SOCIO-TECHNICAL ASSESSMENT OF SEDIMENT MANAGEMENT OPTIONS IN TIDAL BASINS IN SOUTHWESTERN BANGLADESH

MD SHARIF IMAM IB-N-E AMIR

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

Institute of Water and Flood Management

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

January 2010

SOCIO-TECHNICAL ASSESSMENT OF SEDIMENT MANAGEMENT OPTIONS IN TIDAL BASINS IN SOUTHWESTERN BANGLADESH

by

Md. Sharif Imam Ib-N-E Amir

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Development

Institute of Water and Flood Management

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

January 2010

The thesis titled "Socio-technical Assessment of Sediment Management Options in Tidal Basins in Southwestern Bangladesh ", submitted by Md. Sharif Imam Ib-N-E Amir, Roll No. M10072804P, Session October 2007 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Masters of Science in Water Resources Development on January 16, 2010.

BOARD OF EXAMINERS

1. -- Chairman
   Dr. M. Shah Alam Khan
   Professor, IWFM, BUET, Dhaka
   (Supervisor)

2. -- Member (Ex-officio)
   Director
   IWFM, BUET, Dhaka

3. -- Member
   Dr. Md. Rezaur Rahman
   Professor, IWFM, BUET, Dhaka

4. -- Member
   Dr. Mohammad Asad Hussain
   Assistant Professor, IWFM, BUET, Dhaka

5. -- Member (External)
   Mr. Abu Saleh khan
   Deputy Executive Director, Institute of Water Modelling (IWM), Dhaka

CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Md Sharif Imam IB-N-E Amir

DEDICATION

This research is dedicated to the poor and deprived people of Bhabodah area who are always struggling to sustain.

ACKNOWLEDGEMENT

At first, the author would like to praise to almighty Allah who has provided him with the opportunity to complete the thesis. The author wishes to express his profound gratitude and sincerest appreciation to his supervisor Dr. M. Shah Alam Khan, Professor, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology (BUET), Dhaka for inspiring him to conduct this thesis work and to provide him the intellectual guidance.

The author is highly gratitude to Md. Emaduddin Ahamad, Executive Director of IWM for allowing him to work in IWM office and providing him all types of logistic support including data. The author is expressing his profound thanks to Abu Saleh Khan, Deputy Executive Director, IWM for providing valuable idea during the study. He is also expressing his intense thanks to Md. Zahirul Haque Khan, Director, Coast Port and Estuary Management Division, IWM for providing necessary support, during the whole period of this study.

The author expresses his highly indebted to Rubayat Alam and Md. Mobassarul Hasan, Associate Specialist, Coast, Port and Estuary Management Division, IWM, for their cordial cooperation and guidance during development of the numerical model in the study. Sincere gratitude is extended to other colleagues of Institute of Water Modelling for their thoughtful advice, support and encouragement during the thesis work. The author also express his gratitude to Mohiruddin Biswas, Member, Executive Committee, BWDB, for his overall cooperation and support during stakeholder consultations, resource mapping and FGDs.

Last but not least, acknowledgement goes to author's family for their patience and emotional support. Especially deepest gratitude is expressed to his wife, Fatema Akram whose moral support, encouragement and assistance gave him the strength to complete this study.

Md. Sharif Imam IB-N-E Amir

ABSTRACT

Uniformly raising the land inside a beel and maintaining proper drainage capacity of the river are the two main objectives of TRM. However, it is observed that sedimentation inside the beel is not uniform in Beel Kedaria and East Beel Khuksia due to the lack of social and technical limitations in TRM operation The present practice of TRM operation is to construct a link canal to connect the beel with the river. This results in sediment deposition at the mouth of the link canal, preventing further sedimentation inside the beel.

In this study sediment management options for uniform silt deposition in tidal basins have been identified in a participatory approach. Three options for sediment management inside the tidal basins have been identified through FGDs and consultation with the local stakeholders. In Option-1, each beel is divided into three compartments by constructing embankment around the compartment and allowing sedimentation in the compartments one after another. In Option-2, embankments are constructed along both banks of the main khals through the beel and cutting the embankment part by part gradually from upstream to downstream. In Option-3, all existing khals are connected with the river at the same time by constructing link canals, i.e. allowing sedimentation in the whole basin at the same time. Technical feasibility of these options has been assessed by a cohesive sediment transport model using MIKE21 FM modeling system.

Net deposition in East Beel Khuksia and Beel Kapalia for the three options is evaluated. The net deposition volume after 4years in the Option-1, Option-2 and Option-3 are 3.58, 4.51 and 2.61 million m^3 respectively in East Beel Khuksia, and 3.40, 3.43 and 2.45 million m^3 respectively in Beel Kapalia. Maximum deposition was observed for Option-2. The net sediment deposition and areal extent of deposition increase after dredging of khals So, for uniform sediment deposition inside the tidal basin, dredging of khals inside the beel under TRM operation is required within three to four months. It is also seen that the maximum and minimum net doposition occur for Option-2 and Option-3 respectively in both beels. Besides, net deposition volume is higher in East Beel Khuksia than Beel Kapalia because East Beel Khuksia is located at the downstream of the Hari river.

The total costs of operation for TRM in East Beel Khuksia and Beel Kapalia have been estimated. The minimum cost is required for Option-2 in both beels.

Stakeholder consultation was carried out to finalize the acceptable option(s) for sediment management inside the tidal basin. After detailed discussions and consideration of different aspects of sediment management, it is appears that Option-2 is preferred by most stakeholders in the area.

TABLE OF CONTENTS

APPENDICES:

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BKTB	Beel Kedaria Tidal Basin
BRAC	Bangladesh Rural Advancement Committee
BWDB	Bangladesh Water Development Board
CAS	Catch Assessment Survey
CEGIS	Center for Environmental and Geographic Information Services
DAE	Department of Agricultural Extension
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute (now DHI Water and Environment)
DOE	Department of Environment
DOF	Department of Fisheries
DPHE	Department of Public health Engineering
EGIS	Environmental and Geographic Information Services
FFG	Fisher Folk Group
GO	Government Organization
GOB	Government of Bangladesh
IWM	Institute of Water Modelling (erstwhile SWMC)
KJDRP	Khulna-Jessore Drainage Rehabilitation Project
LCS	Labor Contracting Societies
LGED	Local Government Engineering Department
LGI	Local Government Institution
LLG	Landless Group
NGO	Non Government Organization
O&M	Operation and Maintenance
PRA	Participatory Rural Appraisal
PWD	Public Works Department
SSC	Suspended Sediment Concentration
SWMC	Surface Water Modelling Centre (now renamed as IWM)
TB	Tidal Basin
TNO	Thana Nirbahi Officer
TRM	Tidal River Management
VGF	Vulnerable Group Feeding
WGS	World Geodetic System
WMA	Water Management Association
WMC	Water Management Committee
WMF	Water Management Foundation
WMG	Water Management Group
WMO	Water Management Organization

CHAPTER ONE

INTRODUCTION

1.1 Overview

The rivers of the southwestern region in Bangladesh are characterized by active deposition of sediment causing significant reduction in their drainage capacity (IWM, 2009). Besides, construction of costal polders that de-linked the floodplains from the rivers, and diminished upstream flow during the dry season deteriorated the sedimentation problem in this region (IWM, 2005). Consequently, this area has been experiencing severe drainage congestion and water logging since the early eighties. The sedimentation effects of similar river and floodplain interventions were described by Sarker (2004). To solve these long-standing problems, the Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was implemented during 1994-2002 (IWM, 2007). Later on, a popular concept based on generations of indigenous water management practices, formally known as Tidal River Management (TRM), was adopted. TRM would allow natural movement of sediment-borne tidal water into a beel (tidal basin) and allow depositinn of sediment in the beel. During low tide the outgoing water would erode the river bed and increase the drainage capacity. After implementation of the project the prevailing drainage congestion was partially solved and agricultural, social and economic benefits were achieved (SMEC, 2002). However, areas that still need further attention include non-uniform sedimentation inside the beel, inefficient performance of the flow control interventions, and institutional conflicts among government agencies, water management associations (WMA), NGOs and local government institutions (LGI) regarding TRM. Other challenges include reduction of social conflicts among farmers, fishermen and landowners because of shrimp farming and loss of indigenous varieties of fish and crop bio-diversity. Although shrimp cultivation was gaining hold in the project area and had generated additional economic benefit, the shrimp 'ghers' might have added to the causes of drainage congestion (CEGIS, 2002).

Sediment management is the most challenging yet important aspect of TRM in the study area (SMEC, 1997a). People allow their land to be used for tidal basin operation without any compensation, hoping that the land will rise after three or four years. However, monitoring results and community consultation reveal that almost in all cases sedimentation inside the tidal basin does not occur as expected. This results in people's unwillingness to allow their land for basin operation. Therefore, a functional sediment management plan would be very helpful for successful TRM practice in future.

1.2 Objectives

The objectives of the study were.

- to determine and analyze relevant natural, technical, social and institutional causes behind the problems with sediment management; and
- to formulate and analyze different socially acceptable and technically feasible options for uniform sediment deposition inside the tidal basin with the help of a sediment transport model.

It is hoped that this study has provided effective sediment management options for future TRM practices and a numerical model for analysis and planning in tidal basins.

1.3 Scope and Limitations

This study has identified sediment management options for uniform silt deposition in tidal basins. The options were gathered through field surveys using PRA techniques. Technical feasibility of those options has been verified by a cohesive sediment transport model using MIKE21 FM modeling system. The best option(s) has been selected after consulting with the local stakeholders.

The research was conducted with the following limitations:

1. Calibration of the numerical model was performed with very limited observed data due to unavailability of adequate suspended sediment concentration data.
2. Extensive stakeholder consultation and economic analysis could not be carried out due to time and resource constraints.

1.4 Organization of the Thesis

The thesis is comprised of six chapters and includes a list of mentioned reference swap words in the thesis. The thesis also includes seven Appendices.

Chapter One provides detailed background information, objectives, and scope and limitations of the study. In Chapter Two, gives a review of relevant literature. It includes origin of the river sediment in the study area, definition and concepts of tidal basins, definition and history of TRM and performance of tidal basins under TRM.

Chapter Three contains detailed information on the study area including geographical location, water resources, climate, tidal characteristics, sediment characteristics, ecology, socio-economic condition and institutional arrangement for water management. Chapter Four describes the methodology followed in the present study. Several methods for identifying sediment management options for uniform silt deposition have been applied in this study. For primary data collection, semi-structured interviews, resource mapping and focus group discussions were conducted. For numerical model development and analysis the MIKE21 FM modeling system was used.

Chapter Five contains the results and discussions of the present study. Results and discussions describe primary data synthesis from PRA tools, identification of sediment management options, and analysis of results from options simulations and finalization of option after stakeholder consultations. Chapter Six contains the conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Tidal Basins and Beels

A beel is a natural depression. Bangladesh being a deltaic country, land in the plains has been formed by sediments carried down by the Ganges, Brahmaputra and Meghna river systems. Depressions are formed by numerous causes like subsidence of topsoil caused by creation of a vacuum below by decomposition of organic substances mixed with silt, subsidence caused by tectonic movement and non-destructive floods deposit sediment close to the riverbank. Such repeated deposits raise the level of land close to the riverbank. But the land between two rivers remains low-lying. Such a low-lying land is also known as a beel.

A Tidal Basin is a depressed low-laying area or beel adjacent to the sediment-laden tidal rivers. In the Bhabodah area there are several tidal basins (Figure 2.1) which are very useful for management of the sediment laden tidal rivers.

The concept of sediment management in tidal basin originated in the 1880s to serve both as a visual centerpiece and as a means for flushing the Washington Channel, a harbor separated from the Potomac River by fill lands where East Potomac Park is situated (Green, 1974). Peter Conover Hains, an engineering officer in the U.S. Army, oversaw the design and construction. The basin in Photograph 2.1 is designed to release 250 million gallons of water captured during high tide twice a day. The inlet gates, located on the Potomac side of the basin, allow water to enter the basin during high tide. During this time, the outlet gates, on the Washington Channel side, close to store incoming water and block the flow of water and sediment into the channel. As the tide begins to ebb, the general outflow of water from the basin forces the inlet gates to close. This same force is applied to the outlet gates, which open into the channel Silt build-np is swept away by the extra force of water running from the tidal basin through the channel. The gates are maintained as navigable by the U.S. Army Corps of Engineers.

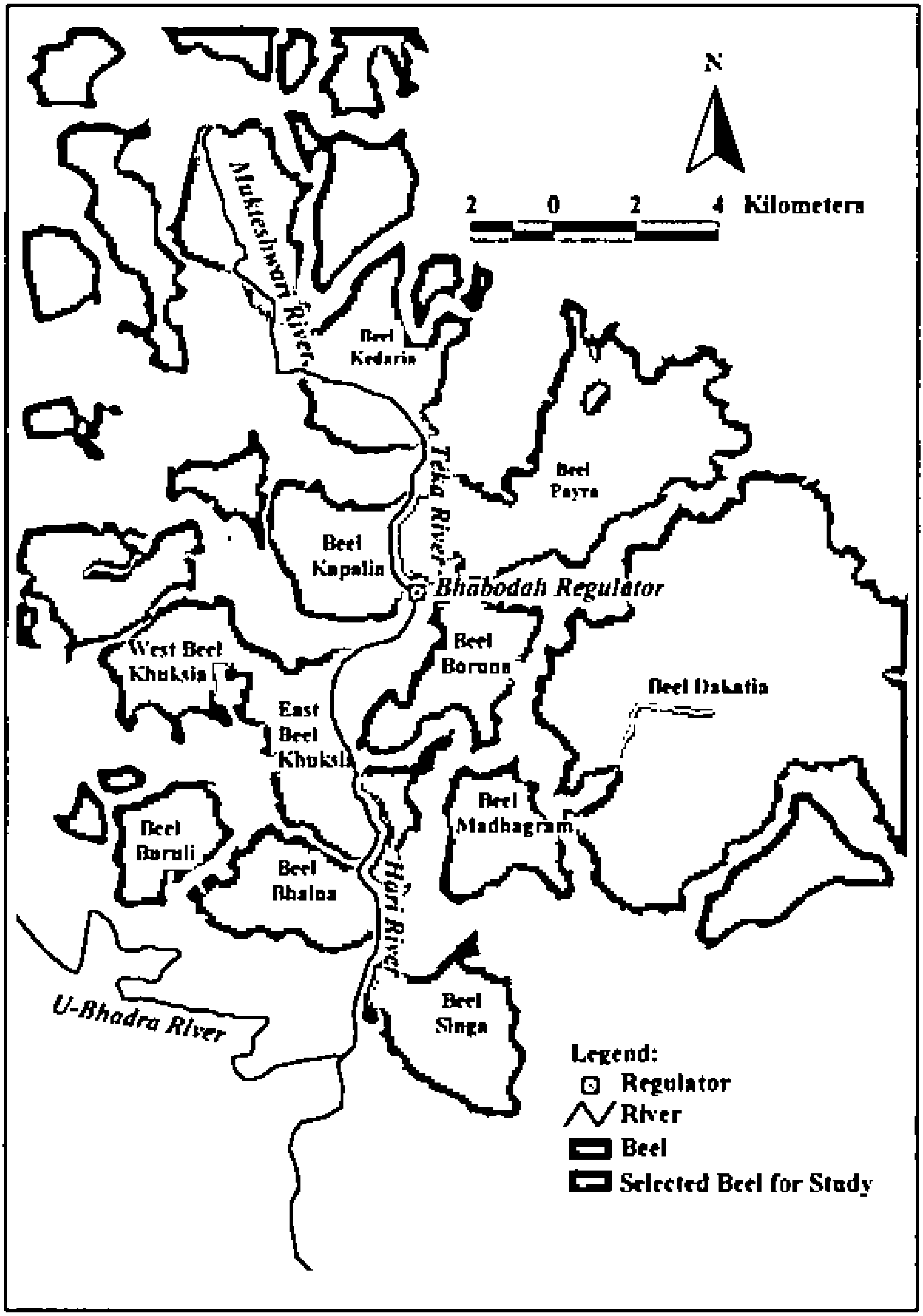


Figure 2.1: Beels in the Bhabodah area.

Photo 2.1: Potomac river tidal basin.

2.2 Theoretical Basis of Tidal Basin Sedimentation

A number of scientists opine that there is a relationship between the general dimensions of the entrance to a tidal estuary or tidal river in a sandy coast and the tidal prism. But it appears that there was no previous attempt to determine a definite correlation until Le Conte (1905) proposed an equilibrium area concept for tidal inlets. O'Brien (1931, 1969) examined field data from tidal inlets through sandy barriers in the West Coast of the United States and determined a relationship between the minimum cross-sectional flow area of the entrance channel and the observed tidal prism, and established a relationship as:

$$A_c = C.P^n \tag{2.1}$$

where, A_c = the minimum inlet cross-sectional area in the equilibrium condition, C = an empirically determined coefficient, P = the tidal prism (typically during the spring tide/mean tide), and n = an exponent usually slightly less than unity.

Similar analysis was carried out for the Hari River. With a view to establishing a consistent relation, data of the Pussur River were incorporated in developing the relationship, as it is also a highly tide dominated river in the South West Region. In doing this, a distinct relationship was found between cross-sectional area and tidal prism:

$$A_c = 43.42\ P^{0.9985} \tag{2.2}$$

where, P = mean tidal prism (million m^3), A_c = cross-sectional area (m^2).

The cross-sectional area and the corresponding tidal volume of the Hari River generated by the East Beel Khuksia Tidal Basin at Ranai is fitted to established relationship of cross sectional area and tidal prism of the Hari River as shown in Figure 2.2.

