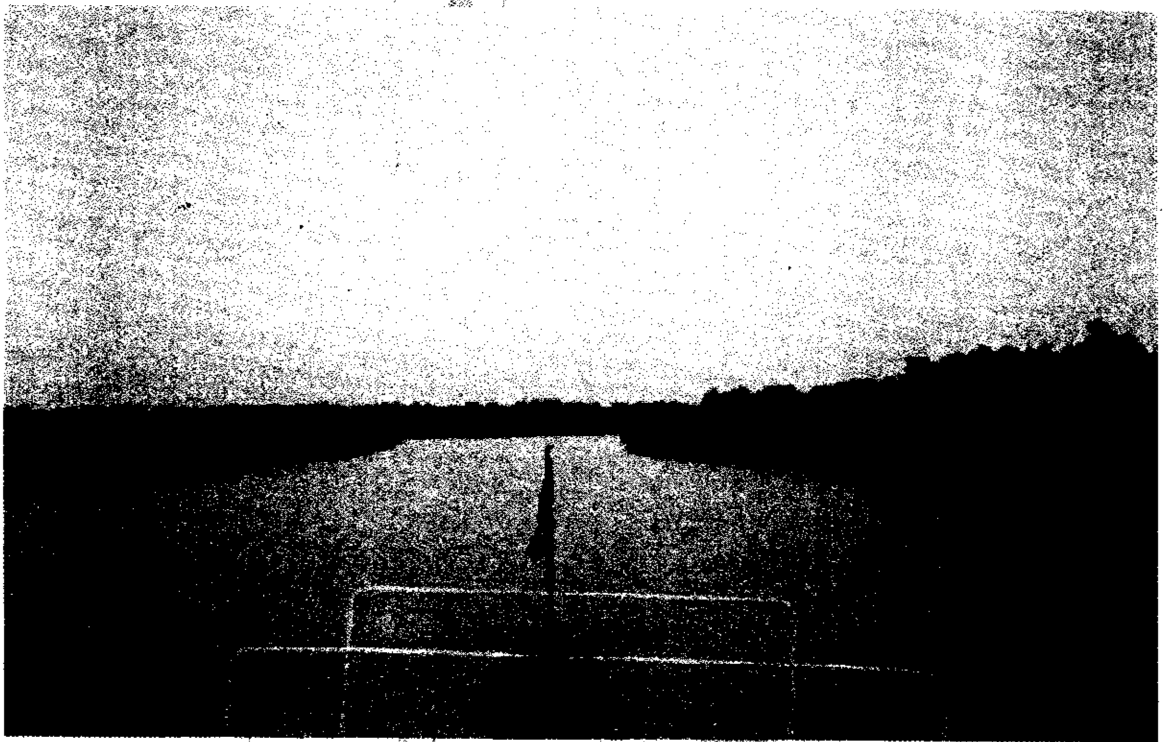
Government of the People's Republic of Bangladesh
Ministry of Environment and Forest
Department of Forest

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



FINAL REPORT
VOLUME 1 : MAIN REPORT
MARCH 2003

INSTITUTE OF WATER MODELLING
(erstwhile Surface Water Modelling Centre)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATION

AEC	Atomic Energy Commission
ADB	Asian Development Bank
BDT	Bangladeshi Taka
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
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
PD	Project Director
PP	Project Proforma (GoB)
PPT	Parts per Thousand
PWD	Public Works Department
SBCP	Sundarbans Biodiversity Conservation Project
SOB	Survey of Bangladesh
SRF	Sundarbans Reserve Forest
SWMC	Surface Water Modelling Centre
TBM	Temporary Bench Mark
UHF	Ultra-high Frequency
UNDP	United Nations Development Program
WaRPO	Water Resources Planning Organization
WQ	Water Quality

Structure of Final Report

Volume 1	Main Report	
Volume 2	Appendix A	: Salinity Maps
	Appendix B	: Water Quality Plots and Tables
Volume 3	Appendix C	: Pilot Area Observation
Volume 4	Appendix D	: Discharge, Velocity & Sediment Observations
Volume 5	Appendix E	: Hydrodynamic Model Calibration Plots
	Appendix F	: Salinity Model Calibration Plots
	Appendix G	: Assessment of Non-point Pollution Load by "Load"
	Appendix H	: Plots of Option Study
	Appendix I	: SWIMS User Manual

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 was supposed to be ended in March 2002. The 1st year data collection started in October 2000 and continued upto March 2001. The 2nd 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 has been submitted in Annual Report, February 2003. During the ADB Mission visit in February-March 2003, it was informed that the activity of the project should be limited within the contract period and they requested to submit the final report by March 2003.

1.3 Structure of the Report

This report is the sixth and final report of the "Surface Water Modelling" component of Sundarban Bio-diversity Conservation Project. This report documents activities performed since inception of the project. This chapter provides an overall development of the project. Chapter 2 provides the data collection activities performed till March 2003. Analysis and Observations on the data has been provided in Chapter 3. The development of Mathmatical Models and output from option study has been provided in Chapter 4 to Chapter 8. Chapter 9 describes the database developed. Chapter 10 summarises the training activities. Chapter 11 presents reports produced so far and Chapter 12 provides recommendations for future development.

Appendix A presents salinity maps prepared from monthly maximum values observed. All plots and tables of water quality parameters is presented in Appendix B. Maps produced from Pilot area observations are arranged in Appendix C. Discharge, sediment and velocity observations are presented in Appendix D. Model calibration and outputs are presented in Appendix E to Appendix H. The user manual of the database developed is provided in Appendix I.

The whole report has been organised in 5 volumes. The volume 1 contains the main report, volume 2 contains Appendix A & B. Volume 3 and Volume 4 contains Appendix C and Appendix D respectively. Volume 5 contains the Appendix E to Appendix I.

2 DATA COLLECTION

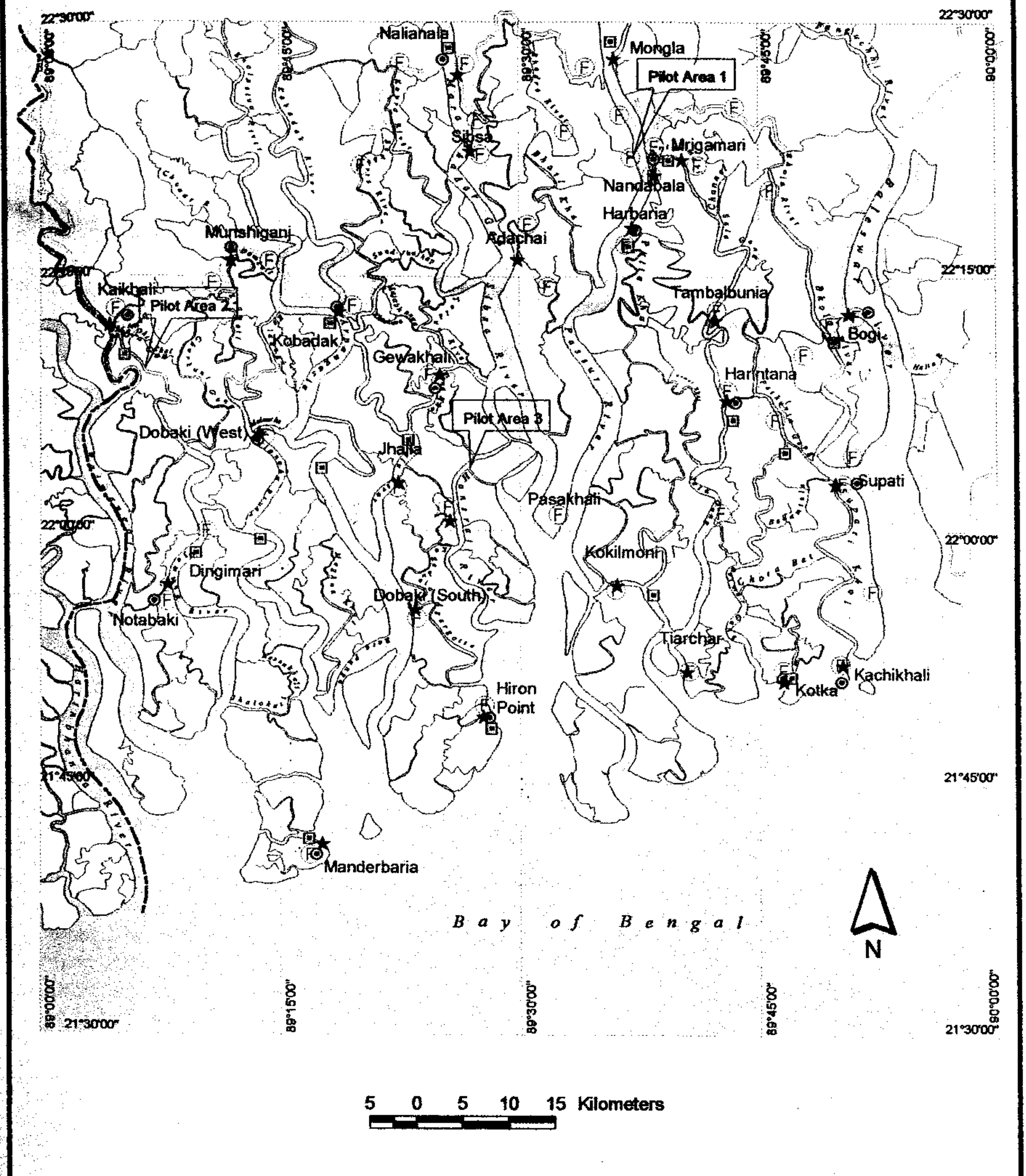
Primary data acquired in connection with this study comprised water level, discharge, salinity, sediment concentration, settling velocity of sediment, river cross-section and water quality. The locations of stations are shown in Drawing 01 and the summary status of field data collection upto December 2002 has been presented in Table 2.1.

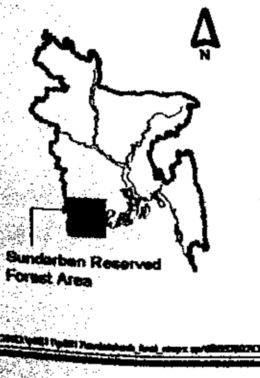
Table 2.1 Status of Primary Data Collection upto March 2003

Type	Station	Frequency	Unit	Total Observations	Period		Remarks
					From	To	
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

IWM has collected a huge amount of data from secondary sources (data outside SBCP programme) to fulfill the requirement of the modelling study. The status of data collection from secondary sources is presented in **Table 2.2.**





LEGEND

- (F) Forest Office
- ★ Salinity
- ⊙ Water Level
- ▣ Water Quality
- International boundary
- River
- Embankment

SUNDARBAN BIODIVERSITY CONSERVATION PROJECT

DATA COLLECTION NETWORK

Figure 1

SWMC

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	Mar'02
Evaporation	09	Daily	BWDB	Apr'00	Mar'02
Groundwater	38	Weekly	BWDB	Apr'00	Mar'02
Water Level	67	3 hourly	BWDB	Apr'00	Mar'02
Water Level	18	24 hourly	BIWTA	Apr'00	Mar'02
Discharge	04	Fortnightly/weekly	BWDB	Apr'00	Mar'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

In connection with the study, Rainfall Gauges have been installed at five locations during monsoon 2001. The locations are at Supati, Jhalia, Notabeki, and Hiron Point inside the Sundarban Reserved Forest. The other station is located at Mongla. The installation has been delayed for selection of flood free locations for the gauges. After failing several approaches an innovative idea of placing the gauges on wooden posts was found satisfactory. The gauges were installed following standard practice. The data collection continued from October 2001 to March 2003 in all the station except Hironpoint where observation interrupted during dry season of 2002 due to stealing of the rain gauge.

2.2 Water Level

15 manual water level gauges have been installed inside and around the forest area and are operated from the beginning of the data collection programme. The gauge locations are shown in **Drawing 01.** Four additional gauges have been installed for monitoring related to Kharma Khal re-opening study on Kharma-Bhola System during 2002. The gauges were made of 3m long wooden plank and clearly visible from the bank. At each station 2 nos. of gauges were installed to cover both high and low water level. The gauges were replaced time to time due to deteriorating of the gauge colour. The zero value of the gauges were connected to the mainland datum mPWD where available while it was connected to arbitrary bench mark inside the forest stations. The connection to these gauges was done later on by using the model result. The gauge connections were checked every month during field visit. To record continuous data

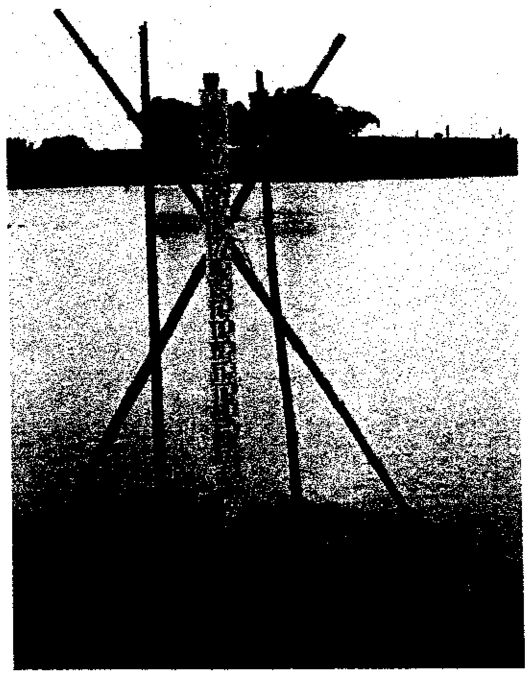


Figure: 2.1 Water Level Gauge

at the remote boundaries, 2 Automatic Tide Recorders have been procured from the project. These were installed at Hiron Point, Mandarbaria, Kochikhali and Dingimari at different times. Sample water

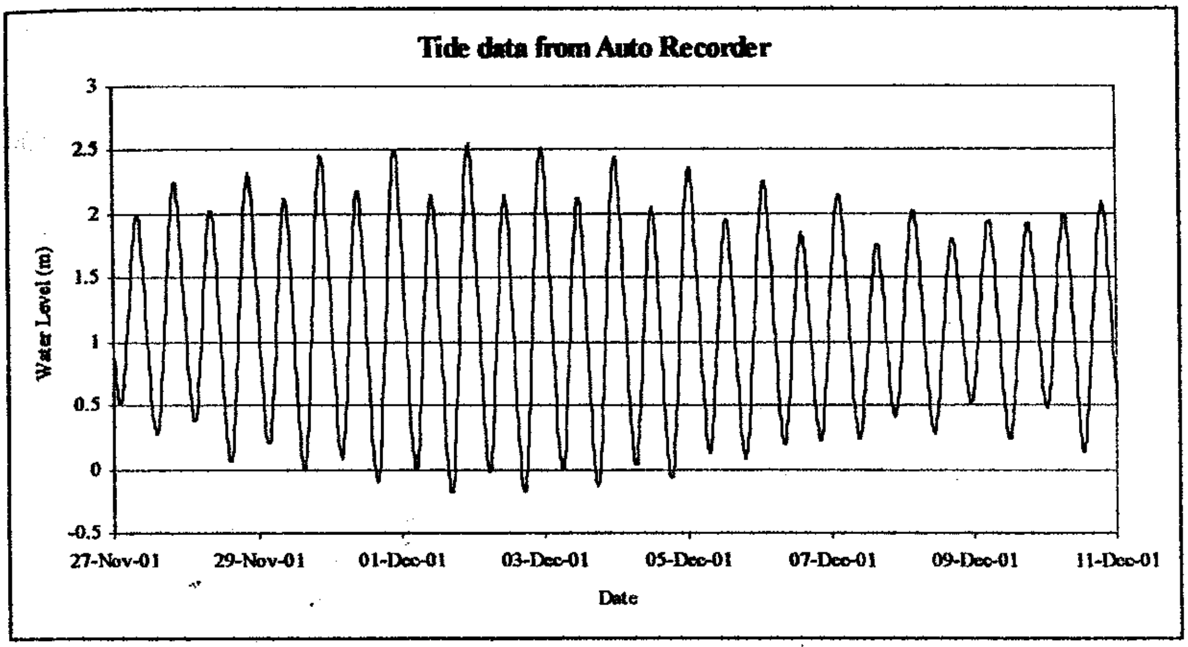


Figure 2.2 Water level data from Automatic Tide Recorder

2.3 Discharge

Discharge observations have been carried out at 15 locations in different channels of the Sundarban during January to December 2001. The observations scheduled for dry season 2002 were dropped following modification of study approach where data collection for detailed study had been performed at 3 pilot areas. Discharge observations at 4 locations for 2 tidal cycles were carried out in connection with the study of Kharma Khal re-opening.

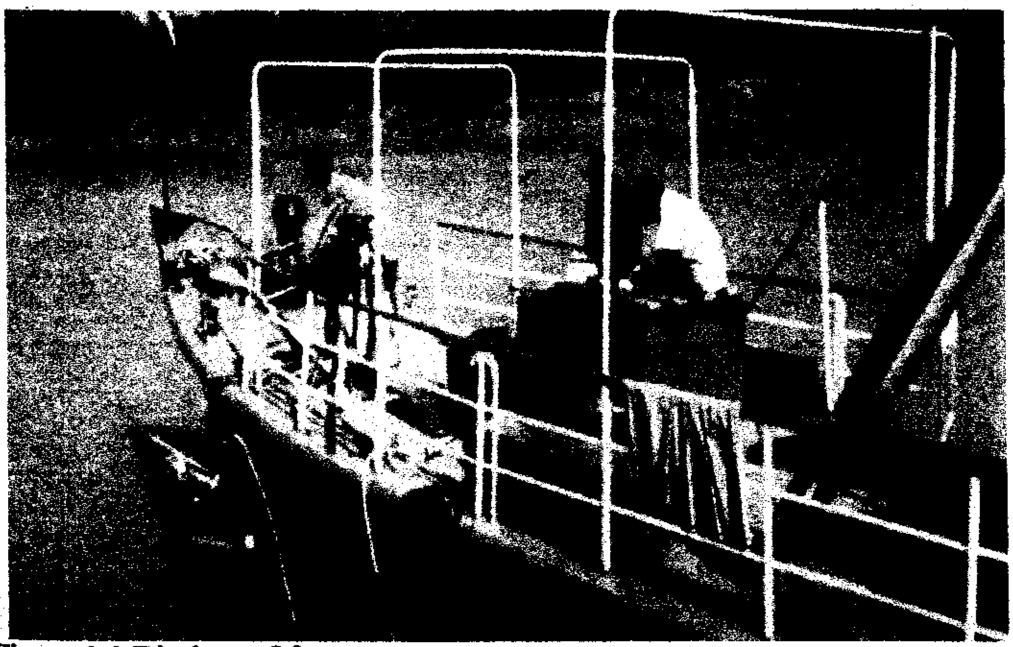


Figure 2.3 Discharge Measurements

The discharge observations were carried out using one to three vessels stationed across a transect line surveyed by using DGPS and Echosounder. Current 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. Special 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, which is necessary for calibration of the model.

2.4 Salinity

2.4.1 Point Sampling

Salinity sampling during the 1st 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 additional 10 stations were installed. Salinity sampling is continuing at 26 stations from October 2001 uninterruptedly. IWM has planned to continue salinity observation from its own resource upto the end of June 2003 so that the data for 2003 dry season is completed. Locations of salinity sampling stations are shown in **Drawing 01.** The sampling at 6 boundary stations are done daily from 6:00 am to 6:00 pm on hourly interval while sampling at remaining stations are done 4 times per week. 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 is 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 are made at 25°C reference temperature.

Figure 2.4 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 give a good indication of water circulation in the rivers.

2.5 Water Quality

Planned Water quality testing schedule was 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 is being done 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 sampling done is mentioned 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	Hironpoint	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	5 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 went under 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 2nd methodology, three samples were collected from one location: from top, middle and bottom. These samples were analyzed in the laboratory as mentioned in the Table 2.4. The sampling was done by using Jabsco pump. 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 ensured. These were preserved and transported upto Laboratory in icebox to maintain the quality.

