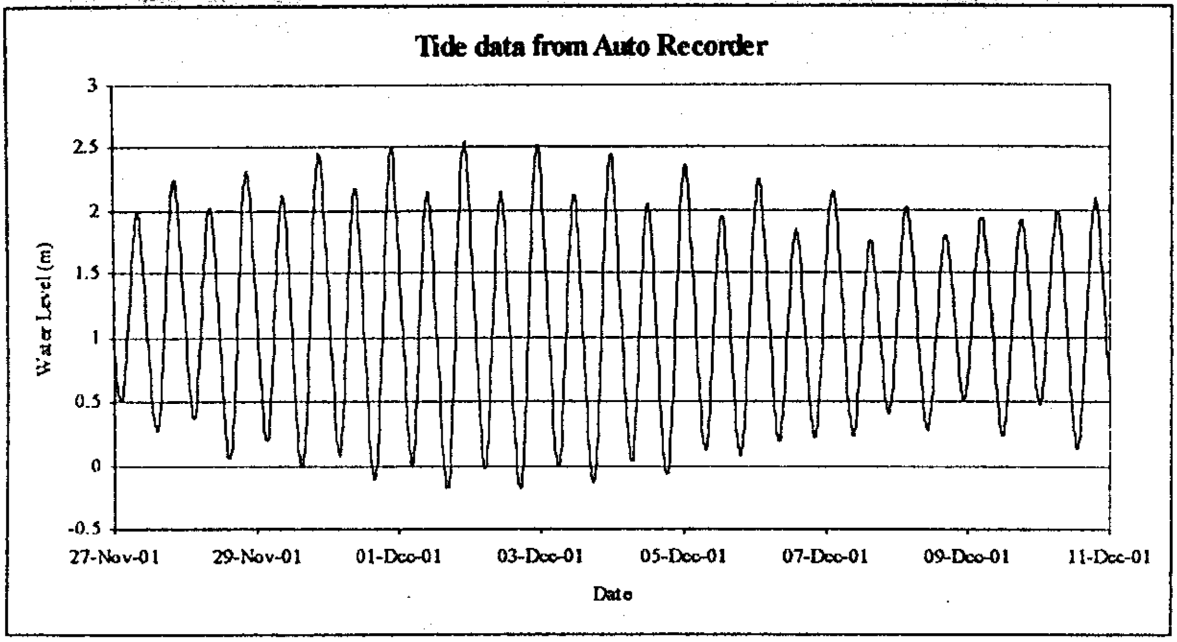


Figure 2.3 Water level data from Automatic Tide Recorder

2.3 Discharge

Discharge observations were carried out at 15 locations in different channels of the Sundarbans during January to December 2001. The observations scheduled for dry season 2002 were dropped following modification of study approach. However, discharge observations at 4 locations for 2 tidal cycles were carried out in connection with the study of Kharma Khal re-opening.

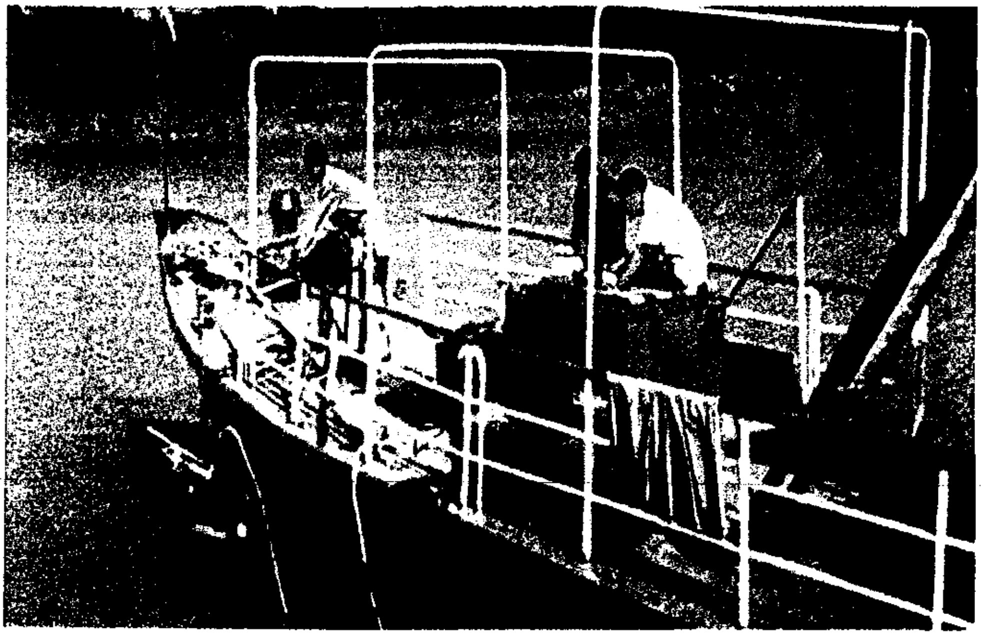


Figure 2.4 Discharge Measurements

The discharge observations were carried out using one to three vessels stationed across a transect line (surveyed by using DGPS and Echosounder). Currents velocities were simultaneously observed at 30-minute time intervals. The number of vessels used was selected depending on the width and shape of the river sections. At each vertical location seven points starting from surface to bottom measurements were taken. Directional current meters were used for measuring both the direction and the velocity of flow to compute the net flow in the river. The duration of each measurement was 12.5 hours to cover one full tidal cycle.

2.4 Salinity

2.4.1 Point Sampling

Salinity sampling during the first year campaign (October 2000 to March 2001) was done at 16 locations. Following outcome of the workshop and interaction with the Forest Department and TAG, IWM reviewed the design and 10 additional stations were installed. Salinity sampling continued at 26 stations from October 2001 uninterruptedly. Locations of salinity sampling stations are shown in Figure 2.1. The sampling at 6 boundary stations were done daily from 6:00 am to 6:00 pm on hourly interval while sampling at remaining stations were done 4 times per week (2 days per week at high and low tide). The testing of the accumulated samples was done once in a month. Standard WTW brand (Germany) Salinometer was used for testing the samples. The measurement was done by inserting probe in the sample. Accuracy of the Salinomter is always confirmed by comparing the results of at least two meters at a time. The salinometers were also tested with standard solutions to check the accuracy level. The measurements were done in parts per thousand (ppt) except for values with very low concentration. All measurements were done at 25°C reference temperature.

Figure 2.5 Salinity Measurement

2.4.2 Profiling

Long profiling of salinity (in-situ sample testing) at major rivers was carried out on different routes during the standard field trips from February 2002 to March 2003. These profiles provide a good indication of circulation of salt water in the rivers.

2.5 Water Quality

Water quality testing schedule was planned once per season at the places of discharge measurement as required for the model study. Accordingly 2 cycles of testing at 13 locations were done during March/April and November 2001. During progress of work, it was felt essential to monitor the water quality more frequently. 2 more stations were added in the sea as per specific suggestion from the Fisheries expert of TAG. However, as per agreed discussion with ADB Mid Term Review Mission during February 2002, water quality sampling locations in the sea were dropped from the schedule (for practical consideration). Instead, 3 additional stations near the coast (Hiron Point, Katka and Mandarbaria) were added. Since then, water quality sampling was carried out at 16 locations every month. On the development of water quality model, 6 additional samplings were made in the upstream rivers for assessing water quality outside the forest area (upstream boundary of WQ model). The list of the sampling is shown in Table 2.3.

Table 2.3 Water Quality Sampling upto March 2003

River	Location	Position		Number of samples tested	Remarks
		Easting (m)	Northing (m)		
Sibsa	Nalianala	441920	482484	15	
Arpangasia	Arpangasia	426817	437470	15	
Bal	Balu	436294	440969	15	
Malancha	Malancha	419139	432834	15	
Jamuna	Jamuna	413965	430742	15	
H. Khal	Harbaria	460790	465369	16	
Sela Gang	Harintana	470484	446195	16	
Betmar Gang	Dudmukhi	477088	442068	16	
Bhola	Shwaran khola	480887	455356	16	
Madargang	Koikhali	404943	455936	14	One sample was damaged during transportation
Kholpetua	Kobadak	429450	456152	15	
Jafa	Jafa	462918	424624	16	
Mrigamari	Mrigamari	465878	472996	16	
Mardat	Hiron Point	448894	412447	10	Additional monitoring stations at the southern part of the Sundarbans near coast
Katka Khal	Katka	476932	416372	10	
Arpangasia	Mandarbaria	425530	399060	9	
In the Bay	20 km South of Hiron point	458248	388346	1	Additional sampling done for requirement by Fisheries Expert (TAG)
In the Bay	20 km South of Kochikhali	482320	404442	1	
Upstream rivers	6 locations	-	-	6	Additional sampling done at model boundary

A total of 12 parameters were monitored for the assessment of water quality. Among the 12 parameters, 2 parameters, viz. Dissolved Oxygen (DO) and Temperature, were recorded *in situ* using a digital Oxygen Meter. For remaining 10 parameters (Table 2.4), laboratory analysis was carried out at the Environmental Engineering Division of Bangladesh University of Engineering and Technology (BUET). From the initiation of the monitoring up till mid-March 2002, one sample per location was collected from mid-depth of the deepest vertical of the river cross-section. Those samples were subjected to laboratory analyses for the mentioned parameters. In line with suggestion of Environmental Specialist from the ADB for the SBCP, the methodology of sampling and laboratory analysis were changed after mid-March 2002. According to the second methodology, three samples were collected from each location: from top, middle and bottom. These samples were analyzed in the laboratory as mentioned in the Table 2.4. .

Table 2.4: Water Quality Parameters Tested from Laboratory

Sl. No.	Name of Parameter	Remarks
1.	Biochemical oxygen demand (BOD)	Middle Sample
2.	Chemical oxygen demand (COD)	Middle Sample
3.	Ammonium NH_4-N	Middle Sample
4.	Ammonia as NH_3-N	Middle Sample
5.	Nitrate as NO_3-N	Middle Sample
6.	Total phosphate as PO_4-P	Middle Sample
7.	Mercury (Hg)	Bottom Sample
8.	Chromium (Cr)	Bottom Sample
9.	Lead (Pb)	Bottom Sample
10.	Oil and grease	Top Sample

Samples were collected by using Jabsco pump fitted with long tube. It has an electric motor connected with a pump housing and operated by 12 Volt DC. The samples were collected by lowering the long tube at desired depth and mixing of water from different layers were avoided. Samples were preserved and transported upto Laboratory in icebox to maintain the quality.

DO and Temperature were measured *in situ*, during tidal discharge observations, at an interval of half-an-hour for a full tidal cycle. Salinity concentrations were also recorded using digital Salinometer in the same fashion. The point profiling of DO were suspended with the suspension of discharge measurement. However, longitudinal DO and Salinity profiles were recorded along the important river systems of the Sundarbans in order to assess the spatial variation of DO and Salinity from river to river.

2.6 Land Topography

Land level data is essential for assessment of the depth and duration of flooding and inundation. It is also essential for the assessment of different environment parameters including WQ and salinity. The land level data is also useful for assessment of the topo-graphic changes.

Due to inaccessibility inside the forest and limitation of resources, detailed topographic survey by conventional or modern survey equipment was not possible. It was felt by IWM and has also been mentioned in the technical report by the Remote Sensing Expert of TAG that the accurate survey by remote sensing is not possible under the dense canopy of the Sundarbans. Topographic survey programme (detailed in Article 2.9) has been taken at three pilot areas. Attempts were made to conduct the survey by satellite based RTK-GPS, but did not succeed as the RTK-GPS requires at least 5 satellite all the time but the thick forest canopy does not permit that numbers. Moreover, multipath error also restricts the accuracy of the survey work by GPS. Land level from aerial survey of FINNMAP was the only secondary source available. The data has the accuracy level of 2 meter. IWM surveyed 4 sample areas at Jongra and Katka (2km X 2km) and smaller area at Kaikhali and Patkusta. The survey was conducted by using conventional level machine. The positions of spot levels were recorded by using Hand GPS. Land levels of the three pilot areas were compared with the level obtained from the FINNMAP aerial survey. A reasonable match was found between IWM survey and FINNMAP survey for some points. However, most of the FINNMAP spot levels vary with those of IWM survey.

Figure 2.6 Poor accessibility inside the forest (Jongra Pilot Area)

2.7 River Cross Section

Rivers play the most important role in the water and environment of the Sundarbans. Active connections of the rivers with the upstream freshwater sources indicate healthy situation for the forest environment and the reverse in detrimental for the forest. River cross-section data is essential to assess the morpho-dynamics of rivers. The cross section data is also required for estimation prediction of flooding/inundation in the river catchment. A total of 139 river cross sections were surveyed under this project during December 2000. Under the additional data collection programme, second round cross-section survey was planned for implementation during December 2002 and January 2003, which had been dropped due to uncertainties of the continuation of the project. However, 61 additional cross-sections have been surveyed during August 2002 in the Pussur, Sibsa, Kharma, and Bhola River for improvement of the model.

The survey was done by using DGPS, Digital Echosounderr and Hydro-Pro Software installed in a Laptop computer. Depth of cross section was converted to reduced level by applying water level correction from model output.

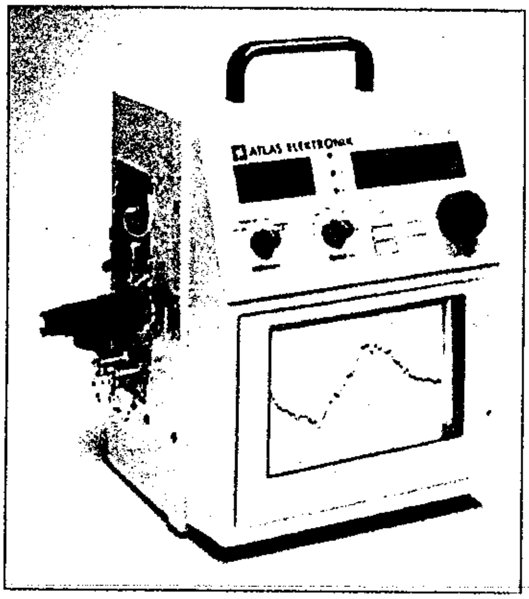


Figure 2.7: Digital Echosounder

2.8 River Sediment

Figure 2.8 Fall velocity observation

Sediment observation is an indirect method of river morphology study and floodplain siltation process as well as an idea on the nutrient in the root zone. Usually the sedimentation is characterised by the suspended sediment concentration in the water, fall velocity of the suspended sediment and the quality of the bed materials. The suspended sediment concentration samples were collected during the discharge observations for a full tidal cycle (13 hours) and sampling was done every 30 minutes interval at each vertical. A total of 42 observations were made in different rivers. All samples have been analysed in the IWM Laboratory at Dhaka. The fall velocity of the sediment was also observed at those locations.

2.9 Pilot Area Study

As mentioned earlier the ADB Mission in October 2001 and February 2002 recognized that the IWM data collection would highly benefit in understanding the water eco-system of the Sundarbans. However, it was found essential to know the impact of hydrological parameters on the sedimentation process and soil quality in forestland. Following interaction with ADB Mission (October 01 and February 02), Technical Advisory Group (TAG) and other stakeholders, a special monitoring programme was formulated. Under this programme, detailed topographic survey inside the selected pilot areas were completed. Change in topography, siltation pattern, soil salinity, soil nutrients, tidal micro-current and inundation pattern on the forestland were monitored directly due to variation in tidal and seasonal cycle in selected pilot areas. The study was planned to be conducted for eight seasonal cycles. Only three cycles of measurement were completed within this reporting period.

Objective of the Pilot area study is to establish a mechanism for monitoring the siltation, soil salinity, soil quality and soil nutrient on the forestland. The methodology and site selection has been done in consultation with FD official, TAG and Members of the ADB Mission. The selected pilot areas are located near Jongra, Patkusta and Koikhali.

The selected pilot areas are:

- Situated in different macro-ecological zone
- Inundated during all seasons
- Having different type of inundation pattern

The area of each pilot area was planned to be around 2km X 2km. Accordingly, topographical survey was carried out at Jongra and Katka (later dropped). During data collection, it was found that such a large area would require lot of resources and practically unmanageable considering the accessibility and risks involved. As such, the detailed study area was reduced to 500m X 300 m size containing all criterion required for the study.

Monitoring was carried out once in every season (3 months interval). The first campaign was conducted from April 2002 to May 2002. The measurements were done starting from low tide condition during neap tide to high tide condition during spring or reverse (Day 1, 4, 7 after during spring or neap tide). However, some scheduled observations were not successful as the rise of water level was not sufficient to inundate forestland.

Different components of the data collection method for the study are described in the following sub-sections.

2.9.1 Topographic Survey

Detailed topographic survey has been conducted once in all the pilot areas. Land level survey was conducted by using Optical Level and hand held GPS. Due to accessibility and visibility problems other sophisticated equipment were not usable at the areas. Spot levels were taken along the transects spaced at about 50m interval. Spacing between points in a transect line is about 10 meters. In absence of connection with mainland, spot levels were taken with respect to an arbitrary benchmark. Later on, Jongra and Koikhali sites have been connected with standard datum. The positions of the spot level were recorded from hand held GPS in WGS 84 co-ordinate system. The positions were then converted to Bangladesh Transverse Mercator (BTM) by using computer software during processing. Alignment of creeks was also recorded using hand held GPS. The data were used for mapping by GIS software.

Figure 2.9: Land level survey inside forestland

2.9.2 Water Level Observation

At every site water level gauges have been installed on the main river and at different location of the pilot area. The gauges are connected with the benchmarks/arbitrary benchmarks. During the monitoring period gauge readings have been taken at an interval of 15 minutes. Standard practice is followed for the installation of gauges. However, the gauges are removed after every cycle of measurement to avoid risk of theft and damage.

Figure 2.10: Water Level observation inside forestland

2.9.3 Siltation Measurement

Siltation pattern is monitored by observing silt deposition/erosion at a number of selected locations in each of the pilot area. Due to impracticability of standard practice for precise measurement, attempts were made by different alternatives mentioned below.

Siltation Gauge:

Siltation gauges are made of wooden plank of approximately 60 cm height. About 10 to 12 gauges have been installed at each of the pilot area. The gauges have been placed at different elevations. Uncovered heights of these gauges were recorded once in every three months. The measurement procedure is quite straightforward and convenient considering the condition of the study area. A total of nos. gauges were installed at three pilot areas. However, the gauges of make them susceptible to damage by the fishermen or other invaders. It was observed that a number gauges had been disturbed or damaged/stolen in all the sites.

Figure 2.11: Siltation measurement

Burried Tiles:

As an alternative to the siltation gauges, locally made earth burnt plain tiles (known as "Tally") were buried approximately 10 to 15cm below the ground. The topsoil was then carefully filled up to represent the original ground level. Depths from ground level to top level of tiles are measured after each cycle of observation. The procedure is safer and the risk of damage could be avoided. However, the topsoil may be disturbed by the fishermen and others while walking around the forest and in the long run, may be difficult in detecting actual position.

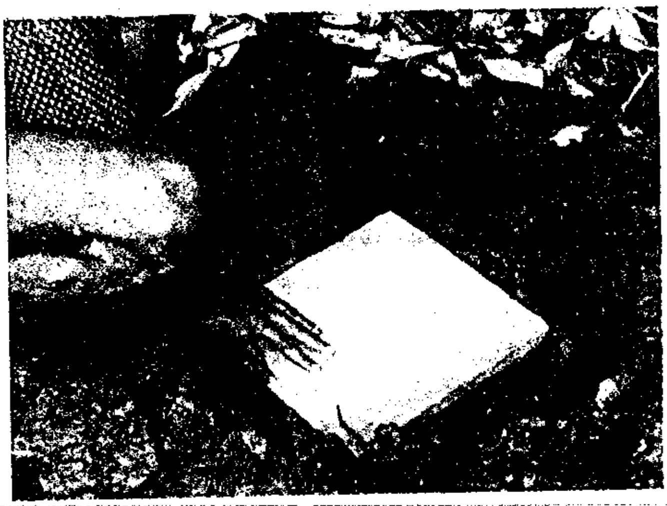


Figure 2.12: Placement of tiles to observe siltation

Land level survey:

For the area of accessible range, land-level survey is the direct means of assessment of the changes of land level for any relevant purposes including inundation and water quality study. A third alternative was to conduct a land level survey. As the forestland is rarely plain in topography, it was difficult to quantify and compare the measurement precisely. This method however could be applied only after a longer gap between two surveys and not applicable to the present scope of study.

2.9.4 Measurement of micro-current

The river spills through many creeks on the forestland during high tides flows like sheets over the land. Gradually the depth of flooding increases. The micro current was measured by using dye on the water. The dye was placed at selected locations. Time and distance travelled by the dye was measured by stopwatch and tapes. The position of measuring points were recorded from hand held GPS. Measurements were conducted for both flooding and ebbing period.

Figure 2.13: Inundation inside the forestland

2.9.5 Soil Salinity and soil Nutrient

Soil samples were collected from the forestland at the end of each cycle of measurement. The samples were taken from the topsoil (0-10 cm depth) and 10 to 20 cm below the ground. Positions of sampling locations were recorded using GPS. The samples were dried naturally inside the room. The samples were then sent to Bangladesh Agricultural University for testing soil salinity and soil nutrients.

2.9.6 Suspended Sediment Concentration

Samples were collected from the flowing water (undisturbed) to observe suspended sediment concentration. The samples have been analyzed in the IWM Laboratory to determine total sediment concentration.

2.10 Benchmark Connection

Connection of all level data (Water level and land level) with the national reference datum of land level is essential for assessment of flooding, inundation and salinity intrusion in any area. So far the data available for the Sundarbans area did not contain such reference. Indirect approach of drawing reference level from the results of the mathematical modelling lacks field truthing. A challenging step was taken during 2002 dry season to connect the land level of Jongra and Katka with the national reference. Conventional fly levelling, electronic Total Station, RTK-GPS and intensive water level observation were applied simultaneously to transfer the benchmark sufficiently accurately. Results of different methods have been verified with each other in this connection. Water level observations were made at five minutes interval from dawn to dusk on both banks of the rivers. Based on this survey, temporary benchmarks have been established at Supati, Kochikhali and Katka.

2.11 Geodetic Reference

Vertical reference used for all the data is PWD datum. The geodetic reference used in the charts and tables is expressed in Bangladesh Transverse Mercator (BTM).

Reference Ellipsoid	: Everest 1830
Semi-major axis	: 6,377,276.345 m
Semi-minor axis	: 6,356,075.415 m
Flatenning (1/f)	: 300.8017

Datum Transformation Parameter :
(7 Parameter)

Translation X (m)	: -283.729
Translation Y (m)	: -735.942
Translation Z (m)	: -261.143
Rotation X (secs)	: 0
Rotation Y (secs)	: 0
Rotation Z (secs)	: 0
Scale Factor	: 1

Projection Parameter:
(Transverse Mercator)

Latitude of origin	: 0°
Longitude of origin	: 90°
False Northing	: -2,000,000m
False Easting	: 500,000m
Scale Factor	: 0.9996

3 ANALYSIS AND REVIEW OF DATA

Consistency check and quality control of all survey data has been carried out by following standard procedures. Hydrological and water quality data have been checked for temporal and spatial variations. In case any abnormal variation observed in any set of data further detailed investigation was carried out with the available information. Similarly, river cross-sections and topographic data could be compared with the historical set of data, but unfortunately the number of observations was limited. The available data have been further reviewed for establishing same trend for different parameters. A statistical function could be the best approach for establishing the trends, but due to the limitation of the length of data series, such analysis could not be followed. Instead, graphs and charts have been prepared to visualise the trend of changes.

3.1 Rainfall and Evaporation

Rainfall

Consistency of daily rainfall data of 63 stations collected from BWDB was checked by using "Double Mass analysis" and doubtful data has been discarded. Data entry errors have been eliminated by comparing monthly-accumulated rainfall with the hard copy data sheet. The corrected data has been applied to generate mean aerial rainfall for computation of river run off from the area.

Rainfall stations maintained by BWDB adjacent to the Sundarbans are located at Koikhali, Chalna and Patharghata. The statistics of these stations for the same period is not available at present. However, analysis of the stations for the same months has been performed from the available data for the year 1998 to 2001. The histogram of monthly average from 1998 to 2001 for these stations has been shown in Figure 3.1. From the chart it is seen that the rainfall at Chalna, at the north of the central part of the Sundarbans, experiences the maximum rainfall while it is less at Patharghata and Koikhali at east and west of the Sundarbans. Rainfall data from 5 stations in and around the Sundarbans have also been processed but consistency could not be checked due to absence of historical data. A histogram of the stations during the monsoon 2002 is presented in Figure 3.2. As the rainfall data of same period from the stations in the mainland could not be made available during the reporting time, no correlation between the mainland and the forest could be made. Figure 3.3 shows the observed cumulative rainfall at different stations from May 2002 to November 2002. The chart shows the extent of rainfall at different stations during the monsoon. It is seen that rainfall recorded inside the Sundarbans is quite high with the exception of one station (Notabeki on the west). Rainfall at the north of the SRF is also quite less than other part of the country.

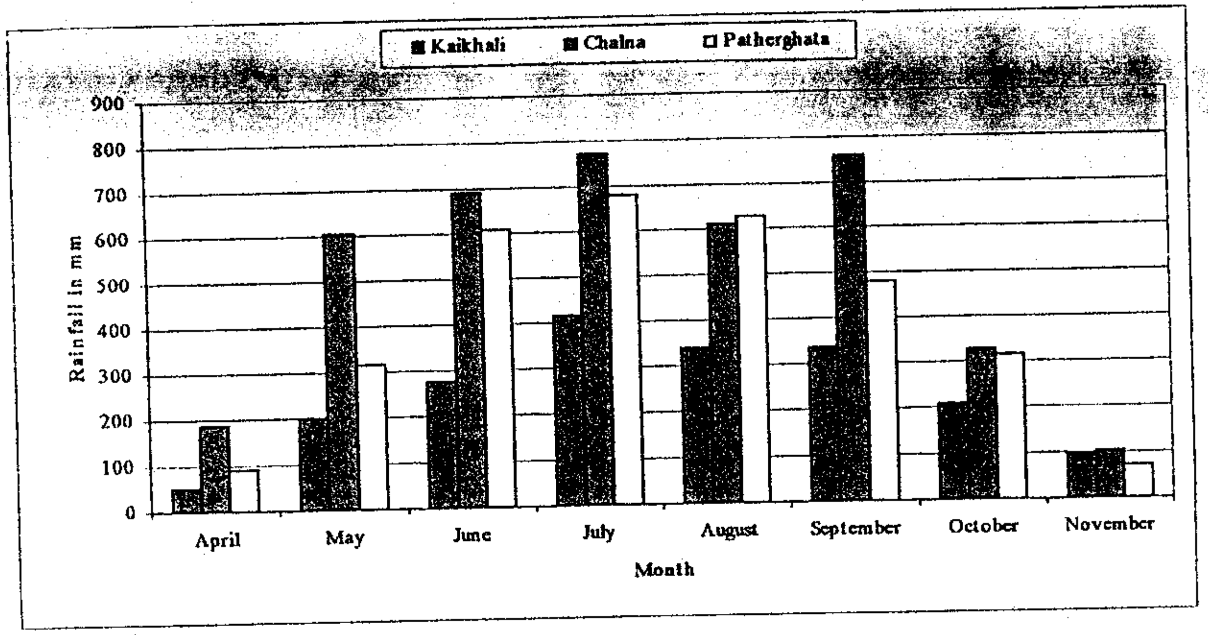


Figure 3.1: Average rainfall at Koikhali, Chalna and Patherghata (Year 1998-2001)

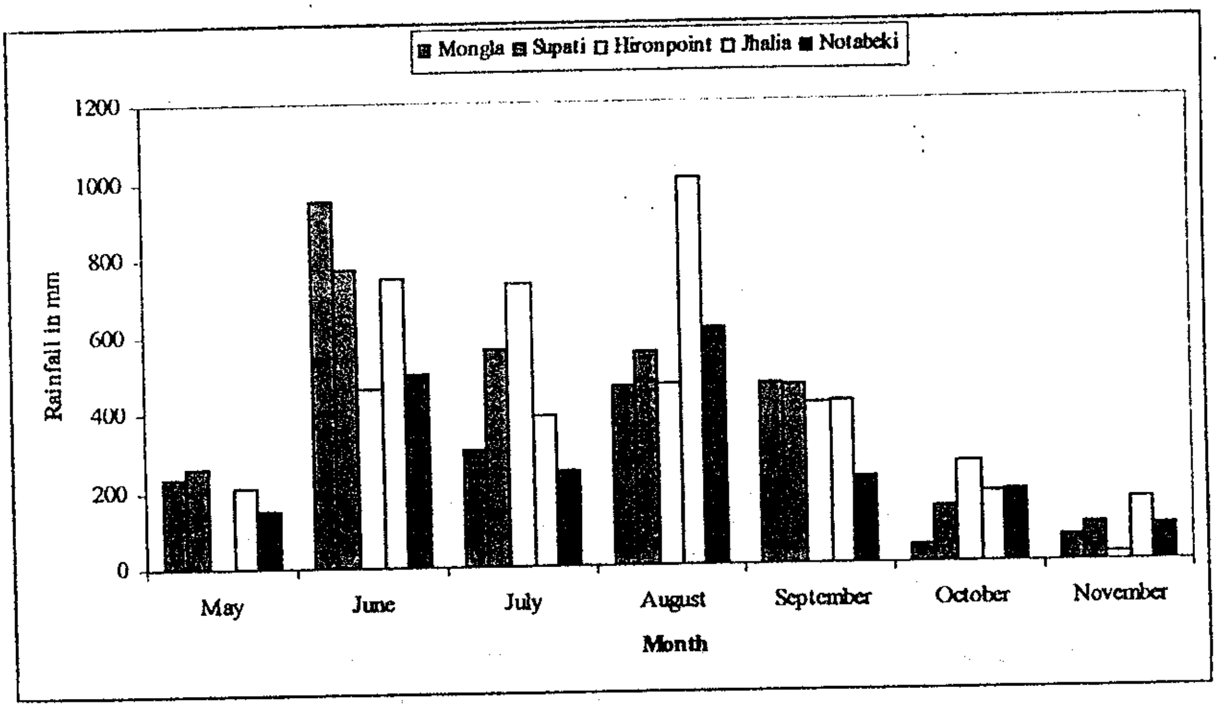


Figure 3.2: Rainfall distribution during Monsoon 2002

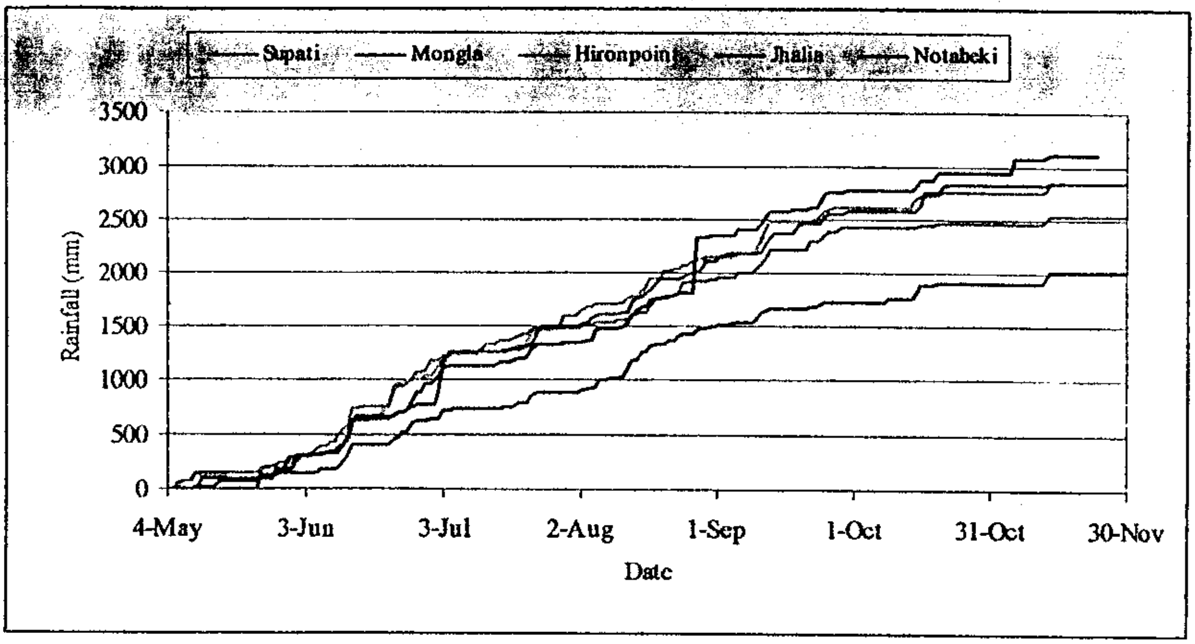


Figure 3.3: Cumulative rainfall from May 2002 to November 2002

Evaporation

Raw evaporation data of nine stations were punched and Pan evaporation of these stations was calculated. The consistency checking of these data was carried out with standard procedure followed by IWM. Mean aerial evaporation of Barisal and Patutakhali stations have been considered as the mean aerial evaporation for catchments SC-1 to SC-17 (detailed in section 4) of south central part, i.e. area east of the Baleswar River. Mean evaporation of Khulna, Benerpota and Bagerhat has been used for catchments SW-1 to SW-27 of the western part of the region. A sample chart of consistency checking is shown in Figure 3.4.

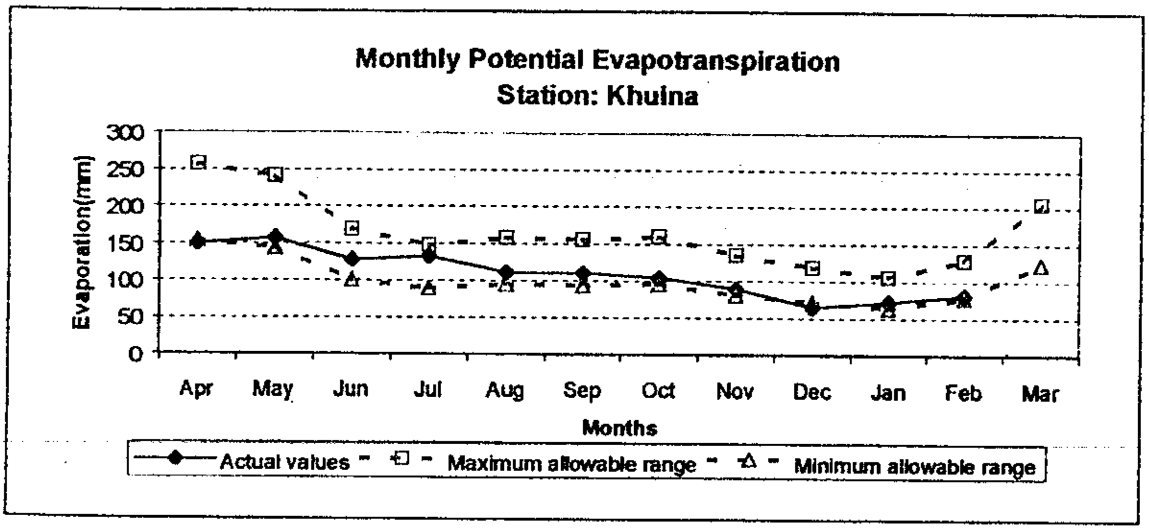


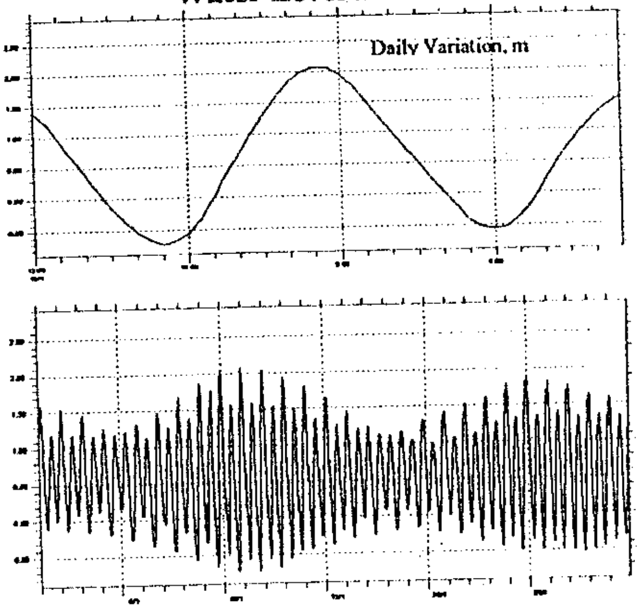
Figure 3.4: Monthly values of Evapo-transpiration of Khulna with allowable ranges

3.2 Assessment of Water Level Data

3.2.1 Water Level in the Sundarbans

Water level inside the Sundarbans is highly dependent on the tidal oscillation at the coast and to a lesser extent on the magnitude of freshwater inflows from upstream. Tides in the Bay of Bengal are semi-diurnal, exhibiting two high waters and two low waters per day. The amplitudes of the two cycles differ slightly. Over a longer term, a fortnightly variation in amplitude between spring and neap tides is also evident, with spring tide amplitudes approximately 2.5 to 3 times higher than amplitudes at neap tide. Figure 3.5 illustrates the semidiurnal (daily) and fortnightly variations in water level at Hiron Point based on field observation.

Figure 3.5: Daily and Monthly Variation of Water Level at Hiron Point



The daily, fortnightly and seasonal variations in water levels and tidal amplitudes experienced at the coast are also propagated inland during each tidal cycle. As the tidal waves travel up the estuaries, the waves become distorted due to shoaling effects. The wave shape changes, and amplification or dampening of the wave may also occur. Table 3.1 show tidal range at several locations in the Sundarbans.

Table 3.1: Tidal Range at Different Locations of Sundarbans

Location	River	Spring Tidal Range (m)		
		Sep'94*	Sep'01	Sep'02
Hiron Point	Pussur	2.74	2.76	2.86
Kobadak	Kobadak	3.93	4.15	4.17
Kaikhali	Jamuna	4.41	4.64	5.12
Nalianala	Sibsa	3.78	4.37	3.87

* Source: FAO/UNDP

It can be seen from Table 3.1 that tidal range in the northern fringe of the forest are higher than in the southern bay with highest range observed at the north-western corner- Kaikhali. Analysis of recorded annual maximum tidal range has been made from the data available at Khulna, Mongla, Nalianala, Koikhali and Patharghata. From the observed charts, it is seen that there is a rising trend in tidal range at all the stations except Koikhali. Analysis of 40 years data at Nalianala shows that the tidal range has increased by approximate 75 cm during this period. The major change is observed during the 1970 to 1980 and it seems to be stable in the later years. Changes in tidal range at Khulna from 1937 to 1960 was very slow while it has started increasing gradually since 1970. An increase of about 80 cm is observed during this period. Similarly annual maximum tidal range at Mongla and Patharghata has also increased by about 1.00m and 0.20m respectively. In contrast, average annual maximum tidal range at Koikhali is around 5.0 m and does not follow any increasing or decreasing trend for the last 30 years. The sample chart showing annual maximum value at Nalianala and Koikhali is presented in Figure 3.6.

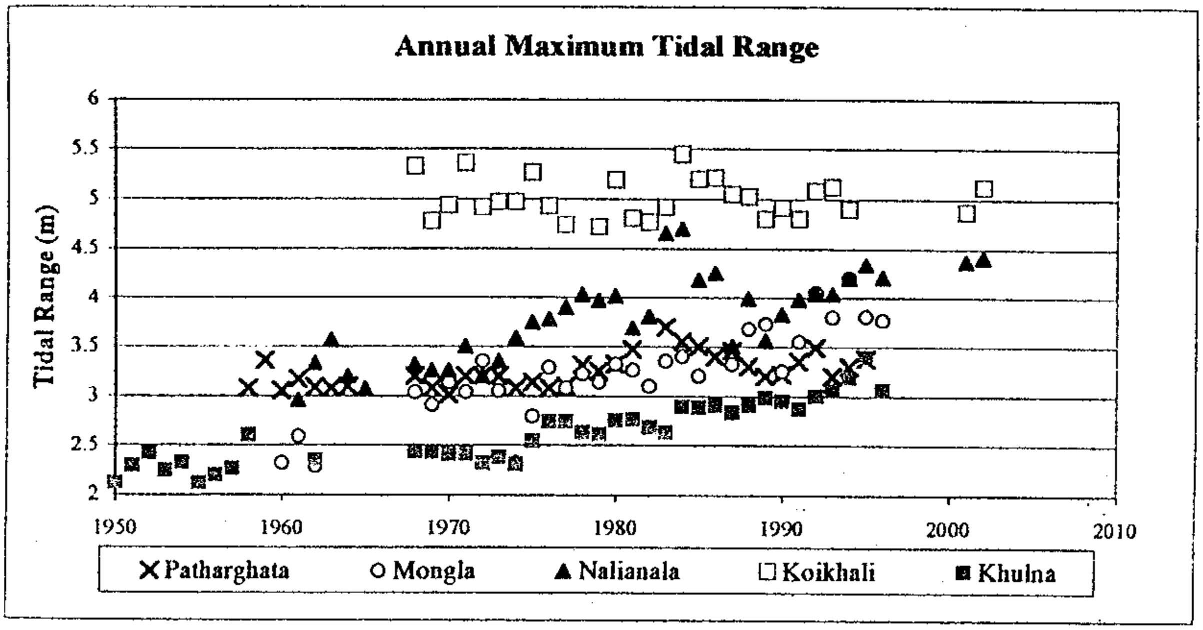


Figure 3.6 Observed Annual Maximum Tidal Range at different stations
* Source BWDB Data

3.2.2 Propagation of Tides

The time of arrival of high tide at the coastal entrances to the main estuaries in the Sundarbans varies due to the distorting effects of the shallow water depths in the Bay on the incoming tide. The western and eastern estuaries experience the high tide before the central Pussur-Sibsa system. High water at Hiron Point at the mouth of the Pussur River occurs about ½ hour later than at both the Jamuna River entrance (Mandarbaria) and the entrance to the Baleswar River (Kochikhali).

Table 3.2 shows travel time of tidewater relative to the mouth of the Pussur (Hiron Point) during spring tides in September 2001 and March 2002. The table indicates that the tidal wave takes about 2 to 2.5 hours to pass through the forest. Furthermore, the effect of the deeper channel the Sibsa from estuary can be seen on the speed of the tidal waves, with high water at Mongla arriving after Nalianala even though they are approximately at the same distance from the coast.

Table 3.2: Phase Difference of Spring Tide at Different Locations

Station name	River	Travel Time (hr.) from Hiron Point	
		Sep'01	Mar'02
Digraj, Mongla	Pussur	+2.5	+2.5
Nalianala	Sibsa	+2.0	+2.0
Mrigomari	Mrigomari	+2.0	+1.5
Kaikhali	Jamuna	+1.0	+1.0
Bogi	Baleswar	+1.0	+1.0
Kobadak	Kobadak	+1.0	+1.0
Notabaki	Jamuna	0.0	0.0
Hiron point	**Pussur**	**0.0**	**0.0**
Katka	Betmargang	0.0	-0.5
Mandardarbaria	Malancha	-1.0	-1.0

3.2.3 Vertical Datum Correction

Water level data collected by BIWTA auto gauges are referenced to the Chart Datum (CD) and those collected by other agencies like BWDB are referenced to PWD datum. Moving average method is applied to relate the BIWTA data with the PWD datum. The Moving Average method uses the data of 56 tidal cycles to develop an average time series data. In this method a relation is established between the average water level of a station of known datum and that of an unknown one.

However, it has not been possible to establish any physical relation of the gauges inside the Sundarbans. So far, these data have been adjusted for benchmarks by using the model results, which remains uncertain unless there are few observations. The corrections applied after data processing by moving average and the model results to different stations are shown in Table 3.3.

Table 3.3: Datum Adjustment for IWM & BIWTA Gauges

Sl. No	Station Name	River Name	Source	Datum Type	Adjustment (m)	Remarks
1	Hiron Point	Pussur	BIWTA	CD	(-) 1.05	Moving average
2	Khepupara	Tentulia	BIWTA	CD	(-) 1.58	
3	Mongla	Pussur	BIWTA	CD	(-) 1.32	
4	Mrigomari	Mrigomari	IWM	GD	4.3	Model Results
5	Harintana	Sela Gang	IWM	GD	4.53	
6	Harbaria	Putia Khal	IWM	GD	4.56	
7	Supati	Supati Khal	IWM	GD	3.5	
8	Kochikhali	Supati Khal	IWM	GD	3.46	
9	Katka	Betmar Gang	IWM	GD	4.1	
10	Hiron Point	Pussur	IWM	GD	2.6	
11	Gawa Khali	Sonakhal	IWM	GD	2.99	
12	Notabaki	Jamuna	IWM	GD	3.09	
13	Mandarbaria	Malancha	IWM	GD	3.78	

Note: *CD - Chart Datum of BIWTA*
PWD - Public Works Datum
GD – Gauge Reading not referenced to any standard datum

3.3 Salinity Data

Salinity in the Sundarbans is highly dependent on the volumes of freshwater coming from the upstream. The variation is also subject to the nature of tide in the area. The salinity on the coast and in the forest channels varies over a number of different timescale. Arrival of high water at the coast generally coincides with peak in daily salinity. Again, the daily range of salinity levels in river entrances vary with seasons. A number of observations have been made that describes different aspects of salinity level changes.

3.3.1 Annual Pattern

Annual pattern of salinity changes inside the Sundarbans is related with the changes of freshwater flow from upstream rivers. Salinity time series of 4 representative stations (1 each from east, north, south and west) for a 12 months period data has been plotted in Figure 3.7. Although it is based on the event of a particular hydrological condition, it represents the overall picture of the whole area, which is summarized below:

Supati

- Salinity at Supati (eastern boundary areas) is influenced by the Baleswar River and the salinity is almost zero throughout the monsoon and post monsoon period
- Rate of increase is slow and the salinity starts decreasing during from later part of April when the flow at Gorai Railway bridge is negligible
- Salinity decreases sharply after the dry season

Nalianala

- Salinity at Nalianala (northern/north central part) is influenced by fresh water flow of the Sibsa which also originates mainly from the Gorai during post monsoon and the dry season. It remains almost zero during the monsoon due to large discharge of the Sibsa
- It increases steadily from post monsoon period
- Starts decreasing from the end of May and falls rapidly from the onset of monsoon flow

Hiron Point

- Salinity at Hiron Point (at the southern part) remains at a low salinity range (less than 5 ppt) during the monsoon and post monsoon period.
- It increases at a steady rate during the dry season
- Salinity decreases from Mid May which is earlier than western

Notabeki

- Salinity at Notabeki station in the western part of the Sundarbans is not reduced to low salinity range even during monsoon period
- It increases at a steady rate (same rate as Nalianala) during dry season
- Decreases slowly from the end of May. It seems to be dependent of fresh water flow from upstream rivers of the western part

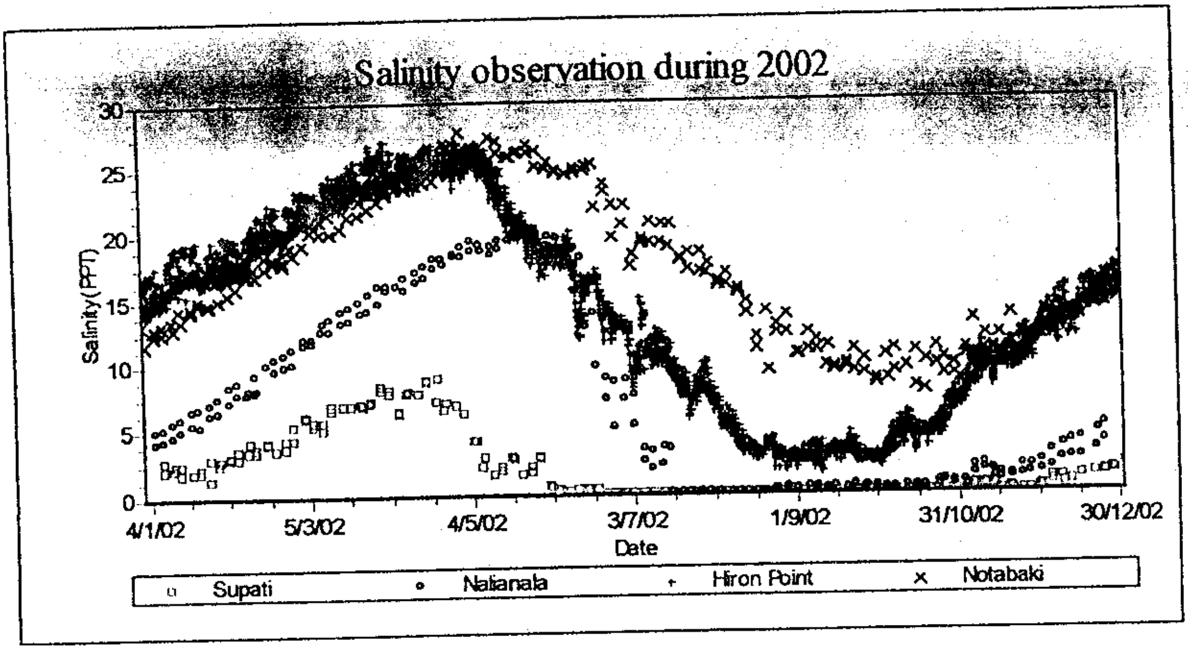


Figure 3.7: Salinity in the Sundarbans during 2002

It may be summarised that the salinity of the rivers in the eastern part (except southern boundary areas) experiences rapid changes with the increase of freshwater flows (through Baleswar, Pussur and Sibsa) after dry season and increases steadily after the in flow reduction in post monsoon period. Decrease of salinity at Mongla and Hiron Point same time before Nalianala represents that the fresh water flow is passing through the Pussur channel at the beginning of May. In contrast, salinity in the western part of the Sundarbans and its upstream countryside areas decreases slowly after the dry season and starts increasing at the later part of the monsoon. Thus the salinity pattern in the eastern part significantly differs with western part. Salinity level of all the stations can be seen in Annexure A.

3.3.2 *Spatial Distribution*

It is very difficult to establish generate exact spatial distribution of salinity by available tools. In the past, number of sampling locations was very negligible except under FAO/UNDP programme. During this study period, comprehensive data collection has been done by increasing number of station across the whole Sundarbans. Thus the resultant output is more reliable. A sample map showing spatial distribution (monthly maximum) generated by using ArcView software is shown in Figure 3.8 while complete salinity distribution maps for maximum monthly salinity have been presented in Annexure A. The maps also reflect the extent and limit of salinity stress at different locations inside the Sundarbans and possess good value while compared with respect to time. Observations from the salinity maps are summarised below:

- Salinity varies from east to west direction during monsoon (minimum salinity period in August/September) and during peak salinity while it varies from northeast to southwest during the remaining period
- Salinity at western part does not get totally diluted even during monsoon
- Inclusion of additional stations from the second year has considerably changed the distribution pattern

The Kobadak and the Betna are the only sources of fresh water on the western part. These rivers are no longer linked with the Ganges as these were in the past. The flow of these rivers at the upstream is very insignificant and carries only runoff coming from local rainfall. It is also observed from Figures 3.2 and 3.3 that the rainfall in the western part is less than the other areas.

3.3.3 Salinity Stress and Salinity Zoning

Extent and duration of salinity is very important for the growth of the vegetation. The level of Table 3.4 shows the salinity stress at different stations in and around the Sundarbans during 2002 while Table 3.5 shows the area covered by each salinity class for different duration. The table also reflects the rate of change in salinity as well as total fluctuation for each location. Salinity stress of one-month duration is plotted in Figure 3.9 and that of 15 days to 120 days are given in Annexure A. It is expected that the salinity duration isohalines will be useful to the forest experts to recommend the type of mangroves to be grown in different areas of the Sundarbans.

3.3.4 Variation with Tide Condition

It has been observed that the salinity changes with tide condition. In general, it increases during flooding while it reduces during ebbing. From Figure 3.10, influence of flooding and ebbing on the salinity is seen. It is observed from the Figures that effect of flooding and ebbing is more prominent in the eastern part of the Sundarbans while in the western region of high salinity such effect is insignificant.