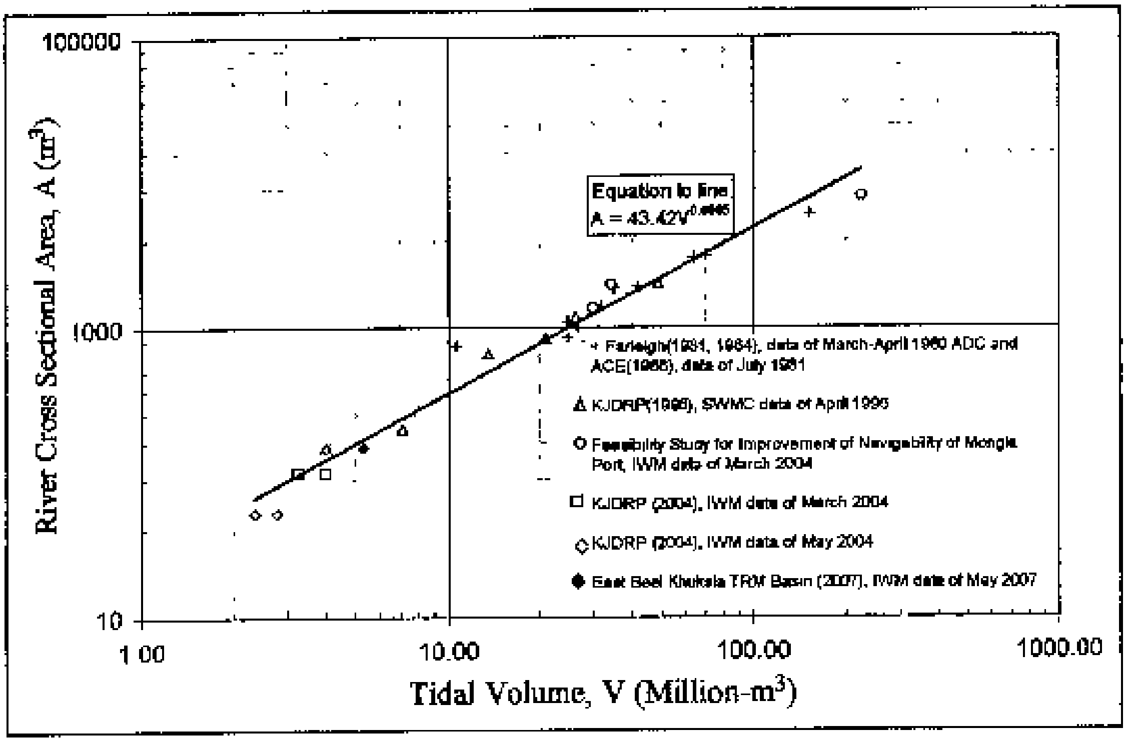


Figure 2.2: O'Brien equilibrium relationship updated with recent data.

This simple empirical equilibrium relationship shows that the cross-sectional area of a tidal channel reduces in size if the tidal prism is reduced. Hence, closing of a tidal river branch from the tidal system causes a reduction in the tidal prism in the whole tidal system downstream of the closure. The related reduction in channel size, which will ultimately occur, can be estimated with the above-mentioned relationship. The validity of the relationship also means that increasiug a cross-section by dredging without increasing the local tidal prism will result in an unsustainable solution. Natural forces will tend to restore the equilibrium conditions by sedimentation in the dredged area. The reduced flow velocities in the enlarged river cross-section will cause a gradient in the river velocity and consequently deposit sediment in the dredged river reach. This process stops when the equilibrium profile has been restored and the gradient in flow velocities has disappeared.

2.3 Origin of River Sediment in the Study Area

Sedimentation in the tidal rivers of the study area is the main reason of the problem of water logging. These troublesome sediments have blocked the rivers and caused upstream drainage congestion and flooding. This is a fascinating environmental problem not always fully understood by stakeholders in the study area.

In most catchments where excessive sedimentation is taking place in the downstream river system, the origin of the problem is in the upstream catchment where land use changes have taken place in relatively steeply sloping areas. These upstream areas become unstable due to the removal of forest or other vegetation and its replacement with unsustainable agricultural, forestry or mining operations. Erosion begins in these areas and the river system carries the eroded material to the downstream river system where it deposits causing the downstream drainage system to lose its natural capacity and hence flooding and drainage problems follow. However, this is clearly not the case in the Bhabodah area where upstream areas are very flat and excessive erosion is not occurring on these mainly agricultural upstream lands.

It is clear from casual observation of the rivers in the study area during the dry season, when upstream flows are non-existent, that sediments are transported into these rivers by tidal flows. This movement of sediment is also confirmed by the field measurements of sediment concentrations and tidal flows by SWMC (June 1996 and October 1996) and other measurement programs. In the Bhabodah area, the sediment derived from the downstream tidal rivers by natural erosion processes and transported upstream by tidal movements seems to be the most plausible explanation of their origin (SMEC, 1997).

2.4 River Management and Implementation of TRM

2.4.1 Concept of tidal river management

Tidal River Management (TRM) involves taking full advantage of the natural tide movement in rivers During flood tide, tide is allowed to enter into an embanked low-lying area (tidal basin) where the sediment carried in by flood tide is deposited. During ebb tide, water flows out of the tidal basin with greatly reduced sediment load and eventually erodes the downstream riverbed The natural movement of flood and ebb tide along the tidal basin and along the downstream river maintains a proper drainage capacity in that river. These merits associated with the TRM approach were recognized by Williams (1919). This is in fact a natural water management process with very little human interventions but it needs strong participation and consensus with a great deal of sacrifice by the stakeholders for a specific period (3 to 5 years or even more depending on the tidal volume and the area of the beel) (Rahman, 2008).

TRM acts as an effective tool for Integrated Water Resource Management in the country. By implementing TRM in the Bhabodah area more and more waterlogged areas were raised by silt deposition and made suitable for agriculture. Job opportunities increased and many employment options opened up. Rivers became de-silted and became more navigable. The TRM is an eco-technological concept and designed to solve the water-logging problem while at the same time improving the environment. By implementing the concept, the natural environment has been restored and the ecology of the wetlands has been conserved. The impact of implementing the TRM concept has been felt mainly in the sub-basins of the branch rivers of this delta region. Waterlogged lands have been retrieved for cultivation, wetland ecology has been restored and rivers have become navigable. In designing and implementing large projects in the Coastal areas, all concerned including government agencies, national and international Financial Institutions are giving due importance to TRM (CEGIS, 2002a).

2.4.2 Historical development of coastal polders in Bangladesh

The study area is almost flat and has relatively low land elevations, and is interspersed with a dense network of semi-diurnal tidal channels carrying saline water that make the area unsuitable for agriculture.

In the 17th century in the period of Zamindari or large landowners, who also served as principal revenue agents for the government, the tenant farmers had to pay large portion of their income, usually a percentage of the crop, to the Zamindars. Since the income of the Zamindars depended largely on crop production, they built low earthen dikes around the tidal flats to prevent tidal intrusion and wooden sluices to drain off surplus rainwater and then cultivate indigenous varieties of flood-tolerant and saline-tolerant rice. Their tenants then cultivated similar indigenous varieties rice, and reaped bumper harvests. The dikes were traditionally cut from November to July, allowing rivers to naturally flow and ebb over the floodplains during rest of the year. After the harvest, the dikes and sluices were dismantled, and the people grazed cattle and fished in the tidal flood plains. Thus, the environment, eco-system and bio-system that evolved in the coastal area were in balance. The dikes were not sufficiently high and strong. Opening the sluice gates was not enough and the gates were weak. Therefore, they were required considerable maintenance each year.

In 1951 the Zamindari system was abolished by the East Bengal State Acquisitiou and Tenancy Act, 1950, and the Zamindars were relieved of their power and authority. Many had been living in other countries and did not return to the area, some residing in the area left; and those who remained were stripped of their power. As a result, there was no one to take the responsibility for the repair and maintenance of existing dikes or the construction of new ones. Gradually the dikes were breached and over-topped by tides and became practically useless. There was nobody to manage the river basins in the age-old manner, leaving farmers unable to cultivate crops due to annual flooding.

Various attempts were made during that time to improve the condition in the coastal areas, but none was fruitful until in the late 1960s and early 1970s. At that time the Government of Bangladesh (GOB) constructed flood protection embankments and various types of drainage structures to safeguard urban and agricultural lands from damage due to frequent tidal inundation, monsoon flooding and prevent intrusion of saline water. The polders were converted into encircled earthen embankments around depressions (keeping the main tidal channels outside the Polder) and by putting gated hydraulic structures on intersecting points (meeting points of embankment and secondary tidal channels). This man-made intervention yielded good results until the 1980s.

2.4.3 Adverse impacts of coastal polders

In the early 1980s polders became a bane rather than a boon for the people, as rivers failed to maintain their natural courses. Tides deposited silt on the riverbeds rather than the floodplains for more than two decades halting the natural flow of the rivers. The consequent dearth of land formation left floodplains inside the polders lower than riverbanks outside the polders. Rainwater, therefore, could not drain from the areas leading to chronic water logging. Adding to the tragedy, by construction of Farraka Barrage on the Ganges river and unilateral diversion of its water by India from 1975 started deteriorating the balanced (fresh water - tidal flow) ecosystem of the region This was further aggravated by construction of reservoirs on the upper catchment of all trans-boundary rivers of the southwestern region. During the dry period of the year (January to April), the area receives almost no upland fresh water flow. Under the changed hydrological situation, many tidal channels outside the polders started experiencing abnormal sedimentation blocking the drainage paths of the polders. Prolonged water logging inside the polders were so severe in some cases the people of the area had the only option of migration.

2.4.4 Action taken by BWDB

Bangladesh Water Development Board (BWDB) was fully aware and concerned about the drainage congestion of the polders of the Southwestern region. But the spatial extent of the problem and prevailing hydro-geo-morphological conditions of the area are so complex that a holistic and well-planned approach was needed. BWDB conducted six studies by engaging international and national consultants between 1986 and 1998. Besides this planning exercise, BWDB dredged some badly silted up channels for immediate relief of the drainage congestion problem. From 1996 to 1998, about 0.610 million cubic meters were dredged and 1.480 million cubic meters were re-excavated (manual and mechanical) to keep the main river system active. Dredging and re-excavation was done several times but it faced siltation every time.

When the coastal Embankment was implemented, all the tidal floodplains were enclosed within polders and tidal intrusion into the polders was stopped. Only surplus rainwater was allowed to drain out through sluices. This had one advantage and one disadvantage.

While it enabled to create a perennial freshwater regime within the polders for agriculture to be practiced round the year, it also denied the land the silt required to maintain the land level. The continued subsidence of the loose delta soil was not compensated. The TRM is an initiative to restore the imbalance.

2.4.5 The people's initiative to address the issue

Fifteen years after construction of the coastal embankments, water-logging began to emerge in the upstream polders in the Bhabodah area. People of the water-logged area petitioned the authority to solve the problem. As the authority paid no heed to their grievances, people themselves took the initiative to organize and mobilize the community, and devised plans for solving the problem. From their owu experience and observation, people identified the polders as the main cause of water-logging and began to present their reasoned arguments for breaching or cutting away polders to allow tidal flows. Their logic was that if tidal waters can be allowed to flow freely navigability of the rivers would be restored, the enclosed lands would be free from water-logging, alluvium would accumulate inside the polders, and as a result, the level of the land would rise. The first manifestation of this logic was seen in September 1990, when the polder of Dakatia beel was breached in four places. This concept is called the Tidal River Management (TRM) system.

2.4.6 Unplanned tidal basin in Beel Dakatia

In mid-September 1990, after prolonged hardship due to drainage congestion, the people of Beel Dakatia made public cuts in the polder embankment at four locations (Figure 2.3). The people made the public cuts to relieve drainage congestion and improve the water quality of the beel. It was also huped that sedimentation would occur in the beel thereby raising the land level appreciably.

The effect of the public cuts on sediment deposition was not as great as had been hoped for. For public cut nos. 1 to 3 no significant sedimentation was recorded near the cuts. For public cut no. 4 appreciable sedimentation was reported but this was not uniform (IWM, 2002). The sediment deposit inside the beel extended outwards in a delta formation over an area of about 900 ha out of 18000 ha (SMEC, 2002). At distances of more than 3.5 km no significant sedimentation seems to have occurred. After the breaching of the embankment of Dakatia beel, the Hamkura river became a strongly flowing river 300 feet wide and 30 feet deep at the new highway bridge on the Khulna-Chuknagar Road. Therefore Beel Dakatia operated successfully as a tidal basin and enlarged the downstream river.

But people in the beel experienced difficulties due to a lack of freshwater, reduced fish yields, death of trees due to salinity and loss of dry season crops due to higher prevailing water levels (Haskoning and Associates, 1993).

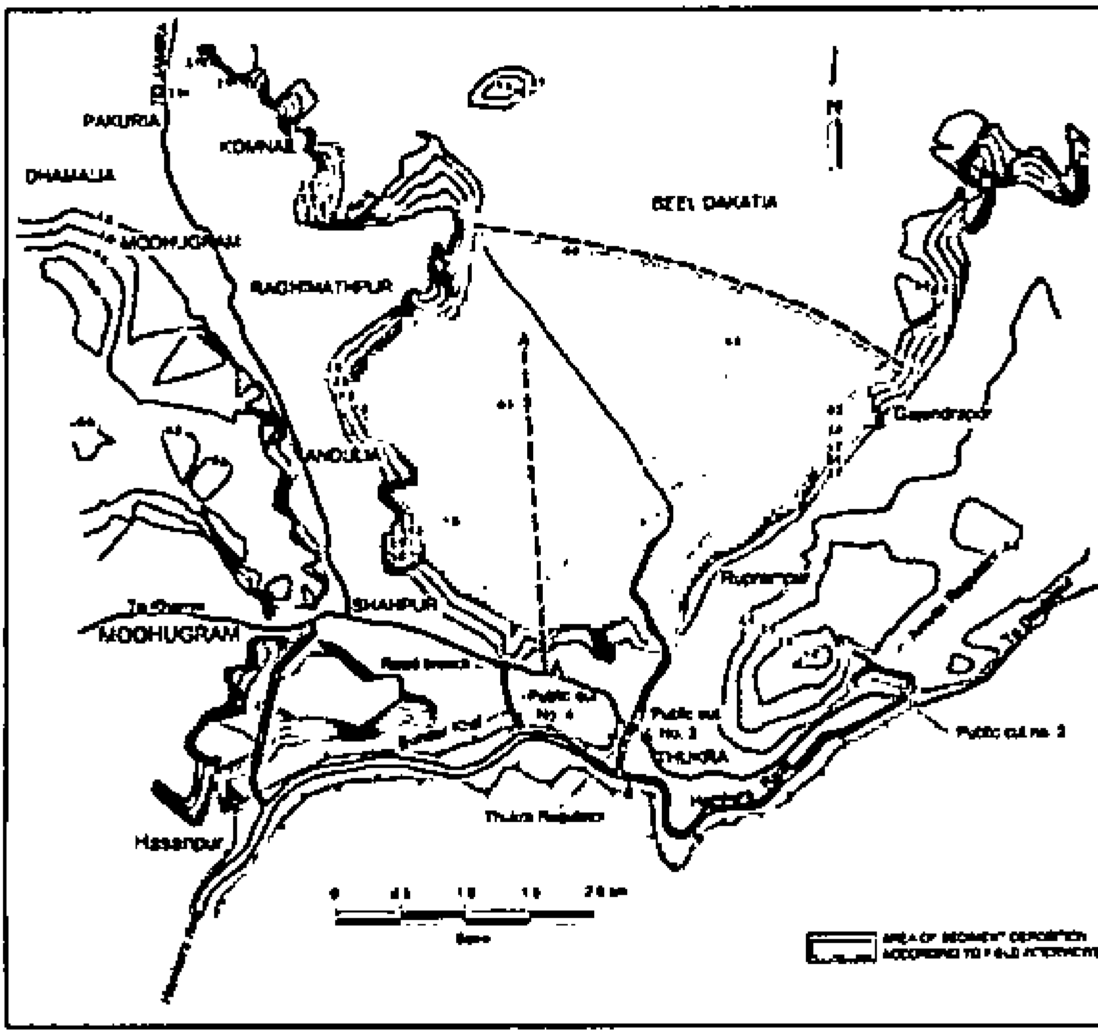


Figure 2.3: Four public cut locations in Beel Dakatia.

The success in draining out water of Dakatia beel encouraged people in the adjacent water-logged areas. They organized themselves and formed committees at different levels and took initiatives to turn their water-logged land into agricultural land again. Madhukhalir beel and Patra beel are examples of such collective efforts. However, these efforts could not achieve the desired results at every stage because of a lack of proper organizational structure and planning. In the meantime, the Bhabodah area (Jessore zone) started to experience widespread water-logging. The people of the area organized themselves and removed the accumulated silt from the exit of the Bhabodah sluice gates every year, and opened a narrow drainage channel. Each year, they retrieved more land for agricultural production. The people there learnt from the Dakatia beel experience and tried the TRM concept on Bharter beel, Golner beel, Bahadurpur beel, and Magurkhali beel. The experiments proved successful

2.4.7 Unplanned tidal basin in Beel Bhaina

Affected people cut the embankment to connect the Hari river with Beel Bhaina in October1997. It was closed in December, 2001. About 600 ha land was raised by 1.0 meter and the Hari River, downstream of the cut, revived for a length of 4 km with more than 8 meter depth. The deposited sediment volumes at different periods from the beginning of the operation in November 1997 until the closing of the basin in December 2001 are presented in Table 2.1.

Table2.1: Deposited sediment volume in Beel Bhaina tidal basin.