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

DO and Temperature were measured *in situ*, during tidal discharge observations, at an interval of half-an-hour for about 13 hours. 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

Due to inaccessibility inside the forestland 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 and the thick forest canopy does not permit that numbers. Moreover, multipath error also restricts the accuracy of the survey work by GPS. However, land level from aerial survey of FINNMAP was the only secondary source available. The data has the accuracy level of 1 meter. IWM carried out 2 sample areas of 2km X 2km at Jongra and Katka. The survey was conducted by using conventional level machine. The positions of spot levels were recorded by using

Hand GPS. Land levels of two 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.

Land level data is essential for assessment of flooding and inundation in an area. It is also essential for the Water Quality Model "Load" being used to estimate non-point pollutions from the forestland. Hard copy of the maps (in 1:10,000 scale) of Sundarban and its adjacent boundary has been collected from BIWTA and the digital data has been procured from the FINNMAP.

Figure 2.5 Poor accessibility inside the forest

2.7 River Cross Section

A total of 139 cross sections were measured during December 2000. Under the additional data collection programme, 2nd round cross-section measurement was planned for implementation during December 2002 and January 2003 which had been dropped due to uncertainties of the continuation of the project. However, additional 39 cross-sections have been surveyed during August 2002 in the Passur, Sibsa, Kharma and Bhola River to improve the model.

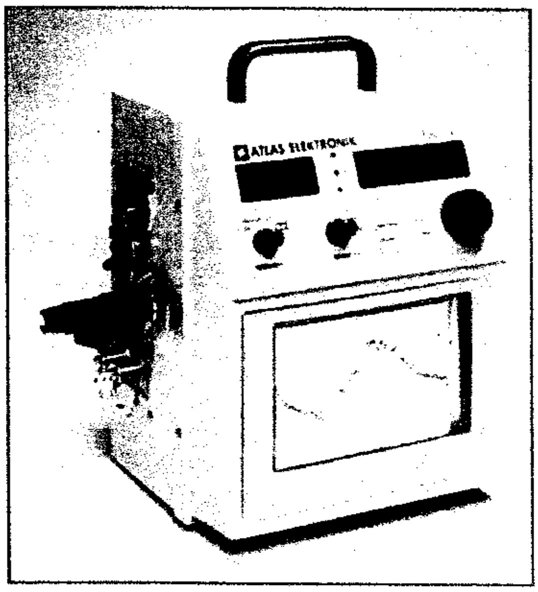


Figure 2.6: Digital Echosounder

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

2.8 River Sediment

Three types of sediment data were collected from the discharge measurement locations. These are suspended sediment concentration, fall velocity measurement and bed sampling. 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.

Figure 2.6 Fall velocity observation

2.9 Pilot Area Study

As mentioned earlier the ADB Mission in February 2002 and October 2001 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 inundation and salinity on the 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 four selected pilot areas as mentioned below have been completed. Change in topography, siltation pattern, soil salinity, soil nutrients, tidal micro-current and inundation pattern on the forestland are being monitored directly due to variation in tidal and seasonal cycle in selected pilot areas. The study is to be conducted for eight seasonal cycles. Only three cycles of measurement have been completed within this reporting period.

Objective of the Pilot area study is to observe the impact of hydrological parameters on the forestland. The methodology and site selection has been made in consultation with FD official, TAG and ADB Mission Representative expert on Mangrove Forest. The selected pilot areas are located near Jongra, Patkosta and Koikhali.

The selected pilot areas are:

- Situated in different macro-ecological zone
- Inundated in all season
- 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 at Jongra and Katka. Later on, 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 has been reduced to 500m X 300 m size containing all criterion for the study.

Monitoring is carried out once in every season (3 months interval). The 1st campaign was conducted from April 2002 to May 2002. The measurements are 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. Results from each measurement cycle are being preserved for analytical purpose.

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 Handheld GPS. Due to accessibility and visibility problem other sophisticated equipment was not usable at the areas. Spot levels were taken along 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 Handheld GPS in WGS 84 co-ordinate. The positions were then converted in Bangladesh Transverse Mercator (BTM) by using computer software during processing. Alignment of creeks was also recorded using Handheld GPS. The data is used for mapping by GIS software.

Figure 2.8: Land level survey inside forestland

2.9.2 Water Level Observation

At every site water level gauges have been installed at 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 2.9: 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 2.10: Siltation measurement

Burried Tiles:

As an alternative to the siltation gauges, local made earth burnt plain tiles (known as "Tally") were buried approximately 10cm to 15cm below the ground. The topsoil 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 can avoid risk of damage. However, top soil may be disturbed by the fishermen and other while walking around the forest and in long run, may be difficult in detecting actual position.

Figure 2.11: Placement of tiles to observe siltation

Land level survey:

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 water spills through creeks on the forestland during high tides. The water starts flow like sheets over the ground. Gradually the depth of flooding increases. The micro current is measured by using dye on the water. The dye was placed at selected locations. Time and distance travelled by the dye were measured by stopwatch and tapes. The position of measuring points were recorded from hand held GPS. One extra point was recorded along the alignment of flow direction (kept using two pegs at start point and end point to calculate the flow direction. Measurements were repeated for the ebbing period.

Figure 2.12: Inundation inside the forestland

2.9.5 Soil Sampling

Soil samples are collected from the forestland at the end of each cycle of measurement. The samples are taken from the topsoil (15 cm deep) and 30 cm below the ground. Positions of sampling locations are recorded using GPS. The samples are dried naturally inside the room. The samples are then sent to standard laboratories for testing soil salinity and soil nutrients.

2.9.6 Suspended Sediment Sampling

Samples were collected from the flowing water (undisturbed) to observe suspended sediment concentration. The salinity of the water was also measured at the river and on the forestland.

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 do not contain such reference. Indirect approach of drawing reference level from the results of the mathematical modelling lacks field truthing. A challenging step has been taken during this dry period 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 has been simultaneously applied to get the benchmark transfer sufficiently accurate. 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.

3 ANALYSIS OF DATA

Study of the temporal and spatial variation of the observed data has been reviewed as one of the important criteria to assess the consistency of the data. Comparisons of salinity and water level of temporal campaign has been presented in the past reports. There had not been sufficient data from past, due to the uninterrupted data collection programme from August 2001, it is now possible to observe the salinity and water level for a full annual cycle. Water quality testing has been performed for a full annual cycle also.

3.1 Rainfall and Evaporation

The rainfall and evaporation data collected from the secondary sources have been processed upto March 2002. Detail of processing has been described in Annual Report (February 2002) and not repeated in this report. Rainfall data from 5 stations in and around the Sundarbans have also been processed. A histogram of the stations during the monsoon 2002 is presented in Figure 3.1. It is observed from the histogram that significant rainfall has occurred inside the Sundarbans during the period May 2002 to November 2002.

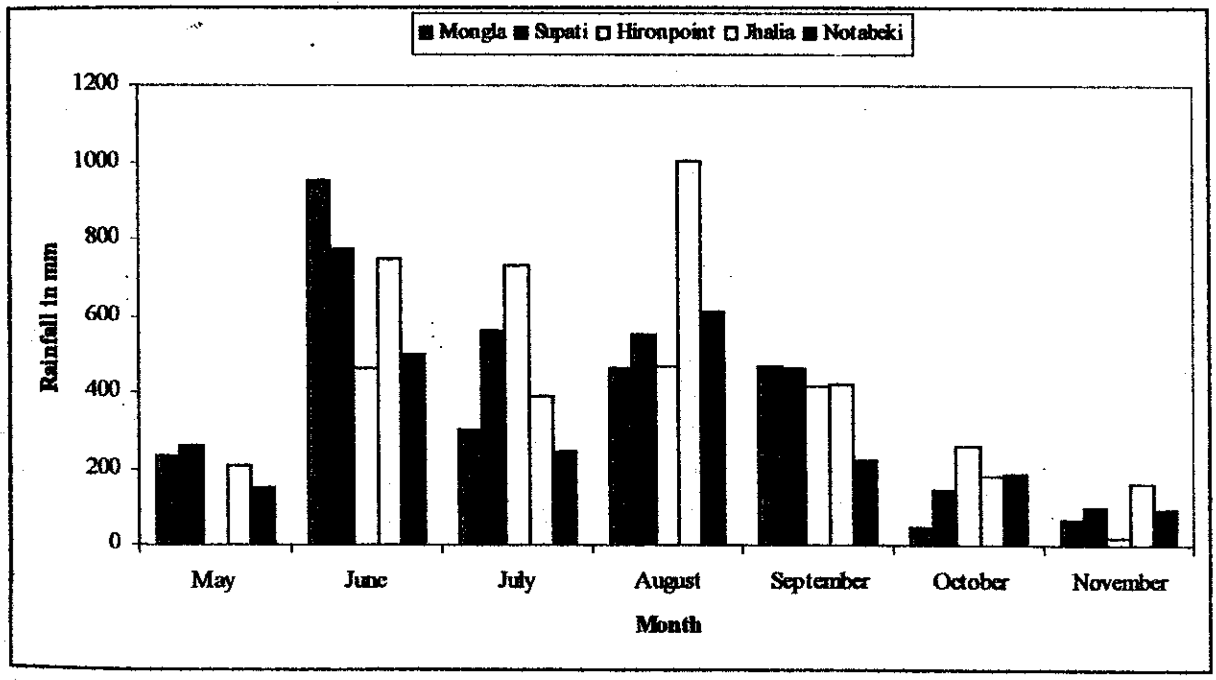


Figure 3.1: Rainfall distribution during Monsoon 2002

Rainfall stations maintained by BWDB adjacent to the Sundarbans are located at Koikhali, Chalna and Patherghata. The statistics of these stations for the same period is not available at present. However, analysis of the stations for the same period 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 at Figure 3.2. From the plot 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 Patherghata and Koikhali at East and West of the Sundarbans. Similarly, maximum rainfall occurred at Jhalia at the central part of the Sundarban while Supati and Notabeki at east and west of the Sundarbans experiences less rainfall. 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 shown here. It might be interesting to see the immediate effect on the salinity level due to rainfall at different stations. Figure 3.3 shows the cumulative rainfall at different stations from May 2002. The plot shows extent of rainfall at different dates. It may be noted also that the amount of rainfall inside the Sundarbans is much higher than that of average rainfall of the country.

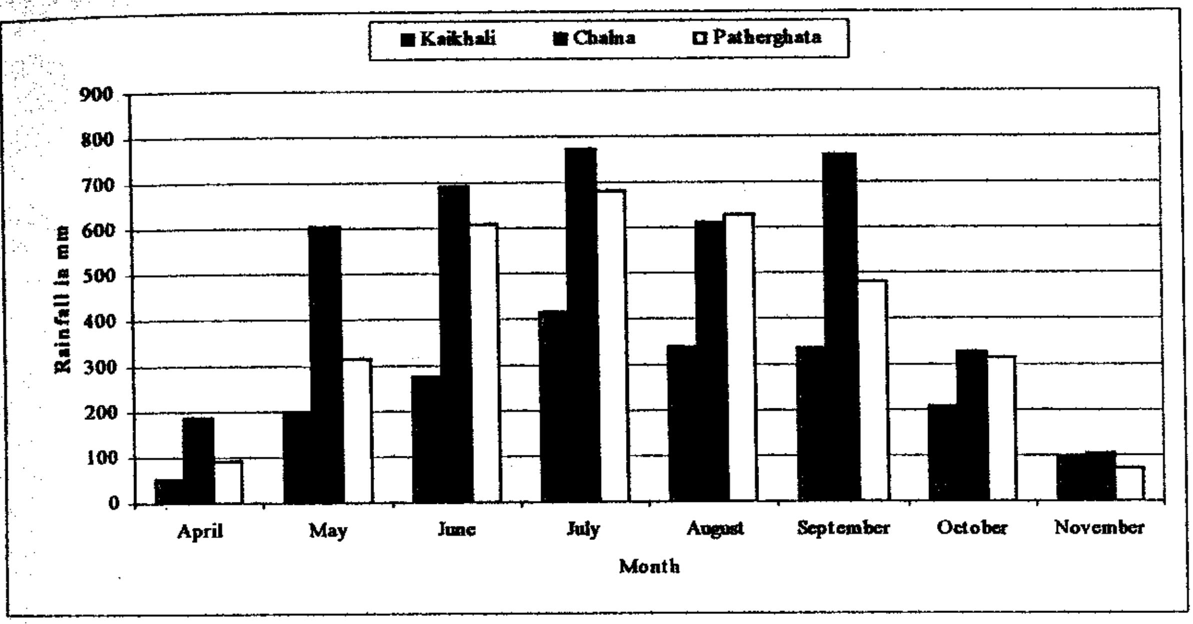


Figure 3.2: Average rainfall at Koikhali, Chalna and Patherghata (Year 1998-2001)

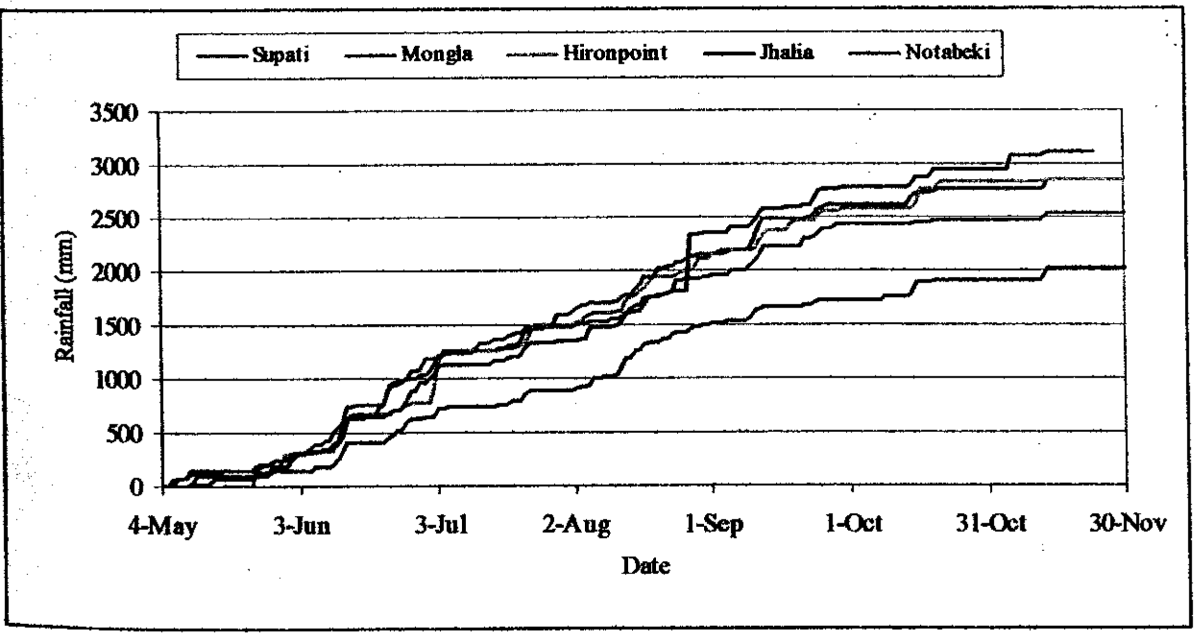


Figure 3.3: Cumulative rainfall from May 2002 to November 2002

3.2 Salinity Data

Salinity in the Sundarbans is highly dependent on the volumes of freshwater coming from 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.

Salinity time series of 4 stations (1 each from east, north, south and west) for a 12 months period data has been plotted in Figure 3.4. The plot shows that salinity at Supati, influenced by the Baleswar River at the eastern part of the Sundarbans, is very negligible during monsoon and post monsoon period (June to December). It slowly increases from December and reaches its March and April and starts reducing from the end of April. Salinity at Hironpoint at the southern part of the Sundarbans, salinity remains around 3 to 4 ppt during monsoon and post monsoon period. It increases slightly higher rate than Supati and reaches its maximum at the end of March and started decreasing from the middle of May. On the contrast, at Notabeki station in the western part of the Sundarbans, minimum salinity during the monsoon and post monsoon period is around 8 to 10 ppt. It increases gradually upto May and started decreasing slowly from the end of May. Salinity at Nalianala station remains negligible from July to November. It increases gradually upto end of May and fall rapidly from the June (at the beginning of monsoon). The conditions reflect that fresh water supply at the eastern part through the Baleswar starts earlier than that through other rivers. It is also evident that fresh water supply at the western part is not enough to reduce the salinity even at wet season (salinity at Notabeki is higher than Hironpoint during wet season). The Kobadak & the Betna are the only sources of water on the western part. These rivers are not perennial now-a-days and has been separated from the Ganges. The discharge of these rivers at the upstream is very insignificant and carries only runoff coming due to rainfall at local catchments. It is seen from the figure 3.1 that the rainfall at the western part is significant from June 2002 which also conforms to the observation. Thus salinity on the western part of the Sundarbans varies only with the rainfall at the upstream river and augmentation of the upstream river flows can reduce the salinity both dry and wet season.

It is also worthwhile to observe the impact of salinity in the upstream areas of the western part of the Sundarbans. From the observed data, it is seen that stations located at the western part namely Koikhali (at the border river at the north-western boundary of the Sundarban), Basantapur (at the border around 30 km north of Koikhali) and Notabeki (at 25 km south of Koikhali) follows unique pattern of increasing salinity during the dry season. It is also notable that salinity at Basantapur was around 22 ppt during the last week may 2002 which also indicates level of salinity intrusion at the western part of the Sundarbans and its impact zone.

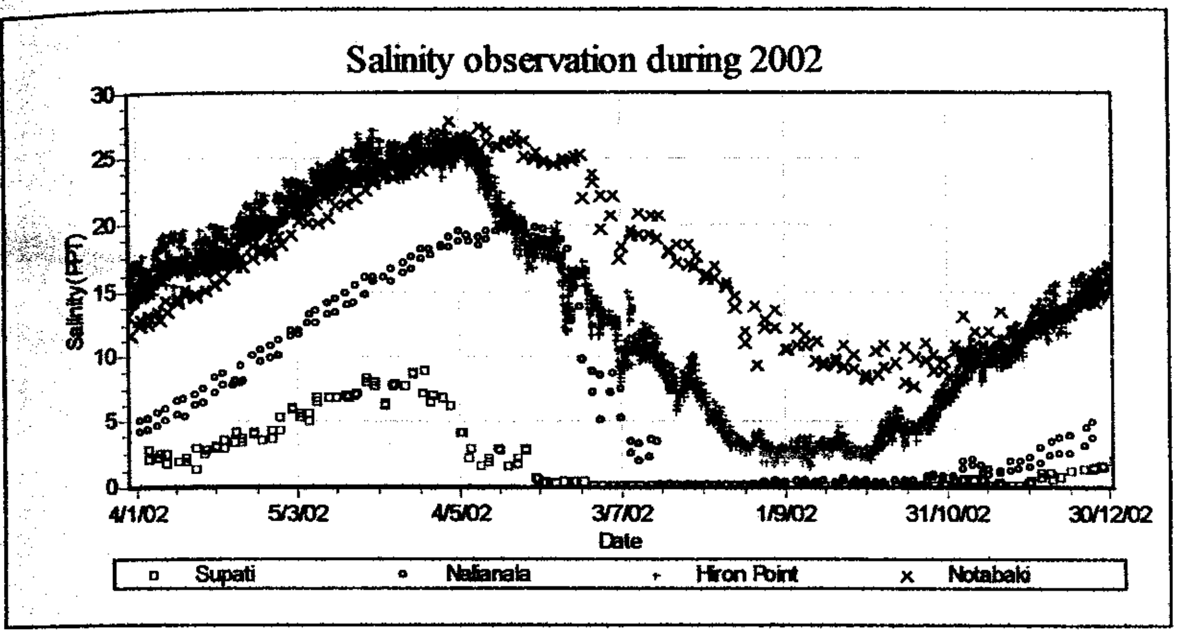


Figure 3.4: Salinity in the Sundarbans during year 2002

It is very difficult to generate exact spatial distribution of salinity by available software, as the mathematical interpolation procedure will not exactly match the practical conditions at the interpolated or extrapolated locations. However, it reflects the pattern to somewhat acceptable limit. Sample map showing spatial distribution (monthly maximum) generated by using ArcView software is shown in Figure 3.5 while complete salinity distribution maps for maximum monthly salinity have been presented in Appendix A. These maps reflect the extent and limit of salinity stress at different locations inside the Sundarbans and possess good value while compared with respect to time. It is observed from the spatial distribution maps that salinity varies east to west direction during pre-monsoon and monsoon season (Maps of May 2002 to September 2002) while it varies northeast to southwest during initial months of dry season (Maps of January 2002 to March 2002). Extent and duration of salinity stress is very much important for the growth of the vegetation of different types. Table 3.1 shows the salinity stress at different stations inside and around the Sundarbans. It may be noted here that the stations like Jhalia and Notabeki are experiencing salinity stress more than 25 ppt for a period of 55 and 43 days respectively. Correlation of vegetation pattern with the salinity may be made from the observed data. However, salinity concentration varies year-to-year depending on hydrological condition. It is, therefore, deserves regular monitoring to find out definite trend of salinity stress at the monitoring stations.