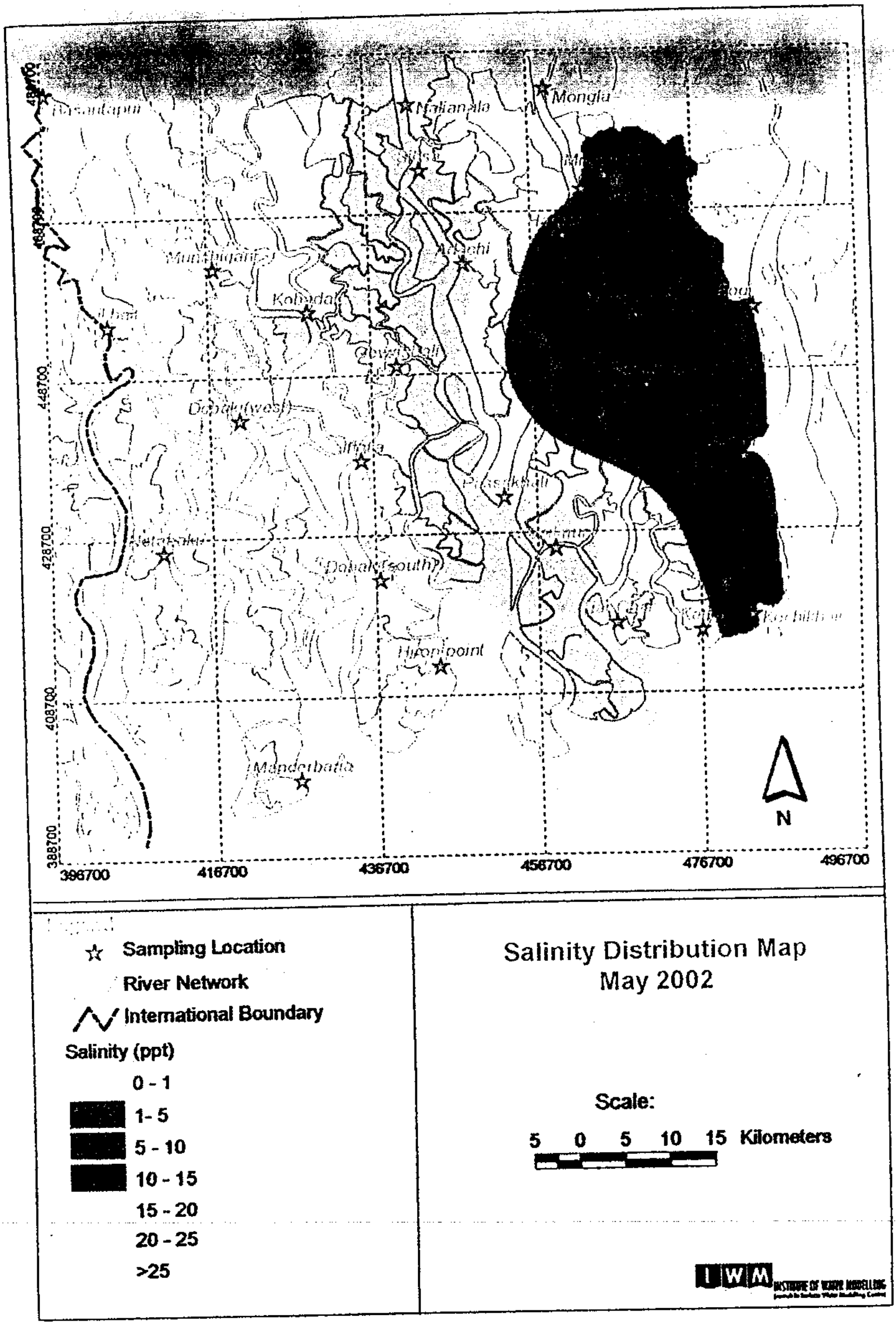


Figure 3.8: Spatial distribution of salinity during May 2002

Table 3.4 Salinity stress at different stations from November 2001 to October 2002

Sl No.	Station Name	Number of days exceeding limit				
		5 ppt	10 ppt	15 ppt	20 ppt	25 ppt
1	Bogi	0	0	0	0	0
2	Supati	83	0	0	0	0
3	Harintana	170	0	0	0	0
4	Tambulbunia	92	0	0	0	0
5	Mrigamari	126	16	0	0	0
6	Harbaria	136	80	0	0	0
7	Passakhali	172	138	76	15	0
8	Mongla	118	81	0	0	0
9	Nalianala	172	121	78	0	0
10	Adachai	204	149	102	52	0
11	Gawa Khali	277	194	139	86	4
12	Patkusta	Full	171	134	52	0
13	**Jhalia**	**Full**	**238**	**148**	**109**	**43**
14	Kobadak	Full	225	134	89	0
15	Munshiganj	Full	232	147	75	10
16	Koikhali	Full	248	166	91	23
17	Dobaki (west)	Full	246	180	102	33
18	**Notabaki**	**Full**	**265**	**197**	**134**	**55**
19	Dobaki (south)	Full	243	193	138	88
20	Katka	192	160	84	2	0
21	Tiar Char	256	170	138	40	0
22	Kokilmoni	253	184	119	56	0
23	Hiron Point	261	204	165	96	37
24	Mandarbaria	Full	257	217	168	88

Table 3.5 Areas of different salinity zones

Duration in day	Percentage Area at different Salinity Level					
	>25 ppt	20-25ppt	15-20ppt	10-15ppt	5-10ppt	<5ppt
120	0	25	28	19	15	13
90	6	31	28	15	14	6
60	6	31	28	15	15	5
45	28	30	17	11	10	4
30	29	30	17	11	9	4
15	29	30	17	11	9	4

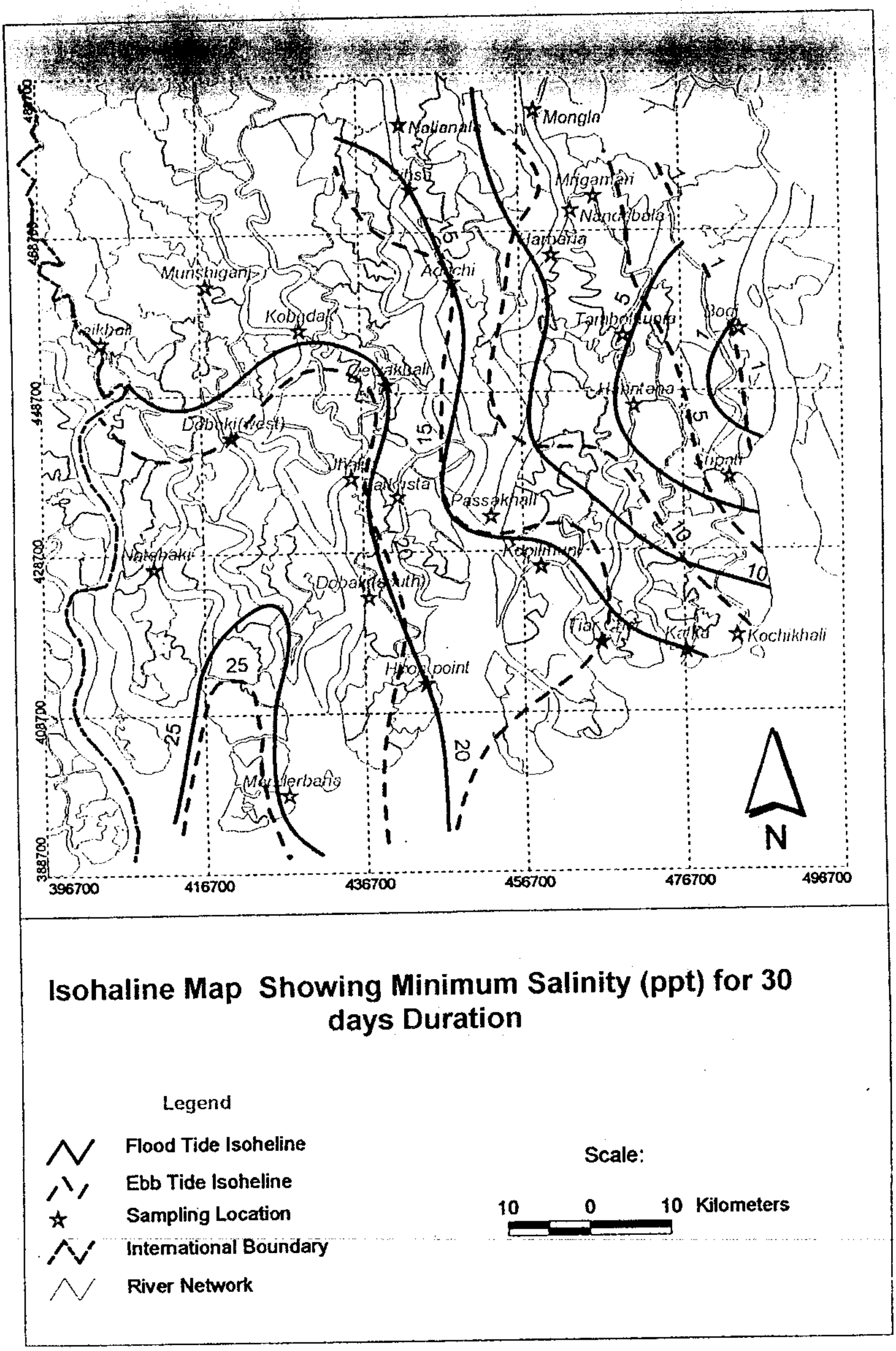


Figure 3.9 Salinity during Flooding and Ebbing Tide

3.3.5 Salinity Trend

As mentioned previously, salinity trend inside the Sundarbans area is difficult to assess. The charts of salinity time series collected during the present study and extracted from the previous studies are presented in the Annexure-A. Sample chart of Mrigamari is presented in Figure 3.10. Some specific observations on these charts are given below:

Hiron Point

- Minimum salinity during the monsoon/post monsoon varies year to year and does not follow any specific pattern but the magnitude of variation of minimum salinity during monsoon is insignificant
- Trend of salinity during dry season is same every year and it increases steadily during March to May
- Salinity band (daily fluctuation) ranges between 2 ppt and 4 ppt during wet and dry season respectively
- Trend of salinity reduction during onset of monsoon is also unchanged
- No relation with the Gorai discharge can be seen (Figure 3.11) with the salinity level at Hiron Point

Mongla

- Minimum Salinity during the post monsoon is around 1 ppt every year
- Salinity band (daily fluctuation) is ranging around 1 to 2 ppt during dry season respectively
- Salinity at Mongla is influenced by dry season flow of the Gorai. (Figure 3.11)

Nalianala

- Minimum Salinity during the post monsoon is around 1 ppt every year
- Salinity band (daily fluctuation) is ranging around 1 to 2 ppt during wet and dry season respectively
- Salinity is influenced by dry season flow of the Gorai.

Gewakhali

- Minimum Salinity during the post monsoon is around 5 ppt every year
- Salinity band (daily fluctuation) is ranging around 1 to 2 ppt during dry season respectively
- Salinity is influenced by dry season flow of the Gorai. (Figure 3.11)

Mrigamari

- Minimum Salinity during the post monsoon is around 1 ppt every year
- Salinity band (daily fluctuation) is ranging around 0.25 to 2.0 ppt during wet and dry season respectively
- Salinity is influenced by dry season flow of the Gorai. Salinity is increasing each year like Mongla and Nalianala and in the long run it would be to 1994-95 situation or worse.

<u>Kaikhali</u>

- Minimum Salinity during the post monsoon is around 7 ppt every year
- Salinity band (daily fluctuation) is ranging around 1 to 2 ppt during dry season respectively
- Salinity is not influenced by dry season flow of the Gorai. Dry season salinity of 2000-01 and 2001-02 are same while peak salinity for both the years is around 26 ppt
- Minimum salinity during 2000-01 might be the effect of extra-ordinary flooding and should be treated as an exception

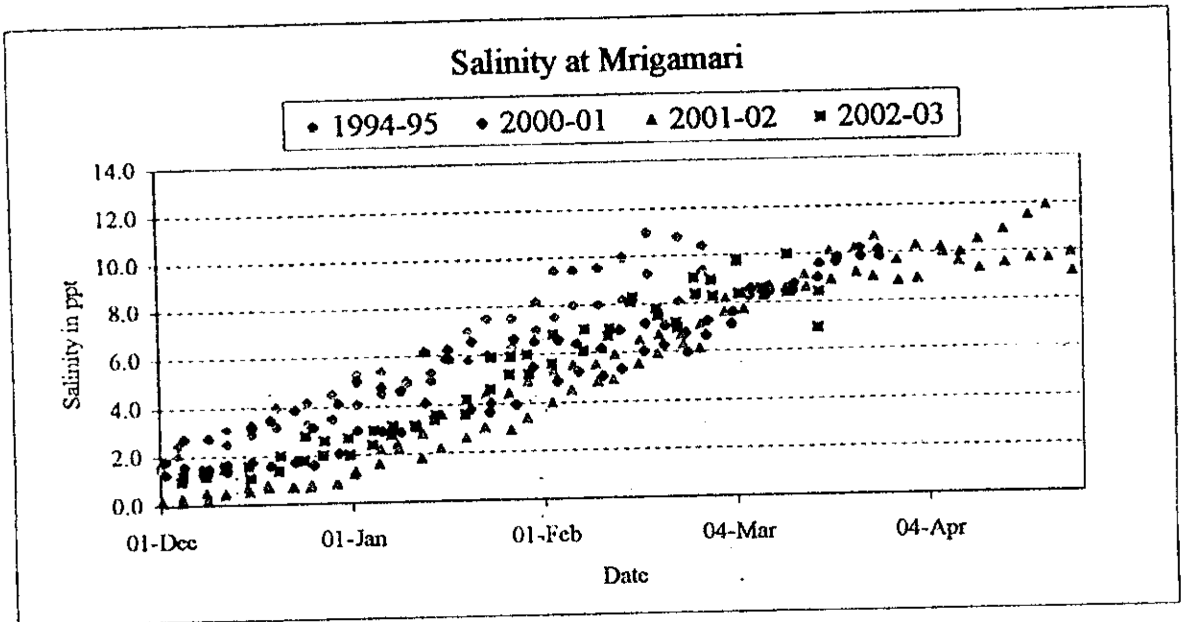


Figure 3.10: Salinity trend at Mrigamari during dry season

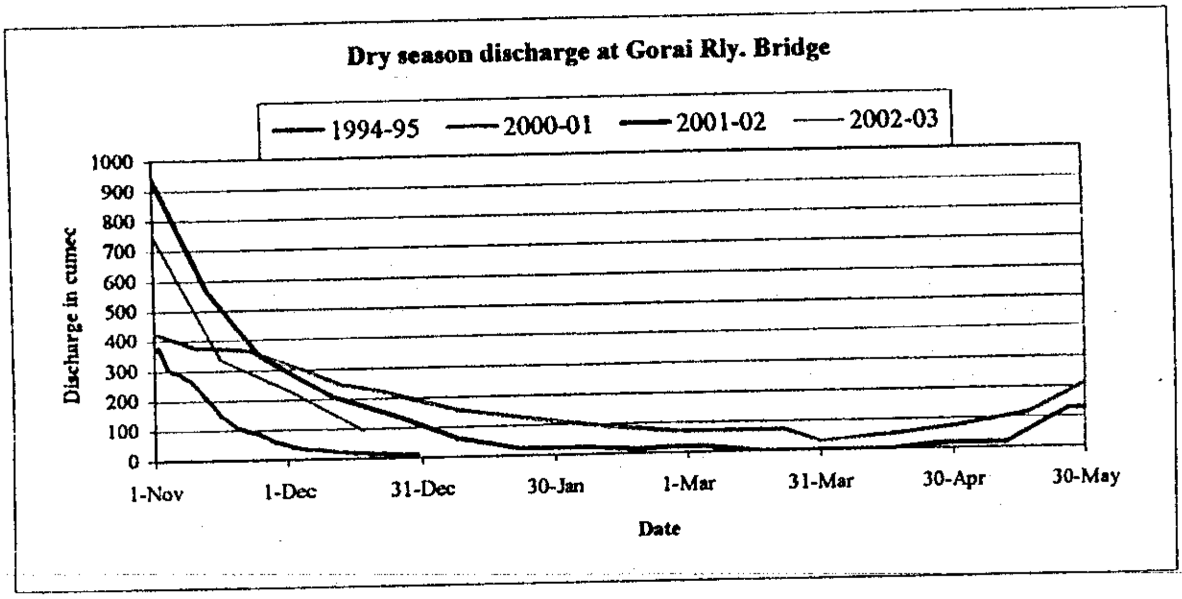


Figure 3.11: Recorded discharge of the Gorai

Source: *1) Gorai River Contractors/BWDB*
2) FAO/UNDP

3.3.6 Comparison with earlier reports

The findings of salinity changes outside the Sundarbans provide close similarity with the earlier studies. However, an appreciable difference is observed in areas west of the Pussur. Higher level of salinity is seen in the current study both in the observed data analysis and also from model results. The present study has considered large number of observations inside the SRF and the findings are based on primary data. In absence of detailed data inside the SRF, the earlier studies were based on sparse data. While the current study covers the full hydrological calendar, the earlier studies considered mostly a part of the dry season.

3.4 Water Quality

One of the important objectives of the study is to monitor and assess the water quality of the river system of the Sundarbans. A thorough review of past literature, during the inception phase of the study, revealed that data acquisition and assessment of water quality of the rivers of Sundarbans was patchy. As such, comprehensive monitoring programme was proposed. During the contract agreement the monitoring Programme was squeezed to 4 times. However, it was increased to once monthly during the year 2002. The detailed of data collection progress, procedures and testing process have been provided in the **Article 2.5** of this report

3.4.1 Literature Review

The following reports, which seemed to have some relevance with the present study, have been consulted during this study.

Final Report Volume 1 and on Hydrological Study of the Sundarbans; S. M. Wahid, Hydrologist, Integrated Resource Development of the Sundarbans Reserved Forest, Bangladesh, FAO/UNDP/BGD/84/056, UNDP and FAO, June 1995.

Project Findings and Recommendations; Integrated Resource Development of the Sundarbans Reserved Forest, Bangladesh, FASO/UNDP/BGD/84/056 Terminal Report, UNDP and FAO, September 1995.

Final Report – Consultant Mangrove Ecology; Dr Georges Grepin, Ecologist, Integrated Resource Development of the Sundarbans Reserved Forest, Bangladesh, FO:DP/BGD/84/056 Terminal Report, UNDP and FAO, June1995.

Final Report, Volume I and Annexure 14, Bangladesh Biodiversity Conservation in the Sundarbans Reserved Forest, Asian Development Bank, PPTA NO.2724-BAN, Ministry of Environment and Forests/ Forest Department/ ANZDEC Limited/ Eusuf and Associates, October 1997.

Port and Shipping Pollution Risks in the Sundarbans Reserved Forest – Background Paper; J.F. Brooks, Bangladesh Resident Mission, Bangladesh Biodiversity Conservation in the Sundarbans Reserved Forest, Asian Development Bank, November 1997.

Findings of the reports could be summarised in the following:

There are about 165 industries in Khulna located in the Rupsha, Khalishpur and Shiromoni industrial zones. The wastes fall into the Bhairab-Rupsha river system, which ultimately find their way towards the Bay of Bengal through the Sundarbans. Loading of municipal wastes (raw sewage and solid domestic wastes) from Khulna and Mongla Port entering the Pussur River was estimated to be 2.2 tons of BOD/day.

There is no road or permanent human settlement in the SRF; coastal fishermen and other resource harvesters establish seasonal camps. There is no industrial development in the SRF; water pollution from upstream industries and ship discharges at Khulna and Mongla Port are likely to have some impacts in the area concerned.

Source of pollution of petroleum and other allied products could be oil spills (during transfer of refined petroleum products from tankers to receiving stations and oil depots at Mongla Port and Khulna), fuel oil spillage, and discharge of oily ballast and bilge water, residual heavy oil sludge, lubricants and engine oils discharged during ship breaking operations in Khulna and Mongla. Approximately 600 ships anchor annually in Mongla Port. However, during the last 2 years, the number of ships has declined to less than 300 in Mongla Port.

From the review of the reports, it appears that water quality/pollution aspects of the river system of the Sundarbans have not been dealt in a comprehensive way with sufficient volume of data. Fragmentary observations are available with some sources, which are mostly qualitative. As such, the findings constitute some glimpses of the features of pollution in and around the Sundarbans.

3.4.2 Point Sources of Pollution

Not much development has occurred to act as point sources of pollution from the industries. Instead, a number of industries at Khulna have been shut down during the recent years. It was found that some large cement industries and LPG Terminal along the left bank of the Pussur River have been functioning. Nothing is discharged from these industries in the Pussur. Development of Mongla EPZ has not progressed during the study period. Only few industries have been established which do not produce any waste material.

There is widespread speculation that international ships anchoring at Mongla Port dump wastes into the Pussur River. Also fishing boats powered by diesel engine, release oils in the rivers. A study has been carried out on the impact of oil pollution at the Sundarbans area by Japan Oil Engineering Co. (2002) recently. That study also does not assess the present oil pollution level inside the SRF. However, need to assess the impact of pollution in case of oil spill on the mangrove forest has been recommended in the study.

Attempts have been made to collect information from the Department of Environment (DOE) at Khulna. DOE, however could not provide any information about the volume of pollutants being discharged from the ships and industries into the Mongla-Pussur river system.

3.4.3 Environmental Quality Standard

The Department of Environment (DOE) under the Ministry of Environment and Forest (MOEF) defines Environmental Quality Standards (EQS) in Bangladesh. The DOE in a Gazette in 1997 defines limiting values for only four parameters, viz. pH, BOD, DO and total Coliform count for different categories of users of the surface water of the inland and estuaries. However, DOE Gazette of 1997 does not define any limiting value for inorganic compound like COD, NH_3-N, PO_4-P etc; or heavy metal like Cr, Pb, Hg etc. An old document of 1991 by DOE provides some indication of those parameters without any confirmation. Table 3.6 presents the limiting concentration/values defined by DOE in 1997 Gazette. The table also present the limiting values of organic compound and heavy metal provided in the unpublished DOE document of 1991.

Table 3.6: Allowable Limits of Pollutants as defined by DOE

Parameter	Allowable Limit	Source
BOD	2 – 10 mg/l	EQS, 1997
Coliform (total)	50 – 5000 nos./100 ml	-do-
DO	5 – 6 mg/l	-do-
PH	6.5 – 8.5	-do-
COD	4-8 mg/l	EQS, 1991
NH_3-N	0.025-3 mg/l	-do-
PO_4-P	6-10 mg/l	-do-
Hg	0.001mg/l	-do-
Cr.	0.05 mg/l	-do-
Pb	0.01-0.2 mg/l	-do-
Oil & Grease	0.001-15 mg/l	-do-

The WQ parameters tested by the IWM could be broadly divided into four groups:

- Organic Matter (consisting of BOD and COD) and Oxygen availability
- Nutrients (consisting of NH3-N, NH4-N, NO3-N and PO4-P)
- Heavy Metals (consisting of Cr, Pb and Hg)
- Oil and grease

To be more specific, the river water and seawater (collected from the coast stations) have been analysed separately. In the following paragraphs, analysis based on available test results and *in situ* monitoring has been presented.

3.4.4 Organic Matter (BOD & COD) and Dissolved Oxygen

BOD is an approximate measure of presence of biodegradable (bio-chemically degradable) pollutants (organic matter) in a stream. Analyzing a total of 181 test results of 13 locations (from March 2001 to December 2002) in the river, it is observed that maximum BOD concentration occurs in the month of April while minimum is found around November/ December. The overall range has been found to be within 2 to 120mg/l, having an average concentration of about 11.3 mg/l, thus exceeding the upper limit of EQS for BOD, which is 10 mg/l. Only one sample from Dingimari in February 2002 has erratic value of 120 mg/l. The detailed observed values of BOD are presented in Tables and charts in Annexure B.

COD is the measure of pollutants, containing biodegradable and non-biodegradable organic matter, thus not fully degradable biologically. COD should always be higher than BOD, and its concentration is about 1.5 to 2 times of that of BOD. It is a crude check against the precision of BOD values. The range of COD concentrations is 5 to 255.4 mg/l with an average of 35.96 mg/l, thus, exceeding the permissible range of concentration of (4 – 8 mg/l) (DOE, 1991). Higher COD concentrations have been found to occur in April. Only one sample from Dingimari in February 2002 has erratic value of 255 mg/l. There are evidences of organic pollution in the river system of the Sundarbans, notwithstanding the effect is not yet pronounced (i.e. concentration of DO is mostly above 5 mg/l) probably due to the huge volume of water having high assimilative capacity. The detailed observed values of COD are presented in Tables and charts in Annexure B.

Although the COD/BOD ratios have mostly been found within the range of 1.5 to 2 (occasionally little more than 2), many samples collected during September to December 2002 have shown very high concentrations of COD in comparison with the corresponding BOD concentrations, yielding COD/BOD ratios much higher than 2 or so. Other parameters, however, do not show abnormal concentrations to corroborate the very high concentration of non-biodegradable organic matter (expressed as COD). No obvious reason behind such phenomenon could be confirmed, thus requiring more data to attribute such occurrences as non-representative of the usual trend.

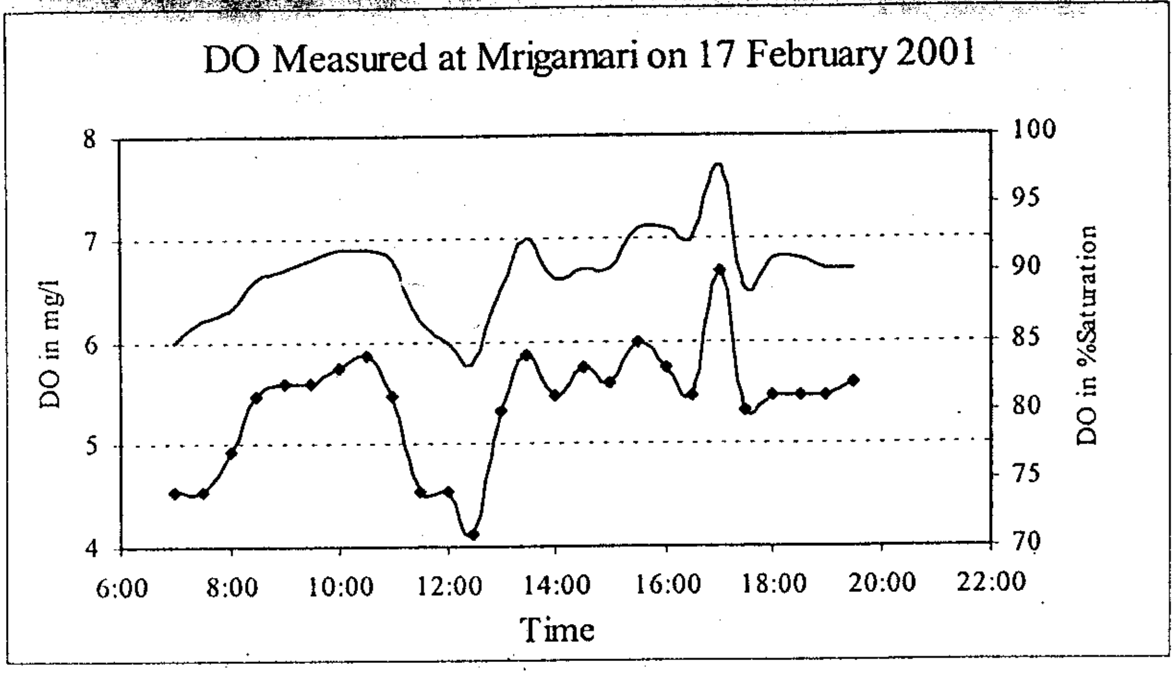
From the limited data (26 samples) available from the locations nearer to coast, it is observed that BOD and COD are little higher than those of the river water. The values of BOD and COD in tabular form are also presented in Annexure B.

Based on *in situ* observation of DO at the locations of discharge measurement carried out during February to November 2001, DO concentration has been found to vary between 5 to 8 mg/l., with an average concentration of 6.4 mg/l. In general, high concentrations of DO were found at the eastern rivers, while low concentrations were found in the western rivers. DO concentrations recorded during February to December 2002, in course of longitudinal profiling along the important river systems, do not contradict with the earlier findings. The observed DO ranges from 4.90 to 6.90 mg/l with an average value of 5.99. Monthly average recorded values of DO during field trips have been presented in Table 3.7. It is found that DO in the rivers increase from July to December.

Table 3.7: Observed values of Dissolved Oxygen from profiling

Month	Sample (nos.)	Maximum (mg/l)	Minimum (mg/l)	Average (mg/l)
March	143	6.50	4.90	5.45
April	103	6.40	5.00	5.47
May	65	6.70	4.90	5.63
June	52	6.00	4.90	5.21
July	424	6.90	5.50	6.22
August	100	6.90	5.90	6.37
September	66	6.50	5.90	6.15
October	63	6.60	5.60	6.16
November	64	6.50	6.00	6.23
December	60	6.90	5.80	6.36

Overall, DO data collected so far show that the river systems in the Sundarbans is healthy with respect to the most important water quality parameter, DO, having an average DO concentration around 6 mg/l. On few occasions, however, DO concentrations below 5 mg/l were also recorded. Sample chart of observed DO during year 2001 is presented in Figure 3.12. However, no definite trend with tide condition (flooding or ebbing) is observed from the point profiling. The charts of all observed point profile of DO values and tables of observed longitudinal profiles are shown in Annexure B.



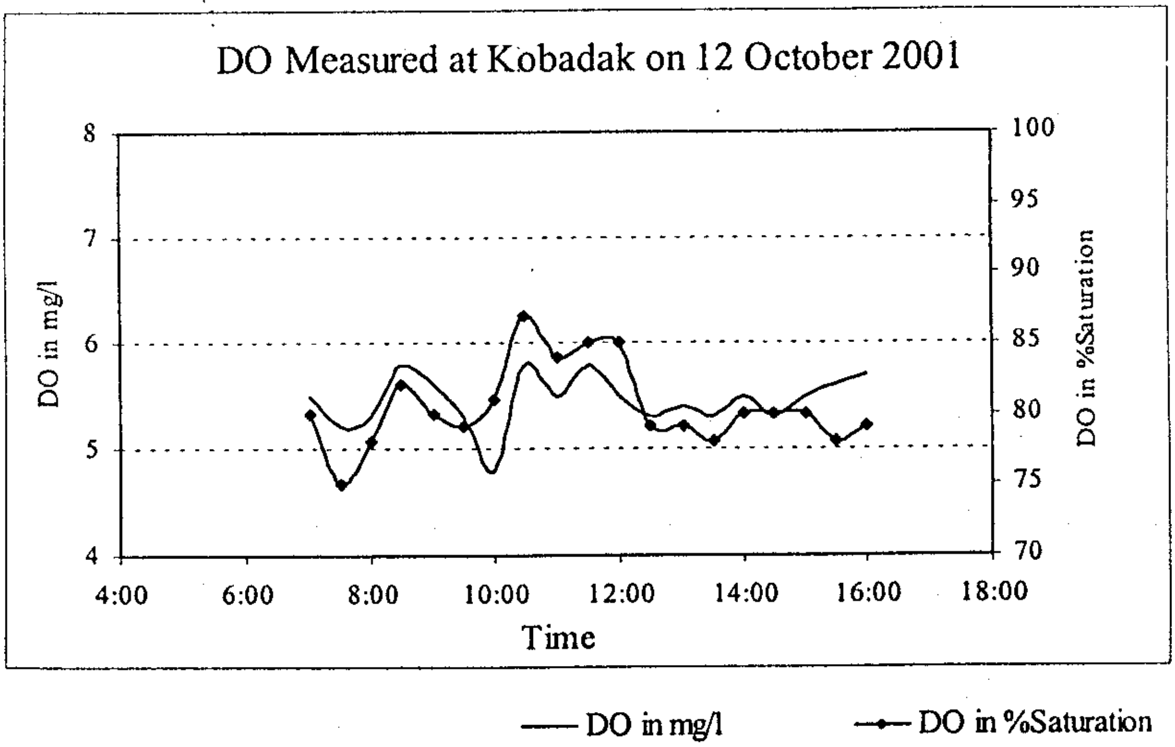


Figure 3.12: Sample chart of DO measured during discharge observation

3.4.5 Nutrients

Concentration range of NH_3-N is between 0.001 to 0.33 mg/l, having an average concentration of 0.043 mg/l, while concentration range of NH_4-N is between 0.040 to 6.74 mg/l, having an average concentration of about 2.183 mg/l. The average concentration of Total Ammonia (NH_3 + NH_4) has been found nearly 2.2 mg/l. Concentrations of Total Ammonia more than 3 mg/l have been found at some locations, which are indicative of little organic pollution, as also found in the case of BOD and COD. However, it is seen that almost all of the Total Ammonia remains in its ionic form (NH_4-N), which indicates (taking into consideration of Temperature) that the pH of the river system is around 7.5 (and never less than 7), i.e. the river water is little alkaline. Presence of non-ionized Ammonia (NH_3-N) in very low proportion is an indication of good quality of river water with respect to Ammoniacal Nitrogen inside the Sundarbans. Although NH_3-N and NH_4-N separately does not show any distinct seasonal pattern, concentration of Total Ammonia does have a seasonal pattern having the maximum concentration in April or May, and minimum concentration around November, as of BOD and COD.

NO_3-N concentrations have been found to be within a range of 0.1 to 2.0 mg/l with an average of 0.461mg/l. These concentrations are indicative of little or no human intervention for the river system concerned. Unfortunately, limiting concentration of NO_3–N was not defined in the old EQS (DOE, 1991). No distinct seasonal pattern of NO_3–N could be observed.

Phosphate concentrations as of PO_4-P are generally low having a range of 0.009 to 0.582 mg/l, average being 0.115 mg/l. The DOE in its old document of EQS (DOE, 1991) set the limiting concentration of PO_4 (not PO_4-P) as 6 –10 mg/l. Converting these values as of PO_4-P (0.2 – 0.3 mg/l) and comparing with the measured concentrations, it is seen that the river system, in general, complies with the requirement of acceptable concentration of PO_4-P. No distinct seasonal pattern of PO_4-P could be observed with the available data.

Like BOD and COD, Total Ammonia and NO_3-N are little higher in the samples collected near the coast than those of the river water while average concentration of PO_4-P is slightly lower than the river water.

Station wise values of Ammonia, Ammonium, Nitrate and Phosphate in tables and charts are presented in Annexure B.

3.4.6 Heavy Metals

Concentrations of Heavy Metals (Hg, Cr and Pb) are, mostly, well within the permissible limits in the river water. Moreover, in most of the samples, no trace of Hg could be found. Only in four occasions (out of 168 sets of data), the Cr concentrations were found to be higher than the permissible limit (0.05 mg/l), and in one occasion the Pb concentration exceeded the permissible limit (0.2 mg/l). These random occurrences of high concentrations are not significant up to the present time, but demand long term monitoring to justify these as unusual. No distinct seasonal pattern of concentrations of Heavy Metals could be observed.

Average concentrations of both Cr and Pb in the samples near the coast are lower than those on the EQS in the river water. No trace of Hg could be detected in the coastal water also. The values of test results of Lead and Chromium in tables and charts are presented in Annexure.B.

3.4.7 Oil and grease

Concentration of Oil and Grease has been detected in only 8 occasions (4.5% samples only). However, those detected are higher than the lower limit of the EQS (0.001 mg/l), but much lower if the permissible concentration for coastal water (15 mg/l) is considered. A little high and detectable concentration may be the result of release (intentional/ unintentional) of petroleum products from ships, etc. into the waterbodies of the Sundarbans.

No trace of Oil & grease could be detected in the coastal water.

3.4.8 Spatial Variation of Water Quality Parameters

To assess spatial variation of water quality parameters within the Sundarbans, sampling stations can be grouped as 'Western Sundarbans' and 'Eastern Sundarbans'. Western Sundarbans comprises of: Nalianala, Arpangasia, Bal, Malancha, Dingimari, Koikhali and Kobadak. Eastern Sundarbans comprises of: Harbaria, Harintana, Dudmukhi, Shwarankhola, Jafa and Mrigamari.

Seasonal variation of BOD (as well as COD) and Total Ammonia in the Eastern Sundarbans is quite prominent having the maximum concentrations around March-April. On an average, Western Sundarbans assumes higher biodegradable pollution than that of in the Eastern Sundarbans as evidenced from the average concentrations of BOD (as well as COD) and Total Ammonia. Comparison of monthly average values of the stations for BOD, COD and Total Ammonia observed during 2002 is shown in Table 3.8 and in Figure 3.13. Seasonal variation of BOD, COD & Total Ammonia for Western & Eastern Sundarbans stations is also presented in Figure 3.14 to Figure 3.16.

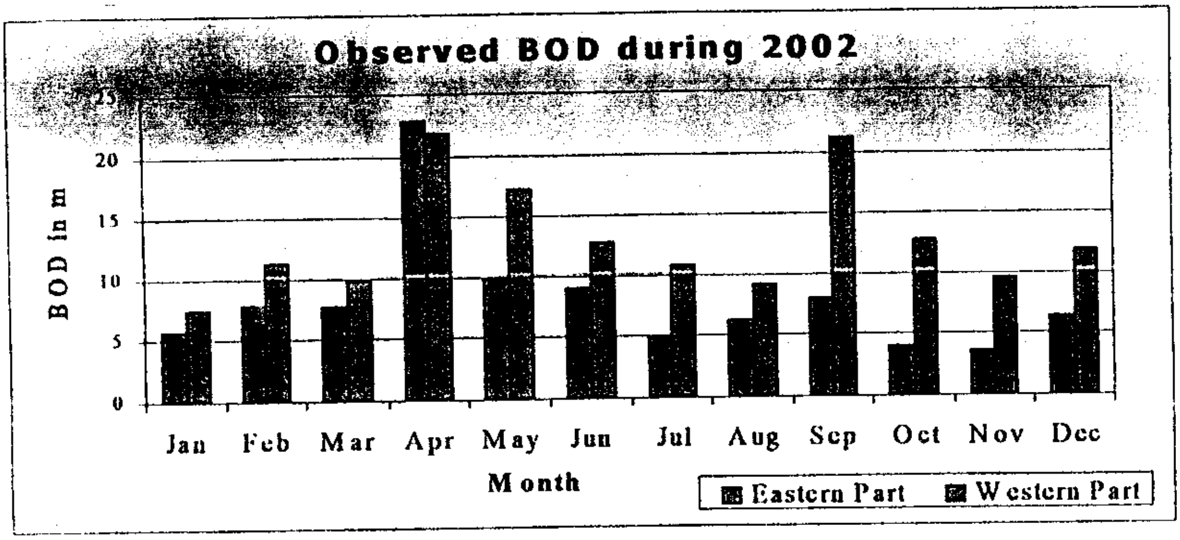
For other parameters (NO_3-N, PO_4-P, Hg, Cr, Pb and Oil & Grease) seasonal variation is not prominent either in the Eastern or the Western Sundarbans. Moreover, average concentrations of these parameters are almost the same except slight differences being observed for Hg and Oil & Grease. However, detectable concentrations for these two parameters are very patchy; thus not really comparable for the differences observed in average concentrations.

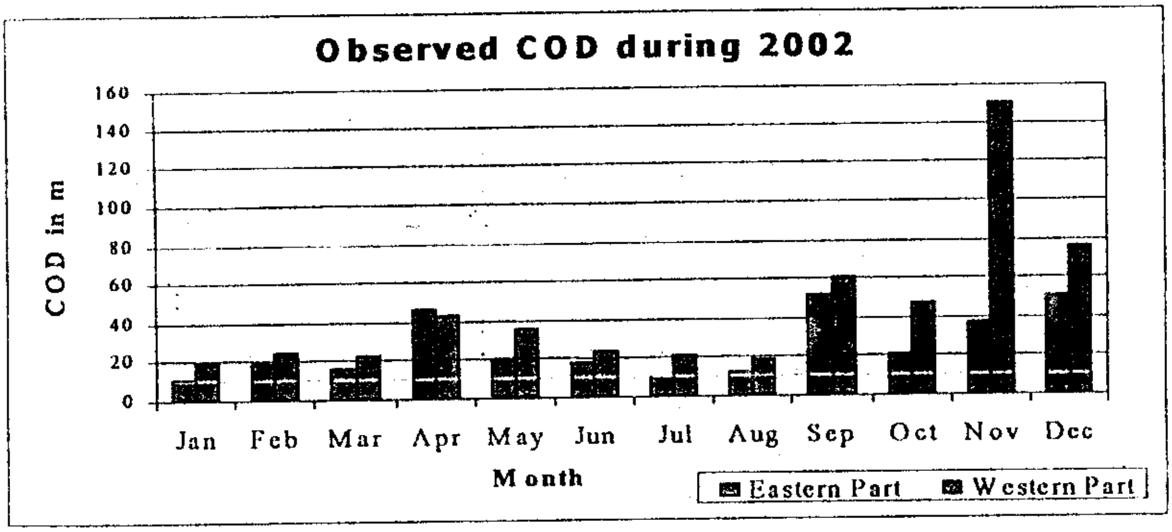
Table 3.8: Observed BOD, COD and Total Ammonia in the East and West

Month	Monthly average during 2002 (mg/l)					
	BOD		COD		Total Ammonia	
	East	West	East	West	East	West
January	5.78	7.43	11.42	19.10	1.23	1.91
February	7.80	11.33	18.59	24.85	1.01	4.68
March	7.77	9.87	16.48	22.69	2.35	0.80
April	22.92	21.79	46.92	42.93	2.64	5.67
May	9.90	17.26	20.12	35.55	2.54	5.20
June	9.05	12.80	18.13	23.76	1.46	5.16
July	4.97	10.76	9.92	21.51	0.66	3.77
August	6.27	9.11	12.57	18.26	0.23	1.61
September	7.97	21.17	51.78	60.66	0.61	1.63
October	3.93	12.80	20.87	47.74	0.42	1.80
November	3.63	9.61	37.67	150.57	0.60	2.40
December	6.40	11.86	50.83	75.86	1.11	3.04

Note: East – Eastern part of the Sundarbans with the Pussur as the border line

An interesting trend has been found for the concentration of Pb in the Western Sundarbans: it is gradually decreasing from March 2001 to October 2002. The reason is not known up till now; more data (preferably of another year) would be necessary to draw an inference on the trend observed. The chart of Pb concentration is presented in Figure 3.17.





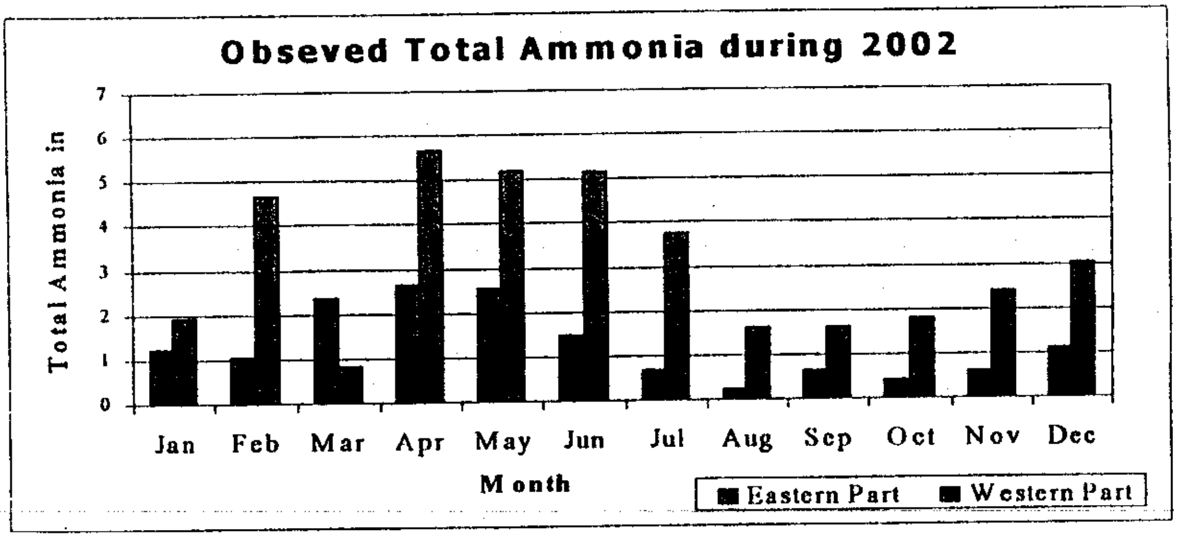


Figure 3.13 Variation of BOD, COD and Total Ammonia between East & West

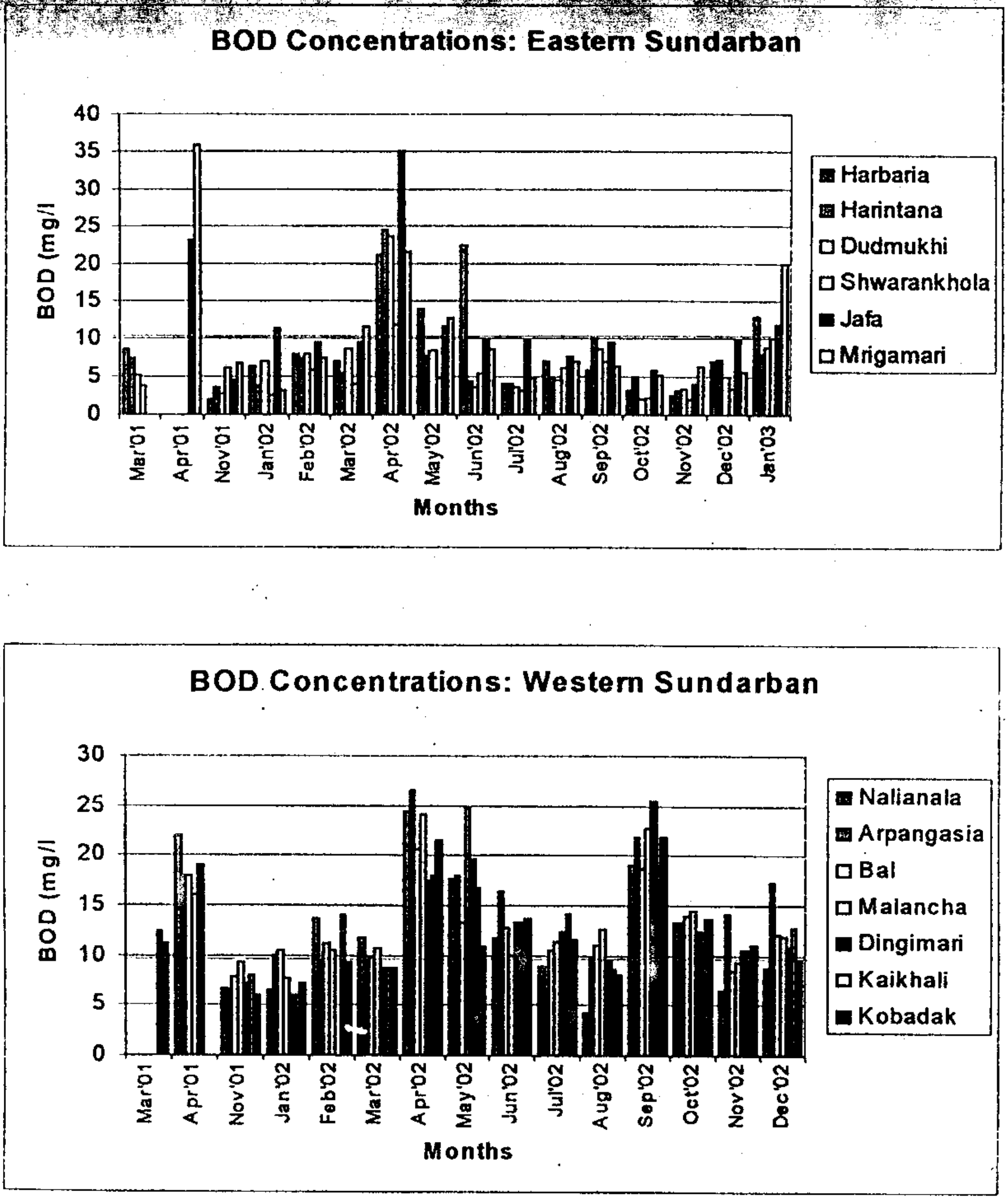
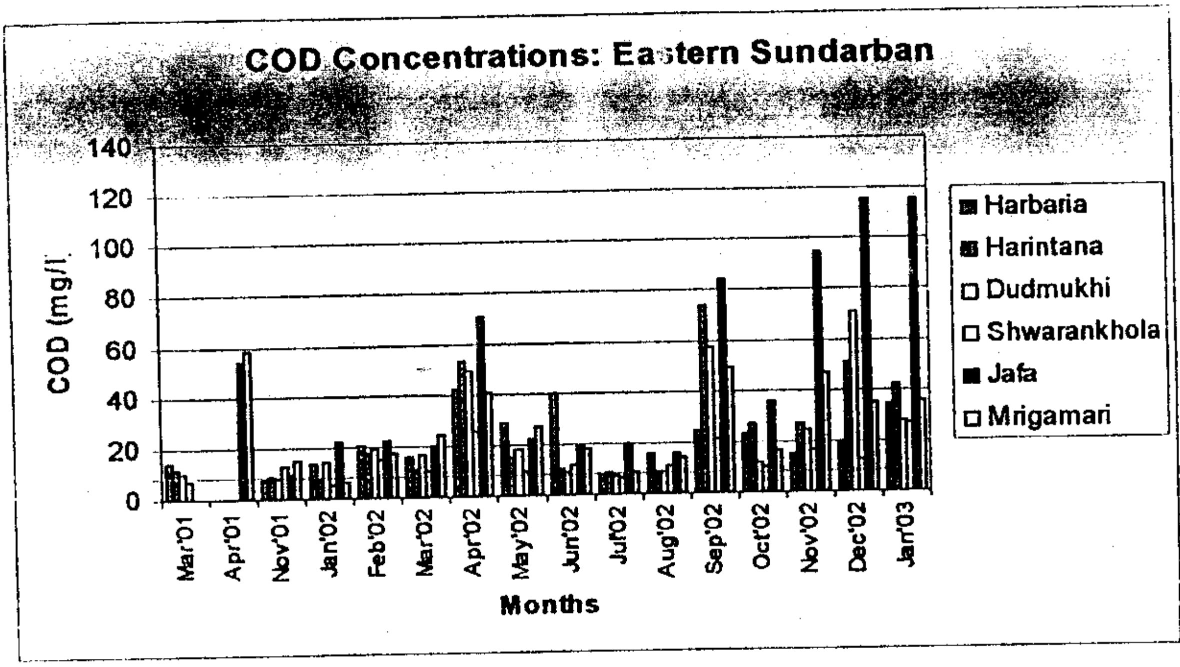


Figure 3.14: BOD Concentrations observed in the Western & Eastern Sundarbans

Note: One sample at Dingimari with exceptionally high BOD value has been screened out.



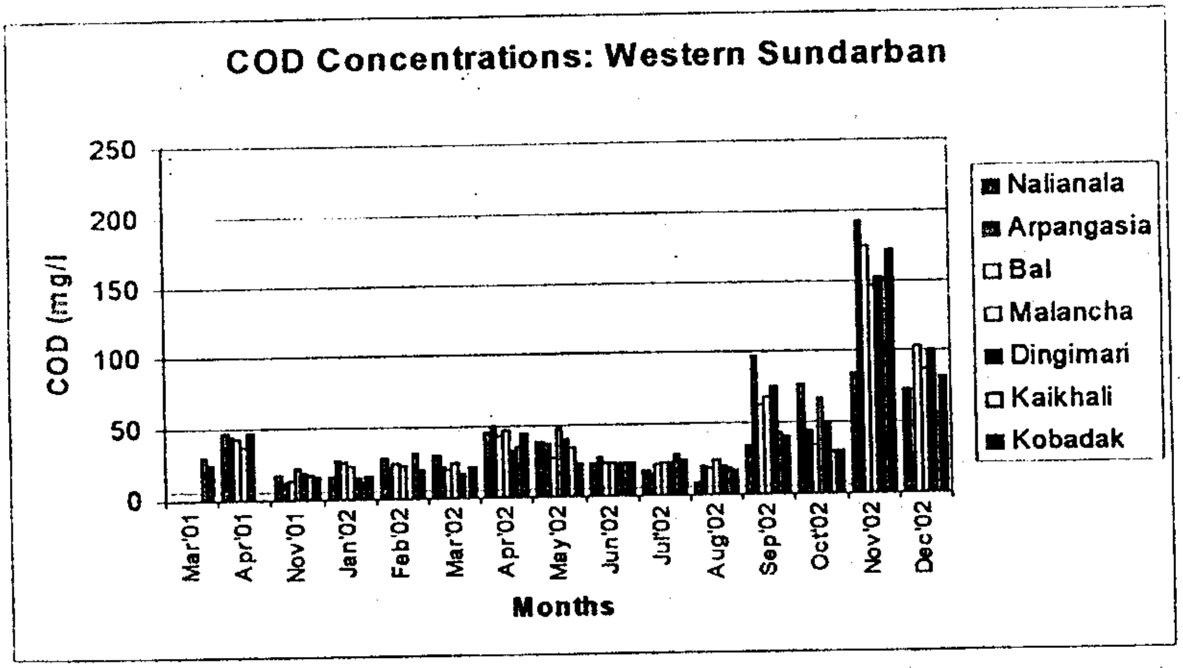
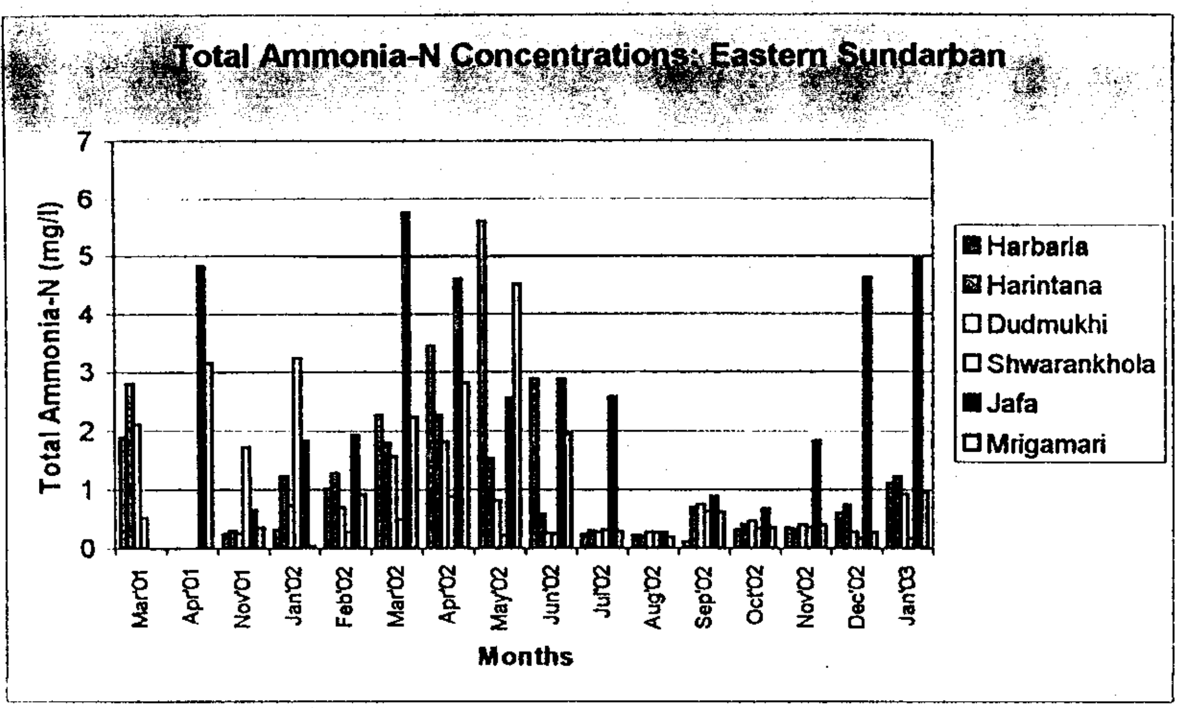


Figure 3.15: COD Concentrations observed in the Western & Eastern Sundarbans

Note: One sample at Dingimari with exceptionally high COD value has been screened out.