Period of Operation	Deposited Sediment Volume (Million m^3)
November 1997-March 2000	1.90
April 2000-June 2000	1.10
July 2000-December2000	1.75
January 2001-December 2001	1.73
Total Period. November 1997-December2001	6.48

It is evident that at the beginning of the operation of the tidal basin sediment deposition is relatively less although sediment deposition is considerably high during dry season in 2000. During the monsoon 2000, sediment deposition is less in comparison to the deposition in the dry season In the last year of the operation, sediment deposition reduced considerably. The rate of sediment varies both temporally and spatially. Higher sedimentation is observed close to the downstream opening of the tidal basin and decreases gradually to the furthest end of the beel.

Another issue is uneven sedimentation inside tidal basins. Such uneven sedimentation created drainage congestion in Beel Bhaina especially in the north-western part of the beel. Appropriate measures such as compartmentalization or rotation of opening need to be taken up so that similar situation does not arise in Beel Kedaria (Rahman, 2008).

2.4.8 Institutionalization of TRM

Since TRM was an emerging successful practice, ADB studied the TRM options in greater details in terms of technical feasibility, and environmental and social impacts based on the feedback of the project beneficiaries and suggestions received from the stakeholders It was found that the TRM is technically feasible and attractive from social and environmental points of view. In response to this situation the GOB, with financial support from the Asian Development Bank, undertook Khulna-Jessore Drainage Rehabilitation Project (KJDRP) during 1994-2002. After implementation of the project the prevailing drainage congestion was solved considerably and agricultural, social and economical benefits were obtained. Later on it has been observed that benefit has been sustained in the Khulna region i.e. in polder 25, 27 and 28, where drainage management was solved by construction of regulators and dredging of drainage channels and keeping the practice of regular removal of silt at the downstream of the regulators. But in the Bhabodah and its adjacent area (Jessore part) sustainable drainage improvement had not been achieved before implementation TRM. This study mainly concentrates on the north-western part of Khulna-Jessore Drainage Rehabilitation Project (KJDRP) named Bhabodah area.

The rotational tidal basin was proposed to share both the inconveniences and the benefits with adjacent beels. In this regards nine beels were selected to operate as tidal basin one after another (Rahman, 2008).

2.5 Experiences from Previous TRM Attempts

2.5.1 Planned tidal basin in Beel Kedaria

Monitoring results show that the Beel Kedaria tidal basin performed as an effective tidal basin in maintaining the design drainage capacity of the Hari River during its operation from January 2002 to January 2005. The analysis of cross-section at Ranai of the Hari River indicates that the river was in dynamic equilibrium condition at this reach during the operation of the Beel Kedaria for TRM as the drainage capacity of the Hari River reached a stable condition with small seasonal change. It is evident from Figure 2.4 that the drainage capacity was also higher compared to the design one during the operation of Beel Kedaria.

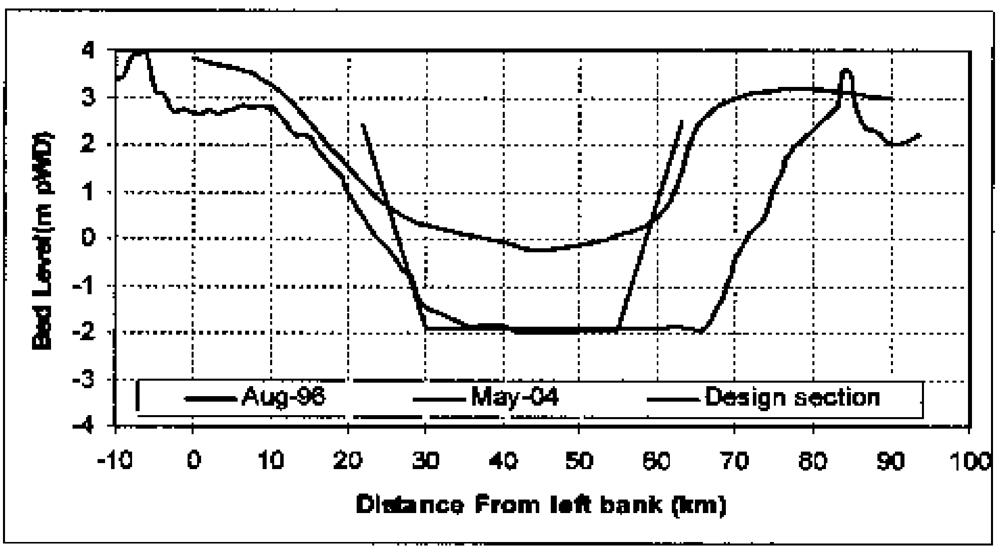


Figure 2.4: Stability of drainage capacity of the Hari river at Ranai during the operation of Beel Kedaria tidal basin.

The net silt deposition in the Beel Kedaria tidal basin since its operation from 2002 to May 2004 is about 0.49 million m^3 over an area of 524 ha. It is apparent that deposition took place almost over the whole area but the deposition is not uniform over time and space (Figure 2.5). Sediment deposition near the opening of BKTB is about 1m higher compared to other areas.

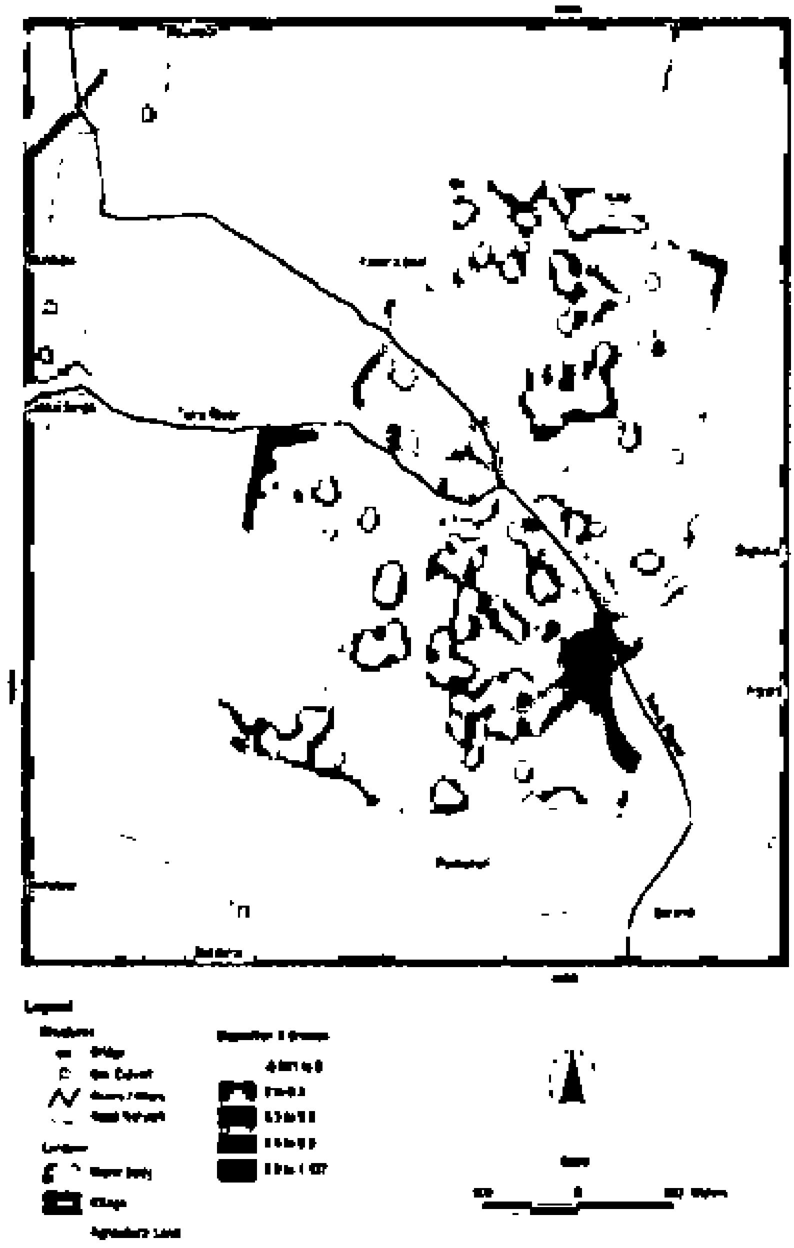


Figure 2.5: Map showing deposition and erosion in the Beel Kedaria tidal basin between March 2002 and May 2004.

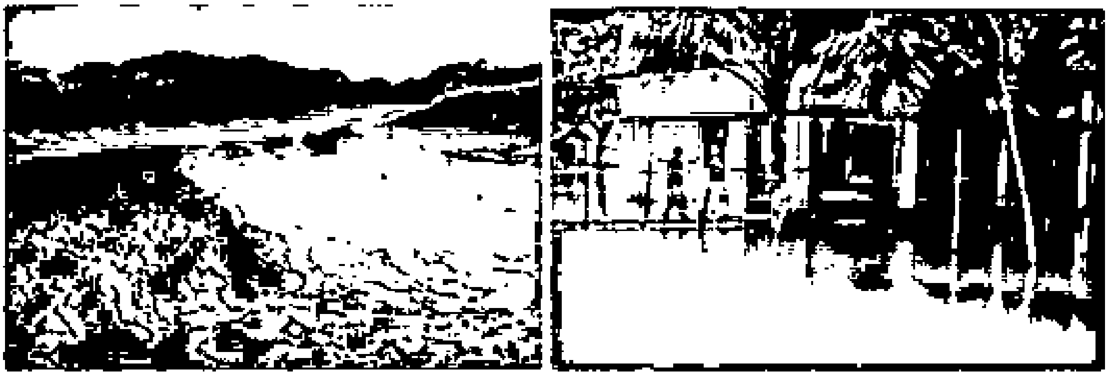
2.5.2 Performance of Beel Bhaina and Beel Kedaria tidal basins

Beel Bhaina tidal basin generated about 10 times higher tidal volume than that generated by the Beel Kedaria basin. This higher tidal volume generated in Beel Bhaina was mainly due to the location of the basin. The Beel Bhaina tidal basin is located near the downstream of the Hari River where the tidal range was more than 1.0 meter, whereas it is about 0.15 to 0.20 meter in the Kedaria tidal basin (IWM, 2002). The higher tidal range at the mouth of Beel Bhaina caused higher flow and flow velocity that led to the river bed erosion and siltation in the basin.

So the success of TRM largely depends on proper selection of beel. The selection of tidal basin needs detailed survey, hydraulic modelling, morphological and environmental studies involving the beneficiaries. The TRM needs routine monitoring of the key hydro-morphological indicators to collect information and knowledge to evaluate its performance, future planning and management.

2.5.3 Water logging after closing of Beel Kedaria tidal basin

The TRM operation in Beel Kedaria basin was stopped by the landowners by closing the gates of Bhabodah regulator. Consequently, siltation occurred along the 17 km stretch of the Teka-Hari river system. Severe water logging problem prevailed in the Bhabodah area from October 2005 to November 2006 due to discontinuation of operation of Beel Kedaria tidal basin for TRM. The area inundated due to drainage congestion was about 18,100 ha in September 2006. The inundated area include agricultural land, homesteads, schools, colleges and roads under the three Upazilas (Manirampur, Keshabpur and Abhaynagar) of Jessore District. The affected areas are 6120 ha, 8980 ha and 3000 ha in Abhaynagar, Manirampur and Keshabpur Upazila respectively (IWM, 2007). Altogether 3,13,045 people in these three Upazilas were affected due to drainage congestion. It was observed that sanitation, drinking water and health were the urgent issues in all the affected areas. There was no scope for cultivation at all. Local communications were disrupted. There was great scarcity of food and drinking water, and all sanitary latrines were destroyed. It was observed that a large number of different social components were also affected due to water-logging. Siltation on river bed and drainage congestion situations are shown in Figure 2.6. The drainage congestion continued until the next TRM started in East Beel Khuksia on 30 November 2006.



(a) Silted up Hari River bed (May 2005). (b)Water-logging (August 2006).

Figure 2.6: Siltation on riverbed and water-logging problem.

2.5.4 Planned tidal basin in East Beel Khuksia

East Beel Khuksia is an ongoing TRM basin and the TRM operation was started in December 2006. A considerable river bed scouring at the downstream reach of the Hari River was occurred due to operation of the East Beel Khuksia tidal basin. The evolving cross-sections of the Hari River at Ranai are shown in Figure 2.7. About 2 m scouring was observed at Ranai, about 5 km downstream of the tidal basin, during December 2006 and April 2007 due to TRM operation.

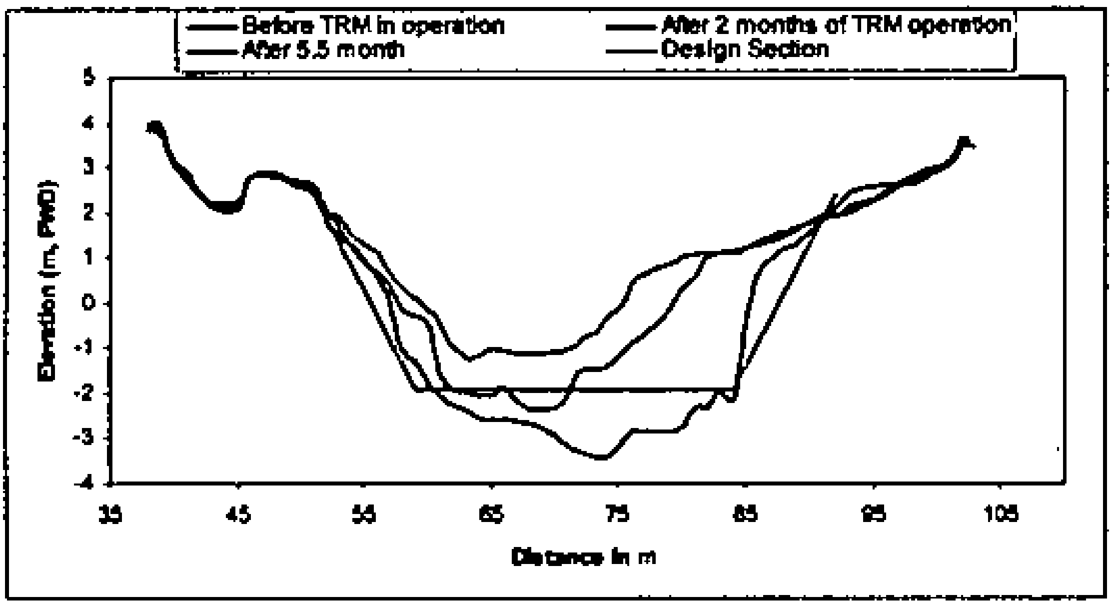


Figure 2.7: Comparison of cross section of the Hari River at Ranai after 5 month of TRM operation.

It was found that the river at this location is still adjusting with tidal prism to reach a new equilibrium under changed morphological condition. The conveyance of the Hari

River at Ranai increased 2.6 times (from 125 m^{3}/s to 338 m^{3}/s) after 5 month of TRM operation (IWM, 2007). It is also found that the drainage capacity of the Hari River at the downstream reaches of the basin increased from its design drainage capacity.

Deposition of sediment in the tidal basin is an important issue as it determines the lifetime of the tidal basin as well as development of land for agricultural production. In order to assess the impact of TRM operation in terms of siltation inside the tidal basin, bottom topography survey of the basin was carried out in February and May 2007. After processing the data, two digital elevation model (DEM) were prepared which shows the actual deposition/erosion pattern inside the basin for a specified time period (Figure 2.8). About 0.9 million m^3 siltation took place in the tidal basin during 5 month operation of the basin. It is apparent that deposition occurred mostly near the downstream area (nearest to the cut point) of the basin. There are lots of fishing infrastructures (ghers) in the basin that create obstruction to uniform spreading of incoming silt over the basin area.

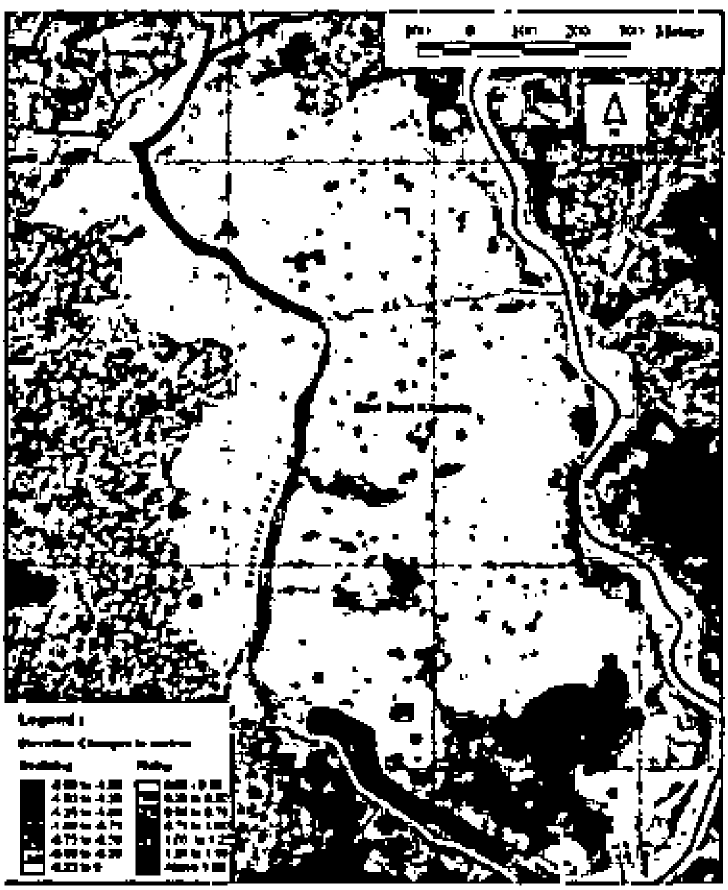


Figure 2.8: Map showing deposition and erosion in the East Beel Khuksia tidal basin between February and May 2007.