Table 3.1 Salinity stress at different station 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	Patkosta	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

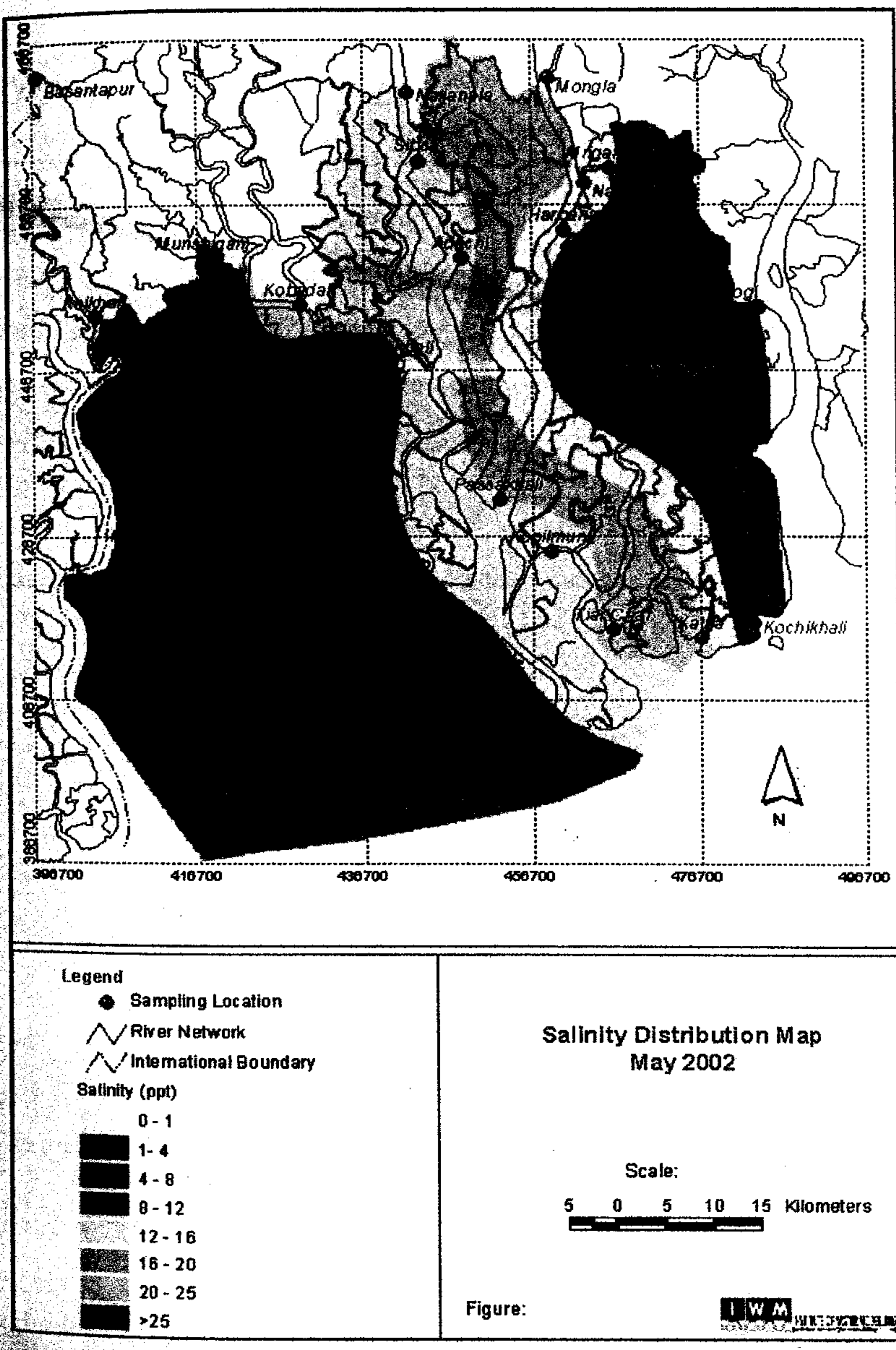


Figure 3.5: Spatial distribution of salinity during May 2002

3.3 Assessment of Water Quality Data

One of the important objectives of the study is to 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 Sundarbans river system was patchy and unsatisfactory. As such, comprehensive programme was undertaken to monitor the water quality of the river system. The detailed of data collection progress, procedures and testing process have been provided in the Article 2.5 of this report

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 in land and estuaries. However, DoE Gazette of 1977 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 3.2** presents the limiting concentration/values defined by DoE in 1997 Gazette. The Table a`lso present the limiting values of organic compound and heavy metal inactive values provided in the unpublished DoE document of 1991.

Table 3.2: 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 being tested can broadly be 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 water 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.

3.3.1 Organic Matter & 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 Plots in Appendix B.

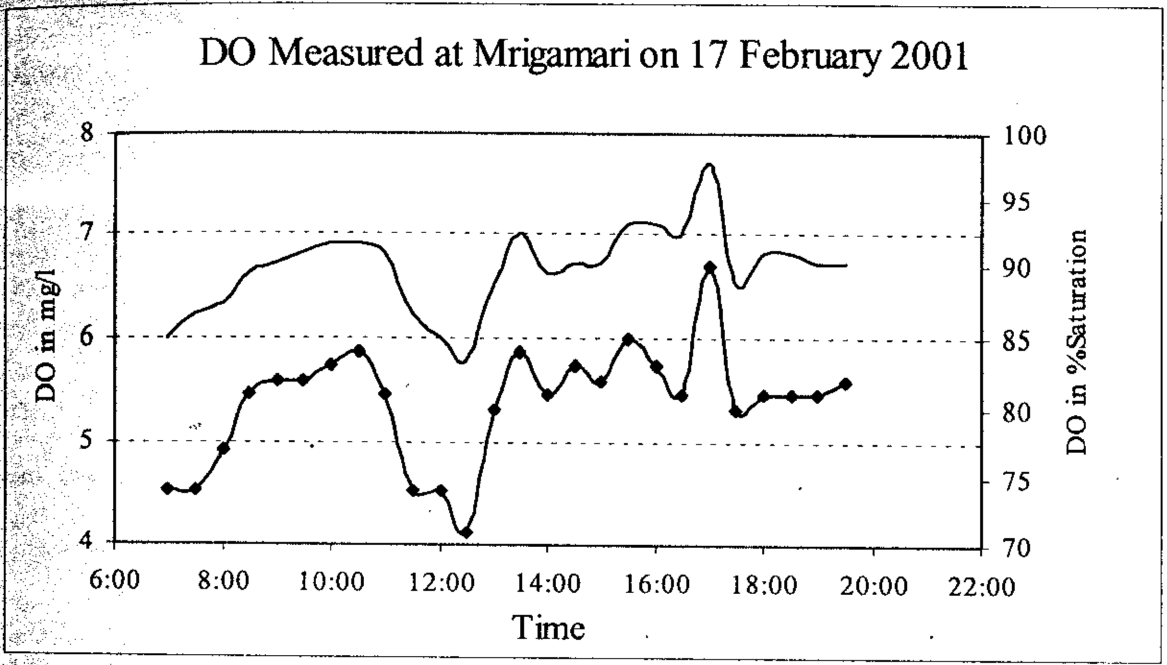
COD is the measure of pollutants, containing biodegradable and non-biodegradable organic matter, thus not fully degradable biologically. COD should always be higher than BOD, and its concentration is about 1.5 to 2 times of that of BOD. It is a crude check against the precision of BOD values. The range 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 Plots in Appendix 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.

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. 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 plot of observed DO during year 2001 is presented at Figure 3.6. However, no definite trend with tide condition (flooding or ebbing) is observed from the point profiling.

The plots of all observed point profile of DO values and tables of observed longitudinal profiles are shown in Appendix B.

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 Appendix B.



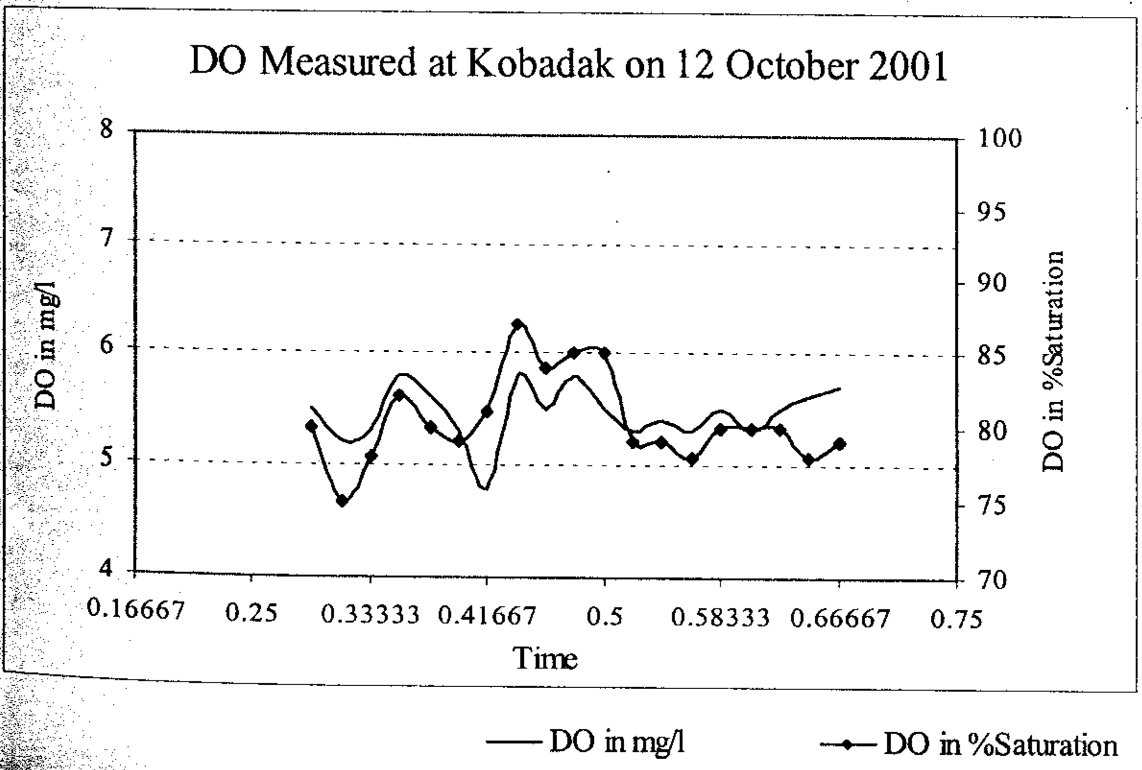


Figure 3.6: Sample plot of DO measured during discharge observation

3.3.2 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 plots are presented in Appendix B.

3.3.3 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) in 4 cases, and in one occasion the Pb concentration exceeded the permissible limit (0.2 mg/l). These infrequent occurrences of somewhat 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 plots are presented in Appendix.B.

3.3.4 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.

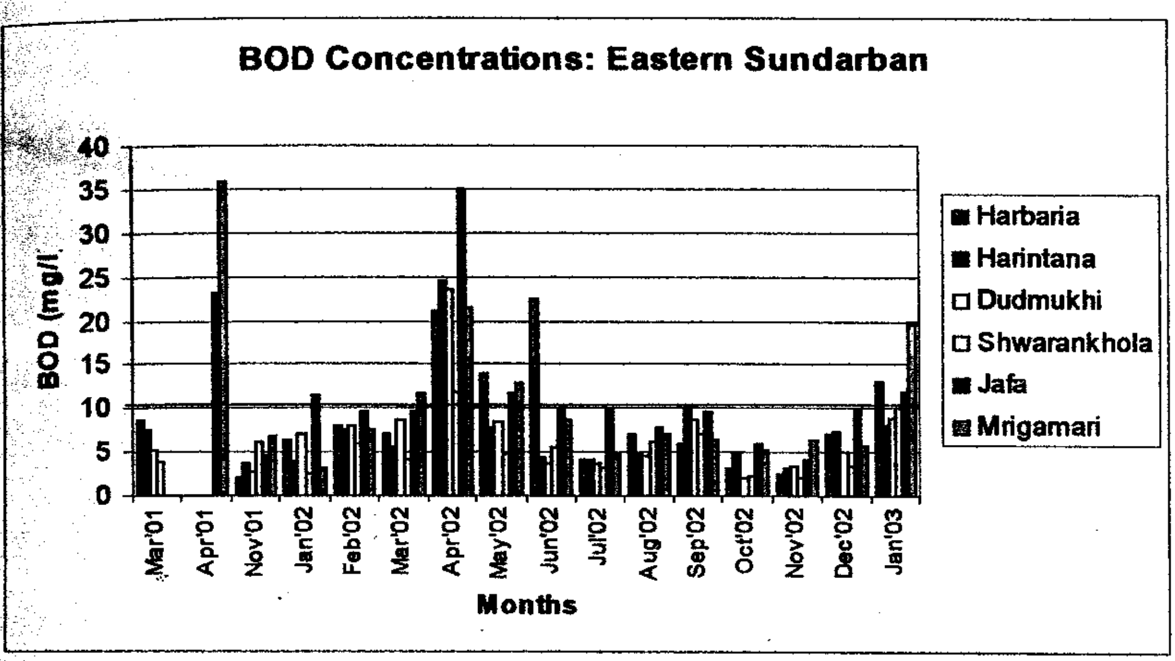
3.3.5 Spatial Variation of Water Quality Parameters

To assess spatial variation of water quality parameters within the Sundarban, sampling stations can be grouped as 'Western Sundarban' and 'Eastern Sundarban'. Western Sundarban comprises of: Nalianala, Arpangasia, Bal, Malancha, Dingimari, Koikhali and Kobadak. Eastern Sundarban 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. The seasonal variation of BOD, COD & Total Ammonia for Western & Eastern Sundarban is presented from Figure 3.7 to Figure 3.9.

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 Sundarban. 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.

An interesting trend has been found for the concentration of Pb in the Western Sundarban: 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 plot of Pb concentration is presented in Figure 3.10.



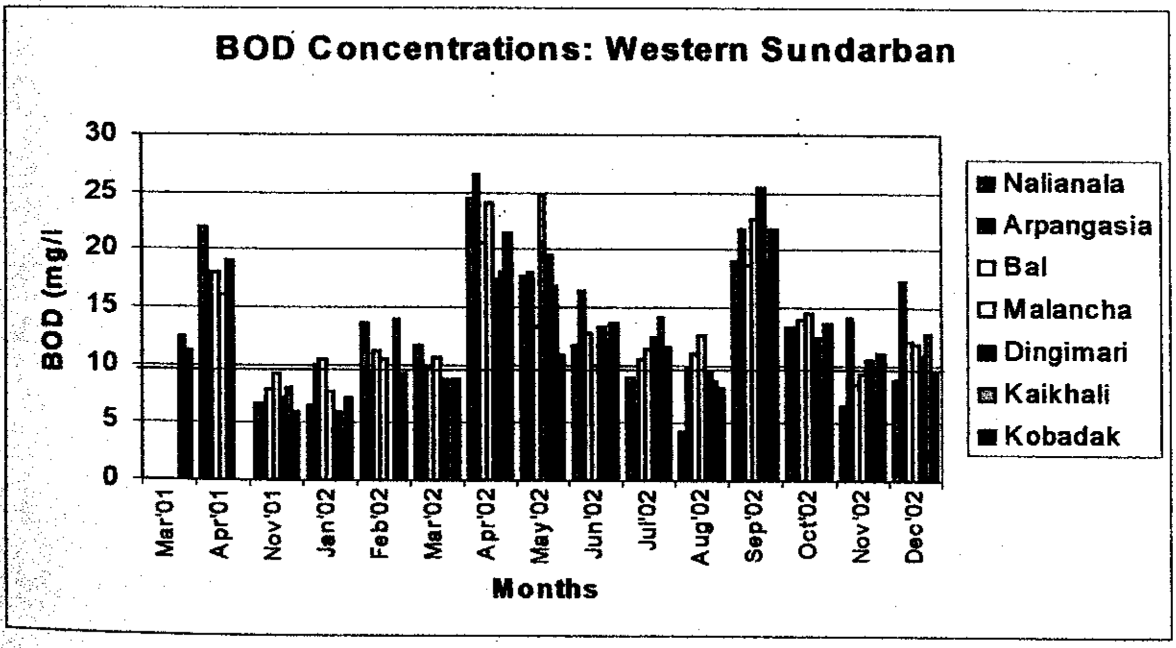
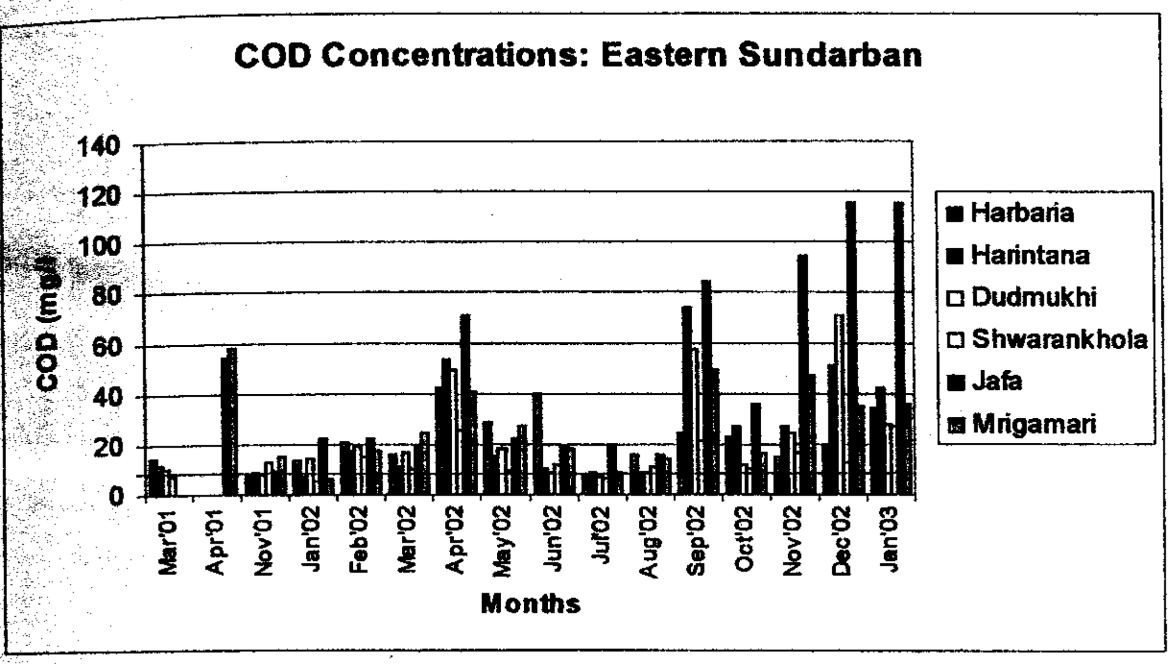