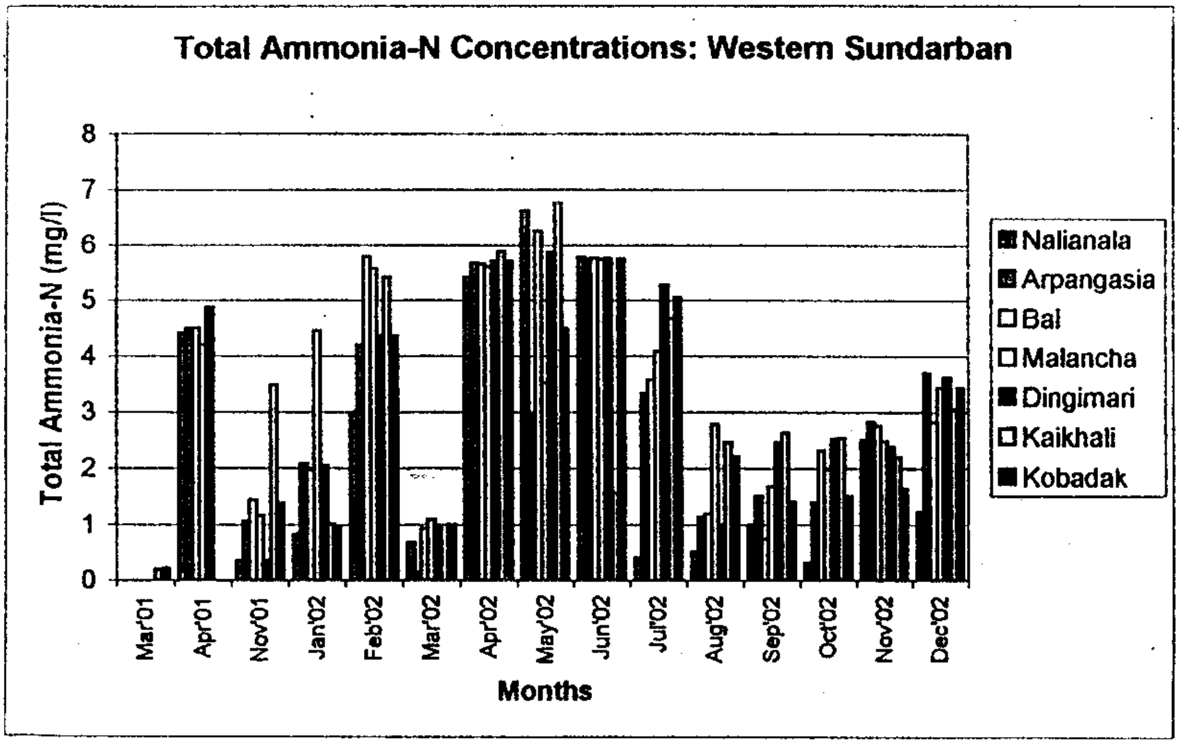
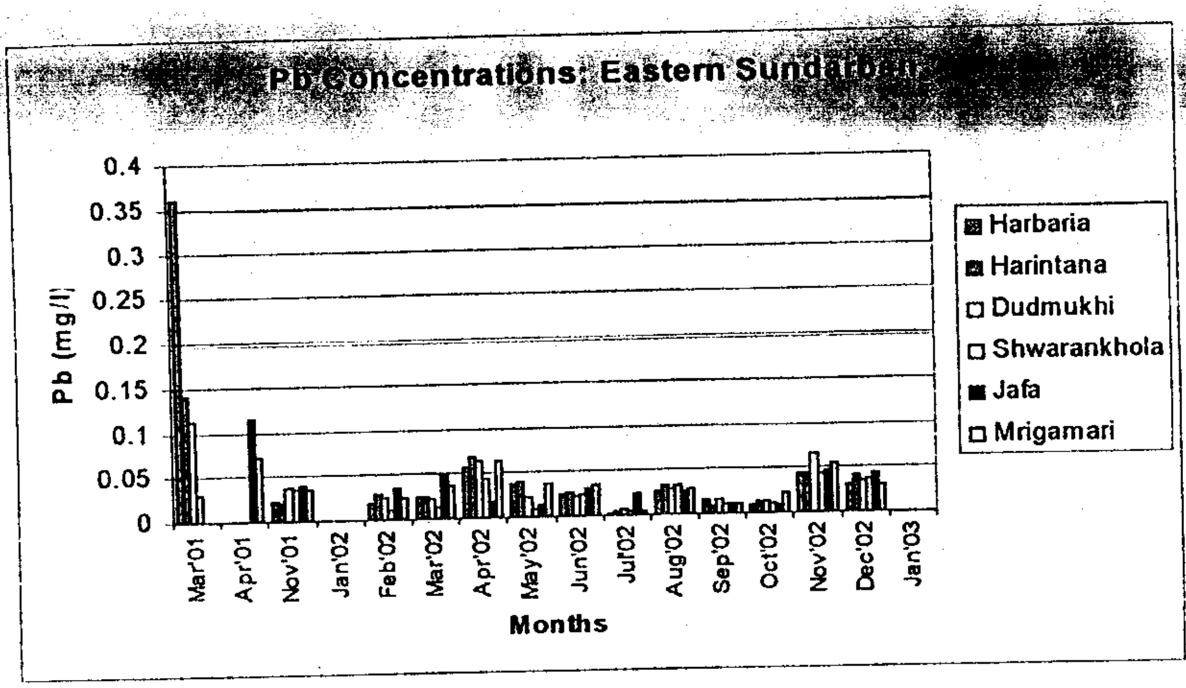


Figure 3.16: Total Ammonia observed in the Western & Eastern Sundarbans



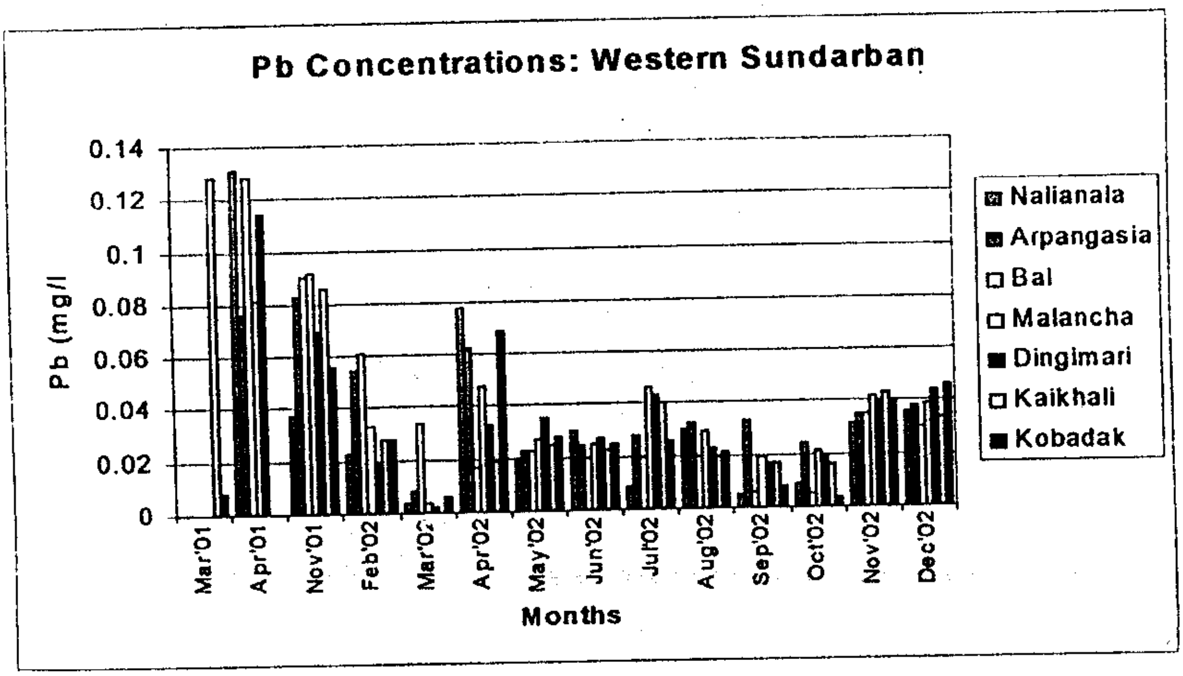


Figure 3.17: Pb concentration observed in the Western & Eastern Sundarbans

Furthermore, spatial variation of water quality parameters can also be assessed by grouping the monitoring stations into Northern and Internal. The Northern Sundarbans consists of Nalianala, Harbaria, Shwarankhola, Koikhali, Kobadak and Mrigamari, while Internal Sundarbans consists of Arpangasia, Bal, Malancha, Dingimari, Harintana, Dudmukhi and Jafa.

Both the Northern and Internal Sundarbans groups show distinct seasonal variation of BOD (as well as COD), but not so for Total Ammonia in case of Internal Sundarbans. In 2002, concentration of BOD (as well as COD) started to decrease gradually from April, but from September BOD (as well as COD) increased again. No apparent cause can be attributed to such unusual increase in the concentration of biodegradable pollutants. One reason might be there: concentration of dissolved organic matter bound to the cohesive sediment had been unusually high, which gave rise to such increase in the concentrations of BOD and COD.

More or less distinct seasonal variation of Total Ammonia and Nitrate could be observed for both the Northern and Internal Sundarbans. For Total Ammonia, maximum concentration occurred during April-May while maximum of Nitrate occurred during June-July.

On an average, concentrations of BOD and Total Ammonia in the Internal Sundarbans are slightly higher than those in the Northern Sundarbans but concentration of COD in the Internal Sundarbans is noticeably higher than that in the Northern Sundarbans. Comparison of monthly average values of the stations for BOD, COD and Total Ammonia observed during 2002 is shown in Table 3.9 and in Figure 3.18. These show that monthly average values of the boundary river samples are less than that of internal river samples. The seasonal variation of BOD, COD & Total Ammonia for Northern & Eastern Sundarbans is presented in Figure 3.19 to Figure 3.21

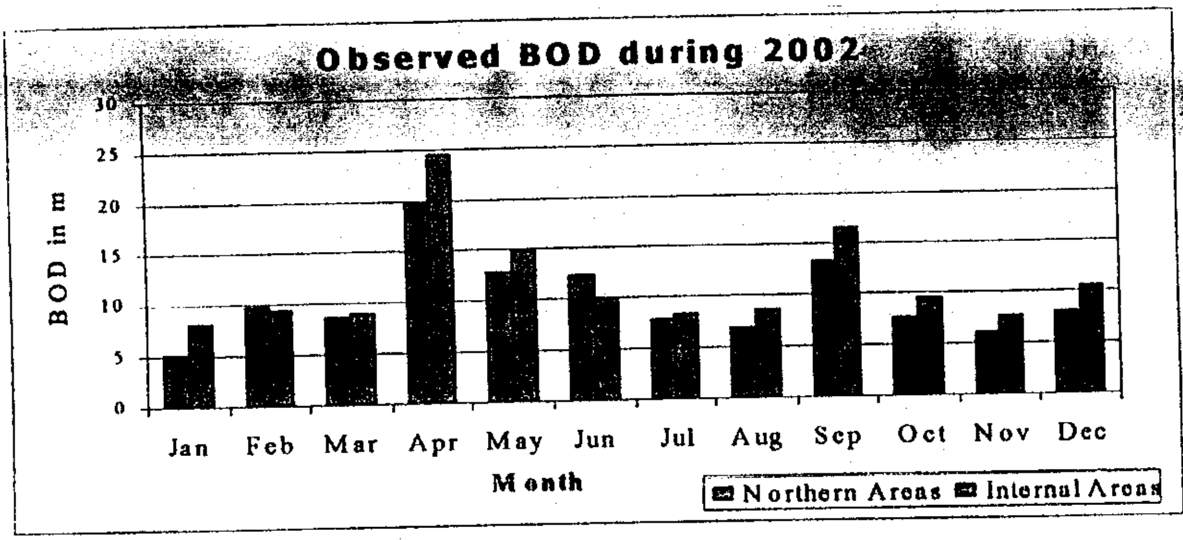
Other parameters (PO_4-P, Hg, Cr, Pb and Oil & Grease) do not show any seasonal variation, and average concentrations of these parameters are almost the same for Northern and Internal Sundarbans.

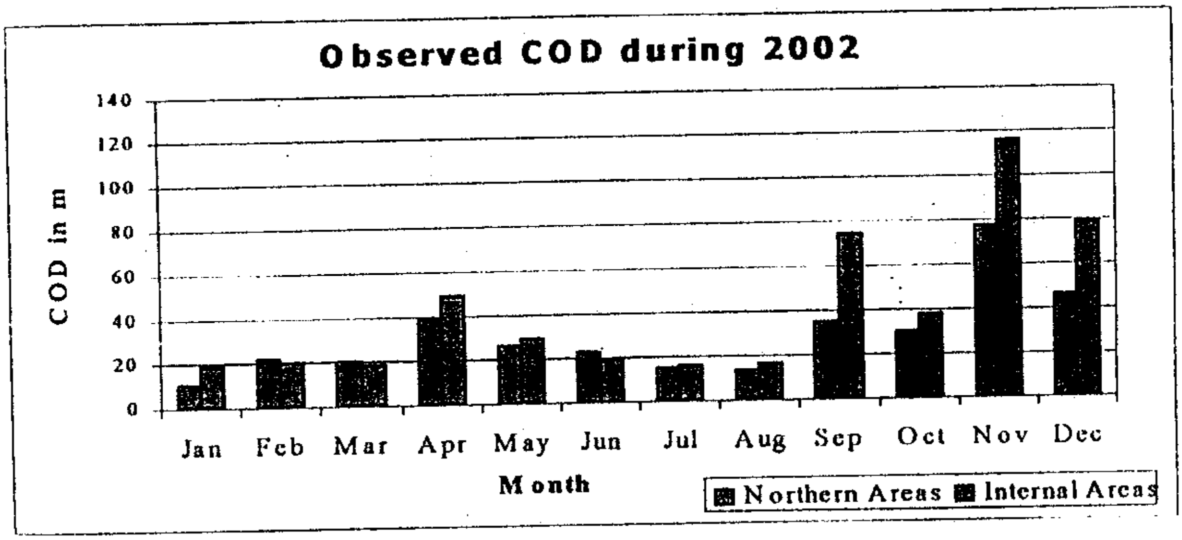
The same peculiar trend of Pb, as of Eastern and Western Sundarbans, could be observed in cases of Northern and Internal Sundarbans: it is gradually decreasing from March 2001 to October 2002. However, it is seen to increase again in November 2002.

Table 3.9: Observed BOD, COD and Total Ammonia in the North and Internal

Month	Monthly average during 2002 (mg/l)					
	BOD		COD		Total Ammonia	
	Northern	Internal	Northern	Internal	Northern	Internal
January	5.03	8.07	11.27	19.23	1.06	2.05
February	9.73	9.40	22.47	20.97	2.50	3.40
March	8.64	8.94	20.80	18.71	1.33	1.75
April	19.75	24.50	39.10	49.63	4.03	4.48
May	12.80	14.77	26.72	29.90	4.70	3.35
June	12.28	10.03	23.27	19.35	3.03	3.82
July	7.78	8.34	15.63	16.61	1.82	2.77
August	6.90	8.57	14.40	16.69	0.97	0.98
September	13.23	16.66	35.69	74.45	1.06	1.24
October	7.70	9.57	31.44	38.68	0.89	1.39
November	6.00	7.59	77.67	116.29	1.24	1.86
December	7.90	10.57	46.50	79.57	1.45	2.74

North: Locations close to the main land





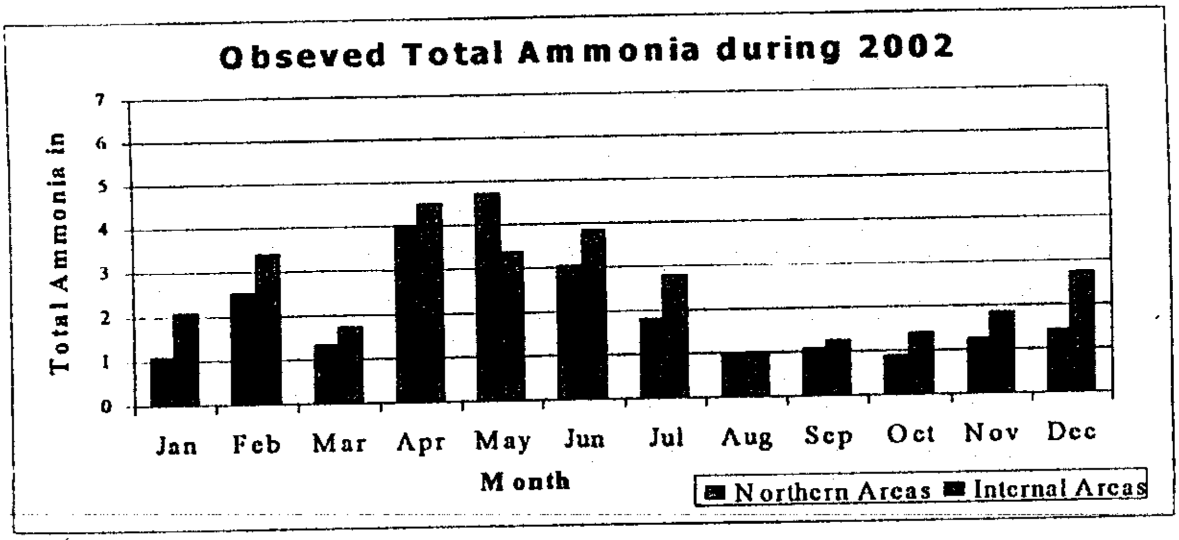
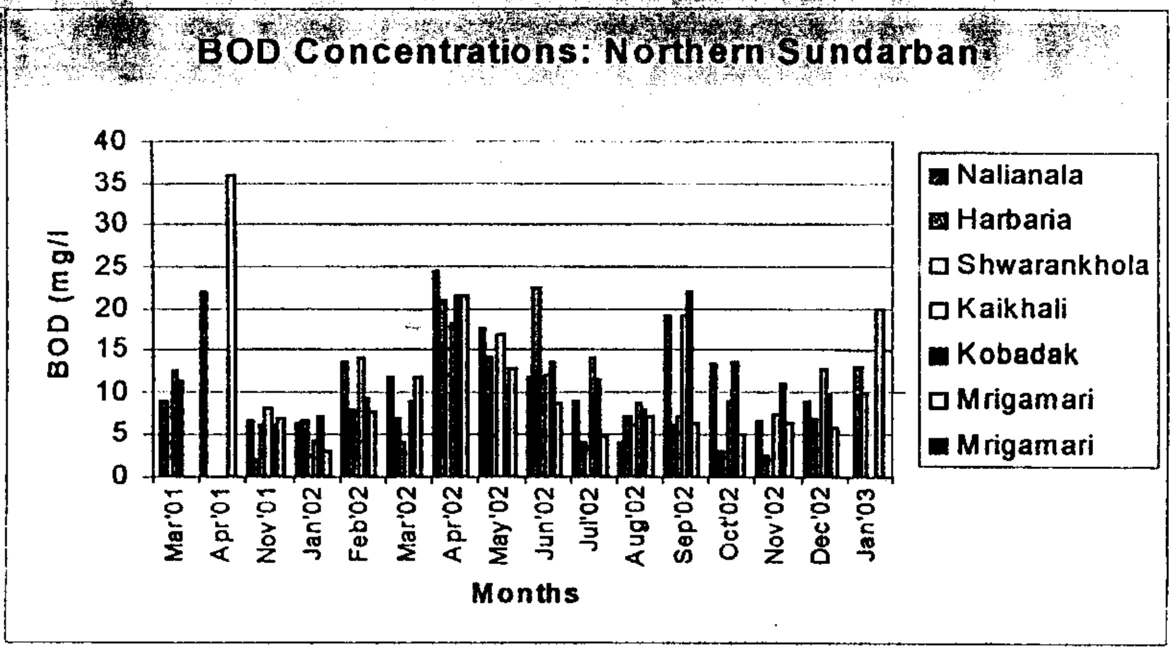


Figure 3.18 Variation of BOD, COD and Total Ammonia between northern and internal areas



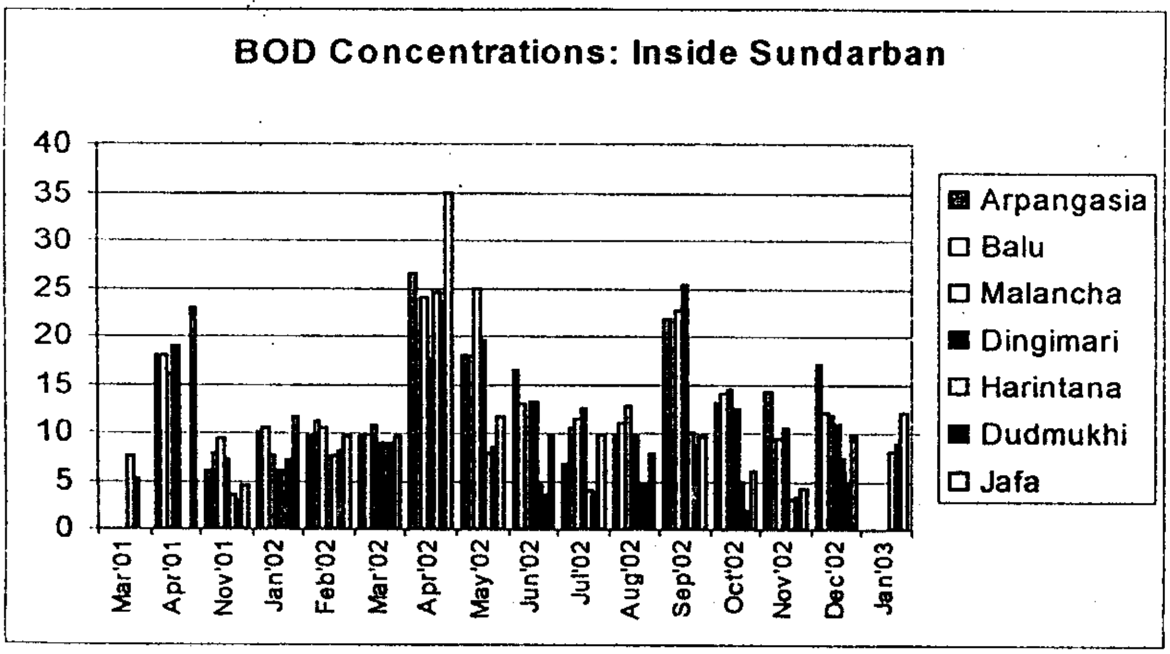
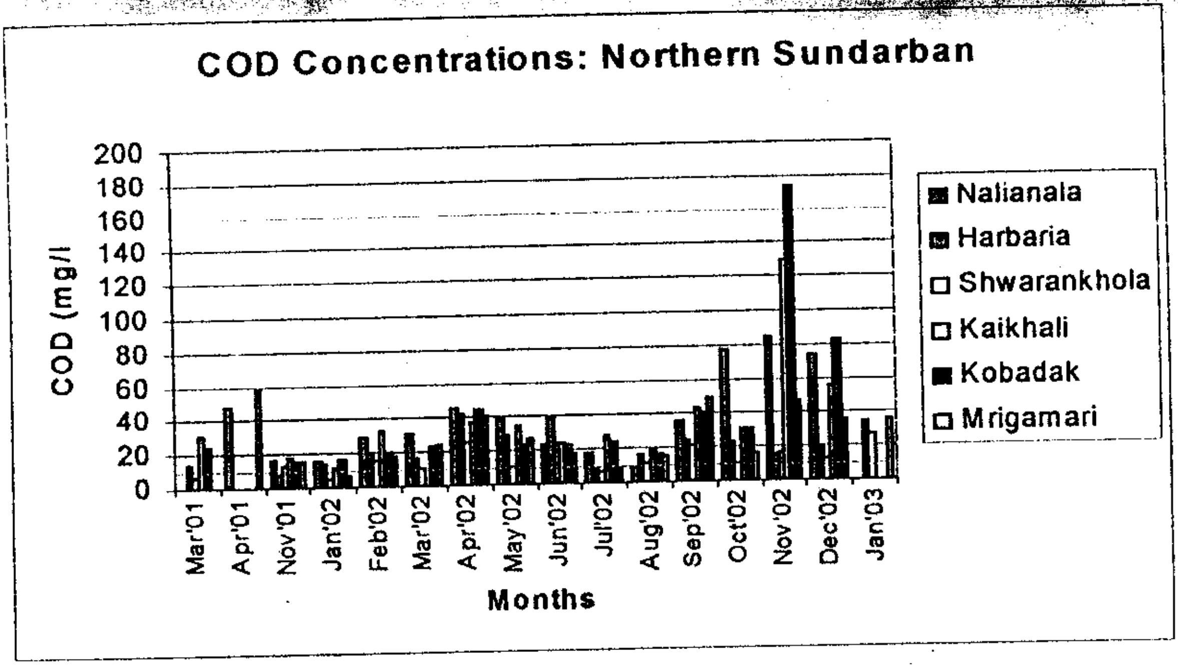


Figure 3.19: BOD Concentrations in the Northern Boundary & Inside Sundarbans



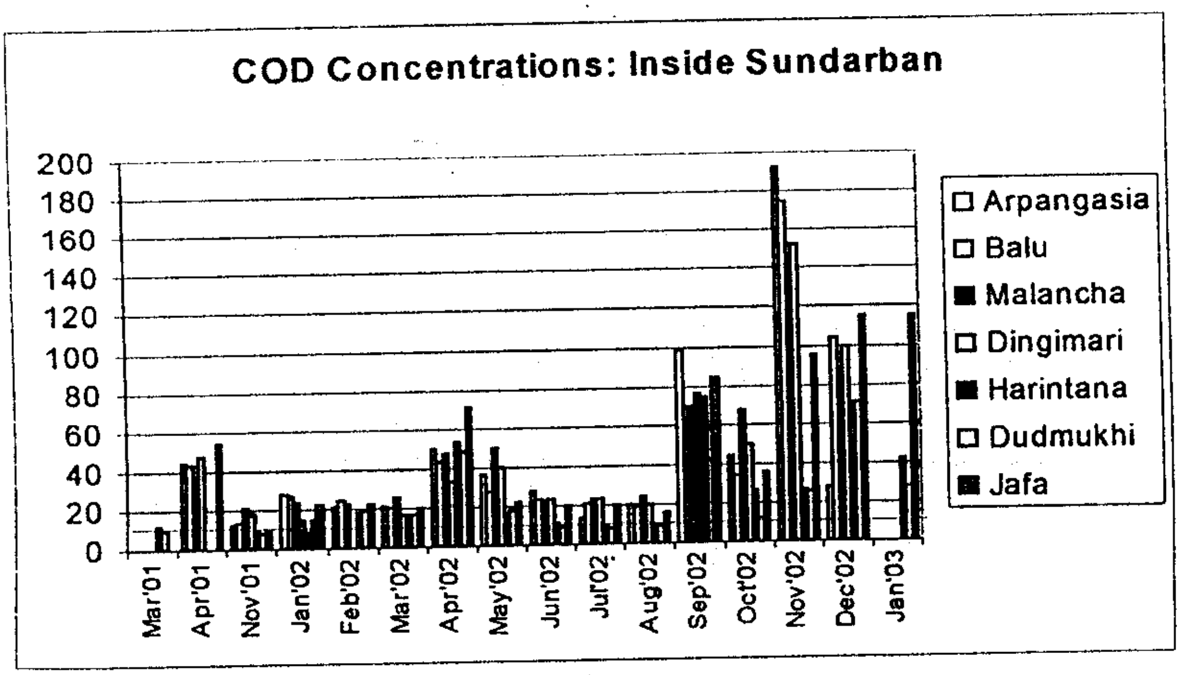
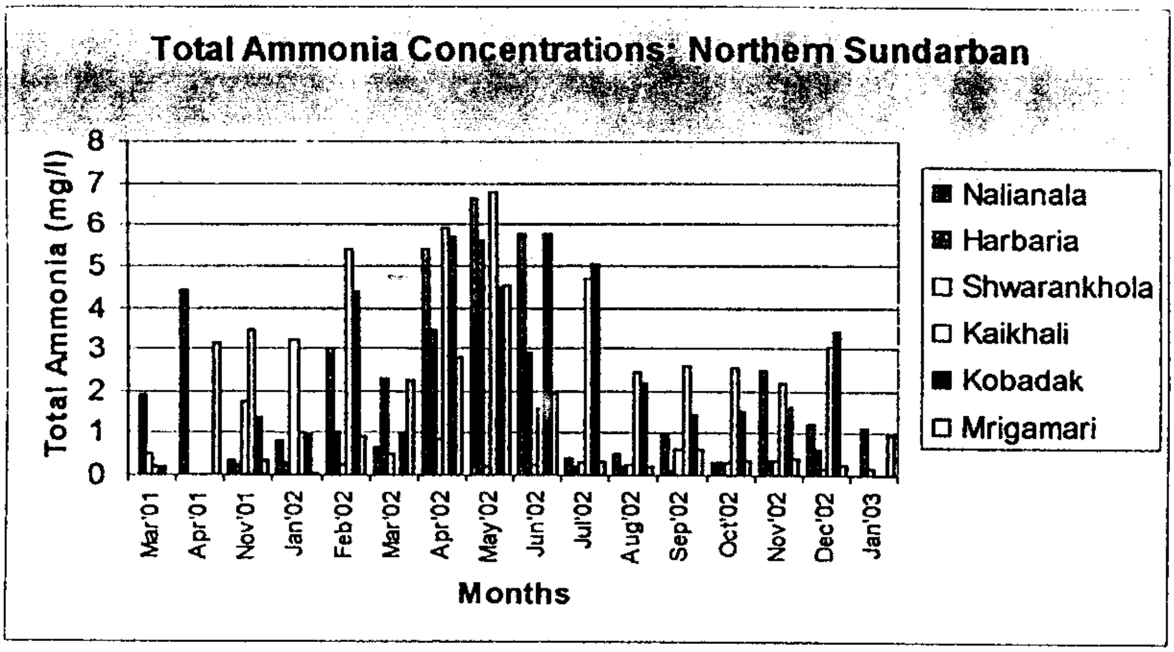


Figure 3.20: COD Concentrations in the Northern Boundary & Inside Sundarbans



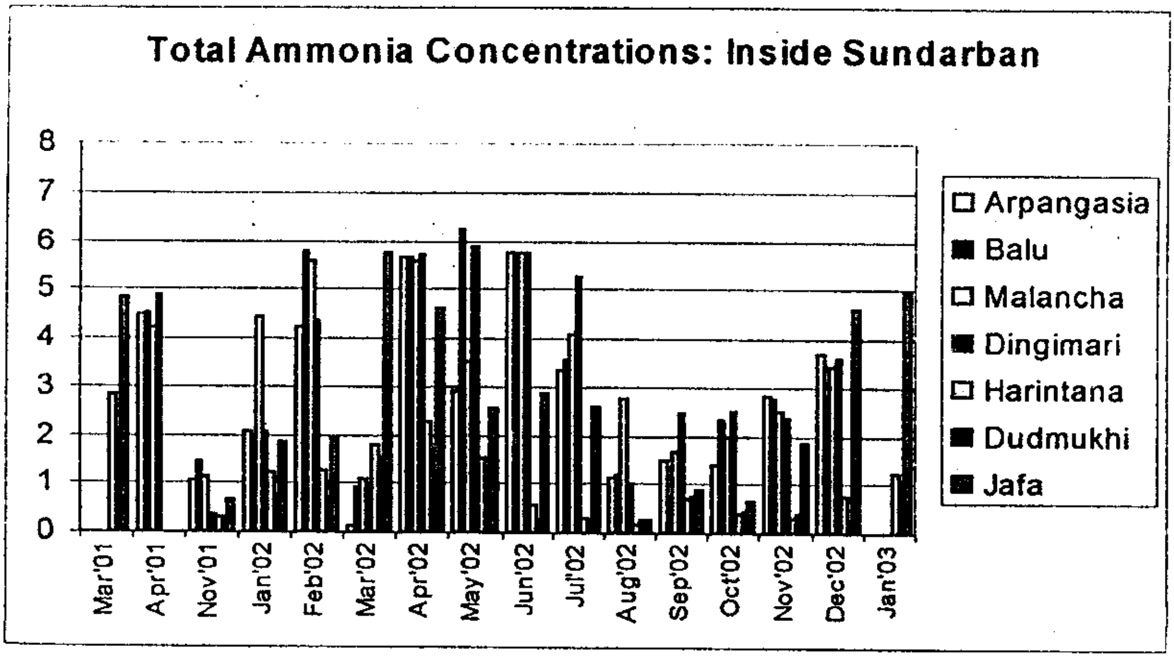


Figure 3.21: Total Ammonia in the Northern Boundary & Inside Sundarbans

3.4.9 Effect of sediment concentration on DO

The Sundarbans river water carries a substantial amount of suspended sediment. The amount of oxygen dissolved in water is subject to fluctuation of temperature, photosynthesis activity, presence of suspended sediment solids in the water etc. Suspended sediment concentration may include a wide variety of material, such as silt, decaying plant, animal matter etc., which can absorb DO very quickly leading to reducing DO in the water flow (D.H. Schoellhamer, 2001). Attempts have been made to observe the relationship between the suspended sediment concentration and amount of dissolved oxygen in different rivers.

In general, high DO is associated with lower suspended sediment concentration (SSC) (S.B. Mitchell et al, 1999). DO values in twelve locations of different river systems during discharge measurements have been analysed to find out a relation between DO and SSC at various locations. A sample chart is shown in Figure 3.22 and all charts are presented in **Annexure D.** Though DO data are few and scattered, Figure below indicates that DO decreases with increasing suspended sediment concentration at most of the river system. Thus, observation from this study is in conformity with the earlier findings. Monitoring of suspended sediment concentration may be considered in future plan also.

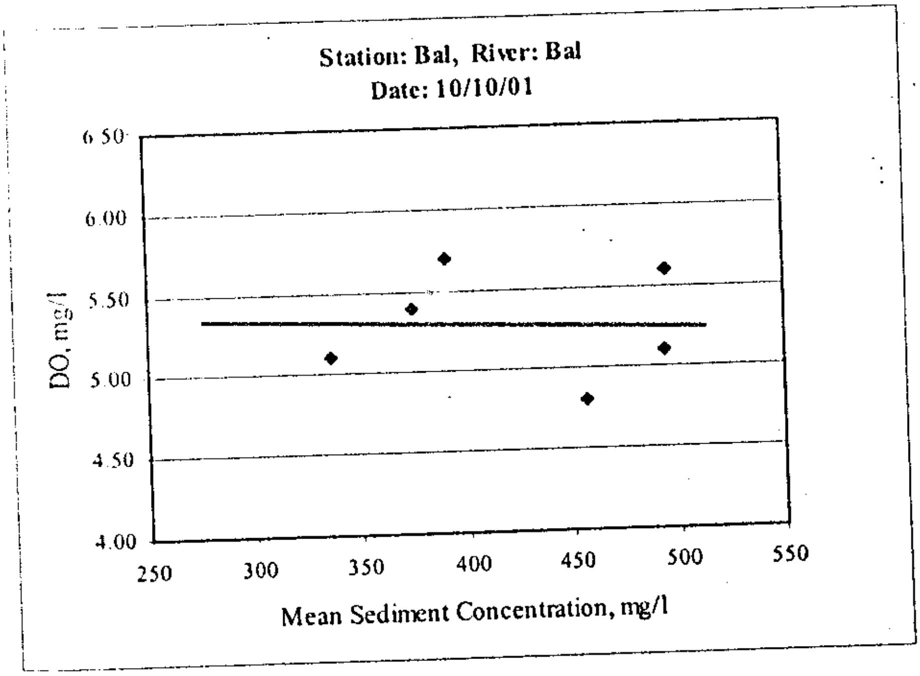


Figure 3.22 Variation of DO with Suspended Sediment Concentration

3.4.10 Impact of Shrimp Farming on Water Quality

Reliable water quality data inside the polders is hardly available from past studies. A study has been conducted by Research & Development Collective on the "Impact of Shrimp Farming on the Water Quality of some selected areas in the Greater Khulna District" which contain some basic data on water quality and soil parameters. The selected locations were at Fakirhat, Tala, Mongla, Paikgacha, Shyamnagar and Koyra. The samples were collected from both shrimp cultivated land and also agricultural land. The mean values of Dissolved oxygen in the shrimp cultivated areas are from 6.40 mg/l to 8.30mg/l while those at agricultural areas are from 4.90 mg/l to 7.00 mg/l. The values observed at agricultural ponds area similar to those observed from the present study. The Dissolved Oxygen in the shrimp cultured land is higher than agricultural land which indicates less organic pollution in the Shrimp Cultivated land. Like, the findings in the IWM study, other parameters also do not show significant variation with IWM test results. Also, not all the parameters follow any distinct seasonal pattern and might be influenced by local phenomenon.

The practice of shrimp culture near the SRF is to filling the shrimp gher (closed land) by river water and keep drying naturally. The objective is to increase the salinity till the harvesting season from June to August. Thus, there is little exchange of water from the shrimp farming land to river. Farmers exchange the water of shrimp cultivation land during July to facilitate rice cultivation. Thus, although some parameters (e.g. salinity) inside the shrimp cultivated land may become higher than the non-shrimp lands, it is not transmitted to the river system. Again, water quality of the plots under shrimp cultivation and those in the agricultural land does not have much variations. Thus, it may be expected that the water quality of the river system should not be affected much by shrimp farming in the area. However, more comprehensive data collection from the shrimp ponds integrated alongwith the associated rivers is essential to make any conclusive remarks.

3.4.11 Summary observation and Recommendation on the WQ of Sundarbans

Although situations of the river changes with hydrological pattern, it was found that parameters like BOD and COD were quite high during March and April at all locations. These represent extreme condition inside the Sundarbans. The higher COD values observed during the late monsoon of 2002 needs some more verification before making any comments. However, BOD and COD should be monitored to track the source of pollution.

There is no definite pattern of nutrient content in the Sundarbans river water. The presence of toxic ammonia (NH3-N) is negligible, and other nutrients were observed within healthy environmental limit. As such these parameters may not be very significant for judging environmental deterioration.

Presence of Lead and Chromium has been observed in most of the samples. A number samples exceeded the limit. Presence of Lead exceeded EQS for river water while it was less than EQS of Coastal water in most of the cases. However, presence of Lead was observed in all the soil samples of the pilot areas. As such accumulation of Lead from river water to forestland may be alarming in future. Presence of Mercury, Oil & grease were below detection level in most of the samples. Those detected in only a few samples were at insignificant quantity. As such, more emphasis should be given on identifying source of Lead and Chromium.

It is revealed from the analysis made on the observed test results that there is an obvious justification for the data collection for a longer period to establish a general trend inside the Sundarbans river system. Measurement of water quality parameters is a sensitive issue and should be conducted cautiously. The test results always vary with the method of sampling and testing procedure. To maintain the consistency of the data, standard practice should be followed for every event. Outcome of the present study has definitely set a baseline condition for the Sundarbans. A long term monitoring programme of some of the water quality parameter is essential for assessing the trend of pollution as well as to identify the source. Recommended monitoring should be (but not limited to) as follows:

- Dissolve Oxygen during monitoring trips along channels and fixed sampling locations
- Seasonal sampling of BOD and COD at the locations taken by IWM during months of high concentrations
- Monthly sampling of Lead and Chromium, especially at the places with high incidence, along the Pussur Channel, Navigation route of the Indian barges (coming through Auro Sibsa) and at places of fishing boats anchoring
- Testing for Lead and Chromium of soil samples from forestland at locations with high concentrations of Lead and Chromium to assess the course of pollutants in the soil

3.5 Observation on Pilot Area Study

3.5.1 Siltation Pattern

Siltation gauges and earthen tiles were installed at the pilot areas during April 2002. Three rounds of measurement have been done during July 2002 to February 2003. At the end of the monsoon, both siltation and erosion have been observed. The summary of the observed values between measurements at Apr-May 2002 (first Cycle) and Oct-Nov 2002 (3rd Cycle) is presented in Table 3.10. The net siltation rates at the end of monsoon season for the selected pilot areas are 20mm, -1mm and 31mm for Jongra, Patkusta and Koikhali respectively (from earthen tiles). The siltation rate depends on the velocity of water on the forestland, nature and depth of vegetation, sediment characteristics and depth and duration of inundation. All 3 sites have almost same bed soil characteristics having silt and clay as main constituent. However, it is difficult to make comments on the basis of few data. The plots of observed siltation have been presented on Annexure C.

Table 3.10 Observed siltation rates at three pilot areas (1st & 3rd Cycle)

Location	Method of measurement	Number	Siltation (mm)			Remarks
			Minimum	Maximum	Average	
Jongra	Siltation Gauge	6	2	32	13	All siltation
	Earthen Tiles	6	2	43	20	
Patkusta	Siltation Gauge	9	-19	18	-1	3 siltation, 6 erosion
	Earthen Tiles	9	-17	13	-1	4 siltation, 5 erosion
Koikhali	Siltation Gauge	7	3	50	22	All siltation
	Earthen Tiles	7	11	45	31	

3.5.2 Inundation Pattern & Tidal Current on forest land

Inundation patterns on the forestland from the observed water levels have been prepared for all the measurement of the pilot areas. Observed micro current as vectors for each measurement day are also plotted on the same maps. These will be helpful in assessing different soil parameters and siltation conditions. A sample copy of the map showing velocity vector and maximum inundation at Jongra Area on 10 Aug 2002 is presented in Drawing 1. While all the maps are presented in Annexure C. It has been observed from the pilot areas that little or no inundation is observed during the month of December to February. Inundation increases but not flooded the whole area during the pre-monsoon period (spring tide). Maximum inundation period during spring tide were around 3 to 4 hours. All area is inundated with longer duration during the spring tide in monsoon. The average velocities of microcurrent vary around 10 cm/sec to 20cm/sec. Higher velocities are observed in the creeks. It was also observed that the velocity during ebbing is slightly higher than velocity during flooding.

3.5.3 Soil Quality Parameters

Soil samples were collected from the pilot area during Topographic survey and during special monitoring programme in each pilot area. The samples have been tested from Bangladesh Agricultural University Laboratory for parameters PH, Ec, Organic Matter, Nitrogen, Phosphorus and Sulphur, Calcium, Sodium and Potassium. The results are presented in Tables and spatial distribution of each parameter plotted on the topographic map is shown in Annexure C. From the test results, it is seen that the parameters vary with location (surface/bottom) and season. Parameter wise observation is given below:

Electrical Conductivity

Jongra: Electrical conductivity of soil at Jongra has been observed to range from 0.361mS/cm to 3.180mS/cm for surface soil and from 0.596mS/cm to 3.270mS/cm for soil at 10cm depth. The mean value ±SD were calculated as 1.123±0.627mS/cm for surface soil and 1.591±0.704mS/cm for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in post monsoon for both surface and bottom soils.

Koikhali: Electrical conductivity of soil at Koikhali has been observed to range from 0.293mS/cm to 11.600mS/cm for surface soil and from 0.509mS/cm to 4.580mS/cm for soil at 10cm depth. The mean value ±SD of the samples are 3.323%±2.491 for surface soil and 2.633±0.993 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in post monsoon for both surface and bottom soils.

Patkusta: Electrical conductivity of soil at Patkusta has been observed to range from 0.652mS/cm to 4.730mS/cm for surface soil and from 0.746mS/cm to 3.530mS/cm for soil at 10cm depth. The mean value ±SD of the samples are 1.730±1.025mS/cm for surface soil and 1.928±0.796 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in post monsoon for both surface and bottom soils.

The average Electrical conductivity of soil at Jongra is substantially lower than those of other two stations. The Electrical conductivity of soil increases spatially from east to west direction of the Sundarbans. It is in conformity with the salinity in the river water. The Electrical conductivity of soil at 10cm depth is slightly higher than that of surface soil for Jongra and Patkusta stations but Koikhali station shows reverse pattern. It is also notable that values recorded at Koikhali shows wider range variation. The electrical conductivity of the soils on the forestland is quite high in comparison to the cultivable land inside the polders.

P^H

Jongra: P^H of soil at Jongra has been observed to range from 7.58 to 8.08 for surface soil and from 7.1 to 8.26 for soil at 10cm depth. The mean value ±SD of the samples are 7.77±0.15 for surface soil and 7.80±0.21 for soil collected from 10cm depth. The highest values were recorded in post monsoon and it decreases to the lowest in dry season for both surface and bottom soils.

Koikhali: P^H of soil at Koikhali has been observed to range from 7.3 to 8.15 for surface soil and from 7.36 to 8.27 for soil at 10cm depth. The mean value ±SD of the samples are 7.80±0.22 for surface soil and 7.76±0.21 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in dry season for surface soil and in post monsoon for bottom soil.

Patkusta: P^H of soil at Patkusta has been observed to range from 7.48 to 8.14 for surface soil and from 7.27 to 8.37 for soil at 10cm depth. The mean value ±SD of the samples are 7.85±0.17 for surface soil and 7.83±0.25 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in dry season for both surface and bottom soils.

The P^H of soil at 10cm depth is slightly lower than that of surface soil for Koikhali and Patkusta stations but Jongra station shows reverse pattern. The seasonal fluctuation of the P^H of soil is clearer in all 3 areas. Dry season lowest value and the monsoon or post monsoon highest value is the salient feature other than some erroneous values. Surface soil changes more rapidly with the seasonal fluctuation than soils underneath.

Nitrogen

Jongra: Nitrogen concentration of soil at Jongra has been observed to range from 0.019% to 0.224% for surface soil and from 0.009% to 0.211% for soil at 10cm depth. The mean value ±S.D. of the samples are 0.088%±0.06 for surface soil and 0.077%±0.053 for soil collected from 10cm depth. The highest values were recorded at high lands and the lowest values observed at the low-lying lands. The nitrogen content is higher during dry season.

Koikhali: Nitrogen concentration of soil at Koikhali has been observed to range from 0.014% to 0.184% for surface soil and from 0.018% to 0.184% for soil at 10cm depth. The mean value ±S.D. of the samples are 0.108%±0.052 for surface soil and 0.104%±0.043 for soil collected from 10cm depth. Lowest Nitrogen concentration recorded in dry season and it rises to the maximum in monsoon for surface soil and in post monsoon for the bottom soil.

Patkusta: Nitrogen concentration of soil at Patkusta has been observed to range from 0.027%to 0.211% for surface soil and from 0.04% to 0.175% for soil at 10cm depth. The mean value ±S.D. of the samples are 0.098%±0.045 for surface soil and 0.113%±0.035 for soil collected from 10cm depth. Lowest Nitrogen concentration recorded in dry season and it rises to the peak in monsoon for bottom soil and in post monsoon for the surface soil.

The Nitrogen content of soil at 10cm depth is slightly lower than that of surface soil at countryside station of Jongra and Koikhali but the seaside station Patkusta shows reverse pattern. As mentioned in the water quality part that the nitrate content does not follow any seasonal pattern, no distinct seasonal pattern could be seen for nitrogen content of the soil.

Phosphorus

Jongra: Phosphorus concentration of soil at Jongra has been observed to range from 2ppm to 26ppm for surface soil and from 2ppm to 28ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 6.81±6.62 for surface soil and 7.43±6.69 for soil collected from 10cm depth. The highest values were recorded in post monsoon and it decreases to the lowest in dry season for both surface and bottom soils.

Koikhali: Phosphorus concentration of soil at Koikhali has been observed to range from 2ppm to 16ppm for surface soil and from 2ppm to 14ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 8.08±4.01 for surface soil and 7.25±4.07 for soil collected from 10cm depth. The highest values were recorded in post monsoon and it decreases to the lowest in monsoon for both surface and bottom soils.

Patkusta: Phosphorus concentration of soil at Patkusta has been observed to range from 2ppm to 18ppm for surface soil and from 2ppm to 14ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 8.13±5.14 for surface soil and 7.71±3.36 for soil collected from 10cm depth. The highest values were recorded in post monsoon and it decreases to the lowest in dry season for surface soil and in monsoon for bottom soil.

The Phosphorus content of soil at 10cm depth is slightly lower than that of surface soil for Patkusta and Koikhali stations but Jongra station shows reverse pattern and it is also notable that variation at Jongra is much wider than other areas. Significant variation of Phosphorus content has been observed with season. The highest Phosphorus concentration of soil at all 3 stations in post monsoon and the lowest in dry season.

Potassium

Jongra: Potassium concentration of soil at Jongra has been observed to range from 16ppm to 89ppm for surface soil and from 13ppm to 120ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 40.86±19.89 for surface soil and 47.62±28.56 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in dry season for both surface and bottom soils.

Koikhali: Potassium concentration of soil at Koikhali has been observed to range from 52ppm to 142ppm for surface soil and from 18ppm to 136ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 87.71±21.63 for surface soil and 90.54±25.63 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in post monsoon for both surface and bottom soils.

Patkusta: Potassium concentration of soil at Patkusta has been observed to range from 37ppm to 152ppm for surface soil and from 45ppm to 126ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 71.08±28.9 for surface soil and 87.08±20.93 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in post monsoon for both surface and bottom soils.

The Potassium content of soil at 10cm depth is substantially higher than that of surface soil. The Potassium content of soil also increases spatially from east to west direction of the Sundarbans.

Calcium

Jongra: Calcium concentration of soil at Jongra has been observed to range from 1250ppm to 4550ppm for surface soil and from 800ppm to 4250ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 3356.25±750.24 for surface soil and 2984.28±852.57 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in monsoon for both surface and bottom soils.

Koikhali: Calcium concentration of soil at Koikhali has been observed to range from 700ppm to 4100ppm for surface soil and from 700ppm to 3500ppm for soil at 10cm depth.

The mean value ±S.D. of the samples are 1821.15±916.43 for surface soil and 1352±764.92 for soil collected from 10cm depth. The highest values were recorded in post monsoon and it decreases to the lowest in monsoon for both surface and bottom soils.

Patkusta: Calcium concentration of soil at Patkusta has been observed to range from 1050ppm to 3100ppm for surface soil and from 850ppm to 3150ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 2039.58±596.71 for surface soil and 1579.17±667.67 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in monsoon for both surface and bottom soils.

The calcium content of soil at 10cm depth is substantially lower than that of surface soil. The calcium content of soil also decreases spatially from east to west direction of the Sundarbans.

Sodium

Jongra: Sodium concentration of soil at Jongra has been observed to range from 1224ppm to 5508ppm for surface soil and from 952ppm to 6188ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 2952.67±1253.87 for surface soil and 3389.07±1176.76 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in dry season for both surface and bottom soils.

Koikhali: Sodium concentration of soil at Koikhali has been observed to range from 3332ppm to 6712ppm for surface soil and from 1156ppm to 6712ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 4821.77±1048.56 for surface soil and 4829.6±1469.18 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in post monsoon for both surface and bottom soils.

Patkusta: Sodium concentration of soil at Patkusta has been observed to range from 2176ppm to 6052ppm for surface soil and from 2108ppm to 6596ppm for soil at 10cm depth. The mean value ±S.D. of the samples are 3468±1062 for surface soil and 4510±1138.86 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in post monsoon for both surface and bottom soils.

The Sodium content of soil at 10cm depth is substantially higher than that of surface soil. It also increases spatially from east to west direction of the Sundarbans. The highest Sodium concentration of soil at Jongra and Koikhali area in monsoon but the Patkusta area shows reverse pattern i.e. in dry season.

Sulphur

Jongra: Sulphur concentration of soil at Jongra has been observed to range from 73ppm to 658ppm for surface soil and from 99ppm to 946ppm for soil at 10cm depth. The mean value ±SD of the samples are 275.78±148.98 for surface soil and 335.61±218.14 for soil collected from 10cm depth. The highest values were recorded in monsoon and it decreases to the lowest in post monsoon for both surface and bottom soils.

Koikhali: Sulphur concentration of soil at Koikhali has been observed to range from 165ppm to 971ppm for surface soil and from 157ppm to 911ppm for soil at 10cm depth.

The mean value ±SD of the samples are 477.5±224.4 for surface soil and 420.3±197.7 for soil collected from 10cm depth. The highest values were recorded in dry season for surface soil and in monsoon for bottom soil but decrease to the lowest in post monsoon for both types.

Patkusta: Sulphur concentration of soil at Patkusta has been observed to range from 80ppm to 572ppm for surface soil and from 88ppm to 876ppm for soil at 10cm depth. The mean value ±SD of the samples are 276.21±134.1 for surface soil and 324.63±216.76 for soil collected from 10cm depth. The highest values were recorded in dry season and it decreases to the lowest in post monsoon for both surface and bottom soils.

The Sulphur content of soil at 10cm depth is substantially higher than that of surface soil for Jongra and Patkusta stations but Koikhali station shows reverse pattern. The wider range of the observed value is also notable. The Sulphur content of soil at Koikhali is substantially higher than those of other two stations. No distinct seasonal pattern is followed other than the lowest concentration observed in post monsoon.

Organic Content

Jongra: Organic Content of soil at Jongra has been observed to range from 0.195% to 3.868% for surface soil and from 0.181% to 4.228% for soil at 10cm depth. The mean value ±SD of the samples are 1.646%±1.13 for surface soil and 1.55%±1.04 for soil collected from 10cm depth. The highest average values were recorded in post monsoon and it decreases to the lowest in monsoon for surface soil and in dry season for bottom soil.

Koikhali: Organic Content of soil at Koikhali has been observed to range from 0.901% to 3.689% for surface soil and from 0.721% to 3.689% for soil at 10cm depth. The mean value ±SD of the samples are 2.31%±0.91 for surface soil and 2.35%±0.76 for soil collected from 10cm depth. The seasonal variation of Organic Content concentration of soil at Koikhali is not remarkable.

Patkusta: Organic Content of soil at Patkusta has been observed to range from 0.541% to 4.238% for surface soil and from 0.811% to 3.509% for soil at 10cm depth. The mean value ±SD of the samples are 1.99%±0.92 for surface soil and 2.26%±0.72 for soil collected from 10cm depth. The lowest average values were recorded in dry season and it increases to the highest in post monsoon for surface soil and in monsoon for bottom soils.

The Organic Content of soil at 10cm depth is slightly higher than that of surface soil for Koikhali and Patkusta stations. Observed values at Jongra vary significantly. The average Organic Content of soil at Jongra is substantially lower than those of other two stations. The exact seasonal pattern is uncertain from the observed data, although it may be the highest in post monsoon. The Organic Content of soil increases spatially from east to west direction of the Sundarbans.

3.5.4 Sediment Concentration

Sediment concentration in the pilot areas has been measured. The ranges of sediment concentrations vary with locations and time. The sediment concentrations measured on the forestland has been presented in the Annexure C. It is observed that the average sediment concentration during flooding at Koikhali is higher than that during ebbing while the sediment concentration observed at Jongra during ebbing was much higher than that of flooding. The overall sediment concentration is higher at Jongra than other two sites. This is in conformity with the high sediment concentration in the Rupsha River (adjacent to Jongra area) than other pilot areas. However, it is difficult to make any conclusive comments based on the too few data.

Station	Month	Average Sediment Concentration (mg/l) during 2002	
		Flooding	Ebbing
Jongra	August	478.88	307.78
	November	176.09	258.91
Patkusta	July	244.13	209.78
	November	113.99	229.73
Kaikhali	July	168.02	179.69
	October	188.02	176.98

3.5.5 Presence of Heavy Metal

Heavy metals may be concern for the Mangrove Forest specially where heavy metal in exists in the river water. In the river system of the Sundarbans, presence of lead is observed in almost all the samples. Although, the amount present in the river system may not be significant, it can be accumulated on the forestland for a longer period, it may be detrimental for some plants. On this view, 3 samples from each pilot area were tested for the presence of lead content from Bangladesh Institute of Nuclear Agriculture. The test results are indicative as it was collected only once and deserves more sampling from other areas for making conclusive comment. The test results are presented at the Table 3.11. The range of lead concentration varied from 14.18 ppm to 22.29ppm. It also shows that the average lead contents at Patkusta, Jongra and Koikhali are 18.57, 16.88 and 17.89 ppm respectively. The presence of lead deserves larger scale monitoring of the parameter.

Table 3.11: Lead concentration observed on the forestland

Location	Sample No.	Lead (ppm)	Remarks
Patkusta	1	18.23	Average: 18.57 (ppm)
	2	22.29	
	3	15.19	
Jongra	4	20.26	Average: 16.88 (ppm)
	5	14.18	
	6	16.21	
Koikhali	7	17.22	Average: 17.89(ppm)
	8	18.23	
	9	18.23	

3.5.6 Soil Texture

The objective of the grain size analysis was to get some indication about sediments deposited at each area. The samples have been collected from 10cm to 20 cm below the surface. Grain size analysis of 9 soil samples (3 from each pilot area) has been performed from Bangladesh Institute of Nuclear Agriculture (BINA). The test results of the samples are presented in Table 3.12. From the analysis it is seen that the average grain size of 3 samples are:

Patkusta: Sand 17.04%, Silt 48.67%, Clay 34.29%
Jongra: Sand 14.37%, Silt 46.67%, Clay 38.96%
Koikhali: Sand 15.71%, Silt 44.00%, Clay 40.29%

Samples from Patkusta content smaller quantity of clay with higher sand & silt than other two sites. Koikhali samples have higher percentage of clay.