2.5.5 Lessons learnt from Beel Kedaria and East Beel Khuksia

The region has been subjected to different kinds of environmental imbalance and natural disasters. So, the people of the region have been contending with the forces of nature for generations, and they know best what is good for them. On the other hand, the people, on the basis of their traditional wisdom and practical experience, have the democratic right to say something about technical projects that may profoundly affect their lives and livelihoods. Therefore, their ideas and views must be taken into account in decision making processes. All the organizations and agencies related to river management should develop a people-oriented approach.

Sediment management inside beel and maintaining proper drainage capacity of the river through sequential operation of a potential beel for TRM by involving people's participation for sustainable drainage management are the two main objectives in this area. From field visits and monitouing results it is observed that sedimentation inside the beel is not uniform in Beel Kedaria and East Beel Khuksia. So, the main objective was not attained by the TRM practice for the lack of technical effectiveness during TRM operation. Besides this, social conflicts among various groups like farmers, fisherman, landowners, etc., and institutional conflicts among government agencies, water management association (WMA) and local government institutions (LGIs) also have made the TRM practices unsuccessful (CEGIS, 2002c). So, it is important to find out the real reason behind the ineffectiveness of the TRM practices considering all relevant technical, social, economical and iostitutional aspects with a view to ensure successful enhancement of the overall environmental condition (CEGIS, 2002b).

CHAPTER THREE

STUDY AREA

3.1 Geographical Location

The study area is located in the southwest region of Bangladesh within the Khulna division and falls under the administrative jurisdiction of Jessore and Khulna. The study area lies in between 22° 49'40.3"N 23° 6' 27 1" North Latitude and 89° 13'32.46" N 89° 26' 15.43" East Longitude (WGS 84). A location map for the study area is shown in Figure 3.1.

3.2 Water Resources

3.2.1 Surface water resources

Surface water resources available in the hydrological region throughout the monsoon comprise of inflows from rivers, soil moisture and surface water standing on agricultural land. The runoff during the months of January to April is negligible and thus the salinity level in the tidal reaches of rivers of the project area increase during this period. The main sources of the surface water are rivers, khals and wetlands.

River System

The area is characterized by morphologically active tidal rivers and creeks, which provide drainage for a system of embanked hydrological units. Rivers in the study area are only rain-fed. The main river system in the study area is the Mukteshwari-Hari river system.

The Mukteswari-Hari river forms a drainage route of about 40 km length meets with Harihar-Upper Bhadra system near Ranai. The Teligati- Gengrail system receives the combined flow of Harihar-Upper Bhadra and Mukteswari-Hari river systems. Upper Sholmari, Lower Sholmari, Lower Salta river are the main drainage channels for Beel Dakatia, Polder 27 and Polder 28. The Teligati-Gengrail system is the only main ontlet for the drainage of the Bhabodah area. These river systems are deteriorating rapidly due to siltation and causing drainage congestion in the adjacent areas.

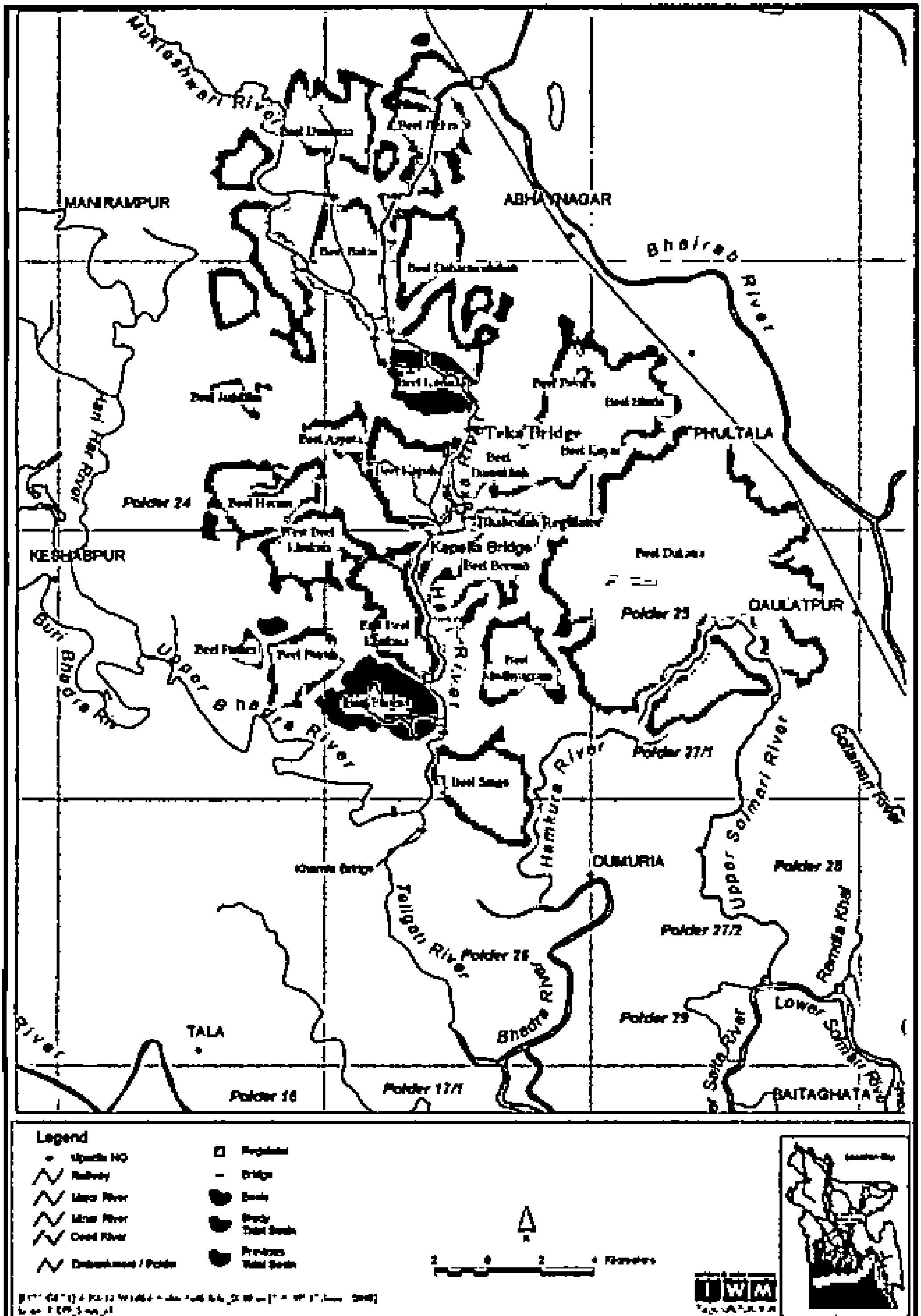


Figure 3.1: Location of the study area in the Bhabodah area.

Mukteswari-Hari drainage system is the largest among the four main drainage systems in the study area. This system drains about 53,000 ha of land, which is about half of the project area. The system comprises of the Hari and Mukteswari rivers as its main drainage arteries. The Mukteswari River and Teka Nadi collect water from 33,000 ha of land and drain it to the Hari River through the Bhabadaha regulator. The Hari River remains free from interventions at the downstream. In addition to the area drained by the Mukteswari River and Teka Nadi, Hari itself drains beels like the Khuksia, Bhaina, Kapalia, and several other adjoining beels with an area of about 20,000 ha.

Khals

There are several khals in this study area which are important for drainage. But most of these are dead because of sedimentation on the bed and grabbed by the people which cause the drainage congestion problem worst. The khals which are not dead carry mainly water from rainfall and runoff to the beels and rivers in the wet season.

Beels and Wetlands

The study area has a huge numbers of beels which are very important for biodiversity, such as freshwater fish and birds. The beel area is about the 45% of the total study area. The names and areas of these beels are given in Table 3.1.

Table 3.1: Name and area of the beels in the study area.

Beel Name	Area (ha)	Beel Name	Area (ha)
Arpata	328.76	Jialdaha	176.29
Arsinagari	288.71	Kapalia	886.52
Bagdanga	344.59	Kedaria	1208.35
Bakar	1091.62	Koyar	248.12
Bhaina	592.41	Madhagram	376.22
Boruna	710.89	Panchbaria	211.57
Buruli	15.50	Panchkatia	149.38
Dahakula	189.52	Payara	662.62
Daharmoshihati	721.54	Singa	142.14
Damukhali	596.63	Thaulia	311.73
Danga-Mohishdia	158.05	West Khuksia	617.93
Dumuria	1039.36	Others	31.57
East Khuksia	1090.00	Others	116.56
Hajrail	325.07	Others	130.29
Horina	985.87	Others	52.63
Jhikra	993.45	Others	82.27
		Total Beel Area	**14876**

Source: KJDRP Database, IWM

3.2.2 Groundwater resources

Groundwater quality is generally good but because the area is near the coast, there is a saline-freshwater interface. There is always a risk in such circumstances that groundwater development will cause movement of the saline front inland. However, most groundwater movement within the study area is vertical. In the dry season water is lost by capillary rise, evaporation and, in areas of groundwater irrigation, by well abstraction. This depletion in storage is replaced by groundwater flow patterns can be identified, hydraulic gradients are low, because the permeability of the surface layers is also low, and the lateral volumetric transfer of water is comparatively small.

3.3 Physical Characteristics of the Area

Important physical characteristics are peat basins, tidal floodplain and the Ganges floodplain. The subject of this article is limited to the tidal floodplain. The tidal floodplain is bounded in the north by the Ganges floodplain and in the south by the Sundarban mangrove tidal forest. The tidal floodplain is strongly influenced by tide, salinity and rainfall. This plain is also crisscrossed by numerous tidal creeks or channels and has high drainage density. The average tide difference is about two meters. Most of the areas are between one to three meters above mean sea level and have a southward regional slope.

The water and the soil are saline but in the rainy season salinity becomes low. Fresh water flows from the upstream regions and the tides normally control the salinity of this region. The major portion of the floodplain is low-lying, barely one meter above mean sea level and below high tide level. Homesteads, roads, vegetable gardens and orchards were developed on areas artificially raised by digging ponds and ditches.

3.4 Climate

The study area has a typical monsoon climate with a warm, dry season from March to May followed by a rainy season from June to October and a cool period from November to February. The mean annual rainfall in the area is 1,750 mm of which approximately

70% occurs during the, monsoon season. Potential evapo-transpiration rates are of the order of 1,500 mm and exceed the rainfall rates from November to May. The relative humidity in the area varies from about 70% in March to 90% in July. The mean annual temperature is 26°C with peaks of over 30°C in May. The temperature in winter may fall to 5°C in January. The climate is favorable for various agricultural activities throughout the year (CEGIS, 2002a). The mean monthly and annual maximum, minimum and average temperature, relative humidity, wind speed, sunshine, evaporation and rainfall are shown in Table 3.2.

Table 3.2: Climate data from 1960-2002 at station Keshobpur (Station Code 936).

Month	Mean Monthly Temperature (°C)			Mean Monthly Relative Humidity (%)	Mean Monthly Wind Speed (Km/hr)	Mean Monthly Sunshine (Hours)	Mean Monthly Evaporation (mm)	Mean Monthly Rainfall (mm)
	Max	Min	Avg					
Jan	25.8	11.6	18.9	71	9.3	7.8	61	11.8
Feb	28.9	14.2	21.6	65	9.3	8.1	70	21.8
Mar	33.3	19.5	26.4	63	11.1	8	113	36.4
Apr	35.8	23.7	29.8	68	16.7	8.1	132	83
May	35.1	25	30.1	75	14.8	7.7	120	179.5
Jun	32.9	25.8	29.4	85	13.0	5.2	93	307.4
Jul	31.9	25.9	28.9	88	13.0	4	78	341.5
Aug	31.9	25.9	28.9	87	13.0	4.8	79	311.8
Sep	32.3	25.6	29	86	11.1	5	73	246.3
Oct	31.9	23.3	27.7	81	9.3	7.1	80	126.8
Nov	29.7	18	23.9	75	9.3	7.8	71	28.9
Dec	26.4	12.4	19.5	73	9.3	7.7	66	10.3
Annual	31.3	20.9	26.2	76	11.7	6.8	1036	1705.5

(Source: BMD)

3.5 Tidal Characteristics

To obtain the tidal characteristics in the Hari river, the water level data measured by IWM at Ranai have been analyzed for the period January to December 2008. The monthly maximum and minimum water levels are shown in Table 3.3.

The maximum tide level during spring tide in August 2008 was about 4.03 m,PWD and the lowest water level was at about 0.11 m,PWD at Ranai in Hari river. The maximum tidal range was found to be about 3.91 m. The observed one day water level hydrograph during the month of August is shown in Figure 3.2.

Table 3.3: Monthly maximum and minimum water level at Ranai in the Hari river.

Month	Monthly Maximum WL (m,PWD)	Monthly Minimum WL (m,PWD)	Tidal Range (m)
Jan	3.02	-0.11	3.14
Feb	3.02	-0.15	3.17
Mar	3.20	-0.15	3.35
Apr	3.53	-0.14	3.67
May	3.69	-0.14	3.83
Jun	3.65	-0.08	3.73
Jul	3.93	0.05	3.87
Aug	4.03	0.11	3.91
Sep	3.97	0.14	3.83
Oct	3.88	0.15	3.74
Nov	3.35	0.04	3.32
Dec	3.32	-0.04	3.37

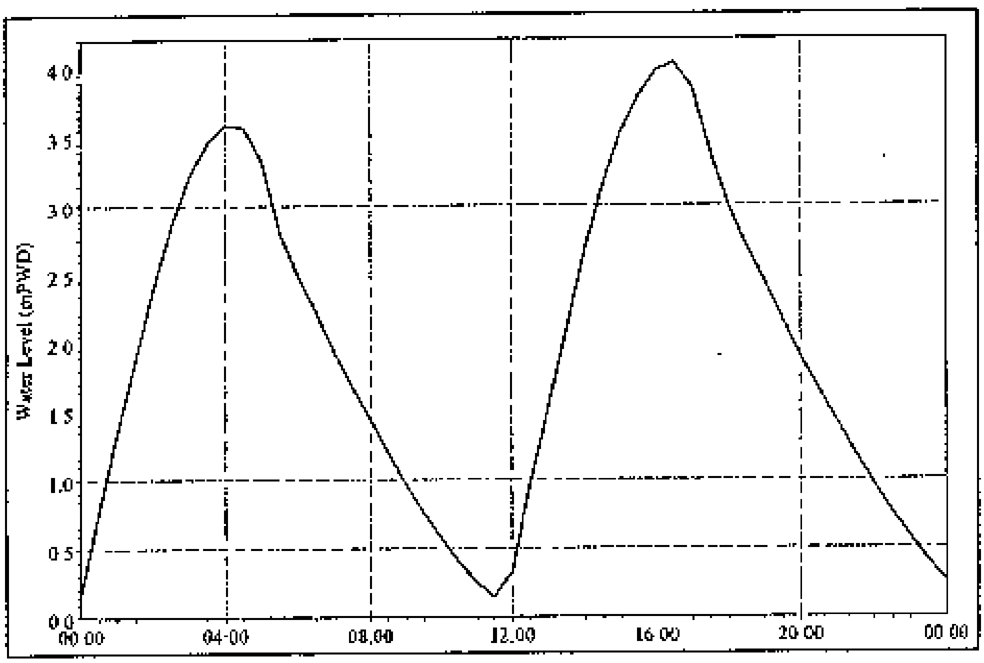


Figure 3.2. Observed water level at Ranai in the Hari River.

3.6 Sediment Characteristics

The Hari river bed is covered with the fine sediment, or mud, originating from the Bay of Bengal. Average grain size is typically less than 0.063 mm and the bed behave as a cohesive sediment bed. Grain size distribution has been done for the Hari river at Ranai from the measured bed sample and it has been found that, D_{50} = 0.017 mm and D_{90} = 0.050 mm.

Measured suspended sediment data of IWM at Ranai in Hari river has been analysis to know the maximum sediment concentration in spring tide. The maximum concentration is shown in Table 3.3. The maximum concentration observed during dry season in the month of May.

Table 3.4: Maximum sediment concentration at Ranai in the Hari River.

Year	Maximum Sediment Concentration (ppm)				
	January	March	May	August	September
2001	1192	2109	3773	1710	1866
2002	1376	1967	12327		3065
2004		21481	24167		
2005			33412		
2007	2416		6361		
2008			4188		

3.7 Present Practice of Tidal Basin Operation for TRM

When a beel is selected for TRM, a potential location for the link canal is identified considering tidal movement and sedimentation inside the beel and drainage of the other beels. This is done in consultation with local stakeholders and with the help of a numerical model study. Then sedimentation inside the tidal basin is allowed through that link canal. In almost all cases most of the sedimentations take place near the entrance of the link canal. In the present TRM basin, East Beel Khuksia, a second link canal has been constructed for uniform sediment deposition inside the tidal basins. Though after three to four months most of the natural khals inside the tidal basin are silted up, no re-excavation or dredging activities have taken place. Stakeholder consultations and focus group discussions indicate that re-excavation and dredging of the khals inside the tidal basin are essential for uniform silt deposition.

3.8 Ecosystem

The existing condition of the study area can be recognized as being an imperfect stagnant ecosystem of the mixed tidal and non-tidal Ganges floodplain. It is imperfect because parts of the floodplain or basin have been drained step-wise from a stagnant condition.