Figure 3.7: BOD Concentrations observed in the Western & Eastern Sundarbans

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



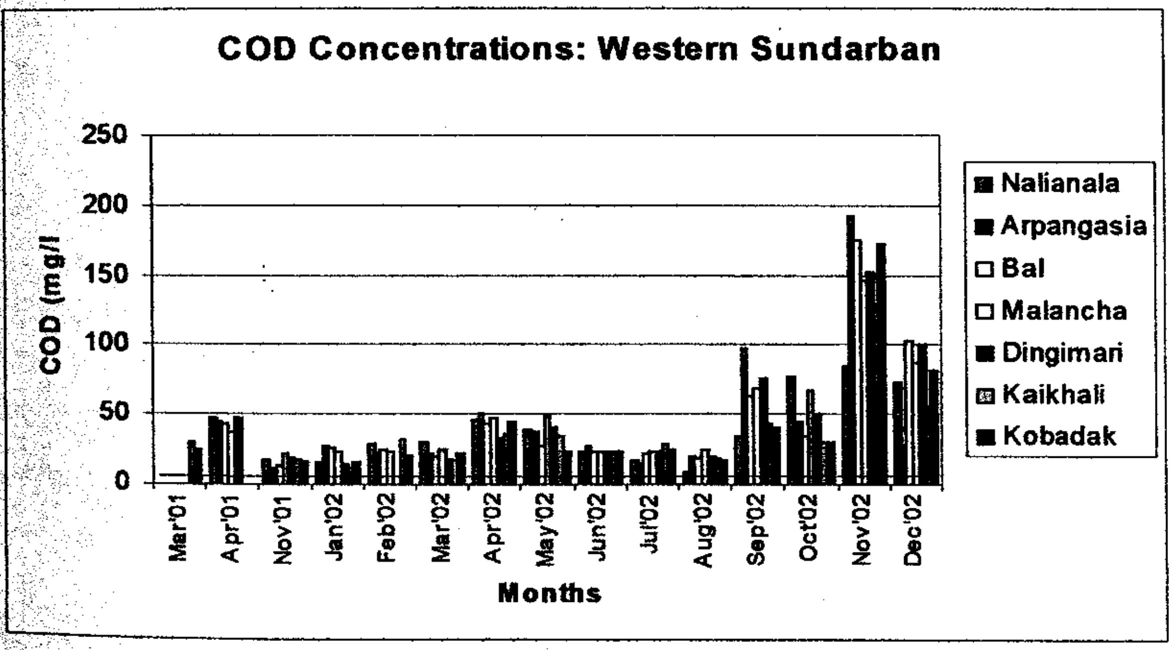
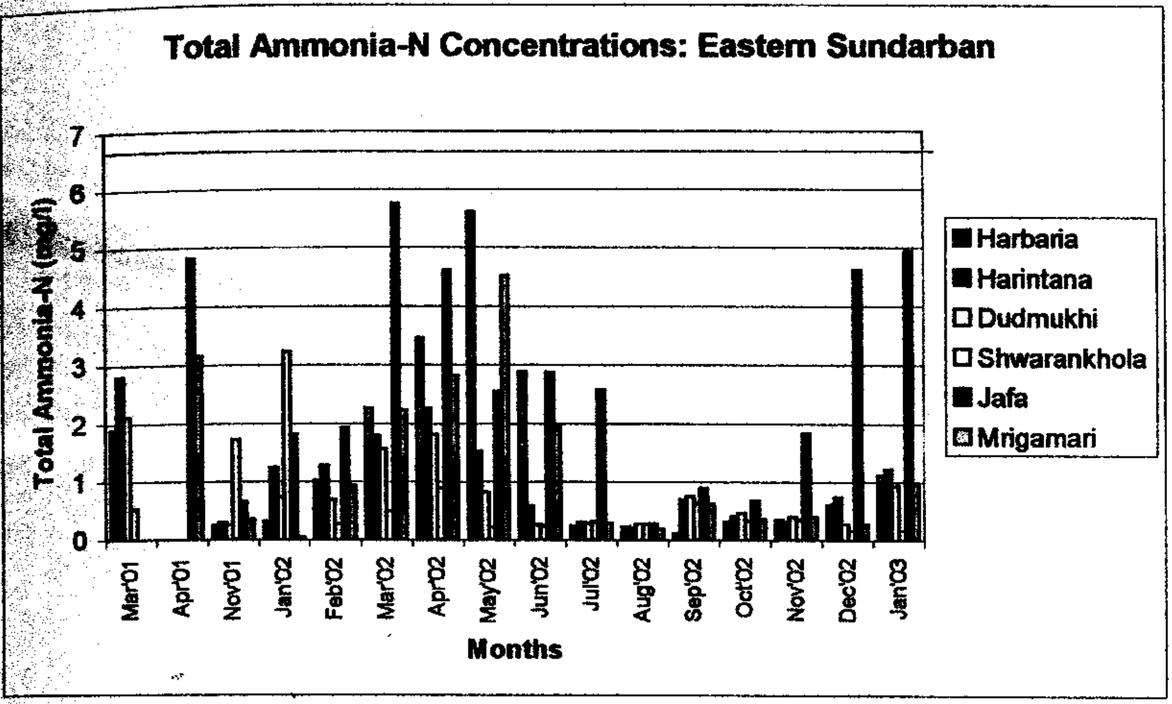


Figure 3.8: COD Concentrations observed in the Western & Eastern Sundarbans

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



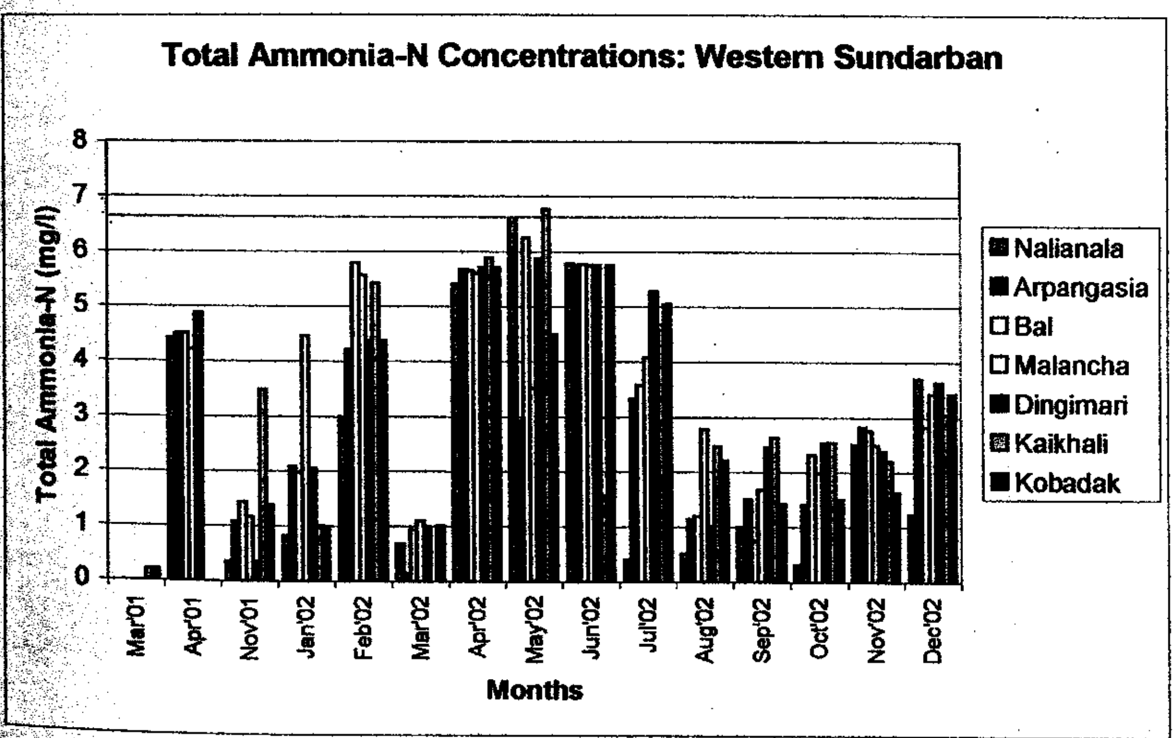
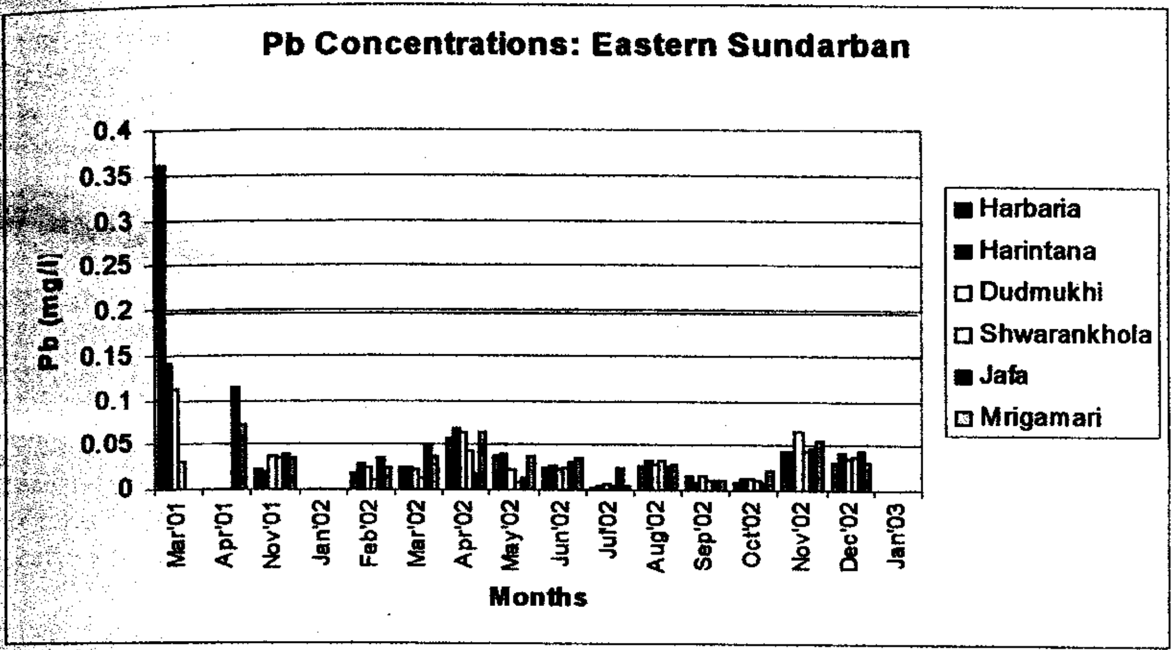


Figure 3.9: Total Ammonia observed in the Western & Eastern Sundarbans



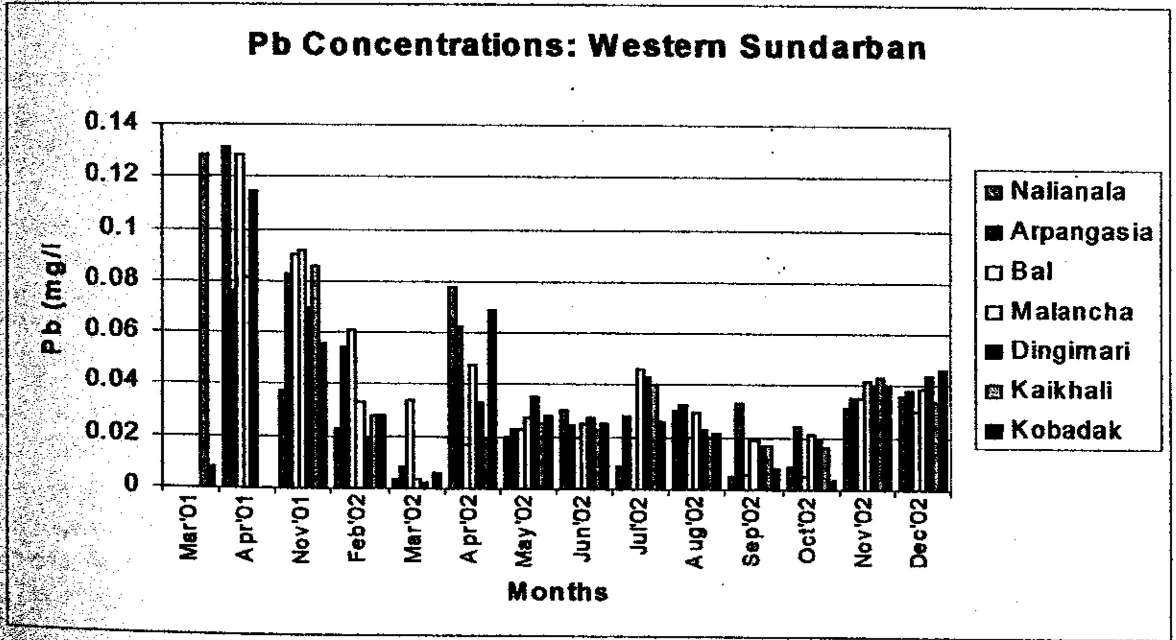


Figure 3.10: Pb concentration observed in the Western & Eastern Sundarbans

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

Both the Northern and Internal Sundarban groups show distinct seasonal variation of BOD (as well as COD), but not so for Total Ammonia in case of Internal Sundarban. 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 Sundarban. For Total Ammonia, maximum concentration occurred during April-May while maximum of Nitrate occurred during June-July.

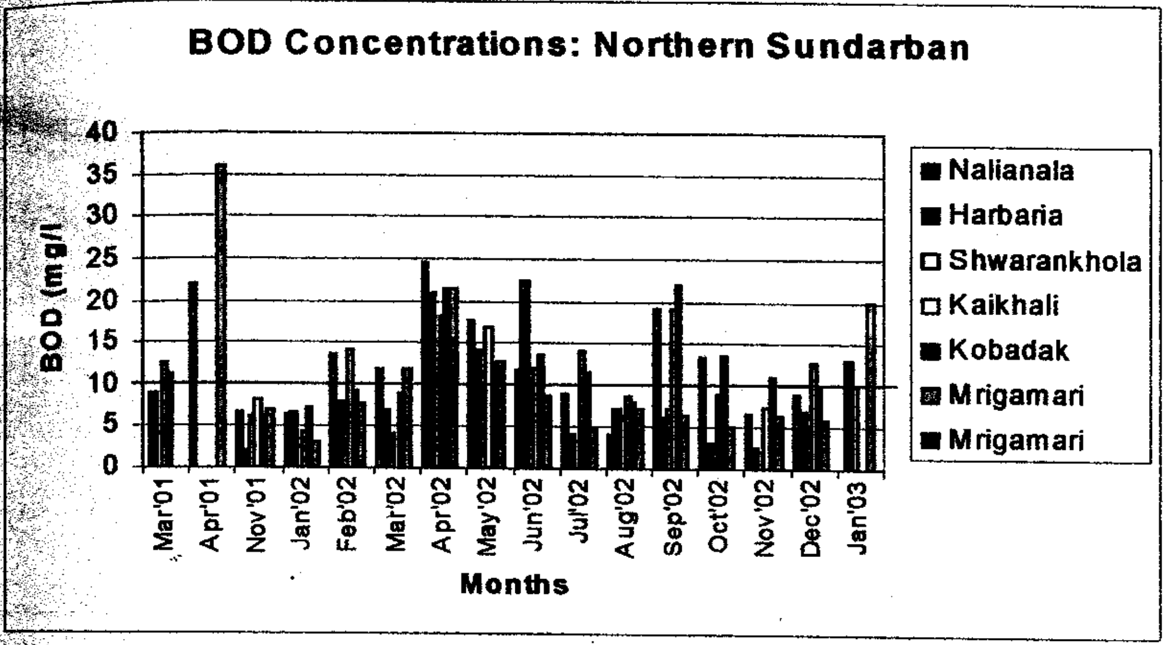
On an average, concentrations of BOD and Total Ammonia in the Internal Sundarban are slightly higher than those in the Northern Sundarban but concentration of COD in the Internal Sundarban is noticeably higher than that in the Northern Sundarban. The seasonal variation of BOD, COD & Total Ammonia for Northern & Eastern Sundarban is presented from Figure 3.11 to Figure 3.13.

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 Sundarban.

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

3.3.6 Recommendation

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. Although, situation in the rivers changes with hydrological pattern, it was found that parameters like BOD & 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, the BOD & COD should be monitored in the stations with higher values to track the source of pollution. There is no definite pattern of nutrient content in the water has been observed. The presence of toxic ammonia (NH3-N) is very negligible. While 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 lead was observed in the soil samples of the pilot areas. As such accumulation of lead from river water to the land may be alarming in future. Presence of mercury, oil & grease were not significant. As such, more emphasis should be given on identifying source of lead and chromium.



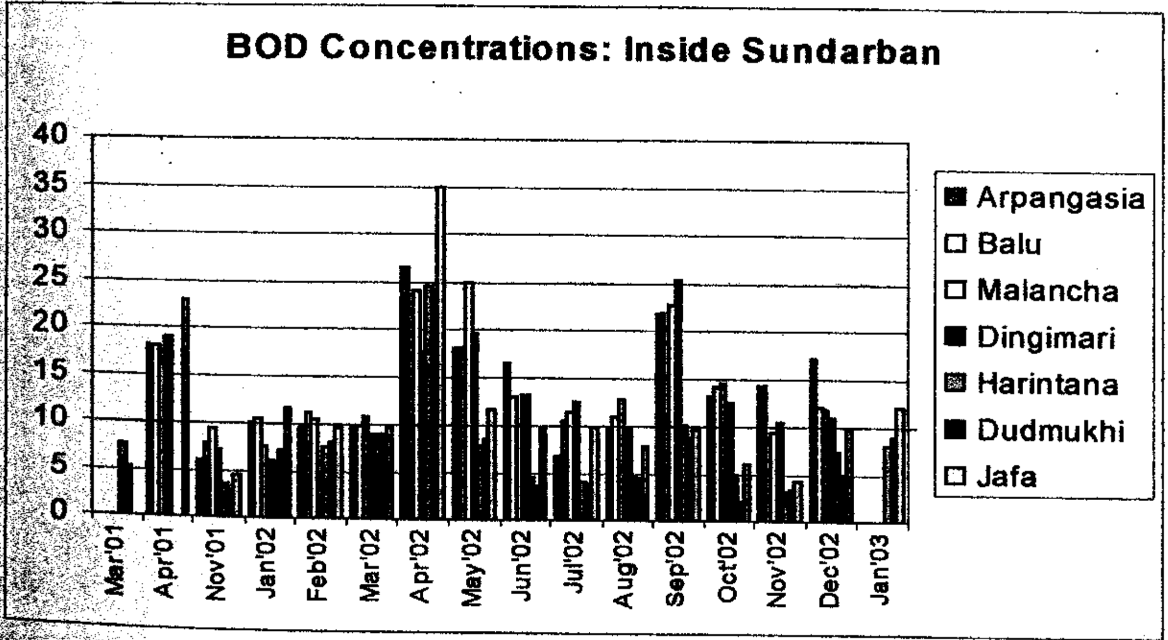
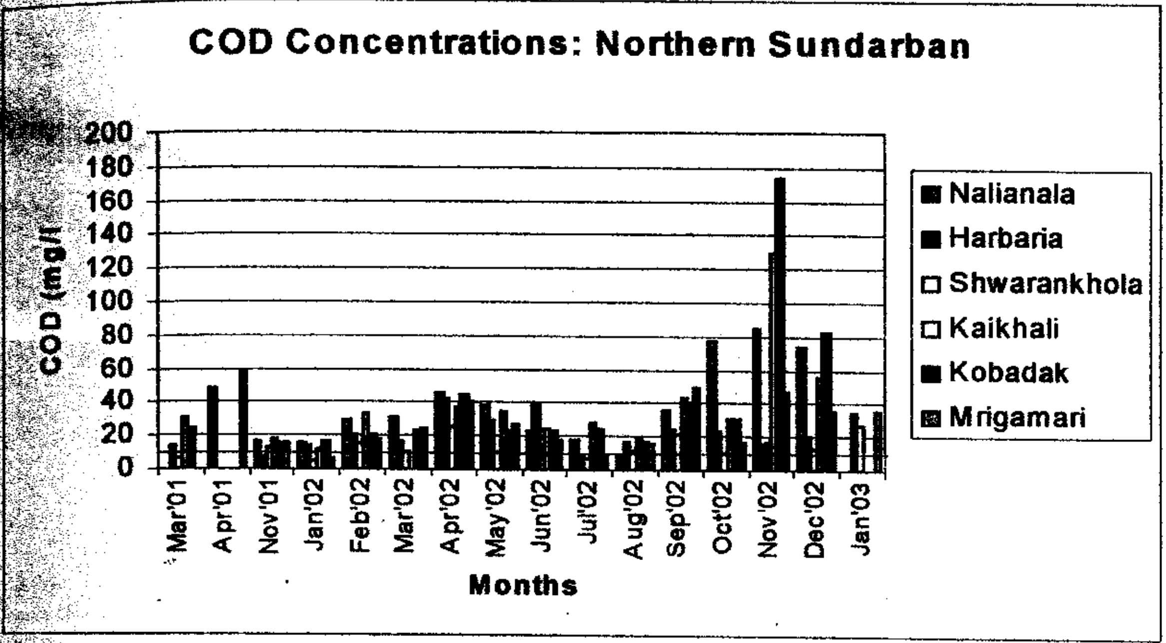