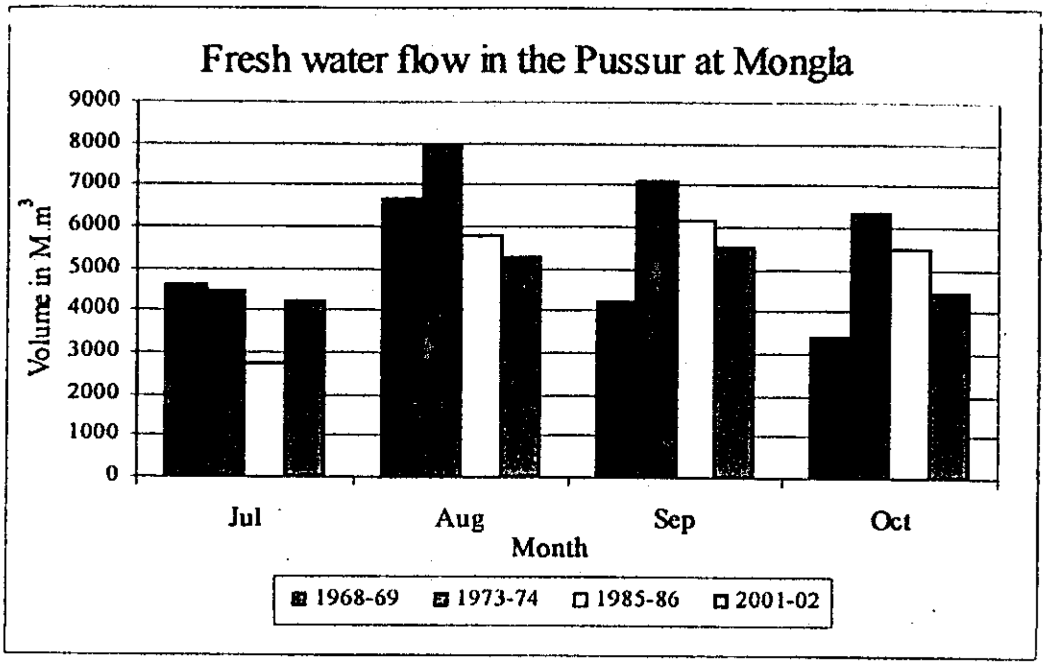
Table 3.12: Grain size analysis of samples from pilot areas

Location	Sample No.	Sand (%)	Silt (%)	Clay (%)
Patkusta	1	15.04	42.00	42.96
	2	15.04	50.00	34.96
	3	21.04	54.00	24.96
Jongra	4	13.04	44.00	42.96
	5	17.04	50.00	32.96
	6	13.04	46.00	40.96
Koikhali	7	13.04	46.00	40.96
	8	15.04	42.00	42.96
	9	19.04	44.00	36.96

3.6 River Flow

Discharge data have been collected in the important rivers of the SRF. Measured velocity has been resolved perpendicular to the cross section to measure the discharge. The velocity & discharge data in tabular form and charts are presented in Annexure D. In general, flow velocity of 1.0metre/sec to 1.5 metre/second has been observed during spring tides while it reduces significantly during neap tides. Volume of fresh water flow through the Pussur and Sibsa during 2001 monsoon season has been assessed from the results of hydrodynamic model (detail of model is given in chapter 4). Mathematical model has been applied to generate wet season flow for the year 1968, 1973 and 1985 for the Pussur and Sibsa systems. Current fresh water flow has been generated from the hydrodynamic model updated during the study period. Results have been used to compare the flow of these rivers. In the Sibsa system, it appears that the freshwater flow has been significantly declined since 1973 (Figure below). The possible reason could be the reduction of fresh water from the upstream channels. It may be mentioned here that after the construction of the Farkka Barrage in the neighbouring country most of its southbound distributaries have been silted up. As a result the dry season as well as the wet season flow in many of those rivers has either been cut off or reduced.

In the Pussur, the model results show less reduction of freshwater flow compared to the Sibsa. This may be because the coastal polders in the Bagerhat area has sealed most of the southbound arteries through the east, and pushed a significant portion of the Gorai flow towards the Pussur.



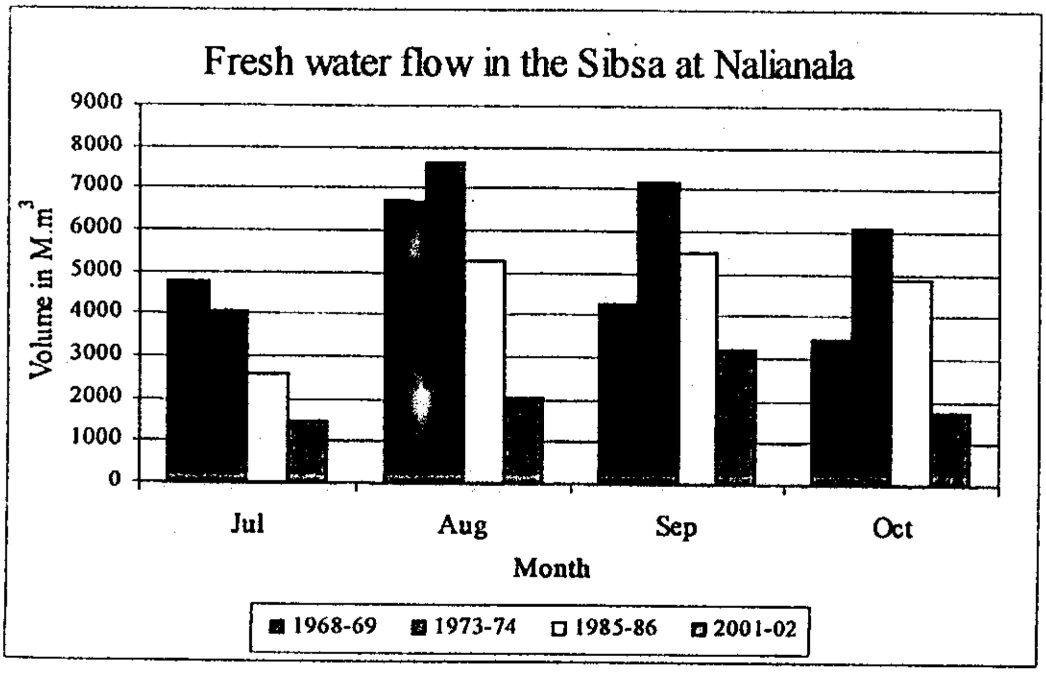


Figure 3.23: Comparison of Fresh Water Flow through the Pussur and Sibsa

3.7 Sedimentation Study

Sediment plays an important role in the water eco systems of the Sundarbans. [illegible] particles of the Meghna systems re-circulated in the area flocculate [illegible] environment and modified to cohesive sediment. A small part of those sediments are carried to the forestland during high tide and get deposited around the natural levee. The remaining part is supposed to be pushed back to the sea by the receding tide. But due to reduction of upland flows in the dry seasons, caused by human interventions, a significant portion of the sediment settles on the riverbed in the recent years and leads to gradual dying up of few important rivers. Direct measurement of river cross-section and the flood plain elevation could be the best way of assessment of sedimentation. Due to extreme slow process of sedimentation any conclusive study requires long time data, which is not available for the Sundarbans area. Analysis of sediment concentration could be another approach. But, that too requires substantial volume of data for the dry period (for low upland flow situations) as well wet period (for high upland flow situations). Unfortunately, the wet period data is rarely available. Under such situation, with the available data a combined approach of sediment data analysis and river cross section study has been carried out to provide an indicative assessment of the changes in the riverbed. The effect of salinity concentration on the sediment has also been studied. It appears that due to increased flocculation the fall velocity of sediment increases at high salinity indicating low concentration in suspension. This might be one of the reasons for enhanced siltation during dry periods.

With a view to understand the sedimentation process of few selected rivers flow velocity, suspended sediment concentration (SSC), settling velocity and salinity concentrations have been analyzed.

3.7.1 Sediment Concentration During Flooding and Ebbing

Comparison of suspended sediment concentration with flow velocity has been carried out with the dry period data of 2001 at sixteen locations presented in **Annexure D** (Figure. D93 – D98). It is observed that sediment concentration during flood tide is higher than that of the ebb tide period indicating deposition on the riverbed and floodplain. However, with the increased flow during the monsoon some erosion may take place, which may reduce rate of total annual siltation on the riverbed.

3.7.2 Impact of Salinity on Suspended Sediment Concentration

Salinity data has been compared with the suspended sediment data at eight locations (Figure. D99 – D101). The graphs show that suspended sediment concentration decreases with the increase of salinity. It appears that due to increased flocculation the fall velocity of sediment increases at high salinity, indicating low concentration in suspension. Due to flocculation the small particles clumped together, become heavier to settle down to the bed. In fresh water the repulsive forces between the negatively charged particles dominate and the particles repel each other but in saline water the attractive forces dominate due to the presence of positive ions forming a cloud of positive ions (cations) around the negatively charged particles resulting in the formation of flocs.

3.7.3 Settling Velocity During Flooding and Ebbing

The settling velocity plays an important role in the sedimentation process of the rivers. Settling velocity of suspended sediment has been measured at sixteen locations during dry period of 2001. The data presented in Table 3.13, shows that overall settling velocity of suspended sediment during ebb tide is higher than that of flood tide. This might be due to the enlargement of flocs, because ebb tide, in combination with fresh water, always contains substantial amount of organic material in the flow. "Organic materials in and on the flocs significantly intensify the flocculation processes owing to binding properties of the organic materials. The binding forces become larger due to presence of biogenetic forces of organic materials, and the flocs become larger" (Leo. Van Rijn). From the above analysis it appears that for the same volume of flow sediment carrying capacity of the receding tide should be less than that of the flood tide.

Table 3.13: Settling Velocity of Sediment Particles in few Rivers

Station Name	River Name	Date	Average Settling Velocity (mm/s)	
			Ebb Tide	**Flood Tide**
Arpangasia	Arpangasia	02.12.2001	0.06	0.04
Bal	Bal River	10.10.2001	0.22	0.07
Digraj	Pussur	13.01.2001	0.16	0.21
Digraj	Pussur	16.10.2001	0.24	0.77
Dingimari	Jamuna	30.11.2001	0.03	-
Dudmukhi	Betmar	25.11.2001	-	-
Harbaria	Putia Khal	10.02.2001	0.36	0.04
Harintana	Selagang	18.10.2001	0.64	0.22
Jafa	Jafagang	16.11.2001	-	-
Kaikhali	Madar Nadi	26.10.2001	-	-
Kobadak	Kholapetua	01.03.2001	0.08	0.06
Malancha	Malancha	01.12.2001	0.22	0.05
Mrigamari	Selagang	17.10.2001	0.49	0.34
Nalianala	Sibsa	27.02.2001	0.16	0.12
Shawrankhola	Bhola Gang	20.03.2001	0.22	0.05
Supati	Supati Khal	11.02.2001	0.16	0.26

3.7.4 Sediment Balances

A sediment balance study of fifteen rivers with at least one measured data has been carried out for dry period. The sediment balance (net sediment transports) is estimated by combining observed discharges with observed concentrations. The transport is calculated by:

$$Q_s = Q_w * C_s$$

Where Q_s (m^3/s) is the sediment transport, Q_w (m^3/s) is the water discharge and C_s non-dimensional concentration, obtained from the measured concentration C (mg/l) by:

$$C_s = C/\rho, \quad \rho = 2.65 * 10^6 \text{ mg/l}$$

The result is presented in Table 3.14. From the table indicate that in few rivers the sediment deposition rate is significant during the dry periods and in few rivers the rate of deposition should be insignificant. Similar computation for the wet period could not be carried out for want of data. The high deposition rate usually occurs in the rivers of eastern part including the Pussur and the low deposition rate occurs in the rivers west of Pussur.

The measured sediment concentration collected from only one location of the river system has been assumed to remain the same for all along the river system throughout the dry season. Simulated discharges have been used at the location where measured discharges were not available. As such accumulated sediment transport and siltation rate calculated from these data are very much indicative. Here it also necessary to mention that due to non-availability bed load, only suspended sediment transports have been considered in the sediment balance study.

Table 3.14: Sediment Balance in Rivers

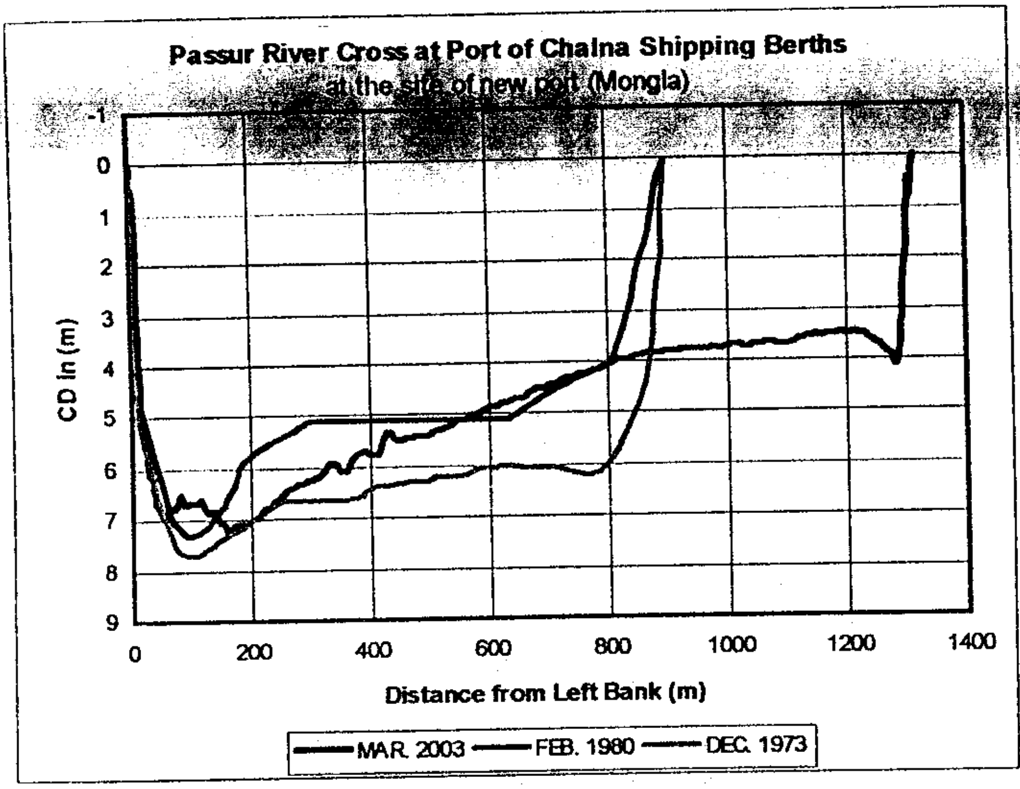
River Name	Average sediment load (m^3/s)		
	Ebb Tide	Flood Tide	Net
Arpangasia	1.8	2.02	0.22
Bal	1.03	1.2	0.17
Betmar	0.13	0.16	0.03
Bhola Khal	0.03	0.05	0.02
Jafa Gang	2.44	3.93	1.5
Jamuna	1.41	1.61	0.2
Kholapetua	0.39	0.48	0.09
Malancha	6.18	6.88	0.7
Madar Nadi	0.02	0.01	0.01
Mrigamari	0.18	0.32	0.14
Pussur	15.59	16.32	0.72
Putia Khal	0.3	0.34	0.03
Sela Gang	2.14	2.5	0.36
Sibsa	7.23	7.16	0.07
Supati Khal	0.52	0.57	0.05

3.7.5 Cross section Analysis

Analysis of long time cross-sections is the most dependable way of morphological status of the rivers. The rivers studied in connection with the present study are shown in Drawing 2. Due to the limitation of historical data the analysis is mostly based on the recent information. One of the oldest reports in respect of river morphology in the area is "Pussur River Study" by DRP Farleigh for the Port of Chalna Authority during 1981 – 84. The study covered the Pussur systems only. However, the forecast of the study in respect of increased siltation in the Pussur due to decrease in freshwater flow in the Gorai and coastal polders appear quite reasonable. The study used few cross section data of 1954, 1973 and 1984; though the exact location of those cross-sections in digital form could not be made available an approximate location has been fixed from the available information. Comparison of the earlier data with the recently surveyed ones shows alarming rate of siltation in the Pussur River Figure 3.24. For other rivers the available cross-sections of 1994 – 95 have been compared with the surveyed data of 2000–01 (Figure D102 – D115). Figure D111 shows alarming siltation at the offtake of Mrigamari from the Pussur. If that continues, Mrigamari including the upper part of the Sela Gang may face the same fate of the Kharma Khal Bhola River System. The thalweg lines of the rivers have also been superimposed (Figure D116 – D121). Though it is difficult to provide a conclusive assessment of the future morphological changes of the rivers with only few sets of data, a general criterion (Table 3.15) could be developed for future monitoring. In general, the analysis shows gradual siltation of the rivers of the eastern Sundarbans while no major change seen in the western part.

3.7.6 Findings

From the sediment study it appears that the rivers of the eastern part of Sundarbans including the Pussur experiences an alarming rate of siltation. Mrigamari at its offtake from the Pussur shows alarming rate of siltation with indication that the connection between the Sela Gang and the Pussur may be closed in a long run, which may ultimately lead to the fate of the Kharma Bhola System. The reduction of freshwater flow due to various interventions at the upstream including the polder embankments could be the possible causes of siltation in the rivers. A number of rivers at the northwestern boundary are also being silted up at present while some of the western rivers appear getting larger with the passage of time. The rivers in the southwestern part (Arpangasia, Malancha, Kesonkhali, Churkuni Gang, etc.) are less active in respect to siltation. Changes in the river morphology influences the inundation pattern as well as fresh water circulation in the future. Follow up programme should be taken to monitor the morphological changes in future.



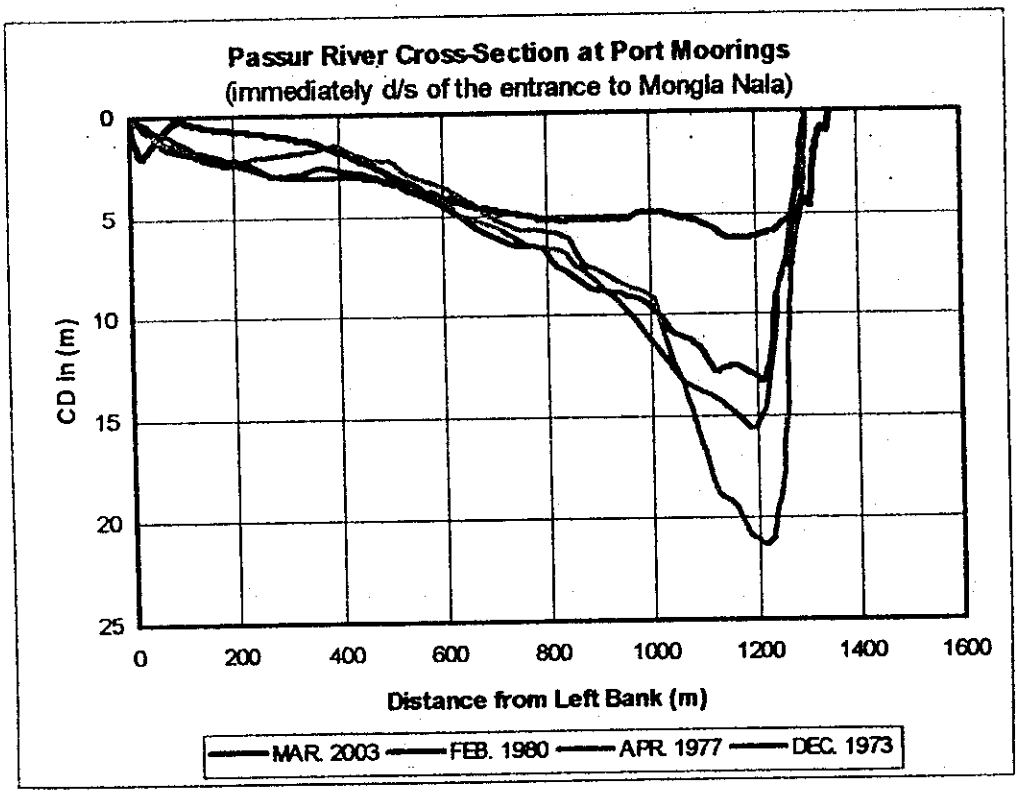


Figure 3.24: Historical Changes in the Conveyance of Passur River

Source: Historical Data of 1973, 1977 & 1980 from Passur River Study, 1981

Table 3.15: Changes of River Cross-sections

Name of River	Location		Survey Chainage (km)	Section Compared	Observation
	Easting (m)	Northing (m)			
Agargotta	442416	419351	12.71	1	No significant change
Arpangasia	426912	449297	8.50	1	Erosion at RB
Badamtola	474974	433170	15.53	1	Bed siltation
Bagidunia	420021	455097	0.00	1	Erosion
Bhola	479272	461070	39.31	1	Bed siltation
Bhola	481762	448991	53.02	1	Bed siltation
Chora Betmar	472126	426262	12.37	1	No significant change
Churkuni Gang	415613	458119	0.56	2	No significant change
	414371	449149	16.88		No significant change
Dhuji Khal	406619	454188	0.00	1	Erosion at RB
Dumkoli	417533	461988	10.21	2	Bed siltation
	416185	458548	16.03		Bed siltation
Esamati	418546	452203	8.35	1	Bed siltation
Firingi	414918	435151	1.67	1	Bed siltation
Harintana	470974	446884	0.52	2	No significant change
	470974	446884	0.00		Bed siltation
Jamuna	414053	434828	30.25	1	No significant change
Jhalokati	423149	413793	8.40	1	Erosion at RB
Kalaghachi	421284	449955	9.39	1	Erosion at RB
Kasitana	433116	456712	0.00	1	Bed siltation
Kesonkhali	423452	414633	11.45	1	No significant change
Mara Gang	406806	454311	18.30	1	Erosion at RB
Meghna Khal	427284	425466	11.11	1	Bed siltation
Mrigamari	469037	467114	11.92	2	Bed Siltation
	463218	472698	1.06		Significant siltation
Patakata Khal	469298	433532	0.81	1	Erosion at RB
PathuriaGang	469190	455661	0.45	3	No significant change
	472632	455532	6.46		No significant change
	479103	441077	24.38		No significant change
Patkusta	440810	435973	7.82	1	Bed siltation
Sakbaria	433059	461157	31.27	1	No significant change
Selagang	469905	466434	0.41	1	No change
	467553	438983	40.67	1	Prominent scour at RB
Sona Khal	440991	450585	0.00	1	Bed siltation
Sund-Jhajhap	433681	462005	8.18	1	Bed siltation
Supati Khal	482498	437780	1.31	2	Erosion at RB
	480559	424126	21.97		Erosion at RB

3.8 Land Topography

Topography of the forestland is required to assess the inundation pattern inside the Sundarbans. Till now it has not been possible to conduct a comprehensive survey inside the Sundarbans due to its inherent hostile conditions as well as limitation of present technology. A full-scale topographic survey was beyond the scope of the present study.

3.8.1 Topographic Map

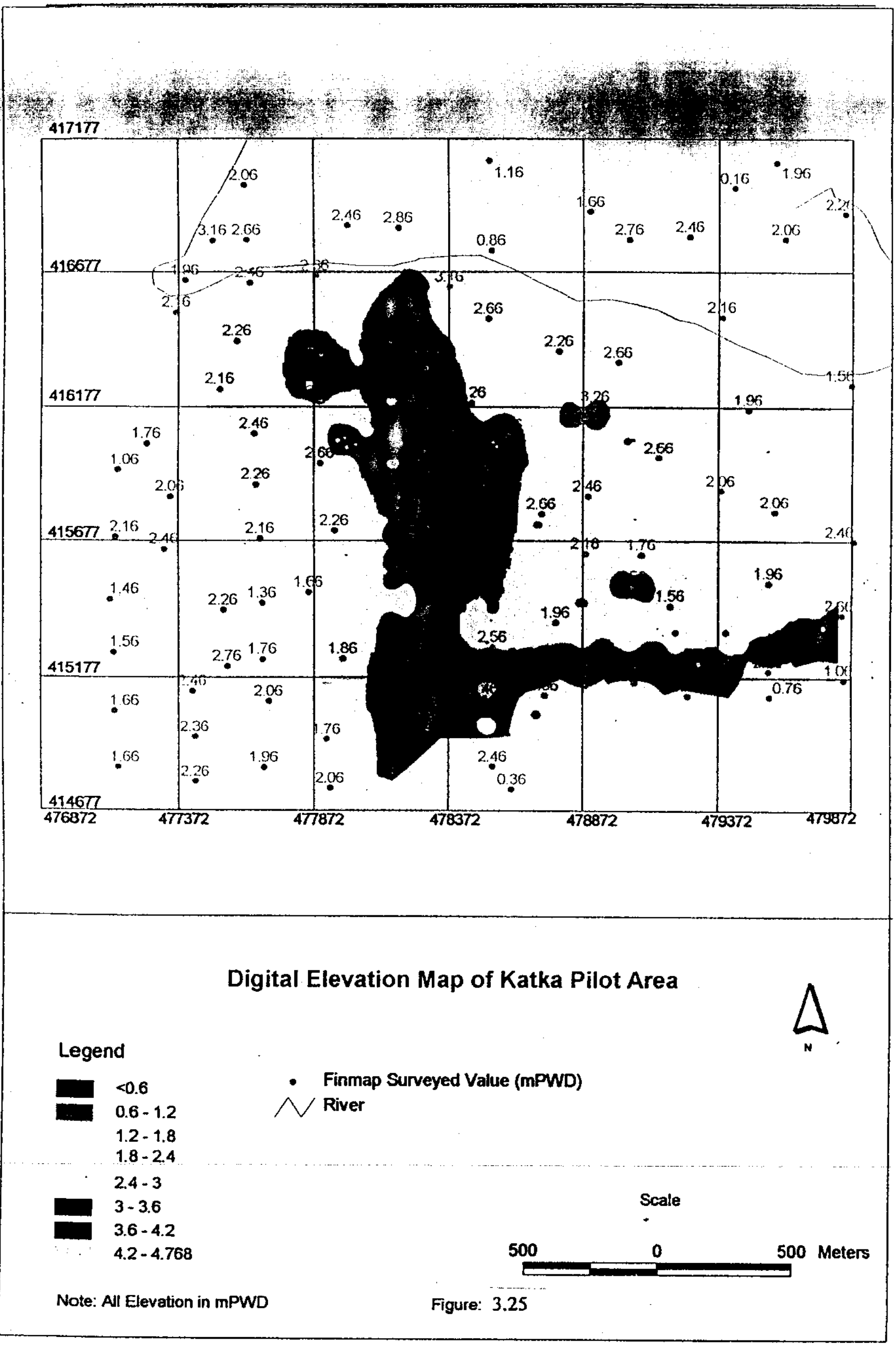
Finnmap has conducted only topographic survey so far from aerial topography. The limitation of the Finnmap Map as well as recommendation by P. Wynia, Geo-information Expert of the project (SBCP Technical Report No. 09) has been described as follows:

- The relative accuracy of the data is (x,y) 10's of centimetre and (z) 1m
- The absolute accuracy is ±2m (including the difference between datum and reality)
- For most of the SRF area accuracy is higher, the figures given are conservative estimates. The density of elevation data for SRF is relatively low on locations with dense forest. On these locations it was not possible to measure the surface level by photogrammetric method. In general, the horizontal detail (distance between measurement) is approximately 200 to 300 meters.
- It is doubtful whether a new survey would yield more accurate result than the available elevation points on the 1:10,000 maps of 1998 (Finnmap Map)

IWM has procured the Topographic Map from Finnmap and used for producing inundation maps, load assessment for non-point pollution sources etc. IWM also carried out topographic survey in the selected areas as mentioned in Chapter 2. The Finnmap levels have been superimposed on the Digital Elevation Model of IWM survey (Figure 3.25 to Figure. 3.28). It has been observed that the land level at Jongra, Katka and Patkusta are much closer with IWM survey than mentioned by Finnmap while that in the Koikhali (high density of vegetation) differs significantly with IWM.

3.8.2 Topography of the Forestland

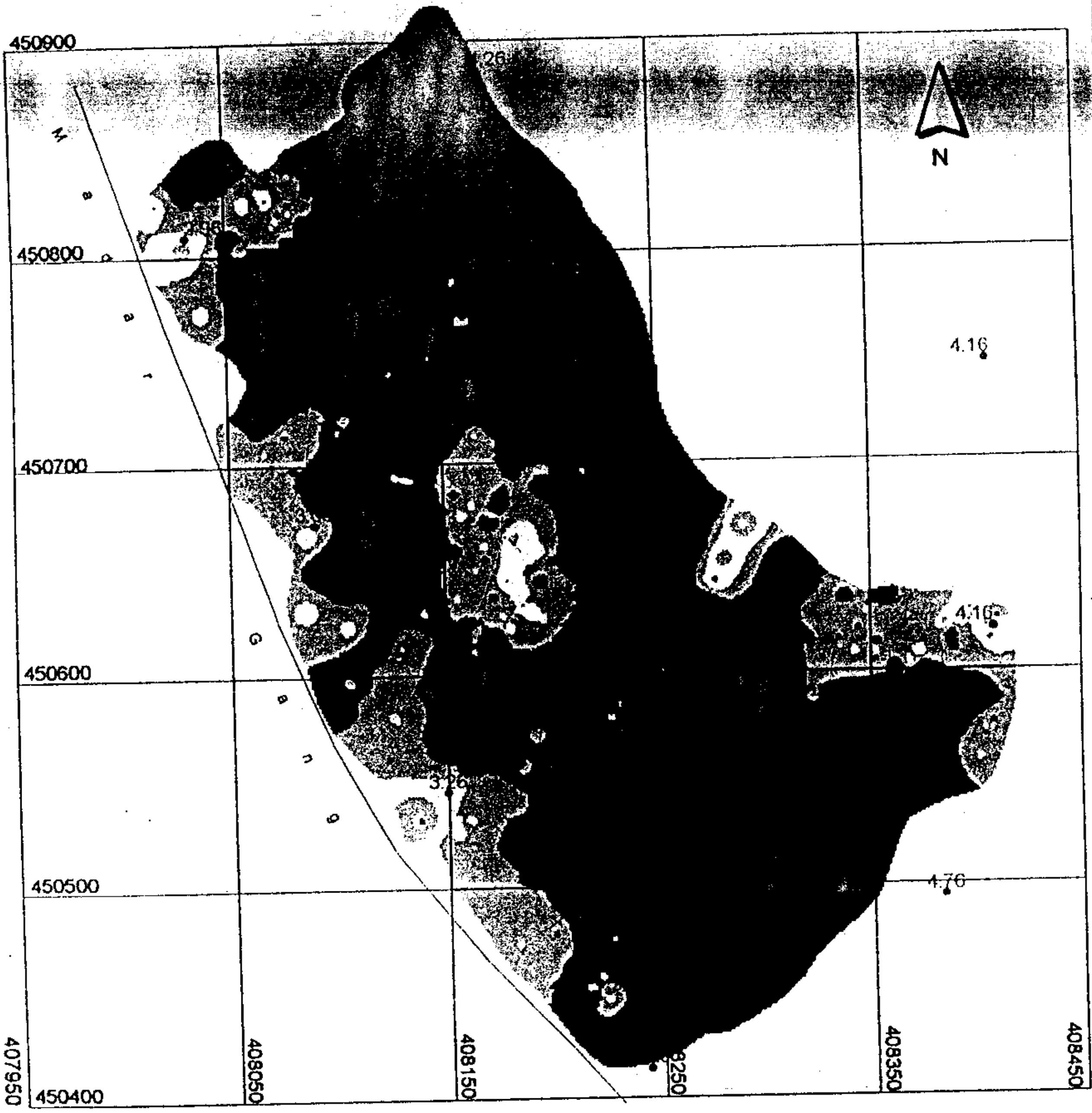
The Digital Elevation Map (DEM) prepared from the Finnmap Data has been shown in Figure 3.29. It has been observed that average land levels at Jongra, Patkusta and Koikhali are 2.0m, 2.5m and 3.0m respectively from the IWM survey. However, from the measured land level as well as the DEM (accepting its limitation), it is seen that topography at the northwestern Sundarbans is relatively higher than other parts of the Sundarbans. This has good correlation with historical high tidal range & higher salinity at the area mentioned in the previous sections The land level at the southern parts is relativcly low with some exceptions.



Digital Elevation Map of Katka Pilot Area

Note: All Elevation in mPWD

Figure: 3.25



Digital Elevation Map of Koikhali Pilot Area

Legend

- 0.6 - 1.2
- 1.2 - 1.6
- 1.6 - 2
- 2 - 2.4
- 2.4 - 2.8
- 2.8 - 3.2
- 3.2 - 3.461

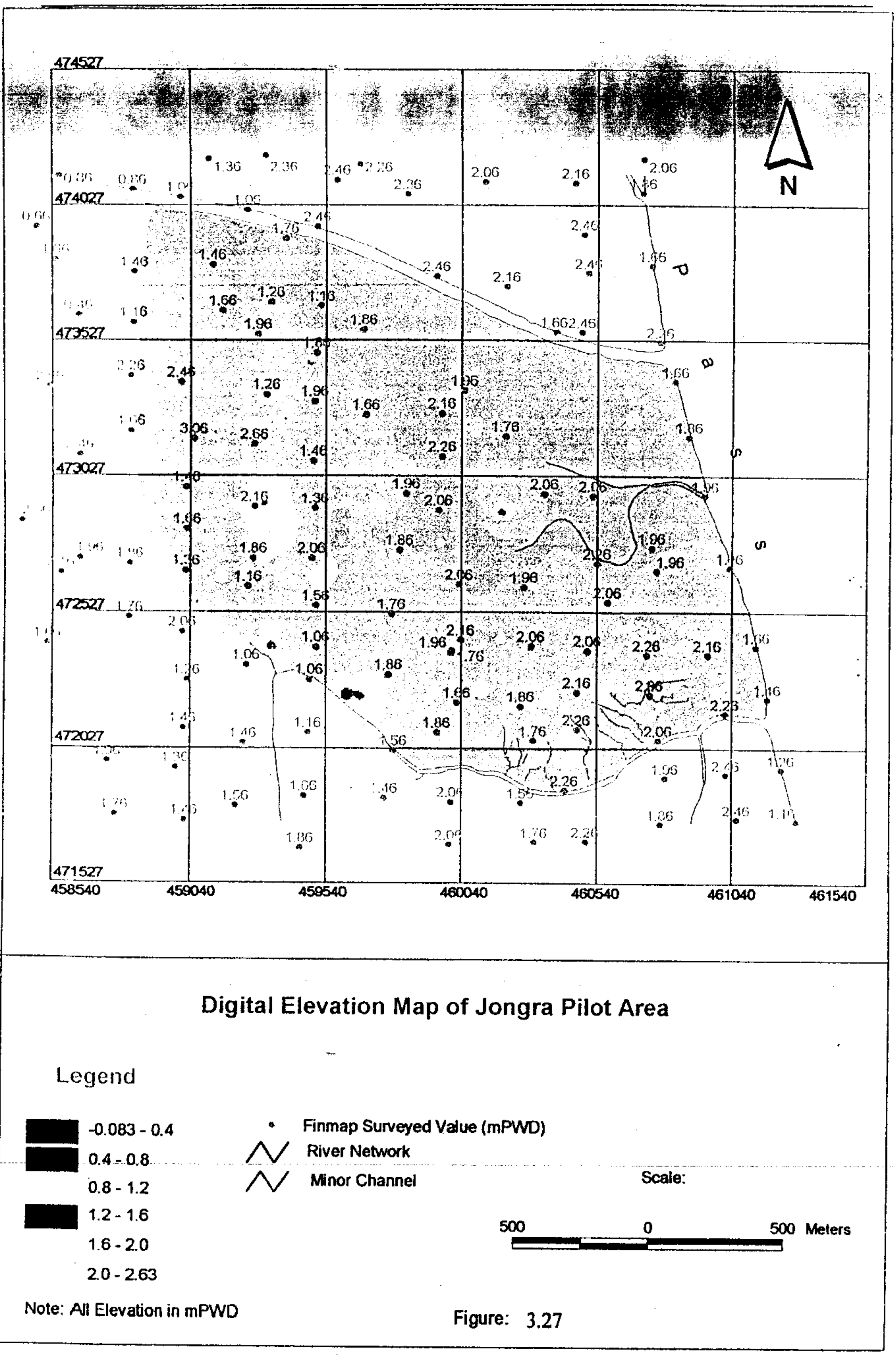
- Finmap Surved Value (mPWD)
- River Network
- Minor Channel

Scale:

50 0 50 Meters

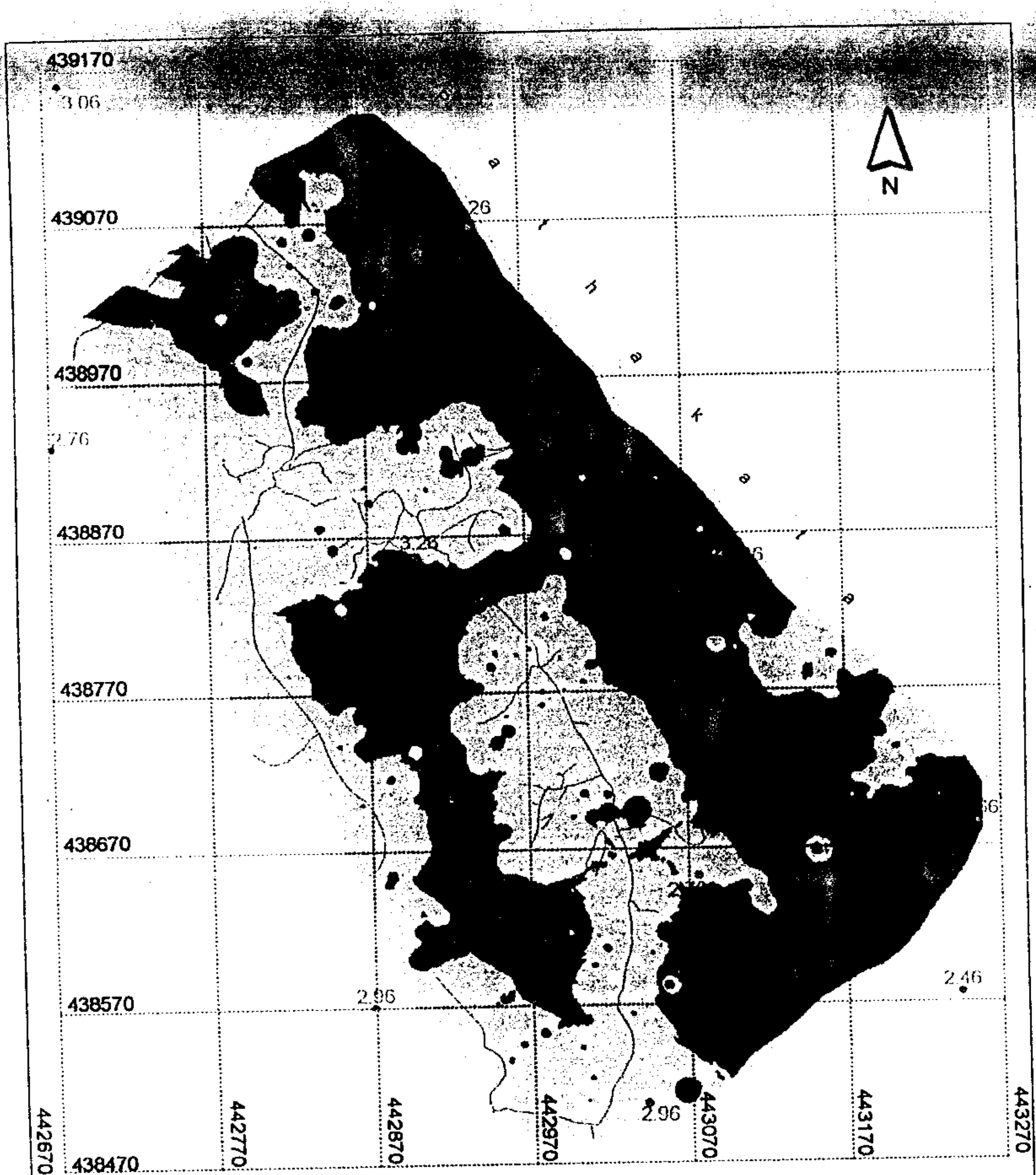
Note: All Elevation in mPWD

Figure: 3.26



Digital Elevation Map of Jongra Pilot Area

Figure: 3.27



Digital Elevation Map Patkusta Pilot Area

Legend:

0.6- 1.2	Finmap Surved Value (mPWD)
1.2 - 1.8	River
1.8 - 2.4	Minor channel
2.4 - 3	
3 - 3.6	
3.6 - 4.2	

Scale: 50 0 50 100 Meters

Note: All Elevation in mPWD

Figure: 3.28

Digital Elevation Model (DEM) of Sundarban Forest Area

Figure no. 3.29

3.8.3 *Sedimentation Process*

Sedimentation on the forestland is a slow process. It depends on the sediment concentration, inundation depth and duration, salinity concentration, vegetation pattern etc. Generally the forestland remains dry during the dry seasons except at the time of peak spring tides when maximum inundation occurs during monsoon seasons while low concentration with lower inundation occurs during the winter seasons. As a result the monsoon inundation has got the maximum potential for flood plain sedimentation. As a natural process the land level near the rivers is always high that creates a natural levee. The interior part of the forest land is saucer shaped.. Water with suspended sediment enters inside the forest initially through the minor khals and creeks and spreads gradually in the saucer area. As the water flows deeper into the forest the velocity of flow decreases and most of the sediments are deposited near the boundary. The sediments are also trapped on the vegetations, dead leave and local depressions. In connection with three pilot areas sedimentation studies have been conducted by tidal micro current measurement, sediment concentration analysis and sediment depth measurements. The details of the study have been presented in Section 3.5. Summary findings of the forestland sedimentation with reference to the pilot area study are given below.

Figure 3.30: Tidal current inside the forestland

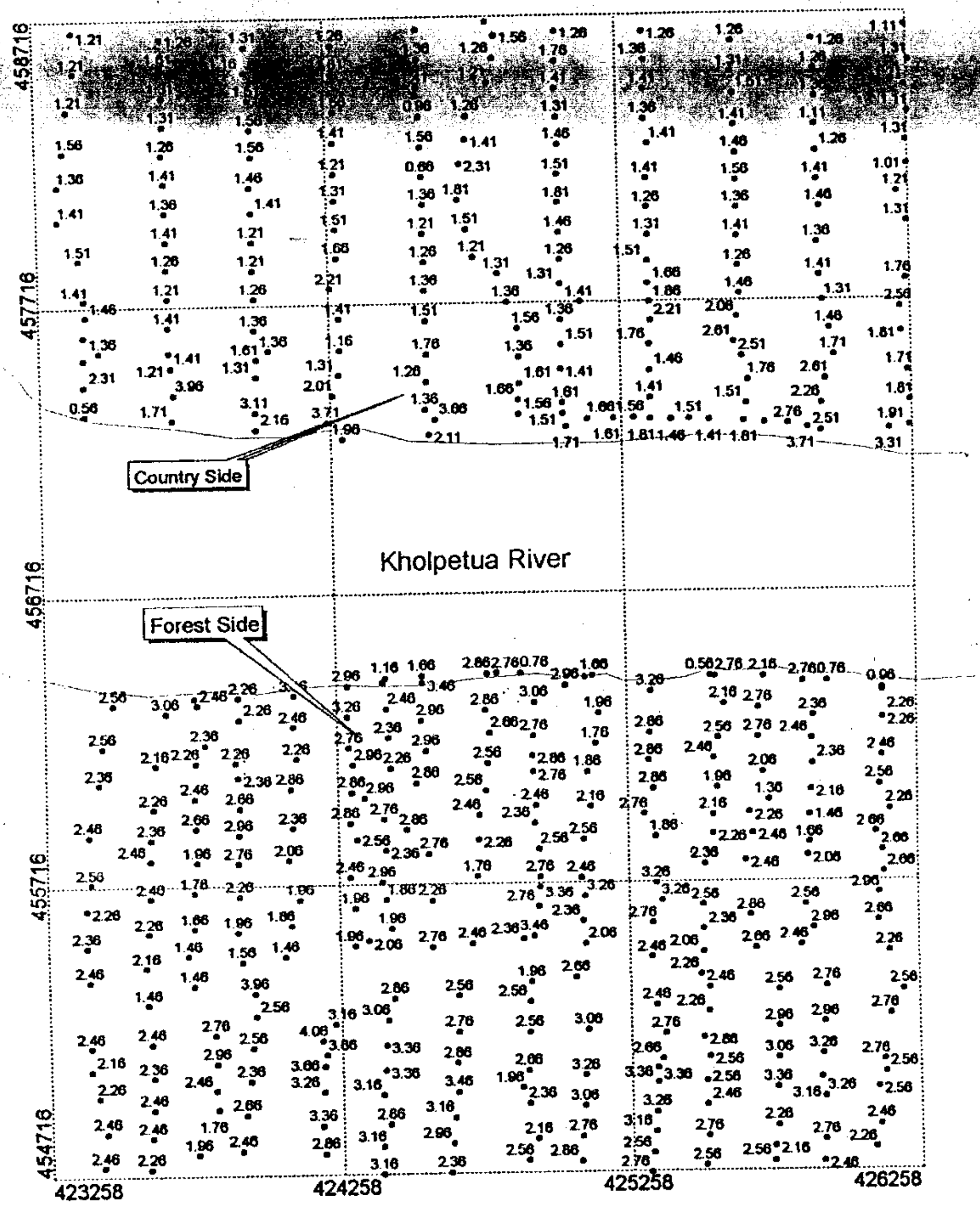
- Maximum duration of flooding on the forestland is about four hours during monsoon spring tide while little or no inundation occurs during January to March;
- The flow velocity in the creeks of forestland varies from 10cm/sec to 20cm/sec, indicating very low sediment carrying capacity;
- Sediment concentration in the eastern part (Jongra) is higher than the western and central part (Koikhali and Patkosta).
- In the eastern part the sediment concentration during flood tide is significantly higher than that of the ebb tide while the situation is reversed during the post monsoon period, indicating siltation during the monsoon and erosion during post monsoon. However, it is difficult to establish any net sedimentation rate from the data of this short duration.
- The deposition on the forestland may also take place due to the degradation of dead foliage and organic matters while high intensity rainfall is likely to wash out some of the topsoil during rainy seasons.

3.8.4 Comparison of Topographic Changes

With the introduction agricultural activities and construction of polders, development of land level was historically slower. Due to blocking of tidal penetration to improve salinity and drainage congestion, level in the countryside area is not developing especially at places relatively far from the main rivers. In absence of historical data, no direct comparison is possible to assess the rate of changes inside the forestland other than the method introduced in the study. However, an indirect approach of making qualitative assessment has been made comparing the land levels inside the polders and the adjacent forest. Map showing land level inside the polder and land level inside the forest is presented in Figure 3.31-Figure 3.32. It is observed that land level of most of the areas adjacent to polders has developed by 1.0m in comparison to the average land levels in the polder areas.

3.8.5 Findings

Sedimentation in the forestland is extremely slow process. However, it appears that changes on the forestland in the eastern part is more prominent than that of the western and central part due to higher sediment concentration of the Pussur River. The early monsoon flow has got more potentiality for sedimentation.



Comparative Picture of Topograpic Change in the Country Side and Forest Side

Legend

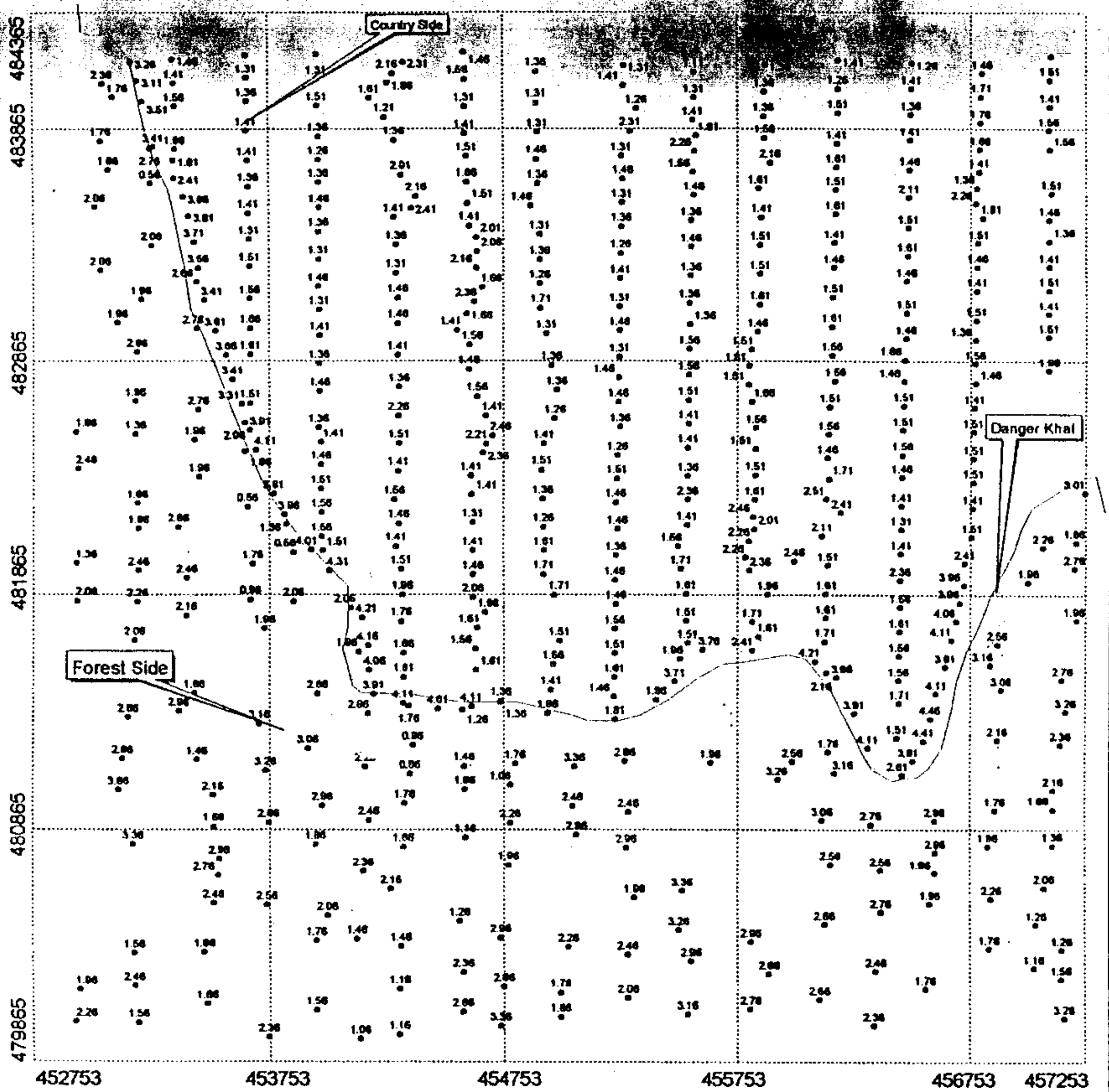
- Finmap Surved Value in mPWD
- River Network

N

Scale:

500 0 500 Meters

Figure: 3.31



Comparative Picture of Topograpic Change in the Country Side and Forest Side

Legend

● Finmap Surved Value in mPWD

River Network

Scale:

500 0 500 Meters

N

Figure: 3.32

4. HYDRODYNAMIC MODEL

4.1 Introduction

The models are mathematical representation of physical processes. The study of a large and complex tidal system, as occurs in the Sundarban, can only be realistically carried out with the aid of mathematical models. MIKE 11, a one dimensional (1D) modeling system developed by the DHI, Denmark, is used by IWM. The modeling system incorporates hydrological, hydrodynamic, advection-dispersion and sediment transport components in a single integrated package. The rainfall-runoff model (NAM) is used to estimate the runoff generated from rainfall occurring in the catchments.

The South West Region Model (SWRM), developed at IWM has been adopted for surface water modeling of the Sundarban (Figure 4.1). A smaller model with denser network could be more reasonable but due to limitation of boundary data it has not been possible.

The hydrodynamic model has been calibrated with available hydrological data for two consecutive hydrological years namely 2000-01 and 2001-02. In this report the latest development of the model for 2001-02 hydrological years has been described. The whole regional model has been calibrated with more emphasis was given to Sundarban part.

4.2 Methodology

It is already mentioned that MIKE 11 mathematical modelling technique of DHI has been used in this study. The MIKE 11 software is based on an implicit finite difference scheme solution of the Saint Vanant equations (MIKE 11 User Guide, 1988; Saint-Venant, B. De, 1949; Abbott, M. B. and Ionescu, F, 1967). For hydrodynamic model the following equations are used:

$$b\frac{dh}{dt}+\frac{dQ}{dx}=q$$

$$\frac{dQ}{dt}+\frac{d}{dx}(\beta\frac{Q^2}{A})+gA\frac{dh}{dx}+\frac{gn^2\,|Q^2\,|}{AR^{\frac{3}{4}}}=0$$

Where	A:	flow area
	b:	width of the channel
	h:	stage
	Q:	discharge
	R:	hydraulic radius
	n:	roughness coefficient
	β:	momentum distribution coefficient
	q:	lateral inflow rate per unit length

4.3 Existing Hydrodynamic Model

The South West Region Model (SWRM) was developed by IWM in 1993 and subsequently validated almost every year. The model covers an area of approximately 37330 km^2 of which the Sundarban forest covers an area of some 5770 km^2 (Figure 4.1). The southwest region is bounded by the Padma and Meghna River on the North and Northeast, Lower Meghna and Shahabazpur Channel on the East, Indian border on the West, and the Bay of Bengal on the South. The hydrodynamic model covers the main rivers of the Southwest Region. The setup of the hydrodynamic model has been presented in **Annexure E** (Table E.1).

The rivers of the southwest area of Bangladesh are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal. The southern rivers mainly comprise tidal estuary systems, the largest being the Jamuna, Malancha, Pussur-Sibsa, Baleswar, Lohalia and Tentulia. There are huge numbers of small tidal channels, which interconnect these large rivers. The tidal channel network is particularly complex in the Sundarban Mangrove Forest in the far southwest corner of the region. In the northern part of the model, the main non-tidal river systems comprise of the Gorai, Arial Khan, Jayanti and Upper Meghna.

The source of fresh water flow coming to the Sundarban is Ganges River through the Gorai river. About 200 km downstream of the Gorai offtake the discharge of the Gorai river divides into two channels, one down the Nabaganga and other down the Madhumati to join the Kocha-Baleswar river. The flow, which passes down the Nabaganga, is conveyed down to the Sundarban via Atai and Rupsa rivers. Chitra and Bhairab rivers join the Nabaganga-Rupsa system and contributing to the flow from their own drainage catchments. The Kobadak, situated in the western part of the southwest region, is also a contributor of some fresh water flow of the western part of the Sundarban. In the past fresh water flow to the Kobadak came from Matabhanga River but now a days the connection was cut-off due to human interventions. Presently flow in the upper part of this river is discontinued due to construction of earthen bunds at different places of this river, especially during dry period. The present reduced fresh water flows come only from the local catchment areas of this river.

There are total 34 boundaries in the hydrodynamic model, of which 23 are upstream inflow boundaries, and 11 are tidal water level boundaries. During 2001-02 hydrological year, measurements of some of the upstream discharges were carried out under "Updating & Validation of General Model & Six Regional Models" project. With theses measured data the upstream boundaries have been updated. Some minor rivers of the SWRM, mainly in the upstream part and some link channels have been discarded to avoid possible numerical instability in the salinity model.