The biological diversity of plants and wildlife is expected to be further improved from the present conditions. This is in spite of the fact that the total wetland area would be reduced as people use more and more land for agricultural practices, such as for paddy or shrimp. It is expected that where land would remain available as wetland (seasonal/perennial), the improved drainage and flushing conditions would result in better water quality, recharged nutrients, and increased stock of fish and other aquatic life forms. Terrestrial plants are dying due to water stagnation, would return, while wetland dependent wildlife would reappear and start razing over land and water Improvements are especially expected for water hens, herons, mudskippers and sand pipers.

Conversion of agricultural land to shrimp farm in the study areas needs to be considered as one of the major ecological alterations. In some parts of the beels in Khulsia, Bhaina and Rudhagara, local people are converting their agricultural land almost permanently to shrimp farms. In the longer term, it might have an impact on the ecological balance of the project area, especially due to the abstraction of the snails from nature. Moreover, use of extra feed for shrimps will create water quality problems. The situation will worsen in those beels where flushing facilities are poor or absent. It is to be noted that the cultivation of the golda along with rice or other crops is not as environmentally damaging as the culture of the bagda alone (EGIS, 2001).

3.9 Socio-economic Condition

Most of the people of the study area are involved in agricultural production either directly or indirectly. According to the 1981 census, the total population of the project area was 666,311 which give an average population density in the order of 662 people per km^2. There are 107 males for every 100 females according to this census. Based on an annual growth rate of 2 17%, it is estimated that the 1997 population would be about 960,000 or about 950 people per km^2 (EGIS, 2002)

The following socio-economic conditions are known to exist in the project area:

- Persistent water logging problems exist in many areas creating inhuman living conditions, the spread of disease and lack of employment opportunities
- The professional fisherman community are extremely poor and earn only about Tk. 80 per day because catches have reduced in the rivers and beels due to over-fishing and fish diseases. They also lack the capital required to change their profession
- The majority of the active population are engaged in agriculture, irrespective of land holding or social status. A majority of the landless and marginal farmers work as agricultural labourers while farmers with medium and large size land holdings mostly cultivate their own land, and
- Brackish water shrimp farming has gradually increased in some areas in recent times. This has greatly affected the environment and has caused the groundwater to gradually become saline in some localities. Social conflicts have occurred between rice cultivators and brackish water shrimp farmers because of conflicting interests.

3.10 Institutional Arrangement for Water Management

3.10.1 Local government

The structure of the local government can be distinguished at three levels:

District level: The district administration (Jessore) is headed by the Deputy Commissioner and has representatives of the major line agencies.

Thana level: There are 4 upazillas within the stndy area. They are headed by an executive officer (TNO) and have more junior representatives of the line agencies attached to them.

Union Level: A union council headed by an elected nnion chairman.

Presently there is very little direct involvement of the local government in water management activities. However, there is a potential for more involvement of local government which will improve the water management in the study area.

3.10.2 Agencies under central government

The activities in water management of different agencies under the central government are given below:

Bangladesh Water Development Board (BWDB):

- Construction of dams, barrages, reservoirs, embankments, regulators or other structures for development of rivers, flood control, drainage, surface irrigation, and drought prevention
- Re-excavation/ de-siltation of water channels and removal of obstacles from the mouths of rivers for improvement of water flows or diversion of water for assisting fisheries, navigation, forestry, wildlife development and up gradation of the environment.
- River training and river bank protection for the protection of towns, bazaars, hats and places of historical and public importance from the hazards of land erosion.
- Construction and maintenance of coastal embankment.
- Flood and drought forecasting and warning.
- Hydrological survey and investigation.
- Development of forestry and fishery on land available a round the Board's infrastructure and construction of roads on embankments in conjunction with relevant government agencies, for the preservation and improvement of the environment as well as for poverty alleviation.
- Basic and applied research on all aspects of the Board's activities.
- Establishment of water user's association and other water users/stakeholders' organizations, their training and participation, in project planning, implementation, operation and maintenance and cost recovery for long-term sustainability of benefits to the beneficiaries of completed projects

Local Government Engineering Department (LGED):

- Rural area development by constructing rural roads, culverts, small bridges and hydraulic structures.

Department of Fisheries (DOF):

- Excavation/ Re-excavation of pond for development of fisheries
- Provide help for the people in fish culture.

Department of Environment (DOE):

- Monitor environment and help the government in policy making.

Department of Public Health Engineering (DPHE):

- Construction of infrastructure for public health and safety

3.10.3 Water management structure

In the study area, a four-tier water management structure was created:

- Water Management Group (WMG, registered);
- Water Management Committee (WMC, not registered);
- Water Management Association (WMA, registered); and
- Water Management Federation (WMF, not registered).

WMGs were formed as the primary institutional entities at all villages within the project area. Initially, WMGs were formed with a participation of at least 25 percent of the households. At a later stage, WMGs were registered under the Cooperative rules and became legal entities. WMGs have their own bank accounts and hold independent savings and shares that were collected from the members and shareholders.

At the second level of institutional formation are the WMCs. These were formed to bring together two or more WMGs to manage the catchment of a primary or secondary drainage channel.

The next level of institutions is the WMAs. All catchment level WMCs are combined in a drainage unit with a distinctly delineated hydrological boundary and were brought under a WMA. These drainage units are commonly referred to as Zones. The project document identifies the formation of WMAs as a pivotal step of beneficiary participation in KJDRP and suggests their involvement in all major spheres of the project. Subsequently, WMAs were registered as multi-purpose cooperative societies and function as the key local level institutions for water management With the legal arrangements made, the WMAs became the 'joint partners' to carry out the O&M tasks of each zone along with the BWDB. Each of the above three water management institutions (WMG, WMC and WMA) are composed of general members that are selected/elected by independent executive committees, and have the portfolio positions of Chairman, Secretary, and Treasurer in respective committees.

Finally, at the top of the institutional framework a WMF was formed to look at inter-zonal and regional issues. As there are many concerns common to all WMAs and many interactions exist between WMAs, WMF proved to be a crucial level of institutional formation (CEGIS, 2002b).

Besides this four-tier water management structure, three other types of institutions or special groups were formed:

- Landless Group (LLG, registered);
- Fisher folk Group (FFG, registered); and
- Labour Contracting Societies (LCS, not registered).

The LLGs and FFGs were formed to ensure participation of landless people and fishers; covering the area of each WMCs. The LCSs were formed for the execution of specific intervention to support WMCs.

3.4 Non government organization

A number of prominent NGOs are working in this study area including Unnayan, Bangladesh Rural Advancement Committee (BRAC), Uttaron, Action Aid, Pradipan, MASES, SIBAS, Jagoroni Chakra and CARE.

NGOs played an important role to guide the government agencies for the project formulation, training and support of Water Management Groups and Associations. Generally speaking, the NGOs selected and contracted had good local knowledge and experience and the capabilities required, although some certainly performed better than others and a few performed below the standard required and had to be replaced.

CHAPTER FOUR

METHODOLOGY

4.1 General Approach

The central research question for the study was identified through literature review and preliminary field visits. Conceptual and methodological frameworks for the study were prepared before execution of the research The methodologies followed in the study can be categorized in three groups.

- selection of beels for the study
- application of participatory rural appraisal (PRA) tools to select socially acceptable options for uniform sediment deposition inside the tidal basin
- assessment of the technical feasibility of the options and finalize the option(s) in the consultation with the local people.

The general approach followed in the study can be summarized in the flowchart given in Figure 4.1.

4.2 Beel Selection Criteria

One major component of the study was selection of two suitable beels, one at the upstream and another at the downstream part of the Hari river, in such a way that would serve the research objectives of the study. Beel selection was guided by a set of criteria devised in line with the objectives. One beel was selected where TRM has been operationalized and another where it is under process. Others considerations were accessibility to the beels and availability of secondary data. The selection process involved extensive review of secondary data and literature and expert consulting with the local stakeholders, BWDB field officials, members of LGIs and representatives of WMA/WMF in the field visits. Finally, Beel Kapalia (upstream and next TRM Basin) and East Beel Khuksia (downstream of Hari River and ongoing TRM basin) have been selected for this study.

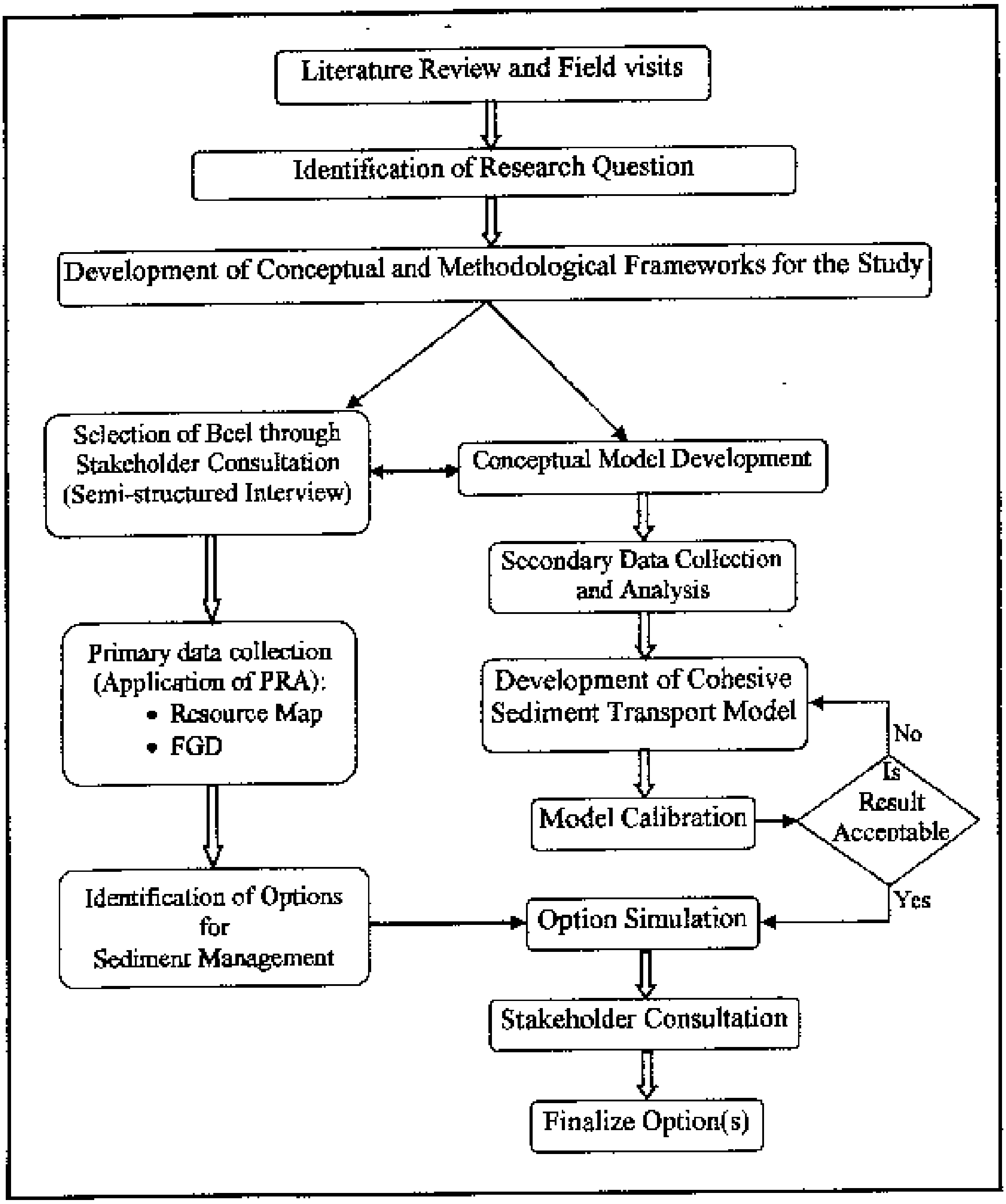


Figure 4.1: Flowchart of the general methodology applied in the study.

4.3 Primary Data Collection using PRA Techniques

Participatory Rural Appraisal (PRA) is a family of approaches and methods to enable rural people to share, enhance, and analyze their knowledge of life and conditions, to plan and to act (Chambers, 2002). Participatory Rural Appraisal is an intensive, systematic but semi-structured learning experience carried out in a community by a multi-disciplinary team, which includes community members. The PRA has different

Information from the field has been synthesized and analyzed to understand the perspectives and priorities of the local communities regarding sediment management. Based on these analyses several options for sediment management in the tidal basin have been developed and analyzed using a sediment transport model to assess the technical feasibility of these options.

PRA approach was used for collection of primary data regarding uniform silt/sediment deposition inside the tidal basin. Out of a suite of different PRA tools, Semi Structured Interview, Resource Mapping and Focus Group Discussion (FGDs) were selected for collection of primary data. In addition to these tools several stakeholder consultations (Photo 4.1) were conducted for collection of important information.

4.3.1 Semi-structured interview

Semi-structured interviews were conducted with a fairly open framework which allowed for focused, conversational, two-way communication. Relevant topics were initially identified and the possible relationships between these topics were the basis for more specific questions. The majority of questions were created during the interview, allowing both the interviewer and the person being interviewed the flexibility to probe for details or discuss issues. The objective was to understand the respondent's point of view rather than make generalizations about behavior.

This technique was used to collect qualitative data by setting up a situation that allowed a respondent the time and scope to talk about their opinions on the particular subjects. The wording of questions was not same for all respondents.

Interviews were conducted at several places in the Bhabodah area. The interviewees were landowners, farmers, fisher folks, members of the WMAs (Photo 4.2). Interviews were also conducted with the key informants from representatives of the LGIs, NGOs and the field offices of BWDB, DOF, and DOE. The focus of these interviews were to collect information to understand the present problems regarding TRM operation, mitigating options, identify major stakeholder groups, locations of community interactions, beels for study and locations for resource mapping.

(a) Kalibari village (b) Enayetpur village

Photo 4.1: Stakeholder consultations.

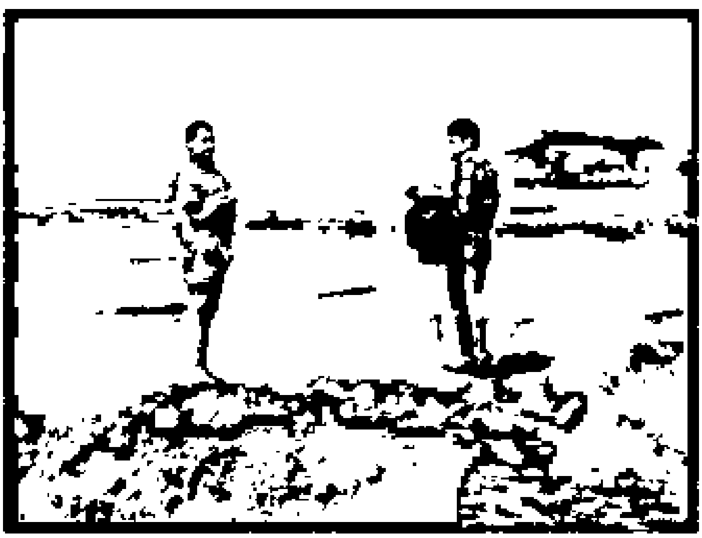


Photo 4.2: Semi-structured interview.

4.3.2 Resource mapping

Resource mapping is a map to depict the resources, mainly natural rivers, khals, beel area, etc., available in the study area. Resource mapping normally covers the area of the entire study area along with some adjacent areas. Resource mapping is often used as a base map at the time of planning as it enlists and visualizes almost all resources. It also acts as a documentation of the situation in the study area during the time of planning.

Resource mapping activity was done in two villages: Kakbadhal in East Beel Khuksia and in Beel Kapalia. To draw the resource map, participants were provided with a brown paper and four color marker pens. One person from the groups of 15-20 people drew the map. In the case there was a mistake, it was immediately corrected by rest of the participants. The whole exercise took place in the open field. Two resources mapping (Figure 4.2 and Figure 4.3) were prepared for two selected beels following the same procedure as described above.

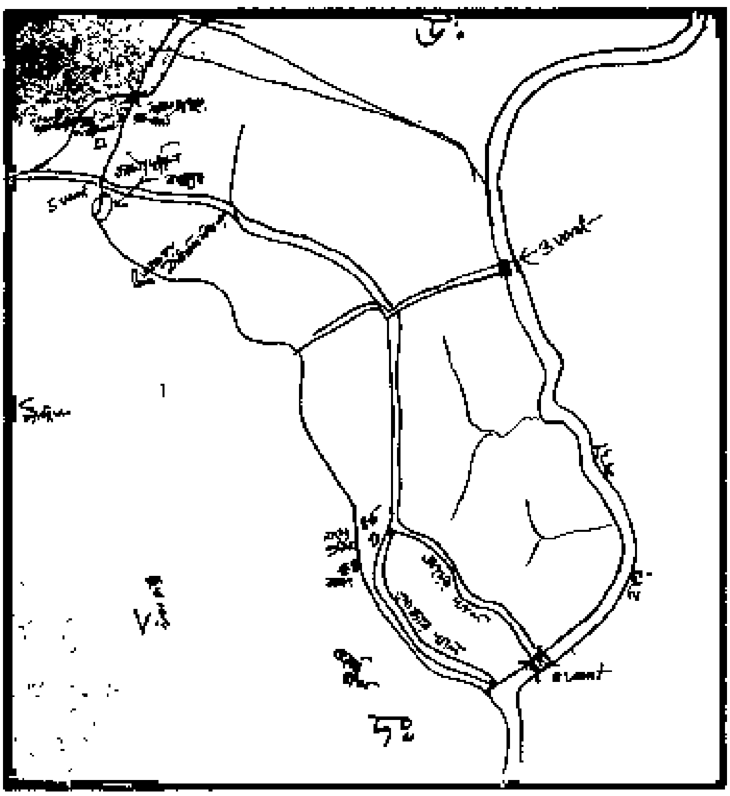


Figure 4.2: Resource map prepared in East Beel Khuksia.