Figure 3.11: BOD Concentrations in the Northern Boundary & Inside Sundarbans



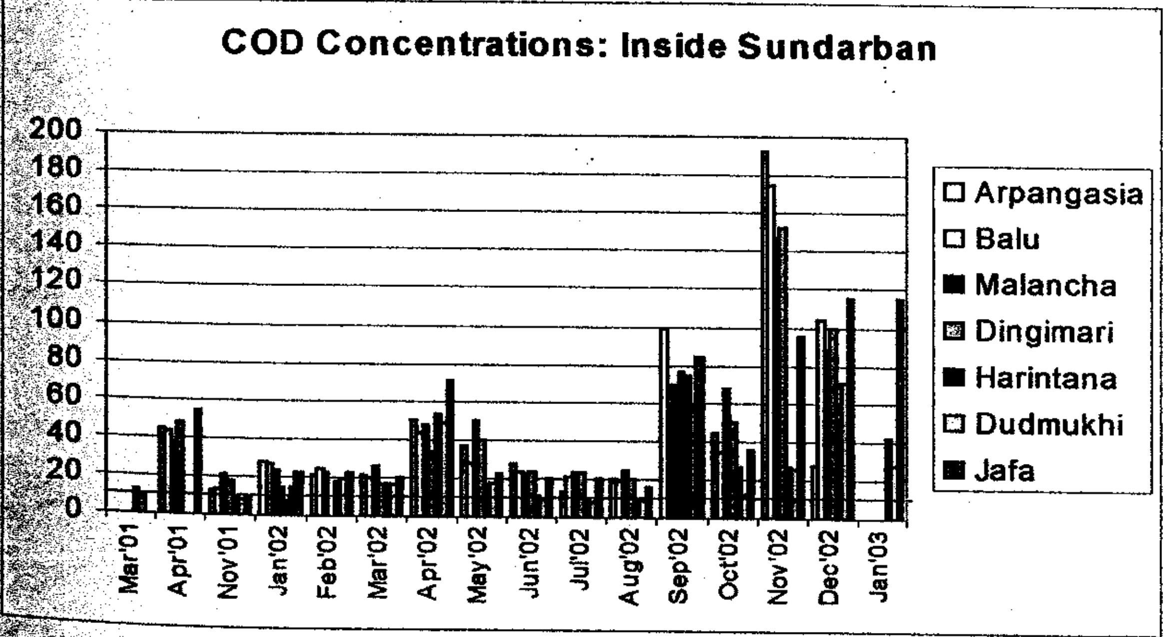
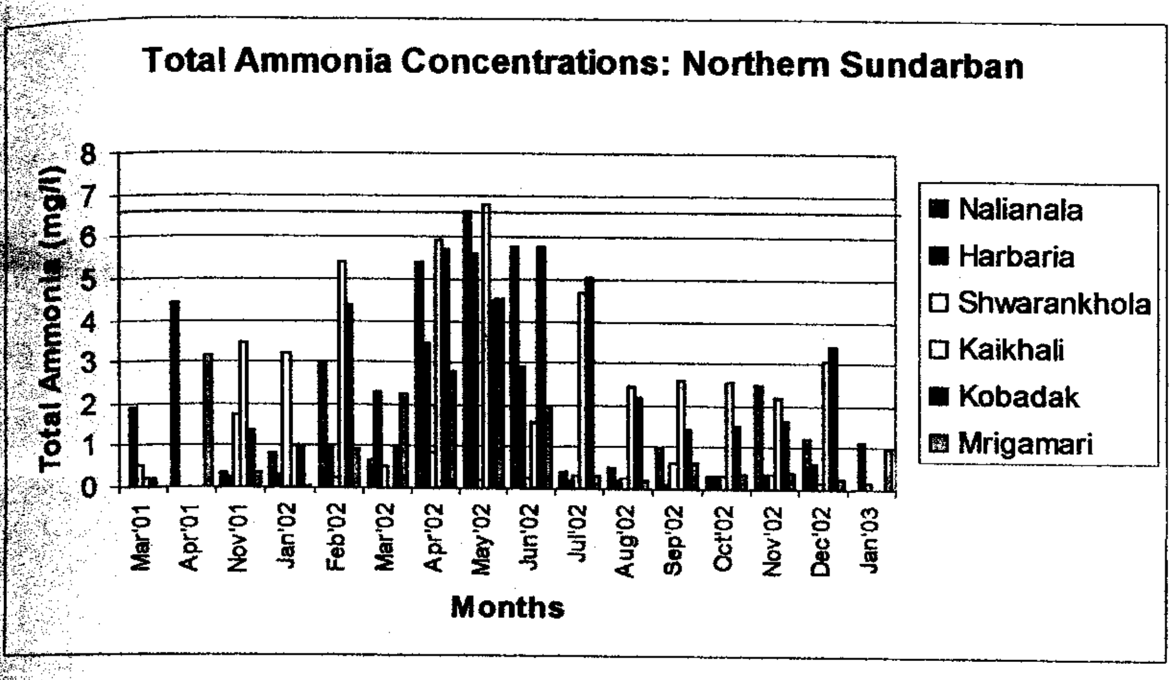


Figure 3.12: COD Concentrations in the Northern Boundary & Inside Sundarbans



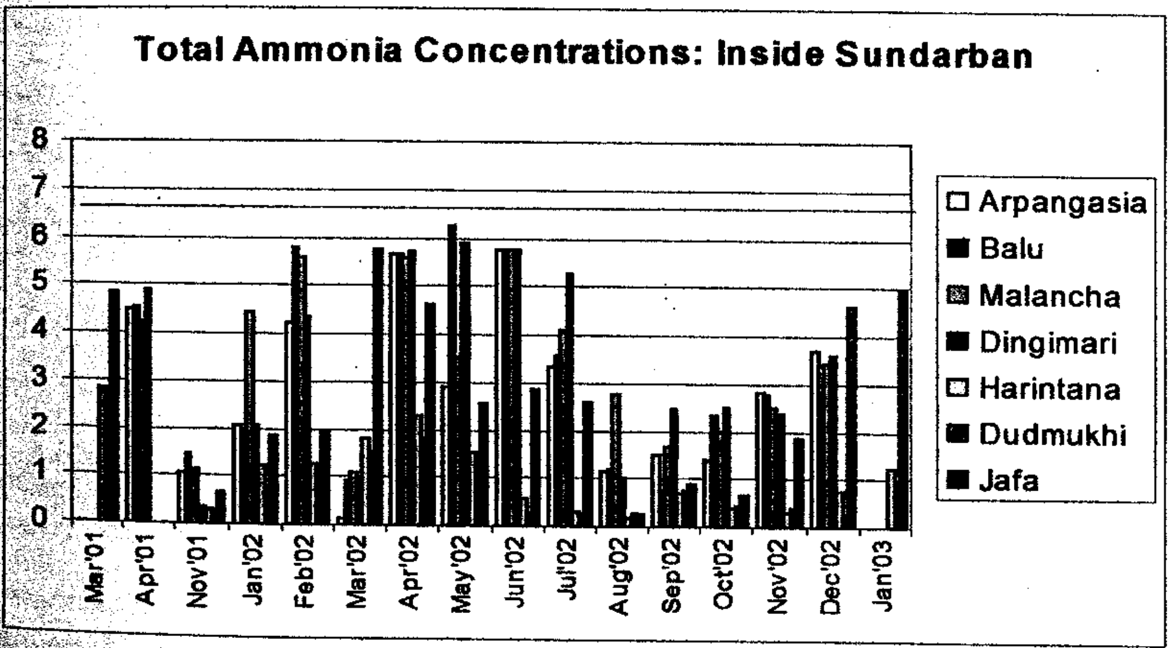


Figure 3.13: Total Ammonia in the Northern Boundary & Inside Sundarbans

3.4 Observation on Pilot Area Study

3.4.1 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 2002. At the end of monsoon, both siltation and erosion have been observed. The summary of the observed values between measurements at Apr-May 2002 (1st Cycle) and Oct-Nov 2002 (3rd Cycle) is presented in Table 3.3. The net siltation rates at the end of monsoon season for the selected pilot areas are 20mm, -1mm and 31mm for Jongra, Patkosta 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 & duration of inundation. All 3 sites have almost same bed soil characteristics having silt and clay as main constituent. However, it is difficult make comments on the basis of one years observation and demands long term observations for definitive conclusion. The plots of observed siltation has been presented on Appendix C.

Table 3.3 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	
Patkosta	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	

3.4.2 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 on the Figure 3.14. While all the maps are presented in Appendix C. The average velocities of microcurrent vary around 10 cm/sec while maximum inundation period during spring tide were around 3 to 4 hours. It was also observed that the velocity during ebbing is slightly higher than velocity during flooding.

3.4.3 Soil Parameters

Soil samples have been collected from the pilot area during Topographic survey and during special monitoring programme in each pilot area. Samples collected during topographic survey will act as benchmark while samples collected later on will be used for comparison. The samples have been tested from Bangladesh Agricultural University Laboratory. Test results of parameters PH, EC, Organic Matter, Nitrogen, Phosphorus and Sulphur, Calcium, Sodium and Potassium have been achieved upto 3rd cycle. The results are presented in [illegible] and Plotting of test results of different parameters showing on the topographic map [illegible] in Appendix C. From the test results, it is seen that the parameters vary with location (surface/bottom) and season. However, it is difficult to find any relationship with the inundation pattern at each site with only a few observations.

3.4.4 Sediment Concentration

Sediment concentration on 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 Appendix C. The average sediment concentrations observed are 205 mg/l, 207 mg/l and 534 mg/l at Patkosta, Koikhali and Jongra area respectively. This is in conformity with the high sediment concentration in the Passur River adjacent to Jongra area than other two pilot areas. It is also observed that the average sediment concentration during flooding at Koikhali is higher than that during ebbing while the average sediment concentrations during flooding is slightly higher than that during ebbing at Patkosta. On the contrary, the sediment concentration observed at Jongra during ebbing was much higher than that of flooding. However, it is difficult to make any conclusive comments based on the too few data.

3.4.5 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 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 3.4. The range of lead concentration varied from 14.18 ppm to 22.29ppm. It also shows that the average lead contents at Patkosta, 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 3.4 Lead concentration observed on the forestland

Location	Sample No.	Lead (ppm)	Remarks
Patkosta	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	

3.4.6 Grain Size Analysis of Soil

The objective of the grain size analysis was to get some indication about sediments deposited at each area. The samples have been collected from 20cm to 30 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 3.5. From the analysis it is seen that the average grain size of 3 samples are:

Patkosta: 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 Patkosta content smaller quantity of clay with higher sand & silt than other two sites. Koikhali samples have higher percentage of clay.

Table 3.5 Grain size analysis of samples from pilot areas

Location	Sample No.	Sand (%)	Silt (%)	Clay (%)
Patkosta	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

3.5 Discharge, sediment and morphological data

Discharge & sediment data have been collected for the model study. Measured velocity has been resolved perpendicular to the cross section to measure the discharge. Discharge profile is important for calibration / validation of the model. However, net volume of water passing through the channel can also be calculated from the observation of a full tidal cycle. Detailed analysis on sediment and river morphology has been made in previous reports (Half yearly report 2001 and Annual Report 2002) and is not repeated in this report. From analyzing morphological data, a number of rivers were found as being silted up while some rivers were identified to become more prominent while compared with common X-Sections available from 1995 and 2000 survey. Provisions were kept for detailed X-Section survey during the additional period of data collection, which was not done due to the completion of the project without extension of time. Apart from morphological study, velocity and sediment concentration provides good information about the river condition. The discharge data in tabular form and plots of sediment & absolute velocity observations are presented in Appendix D.

4 HYDRODYNAMIC MODEL

4.1 Introduction

MIKE 11, a one dimensional (1D) modeling system developed by the DHI, Denmark, is used as the basis for all IWM's 1D models. The South West Region Model (SWRM), developed at IWM has been adopted for surface water modeling of the Sundarban considering the availability of the boundary data. Because the regional model has limited number of upstream boundaries where water level and discharge data are readily available from Bangladesh Water Development Board (BWDB). A smaller model with denser network could be more reasonable but due to practical reason of non-availability of boundary data it has not been possible within present resource. The model has been validated with available hydrological data for 2000-01 and 2001-02 hydrological years. In this report the latest development of the model for 2001-02 hydrological years has been described. The whole model has been calibrated but more emphasis was given to Sundarban part of the model. A dedicated model for the river system of the Sundarban area has been developed using the regional model. However, this Sundarban model needs further improvement with the inclusion of the internal crisscross before it is ready for developing more application scenarios inside the forest. Those will require some more data and will be done in any available scope in future.

4.2 Existing Hydrodynamic Model

The South West Region Model (SWRM) was developed at SWMC 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 (Drawing no: 4.1) and bounded by the Padma and Meghna River on the North and North-East, 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 River topography was updated on various validation periods and also through many projects implemented within the region. In connection with this study, the river cross sections inside the Sundarban were measured mostly in 2000-01 period and later.

There are total 34 boundaries in the hydrodynamic model, of which 22 are upstream inflow boundaries, and 12 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.

4.3 Updating of the Hydrodynamic Model

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. During the project period, around 160 number of river cross sections have been collected in different rivers of the Sundarban. Continuous water levels were recorded at some downstream locations; some of which were related to PWD datum. Moreover, under the "Updating & Validation of General Model & Six Regional Models" project, discharges were measured at some upstream locations of SWRM 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 results of Sundarban HD model.

4.3.1 Data collection and processing

Simulation of SWRM requires different types of hydro-metrological data. In addition to the data collected under the present 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. BIWTA collects continuous water levels at several locations at the southern part of SWRM. The tidal water level data of BIWTA auto gauge stations correspond to Chart Datum, which were adjusted to PWD datum by Moving Average Method. All collected data were checked to detect punching and bench mark errors. Both visual observations and comparison of hydrographs were done at this stage.

4.3.2 Boundary generation

There are total 34 boundaries in the Sundarban HD model, among which 23 are upstream boundaries and rest 11are downstream boundaries.

Upstream boundaries: In the model simulation for 2001-02 hydrological year, out of 23 upstream boundaries 11 nos. boundaries were considered as closed where runoff from hydrological model (NAM) simulation was considered. At two locations (Jamuna 0 & Upper Meghna 0) water level time-series were used. At rest 12 locations discharge time series were considered. Rating curves were updated with 2001-02 data at Gorai Railway Bridge of Gorai River and Baruria of Padma River. At some minor rivers like Kumar, Sitalakhya rating curves were generated using observed data of 2001-02.

Tidal boundaries: Hironpoint 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 Hironpoint data with proper phase and amplitude correction. During 2001-02 hydrological year CPT 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 (datum correction was determined using model results; moving average has been done for both simulated and observed water level, and comparing the two necessary correction factor was determined). At Katka hourly data referenced to PWD datum, was collected from August 2002; at this boundary WL time-series was generated using Hironpoint data and comparing it with observed data of Katka. At other locations like Jamuna entrance, Selagang and Haringhata water level data were generated using Hironpoint data with proper phase and amplitude correction.

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.

4.4 Hydrodynamic model calibration

The Sundarban HD model simulation and calibration 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 briefly 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 values of these locations.

In most of the cases, simulated water level and discharge matched satisfactorily with the observed water level and discharges 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 Raymongal 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 a full satisfactory model results of this river. However, the overall performance of the hydrodynamic model has improved. The calibration plots (comparison of water level and discharges) have been presented in Drawing E.1 to E.23 of Appendix E.

4.5 Limitations of the present hydrodynamic model

The calibration of the hydrodynamic model considering water level and discharge of the Sundarban area is acceptable. In most of the cases, simulated water level and discharge matched satisfactorily with the observed water level 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 Raymongal 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 acceptable, but there are deficiencies in the same. The following are the main limitations of present HD model:

- The downstream boundary at Mandarbaria and Hironpoint are referenced with arbitrary datum; for further improvement of the model those boundaries should be connected to with national datum of PWD. Additional number of continuous water level observation station will be also 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 Indian side is not known.

- In the existing South West Region Model the criss-cross of khal/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 khal/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 with PWD datum.

5 SALINITY MODEL

Salinity modeling is carried out using Advection-Dispersion (AD) module of MIKE 11. In order to understand the salinity intrusion process of the river system, a salinity model has been developed for the rivers of Sundarban. The salinity model is based on one-dimensional equation of conservation of mass of a dissolved or suspended material. The salinity simulation is based on the results (velocity, discharges) of the hydrodynamic model. Two transport mechanisms are considered in AD module: advective or convective transport with the mean flow and dispersive transport due to concentration gradient. The main assumption underlying the advection dispersion equation is that it considers salinity is completely well mixed over the cross-section.

The salinity model has been calibrated both for dry and wet seasons to understand the seasonal variation of the salinity of the river system of the Sundarban area. For dry season the model has been calibrated for February-March '02 and for wet period the model has been calibrated for August-September '01.

5.1 Model Boundaries

Boundaries of the HD model are considered as the boundaries in the salinity model, but some are open and some are closed. In closed boundaries it is assumed that no net transport of salt occurs. In open boundaries salt can enter or leave the system; as such, time series of salinity concentrations need to be specified in such boundaries. 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.

At the downstream open boundaries salinity concentration have been applied using the observed data at downstream locations. Simulated salinity concentrations of internal stations have been compared with the observed data at many locations.

5.2 Calibration of salinity model

The overall calibration of the salinity model looks satisfactory given the limitations of the HD model. The model has been calibrated for dry period during February-March '02 and for wet period during August-September '01. All the available salinity measurement data collected under the Sundarban project have been compared with the simulated results both for dry and wet period. In the dry period the simulated results show a good agreement at most of the observed stations except Sela gang (upstream part), Harintana and Supoti khal. Most of these rivers lie in the eastern part of the Sundarban. The possible cause may be the use of synthesized water level at the downstream boundary of the Baleswar River.

In the wet period the results are satisfactory at most of the stations, though there are some deviations at Malancha, Kobadak and Dumkoli rivers. The model results are under-simulated in these locations. In the HD model, some differences between observed and simulated results at Kobadak River could be observed, which may be the cause of such deviations. The calibration plots of the salinity model have been presented in Drawing F.1 to F.6 of Appendix F.