4.4 Updating of the Hydrodynamic Model

The rainfall-runoff model or NAM computes runoff discharge, generated from rainfall, which is used as lateral inflow to the hydrodynamic module. Rainfall, evaporation and groundwater/surface water abstraction data are used as input to the NAM module, and runoff is calibrated against measured discharges at gauging locations. In absence of observed discharges, ground water level is used to calibrate the model indirectly. The

Surface Water Modelling for the Sundarban

South West Region Model
River Network

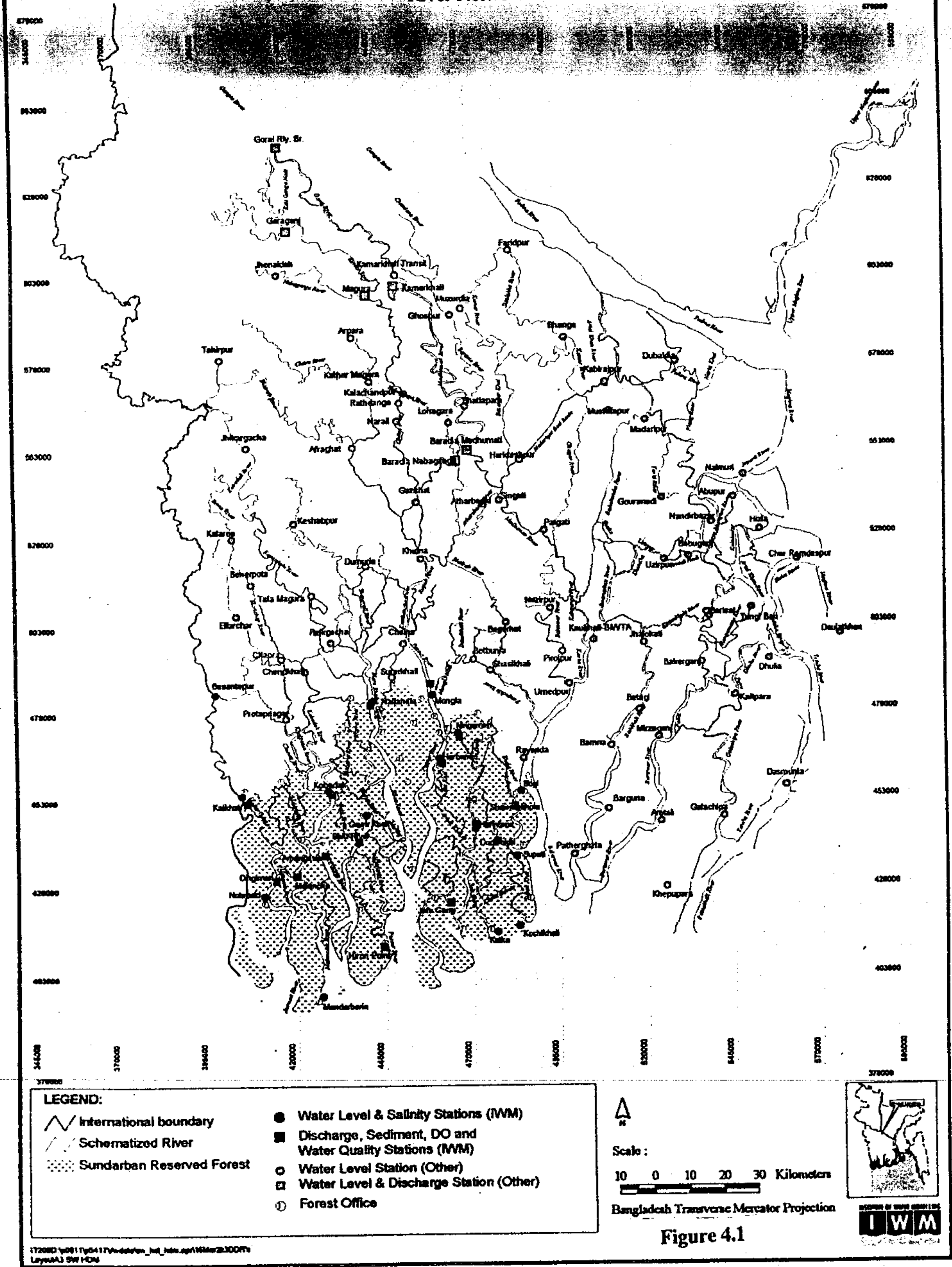


Figure 4.1

NAM of the southwest region has been calibrated for 2000-01 and 01-02 hydrological years using the hydro-metrological data of those years of different stations collected from BWDB. The region has been divided into 44 sub-catchments based on the natural drainage pattern (Figure 4.2). The entire Sundarban forest area lies in catchment 27. The connections of different catchments to the rivers have been presented in **Annexure E** (Table E.2)

The Sundarban HD model was updated for the hydrological conditions of 2001-02 under the present study. The latest cross-sections of the rivers were incorporated into the model during updating. Continuous water levels were recorded at some downstream locations; few of which were related to PWD datum. Others were collected with referenced to arbitrary datum later those were connected to fixed datum with the help of model result. In addition to that, under the "Updating & Validation of General Model & Six Regional Models" project, discharges were measured at some upstream locations of southeast model where constant discharge or water level time series had been used in previous model calibration. Moreover, inclusion of Bogi-link (connection between Baleswar and Bhola river), cut-off of the Sela-gang (Sela-cut), latest topography of the Bhola river (Kharma khal) have improved the calibration of the hydrodynamic model of the Sundarban. The major activities to update the Sundarban model are described in the following articles.

4.4.1 River Cross-Section Updating

One of the major works carried out during the data collection campaign in the Sundarban was river cross-section survey. A total of around 200 cross-sections were measured during 2000-01 and 2001-02 period. During the campaign cross-sections of small rivers as well as big rivers like Pussur, Sibsa were collected. The latest information of the Kharma khal (upper part of Bhola River) was also very important to study the sedimentation process of the Kharma khal. Moreover, cross-sections collected under other projects of IWM have also been incorporated into the model set-up. A complete list of cross-sections surveyed and used in the model has been presented in the following in **Annexure E** (Table E.3). The cross-sections Topo ID of all the rivers used in the model are listed in Sundarban Model Setup **Annexure E** (Table E.1).

4.4.2 Boundary of the HD model

There are total 34 boundaries in the HD model of the Sundarban, among which 23 are upstream boundaries and rest 11 are downstream boundaries. A complete list of the hydrodynamic model boundary is given in Table 4.1.

To simulate the Sundarban HD model different types of hydro-meteorological data are required. In addition to the data collected under the Sundarban project, large quantities of data have been collected from secondary sources like BWDB and BIWTA. Rainfall, evaporation, ground water abstraction, water level and discharge data of several stations have been collected from BWDB. The tidal water level data were collected from BIWTA. All collected data were checked to detect punching and bench mark errors. Both visual observations and comparison of hydrographs were done at this stage.

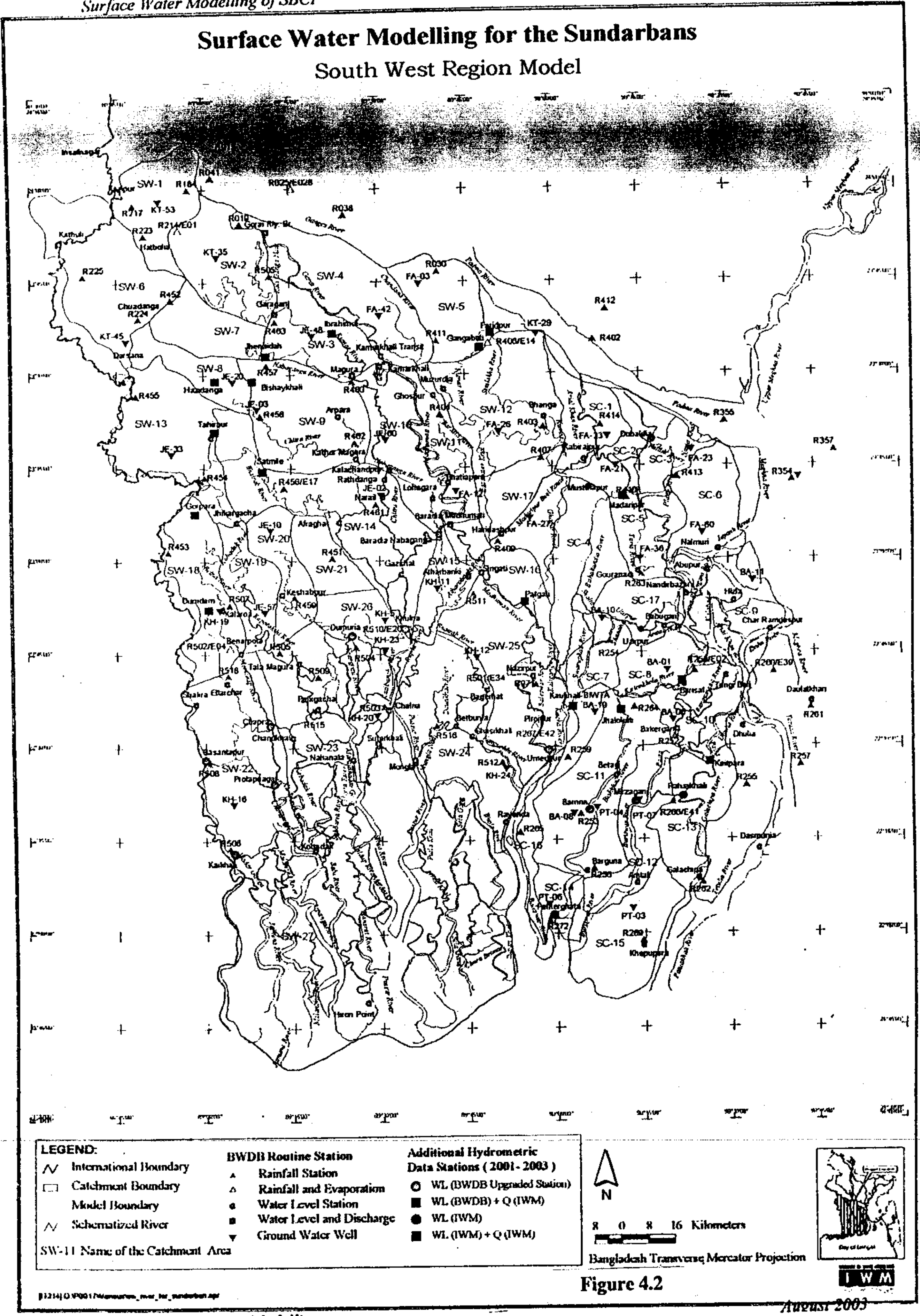

Surface Water Modelling for the Sundarbans
South West Region Model
LEGEND:
International Boundary
Catchment Boundary
Model Boundary
Schematized River
SW-11 Name of the Catchment Area
BWDB Routine Station
Rainfall Station
Rainfall and Evaporation
Water Level Station
Water Level and Discharge
Ground Water Well
Additional Hydrometric Data Stations (2001-2003)
WL (BWDB Upgraded Station)
WL (BWDB) + Q (IWM)
WL (IWM)
WL (IWM) + Q (IWM)
N
8 0 8 16 Kilometers
Bangladesh Transverse Mercator Projection
IWM

Figure 4.2

Table: 4.1 Boundaries of South West Region Model used for Sundarban 2001-02 Hydrological year

Sl No.	River	Chainage	Type	Station	Remarks
1	Begabati	48.00	Qt		Bishaykhali
2	Betna	70.00	Qt		Gorpara
3	Bhairab U	0.00	Qt		Satmail
4	Buribhadra	0.00	Qc		Closed boundary
5	Chitra	50.00	Qt		Hazidanga
6	Chitra	120.00	Qc		Closed boundary
7	Gorai	11.90	Q_t	Gorai R B	Open boundary
8	Bhadra	1.00	Qc		Closed boundary
9	Harihar	0.00	Qc		Closed boundary
10	Haringhata	17.00	H_t	Hiron Point	-30 min. Phase corr 1.2 times amplitude and -0.3 m datum
11	Hatia	0.00	Qc		Closed boundary
12	Kanksiali	17.00	H_t	Basantapur	Open boundary
13	Kobadak	0.00	Qt	Taherpur	Closed boundary
14	Kobadak	180.00	Qc		Closed boundary
15	Kumar	9.00	Q_t	Kumar- rated Q	Open boundary
16	Labangabati	0.00	Qt		Dumdom
17	Malancha	55.70	H_t	Hiron Point	-45 min. Phase corr. 1.1 times amplitude and 0.15 m datum
18	Hari-River	0.00	Qc		Closed boundary
19	Atharobanki	32.00	Qc		Closed boundary
20	Old Pussur	0.00	Qc		Closed boundary
21	Pussur	98.21	H_t	Hiron Point	Open boundary
22	Sitalakhya	0.00	H_t	Faridpur	Open boundary
23	U-Solmari	0.00	Qc		Closed boundary
24	Daudkhali	0.00	Qc		Closed boundary
25	Padma	12.00	Q_t	Baruria	Open boundary
26	Upper Meghna	0.00	H_t	Bhairab Bazar	Open boundary
27	Shahbazpur	21.00	H_t	Charchenga	Result of 2D Model
28	Tentulia	90.00	H_t	Khepupara	Result of 2D Model
29	Jamuna (Entrance)	61.74	H_t	Hiron Point	-30 min. Phase corr. 1.15 times amplitude and -0.2m datum
30	Pussur Khal	30.83	H_t	Hiron Point	No Phase corr.
31	Sela Gang	73.29	H_t	Hiron Point	-10 min. Phase corr.
32	Betmar Gang	36.89	H_t	Hiron Point	-30 min. Phase corr. 1.2 times amplitude and -0.3 m datum
33	Supoti Khal	28.63	H_t	Hiron Point	-30 min. Phase corr. 1.2 times amplitude and -0.3 m datum
34	Jamuna	0.00	H_t	Kaikhali	Open boundary

N.B H_t - Water Level time series, Q_t - Discharge time series, Qc - Constant discharge time series

The tidal water level data from BIWTA auto gauge stations correspond to Chart Datum, these data have been adjusted to PWD datum by Moving Average Method. In moving average analysis, Hiron Point and Khepupara stations have been compared with Patharghata station. The Patharghata station of BWDB is the only nearby station of the aforementioned two stations, which corresponds to PWD datum. Another BIWTA station, Char Ramdaspur, has been compared with nearby Daulatkhan station (PWD referenced). A sample plot of moving average analysis is shown in Figure. 4.3.

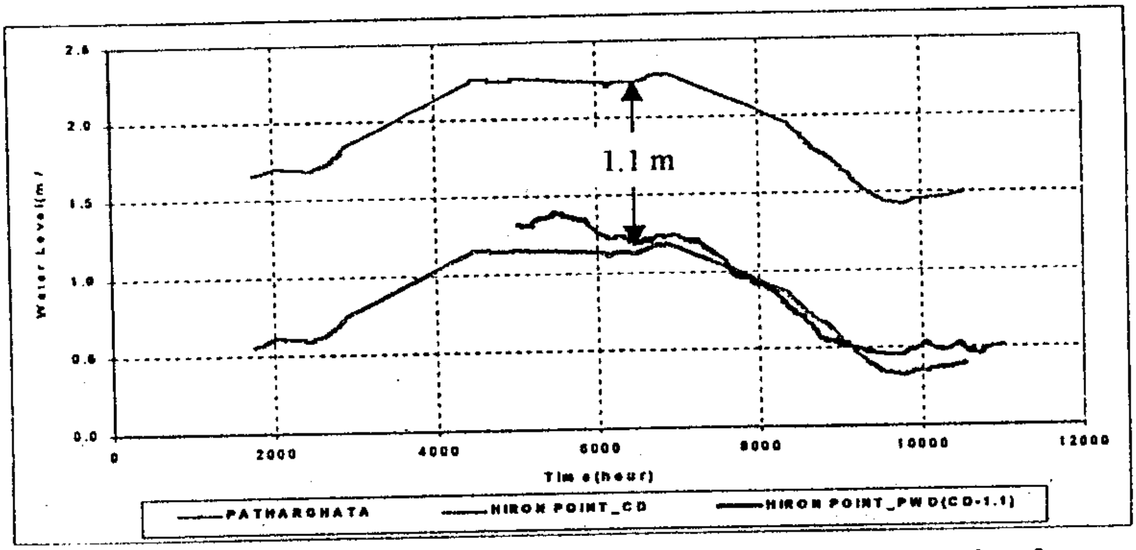


Figure. 4.3: Moving average (56 cycle) lines of Hiron point and Patharghata stations for calculation of Hiron point PWD datum

In most part of the Sundarban there is no established Benchmark, however some stations in the eastern part have been connected to the fixed PWD datum (Katka, Supoti, Harintana etc). But in other areas gauges installed by IWM could not be connected with fixed datum. These stations were related to PWD using model results. Moving average technique have been applied for both simulated and observed water level, and comparing moving average line necessary corrections factors for different stations were determined. However, since there are some uncertainties in the model result, the adjustment may not be accurate to that extent for all the stations.

Hiron Point is the only available half-hourly water level station of BIWTA at the downstream of the Sundarban. In the past, water level data at other locations were generated using Hiron Point data with proper phase and amplitude correction. During 2001-02 hydrological years CTP data of some duration were collected at Mandarbaria under the present project. The data were collected in reference to arbitrary datum; later a correction factor was applied to relate it to PWD datum. At other locations like Jamuna entrance, Sela Gang and Haringhata water level data were generated using Hiron Point data with proper phase and amplitude correction. Previous correction factors were used with some modification.

The downstream boundaries of Shahbazpur channel and Tentulia River are Daulatkhan and Khepupara respectively, but continuous data for these stations are not available from existing sources. To overcome the situation two-dimensional Bay of Bengal (BoB) model (available with IWM) was used to generate the water level time-series at the two boundary locations. Figure 4.4 illustrates that the simulated data have matched reasonably well with observed ones.

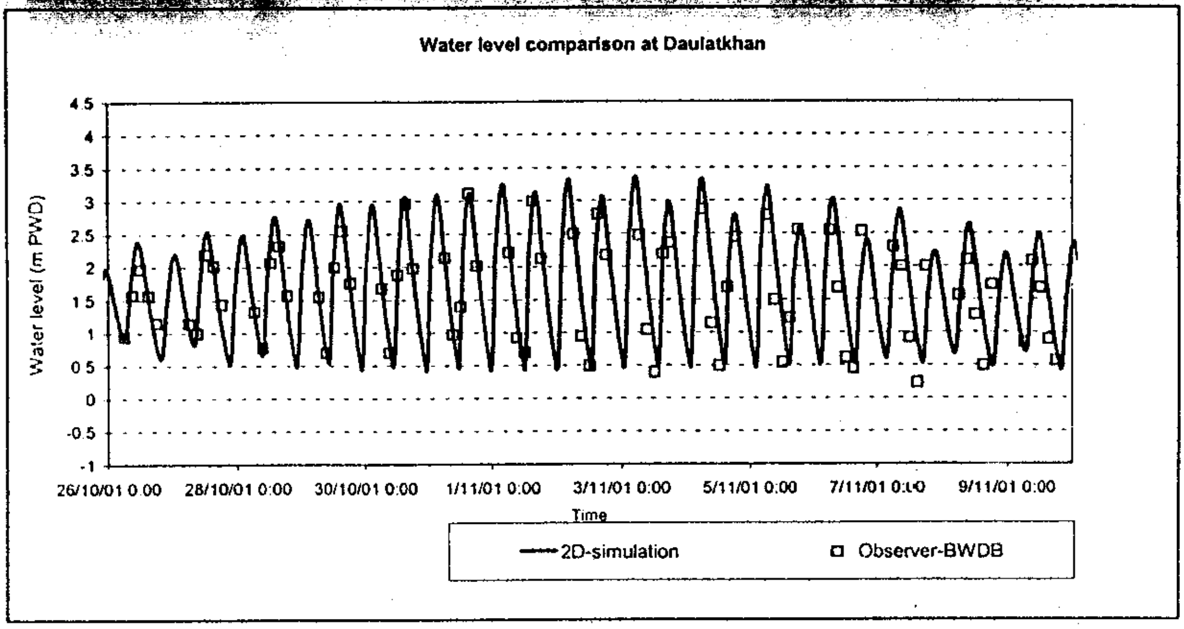


Figure 4.4: Water level comparison between the BWDB observed data and 2D simulated result at Daulatkhan

At the upstream boundaries of two major rivers of the model; rating curves have been used to generate discharge time-series. The rating curves of Gorai and Padma rivers have been upgraded with data of 2001-02 hydrological years. For another major river, the Upper Meghna, water level time series has been used as boundary instead of discharge time series as available data of this station was insufficient for the generation of a satisfactory rating curve. Moreover, the recently collected discharge data of Taherpur, Faridpur and Ibrahimdi were used to generate rating curves at Kobadak, Sitalakhya and Kumar rivers respectively. The rating curves of the major rivers used in the model have been presented in Figures 4.5 and 4.6.

River: Gorai

Station: Gorai Railway Bridge

$$Q = 17.37\,(H-2.93)^{2.33} \quad H<11.0$$
$$ 9.28\,(H-3.68)^{2.80} \quad H>11.0$$

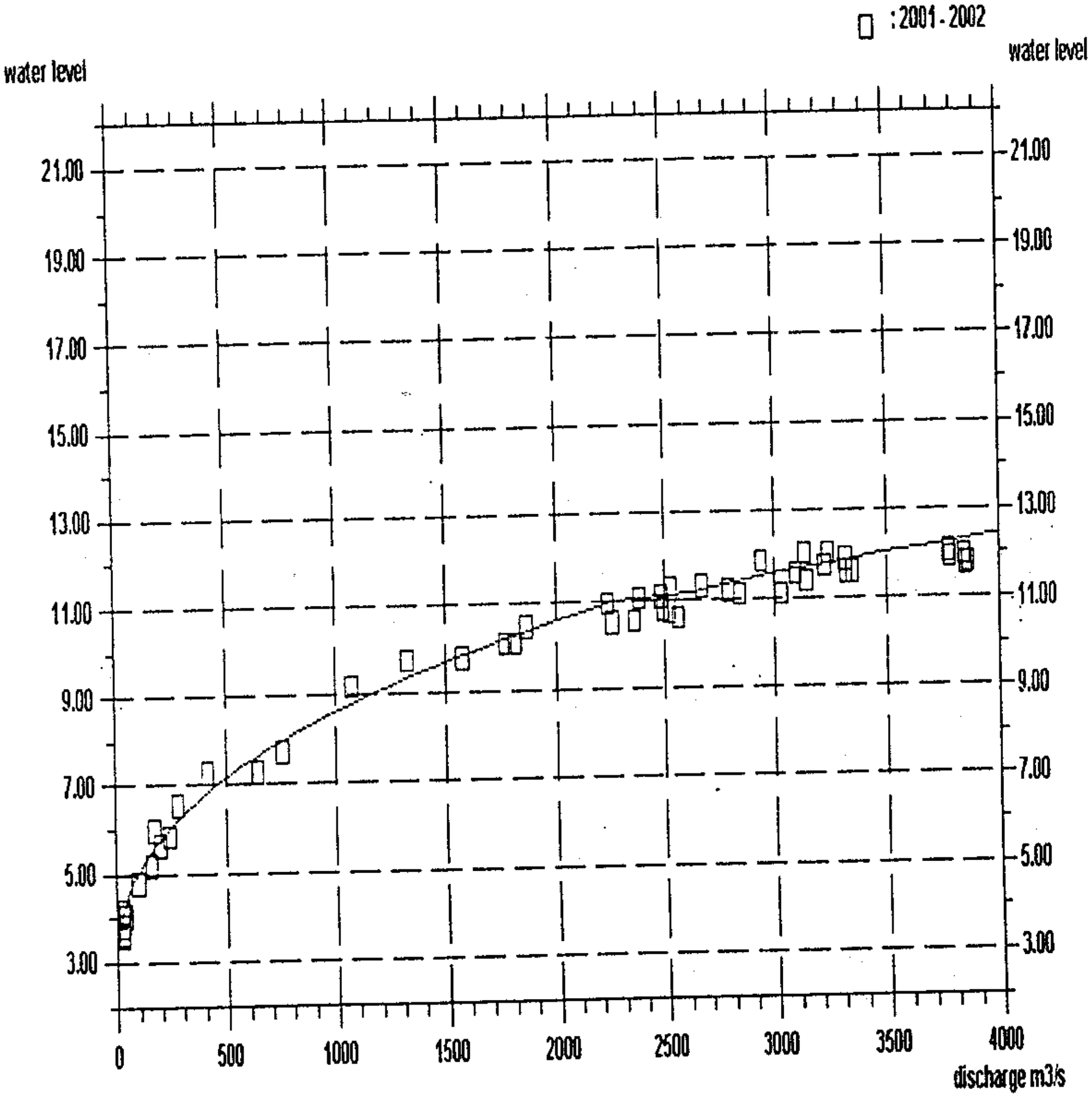


Figure 4.5 : Rating Curve of Gorai Railway Bridge

River: Padma
Station: Baruria

Q= 12.4115 $(H+2.50)^{2.56}$	**H<=5.62**
134.28 $(H+0.25)^{2.99}$	**5.62<H<=7.17**
497.06 $(H-2.00)^{2.87}$	**H>7.17**

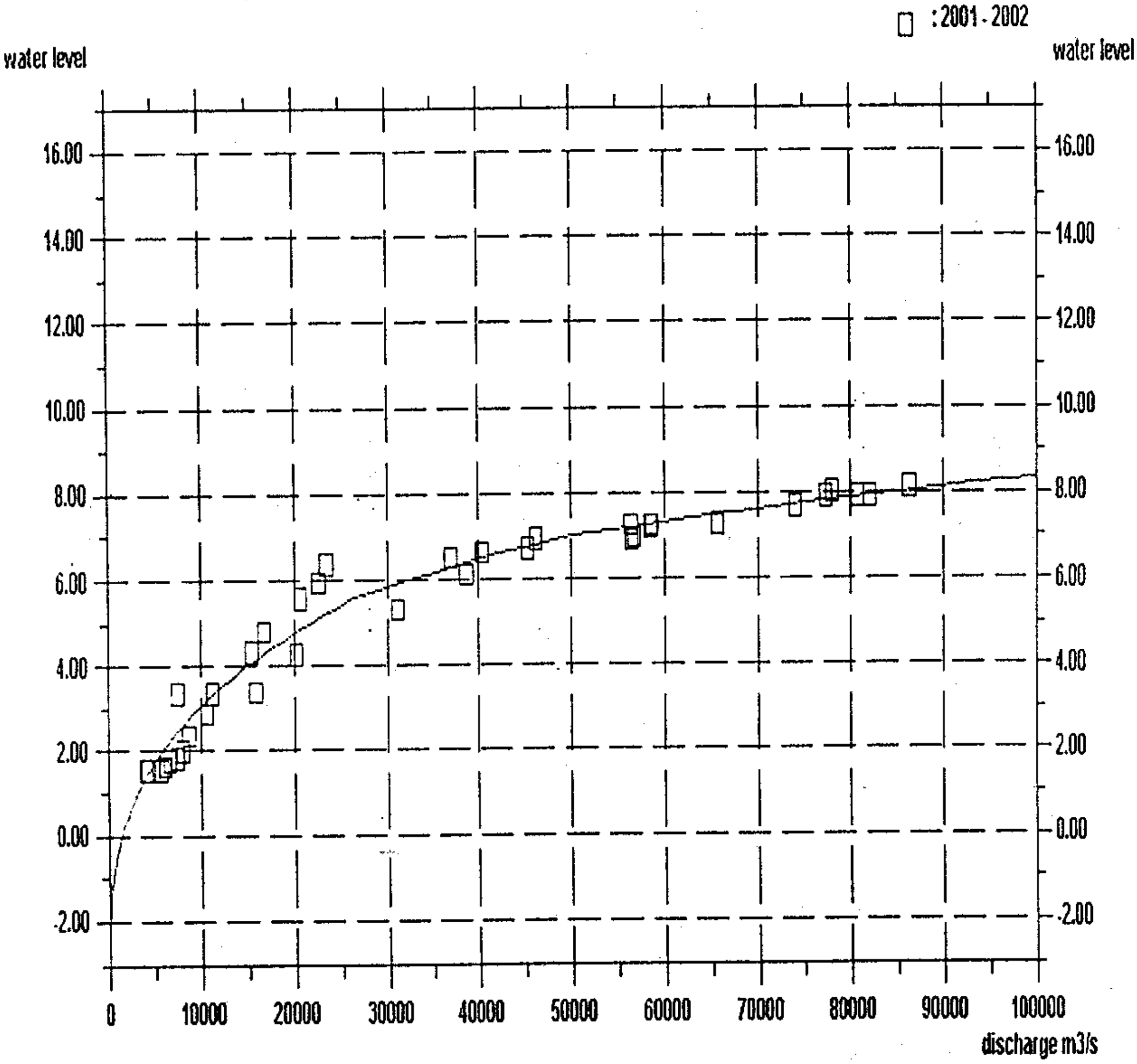


Figure. 4.6 : Rating Curve of Baruria

4.4.3 Initial conditions and calibration parameters

In a tidal model, effect of the initial conditions specified at the start of a model simulation disappears after one or two tidal cycle computation. Therefore, the initial conditions throughout the model were specified as zero discharge, and a constant water level of 1.0 m PWD. The exceptions were in some rivers like Padma, where initial discharges and water levels, commensurate with the actual measured conditions, were specified. A complete list of initial condition used to simulate the model has been presented in **Annexure E** (Table- E.4).

The HD model of the Sundarban was subjected to rigorous calibration prior to the present study. The main calibration parameter of the HD model is Manning number (M), which has been adjusted during the calibrations. The inverse of M is the more conventional Manning's n. The factor depends on flow condition, channel geometry, soil type etc. A complete list of Manning's M used for different rivers have been presented in **Annexure E** (Table E.5)

4.5 Hydrodynamic model calibrations

Under the present study the simulation of the Sundarban HD model has been carried out for two consecutive years: 2000-01 and 2001-02. The status of the 2000-01 hydrological year simulation has been described in the Half-yearly report. The latest simulation for 2001-02 hydrological year is described in this report. Under the present project water level and discharge data were collected at a number of locations inside the Sundarban area; the model has been calibrated by comparing the simulated results with the observed data of these locations. The results of different stations are shown for two durations of fifteen days each, one for typical dry period and another for typical monsoon. Assessments of the simulated results for 2001-02 hydrological years have been discussed below, comparisons between observed and simulated data are presented in ANNEXTURE E.

__Jamuna River:__ Water level of this river has been compared with observed data at Kaikhali and Notabaki (Drawing E.1 & E.2). The upstream boundary of the river is at Kaikhali, where observed water level have been used as boundary. There is no observed data at the downstream location of this river, so synthesized water level prepared from Hiron Point data, with phase and amplitude correction. The water level at Notabaki satisfactorily matched with the observed water level though there are some variations during ebbing. The simulated discharge has been compared at Madargang (near Kaikhali) and Jafa Gang (Drawing E.15). At Madargang the discharge simulation is not satisfactory, but at Jafa Gang the simulated discharge matched satisfactorily with observed data. From the comparisons plots it can be concluded that there are some problem in generating hydraulic condition in this river system. In reality there are some channels coming from Raymongal River, which are not considered in the model, moreover at the upstream of this river water level is assigned as boundary data. For these limitations it is not possible to obtain a fully satisfactory model results of this river.

__Kobadak-Arpangasia-Malancha__: The simulated water level of Malancha and Kobadak rivers have been compared with observed water level at Mandarbaria and Kobadak stations (Drawing E.3 & E.4). From the comparison plot it seems that there exists a constant difference in datum at Kobadak station but at Mandarbaria the result matched well with CTP data. The simulated discharges of the Malancha, Arpangasia and Kobadak rivers have been compared with observed data at Malancha, Arpangasia and Kobadak stations respectively (Drawing E.16, E.17 & E.18). The simulated results matched satisfactorily with observed data.

Sona Khal: The simulated water levels at Gawakhali on the Sona Khal (Drawing E.5) match well with the observed data.

Sibsa River: At Nalianala on Sibsa River the simulated water level and discharge matched satisfactorily with observed data (Drawing E.6 and E.18 respectively).

Pussur River : Water level of Pussur River has been compared at Mongla with BIWTA data using datum correction factor (as BIWTA data are in Chart Datum) and it is found that simulated water levels agreed well with the observed data in phase and amplitude (Drawing E.7). At the downstream, simulated water level has been compared with IWM measured data at Hiron Point (Drawing E.8). Drawing E.19 illustrate the comparison of simulated and observed discharges at Digraj station of this river. There are some differences between the observed and simulated values; further improvement of the model is required at this area.

Mrigamari -Harintana –Selagang: Simulated & observed water levels at Mrigamari matched well during dry period but there are some differences in wet period (Drawing E.9), at Harintana station the simulated & observed matched well (Drawing E.10). The discharge comparison of Mrigamari (Drawing E.20) and of Sela gang (Drawing E.21) indicate that there are some mismatches between the observed and simulated values. Actually in the Sundarban there present numbers of criss-cross channels all of which are not included into the model. It is very important to incorporate the channels to improve the aforesaid system.

Betmar Gang: Comparison of simulated water level with observed at Katka is satisfactory (Drawing E.11), but simulated discharge does not matched well at Dudmukhi station of the same river (Drawing E.22), there are some phase difference between observed and simulated values. Further improvement would be done including the interior channels as discussed earlier.

Baleswar -Supoti Khal: Comparisons at Bogi on Baleswar river and at Supoti on upstream of Supoti khal are satisfactory with respect to phase and tidal range (Drawing E.12 and Drawing E.13).

4.6 Conclusions and recommendations

The calibration of the hydrodynamic model considering water level and discharge of the Sundarban area is acceptable. In most of the cases, simulated water levels and discharges matched satisfactorily with the observed water levels and discharges respectively at different observed stations. However there are some deviations in water level comparisons in the rivers like Jamuna, Kobadak, Supoti Khal and Mrigamari. Discharges do not match well in Betmar Gang, Sela Gang and Jamuna River. Along the Jamuna River there are some inter-connecting channels coming from Raimangal river (near Indian border), no information regarding discharges could be made available for practical constraints. Moreover, at the downstream of this river synthesized water levels have been assigned as boundary data. For these limitations, it is not possible to obtain full satisfactory model results of the rivers situated at this area. However, the overall performance has been improved compared to the previous year calibrations and there are scopes for further improvement of the present HD model.

Although the overall performance of the hydrodynamic model is satisfactory, there are some deficiencies. The following are the main limitations of the present HD model:

- The downstream boundary at Mandarbaria and Hiron Point are referenced with arbitrary datum; for further improvement of the model these boundaries should be connected to the national datum of PWD. Additional number of continuous water level observation stations will also be useful in between Mandarbaria and Kochikhali.

- Simulated discharges have been compared with very limited number of observed data; more frequent measurements could be useful in this respect.

- Due to non-existence of any data transfer policy between the cross border countries, the flow of water in the Sundarban from the Indian side remaining unknown.

- In the existing South West Region Model the criss-cross of khals/creeks in the forest could not be accommodated. It is expected that a dedicated Sundarban Model will be developed to address this issue. Additional data collection with respect to the cross-section of the connecting khals/creeks will be necessary for that purpose.

- The flood map generated from the model is not sufficiently accurate because accurate land level data of the forestland is not available. The topographic map collected from FINMAP should be updated with ground truthing survey data referenced to PWD datum.

5 SALINITY MODEL

5.1 Model Description

Study of salinity has been carried out by using the Advection-Dispersion (AD) module of MIKE11 Model. The model is based on the one-dimensional equation of conservation of mass and conservation of dissolved or suspended materials and uses the results of the hydrodynamic model. The MIKE11 AD module applies two transport mechanisms advective or convective transport with the mean volume of flow and depressive transport for concentration gradient. The assumption underlying the AD equation is a well-mixed salinity front, which fits well with the coastal areas of Bangladesh. The salinity model of the Sundarbans has been calibrated separately for the dry and wet seasons to understand the seasonal variation of the salinity in the rivers. The dry season covers the months of February-May and the wet season covers the month of August-September.

5.2 Model Boundaries

The locations of the boundaries of the salinity model are same as that of HD model. However there are minor changes in the nature of the boundaries. Few boundaries are closed, that is no net transport of salt is assigned and few boundaries are open where salinity concentration changes with the changes in the volume of flow. The closed boundaries in the HD model (where contribution of rainfall runoff were considered only) are treated as closed in the salinity model. All the tidal boundaries of HD model are considered as open, where salinity concentrations have been specified from the observed data. A complete list of salinity boundaries has been presented in Table 5.1.

5.3 Initial Conditions

Initial conditions of salinity model play an important role in simulation because it takes a long time to stabilize the model with respect to the boundary conditions. For this reason, initial conditions in all the rivers in the Sundarban have been specified individually from the observed data for both monsoon and dry season calibration.

5.4 Calibration Parameters

In MIKE11 AD concentration at open boundaries depends on the calibration Parameter K_{mix}. This parameter is used to ensure a smooth transition between calculated and specified boundary in the case of flow reversal (Ref. Mike 11 Reference Manual, DHI). A list of K_{mix} values used in different open boundaries has been presented in Table 5.2. In the Sundarban Salinity Model the values of K_{mix} vary from 0.043 to 0.083.

Another important calibration parameter is the dispersion coefficient that is determined by the function of flow velocity and channel conveyance, which in another turn lead to the volume of flow passing through the channel section. (Ref. Mike 11 Reference Manuals, DHI). For the salinity model of the Sundarbans, the parameters for different rivers have been selected from previous salinity study of IWM. Dispersion coefficient in those studies varies from 30 to 5000 in different river branches. Due to the high sensitive nature of the salinity model the dispersion coefficients for dry and wet period has been made different. In the deepest rivers, comparatively high dispersion coefficients have to be used to compensate for the effects of pressure gradients induced by longitudinal density gradients. The density induced contribution to the pressure gradient increases linearly with the water depth, thus the effect is larger in deeper rivers where density driven flows develop during slack water with a negligible surface slope and affect longitudinal mixing. Lists of dispersion coefficients used in the Sundarban Salinity Model have been presented in Appendix F (Table F1A and F1B)

Table 5.1: List of boundaries used in the salinity model

SL No.	River Name	Chainage	Type of boundary
1	Pussur	98.21	Open Concentration
2	Haringhata	17	Open Concentration
3	Malancha	62.7	Open Concentration
4	Tentulia	90	Open Concentration
5	Shahabaz-1	21	Open Concentration
6	Jamuna	61.74	Open Concentration
7	Pussur Khal	30.83	Open Concentration
8	Sela Gang	73.29	Open Concentration
9	Betmar Gang	36.89	Open Concentration
10	Supoti Khal	28.63	Open Concentration
11	Kanksiali	17	Open Concentration
12	Jamuna	0	Open Concentration
13	Padma	12	Closed
14	Sitalakhya	0	Closed
15	Gorai	11.9	Closed
16	Upper Meghna	0	Closed
17	Kumar	9	Closed
18	Begabati	48	Closed
19	Betna	0	Closed
20	Bhairab U	0	Closed
21	Buribhadra	0	Closed
22	Chitra	50	Closed
23	Bhadra	1	Closed
24	Harihar	0	Closed
25	Hatia	0	Closed
26	Kobadak	0	Closed
27	Kobadak	180	Closed
28	Labangabati	0	Closed
29	Chitra	120	Closed
30	Old Pussur	0	Closed
31	U-Solmari	0	Closed
32	Daudkhali	0	Closed
33	Hari-River	0	Closed
34	Atharobanki	32	Closed
35	Channel X	0	Closed

Table 5.2: Values of K_{mix}

No	River Name	Chainage (m)	K [illegible]
1	PUSSUR	98210	0.083
2	HARINGHATA	17000	0.043
3	MALANCHA	62700	0.083
4	SHAHABAZ-1	21000	0.083
5	TENTULIA	90000	0.043
6	JAMUNA	0	0.043
7	JAMUNA	61740	0.043
8	PUSSUR KHAL	30830	0.083
9	SELA GANG	73290	0.083
10	BETMAR GANG	36890	0.083
11	SUPOTI KHAL	28630	0.043
12	KANKSIALI	17000	0.043

5.5 Results of salinity model

As discussed above the results of salinity model mostly depends on the volume of flow generated from the HD results. In the complex tidal reworks of the Sundarbans it is difficult to simulate real life situation of flow, due to the non-availability of sufficient data on the internal criss-crossing of rivers as well as in the model boundary. In addition to that the water level boundaries in the downstream locations along the coast are not properly referenced with the national benchmarks related to the mean sea level. Because, such relation by a land level survey has not been done by any agency. IWM initiated an attempt to do so by conducting a benchmark survey from Patharghata to Hiron Point, but due to uncertainty in the project extension, the survey ended at Katka. Under such situation it is difficult to get a good salinity model. However with the best efforts of the modellers a nearly acceptable calibration has been achieved. The results of salinity model for the dry and the wet period for the Sela Gang, Pussur, Sibsa, Jamuna and Kobadak rivers have been presented in Figures F3 & F8. In the wet period the results are satisfactory at most of the stations, though there are some deviations in Malancha and Jamuna Rivers. In the dry period the simulated results show a good agreement at most of the observed stations except Sela Gang, Harintana and Supoti Khal. Most of these rivers lie in the eastern part of the Sundarban. The possible cause may be the water level boundary at the downstream without having connection with the nation benchmarks.

5.6 Salinity Mapping

The results of the salinity model have been applied to demonstrate the spatial variation of salinity. The maps are presented in Figures H1 and H2 for the dry and wet period respectively. In the wet period the salinity in the Sundarbans varies from 1-12 ppt whereas in the dry period (March) it varies from 8 to 25 ppt.

The maps developed from the model results have been compared with those from observed data. The salinity maps reflect the level of salinity in different areas during critical situations. In the absence of intensive data collection networks these maps from the model is capable to provide a good indication of salinity distribution. The area of the forest exposed to different salinity concentration could be observed from the distribution maps.

5.7 Limitations of the Salinity Model

The computation of Salinity Model is highly sensitive to the computation of discharge (flow volume) in the Hydrodynamic (HD) Model. Due to reasons mentioned above the flow computation in the HD model is not sufficiently accurate to mimic the actual situations. Under such situations the salinity model has got some obvious limitation to reproduce the exact level of salinity as observed at different locations. However, the relative level provided in the model could be good enough to understand a reasonable distribution pattern.

5.8 Recommendation for Further Improvement

Based on the experience with the river networks, flow and salinity distribution it is expected that the salinity model could be further improved to suit the need of the forest and environmental experts with the implementation of the following measures.

- Further improvement of the Hydrodynamic model with the inclusion of more number of interconnected rivers that exist in the forest area.

- Improving the Hydrodynamic model with the downstream boundaries referenced with the established benchmarks of the main land. At the moment these are referenced with chart Datum (CD), the upstream boundaries are referenced with the national benchmarks of MSL/PWD, though a theoretical co-relation between PWD and CD has been established for the purpose of modelling, the accuracy level of such co-relation should be confirmed by benchmark connection survey.

- Calibration of the Hydrodynamic model with more number of observed discharge stations.

6 WATER QUALITY MODEL

6.1 Background

An attempt was taken up to develop a water quality model for the river system of the Sundarban. The most crucial point in developing a WQ model for such a river system is the estimation of pollution loads. Except for the Rupsha and Bhairab rivers, which are at much upstream of the Sundarban, there are no distinct point sources of pollution in and around of the Sundarban. As such, pollutants arising out of non-point sources dominate in the river system concerned.

To arrive at a reasonable estimate of pollutant loadings, MIKE LOAD software of the DHI Water & Environment (of Denmark) has been used. Based on the river system, land topography (expressed in terms of a Digital Elevation Model, DEM), landuse pattern, population and some other auxiliary data, LOAD has produced pollutant loadings at the outlets of each sub-catchment in terms of BOD, Nitrogen and Phosphorus. Detailed description of the computation of non-point pollutants using LOAD has been provided in Annexure G. These data were used in the WQ module of MIKE 11.

Efforts were devoted to procure data/information, about the industrial pollution of the Rupsha and Bhairab rivers, from the Department of Environment (DOE), Khulna. However, nothing positive came out. A detail surveillance and characterization of the wastes being released from the industrial belt along the said river systems is out of the scope of this project. As such, to compromise with the situation, random sampling were carried out at some of the upstream stretches of the rivers entering into the Sundarban, during August-November 2002, for getting a snapshot idea about the status of pollution being carried over by the river system.

6.2 WQ Modelling

The river system of the Sundarban is quite complex, having numerous channels besides the major ones like the Passur, Sibsa, Arpangasia, Jamuna, etc. All the minor channels are not included in the current model setup to avoid complexity of simulating a too large model. Nevertheless, in reality, the minor channels often play significant role in mass-balance of solutes (pollutants). There are limitations in the basic hydrodynamic (HD) model, which is used as the basis of developing a WQ model. Improvement in the model setup demands substantial input regarding hydrometric and topographic data acquisition, which could not be achieved under the existing resources and time frame. In view of the above shortcomings, a simple BOD-DO model has been developed for the Sundarban river system.

The BOD-DO model describes the process of bio-degradation of organic matter (BOD) in the water phase with resultant consumption of dissolved oxygen (DO) thereof. For a relatively unpolluted river system having rivers/channels with high flow volumes and velocities, the BOD-DO description often suffices the purpose of assessing the health of the rivers.

A dedicated WQ sub-model out of the SWRM has been developed for the Sundarban river system. The model has been simulated for four different periods: Pre-monsoon (April-June), Monsoon (July-October), Post-monsoon (November-December) and Dry (January-March) to visualize the seasonal variation of DO concentrations in the related river system. Reviewing the four plan plots of DO concentrations in the Sundarban river system, distinct seasonal variation of DO in the river system along with spatial variation from river to river has been observed.

6.3 Sensitivity Analysis

The WQ model developed for the Sundarban river system has been simulated by increasing the non-point waste load (BOD) by 100%. This has been done to observe the sensitivity to waste load of the huge waterbody of the Sundarban river system, which remains almost unaffected by increasing the load by some percentage.

The changes due to increased loading on Dissolved oxygen (DO) is clearly visible in three hydrological conditions (i.e. pre-monsoon, monsoon and dry), while the change is minimal during the post-monsoon condition (Fig 6.1 to Fig 6.8). This is probably due to the fact that the waste assimilation effect of huge freshwater generated inland becomes pronounced during the post-monsoon period around the coast/estuary near the Bay of Bengal.

6.4 Concluding Remarks

The WQ simulations with increased loading of biodegradable pollutant (BOD) sheds some light on the fact that whatever be the vastness of the water body of the Sundarban, it definitely has a threshold beyond which the water quality would surely deteriorate.

It should be noted here that the WQ modelling as well as analysis of water quality of the Sundarban has been done based on very patchy data. As such, all the results of analyses and inferences should be considered as qualitative and indicative. It has been the object of getting 'range values' of DO in different rivers under different flow conditions (i.e. seasonal variation). Nevertheless the results were checked against the measured concentrations of DO. Intensive, long-term monitoring of water quality parameters (as stated earlier) along with improvement of the HD and AD models to a much finer level would be able to yield much reliable pieces of information in these respects.

As of observed data, the plan plots show that the Sundarban river system is, in general, healthy with respect to the most important water quality parameter, i.e. DO. The persistent under-simulation of DO at the western part of Sundarban has been caused from the influence of the border river, the Raimangal, of which no data could be procured for practical constraints.

The WQ model, at its current development, paves the basis towards the development of an operational WQ model for the assessment of water quality in the Sundarban river system. To accomplish the task, in the first place – the HD model needs to be tuned to a much finer level having back up from requisite data. Intensive water quality data – collected over a relatively shorter period – would be useful to update the WQ model. The suite of model would, then, prove to be useful tools to assess the hydraulic and pollution characteristics of the Sundarban river system more precisely, which is but a sheer necessity to preserve the aquatic environment of the World Heritage Site conducive to the sustainability of the rich bio-diversity.

Period: <u>Pre-monsoon (Apr – May)</u>

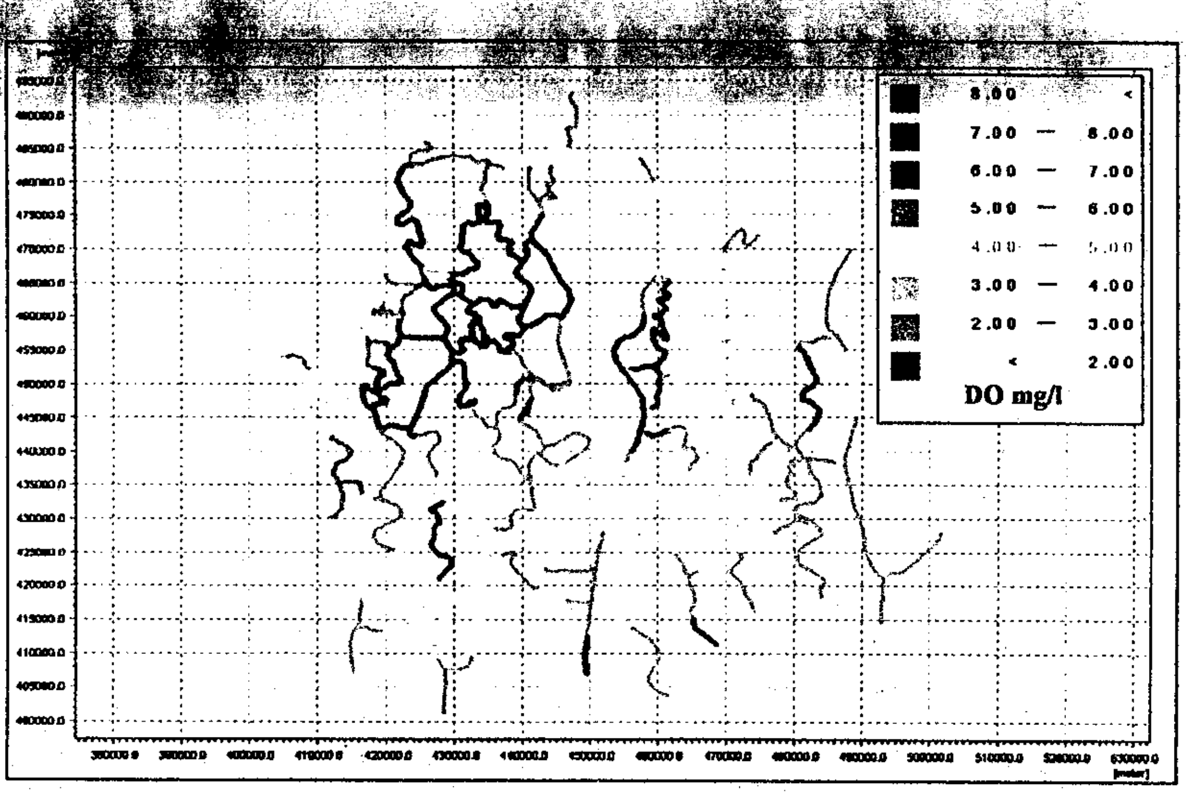


Figure 6.1: DO level on 16-05-2001 18:00:00 (Pre-monsoon) for <u>Base Condition</u> of Sundarban Forest area

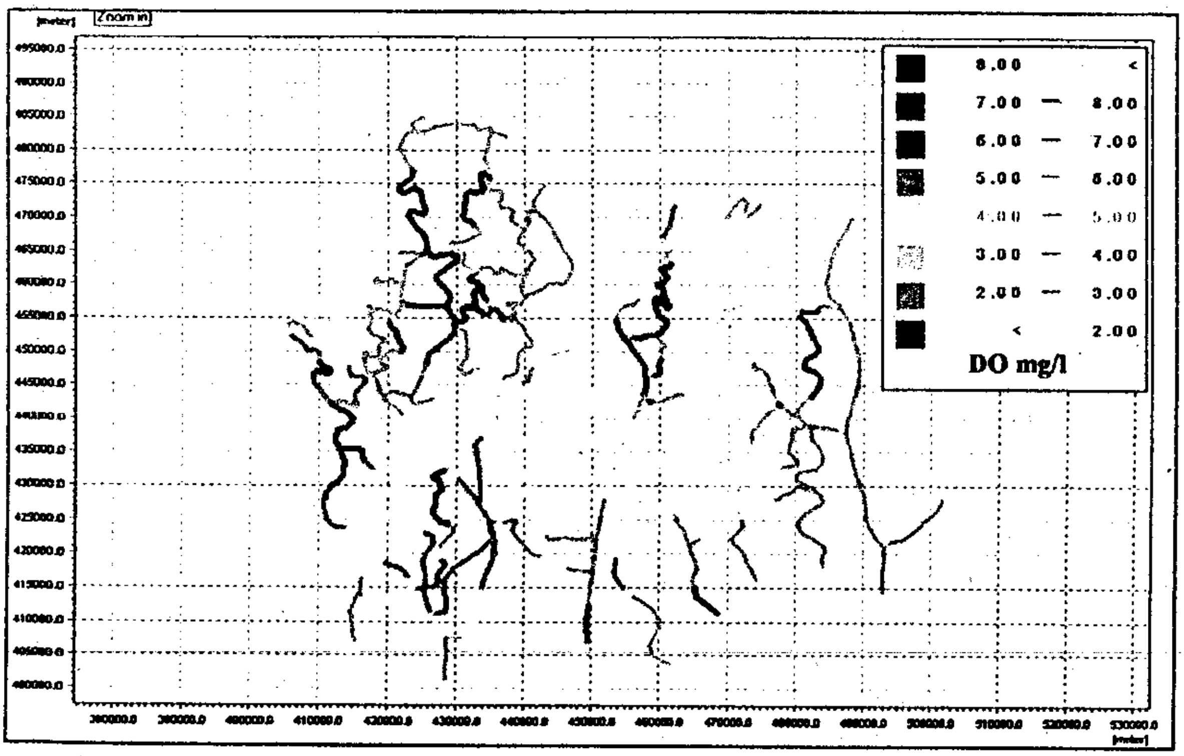


Figure 6.2: DO level on 16-05-2001 18:00:00 (Pre-monsoon) for <u>Increased Load Condition</u> of Sundarban Forest area

Period: <u>Monsoon (Jun – Sep)</u>

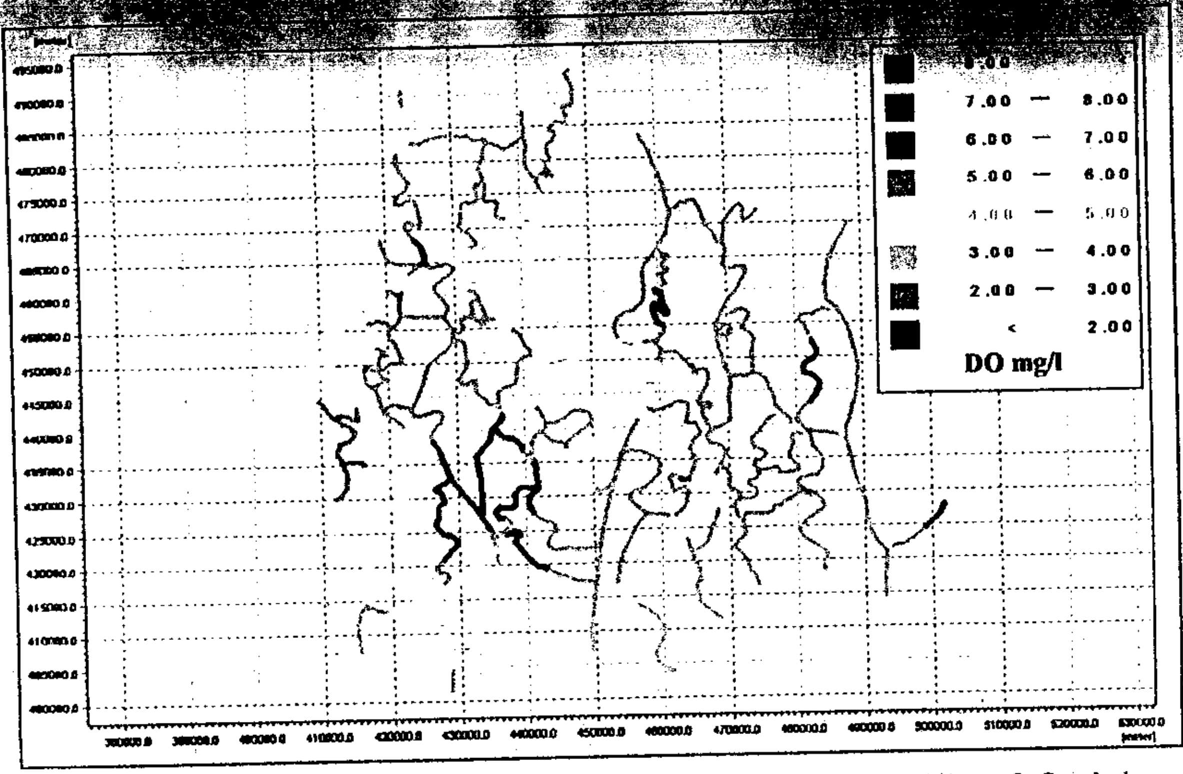


Figure 6.3: DO level on 17-08-2001 10:00:00 (Monsoon) for Base Condition of Sundarban Forest area