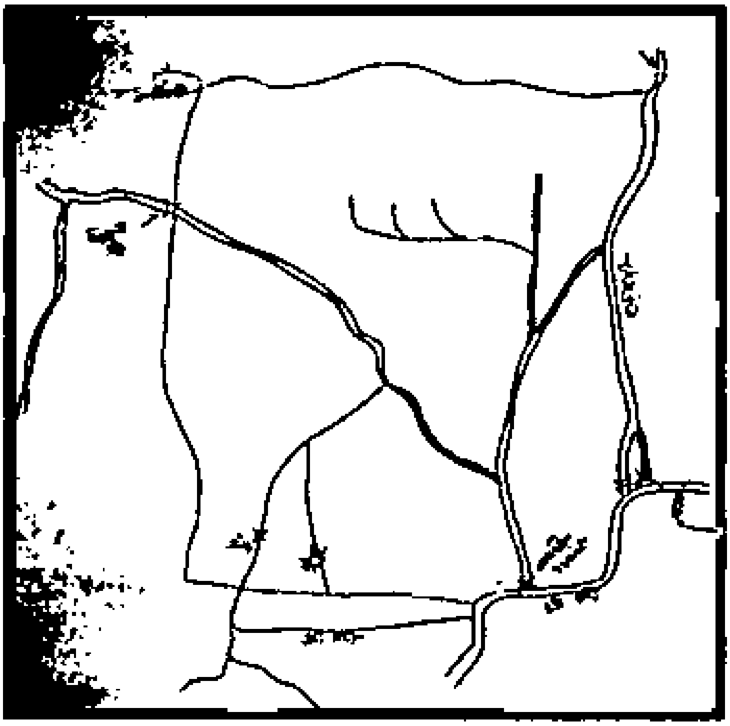


Figure 4.3: Resource map prepared in Beel Kapalia.

4.3.3 Focus group discussion

FGD is an efficient and effective tool for collecting information. Focus Group Discussion brings together a small and homogeneous group of 6-8 people who are the representatives of a much larger sector of a society or of the community. The purpose is to create an informal situation in which the members of the group discuss the topic of concern among themselves with the help of a facilitator and in the presence of one or more observers.

The conventional way to perform FGDs is to do it in a group. The FGDs were conducted by the author himself. The author himself acted as the facilitator and observer simultaneously. For collecting information, four FGDs were conducted in the two beels. Farmers and fisher folk groups were the main source of primary information. Visits were made to both the villages for collection of primary information. The names of the villages are Kakbadhal and Kalicharanpur in East Beel Khuksia, and Kapalia and Monoharpur in Beel Kapalia. Two Focus Group Discussions were conducted in each beel. Each FGD involved 6-8 persons. Average age of the people was 40. Most of the FGDs were done in the open field of the villages. The earlier prepared resource maps were used during these discussions. For smooth guidance of the discussion a checklist of some questions was used which is shown in Appendix-A.

(a) Farmers in Kakbadhali

(b) Fisher folk in Kakbadhali

(c) Farmers in Kalicharanpur

(d) Fisher folk at Kalicharanpur

Photo 4.3: FGD in East Beel Khuksia

(a) Farmers in Kapalia

(b) Fisher folk in Kapalia

(c) Farmers in Monoharpur

(d) Fisher folk at Monoharpur

Photo 4.4: FGD at Beel Kapalia

4.4 Secondary Data Processing for Numerical Modelling

Secondary data were collected from various research related literature, government and non-government organization, published and unpublished reports, thesis papers etc. The secondary data were collected from the following government and non-government offices.

- Institute of Water Modelling (IWM)
- Bangladesh Water Development Board (BWDB)
- Center for Environmental and Geographic Information Services (CEGIS)

According to the modelling requirements, a significant amount of data has been collected from the Institute of Water Modelling (IWM). The data used in this study was checked for quality and consistency and then processed in the required format of the model. In addition to the data quality checking, data analysis has also been carried ont for estimation of different model parameters. For the model development using MIKE FM the following data were required:

4.4.1 Topographic data of beels

To develop the cohesive sediment transport model, the existing bottom topography data of East Beel Khuksia and Beel Kapalia were collected from Institute of Water Modelling (IWM). After simulation of model the assessment of sedimentation in the tidal basin and its distribution pattern over the whole basin in respect to base condition has been found.

The land level data is processed to prepare DEM (Digital Elevation Model). The generated DEM of East Beel Khuksia and Beel Kapalia are presented in Appendix-B Using the generated DEM, area-elevation curve of the beel has been prepared and is also shown in Appendix-B.

4.4.2 Water level and discharge

Water level and discharge data were collected from IWM which were used to produce boundary and to calibrate the model. Inventory of collected water level and discharge data are presented in the Table 4.1. Quality of data has been assured by visual checking and plotting hydrograph. All water level and discharge data plots are attached in Appendix-C.

Table 4.1: Inventory of water level and discharge data.

Data Type	Stations/ Locations	River/Beel	Collection Year	BTM Coordinate		Frequency
				Easting	Northing	
Water Level	Ranai	Hari	2008	433790	525575	Hourly, 12 hours a day
	Kanchannagor	Generail	2008	438478	507334	Hourly, 24 hours a day
Discharge	Ranai	Hari	March 2008	433790	525575	Hourly, 13 hours a day
	Kanchannagor	Generail	March 2008	438478	507334	
	First link canal	East Beel Khuksia	April 2008	433812	529395	
	Second link canal	East Beel Khuksia	April 2008	433739	531718	

4.4.3 Cross section and bathymetric data

Cross section data is essential to generate the bathymetry of the model. Extensive bathymetric survey data of March 2007 have been collected from IWM. The data comprised of 45 km transect having very dense spacing, 500 meter interval. Bathymetric data used in the present study were surveyed in March 2007 under the projects titled "Monitoring the Effects of Beel Khuksia TRM Basin and Dredging of the Hari river for Drainage Improvement of Bhabodah Area". Some plots of cross sections data are given in Appendix-D.

Table 4.2: Inventory of cross section data

River	No of cross section	Period of survey
Teka	12	March 2008
Hari	30	March 2008
Teligati	26	March 2008
Gengrail	19	March 2008

4.4.4 Sediment data

Suspended sediment concentration data is required to develop the cohesive sediment transport model and to calibration of model The total sediment transport is composed of bed material and suspended material Hourly suspended sediment samples were collected from IWM for one tidal cycle (13 hours) at different locations in rivers. An inventory of suspended sediment concentration data is shown in Table 4.3 and all data and plots are attached in Appendix-E.

Table 4.3: Inventory of suspended sediment concentration data.

Station	River/Beel	Frequency
Ranai	Hari	Hourly, 13 hours a day
Kanchannagor	Generail	
First link canal	East Beel Khuksia	
Second link canal	East Beel Khuksia	

4.5 Model Setup

Long-term sediment transport processes in a coastal system is usually driven by short term hydrodynamic events. Sedimentation and erosion at a river reach depends on the net sediment transport at that specific reach of the river Erosion rate is a function of stream energy whereas sedimentation rate is a function of suspended sediment concentration (SSC), settling velocity of particles, inundation time and local flow field. The higher the value of the first three factors the higher is the sedimentation rate and the lower the value of the local velocity below a certain level the higher is the sedimentation rate. The general description of the numerical model is attached in Appendix F.

In order to know the sedimentation inside the beel, which determines the duration of operation of tidal basin for TRM, two dimensional sediment transport/morphological model has been developed using MIKE21 FM Modelling system and duly calibrated. The calibrated hydrodynamic model is coupled with sediment transport and bed changes module. As the sediments are cohesive in nature, a cohesive sediment transport model is developed. This model has been calibrated against suspended sediment concentrations nsing settling velocity, bed roughness height, critical bed shear stresses, dispersion coefficient and concentration at the open boundaries. The layer which has been recently relocated is considered as soft layer and used to describe the bed in the sediment transport model. The layer is assumed to form the bed surface consolidated for approximately one day to one week. The numerical sediment transport module solves the two-dimensional, depth-integrated governing equation for sediment transport. The integrated hydrodynamic and mud transport model is simulated parallel. The governing equation for sediment transport is solved on the same mesh (computational grid) and applies information on water levels and currents from the hydrodynamic module to calculate the sediment transport.

Depositing material always enters the top bed layer. Deposition of weak or strong flocks is calculated on the basis of bed shear stress from the hydrodynamic module, critical shear strength for deposition and settling velocity of the suspended sediment The settling velocity is related to the depth averaged concentration is also related to the concentration Only if the bed shear stress is smaller than the critical shear stress for deposition then deposition of suspended sediment in the water column takes place.

Critical bed shear stresses and dispersion coefficients have been used as constant spatially and temporally. Critical bed shear stress for both erosion and deposition being a calibration parameter and has been used 0.1 N/m^2 and 0.05 N/m^2 respectively.

Dispersion in tidal river is expected to be higher than in non-tidal river. Empirical dispersion formulation is used where dispersion coefficient 5 m^2/s is applied depending on the current speed and water depth

$$D=K_2.\Delta x.u \quad (4.1)$$

where, D = the dispersion coefficient, Δx = the grid spacing, K_2 = the constant and u the local current speed.

Settling velocity of sediment particle mainly depends on sediment sizes. It also depends on formation of flocks, which in turn depends on salinity and temperature. Based on the measured fall velocity, 0.0002 m/s of settling velocity has been used. Usually flocculation occurs when salinity level is higher than 10ppt, as salinity level in most of the location is less than 10 ppt, influence of salinity has been ignored. The numerical model is developed integrating the main river system Teka-Hari-Teligati-Gengrail and East Beel Khuksia and Beel Kapalia Tidal Basin. The downstream model boundary is defined by measured time series suspended sediment concentration and the upstream boundary is defined by constant concentration. The schematic diagram of the sediment model is shown in Figure 4.4.

The total sedimentation inside the tidal basin has been assessed from cohesive sediment transport model result.

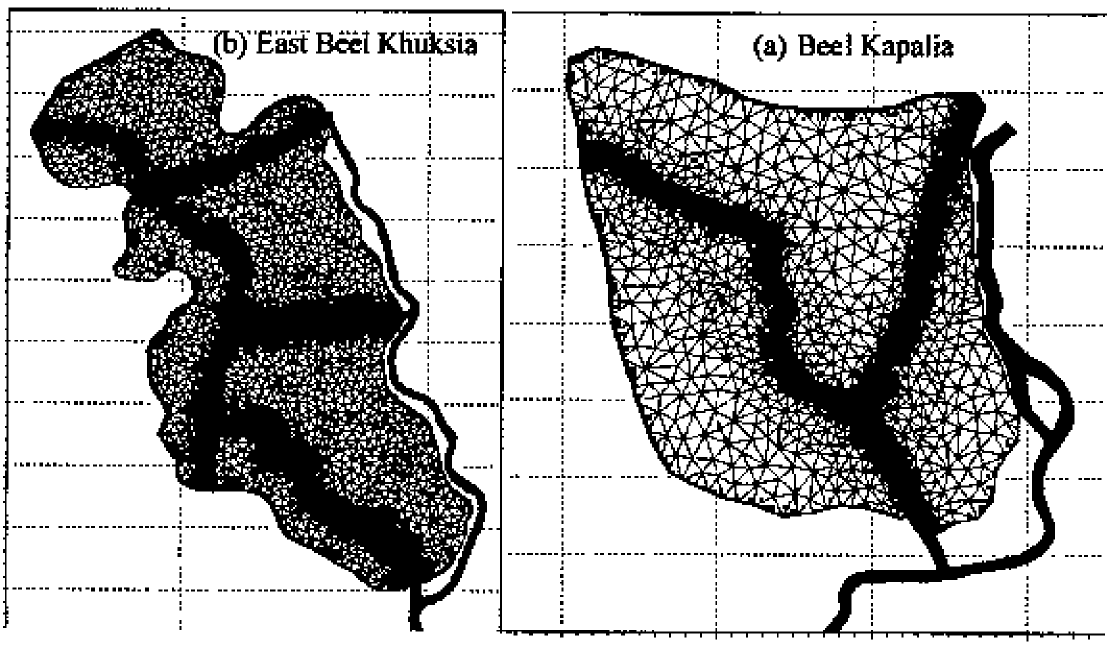


Figure 4.4: Schematization of sediment transport model.

4.6 Model Calibration

The model has been calibrated against suspended sediment concentrations nsing settling velocity, bed roughness height, critical bed shear stresses, dispersion coefficient and concentration at the open boundaries. The layer which has been recently relocated is considered as a soft layer and used to describe the bed in the sediment transport model. Cohesive sediment transport calculations are influenced by significant uncertainties, and cohesive sediment transport modelling is still an empirical science. At the same time the required information is often scattered and limited. Comparison of observed and simulated discharge and sediment concentration data are shown in Figure 4.5 and Figure 4.6, respectively, indicating that a reasonable calibration has been achieved with these limited available data. More observed suspended sediment concentration data are required for a better calibration

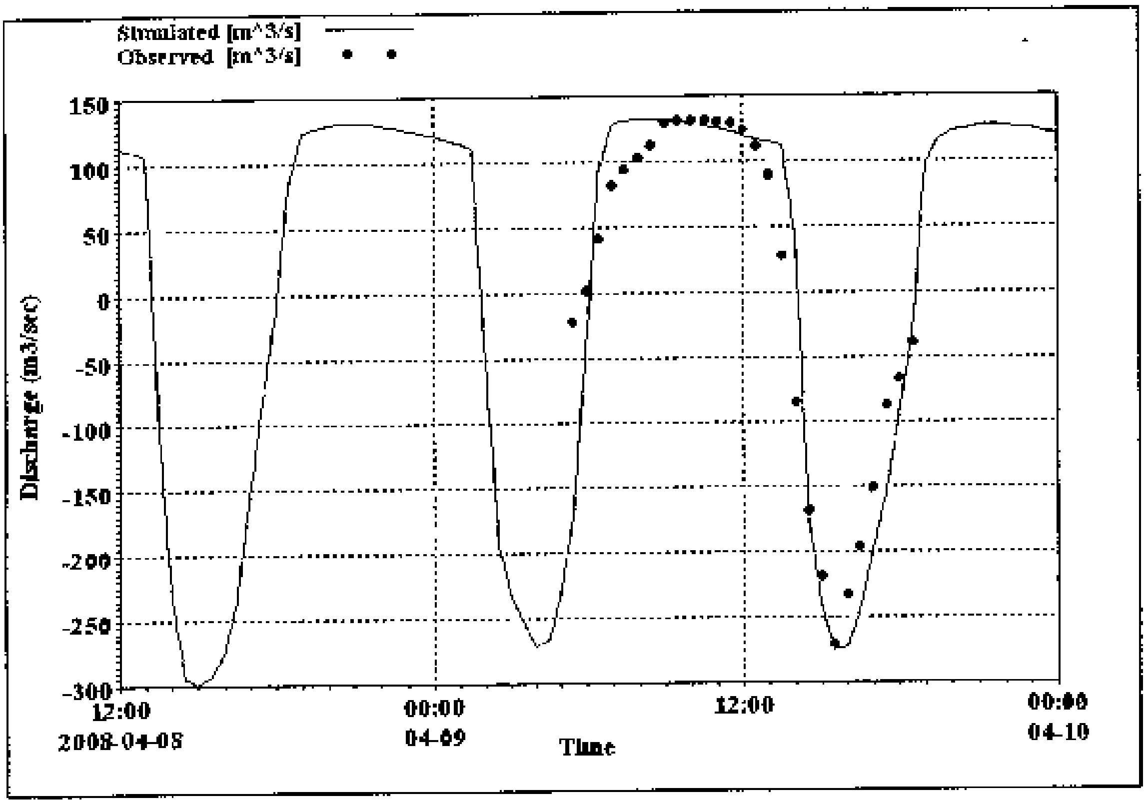


Figure 4.5: Observed and simulated discharge in the Hari River near Dierkatakhali link canal of East Beel Khuksia.

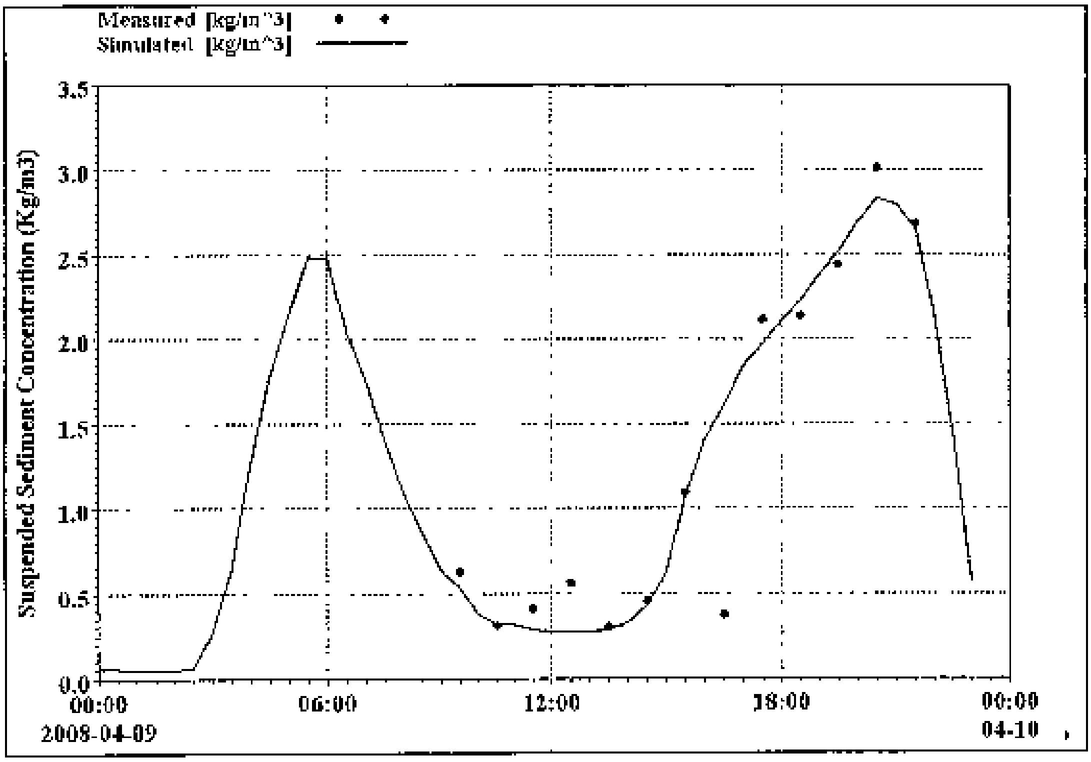


Figure 4.6: Observed and simulated suspended sediment concentration in the Hari River near Dierkatakhali link canal of East Beel Khuksia.