Salinity maps based on the model results have been presented in Figures H.1 and H.2 of Appendix H for dry and wet period respectively. Distribution of salinity for both the period can be observed from the maps. In the wet period the salinity in the Sundarban varies from 1-12 ppt whereas in dry period (March '02) it varies from 8 to more than 25 ppt. The maximum salinity occurs near Mandarbaria.

5.3 Conclusions

The rivers in the Sundarban make a very complicated network, where large numbers of interconnecting small channels exist. All of these are not included into the model. So exact reproduction of salinity concentration of such complex river system is a task to be taken up step by step.

For further improvement of the salinity model the following steps need to be taken up:

- Further improvement of the HD model;
- Salinity measurement at all boundary locations;
- Salinity measurement at more locations along the rivers;
- Development of a refined 2D Bay of Bengal (BoB) model as a source of boundary salinity data at the deep sea.

All these recommendations unfortunately targets one direction ie more extension of time at more locations at boundary at deep sea to be taken. May I ask what is benefit of this study for last 3 yrs. for FD / → Sundarban vegetation or change in composition / regeneration / etc or otherwise in clear terms of for increase / fluctuation of salinity degree of increase / decrease.

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.

No distinct pollutant sources except Rupsh + Bhairab. 2. Pollutants are pollution out of non point sources

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 Appendix 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.

The WQ model is highly sensitive on the accuracy of HD model. A minimum imperfection in HD model can influence the whole model setup. As such, WQ model cannot be expected to simulate the variation of DO on a very precise level with the present condition of the HD model. Rather, 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.

Reviewing the four plan-plots of DO concentrations in the Sundarban river system (Figures 6.1 to 6.4), it can be seen that there are distinct seasonal variation of DO in the river system along with spatial variation from river to river. 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.

A lot of convincing words to provide more model for future — everywhere but no definite conclusion / suggestions made!

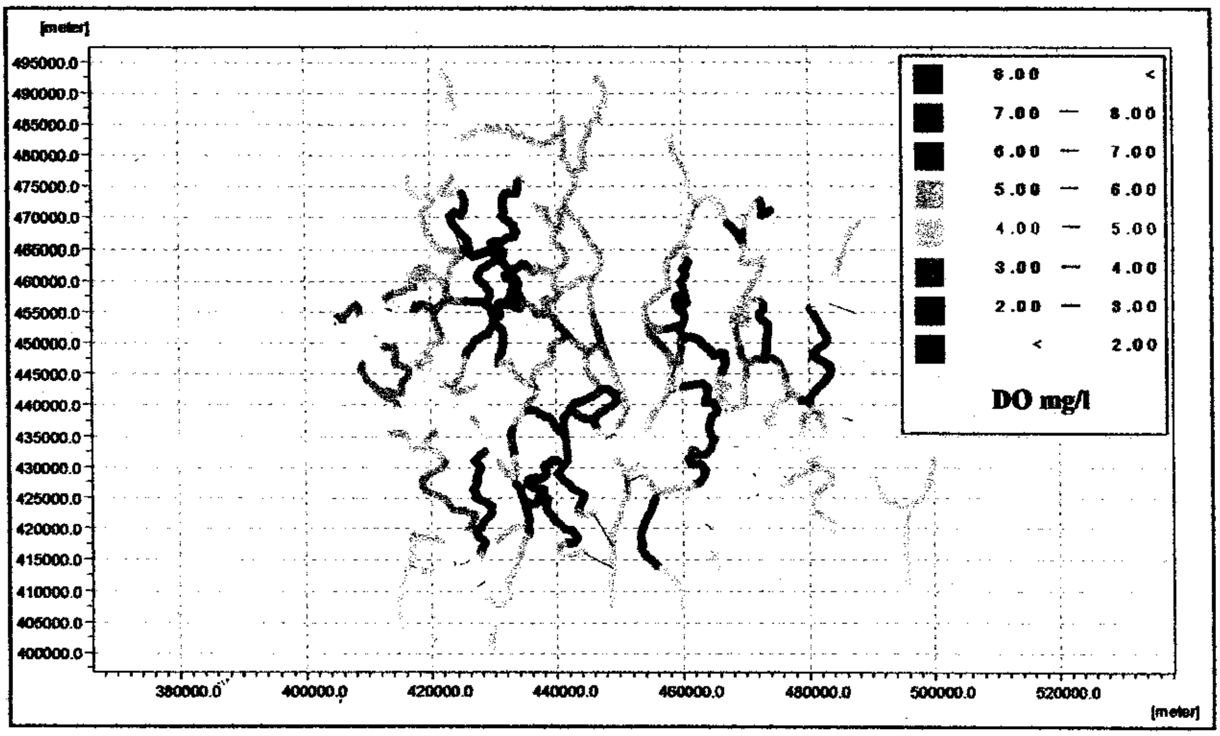


Figure 6.1: DO level on 17-8-2001 03:00 (Monsoon)

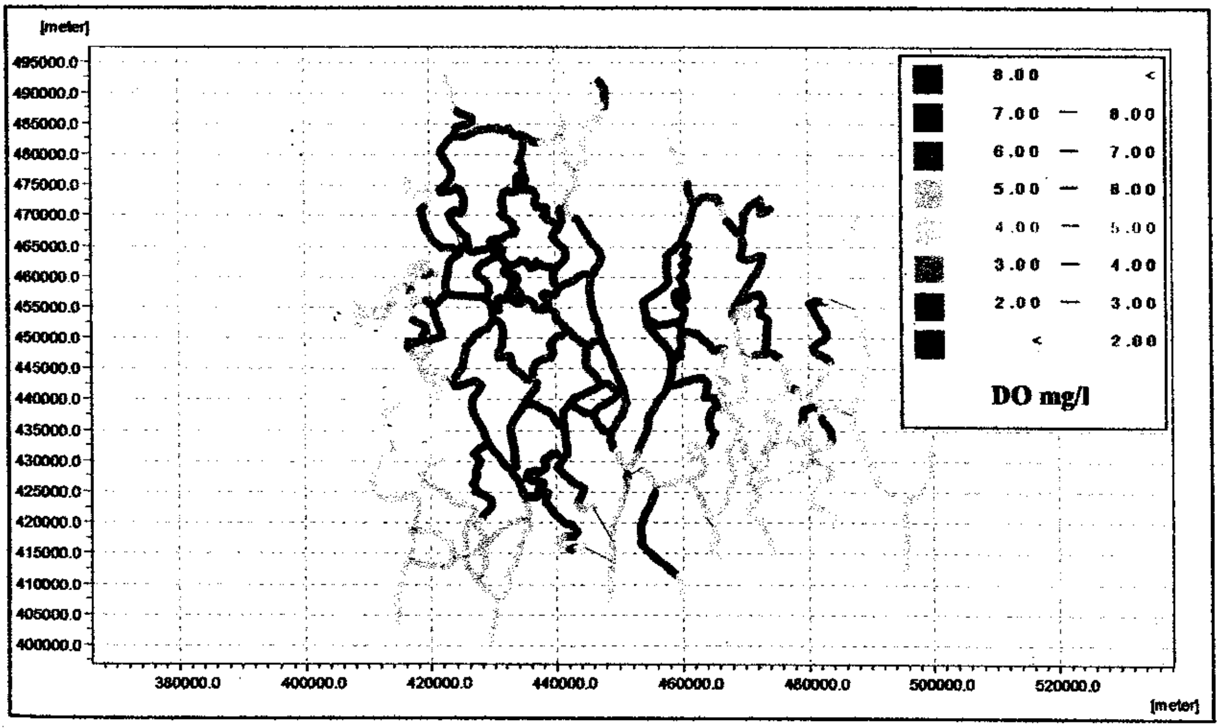


Figure 6.2: DO level on 9-12-2001 19:00 (Post-monsoon)

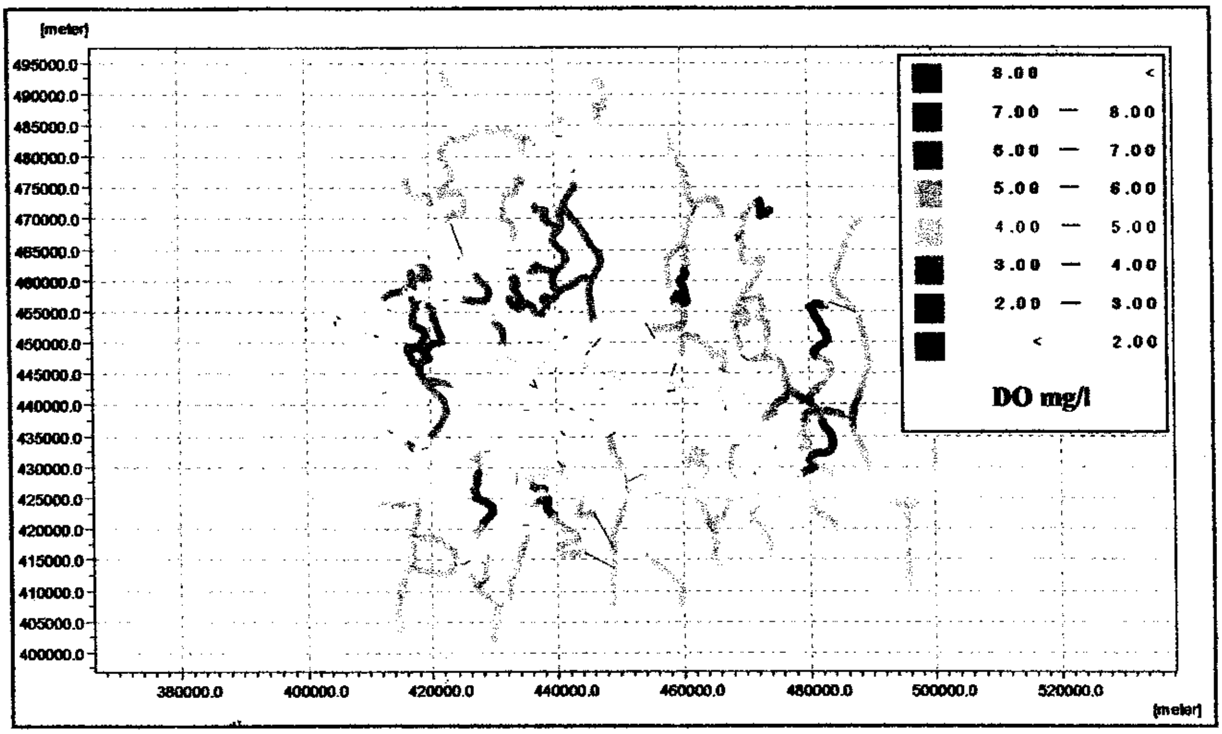


Figure 6.3: DO level on 3-2-2002 14:00 (Dry)

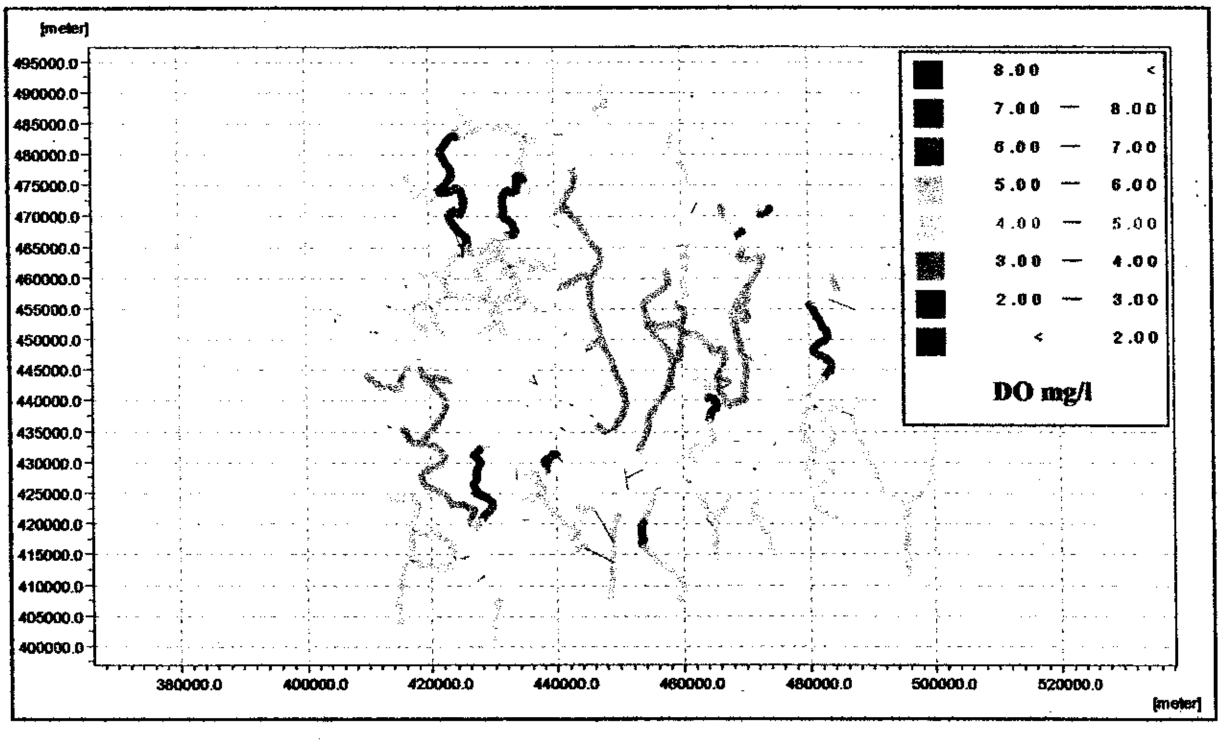


Figure 6.4: DO level on 28-6-2001 01:00 (Pre-monsoon)

7 SEDIMENT STUDY

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.

Silt deposition in Khorma was not studied as it is not included. To me, change in compon of flora & fauna is already taking place in compH-26 but this significant silt deposition area is not included!

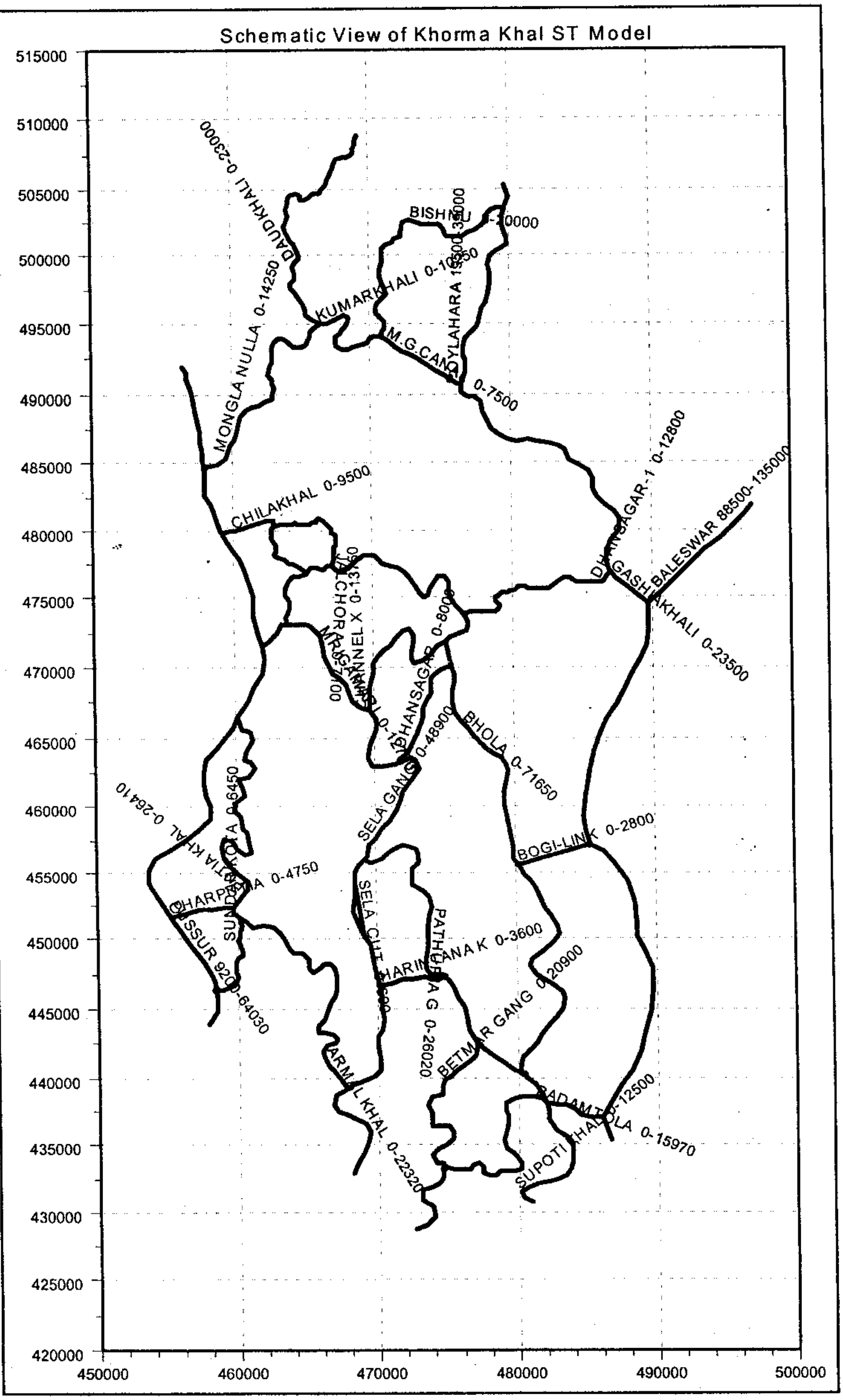


Figure 7.1: Overview of the model set up.

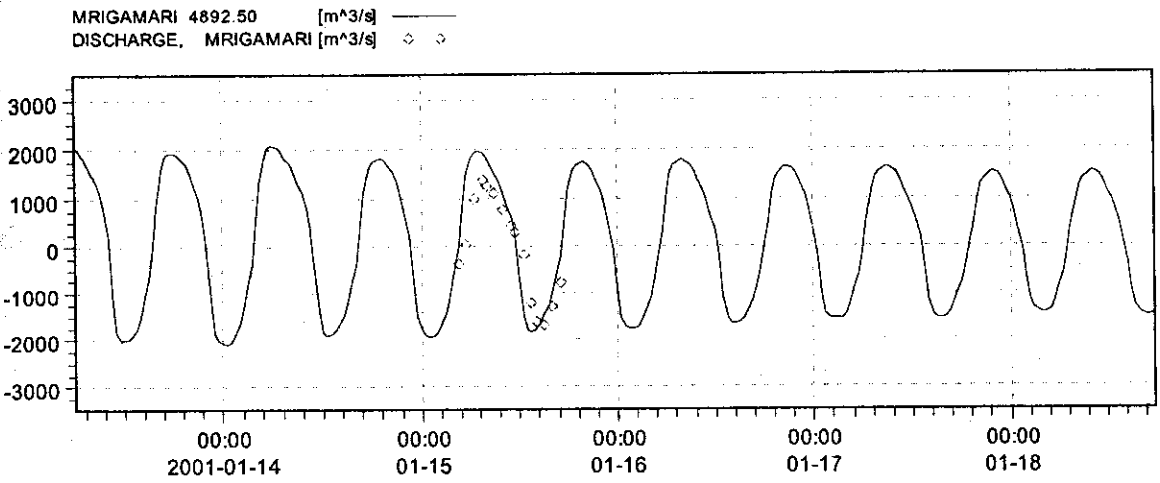


Figure 7.2: Comparison of modelled and observed discharges at Mrigamari.