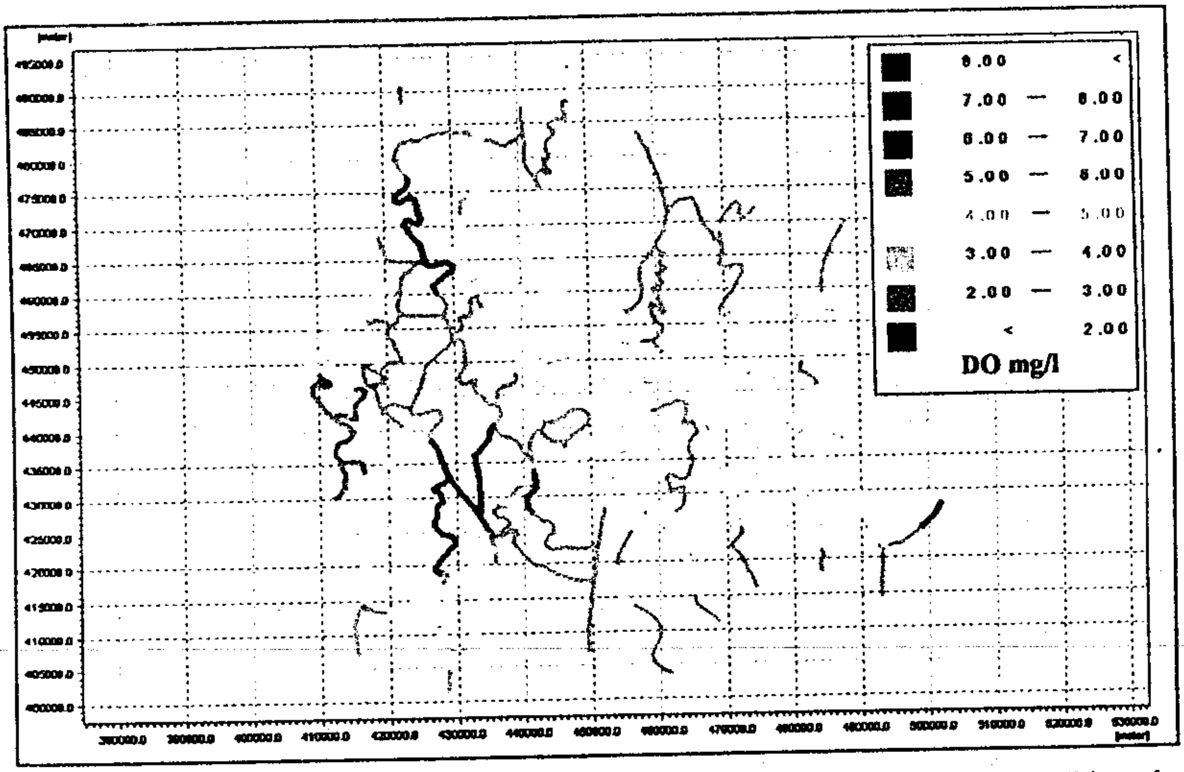


Figure 6.4: DO level on 17-08-2001 10:00:00 (Monsoon) for Increased Load Condition of Sundarban Forest area

Period: <u>Post-monsoon (Oct – Dec)</u>

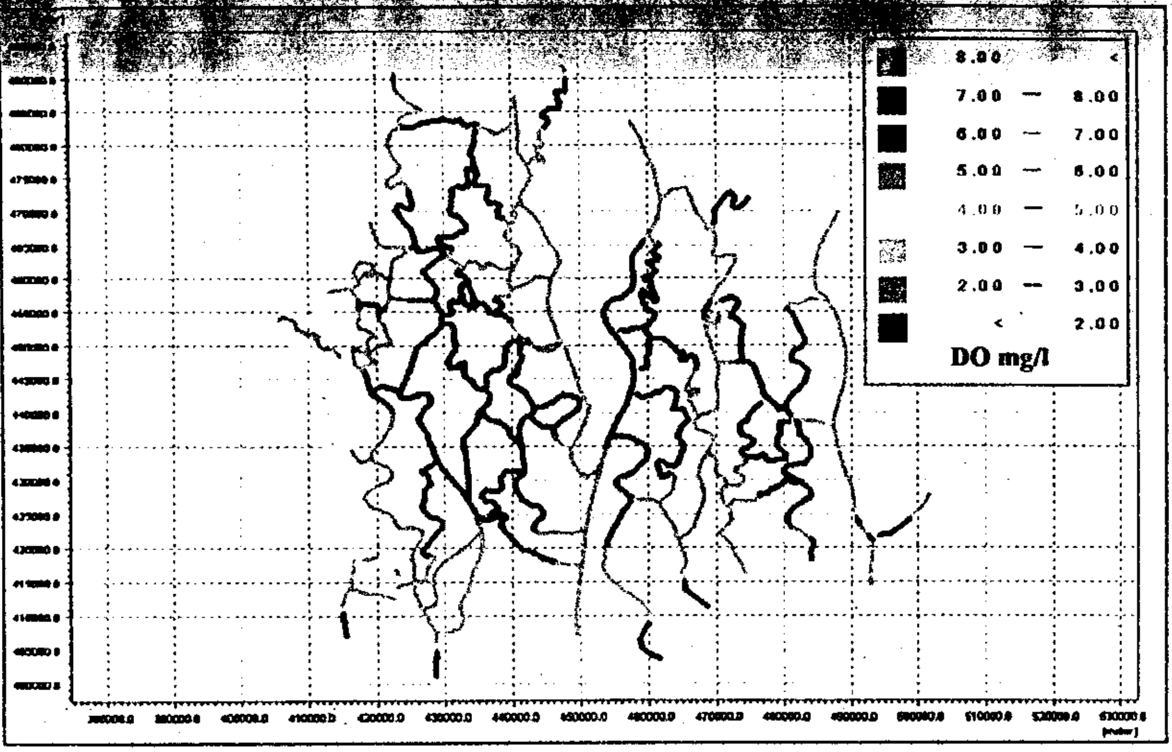


Figure 6.5: DO level on 15-12-2001 19:00:00 (Post-monsoon) for <u>Base Condition</u> of Sundarban Forest area

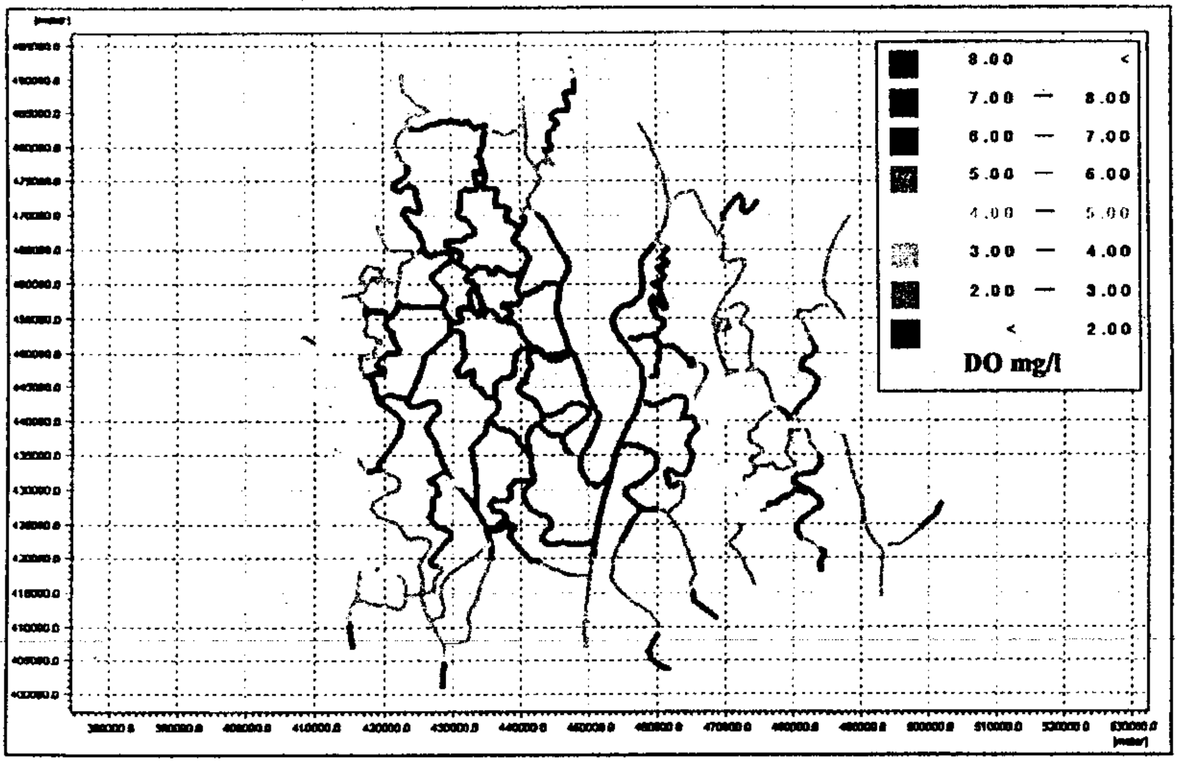


Figure 6.6: DO level on 15-12-2001 19:00:00 (Post-monsoon) for <u>Increased Load Condition</u> of Sundarban Forest area

Period: Dry (Jan – Mar)

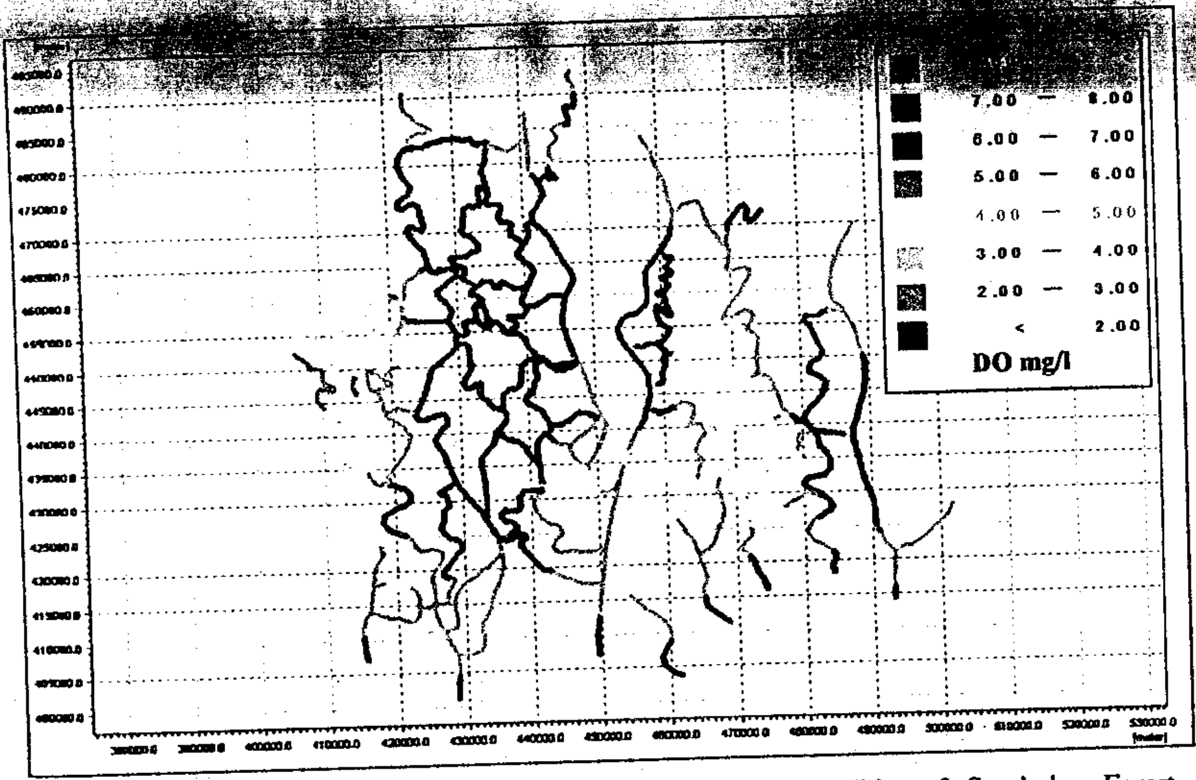


Figure 6.7: DO level on 20-01-2002 7:00:00 (Dry) for Base Condition of Sundarban Forest area

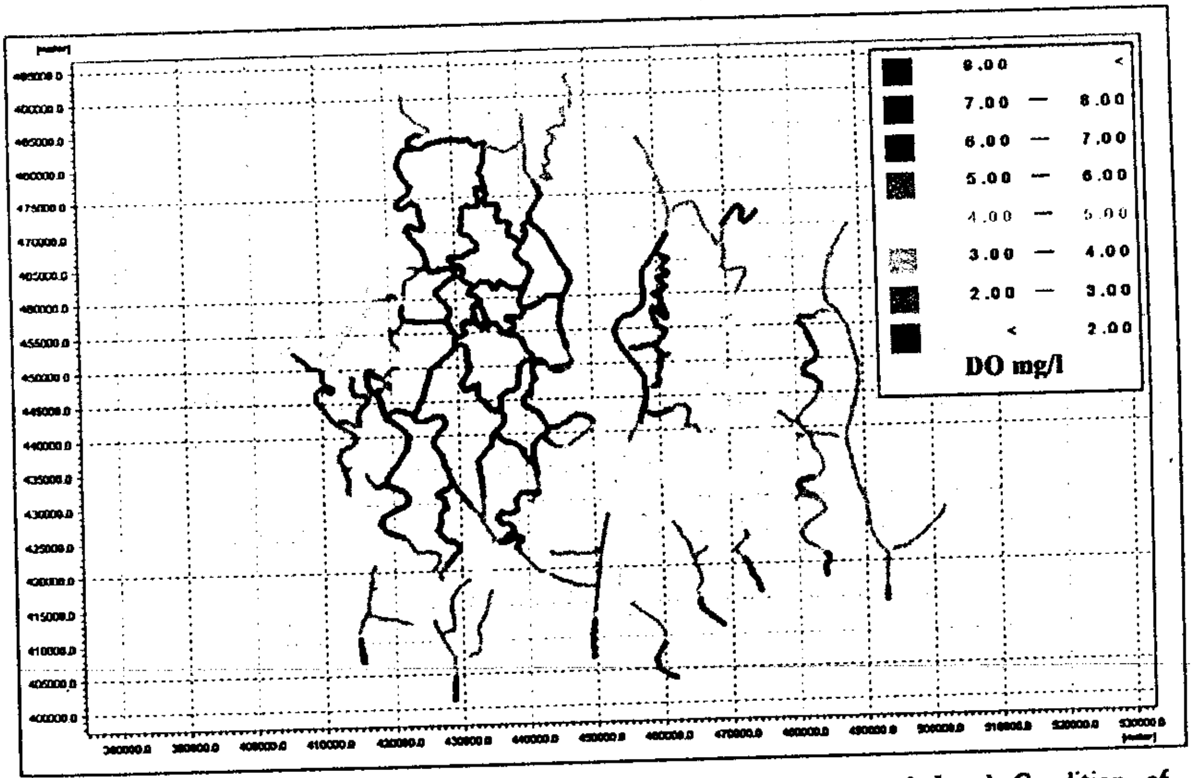


Figure 6.8: DO level on 20-01-2002 7:00:00 (Dry) for Increased Load Condition of Sundarban Forest area

7 SEDIMENT TRASPORT MODEL

7.1 Development of a Sediment Transport Model

In order to study the sediment transport and deposition process in the rivers of the Sundarbans a pilot Cohesive Sediment Model for the Pussur-Baleswar-Khorma-Bhola system has been developed. The ultimate intention of selecting the said system is to study the sustainability of dredging the Khorma-Bhola system. The hydrodynamic modelling study for the same area indicates such possibilities. However, the hydrodynamic model does not consider sediment character with relevance to flow velocity. Such relation could be only modeled in a sediment transport model. Also considering the cohesive nature of the sediment in the area a cohesive sediment modelling study has been considered as a possible option. The rivers included in the pilot model have been shown in Figure 7.1. The MIKE 11 modelling system from DHI has been applied for the said study. The river cross-sections sediment and flow data obtained from the SBCP field survey and monitoring has been applied for the development of the model.

7.2 Initial calibration

The initial calibration of the model with respect to the observed discharge, water level, sediment concentration, sediment transport and flow velocity at different stations within the model area are shown on Figures 7.2 to 7.7.

The comparison between model output and observed discharge at Mrigamari seems reasonably well though the simulation does not show perfect match at ebb tides. The comparison between simulated and observed water level is also satisfactory, though there are slight differences at high and low peaks. The comparisons between simulated and observed velocity at Mrigamari and Digraj appears highly satisfactory except slight differences at high and low peaks. The comparison between simulated and observed sediment transport and concentrations also appears satisfactory at certain range.

7.3 Scope of further works

Further improvement in the calibration of the model is necessary before it could be applied for option studies. However, that will require additional data relating to river cross-sections, flow & sediment of the connecting channels from Kharma Khal. That will require field measurement and monitoring campaigns, which was not possible at the closure of the project.

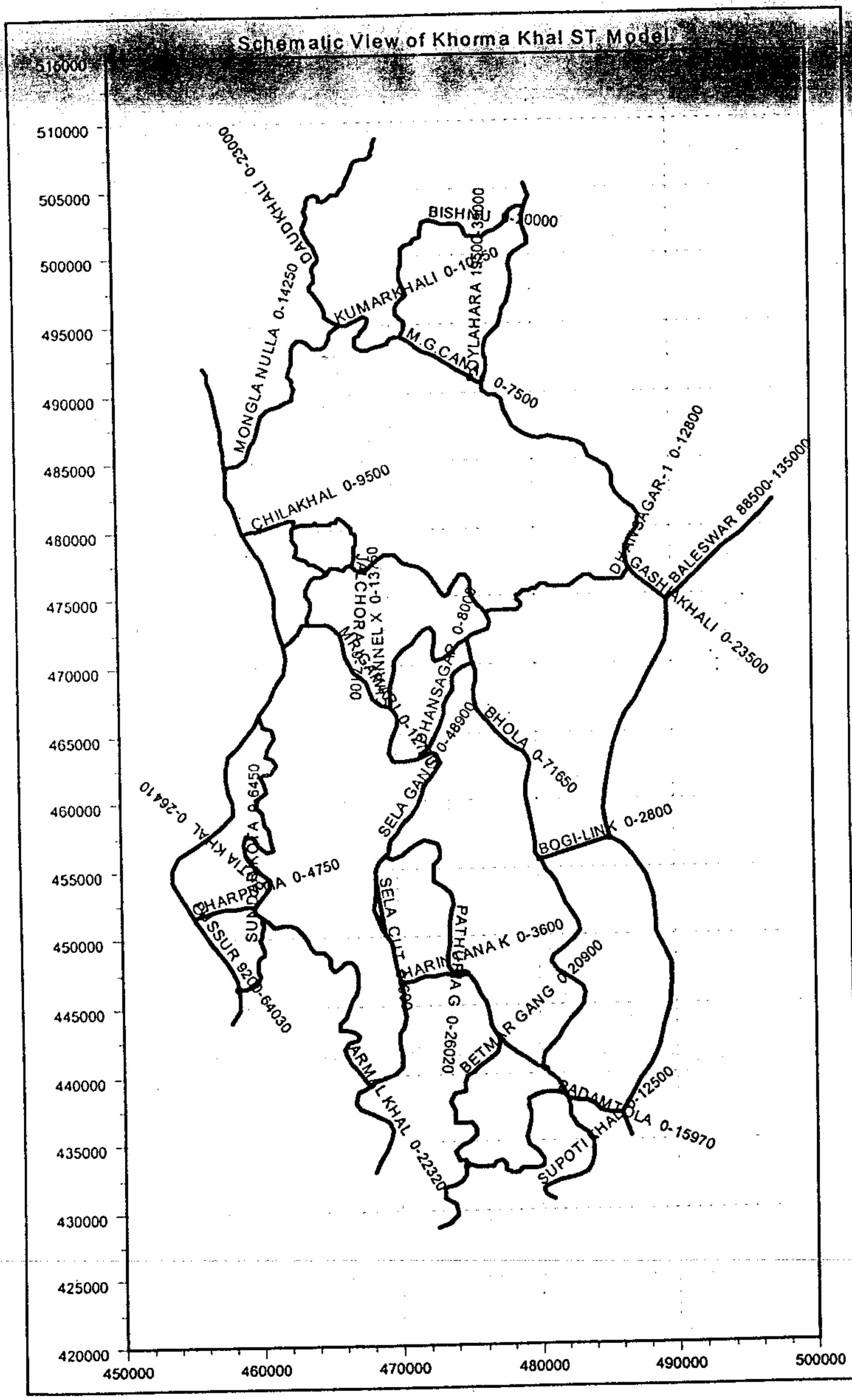


Figure 7.1: Overview of the model set up.

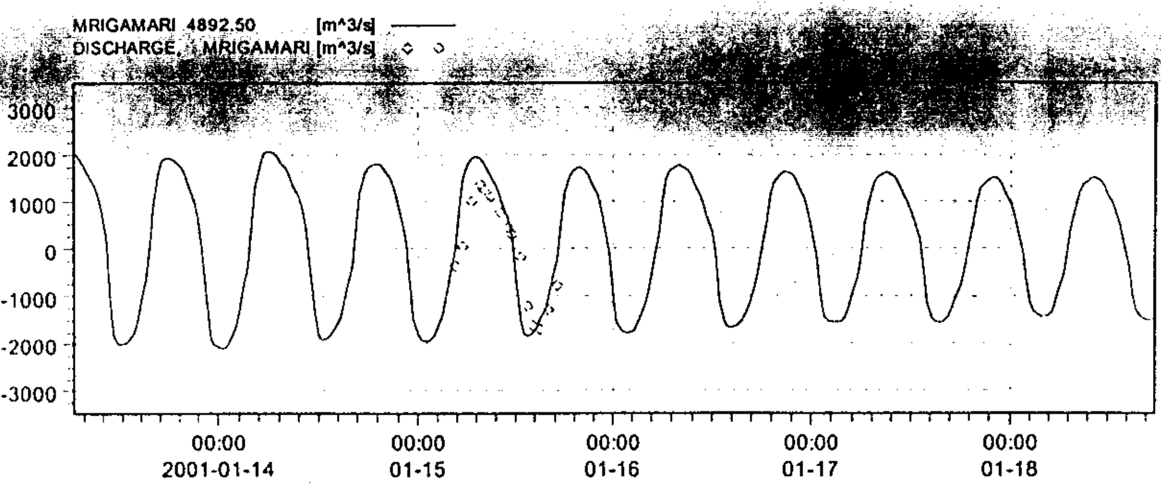


Figure 7.2: Comparison of modelled and observed discharges at Mrigamari.

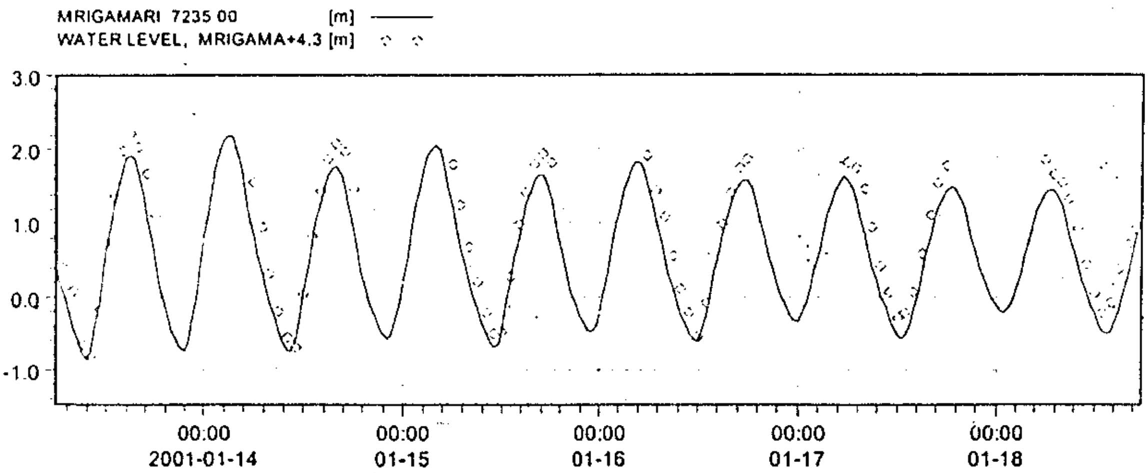


Figure 7.3: Comparison of modelled and observed Water Level at Mrigamari.

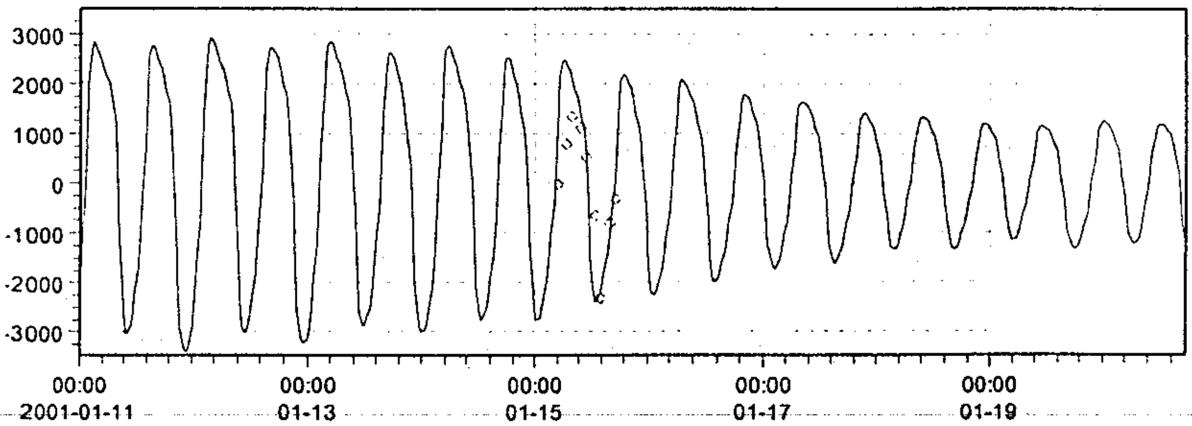


Figure 7.4: Modelled and observed sediment transport (kg/sec) at Mrigamari

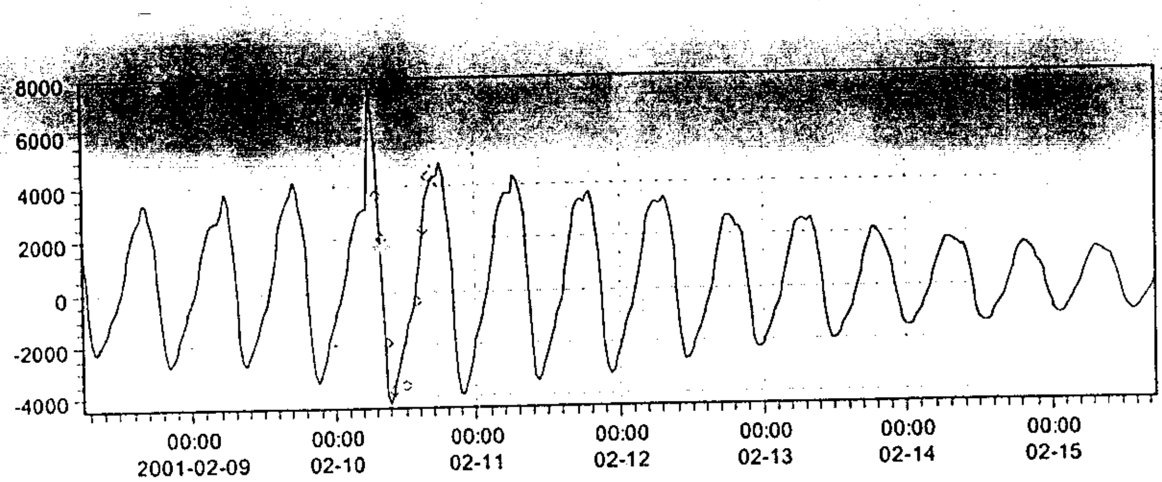


Figure 7.5: Comparison of modelled and observed sediment transport at Harintana

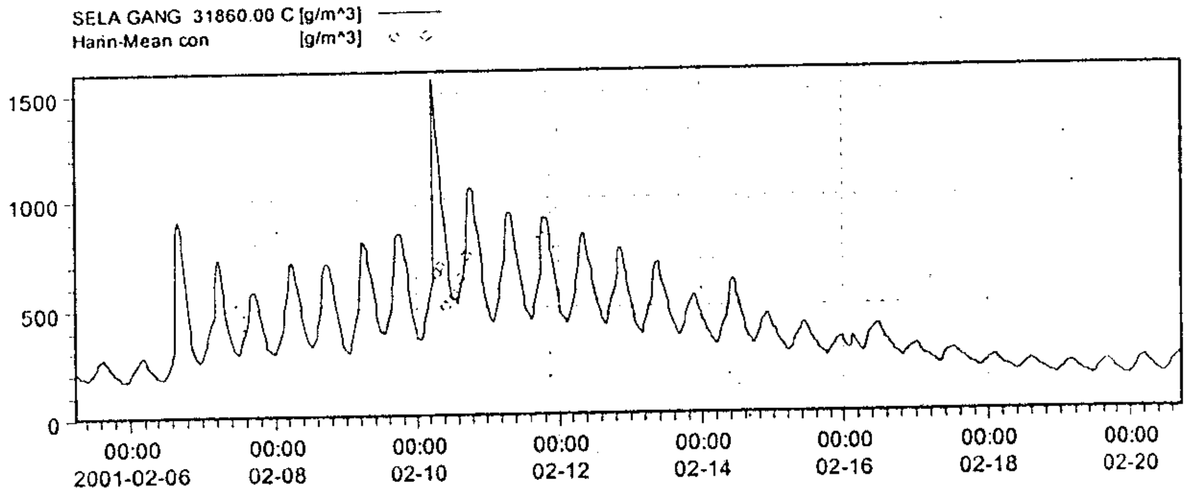


Figure 7.6: Comparison of modelled and observed sediment concentration at Harintana

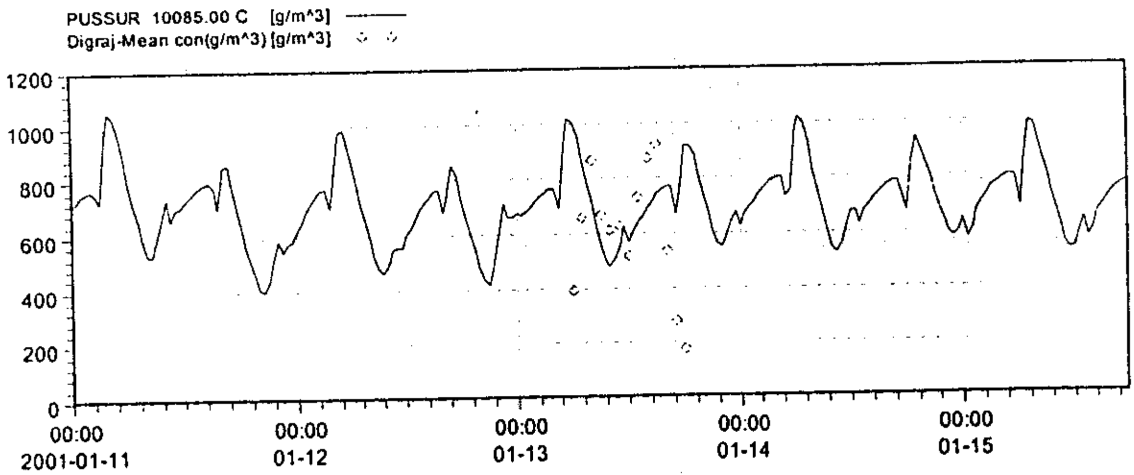


Figure 7.7: Comparison of modelled and observed sediment concentration

8. OPTION STUDIES

The salinity intrusion in the Sundarbans area is dominated by the balancing effect of the fresh water inflow from the upstream rivers, and the tidal propagation from the bay. The Gorai is the main source of fresh water to the Sundarbans. Some other rivers like Kobadak and Betna situated in the western part was also a good source during the early days. The said rivers used to carry the spills of the Ganges towards the south. At present those are mostly dry, especially during the dry period. With the dredging of the Gorai River, the duration of recession hydrograph as well as minimum flow during the dry period could be increased. Similarly, with the availability of flow in the Ganges, re-excavation of the Kobadak – Betna system may also improve the situation in the rivers of the southwestern part of the Sundarbans.

One of the advantages of mathematical model is that it could be used to generate hydraulic variables for the possible future situations. In connection with this study several option scenarios have been identified to see the impact of salinity intrusion and inundation in the Sundarbans area. The options have been selected on the basis of the findings of earlier studies. Few options have also been selected in consultation with the Forest Department (FD) and other relevant agencies. Considering situations mentioned above, five options have been designed to address the salinity intrusion in the forest area by increasing fresh water flow. Two options have been designed to address the effect of sea level rise and one option for improvement of the navigability in the Kharma-Bhola system. Further details of the options are shown in Table 8.1

Table 8.1: Description of the Option Models

Option No.	Description of the Options
Base	The 2001-02 hydrological year has been considered as base model situation and that of 10-20 m^3/s was recorded at the Gorai Railway bridge during February-March 2002
1	Minimum discharge at Gorai is 100 m^3/s without changing other existing conditions.
2	Minimum discharge at Gorai is 200 m^3/s without changing other existing conditions.
3	A Minimum of 200 m^3/s in the Kobadak - Betna system during dry period in addition to the Option 2.
4	A Minimum of 300 m^3/s in the Kobadak - Betna system during monsoon period.
5	The connecting channels between Kobadak and Sibsa river closed without changing existing condition
6	Option 5 plus 50 m^3/s to the Kobadak River during dry period and 300 m^3/s in the wet period.
7	50cm rise in the sea level with other existing conditions.
8	20cm rise in the sea level with other existing conditions.
9	Improvement of Kharma Khal Navigability
10	Closing the intake of Mrigamari River

8.1 Results of Option Study

Base Option: The 2001-2002 hydrological year has been considered as base model situation when a minimum flow of about 20 m^3/s flow under the Gorai Railway bridge during February-March. The result of salinity distribution from the base model has been presented in Figure H1 and H2 in Annexure H. The Figure shows a maximum salinity of 25ppt during the dry period and 8-12ppt in the wet period at Manderbaria in the southwest corner of the Sundarbans.

Option 1: Minimum 100 m^3/s inflow in the Gorai during the dry period. The recession curve of the proposed inflow hydrograph is shown in Figure. 8.1.

The result of the Option 1 has been presented in Figure H3. Comparison of Figure H1 & H2, shows that the 1- 4 ppt salinity zone has been shifted from Bardia to Khulna during the dry period due to increased fresh water flow. The result is also presented in the form of salinity time series (Figures. 8.2 – 8.4). The time series also shows prominent changes in the salinity level under the option situation. The improvement is more prominent during the month of May compared to February. However, the impact of option 1 at Nalianala in Sibsa towards the west is not pronounced (Figure. 8.4).

The changes in longitudinal profile of salinity of Rupsha-Pussur and Kobadak-Malancha river systems have been presented in Figure 8.5 while changes in spatial distribution has been presented in Figure 8.6.

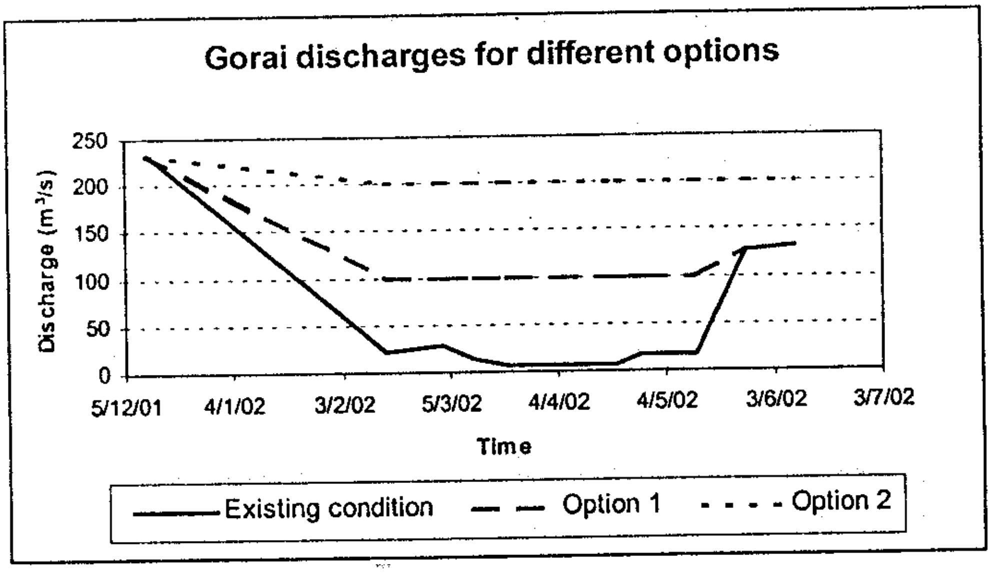


Figure. 8.1 Recession Hydrograph under Option 1 and Option 2

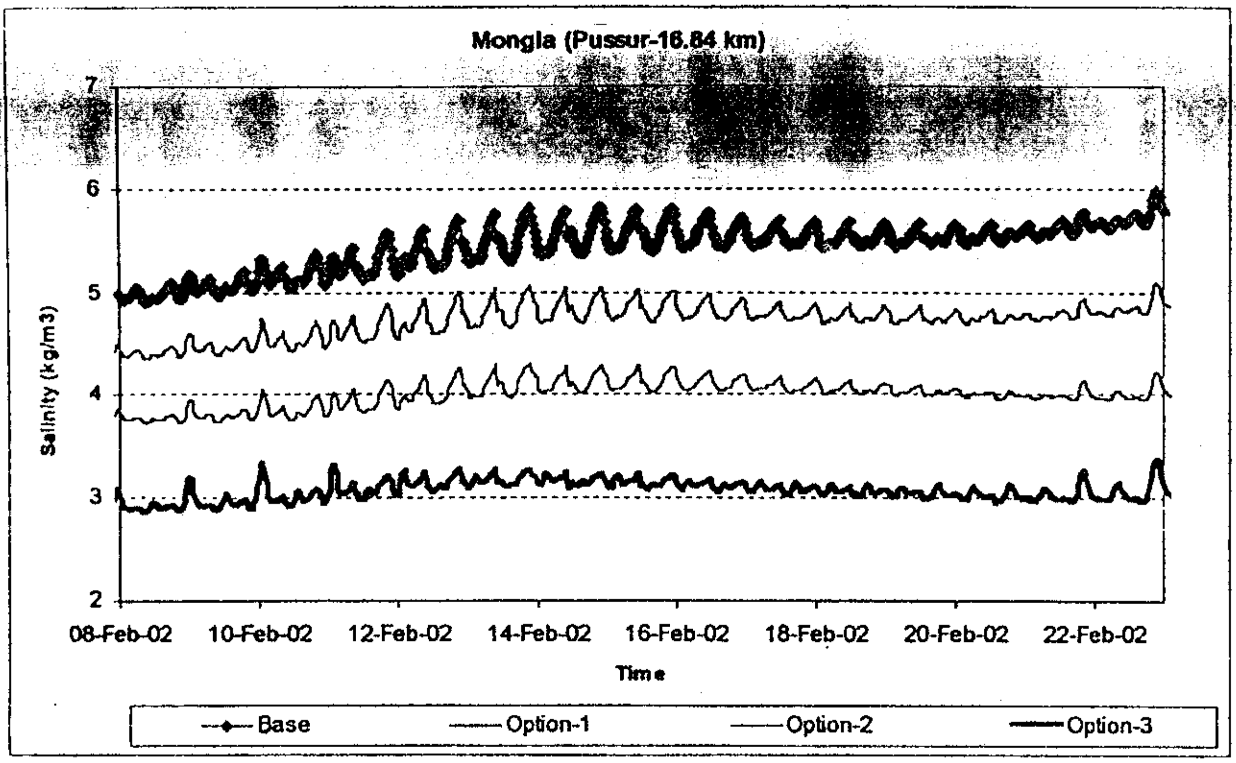


Figure 8.2: Changes in Salinity at Mongla in the Pussur for Options 1, 2 & 3

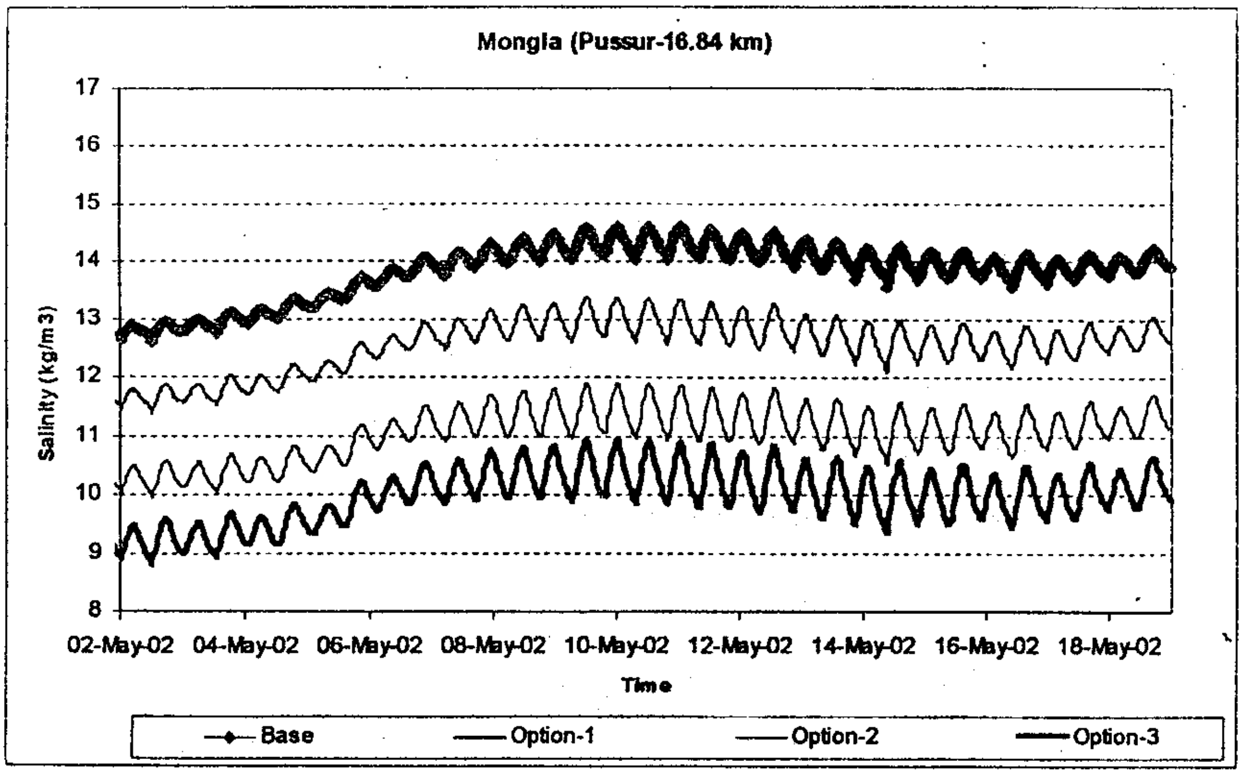


Figure 8.3: Changes of salinity at Mongla at Pussur River due option 1, 2 & 3

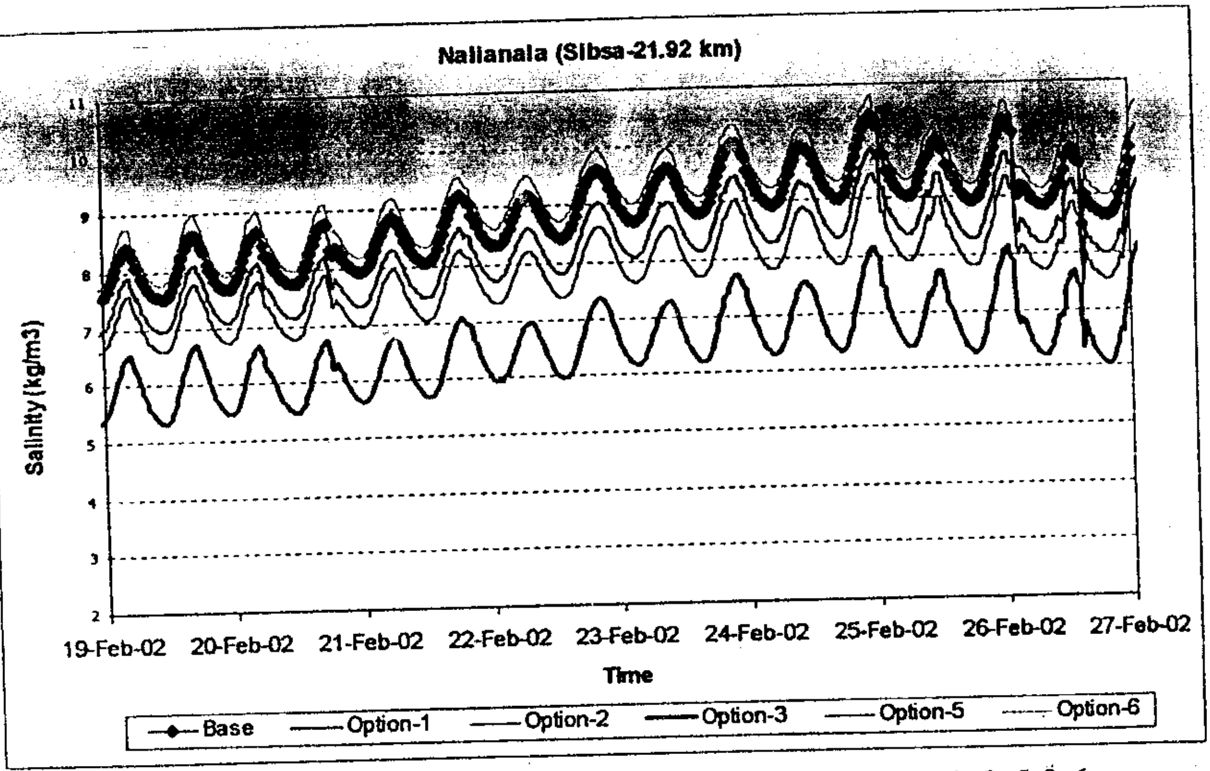


Figure 8.4: Changes of salinity at Nalianala in the Sibsa River options 1, 2, 3, 5 & 6

Option 2: Minimum 200 m^3/s flow in the Gorai

The result of option 2 is shown in Figure H4. The Figure indicates further reduction salinity in the northeast part as compared to option 1. The salinity time series of option 2 (Figure. 8.2 – 8.4) also indicate prominent reduction in salinity in the northeastern part of the Sundarbans with a visible effect at Nalianala in the Sibsa.

Option 3: Option 2 plus minimum 200 m^3/s in the Kobadak– Betna System during dry period.

Figure H5 shows the results where the salinity front moves to the downward direction in the northeastern part of the Sundarbans. Salinity at Mongla reduces by more than 2 ppt and at Nalianala the reduction is around 1 ppt (Figures 8.2 – 8.4) at Harintana, Herbaria and Nalianala lies in the 8-12 ppt zone.

Option 4: Minimum of 300 m3/s in the Kobadak-Betna system during monsoon

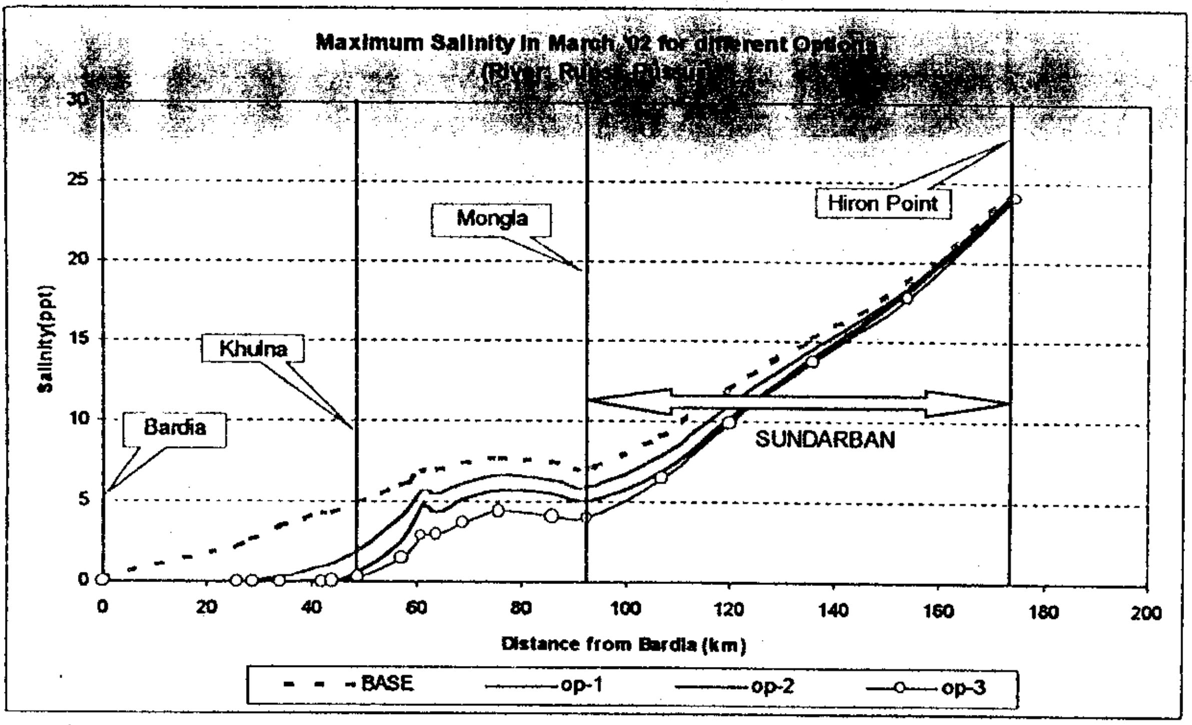
Possibilities to divert some additional flow from the upstream rivers like Mathabhanga, then the probable situation is simulated in this option. The result of salinity distribution has been presented in Figure H6. Prominent Reduction in salinity could be observed in the western part of the region near Chapra situated outside the Sundarbans.

Option 5: The connecting channels between Kobadak and Sibsa River closed.

The results have been presented in Figure H7 & H8. Reduction in salinity along the upstream part of Kobadak could be observed in Option 5. Salinity in the Sibsa at Nalianala increased slightly with no change in the Pussur at Mongla. Option 5 also indicate that there is some spill of the tidal flux from Sibsa to the Kobadak system, which eventually drains towards the west during ebb tide.

Option 6: Option 5 Plus additional 50 m^3/s inflow to the Kobadak River during dry period and 300 m^3/s during the monsoon to see the impact of increased monsoon flow in the system and a nominal flow during the dry period

The results have been presented in Figure H9 & H10. Prominent reduction in salinity along the upstream part of the Kobadak has been observed for both dry and wet period, but insignificant changes in salinity of the Sibsa at Nalianala and the Pussr at Mongla have been observed.



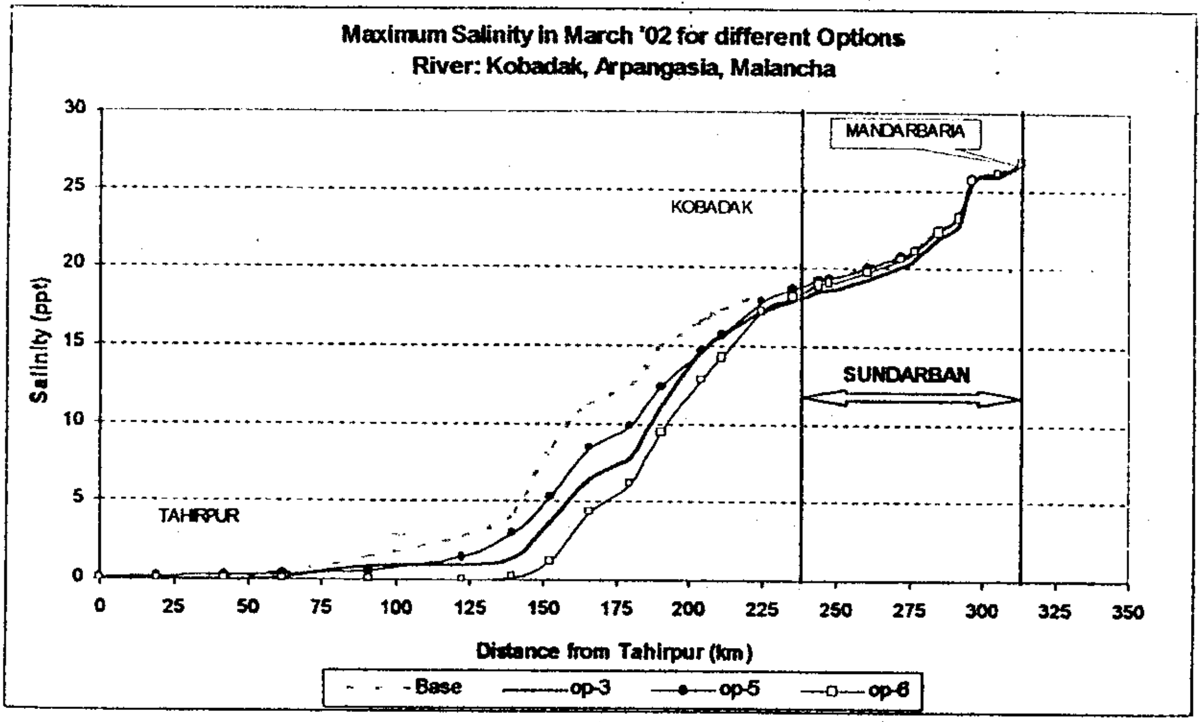
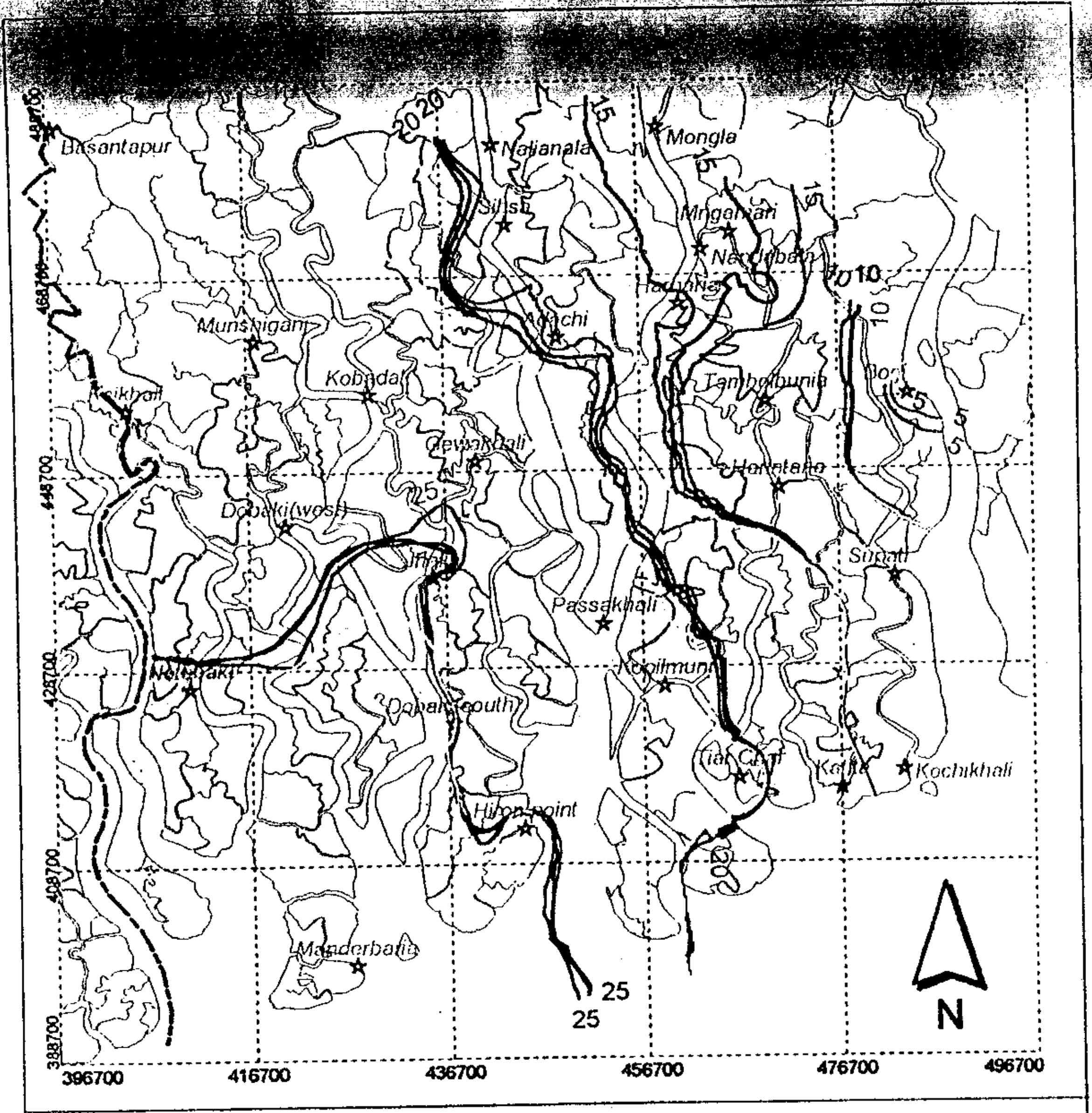


Figure 8.5 Changes of longitudinal profile of salinity in the Rupsha-Pussur and Kobadak-Arpangasia- Malancha river system due to different conditions of upstream flow



Impact of increasing fresh water flow on Salinity

Legend

- Base Condition of May 2002
- Aditional flow of 100 m3/s in the Gorai
- Aditional flow of 200 m3/s in the Gorai
- Aditional flow of 200 m3/s in the Kobadak-Betna system in adition to the Option 2
- River Network
- International Boundary

Scale: 10 0 10 Kilometers

Figure: 8.6

Option 7: With 50 cm Sea Level Rise without changing other existing conditions
Option 8: With 20 cm Sea Level Rise without changing other existing conditions

In Option 7, impact due to sea level rise of 50 cm and in Option 8, impact due to sea level rise of 20 cm has been simulated. Water level changes at Mongla due to sea level rise can be observed in Figure 8.7. Due to sea level rise the salinity of the Sundarbans will increase; for example at Notabaki (Jamuna River) there will be an increase of around 2 ppt in option 7 and more than 1 ppt in option 8 during the month of March (Figure 8.8).