To check whether the calibrated model is an adequate representation of the physical system, simulated land elevation were verified with the observed data. Comparison of observed and simulated land elevations after six month operation of East Beel Khuksia tidal basin is shown in Figure 4.7. The observed land surface was generated from land elevation measurements by topographic survey inside the tidal basin. The comparison shows that there is a reasonable agreement between the observed and measured data within different ranges of elevation inside the basin (Figure 4.8).

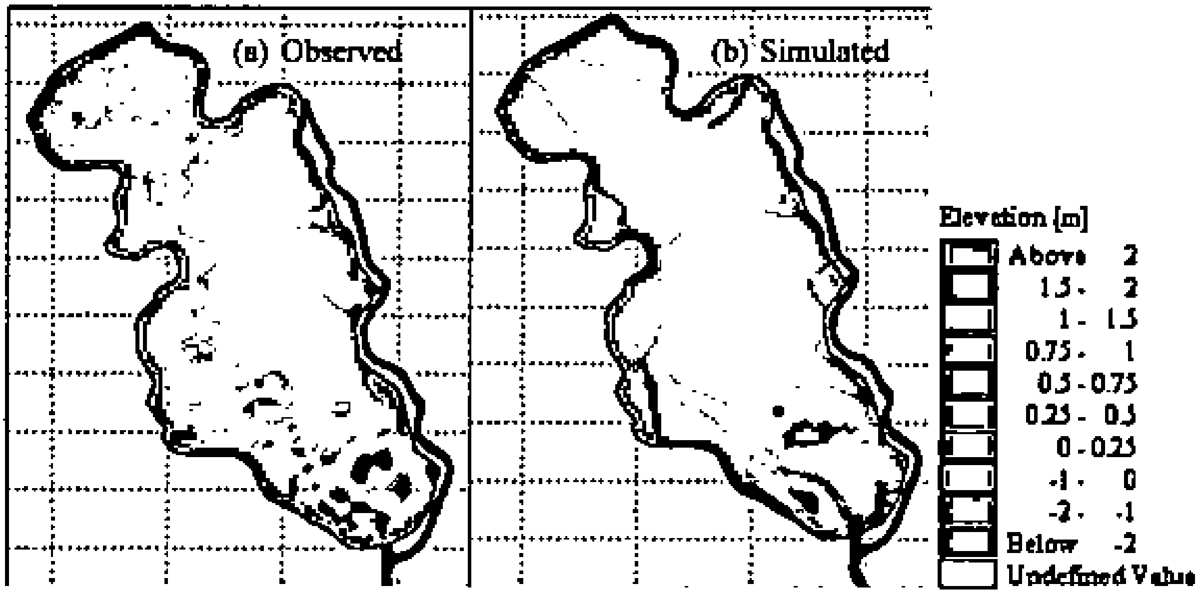


Figure 4.7: Land elevation (m,PWD) after six month operation of East Beel Khuksia tidal basin.

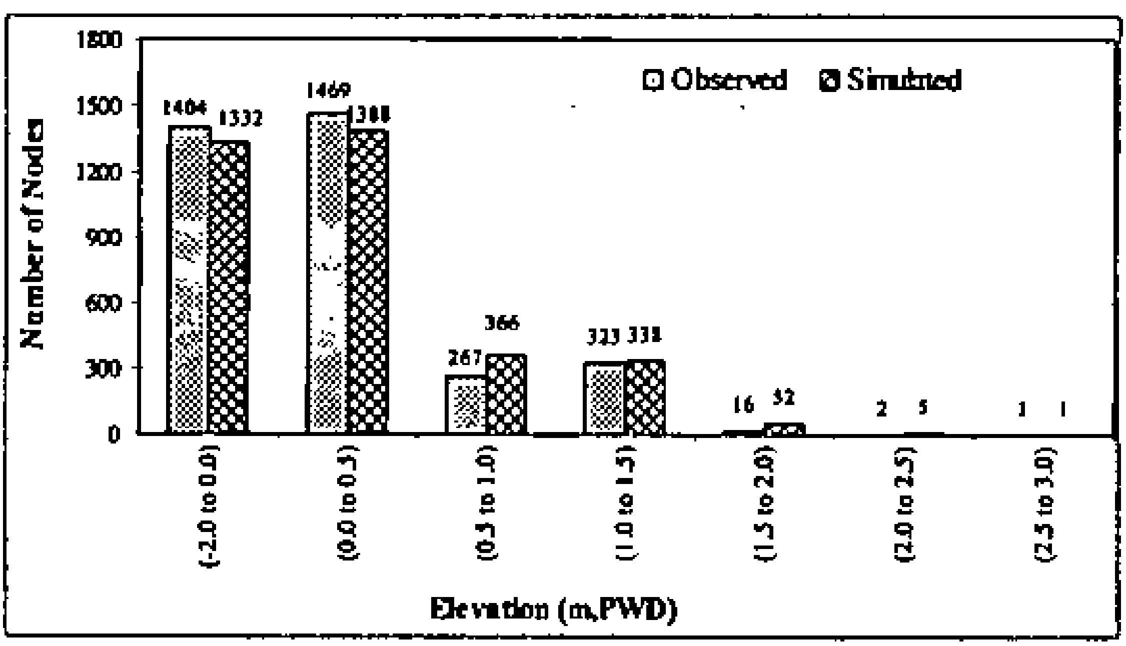


Figure 4.8: Comparison of observed and simulated land elevation within different ranges of elevations.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Synthesis of Primary Data from PRA

Stakeholder consultations and semi-structured interviews were carried out at the beginning of the study. These were done for collection of information regarding present problem during TRM operation, identification of major stakeholder groups, location of community interactions, beels for the study and locations for resource mapping. After stakeholder consultation, it was identified that farmers and fisher folks are the major stakeholder groups. It was also found that coordination among local stakeholders is required for effective sediment management

Resource maps are very useful media for interaction with the local people In all the FGDs in East Beel Khuksia and Beel Kapalia, resource maps were used to understand the views of major stakeholder groups, farmers and fisher folks. In the discussions the main issue was to identify options for uniform sediment deposition inside the tidal basin. Besides, other important issues like compensation for the land, alternate job opportunities for the landless and fishermen, main obstacle against uniform sediment deposition inside the tidal basin were discussed. After the discussion, three sediment management options, mechanism of compensation, conflicts among farmers and fishermen and probable alternate job opportunities for farmers and fisher folks were identified The brief descriptions are presented in the following sections.

5.1.1 Coordination among local stakeholders

Field investigation from stakeholder consultation and semi-structured interview indicate that there is a lack of coordination among different stakeholders in the study area. Local stakeholders are also interested to establish a mechanism for joint effort of government agencies, LGIs, WMA and NGOs for the sustainable water management in the study area. For inter-institutional coordination, BWDB should maintain contact with other government agencies like DAE, DOE, and LGED etc whose activities have impact on water management in the study area BWDB would make liaison with LGIs and harmonize the works of LGIs and WMOs. BWDB will retain the responsibility of periodic and emergency maintenance works, but will accomplish them with due participation of WMOs and LGIs. Besides O&M works, BWDB would assist in strengthening of WMO both institutionally and technically. Information campaign and motivation work are also to be carried out by them with close co-operation with WMOs and LGIs. It is required for arranging training and capacity building of WMA and LGIs to ensure active participation of local people at all stages.

During execution of O&M works and also in operation of gates for water management, WMF will be involved in overall supervision and monitoring. WMF will assist WMA to keep liaison with LGI and other GO and NGO working in the study area.

WMA do not have any fund for their operation. So it is essential to hand over the khas land, open water bodies, and canals to WMA that can be a source of their income. Besides, savings and fees from WMG, fund from local and international donor agencies are needed to keep WMA alive.

5.1.2 Conflict between farmers and fisher folks

In many parts of the study area widespread practice of shrimp cultivation is taking place. For economic benefit often people acquire the drainage canals, preparing fishing ghers without considering the drainage problems. Peripheral embankment of fishing ghers inside the tidal basin and fishing patta in the river and link canal should not be allowed during the operation of TRM since it restricts the smooth spreading of incoming sediment over the entire basin To solve this problem, BWDB should hand over the canals and lands that are under their control to WMA and they will remove the illegal ghers and patta with the help of local initiatives and local administration. For the sustenance of the fisher folk group it is essential to develop public awareness against improved rice-fish culture and indigenous fish culture.

To avoid indiscriminate fishing and to save open water fisheries the TRM basin may be well-managed organizing the present fishers through conservation and harvesting fishes in a suitable manner. It would be wise to manage the expected increased fish resources through the WMA. Coordination is essential among WMA/WMG, Department of Fisheries, LGIs, NGOs and local community for integrated fisheries development.

5.1.3 Crop compensation

In the field investigation, the issue of compensation was discussed at a great length. Landowners demand compensation of their crops for the period of tidal basin operation. A significant number of participants, however, felt that it would be difficult to maintain such spirit for very long. Some suggested that the Union Parishad (UP) should be given the authority to collect taxes to be distributed among the affected households according to certain pre-defined criteria. This, however, would require detailed field-level investigations and negotiations to develop co-operation among the different regions and local councils. Landowners whose land will be used for the designated basin should be compensated through payment of a fixed rent. The rate of compensation should be followed in accordance with market prices of food grains and average productivity of the land. Therefore, smooth and long-term operation of Tidal Basin for TRM, compensation mechanism should be introduced. This system would enable the land owners/farmers to manage alternative livelihoods during the operation of tidal basin for TRM

5.1.4 Alternate job opportunity for fisher folks and landless

There are many landless and fisher folk people in the study area who are involved in the farming and fisheries activities When a beel is under TRM operation, these groups of people are jobless. So, alternate job opportunity is essential for the survival of these people. In the recent times many of these people are getting support from NGOs but they have specific reservation of rules and regulations and not helpful for the overall water resource development at all. Water management associations, in this case, are not linked with greater socio-economic developments and even with the rehabilitation activities of economic life. WMA can play specific roles to solve economic problems of the study area if WMA activities and other NGO initiatives can be incorporated together for greater rehabilitation of economic situation.

To mitigate the sufferings of the affected landless people, it has been suggested to enroll them under the vulnerable group feeding (VGF) program. Once the area is demarcated, the appropriate authority should record the names and particulars of the affected landowners and each abould be given a VGF card to enable them to receive a fixed amount of food grain per month. Existing rules of the VGF program should be followed in implementing the program.

Support from government organizations and NGO to develop the technical knowledge to do other things like handicrafts, livestock other than agriculture and fisheries for the jobless people. Much civil works are needed when a beel is selected for TRM operation The jobless people should get the priority for that construction work. Beside this interest free loans/credit from government is essential for the jobless people. Financial support/assistance from donor agencies will be very useful for the jobless people.

People affected by the tidal basins should be given material and technical help for resettlement both in an economical and a professional sense. In assessing compensation, criterion such as land loss as a proportion of the absolute land size of the household should be considered Households for which proportional land loss would be above a critical percentage (to be defined in the light of the national standard) would be categorized as a separate group either for a better compensation rate (through arbitration suits) or for specific resettlement programs.

5.2 Sediment Management Options

Three options for sediment management inside the tidal basins have been identified in a participatory approach through FGDs and consultation with the local stakeholders For this purpose, four FGDs in East Beel Khuksia and Beel Kapalia and six stakeholder consultations have been conducted These options are described in Table 5.1.

Table 5.1: Different options for sediment management in tidal basins.

Option Number	Description
0	Business as usual (current sediment management practices)
1	Each beel is divided into three compartments by constructing embankment around the compartment and one compartment is connected to river at a time by constructing an artificial link canal in between the river and existing canal in that compartment i.e. allowing sedimentation in the compartments one after another.
2	Embankments are constructed along both banks of the main khals through the beel and thereby allow sedimentation by cutting the embankment part by part gradually from upstream to downstream.
3	All existing khals are connected with the river at the same time by constructing link canals, i.e. allowing sedimentation in the whole basin at the same time.

Option-0:

This is the existing practice of TRM operation. In this practice, one or two link canal is constructed that connect the beel with the river. Figure 5.1 shows the schematization for Option-0 in Beel Kapalia.

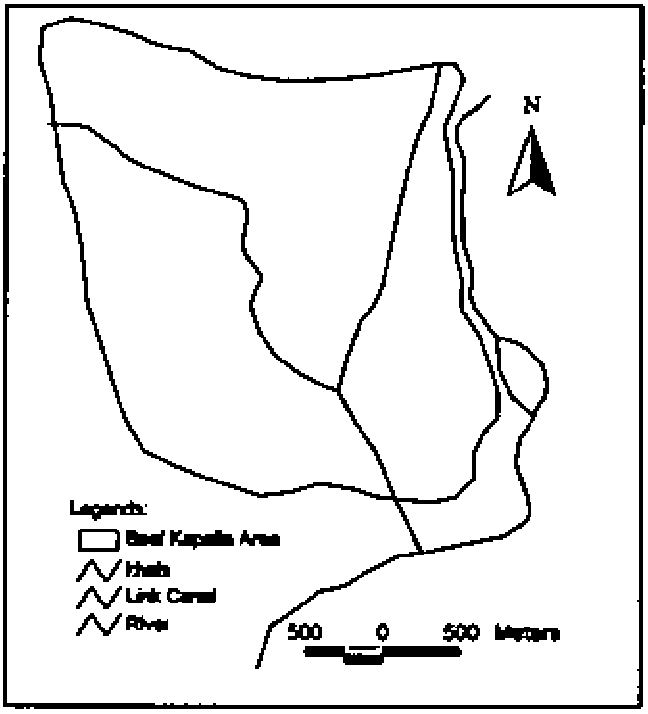


Figure 5.1: Schematization for Option-0 in Beel Kapalia.

Option-1:

In this option, each beel is divided into three compartments by constructing embankment around the compartment. To allow sedimentation in one compartment, only that compartment is connected with the river by cutting an artificial canal, which is called link canal (Figure 5.2). In this way all the three compartments are filled up one after another.

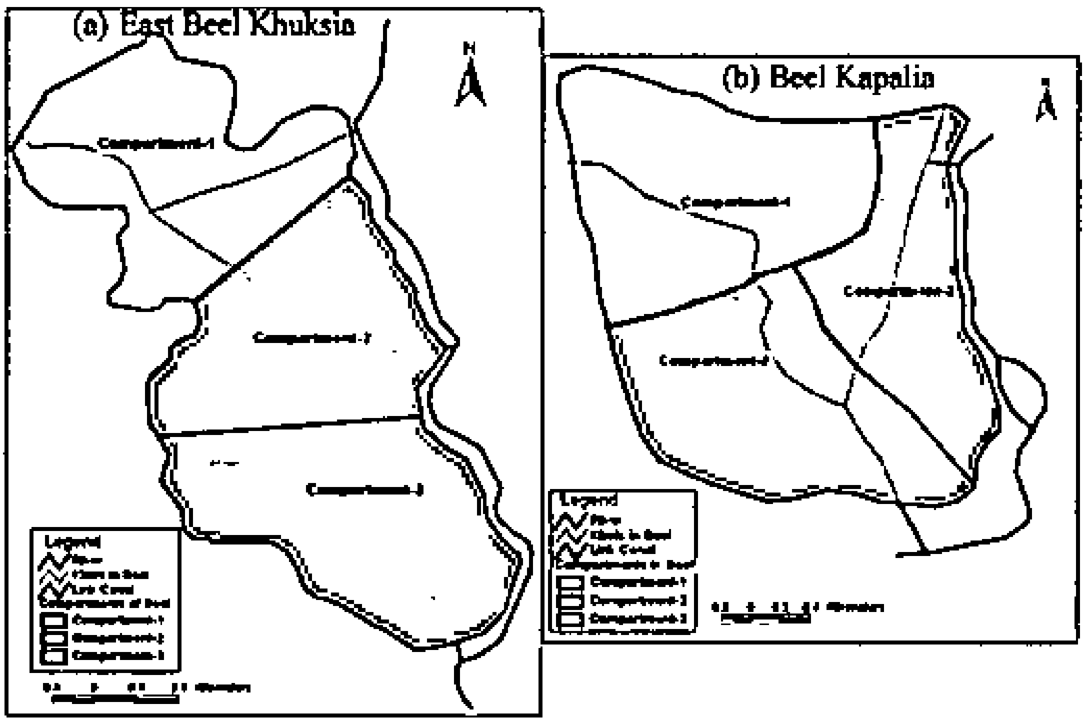


Figure 5.2: Three compartments of Option-1.

The compartments have been devised considering three criteria: area of the compartment, existence of khal in the compartment, and land topography of beel. The areas of the compartments for both beels are given in Table 5.2.