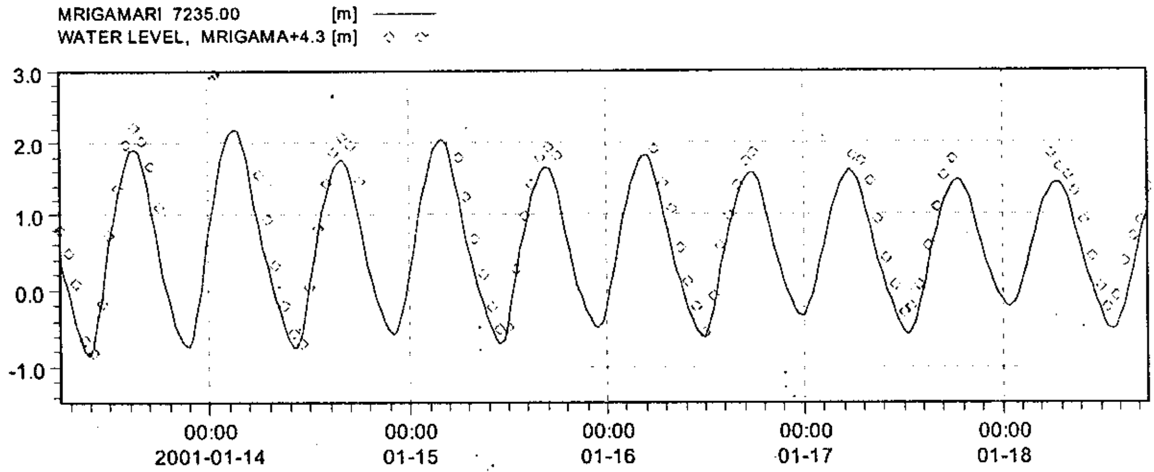


Figure 7.3: Comparison of modelled and observed Water Level at Mrigamari.

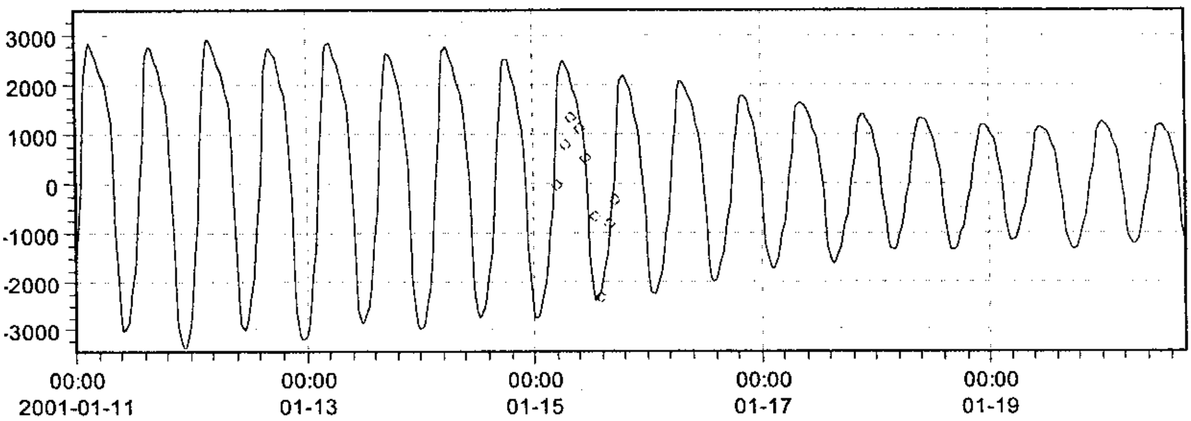


Figure 7.4: Modelled and observed sediment transport (kg/sec) at Mrigamari

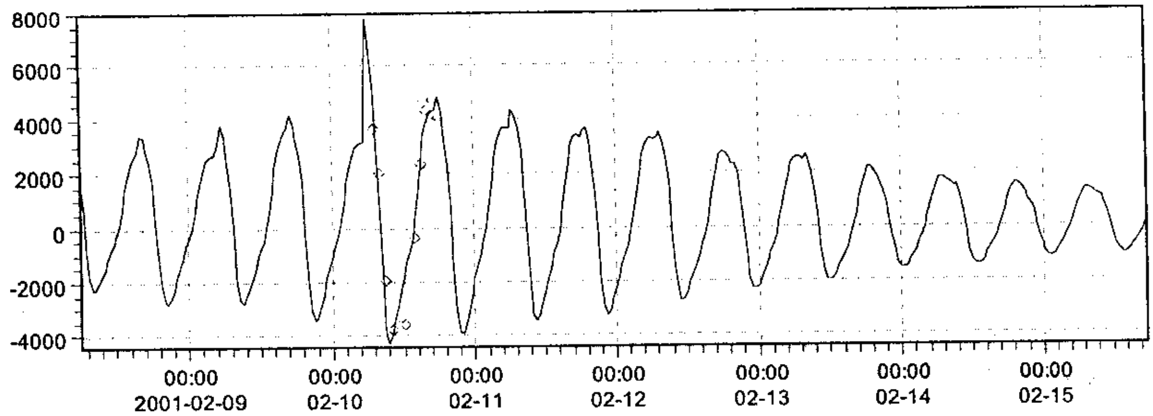


Figure 7.5: Comparison of modelled and observed sediment transport at Harintana

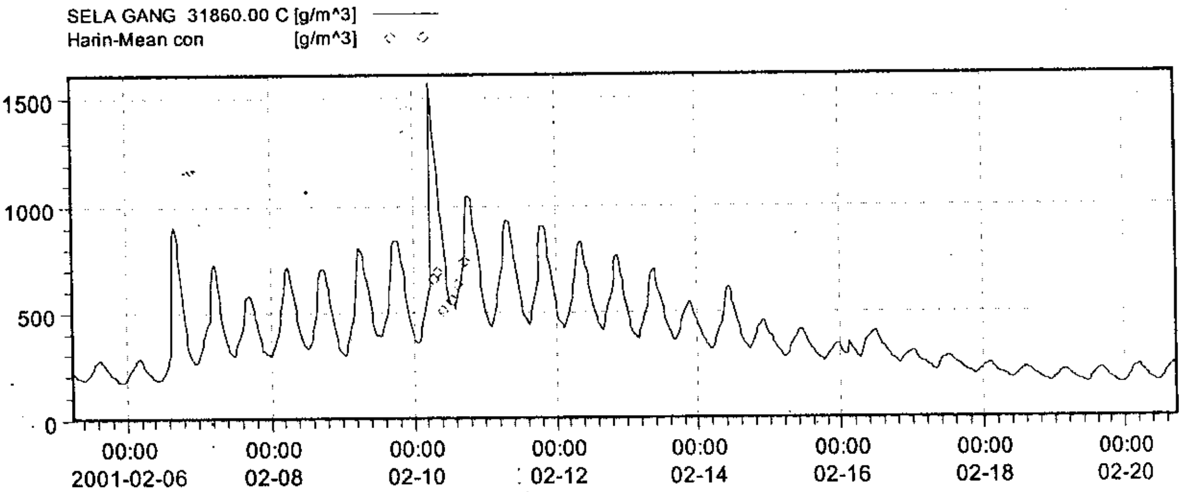


Figure 7.6: Comparison of modelled and observed sediment concentration at Harintana

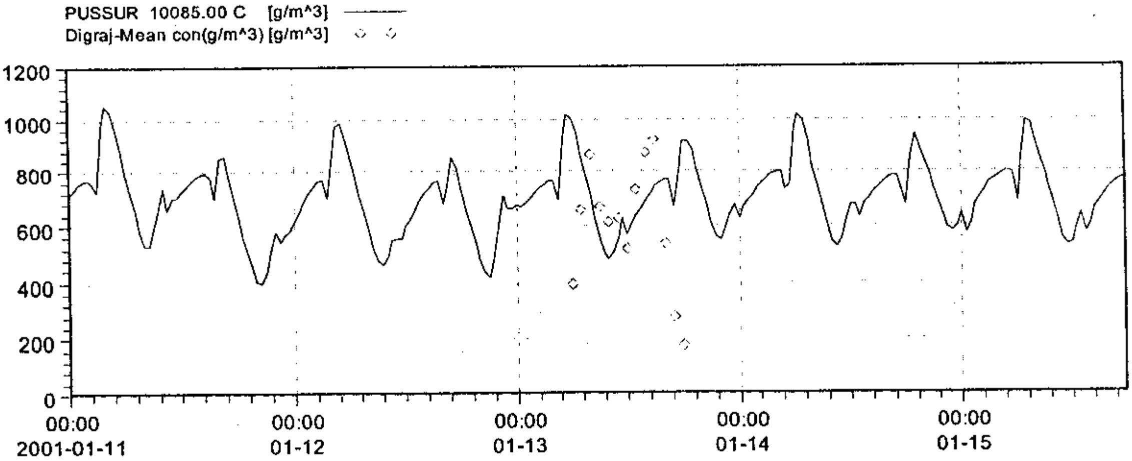


Figure 7.7: Comparison of modelled and observed sediment concentration

8 OPTION STUDY

One of the advantages of mathematical model is that it can be used to generate hydraulic variables for different changed conditions. Based on the calibrated hydrodynamic and salinity models developed for the Sundarban, several option scenarios have been simulated to analyze the salinity and inundation pattern at different locations of the Sundarban area due to the impact of selected options. The results of the study of different options have been discussed in this chapter.

8.1 Development of option scenarios

To understand the change of flooding and salinity intrusion process in the river system of Sundarban due to different options like sea level rise or due to change in upland discharges, several preliminary application runs have been performed. The options were selected by consulting with Department of Forest officials and using past experience of IWM (Table 8.1).

The salinity intrusion of the river system of Sundarban is sensitive to the fresh water inflow from the upstream rivers, and the saline water coming from the sea. Gorai is the main upstream river, which carries maximum fresh water towards the Sundarban. Some other rivers like Kobadak, Betna, Hari, etc. situated in the western part of the Sundarban, can be used as source of fresh water for the Sundarban, but at present those are mostly dry, specially, during dry period. With the dredging of Gorai River, a minimum flow through the river can be maintained. Also some flow can be increased in the northwestern boundary rivers by dredging and connecting them with some big upstream rivers like Mathabhanga. To understand the change of salinity intrusion process in the river system of the Sundarban due to change of upland flow Options 1, 2, 3, 7, 8 & 9 have been analyzed. The changes due to sea level rise have been studied in Option 4 & 5. Impact of dredging of the Kharma Khal has also been studied in Option 6. Different figures of the option study have been presented in Appendix H in addition to the figures presented in this chapter.

Table 8.1 List of options selected for model simulation

Option No.	Option description
0	Base condition: the 2001-02 hydrological year data has been used to generate base model situation, during this period a minimum flow 10-20 m^3/s was recorded in the Gorai Railway bridge during February-March 2002.
1	Minimum discharge at Gorai is 100 m^3/s without changing other existing condition.
2	Minimum discharge at Gorai is 200 m^3/s without changing other existing condition.
3	A Minimum of 50 m^3/s was diverted into the Kobadak, Hari, Harihar and Betna rivers in addition to the Option 2.
4	With 50 cm Sea Level Rise without changing other existing condition.

Option No.	Option description
5	With 20 cm Sea Level Rise without changing other existing condition
6	Introduction of dredged channel of Kharma khal (upper portion of Bhola River)
7	A Minimum of 300 m^3/s was diverted into the Kobadak, Hari, Harihar and Betna rivers during monsoon period.
8	The connecting channels between Kobadak and Sibsa river were closed, other conditions remain same as existing one.
9	In addition to Option 8 additional 50 m^3/s was diverted to the Kobadak River during dry period and that of 300 m^3/s in the wet period.

8.2 Impact of fresh water flow on salinity

Distribution of salinity in the Sundarban and surrounding area have been generated using salinity model result. The salinity distribution maps have been presented in Appendix H. The existing salinity distribution has been presented in Figure H.1 & H.2. Figure H.1 illustrates dry period (maximum salinity of March '02) salinity distribution and Figure H.2 that of wet period (maximum salinity of September '01) salinity distribution. Maximum salinity occurs at the southwest corner of the Sundarban, near Mandarbaria where salinity is more than 25 ppt during dry period (March 02) and 8-12 ppt in the wet period (September 01).

In Option 1, 2 & 3 the impact of dry season Gorai flow on the salinity distribution have been studied. In Option 1, a minimum discharge of 100 m3/s was maintained in the Gorai river during the dry period; in Option 2 the minimum discharge was increased to 200 m3/s. In Option 3 a constant flow of 50 m3/s was used in the Kobadak, Hari, Harihar and Betna rivers along with the 200 m3/s flow in the Gorai River.

The impact of flow variation through rives in the western part (Kobadak, Betna, etc.) have been studied in Option 7, 8 & 9. The impact on wet period salinity due to additional flow through the rivers situated in the northern part of the region have been studied in Option 7. The rivers are Kobadak, Betna, Hari and Harihar. At present, during wet period the discharges of these rivers are generated from their own catchment runoff only. If it would be possible to divert some flow through these rivers from upstream rivers like Mathabhanga then the probable salinity changes have been studied in this option. The influence of water flow the Kobadak River in the salinity on the northwestern part of the Sundarban has been studied in Option 8 & 9. The Kobadak River has been separated from the Sibsa river in Option 8, the model has been simulated with full upstream flow diverting through the Kobadak system. In Option 9, some additional flow was added through the Kobadak river (50 m3/s during dry and 300 m3/s during wet period) using the same river set-up of option 8.

Changes due to the different upstream flow have been illustrated in the following paragraphs. Figure 8.1 & 8.2 illustrate the salinity changes at Mongla and Nalianala due to different options. The changes in longitudinal profile of salinity of Rupsa-Pussur and Kobadak-Malancha river systems have been presented in Figure 8.3 & 8.4 respectively.

OPTION 1: Due to the additional fresh water flow the salinity of the river system of Sundarban and surrounding area have decreased. The changes are different at different locations. Changes in salinity at Mongla and Nalianala can be observed in Figure 8.1 & 8.2. The salinity distribution, as can be observed in Figure H.3, the increased fresh water flow pushes the salinity front downward. The 1-4 ppt salinity zone is shifted from Bardia to upstream of Khulna. This impact is maximum near Mongla and reduces towards south. The impact also can be visualized in the northeastern part of the Sundarban; the upper portion of Bhola river (Kharma Khal) near Mrigamari lies in the Zone of 8-12 ppt in the base condition, but in option 1 the salinity of this area reduces to 4-8 ppt. However, the impact reduces towards the sea and western part of the Sundarban.

OPTION 2: In Option 2, a minimum of 200 m3/s is maintained in the Gorai River, whereby a further downward shifting of salinity can be clearly visualized from Figure H.4. Due to this option the salinity at Mongla reduces by more than 1.5 ppt whereas at Nalianala the reduction is around 1 ppt (Figure 8.1 and 8.2).

OPTION 3: This option is similar to Option 2 except that an additional 50 m3/s is maintained in the Kobadak, Harihar, Hari and Betna rivers situated above the western part of the Sundarban. For the additional flow, salinity front moves to the downward direction in the northeastern part of the Sundarban (Figure H.5).

OPTION 7: In this option the impact of additional flow during the monsoon period salinity of Sundarban has been studied. Additional 300 m^3/s constant flow was maintained in the Kobadak, Hari, Hariha and Betna rivers during monsoon. At present, little flow comes from the upstream; only flow from catchments runoff. If it is possible to divert some additional flow from upstream big rivers like Mathabhanga, then the probable situation is studied in this option. The salinity distribution map has been presented in Figure H.6. Reduction in salinity can be observed in the western part of the region near Chapra situated outside the Sundarban. Slight reduction in salinity in the forest can be observed in the salinity distribution map.

OPTION 8&9: To see, what would happen when the full flow is flushed through the Kobadak system into the Sundarban, option 8 has been selected. In Option 9, an additional constant flow was diverted through the Kobadak River in the set-up of Option 8. Reduction in salinity along the upstream part of Kobadak can be observed in Option 8 (Figure H.7 & H.8), but the effect is more pronounced when there is an additional flow in the Kobadak river, i.e. Option 9, for both dry and wet period (Figure H.9 & H.10). The salinity around the Kobadak forest station reduces by about 2 ppt due to Option 9 (Figure 8.4). The salinity of Pussur River at Mongla does not change in Option 8 & 9; but in Sibsa River at Nalianala salinity slightly increased for these two options (Figure 8.1 & 8.2).

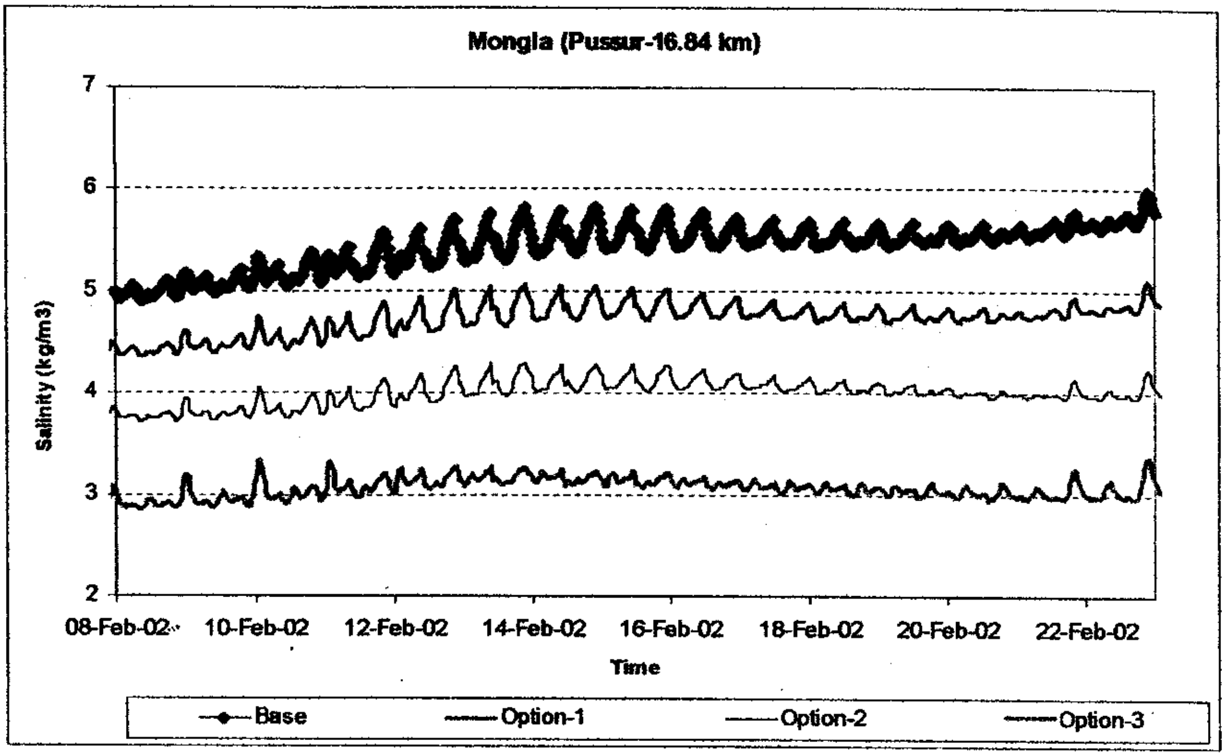


Figure 8.1 Changes of salinity at Mongla of Pussur River due to different conditions of upstream flow (base and option 1, 2, 3, 8, 9)