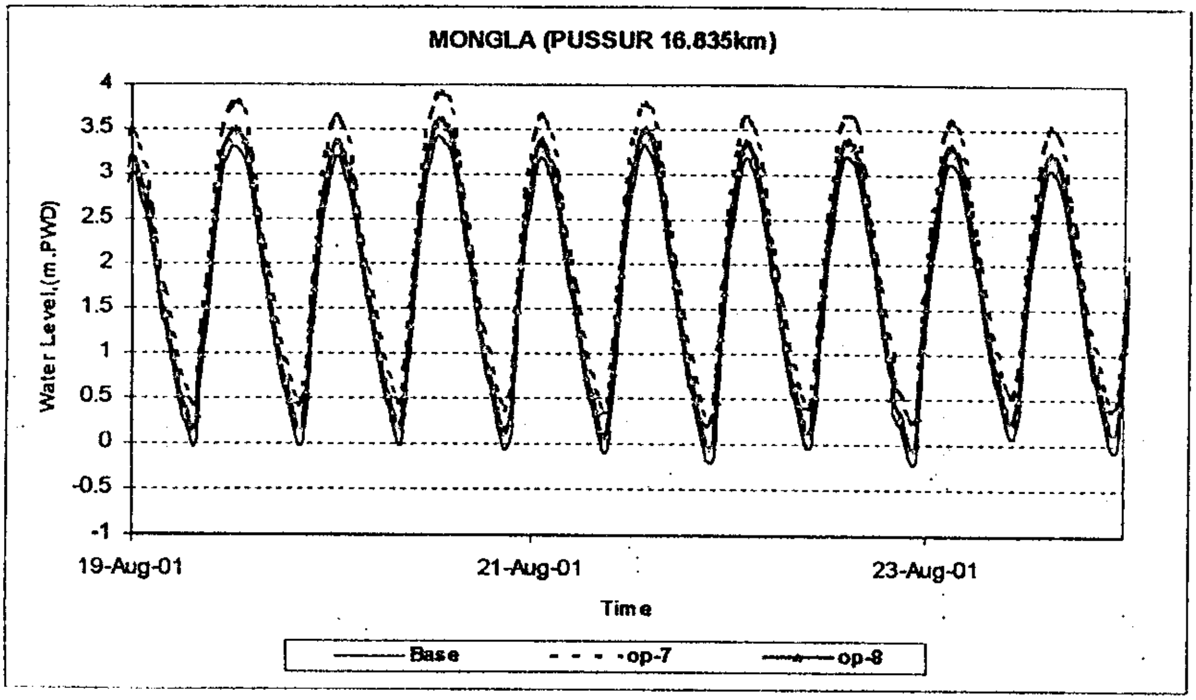


Figure 8.7 Water level changes at Mongla due to sea level rise (Option 7 & 8)

Figure H11 illustrates the maximum salinity distribution (March '02) condition in the Sundarbans due to 50 cm sea level rise. From the figure it can be observed that the >25 ppt salinity zone intrude into the Sundarbans with a greater extent; maximum increase of salinity occurs along the Pussur - Sibsa river system.

Impact on inundation pattern of the Sundarbans due to sea level rise has also been studied with the help of Flood Map. For the study, the updated DEM of the Sundarbans, based on FINNMAP data, have been used. For base condition the inundation pattern of the Sundarbans has been presented in Figure H12 & H13. Flood maps were generated for two times i.e., at 12:00 hrs and 13:30 hrs of August '01. The times have been selected during ebbing of a spring tide at Hiron Point (Figure 8.9).

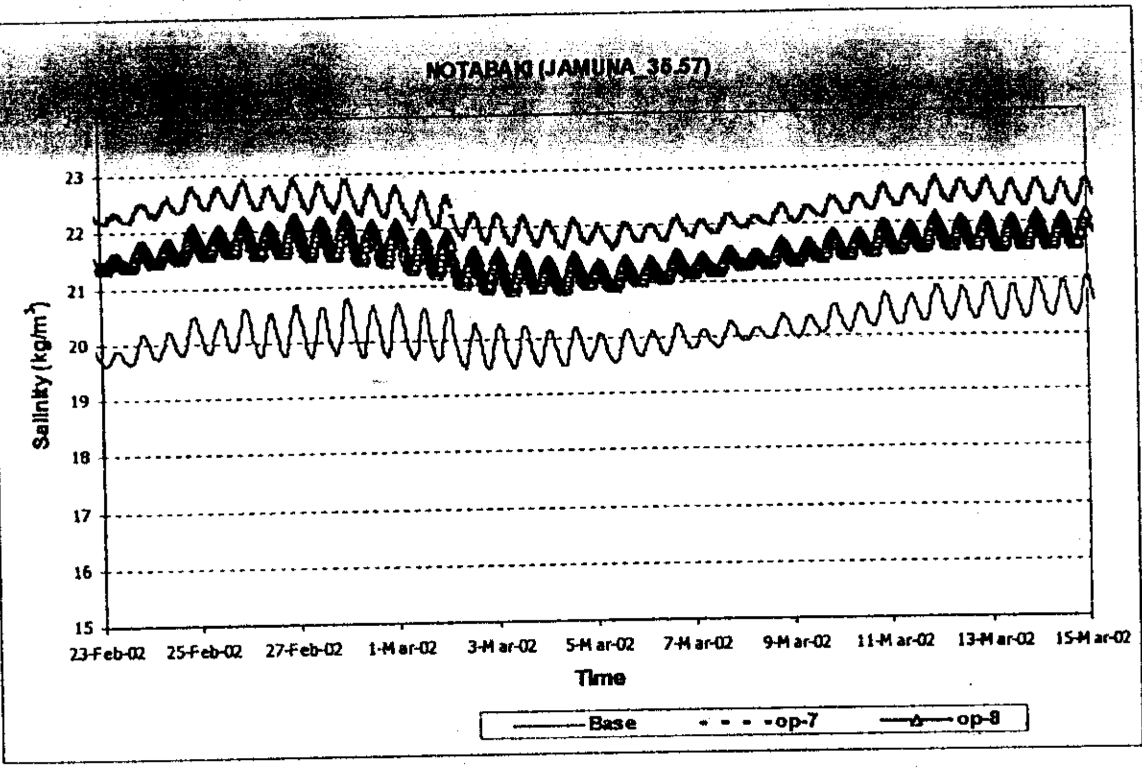
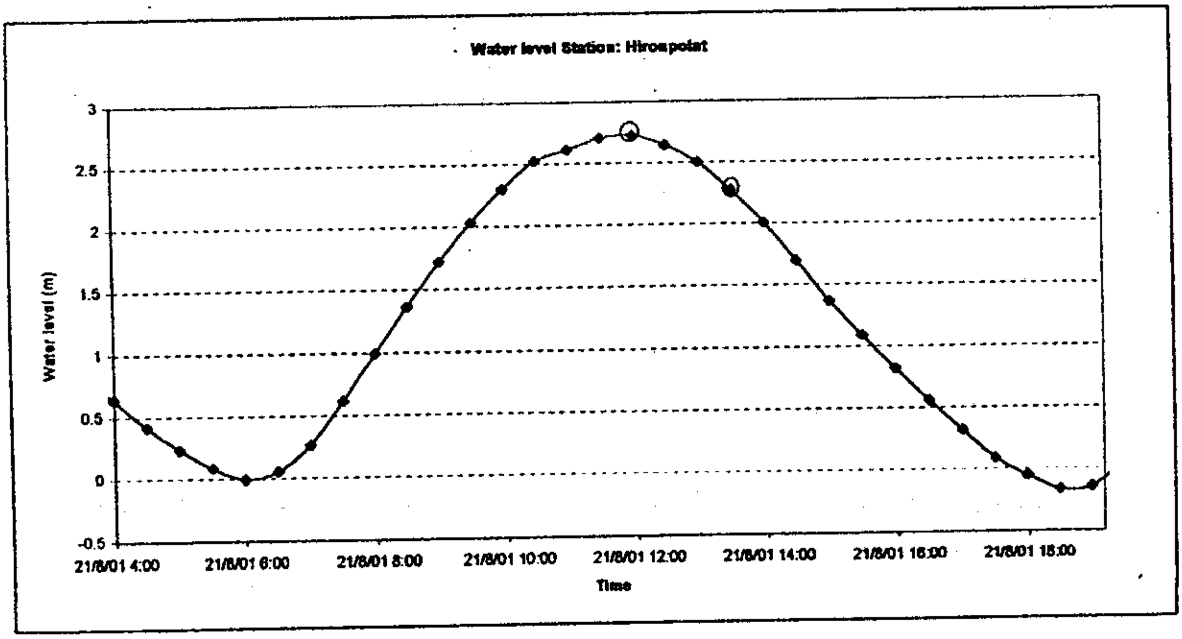


Figure 8.8 Increase in salinity at Notabeki due to sea level rise (Option 7 & 8)



The inundation pattern on 21st August 2001 at 12:00 PM due to 20 cm sea level rise has been shown in Figure H13 (Option 7). Comparing with the base Figure, higher inundations, which are obvious, can be noticed.

Option 9: Improvement of Kharma Khal Navigability

Kharma Khal is the upper part of the [illegible] with the Mirgamari river near Chandpai (Figure H14). At present the Khal is [illegible] dead due to heavy siltation on the bed and bank. In the past this Khal was navigable, which was used by the forest department for communicating different forest offices situated around this area. At present, in some places, the Khal is totally dried up or in some portion a narrow strip of water can be observed during high tide. To see the impact of excavation, one dredged section was included in this portion of the river. Several option scenarios have been tested with the dredged Kharma Khal. The options are as follows:

Sl. No	Option description
Base	Base condition: the 2001-02 hydrological year
Option 9a	Dredging of Kharma Khal only
Option 9b	Dredging of Kharma Khal and Dhansagar-1 Khal
Option 9c	Dredging of Kharma Khal, Dhansagar-1 Khal and connecting the Kharma with Sela gang through a dredged channel

The longitudinal profile and dredging section of the Kharma Khal has been presented in Figure 8.10 and 8.11. In Option 9a the dredged section of the Khal is incorporated into the model. Analysing the model results the changes in hydraulic conditions of the Khal can be observed. Figure 8.12 illustrates the increased flow through the Khal due to excavation. From Figure 8.13 it could be observed that after excavation, velocity of the flow would increase, which is likely to erode the deposited sediment, and would help keeping the channel open.

In Option 9b the Kharma Khal was connected with Gashia Khal situated northeast of the Khal, to do this the dredged channel of Dhansagar-1 Khal was incorporated into the model along with the dredged Kharma Khal. To increase more flow circulation, the Kharma Khal was connected with Selagang by excavating an existing shallow creek (named Kharma 1 in the model), and this analysis was done in Option 9c.

The impact in water level and in discharge during monsoon period can be observed in Figure 8.14 & 8.15: in Figure 8.14 maximum and minimum water level has been drawn for a spring tide at different chainage of Kharma khal. Figure 8.15 illustrates the same feature for discharges. An increase in tidal range of approximately 1.6m, 1.7m, and 2.6m have been observed due to option 9a, 9b and 9c respectively. The net flow also has been increased due to different options; the net flow increased by the amount of 3.7 m^3/s, 3.6 m^3/s, 3.2 m^3/s for option 9a, 9b, and 9c respectively.

It can be concluded from the study that when only the Kharma khal is excavated, it would increase the tidal range & discharge to some extent. But when the khal is connected to some major rivers through cutting some channels, the situation improved, tidal range increased with higher values. But for detail understanding of the process sedimentation study of the khal should be carried out which would be useful in identifying a long-term sustainable solution for the sedimentation problem.

Impact on salinity due to dredging in the Kharma Khal has also been studied. Insignificant changes in the salinity of surrounding rivers have been noticed due to this option. The salinity near Mrigamari seems to increase slightly due to incorporation of dredged channel at the Kharma Khal.

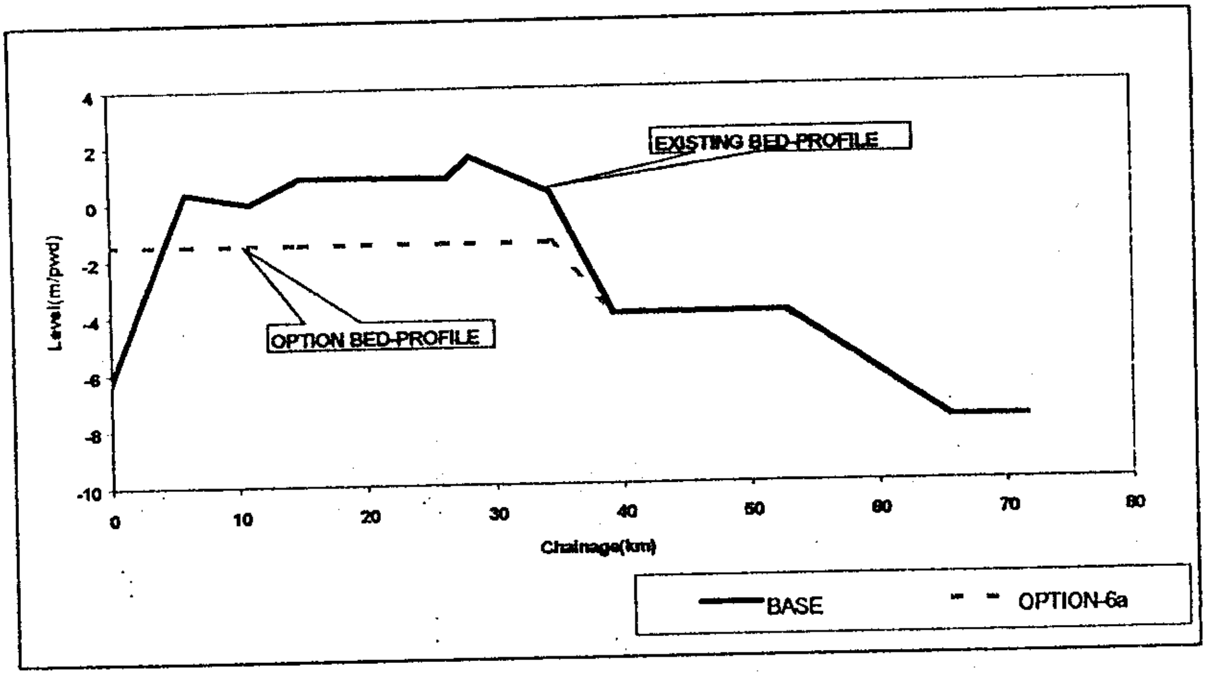


Figure 8.10: Longitudinal bed profile of Kharma Khal (upper part of Bhola River) before and after dredging

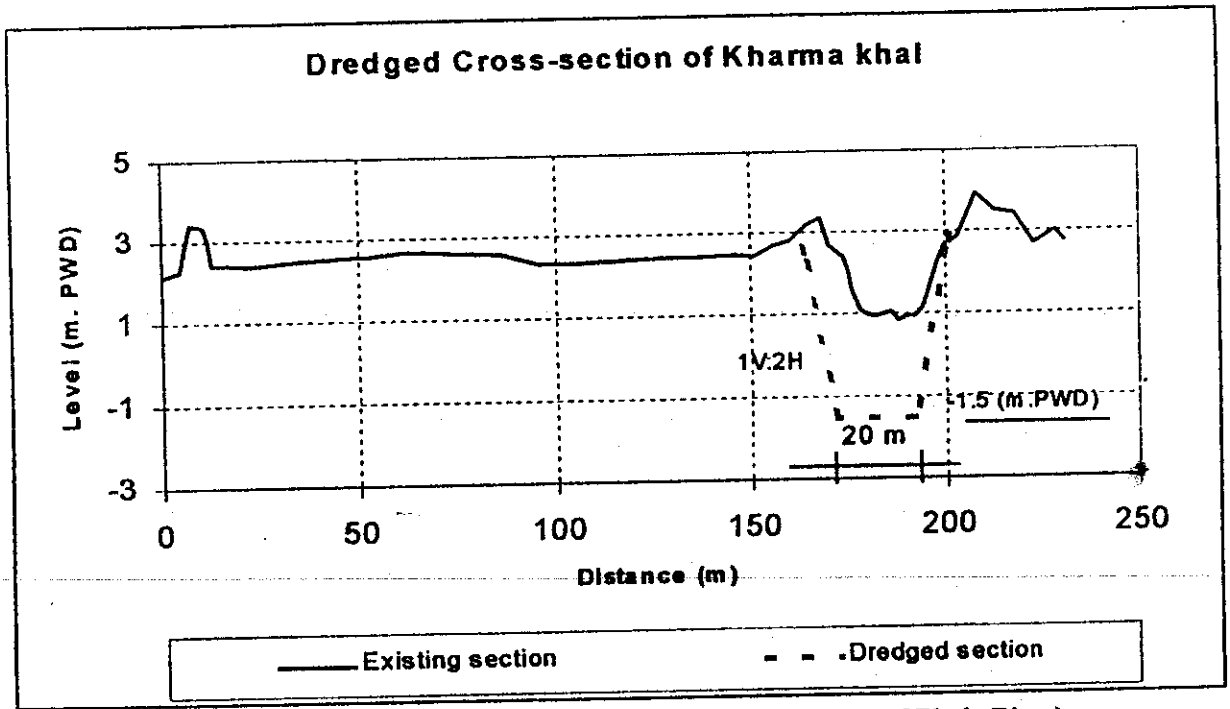


Figure 8.11: Existing and dredged section of Kharma khal (upstream of Bhola River)

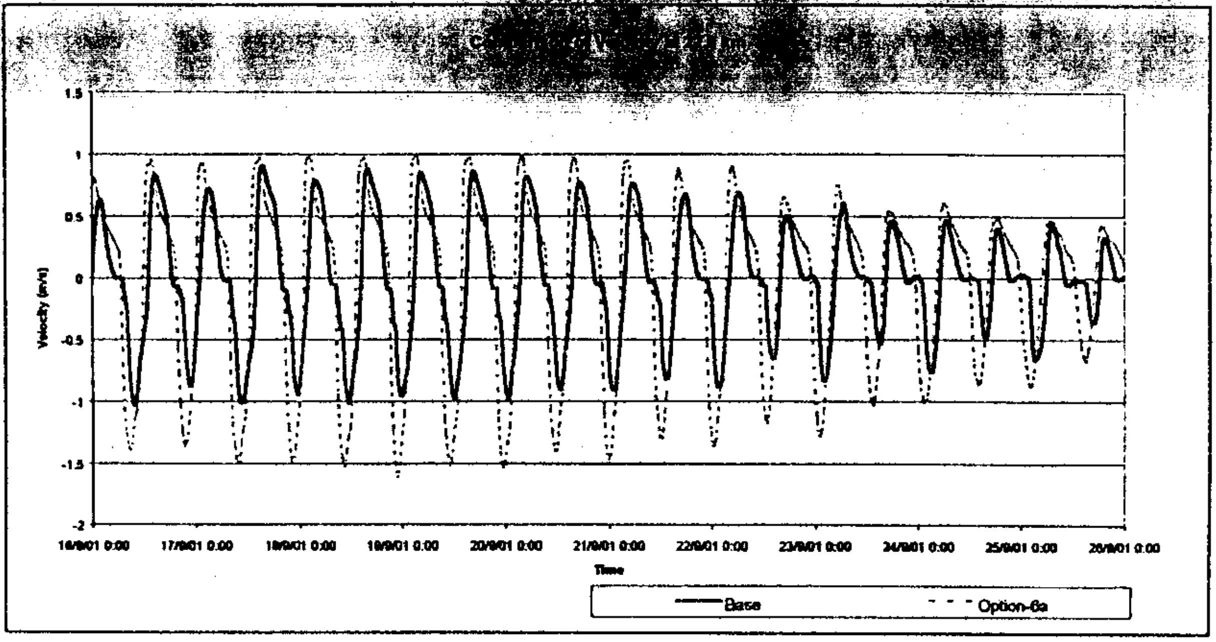


Figure 8.12: Discharge through the Kharma khal before and after the dredging

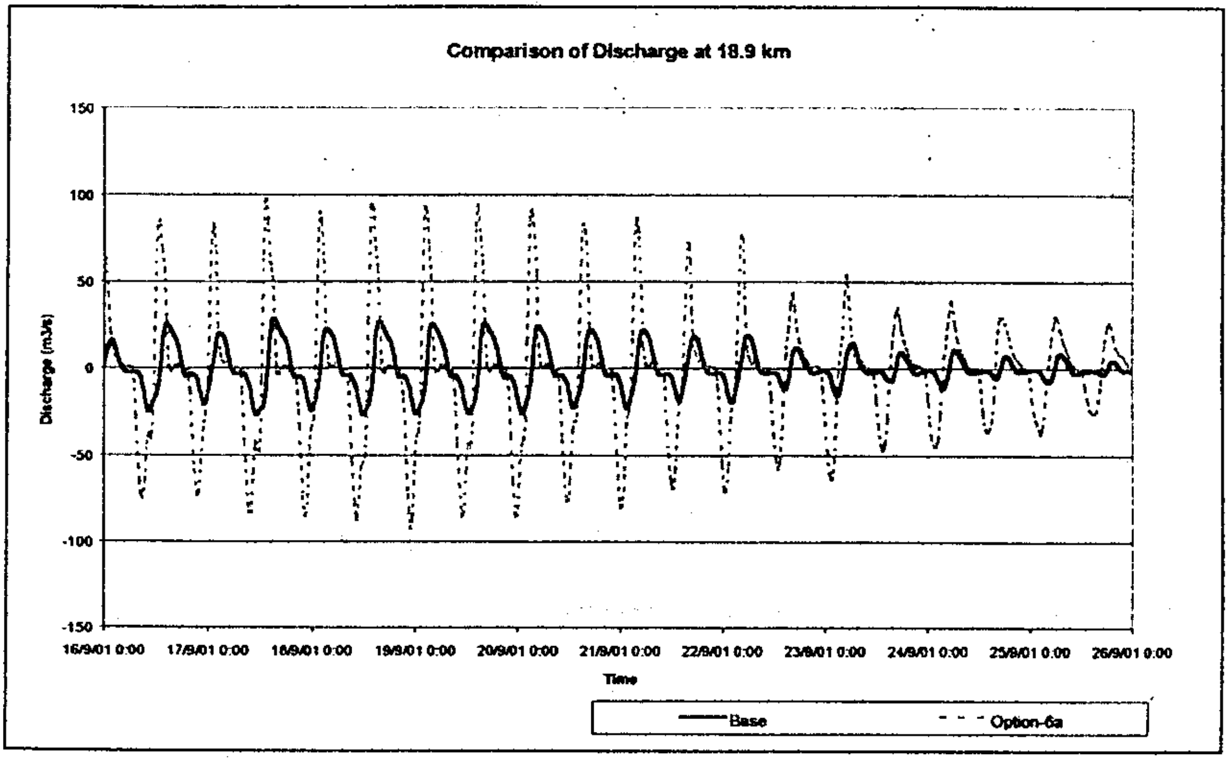


Figure 8.13: Velocity changes in the Kharma Khal before and after the dredging

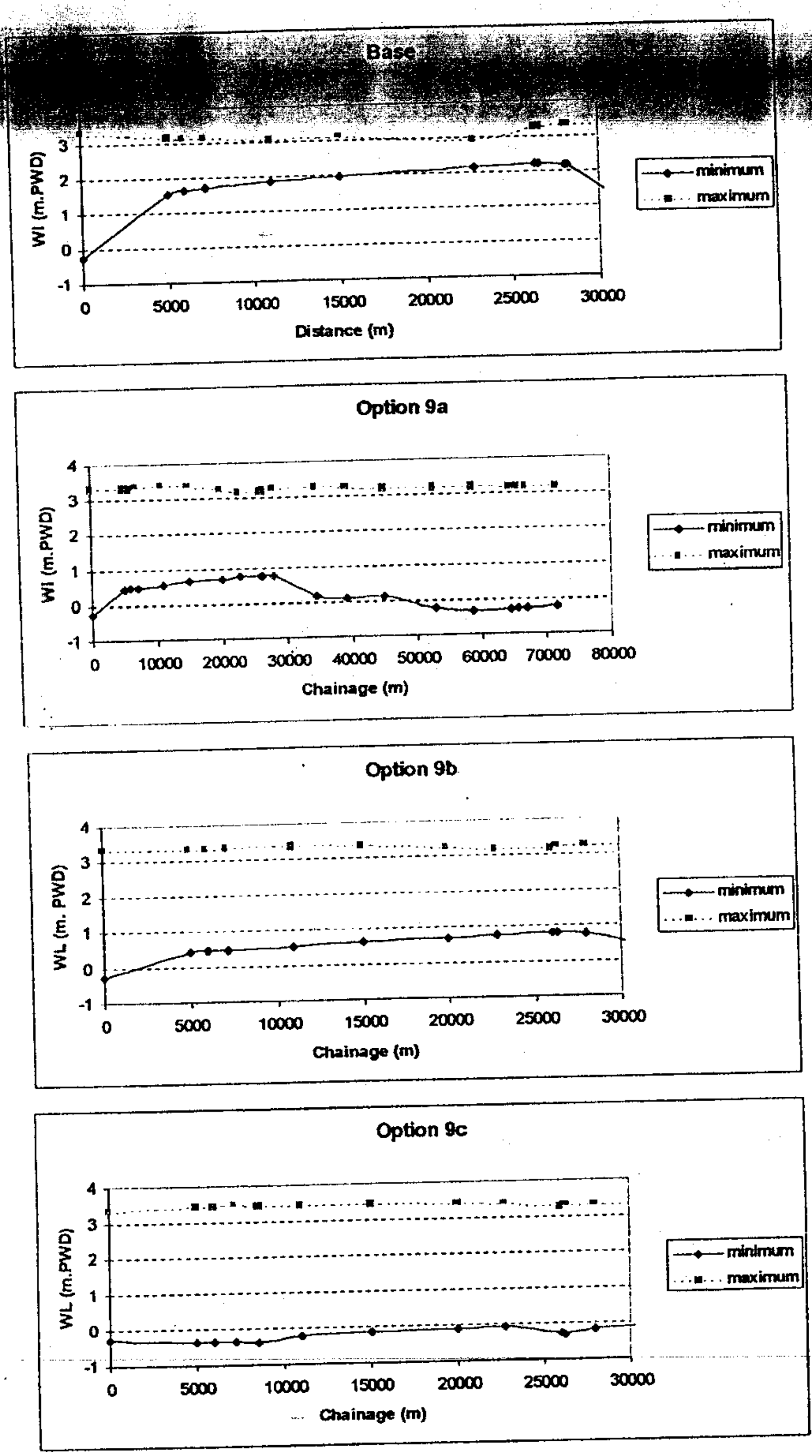


Figure 8.14: Variation of tidal range in the Kharma khal due to different options

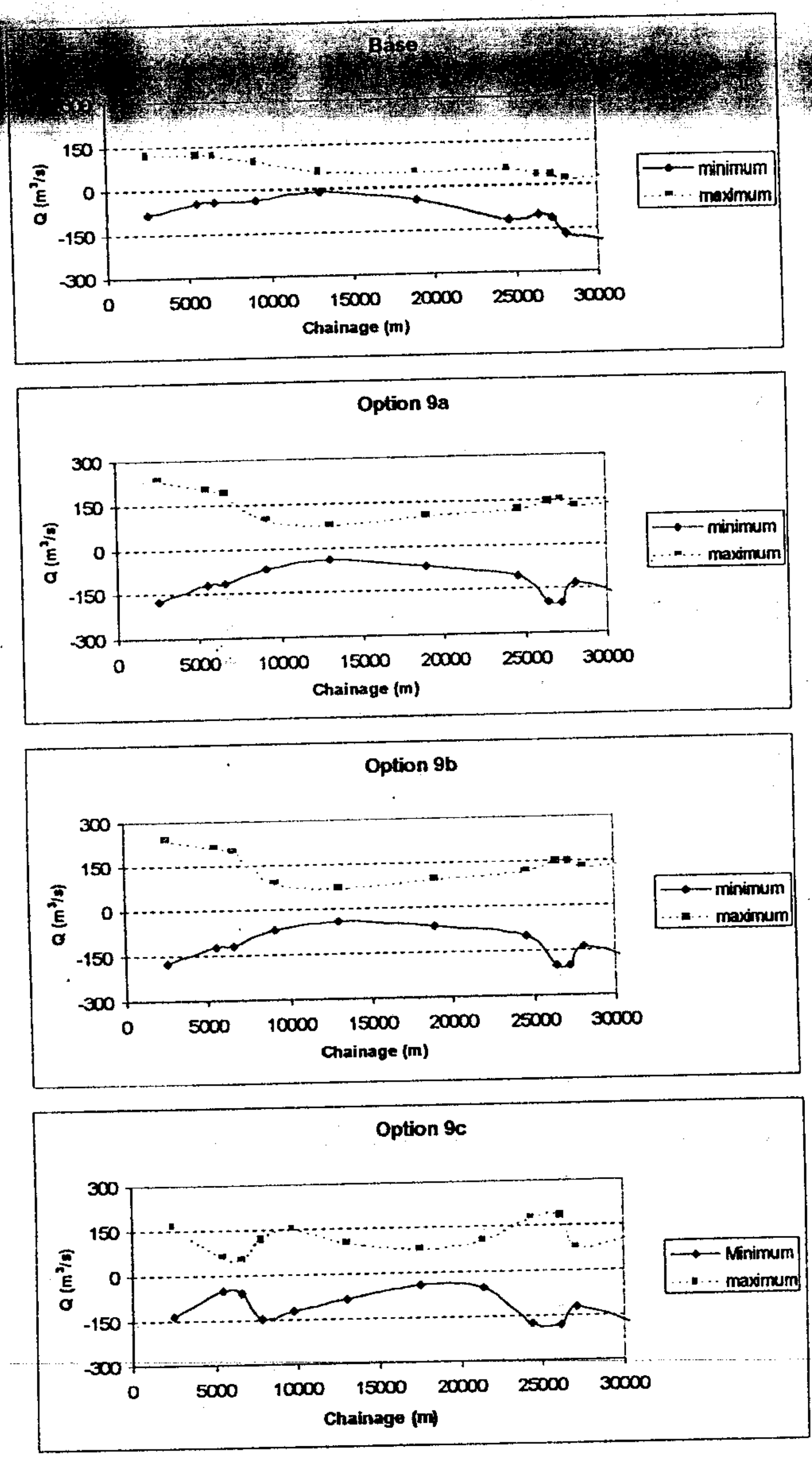


Figure 8.15: Variation of discharges in the Kharma khal due to different options

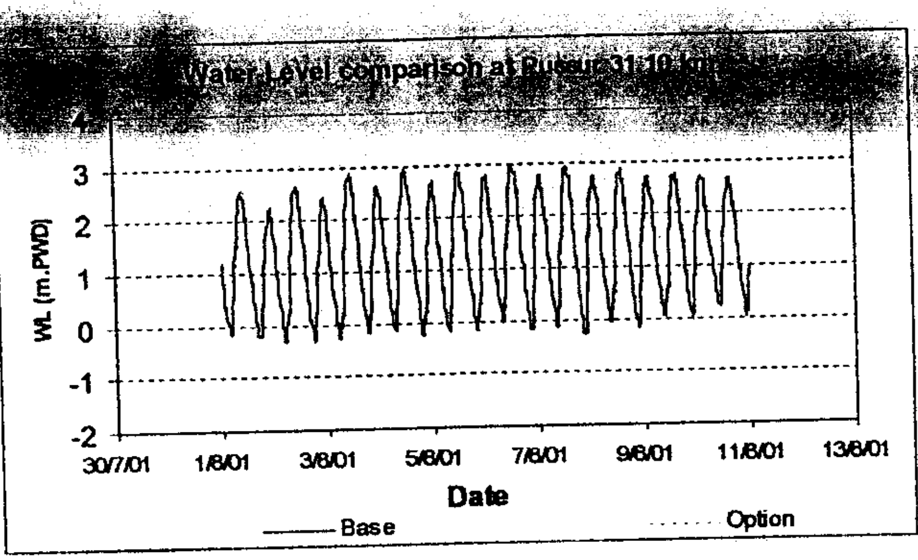
Option 10: Closing the intake of Mrigamari River

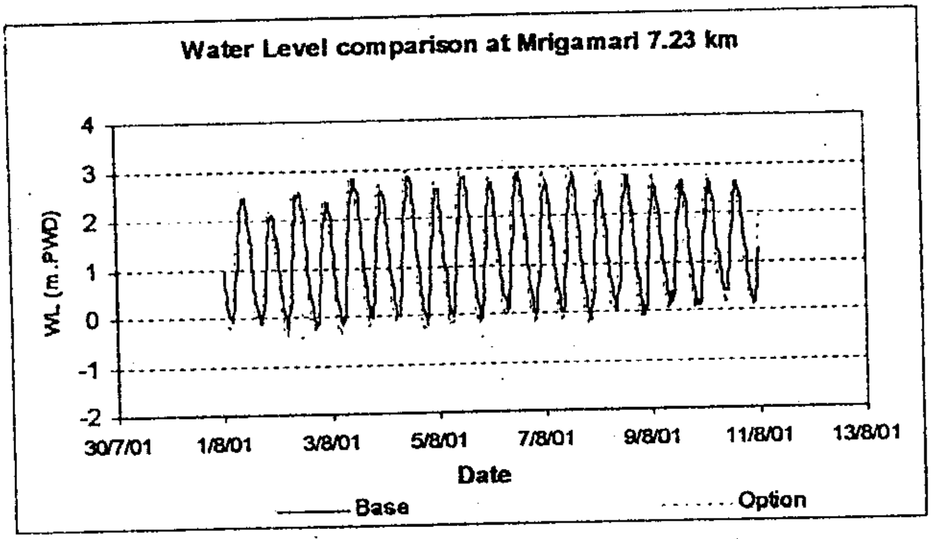
The Mrigamari River is a connecting channel between Pussur River and Selagang inside the Sundarbans. It is connected to Pussur River at chainage of 31 km and at the downstream it is connected to the Selagang. It is evident from the comparison of 1994-95 cross-sections with the present one (2001) that the mouth of the Mrigamari with Pussur is gradually being raised and constricted by siltation. So, in future there is a possibility that the Mrigamari River may be disconnected from the Pussur River. To see the impact of the closing, one option has been tested disconnecting the Mrigamari from Pussur River in the model network. To see the impacts due to this change, the water level, discharge and velocity have been compared for the existing and changed condition in Mrigamari and surrounding rivers. The comparisons are presented in Figure 8.16, 8.17 and 8.10

Figure 8.16 illustrates the water level changes at different locations during monsoon 2001. In the Pussur there is no change, but in the Mrigamari river there is a slight increase of tidal range. As such, increased flooding can be expected in the area along the Mrigamari River. The changes in discharge have been presented in Figure 8.17. Discharge decreases in the Mrigamari River, the reduction being the maximum near the closed end and gradually the effect is reduced towards the Selagang. The discharge in the Pussur River has been compared at upstream and downstream of the confluence point. There is no change in discharge at the upstream of the confluence, but at downstream of the confluence there is an increase in the discharge. This phenomenon indicates that some flow of the Pussur River is usually diverted to the Mrigamari, but when the mouth is closed, all the flow is following the Pussur River alone. The same trend has been observed in velocity comparisons (Figure 8.18).

From the above discussion, it can be concluded that there is little impact on the water levels due to the closing the mouth of Mrigamari River. But the changes are remarkable with respect to discharge and velocity, especially in the Mrigamari River as well as in the upstream part of the Selagang. When velocity would reduce, there is a possibility of increased siltation in the riverbed. So, once the mouth of the Mrigamari River is closed - the effect would be gradual siltation along the rest of the river length; this tendency of siltation would propagate towards the Selagang.

The impacts due to the closing of the Mrigamari River mouth, as discussed above, are all based on the results of a one-dimensional hydrodynamic model. In reality, it is unrealistic to conclude about the siltation process in a dynamic river system with only the results of a hydrodynamic model. A cohesive sediment transport (CST) model for the river system, developed with observed data, needs to be used to study the siltation process in detail before drawing any inference of practical utility.





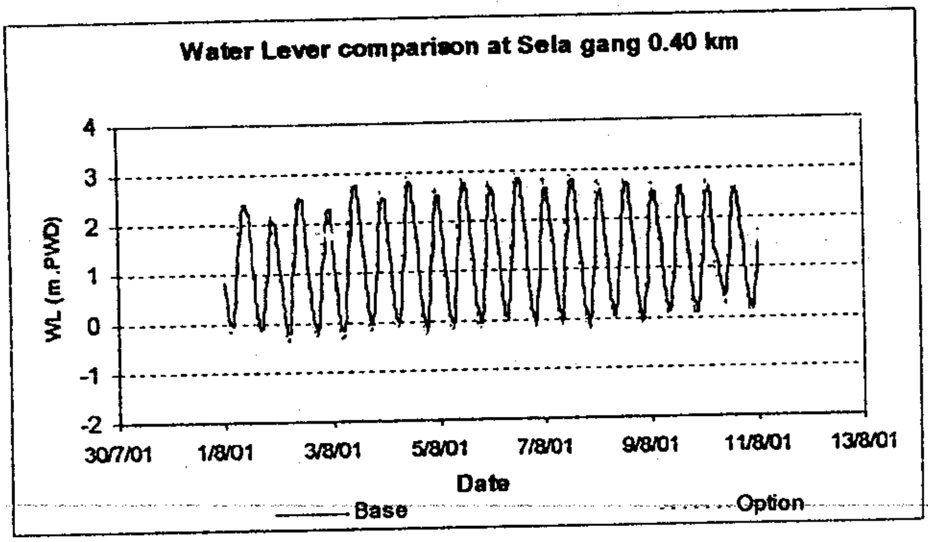
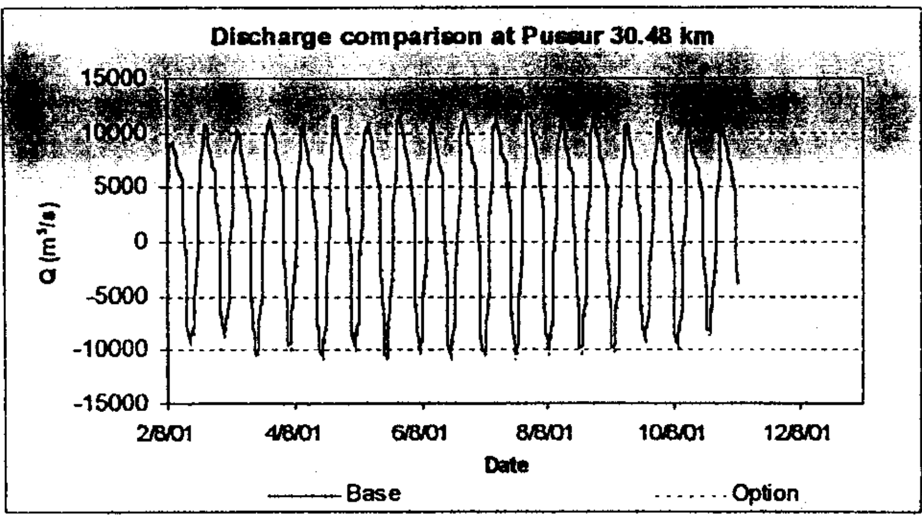
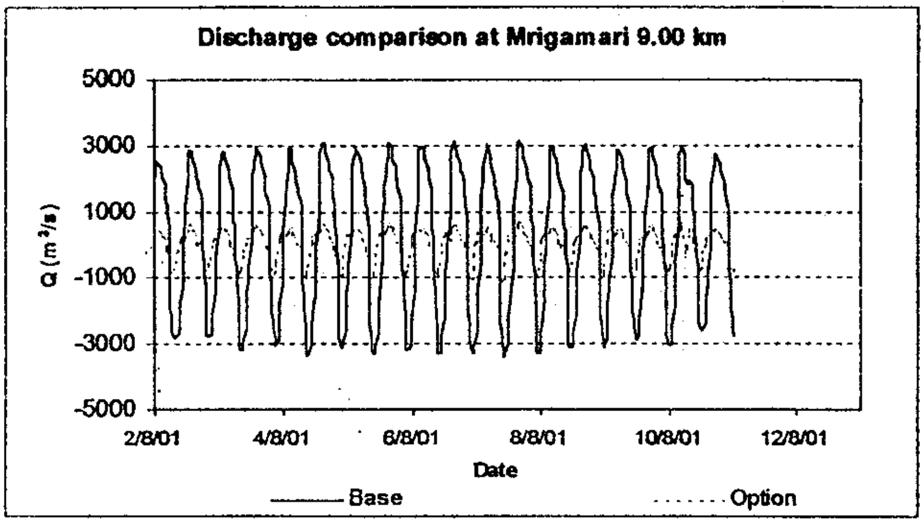


Figure 8.16: Changes in water level in different due to closing the intake of Mrigamari River





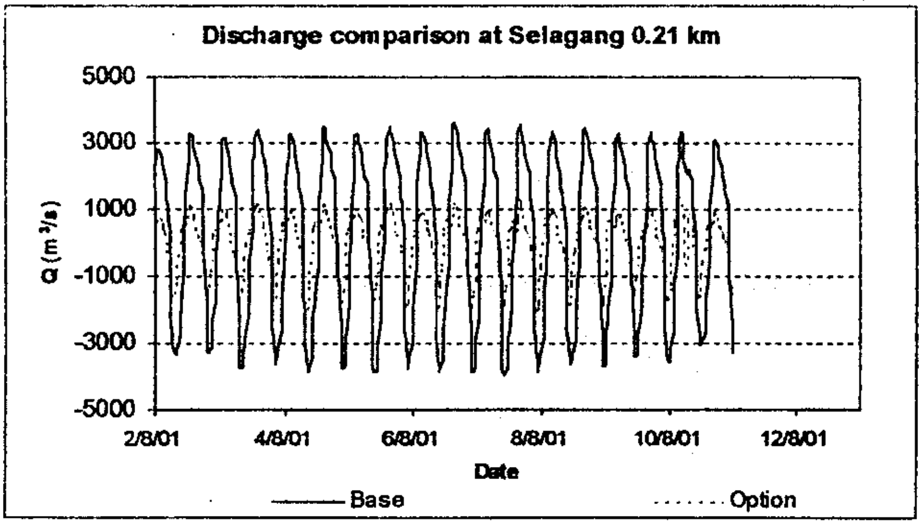


Figure 8.17: Changes in Discharges at Mrigamari due to closing the intake of Mrigamari River

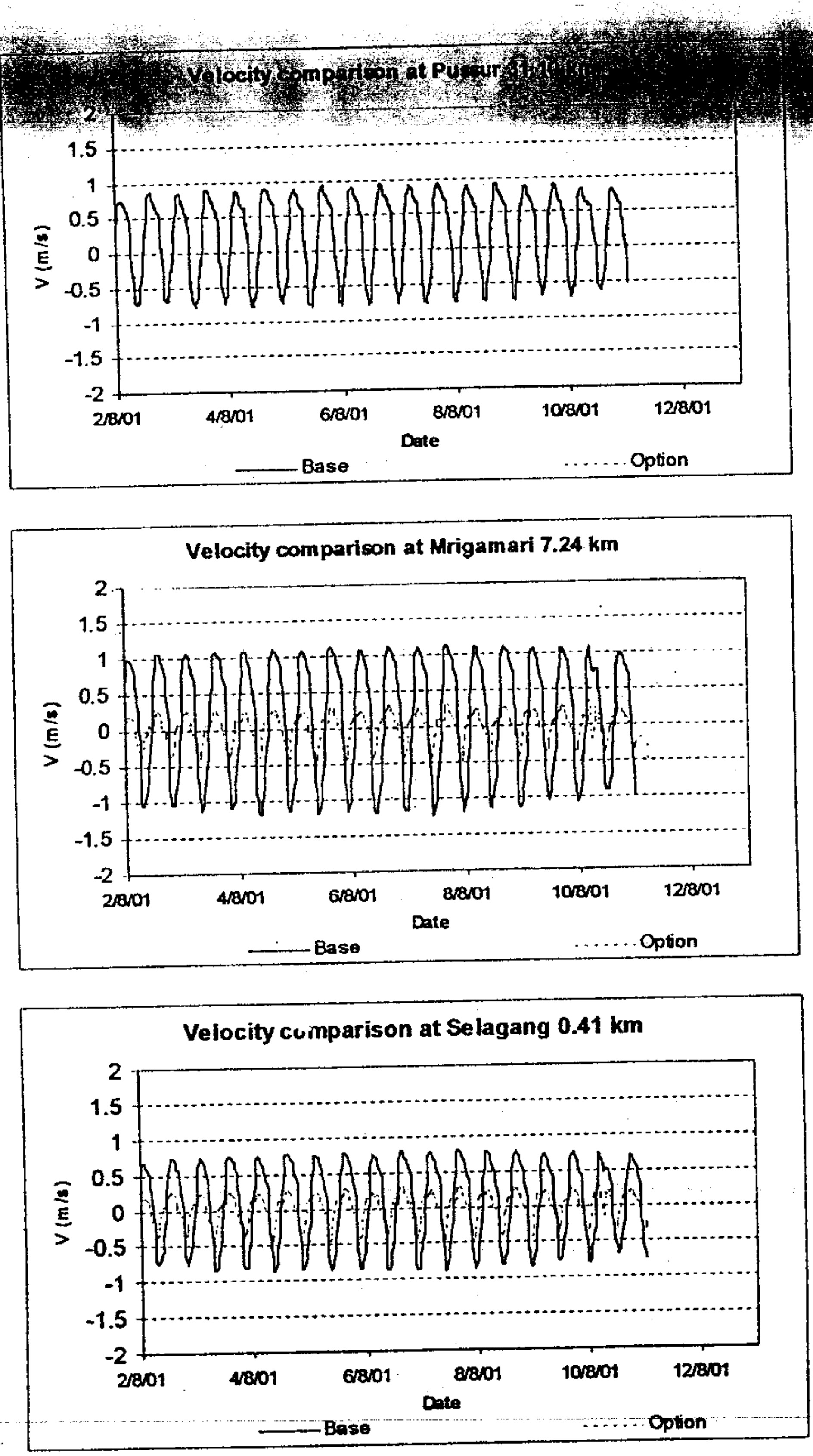


Figure 8.18: Changes in Velocity at Mrigamari due to closing the intake of Mrigamari River

8.2 Comparison of option results with historical data

Salinity of the rivers of Sundarbans and surrounding area has been simulated for different option scenarios (option 1 & 2) with the aid of salinity model. From the option study it is obvious that Gorai flow has great influence in the salinity of the southwest region. However, the reliability of the option results still may be a question because calibration of the salinity model is not good in all rivers. But for this reason it should not concluded that the option study is meaningless, because the option model contains the same limit of errors as that of base model. So the salinity model can indicate the relative impact on salinity due to different upstream flow conditions. As the options are the scenarios of the future, there is no direct way to compare the accuracy of the forecast. However, in an alternative way, the impact of Gorai flow on the salinity of several stations in the region has been studied using historical data analysis and comparing it with the model results.

The Gorai flow data in the Gorai Railway Bridge of different years, for the period of 1989-2000, have been collected. The salinity data for the same period is available for Khulna and Mongla stations. From the time series of Gorai flow, the minimum discharges for different months have been determined. Also, the salinity for the same month for Mongla and Khulna stations has been compiled. Salinities of Mongla and Khulna stations for the month of February and March have been plotted against corresponding discharges of Gorai River. In the option study, salinity in different stations have also been determined for different flow conditions in the Gorai River with the help of salinity model. Gorai flows and corresponding salinities of Mongla and Khulna stations have been plotted in the corresponding Figures. All the plots have been presented in Figure 8.19 & 8.20 for Mongla and Khulna stations.

Figure 8.16 illustrates the variation of salinity at Mongla due to different flow in the Gorai River. The historical salinity data indicates that there is a relation between Gorai flow and salinity of the region; a decreasing trend of salinity can be observed due to increase in Gorai flow. The model results also show the similar trend but there are some differences in the values. Figure 8.17 illustrates the same features at Khulna station. There may be some causes for the differences. For example, the model is based on the present physical condition of the rivers and flows in the region. But in the past there may be some changes in physical conditions of the rivers compared to the present situation. For example, the Atharobanki River used to carry fresh water flow from Gorai-Modhumati system towards Sundarbans, but now-a-days off take of this river is deteriorating by siltation. Moreover, the Mongla Nullah near Mongla has also been narrowed down by siltation presently; so the flow circulation in that area has changed.

So there may be some differences due to the changes in physical characteristics of the rivers in the region. However, for both the stations model data are within the range of historical data.