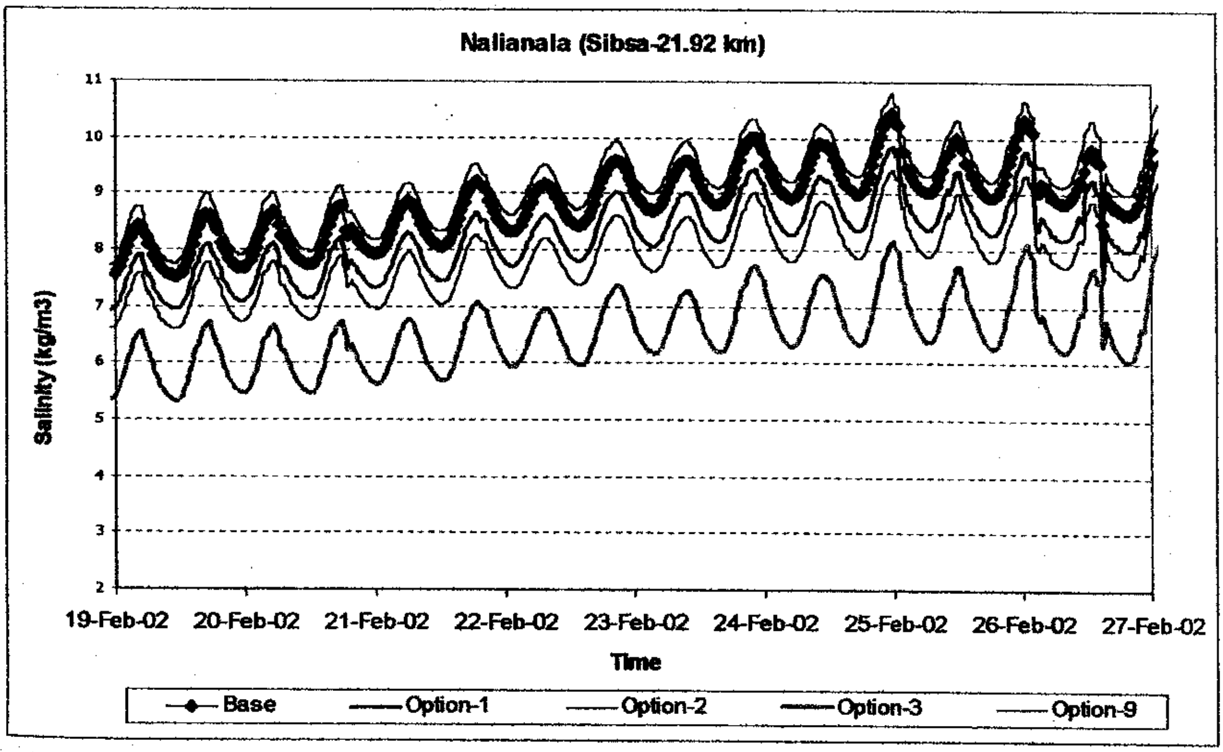


Figure 8.2 Changes of salinity at Nalianala of Sibsa River due to different conditions of upstream flow (base and option 1, 2, 3, 8, 9)

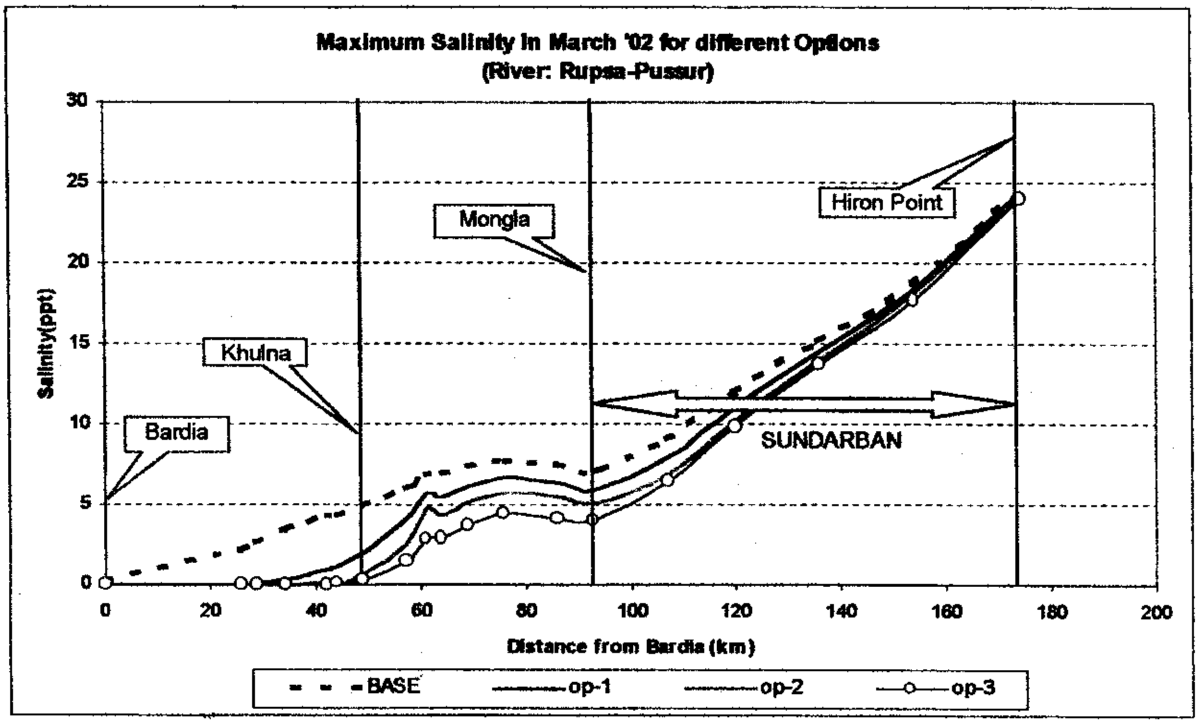


Figure 8.3 Changes of longitudinal profile of salinity in the Rupsa-Pussur river system due to different conditions of upstream flow

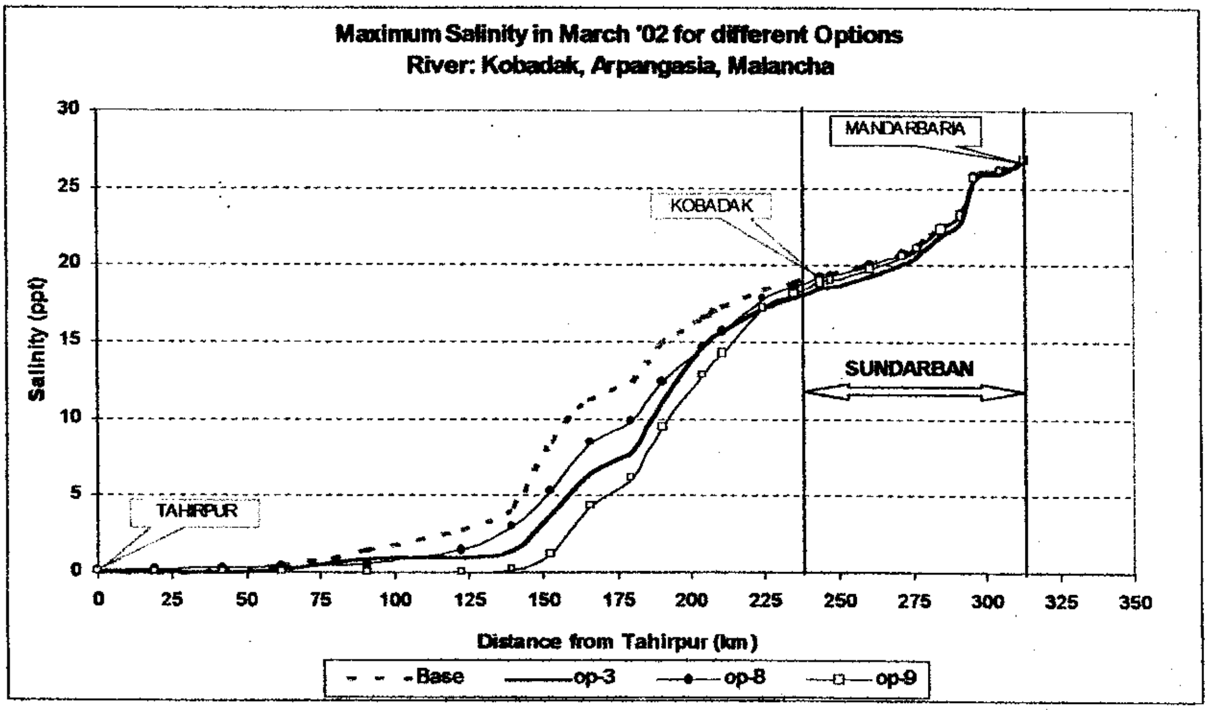


Figure 8.4 Changes of longitudinal profile of salinity in the Kobadak-Arpangasia-Malancha river system due to different conditions of upstream flow

8.3 Impact of Sea Level Rise

In Option 4, impact due to sea level rise of 50 cm and in Option 5, impact due to sea level rise of 20 cm have been studied. Water level changes at Mongla due to sea level rise can be observed in Figure 8.5. Due to sea level rise the salinity of the Sundarban will increase; for example at Notabaki (Jamuna River) there will be an increase of around 2 ppt in option 4 and more than 1 ppt in option 5 during the month of March (Figure 8.6).

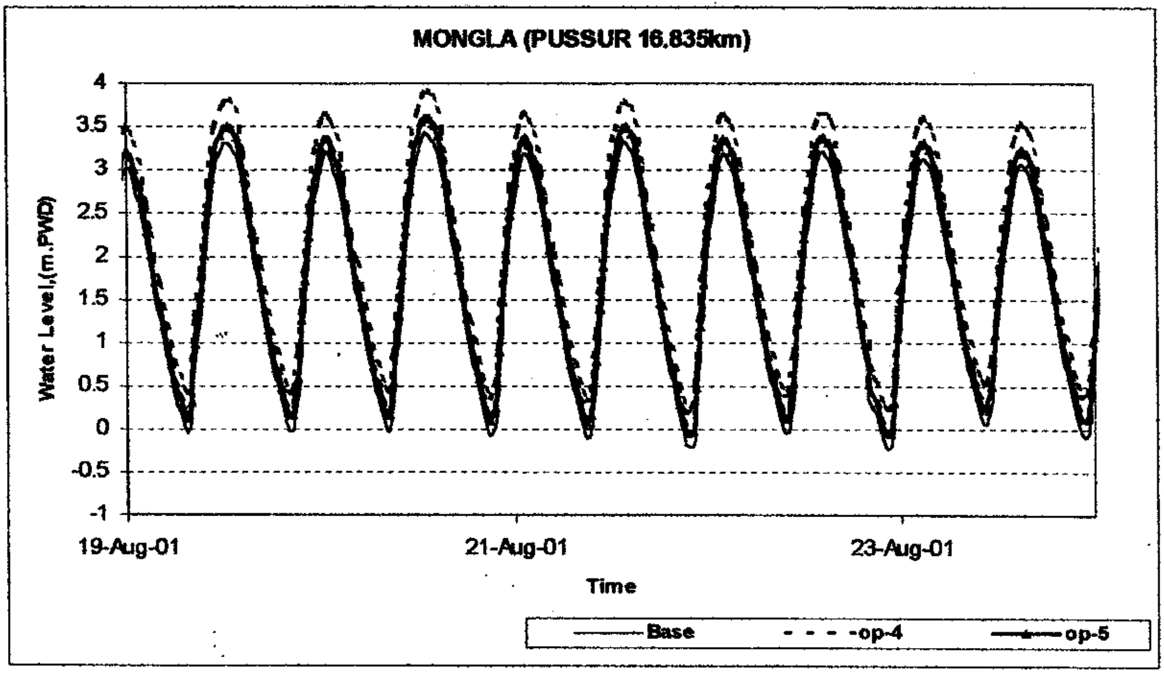


Figure 8.5 Water level changes at Mongla due to sea level rise (Option 4 & 5)

Figure H.11 illustrates the maximum salinity distribution (March '02) condition in the Sundarban due to 50 cm sea level rise. From the figure it can be observed that the >25 ppt salinity zone intrude into the Sundarban with a greater extent; maximum increase of salinity occurs along the Pussur - Sibsa river system.

Impact on inundation pattern of the Sundarban due to sea level rise is also studied with the help of Flood Map. For the study, the updated DEM of the Sundarban, based on FINNMAP data, have been used. For base condition the inundation pattern of the Sundarban has been presented in Figure H.12 & H.13. Flood maps were generated for two time 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 8.7).

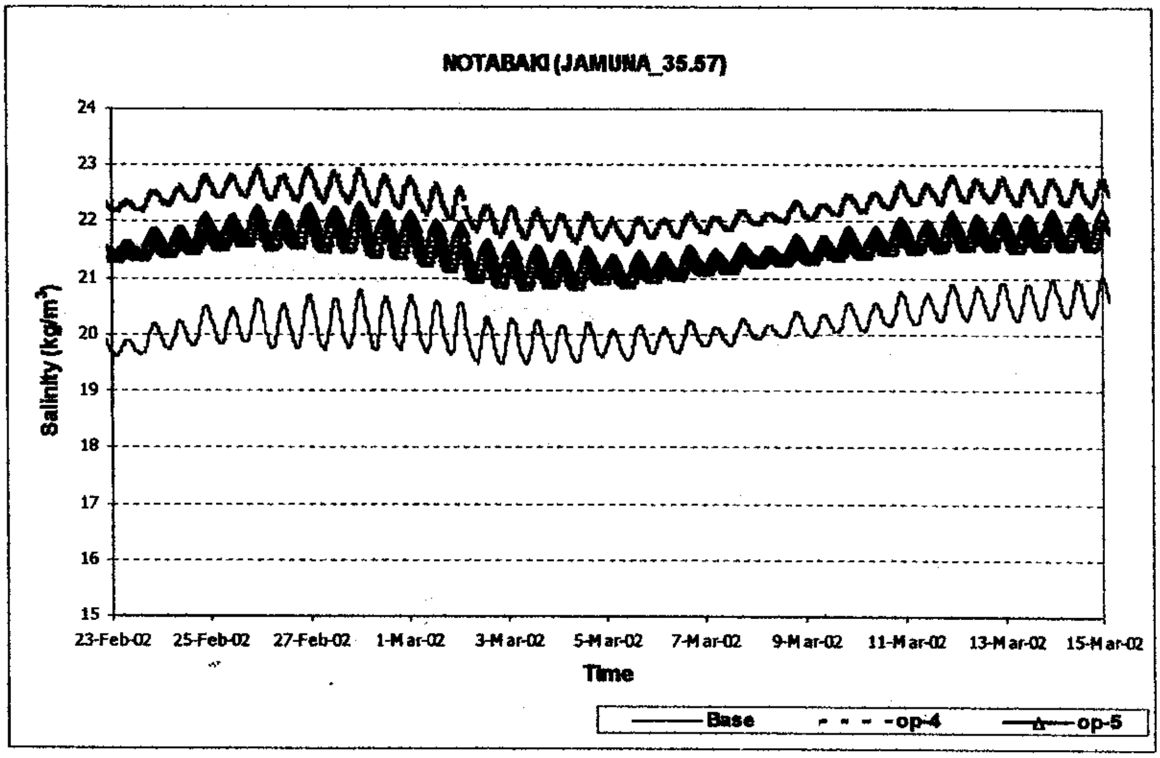


Figure 8.6 Increase in salinity at Notabaki due to sea level rise (Option 4 & 5)

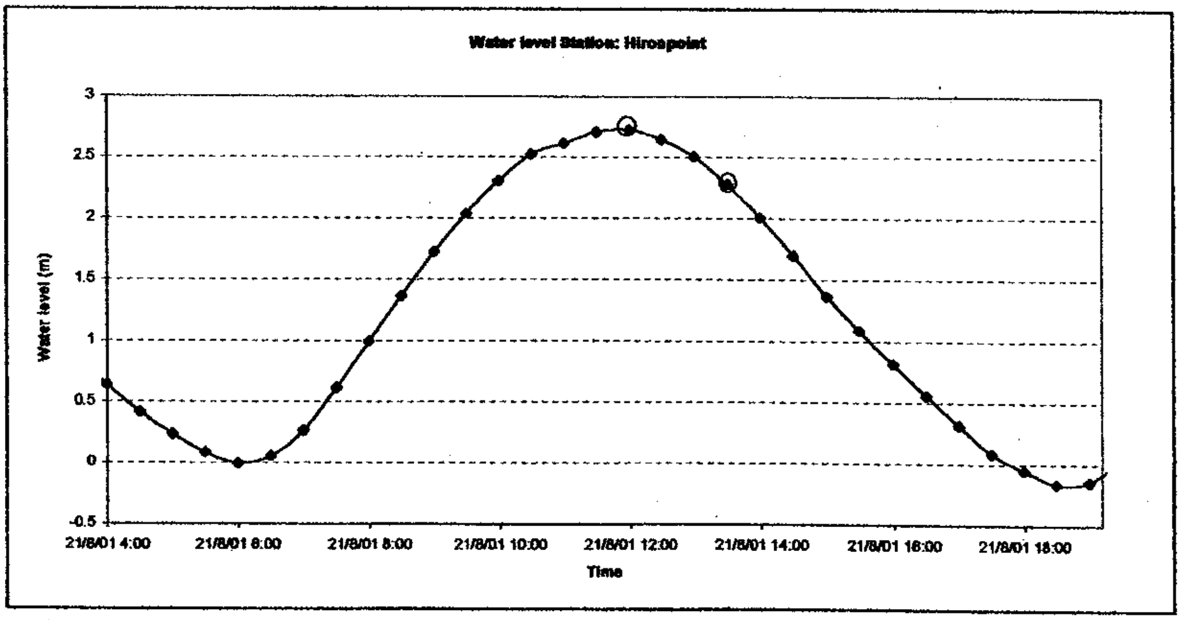


Figure 8.7 Time for which water level was selected for flood map generation

The inundation pattern on 21st August 2001 at 12:00 PM due to 20 cm sea level rise has been shown in Figure H.14 (Option 5). Comparing with the base map higher inundation can be noticed, which is obvious.

8.4 Impact of re-opening of Kharma Khal

Kharma khal is the upper part of the Bhola river connected with the Mrigamari river near Chandpai (Figure H.15). At present the khal is nearly 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 (Option 6). The longitudinal profile of the Kharma khal has been presented in Figure H.16. Analysing the model results the changes in hydraulic conditions of the khal can be observed. Figure H.17 illustrates the increased flow through the khal due to excavation. From Figure H.18 it can be observed that after excavation velocity of the flow would increase, especially during ebb, which is likely to erode the deposited sediment, and would help keeping the channel open. However, a detail sedimentation study of this khal has carried out separately, 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 is seem to increase slightly due to incorporation of dredged channel at the Kharma khal.

If it is insignificant due to dredging then there shall not be any significant change in flora composition but this study does not fully with coop composition.

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 Appendix I

10 INTERACTION AND TRAINING

IWM considers interaction with the client and users as a basic need 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 2002. 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 2002
6.	Final Report	March 2003

12 RECOMMENDATION

During the progress of work, schedule of activities has been changed a number of times to include additional activities suggested by the TAG and ADB. Such activities were also conceived by the IWM at the proposal preparation stage. Due to limitation of resources and other reasons those could not be accommodated in the project inception stage. The duration of study was limited to two and half years with a minimum frequency of measurement and monitoring survey in the field. Following a detailed discussion with the ADB a revised works schedule was prepared in March 2002. The duration and frequency of measurement was also increased in this revised schedule along with inclusion of some additional parameters for monitoring. However, the main focus of the revised schedule was to obtain a long time continuous set of data. Due to the change of activity schedule, whole mode of work was changed to fit with the revised programme. As such, some important activities remained incomplete. Nevertheless, the organized data and option studies completed will be highly useful for the project and will minimize the resource requirement if any such research activities are carried out in future. Following are list of some works, which should be taken up to maximize the output of the project:

- The salinity and selected water quality data collection should be continued for as long as possible
- The gauging points at the southern boundary should be connected with the national datum of PWD. Attempts should be made to connect the internal gauging points with the same datum.
- The cycle of measurements in the pilot areas should be repeated for a long time to study the changes in respect of inundation and siltation on the forestland. If possible, more areas should be selected for study
- A dedicated HD Model for SBCP area will be developed with inclusion of the major creeks. Additional cross sections of the creeks will be surveyed for this purpose.
- The calibration of Salinity, Water Quality, and Cohesive Sediment Model will be improved by incorporating the results of dedicated HD model of SBCP
- The options for sustainability of Kharma Khal through siltation study by Sediment Transport Model to be completed
- Dissemination of the Study Results through workshop/seminar.