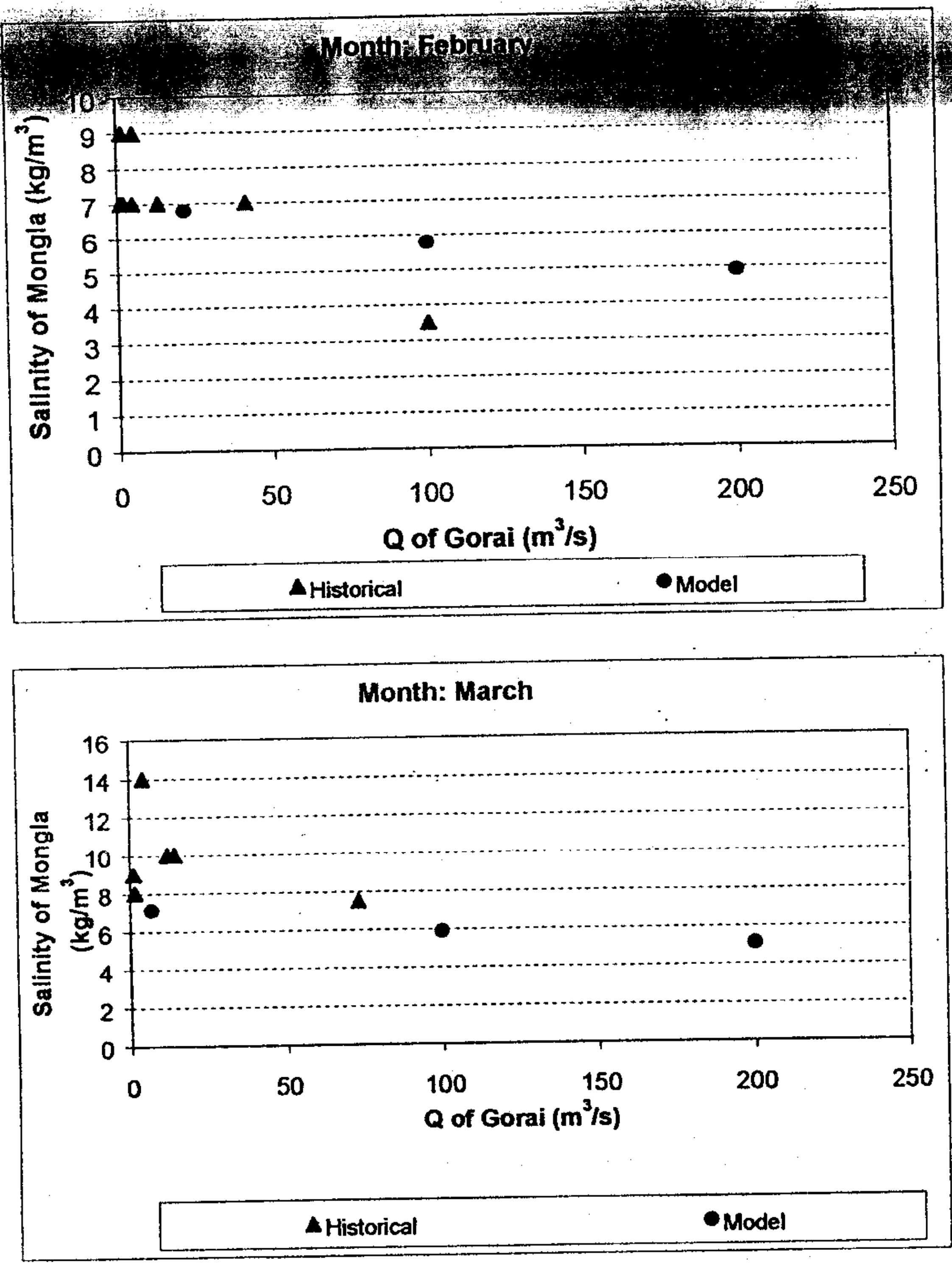
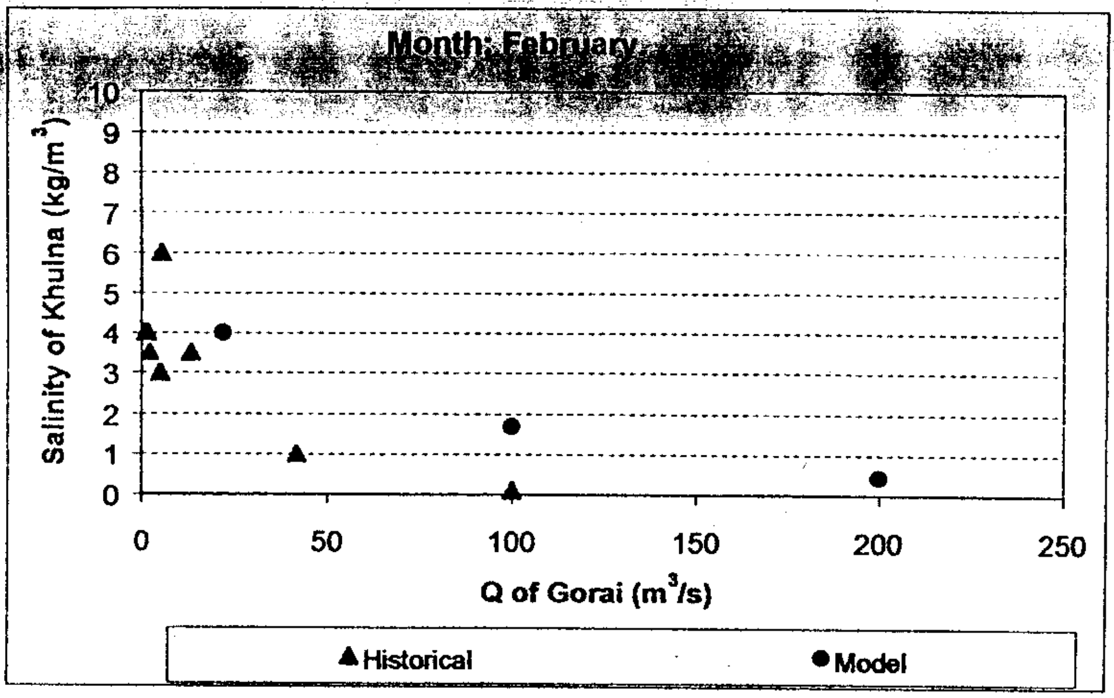


Figure 8.19 Salinity of Mongla station for different discharge of Gorai river



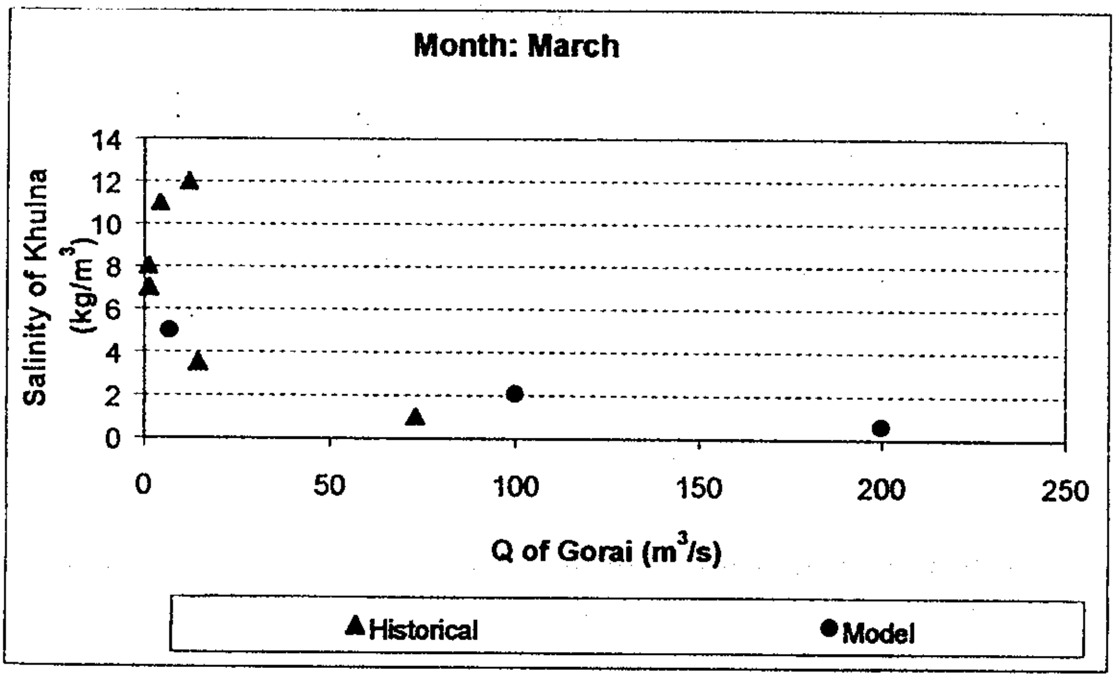


Figure 8.20 Salinity of Khulna for different discharges of Gorai River

9 DATABASE DEVELOPMENT

9.1 Introduction

A large volume of data, both in space and time frame, relating Sundarban Reserve Forest (SRF) and its Impact Zone (IZ) are being used to carry out Sundarban Bio-diversity Conservation Project (SBCP). The development of an efficient data management system or the MIS has been undertaken under this project. As a component of the whole MIS the Sundarban Water Information Management System (SWIMS) is being development by IWM with many of the parameters relating water and environment of Sundarban area, and finally be integrated with other systems developed under this project. The SWIMS has been designed as per the recommendations described in the MIS development plan on the SRF by the MIS Specialist in the Technical Report No. # 2. Interaction meeting was held with MIS staffs of SBCP and modification of the initial design has been made during progress of the project. A comprehensive manual of the software has been prepared to facilitate the user.

9.2 Data Types and Data Sets

The SWIMS contains hydrometric, topographic, morphological, water quality and other relevant data from different projects/agencies as well as data collected under this project. The entire collection of data has been divided into a number of groups based on their characteristics. Each group consists of a number of data types having several data sets. The data sets may have three different components: spatial, time series and attributes information. The time series and attribute data are tabular data and stored within the database as tables. Spatial or geo-location based data are stored in their native file formats in a directory-file hierarchy manner. These data are directly retrievable through the interface application. The major data types being stored in the database are given below:

- Administrative Data
- Water Level
- Salinity
- Sediment
- Water Quality
- River Morphology
- Model outputs

9.3 SWIMS Design Overview

At present SWIMS has been developed with MS Access 2000 as backend data server and Visual Basic application in the front end. Geo-referenced data are stored in their native software formats and maintained through Directory-File hierarchy manner considering data types and relevant software to be used for data retrieval.

Provision is there to keep meta information that holds sufficient descriptive information of all data sets. The meta information system maintains the following information about any data set.

- The format in which the data is stored
- The classification and coding to be used
- The source and ownership of the data

- The reliability and accuracy of the data
- Spatial and time extend of the data set

A number of user interface tools have been developed to facilitate hierarchical navigational search, time series and non-time series data display both in tabular and graphical formats, map or image display of different project features. The system provides extensive plotting facility of data with an ActiveX charting control. Overall development environment is given below:

Platform	: Windows9x/NT/2000
Database	: Microsoft Access
User Interface	: Visual Basic
Charting	: Tee Chart Pro ActiveX Control
Mapping	: Map Objects ActiveX Control

9.4 Application Tools Developed

All the relevant data of the Sundarban area are being stored within the database of the SWIMS. The data can be accessed or retrieved for different purposes. Some of the proposed tools have been developed through which data can be accessed or retrieved for display or analysis. The tools have been conceived and designed as per the suggestions of the associated officials. Interaction and technical discussions have been done with SBCP officers. They have given their ideas to modify/upgrade some of the tools and to incorporate new tools, which will be helpful in their activities.

9.4.1 Generic Query and Display Tool

The Generic query and display tool is a very simple interface application that can be used to display both spatial and non-spatial data of SWIMS. It is useful for both general people of the projects or the forest department and the advanced level users/planners. It facilitates navigational search of different data layers and display the selected layer with few clicks. Superimposition of different spatial layers can also be done with this tool.

This tool works interactively between spatial and time series data sets. For example, if hydrometric station network is displayed on the view window, by clicking a particular station time series plot of that station of the selected data type can easily be seen both in tabular and graphical forms on another window. This Tool has been developed in Visual Basic with MapObjects and TeeChart Pro ActiveX Control.

9.4.2 Time Series Tool

The time series tool deals with exclusively different time dependent data sets, such as water level, discharge, rainfall, evaporation, etc. It has extensive plotting facility to plot single station hydrograph, multiple-station hydrograph super-imposition for same time span and multiple year hydrograph super-imposition for same station. Historical trend of time series data is also possible. Tabular display of data for a given time span can also be seen. Tabular display can also be done by summarizing data in various combinations of functions and intervals, such as, monthly maximum, monthly minimum, dry period minimum, wet period maximum, etc.

9.4.3 Non-time Series Tool

This tool deals with non-time series tabular data, such as river cross section in terms of distance and reduced level. It facilitates both tabular and graphical display of selected cross section. Super-imposition of cross sections is also possible with this tool. Besides river bed profile (longitudinal profile) and transect line of the cross section survey can also be plotted.

9.4.4 Map Viewer

The map viewer shows different previously generated maps, such as project location with other pertinent layers, DEM, flood maps, etc. The map viewer shows the image data and related information cannot be extracted interactively. Flood maps are generated from model outputs filtering the data for monthly maximum and minimum flood of three months of dry and wet seasons each. Similarly spatial distribution map or maps of different water quality parameters will be prepared and stored as image files to be viewed with this tool.

9.4.5 Reporting Tool

Reporting tool has been incorporated as per the suggestion given by SBCP officers during interaction program. This will facilitate to have status reports on data availability of different data sets, list of stations with location information of any data set, periodic report on different parameters for selected stations etc.

9.4.6 Export Tool

This tool has the facility to export data from the database into different predefined usable formats. This tool mainly works for time series and other tabular data. But it can be extended to export attributes from spatial data. Predefined SQL Query or Views will be made and be stored with in the database. Export definitions will be stored in the database as table.

In the inception report of IWM Advanced Analysis Tool was proposed which would facilitate online mapping facility and many other spatial analyses. But it would require ArcView GIS software with Spatial Analyst Extension for each computer from where it would be operated. It would be complicated to use as well for one who does not have excellent GIS knowledge. After discussing with SBCP officers the idea was dropped. Instead a set of pre-processed maps of different parameters for different time will be stored time to time as images and will be displayed by the Map viewer.

9.5 User Manual

A comprehensive user manual has been prepared for the SWIMS installation and operation. It will help the users to navigate through menus and update the database. The user manual is presented at Annexure I

10 INTERACTION AND TRAINING

IWM continues interaction with the client and [illegible] for improving the quality of outputs. As such frequent interaction with the Forest Department and the TAG has been maintained to understand the user's need of IWM monitoring and study. The FD staffs in the forest area have been trained for observation of the gauges and collecting samples for testing water quality and salinity. They have been trained in testing salinity and Dissolved Oxygen by Salinometer and DO meter both at office and field. The officials have been trained on the installation of water level gauges and data collection on pilot area. Training and technology transfer to the project staff is considered highly important on the view of continuing the monitoring programme with minimum external support.

The achievement so far made is shown in the Table 10.1.

Table 10.1 List of Training

Staff Discipline	No. of Staff trained	Field of training
MIS Staff	4	Updating/editing SWIMS Analysis of the data (some extent) Preparation Report Mathematical Modelling (Overview)
MIS Staff	4	Data collection Data Processing Data Quality Check
MIS Staff	2	Field survey in pilot area
Camp in-charge/Station Officer	6	Supervision of field sampling, preservation of samples, gauge reading
Forest Guard	30	Sampling and testing salinity of water, recording water level gauge reading

11 REPORTING

IWM has time to time published reports with the progress of work. Due to the inclusion of additional works, 2 additional reports submitted during October 2002 and February 2003. Accordingly, IWM submitted the Final Report (Draft) as per deadline fixed by ADB Missions during March 2003 in the shortest possible time. At that time it was not possible to make a comprehensive analysis of the data to address all the issues mentioned in the ToR. After receiving the report, ADB and FD made some valuable comments for further improvement. Accordingly this Final Report has been prepared. The reports so far submitted are given below:

1.	Inception Report	February 2001
2.	Half Yearly Report	August 2001
3.	Annual Report	February 2002
4.	Half Yearly Report	October 2002
5.	Annual Report	February 2003
6.	Final Report (Draft)	March 2003
7.	Final Report	August 2003

12 FINDINGS OF THE STUDY

The findings of this study could be summarised in the following:

- Eastern boundary of the SRF has been connected with the national datum (vertical reference) which has improved the model results in the Pussur system significantly;
- Salinity and water quality data collection have been conducted for the entire Sundarban area for a continuous period of more than one and a half year, which was never possible earlier;
- A Sundarban Water Information Management Systems (SWIMS) database has been developed. The data collected during this study and those from earlier studies has been accumulated in the same database and assessed in a comprehensive way to develop a historical trend for different indicators especially for salinity and sedimentation in the rivers;
- An assessment of the temporal and seasonal variation of tidal range has been made and a significant increase in the tidal range has been observed in the Pussur, Sibsa and Kobadak during the last decade;
- Fresh water flow in the Sibsa during the wet season has generally decreased after 1960; dredging in the Gorai offtake during 1999 – 2000 has been found effective to restore the flow for a short period;
- Assessments of sedimentation with the available cross section data shows that the rivers in the east are more vulnerable to sedimentation than those in the west; the data also shows that Mrigamari the connecting channel between the Pussur and Selagang is threatened with siltation; The results of option model shows that if the present trend of siltation in the Mrigamari continues there is a possibility of disconnection of the same from the Pussur which may ultimately lead to the dying up of the upper part of the Selagang.
- Assessment of the salinity for temporal and spatial variation has been made with a comprehensive set of primary data; the data collected in connection with the other studies have also been considered. However, most of those data covers only short period mostly in the dry seasons, in no way they covers round the year. It has been observed that the salinity in the eastern part is significantly less than that of the west. The rate of reduction with the onset of monsoon is also fast in the eastern part. While in the southwestern corner near Notabaki the response is insignificant.
- Augmentation in the Gorai flow reduces the salinity in the Passur and Sibsa, but has got minimum effect on the channels in the west;
- The model results show that increase of flow in the western rivers may reduce the salinity in the western part (Kobadak – Betna system) of Sundarbans. Even increase in wet season flow through the said system reduces salinity in the impact zone.
- Hydrodynamic computation of option models indicate prospect for improvement of the conveyance of Kharma-Bhola system. However, before going for any implementation measure dedicated cohesive sediment modelling study should be carried out in this respect.

- Organic pollution observed in the SRF waterways do not seem threatening at the moment, however, further monitoring should be continued to avoid any harmful occurrences;
- In few occasions Chromium pollutant has been found to exceed EQS limit in the western part (Kobadak, Nalianala, Arpangasia and Malancha) of the SRF;
- The topographic data of FINNMAP and the land level surveyed on the pilot areas show that land level inside the SRF area is higher than that inside the coastal polders in the vicinity; that indicates increasing threat of drainage congestion in the polder areas.
- Relevant staffs of the Forest Department have been trained in the hydrological and salinity monitoring. The MIS staffs of SBCP have been also trained in the operation and maintenance of the SWIMS database.

The data collection and analysis so far made provides an improve basis for understanding of the complex water eco systems of the SRF area. However, to be able to support the relevant user groups with a desirable level of confidence the monitoring and study should be continued for another two to three years.

13 RECOMMENDATIONS FOR FURTHER WORKS

The data collected under the current study and the analysis of the data by conventional as well as mathematical modelling provides good basis for understanding the water related environment in and around SRF. However, in order to address the needs of various study groups as observed during study period and also at the final workshop, an additional monitoring for at least two more years are required. This should also encompass Gorai as well as Kobadak-Betna contributing to the SRF impact zone. Further monitoring and study should include:

A. Sundarbans Area

Hydrological Monitoring

- Quantification of fresh water flow through direct measurement in the key rivers (Gorai-Rupsha and Kobadak-Betna systems contributing to the SRF impact zone and Pussur, Sibsa in the SRF area) during dry and wet season for two to three years. This will allow developing a relationship between changes in the external rivers of freshwater source and their relative contribution in to the SRF area.
- Continuation of measurement of rainfall for at least ten years to develop a relation between the rainfall patterns inside the Sundarbans with neighbouring stations.
- Development of relationship of tidal inundation with changes in soil salinity and relevant chemical properties for six representative sites (including present three) inside the SRF capturing data for two to three years.
- Development of tide database to monitor the changes in mean sea level in the Sundarbans by installing automatic tide recorder in the southern boundaries for a minimum period of two to three years. (Present mean sea level for Bangladesh is measured at the east coast only).
- Monitoring of the siltation of the identified vulnerable rivers at least 10 key rivers for next two to three years.
- Establish datum at the southern boundary in conformity with the national datum and connect the hydrological stations of the southern boundary of the Sundarban with the national reference.
- Update the present topographic map available from the FINNMAP survey through field truthing.

B. Sundarbans and the upstream area

Water Quality Monitoring

- Standard monitoring of salinity inside the SRF and the upstream channel of Pussur, Sibsa and Kobadak for two to three years at stations established in connection with this study.

- Monthly monitoring of organic pollution and DO level inside the Sundarbans at the current monitoring location and probable upstream point sources for two to three years.
- Seasonal monitoring of nutrient level inside the Sundarbans for at least two to three years.
- Seasonal monitoring of heavy metals (Lead and Chromium) at the places of high values like Pussur, Sibsa, Auro Sibsa, Kobadak, Madargang, Jamuna and Jafagang for few years.
- Development of relationship between presence of heavy metals in the river and neighbouring soil quality

Model Study

- Update the mathematical Hydrodynamic (HD) model of the SRF incorporating the latest hydrological data geo-referenced with the national grid and incorporating the internal channels in the SRF and generate reliable basis for water level flow and bed level changes.
- Update the salinity model with updated HD model and provide improved prediction of impact of probable development options.
- Update the Water Quality Model with updated HD model results and determine the changes of water quality parameter with the changes in fresh water flow.
- Extend further study and research like the recently completed Tidal River Management Study of the KJDRP area to minimise canal blockage and siltation and improve life security of the people leaving in the impact zone.

C. Gorai Corridor

As the only significant sources of fresh water to the Sundarbans, monitoring of the Gorai River should be integrated with the future studies.

- Measurement of X-sections at the Gorai offtake and at locations identified during the past studies (GRRP).
- Additional measurement of flow through the Gorai during wet and dry season.
- Monitoring the salinity level at key locations across the Gorai-Rupsha to observe the salinity intrusion.

The data collection above for two to three years is expected to form a reliable basis.

D. Database Updating and Training

The Database developed during the current study is to be updated with collected data. Training of the FD staff is to be associated with data collection programme for continuation of data collection beyond the project period.

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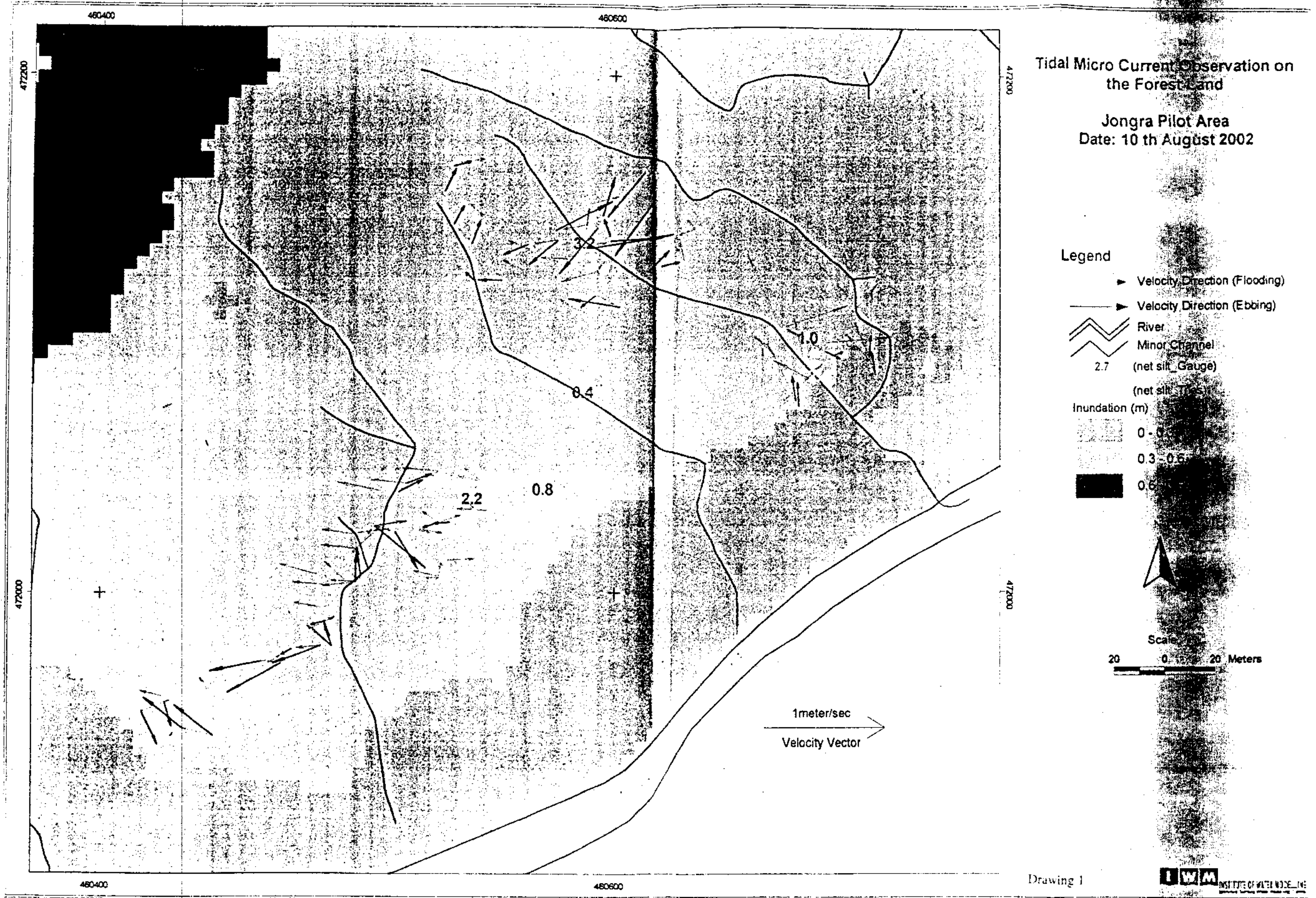
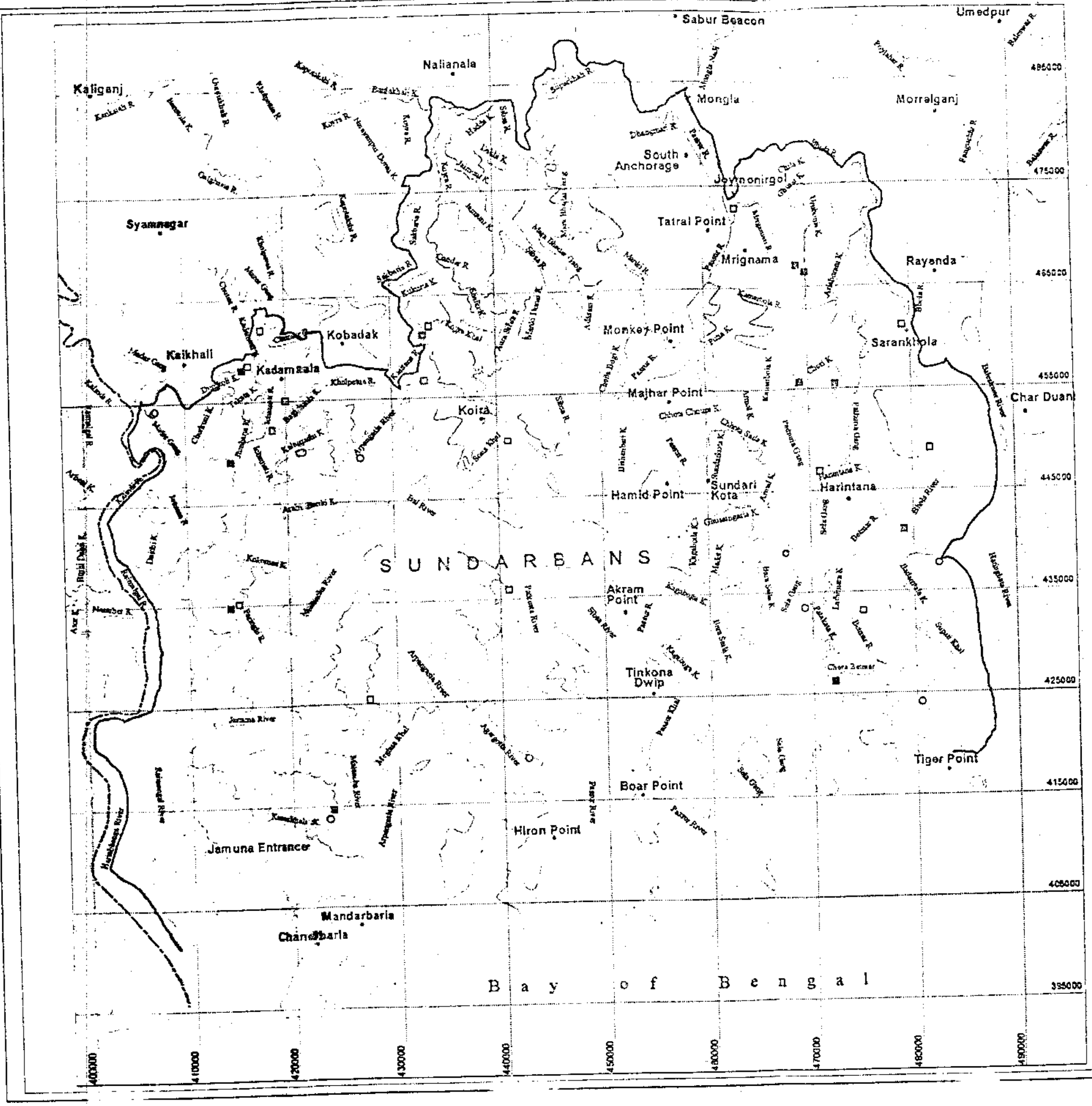

Tidal Micro Current Observation on the Forest Land
Jongra Pilot Area
Date: 10 th August 2002
Legend
Velocity Direction (Flooding)
Velocity Direction (Ebbing)
River
Minor Channel
2.7
(net silt_Gauge)
Inundation (m)
Scale
20
0
20
Meters
1meter/sec
Velocity Vector
460400
460600
472200
472000
3.2
1.0
0.4
2.2
0.8
IWM

Drawing 1



Erosion and Deposition at Different Rivers

Legend

- International boundary
- River
- Sundarban forest area

Erosion and deposition at cross section point

- □ Bed siltation
- □ Erosion
- ○ Erosion at right bank
- ■ No significant change
- ● Prominent scour at right bank

N

4 0 4 8 12 16 Kilo

Drawing - 2

Index Map

INSTITUTE OF WATER MODELLING

IWM

Appendix A

T3158-BAN(GEF) – Sundarbans Biodiversity Conservation Project
Outline Terms of Reference for Hydrological Investigations in the Sundarbans Reserve Forest

I. Background

1. The Sundarbans Reserve Forest (SRF) is a complex ecosystem comprising a diverse mangrove forest at the mouth of a coastal flood plain, crisscrossed by numerous rivers, channels, and ponds. The SRF provides habitat for a large number of flora and fauna, including more than 20 endangered species of mammals, reptiles, birds and fish. The survival of this ecosystem depends crucially on water – the level of salinity, tidal surges, pollution, wave action and other attributes. Long-term conservation and management of the ecosystem thus requires a much deeper understanding of its hydrological features, and human-induced changes therein.

2. During preparation of the Sundarbans Biodiversity Conservation Project (the Project), it was determined that Dhaka-based Surface Water Modeling Center (SWMC), established as an independent trust by the Ministry of Water Resources, was the only local agency with the expertise and experience to conduct such research. SWMC developed an early database of key hydrological variables in the SRF in the early 1990s under a UN-financed project, and has worked upstream of the Sundarbans under the ADB-financed Khulna-Jessore Drainage Rehabilitation Project and World Bank-financed Gorai River Restoration Project.

II. Outline Terms of Reference

3. SWMC will conduct research activities and produce analytical studies as specified below:

a. Through field surveys, data collection and mathematical modeling, SWMC will analyze current fresh water flows in the SRF from river and lowland sources, through a full cycle of seasonal variation. These results will be compared with those from earlier efforts to assess the severity in the decline in freshwater flows.

b. Assess the impact of human interventions, such as irrigation schemes, rural road construction and canal blockage, on freshwater flows and siltation. On the basis of these findings recommend mitigation measures such as culverts and bridges that may be funded under the community development component of the Project.

c. Assess the impact on freshwater flows and water quality caused by the gradual shift from rice farming to shrimp farming.

d. Model the siltation process on key rivers to project future water flows into the SRF.

e. Analyze the impact of tidal variations on seasonal forest inundations zones to assist wildlife ecologists and foresters in their studies of habitat and species migration.

f. Analyze topographical changes within the forest caused by siltation and build-up of biomass, to assist foresters in their understanding of the *Sundri* top-dying phenomena.

g. Analyze water quality and identify major pollutants and their probable course through the waterways and into the soils of the SRF.

h. Using computer modeling techniques forecast the impact of predicted sea-level rises on the key hydrological indicators in the Sundarbans.

i. Analyze salinity intrusion within SRF waterways in the dry and monsoon seasons and the probable impact of major projects such as the Gorai River Restoration Project on salinity intrusion.

III. Outputs

4. SWMC will produce or update a host of models and databases describing their research results, and produce color maps to illustrate key findings on siltation patters, salinity, drainage patterns, etc. Several months after mobilization SWMC will produce an Inception Report and circulate it for comments to the Forest Department and ADB. Semi-annual reports will describe ongoing activities and progress, and an annual report and final report will cover the analytical results of all research activities described above.

Appendix B

LOAN 1643-BAN(SF): SUNDARBANS BIODIVERSITY CONSERVATION PROJECT INCLUDING TA 3300-BAN AND TA 3158-BAN(GEF)

Aide Memoire of Loan Review Mission[1] (18-31 October 2001)

A. Introduction

1. This Aide Memoire describes the findings of a review mission (the Mission) which visited Dhaka and the project site in Khulna from 18-31 October 2001. During the mission, meetings were held with the Forest Department (FD) and Local Government Engineering Department (LGED), Royal Netherlands Embassy, and other partners including the World Bank, Surface Water Modeling Center (SWMC), World Conservation Union (IUCN), Palli Karma-Sahayak Foundation (PKSF), Bangladesh Rural Advancement Committee (BRAC), Food and Agriculture Organization of the United Nations (FAO), and the team of consultants working within the Technical Advisory Group (TAG). A list of persons met is shown in **Appendix 1.**

2. The specific objective of the Mission was to lay the groundwork and set objectives for the Project mid-term review mission scheduled for January/February 2002. As part of this, the Mission provided guidance to FD and the TAG consultants for preparation of the Mid-Term Report (due to be submitted before end-December 2001). In addition, the Mission reviewed progress, helped identify impediments to efficient project implementation, and assisted FD in its ongoing revision of the Project Proforma (PP). Visits were made to key sites within the Sundarbans Reserved Forest (SRF) and the impact zone.

3. The Project is generally making good progress, and this Aide Memoire focuses only on those critical activities for which the Government's attention is needed to help overcome identified obstacles to efficient implementation.

B. Mission Findings

1. Forest Resources Management

4. The ecological setting and the inherent dynamics of the Sundarbans wetland system are constantly changing and will determine the sustainability of any prescribed management practices. This needs to be reflected in a conceptual approach embodied in new policies and management strategies. Biodiversity and ecosystem integrity, however, will largely depend on the social organization of the extractors, individual decision-making and market conditions for certain products (e.g. modification of the current logging moratorium for selected tree species), institutional factors, and technical aspects in forestry operations. Above all, sustainability will depend on new policies and strict implementation of regulations,[2] including willingness on the part of FD to revise current revenue practices and policies.[3]

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[1] The Review Mission comprised Ian Fox, Mission Leader/Senior Project Specialist, Ms. Monowar Sultana, Social Development Specialist, and Mr. Michael Mastaller, Biodiversity Conservation and Applied Ecology Specialist/Staff Consultant. The Mission was assisted by Ms. Ferdousi Sultana, Gender Specialist/BRM.

[2] Examples are: observation of closed season for shrimp fry and mud crab collection, certificates and payments based on actual (quantified) catch or harvest, permissible gears, permissible NTFPs

[3] There is a need to explore an alternative revenue system based on taxation of the large commercial businesses using SRF products, rather than concentrating on revenues collected from mostly poor resource users.

5. Based on FD's integrated management plan for SRF, sanitation felling is needed to maintain healthy stands of *Sundri* and to help prevent spreading of the top-dying disease. Although the Government's current moratorium on tree felling has effectively curtailed over-exploitation of timber products from SRF, it also prevents FD from carrying out sanitation felling of *Sundri* suffering from top-dying. In addition, the affected trees represent a significant source of Government revenue and should be extracted and sold before the timber deteriorates. The Mission requested the Minister of MOEF to assist FD by obtaining an exemption of the moratorium in the case of *Sundri* sanitation felling in SRF.

6. There is an obvious need to revise management options for *goran* (*Ceriops decandra* and *C. tagal*). Currently regarded by the FD as a minor non-timber forest product, this mangrove species offers potential for social forestry silviculture aiming at charcoal production. The Mission recommends that a pilot project be initiated for this in line with the Project design.

2. Sundarbans Stewardship Commission

7. Following appointment of a new Government, the Mission requested the Government to reformulate the Sundarbans Stewardship Commission (SSC) and to convene a formal meeting with public advance notice and an agenda of issues. The Mission requested FD to set a date for the next SSC meeting, and to give sufficient notice to ADB, the World Bank, and other stakeholders so that their participation may be arranged if considered necessary.

3. Sundarbans Management Unit

8. The organizational structure for the Sundarbans Management Unit (SMU)/Forest Circle, Khulna has been under discussion for some time, and its finalization is now urgently needed as a prerequisite to finalization of the PP (see also para. 12). Hence, it has been agreed that FD will now hold internal discussions to formulate a *draft final* organization chart, and that it will conduct workshops among relevant stakeholders in November and December 2001 to achieve broad consensus on the *final* organization chart, including key posts and job descriptions. Particular attention will be given to (i) deciding how to incorporate into the SMU, if applicable, the Wildlife and Environmental Management Divisions created under the World Bank-financed Forest Resources Management Project (FRMP); (ii) determining whether or not to split the proposed Wildlife and Eco-Tourism Division into two separate divisions; (iii) providing effective linkages to the central level Wildlife and Nature Conservation Division; (iv) preparing an action plan to convert development budget positions to revenue budget positions to ensure SMU sustainability; and (iv) clarifying the role and responsibility of the Project Director (PD) vis-à-vis the Conservator of Forests (CF) within the Khulna Circle. Consideration is to be given to the possibility of creating a trust fund to finance operations in SRF. The TAG consultants are to provide assistance to FD for completion of the above tasks as necessary.

4. SMU Office Building

9. Architectural design of the new SMU office building has been prepared and finalized by LGED following review by FD. LGED has undertaken to complete the engineering design of the building and submit to ADB, by end-November 2001, draft tender documents for review and approval. The Government's standard local competitive bidding procedures will be used subject to confirmation by the Mission of their conformity with ADB's procurement guidelines.[4] On

[4] Para. 7 (a) of Schedule 4 of the Loan Agreement.

completion of tender evaluation, LGED will send an evaluation report and draft contract to ADB for review. Signing of the contract may not take place until ADB has approved the proposal for award as set out in the evaluation report. A copy of the signed contract will then be sent to ADB for registration into the loan account, issuance of a PCSS number, and determination of maximum amount of loan funds which may be drawn. Following receipt of ADB's notification of issuance of the PCSS, LGED may make advance payment to the contractor, either using its own Imprest Account funds or by requesting ADB to pay directly to the contractor. Similar procedures may be used for progress payments. Government's contribution to the cost of the contract would follow normal Government procedures for transfer of funds from FD to LGED.

10. Construction of the SMU office building is expected to start by January 2002 and to be completed within about 15 months.

5. Revision of Project Proforma

11. Due to various changes which have been introduced into the Project since its original formulation and inception, the PP needs to be revised.[5] This has been in process for at least the last 12 months, but has been constrained by a general lack of familiarity of both FD and TAG staff with the inner workings of the Project financing arrangements, lack of separation of GEF grant-financed activities from loan-financed activities, and inappropriate attribution of costs for certain items already procured. In accordance with recommendations of the July 2001 review mission, the international Natural Resources Economist was assigned in September 2001 to work for a period of 10 days in ADB's headquarters to update the cost tables. This work was completed in a generally satisfactory manner. Nevertheless, there remain some inconsistencies and anomalies which need to be resolved, and the Mission has undertaken to provide a more readily comprehensible presentation of all financing information as an aide to budget management. The Mission prepared a new loan allocation table setting out more clearly the percentages of reimbursement to be used in withdrawal applications, and undertook to obtain ADB's formal approval of this loan allocation table. The Mission will also seek ADB's clarification regarding utilization of loan funds to cover incremental staff salaries in SMU and training per diems for local training.

12. Finalization of the PP cannot, however, be completed until after the mid-term review mission of January/February 2002, at which time any additional changes in scope and/or implementation arrangements would be incorporated before submission of the revised PP for Government approval. Until that time, the TAG consultants will assist FD to manage procurement in accordance with the current budget allocations.

6. Imprest Account

13. ADB recently approved an increase in the Imprest Account ceiling from $800,000 to $1.5 million. However, because civil works contracts in remote parts of SRF are spread over long periods and follow force account procedures, FD has experienced difficulty processing invoices and preparing requests for replenishment of the Imprest Account in a timely manner. FD requested a further increase in the ceiling of the Imprest Account to help avoid cash flow

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[5] Such changes include, among others, deletion of the technical assistance for treating effluent from the Khulna Newsprint Mill and inclusion of grant financing from the Netherlands Government.

problems. The Mission undertook to pass this request to ADB for consideration and urged all field staff handling project works to submit invoices more rapidly.[6]

7. Submission of Financial Statements

14. The Mission undertook to ensure that quarterly financial statements, audited annual statements, and annual reconciliation reports (including projections for project expenses over the next 12-month period) are forwarded to the GEF implementing agency (World Bank) in accordance with the terms of the Memorandum of Agreement signed on 30 March 1999.

8. TAG Consultants Staffing Schedule

15. The Mission is concerned that the remaining inputs of the TAG consultants are not sufficient to realize Project objectives relating to capacity building in view of delays which have developed in Project implementation, many of which were beyond the control of the TAG consultants. The Mid-Term Report should provide recommendations concerning reallocation and/or extension of consultants' inputs. Attention should be given to consolidating short inputs into fewer and longer inputs for selected key specialists.

16. There are insufficient inputs in the present TAG contract to cope with the tasks to be handled by the international and national MIS consultants. The Mission recommends that adjustments be made during the mid-term review mission to ensure proper execution of the GIS and related capacity building tasks.

17. The Mission proposed that a new domestic consultant position be created for an Accountant/Financial Specialist to assist the PD in day-to-day management of procurement and disbursement for the Project, and this was accepted by FD. The Mission undertook to organize, subject to ADB's approval, a special training course for the domestic Accountant/Financial Specialist in ADB's accounting, procurement, disbursement, and liquidation procedures. Such training would also be made available to selected FD staff.

18. An international Natural Resources Economist is to be recruited and fielded as soon as possible to replace the consultant who recently withdrew from the Project. The candidate for the position of Natural Resources Economist should be familiar with COSTAB software for tabulating Project costs, and should be fielded sufficient early to permit his familiarization with Project costing and financing arrangements prior to the mid-term review mission in January/February 2002.

19. A domestic Gender Specialist is now needed to help prepare a Gender Action Plan covering all project activities, and particularly training materials for NGOs, SMU staff, and trainers in the training of trainers (TOT) courses related to social mobilization in the impact zone. Considering that training for staff of the partner NGOs is to be initiated in December 2001, the Gender Specialist should be recruited as soon as possible.

9. NGOs for Social Mobilization and Microcredit Operations

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[6] To expedite the release of funds, replenishment applications for the Imprest Account should be submitted to ADB as soon as expenditures are incurred, and withdrawal applications as soon as the minimum requirement of $50,000 equivalent is reached. All procurement contracts valued at $50,000 equivalent and above should also be submitted to ADB for processing as soon as they have been signed to avoid disbursement delays.

20. In discussions among FD/TAG, Palli Karma-Sahayak Foundation (PKSF), and the Mission on 29 October 2001, FD stated its commitment and desire to integrate PKSF into the Project and its willingness to make all necessary arrangements, within the limits of its resources, for accommodating and working closely with PKSF's Credit Supervisor. PKSF, for its part confirmed that it will remain fully engaged as a partner in the Project, and that it would field its full-time Credit Supervisor in Khulna as soon as possible. All parties agreed that PKSF would be consulted on matters relating to the implementation of the Project's microcredit activities, and that PKSF's advice on matters concerning NGO microcredit operations would be followed. Any problems which may be identified during implementation of the community development component would be resolved through discussion among all partners. PKSF confirmed that its lending terms would be flexibly applied depending on the needs and capabilities of the resource user groups.

21. Twenty-three NGOs have signed contracts with FD and will start working from 1 November 2001 in the 17 targeted *thanas*. During the mission, a workshop was conducted on 25 October 2001 with the contracted NGOs to elicit their views on the community development activities and assess their capacity to implement the community development component in an integrated manner. The NGOs have expressed a strong need for a Project-organized meeting with PKSF to discuss and agree detailed implementation arrangements, procedures for release of credit funds to the NGOs, ways of avoiding overlapping among NGOs, and flexibility in loan repayment terms for certain types of microenterprise activities. FD/TAG have agreed to arrange this workshop before the end of 2001.

22. The Mission emphasized that the goal of the community development component is to empower the resource extractors/user groups to participate in planning and managing of SRF with FD. Training of FD staff in the Liaison, Extension and Education Unit of SMU is needed to facilitate socioeconomic development of the impact zone. This should comprise a short (one day) course on group dynamics followed by more extensive training in monitoring of community development activities. The Mission recommends the following training for the NGOs:

(i) Orientation on Project concept, goal, and various components of the Project (December 2001);

(ii) Training plan and assessment of training for NGO training coordinators;

(iii) TOT for selected staff of SMU and the NGOs on conservation, biodiversity, and educational awareness campaign for SBCP (January/February 2002);

(iv) Training for NGO field workers on (a) social mobilization activities related to the Project, (b) conservation and environmental awareness raising; (c) planning of income generating activities for credit program; (d) gender sensitization; and (e) monitoring.

23. The Mission recommends that the Liaison, Extension and Education Unit of SMU should prepare the following:

(i) Handbook for NGO field workers (December 2001);

(ii) Uniform training plan on skill development for income generating activities for resource user groups, prepared in consultation with the NGOs;

(iii) Training plan and motivational activities on sustainable harvesting of SFR for the resource user groups; and for TOT for SMU staff, NGO trainers, and NGO field workers;

(iv) Consistent educational statement on Sundarbans conservation and biodiversity prepared by FD/TAG; and

(v) Training plan and materials for elected officials of the local government (male and female), village elders, religious leaders, school teachers, sectoral agency staff, and other relevant stakeholders.

24. Identification of resource user groups and collection of basic information on them should be initiated from the first week of November 2001 and be completed within one month. The villages in the immediate vicinity of the Sundarbans and with high concentrations of resource users should be the given priority in the community development component.

25. The Mission recommends that, based on experience in similar programs, microcredit activities should be introduced after three months of group formation. The TAG consultants and the NGOs are to develop criteria to assess a group's maturity and readiness for involvement in the credit program.

26. In consultation with staff of the Liaison, Extension and Education Unit of SMU, TAG consultant are to develop a systematic plan for monitoring of NGOs activities on socioeconomic development in the impact zone. This should include both quantitative and qualitative monitoring, and gender-disaggregated data should be presented in reports.

10. Micro-Credit and IGA Activities

27. The recent ban imposed by FD on collection of fish fry has caused an immediate loss of income for many poor resource users, especially women. To help overcome this problem, FD/TAG will work out suitable compensation and substitute activities for fish fry collectors. This could include such actions as an offer to replace shrimp collection nets with gill nets for normal fishing, and targeting of fish fry collectors for microcredit on a priority basis.

11. Infrastructure Development of the Impact Zone

28. LGED, which is the lead agency in the impact zone for the social infrastructure development program, had been requested to delay implementation of civil works pending fielding of NGOs, formation of user groups, and identification of priority community facilities (refer to the Aide Memoire of the July 2001 review mission). LGED has generally followed this recommendation, but has now requested that it be allowed to implement those works recently selected in consultation with the DFOs and field staff of FD. The Mission agreed, subject to confirmation by the TAG consultants, that as many as possible of these works should be approved for implementation as soon as possible. However, beyond the current program of works, future work plans in the impact zone will be prepared in close consultation with the contracted NGOs.

12. FAO Training Program

29. FAO developed a training program for 50 fellowships in 1999 and signed an agreement with the Government for management of their implementation under the Project. The agreement

was submitted to ADB for review and approval in September 2001. The Mission has undertaken to expedite ADB's formal response on the agreement for which some changes will need to be introduced to comply with ADB's procurement guidelines and other requirements under the Loan Agreement for the Project.

13. IUCN Biodiversity Conservation Monitoring

30. The Mission reviewed the latest version of IUCN's biodiversity conservation monitoring proposal (received in Khulna on 23 October 2001), which has incorporated comments provided on earlier versions and is now considered to represent a good basis for proceeding to contract negotiations. It is notable that this proposal emphasizes the involvement of FD staff in the initial phases covering baseline study and institutional assessment, and the participatory capacity building of FD staff is a major thrust of this proposal which was highly appreciated by both the FD and the Mission. The Mission assisted IUCN staff in Dhaka to make clarifications in the approach and methodology and IUCN has agreed to submit the finally revised proposal to ADB by mid-November 2001.

31. The revised concept agreed among FD, IUCN, World Bank (as implementing agency for GEF), and the Mission incorporates the following: IUCN will conduct an initial workshop to determine the views of key stakeholders, and will agree on indicators to be monitored through the first five years. For biodiversity assessment IUCN will rely on SBCP and TAG to facilitate collaboration, but will be wholly responsible for actual monitoring activities. A number of highly experienced national and international experts will be recruited to conduct sectoral (indicator group) surveys. An initial status report on the SRF biodiversity will be prepared by reviewing existing information. The field surveys seek to incorporate the FD at both monitoring and validation stages to ensure sustainability beyond project life. Activities include in-situ training on monitoring methodologies, data collection and processing, and management options to respond to key changes observed at either eco-zone, habitat, or species level. To accomplish their mandate of an external audit, IUCN will call upon an international group of experts affiliated with renowned conservation agencies. The independent panel will review and comment on the Final Status Report of the Biodiversity of the Sundarbans, including the recommendation of a biodiversity monitoring system to be adopted by the Forest Department.

14. Project MIS/GIS

32. Most data entry programs for fisheries, community development, and training needs assessment are now in place, and the Mission requests SMU to expedite recruitment of the computer operators to speed-up data entry. Care will need to be exercised in structuring and optimizing the database to compile the expected large volume of ecological data being generated in the ongoing and planned biodiversity monitoring programs. The database should provide in-built "early warning systems" to flag pre-defined threshold values for changes in indicator parameters, the details of which are to be determined during the indicator identification workshop to be organized by IUCN.

33. In terms of the remote sensing (RS) component, there is an apparent lack of manpower in RIMS (the GIS unit of the FD in Dhaka). Given the importance of the MIS/GIS and the large amount of data to be processed from different remote sensing techniques, additional expertise should be recruited to fill this gap. The TAG consultants have proposed recruiting a national GIS consultant via EGIS, reportedly the best qualified and equipped GIS/RS organization in Bangladesh. The Mission requests FD's approval to proceed with this proposal.

15. Surface Water Quality Modeling

34. The present contract with the Surface Water Modelling Center (SWMC) provides for preparation of a water quality model covering the whole SRF. Based on the results presented in SWMC's half-yearly report (August 2001), the Mission requested that analytical sections be added describing the significance of measured data. Particular attention is to be given to high concentrations of heavy metals measured in SRF. Additional discussion is needed of apparent inconsistencies in the salinity data and the difficulty of calibrating the model. The Mission proposed that SWMC give more emphasis to training FD staff, both for data collection and operation on the SRF water information management system.

35. In terms of biodiversity and forestry management, the Mission expressed concern that an overall inundation model of sufficient accuracy would be too difficult to achieve within the resources and time available. The originally proposed kinematic survey method will not yield the desired results, and SWMC confirmed that the present study would not be able to determine the impact of tidal variations on seasonal forest inundation zones as intended. It was agreed that more detailed information on the hydrodynamic regime within the mangrove wetlands is needed to understand ecological functions and forest development.

36. The following modifications in approach and methodology were discussed and agreed:

(i) preparation of an DEM with desired accuracy in each of three macro-ecological zones of the Sundarbans based on pilot areas of approximately 4km² (selected according to agreed criteria);

(ii) measured parameters including inundation patterns, tidal currents, nutrient content of top-soil and at 30cm depth, and surface soil salinity;

(iii) reduction of measurements for certain parameters, such as river profiles, discharge/flow regimes;

(iv) analytical review of alarming water quality results (e.g. heavy metals), including investigation of point sources of pollution and come preparation of recommendations concerning accumulation in trophic chain; and

(v) recommendation of training for FD/SMU staff and continuity of data collection covering water levels, water sampling for a defined set of hydrological parameters, and operation and management of the water MIS.

16. Next Loan Review Mission

37. The next loan review mission will be the Mid-Term Review (MTR) of the Project. It is anticipated that the MTR mission will take place in January or February 2002. In preparation for the MTR mission, TAG will assist FD and LGED to prepare a Mid-Term Report to be submitted to ADB before the end of 2001. The Mid-Term Report will present a detailed analysis of Project accomplishments, together with conclusions and recommendations for adjustments in Project scope and implementation arrangements. TAG will give particular attention to graphic presentation of progress in different activities against the implementation schedule envisaged during Project design.

38. The Mission wishes to express its appreciation to the Government and to the staff and representatives of different organizations who participated in the Mission. In particular, Mr. Shamsul Huda, Project Director, Mr. Osman Gani, Conservator of Forests, Khulna, and the TAG consultants provided full cooperation and assistance to ensure the success of the Mission.

39. This Aide Memoire was signed in Dhaka on 30 October 2001.

For the Asian Development Bank

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Ian B. Fox
Mission Leader

Appendixes 1. List of Persons Met
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Justification for Modification

Following concerns[1] about the applicability and usefulness of the major outputs of the inundation model study carried out by SWMC up to date, more detailed information on the hydrodynamic regime within the mangrove wetlands is needed to understand ecological functions and forest development. SWMC confirmed that the study activities insofar undertaken will not be useful to meet these requirements, particularly when direct forestry interventions and/or biodiversity conservation actions need to be planned.

To overcome these difficulties a **new conceptual approach** is to be pursued. Based on field work[2] with SWMC staff and two meetings[3] with SWMC representatives and the MTR Mission, the following has been agreed:

1. There is appreciation that the focus of the SWMC program needs to be shifted from a large-scale flow regime and water modelling exercise to a more management-oriented investigation of the inundation pattern and related nutrient/sediment distribution in defined test areas. Such concept will (i) provide more insight in the interactions between the forest vegetation, soil physiography and basic trophic conditions in representative eco-zones of the SRF, (ii) enhance knowledge of the nutritional regime in specific inundation situations (iii) gives understanding of the rapid and dynamic changes resulting from erosion and sedimentation forces acting on the mangrove system.

2. The results are expected to provide substantial inputs for planning forestry management, such as (i) identification of areas where plantation efforts might be feasible or non-feasible (ii) recognizing the limitations to certain plantation programs, (iii) identify the need for preserving undergrowth as natural motor providing soil fertility, (iv) revision of schedules for forestry inventories in relation to bio-physiographic alterations resulting from hydrodynamic changes.

3. At this moment, **no large-scale hydrodynamic modelling is required.** However, the data obtained during the planned 2-year observation within the 3 test areas would result in a site-specific inundation model. It will be decided at later stage if the findings from this test area program can be extrapolated to a large-scale model.

[1] See preparation Mission Report and Aide Memoire, Nov.01
[2] Joint site inspection of two existing test areas and selection of a third site; at sites - detailed discussion of monitoring program and site-specific sampling methodologies
[3] 5th Nov. 01 and 21.Feb.02, both in Dhaka

Methodological Modifications

The following modifications in the study and monitoring program have been agreed:

(i) In each of the 3 macro-ecological zones of the Sundarban representative pilot areas of defined (manegeable) size of 2-4 km^2 are selected and topographically measured. Since November 01, SWMC had selected two plots at Jongra and around Katka observation watchtower. Since the second site[4] does not fully meet the requirements to determine inundation patterns, it is agreed to drop this test area. Instead, it was agreed to select a site in the central Southern part of the SRF where hydrodynamic changes seem to occur most rapidly. During this mission, a third (representative) plot has been identified South of Koikhali.

(ii) Parameters to be measured will include inundation pattern and tidal micro-currents[5], sedimentation load[6], nutrients[7] and suspended organic matter, nutrient content on top-soil and at 10 cm depth and surface soil salinity. A summary of the foreseen activities is outlined in Diagram 1. Detailed workplans with a standardized schedule[8] need to be elaborated to cover for each test site a full tidal observation for two years (total 72 observation field days).

(iii) During each quarterly observation cycle photographic documentation will be made to monitor and assess morpho-topographic changes in the test sites.

(iv) SWMC will continue collection and testing water quality sample every month. The test results should be carefully verified and any results varying/deviates more than 20% of the standard variation needs to be re-examined. A sub-sample (250 ml) needs to be stored at least for the period of contract. In case of abnormally high lead concentrations it is agreed to intensify the measuring schedule by adding 2 more stations near the highest concentration area. It has been further agreed to double in such case the sample frequency, and to elaborate a pollutant point source investigation program to be followed up by SBCP.

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[4] elevated grassland with sand ridges; waterlogging exceptional, only during peak monsoon

[5] using dyeing methodology

[6] direct determination, e.g. photometrically in stirred standard samples

[7] standard laboratory tests

[8] In each test site, once per quarter a three days current and in/outflow monitoring during a full daytime tidal cycle from 6.a.m. to 6 p.m., one at spring tide, one at following mid-tide, one at following neap tide. In such way, 3 test sites can logistically investigated in one lunar months per quarter, i.e. on day 1,4,7,8,11,14,15,18,21, whereby day 1, and 14 represent spring tides, day 7 and 21 represent neap tides.

Other Requests to SWMC

The Mission asked to include more analytical assessment on data that are of environmental concern, such as the findings for heavy metals occurring in some samples beyond permissible level. Additional analytical analysis is still needed of apparent inconsistencies in the salinity data.

According to the proposal, SWMC will provide training service to FD personnel in monitoring specific hydrological parameters that bear immediate relevance for forestry management. The task includes (i) identify training needs and beneficiaries for hydrological monitoring, (ii) elaborate curricula and (iii) initiate training for data collection and operation on the SRF water information management system.

SWMC is requested to outline their concept and mechanisms to ensure continuity of data collection within FD/SMU after the completion of their contract. For mid-term review. SWMC is requested to describe a defined set of hydrological parameters such as water quality, inundation and sedimentation pattern to be continually monitored by FD personnel being trained under this contract.

It has been agreed to reduce the Water Quality Parameters at seaside on certain boundaries to standard visit frequency at Manderbaria, Hiron Point and Katka. Monthly sampling at sea is not practicable at present.

Diagram 1: **Suggested Activities and Outputs for Modified (Representative Test Area) Studies Carried out by SWMC in the Sundarban**