Table5.2: Area of three compartments in each beels.

Beel Name	Area (ha)		
	Compartment-1	Compartment-2	Compartment-3
East Beel Khuksin	265	242	274
Beel Kapalia	254	169	235

Option-2:

In this options, an embankment is constructed along both banks of the major khals in the beel and thereby allow sedimentation by cutting the embankment part by part, gradually from upstream to downstream, as shown in Figure 5.3 and Figure 5.4 for East Beel Khuksia and Beel Kapalia, respectively.

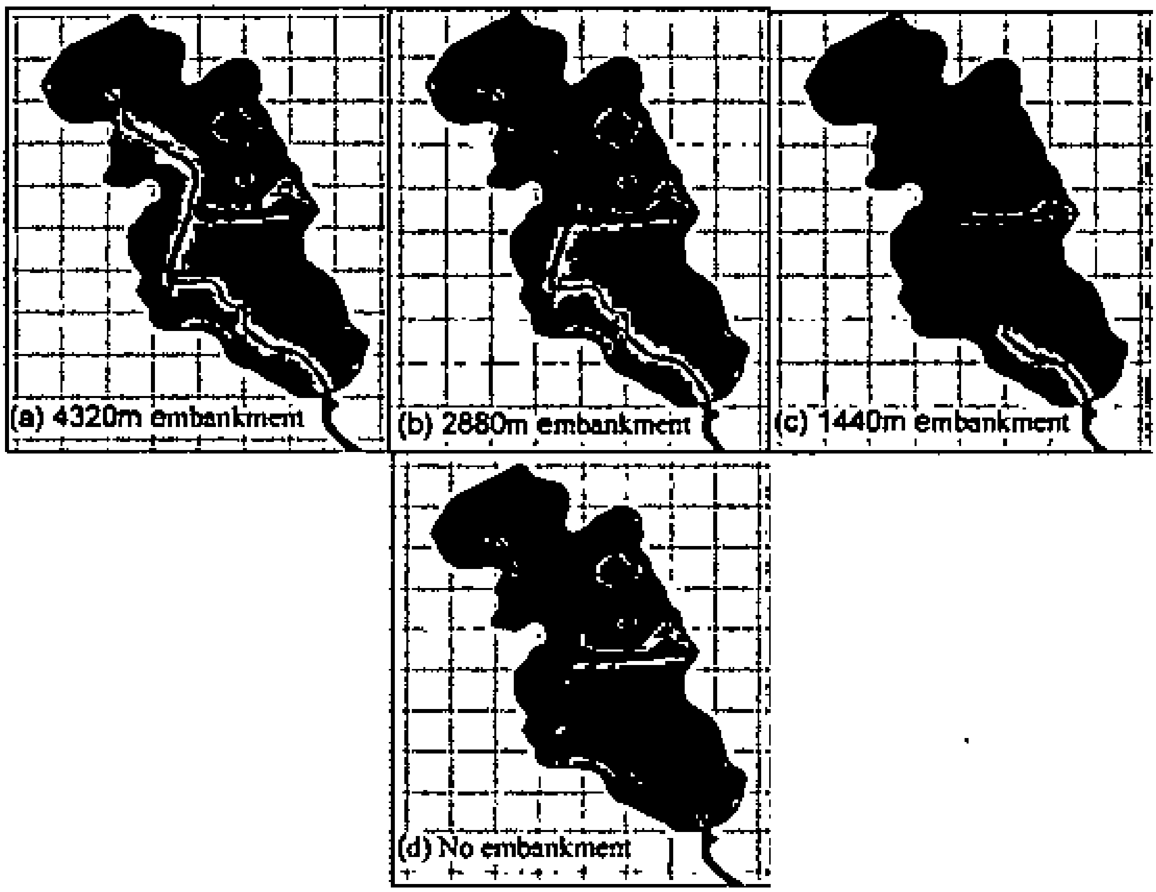


Figure 5.3: Different stages of Option-2 for East Beel Khuksia.

The total length of main khal of East Beel Khuksia and Beel Kapalia is 5760 m and 3660 m, respectively. The first embankment has been constructed for a length of three-fourth of the main khal and sedimentation has been allowed for the first year. Then the embankment was removed from one-third of its original length and sedimentation has been allowed for the second year. Similarly in the third year the length of the embankment was one-third of its original size and there was no embankment in the fourth year.

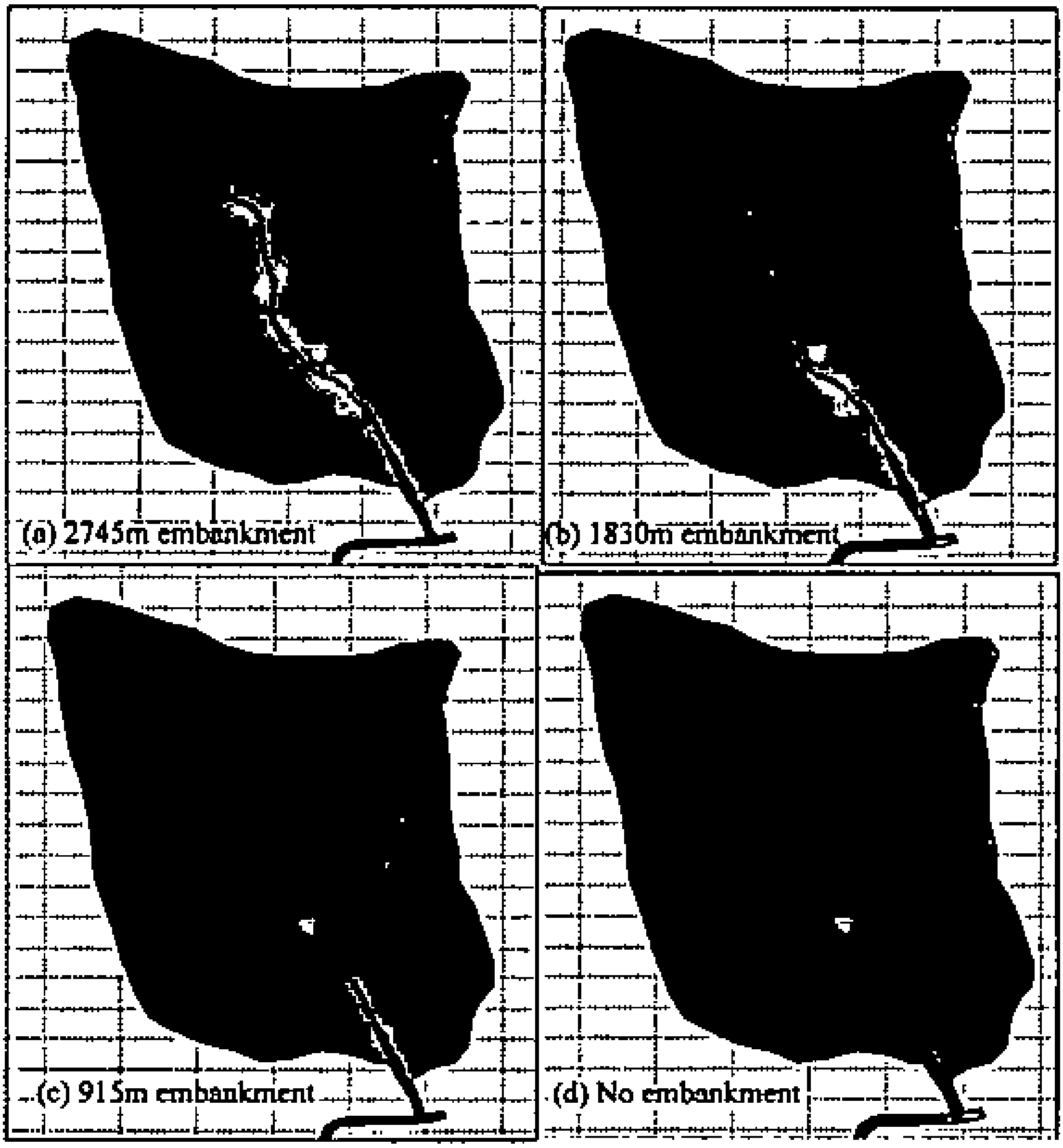


Figure 5.4: Different stages of Option-2 for Beel Kapalia.

Option-3:

In this option, all the existing major khals of the beel are connected with the river at a time by constructing link canals, i.e. allowing sedimentation in the whole basin at a time (Figure 5.5). There are three khals in East Beel Khuksia which are nearer to the Hari river and connected with the river by link canals. Similarly, two khals of Beel Kapalia have been connected with the river.

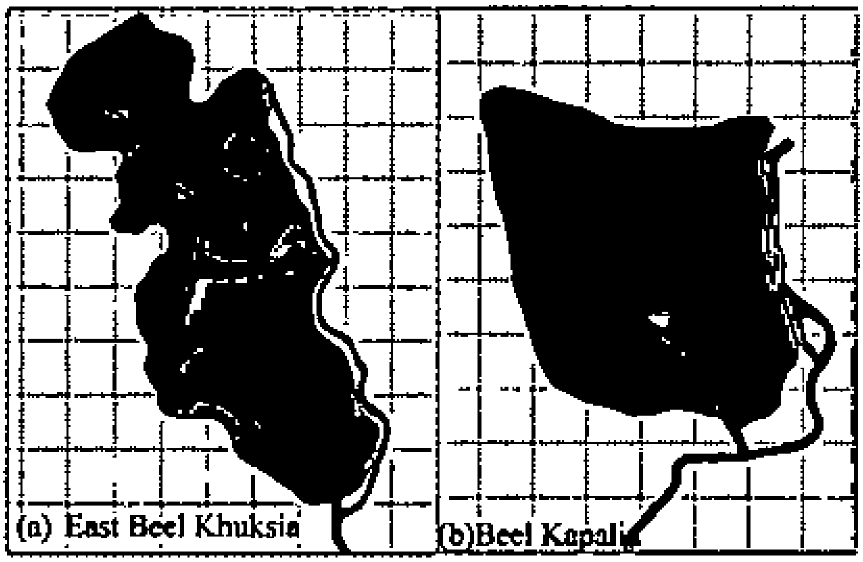


Figure 5.5: Schematization of Option-3.

5.3 Option Simulation

Options identified from the field have been analyzed for their technical feasibility using a cohesive sediment transport model developed by DHI. To set the options in the model, the size of the grid is used very fine. For all the options, total bed thickness change and net deposition in the beels are calculated and detailed in the following section.

5.4 Analysis of Results from Option Simulations

Option-0

The cohesive sediment transport model simulated one year of sedimentation in Beel Kapalia. Simulation was first done for the dry period. Then the monsoon flow was simulated with the updated bed level. In this way prediction for a year was obtained. Figure 5.6 Shows that most of the sedimentation will take place in the khal and in the immediate vicinity of the khal and silt cannot spread out in the areas far away from the khal. Figure 5.6 also indicates a very non-uniform sedimentation in the basin.

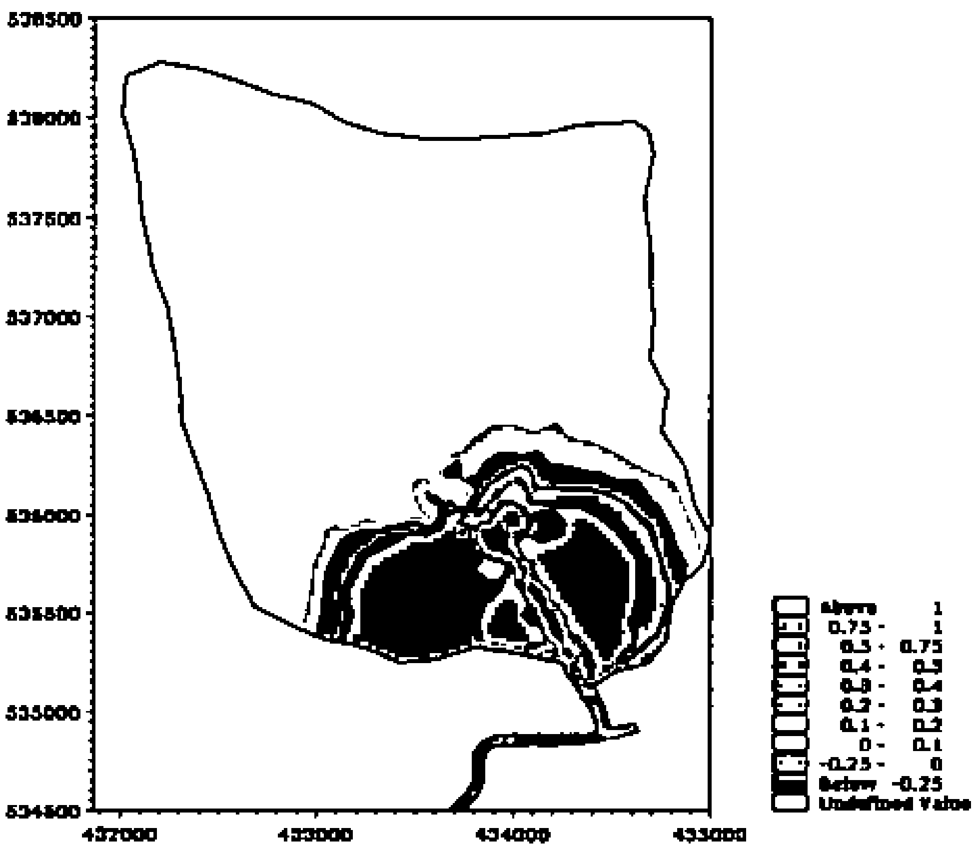


Figure 5.6: Simulated deposition pattern inside the tidal basin for Option-0 in Beel Kapalia.

Option-1

The cohesive sediment transport model has been simulated for four years. Continuous 4 years model simulation for tidal river is quite complex and time consuming. Simulation was done for the dry period then with the updated bed level the monsoon flow was simulated. In this way one year prediction was obtained. Similarly, the net deposition inside the tidal basin changes were computed for the next three years considering the changes that occurred in the past year. Figure 5.7 and Figure 5.8 shows predicted net deposition pattern inside the tidal basin after 6 months and after 12 months consecutively.

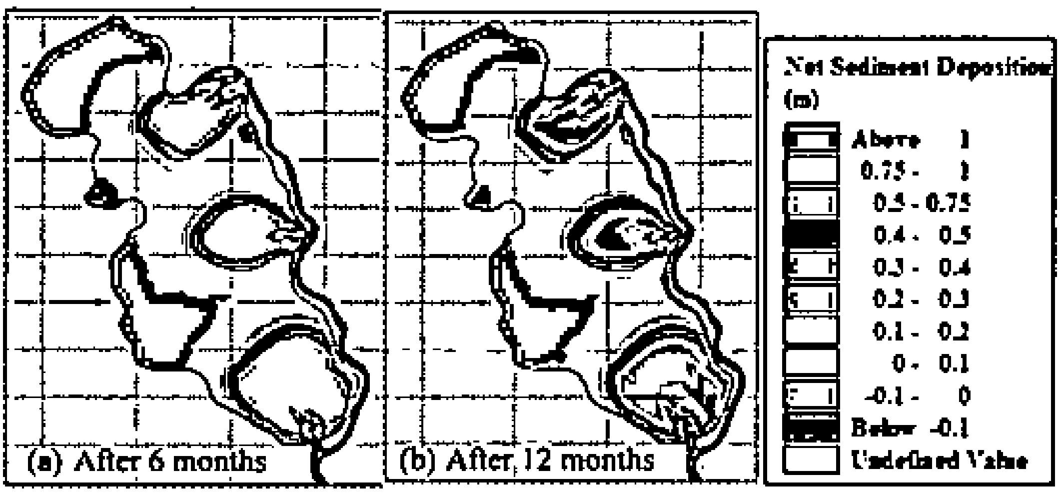


Figure 5.7: Predicted net deposition pattern inside the tidal basin for Option-1 of East Beel Khuksia.

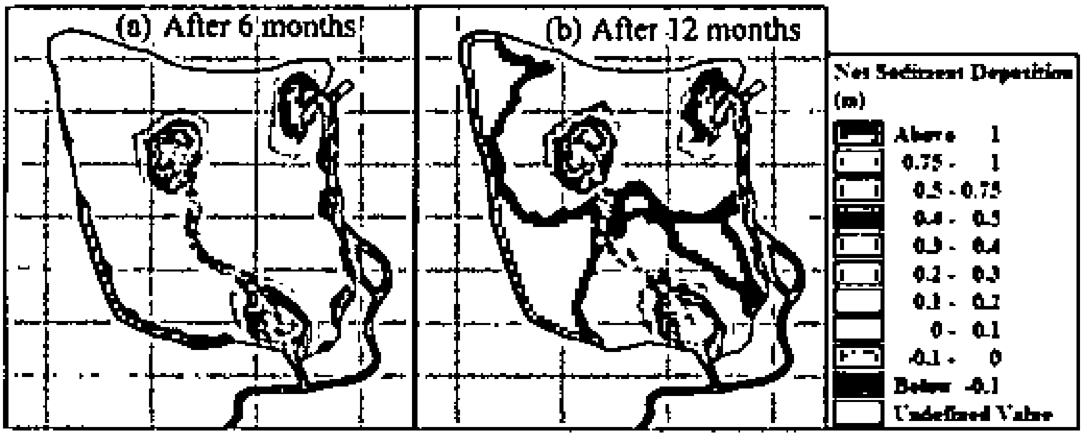


Figure 5.8: Predicted net deposition pattern inside the tidal basin for Option-1 of Beel Kapalia.

It is clear that re-excavation or dredging is required in the khals of the tidal basin after two or three months for uniform sedimentation inside the basin. Without dredging sedimentation will take place in the khal and the silt cannot spread out in the area far away from the khal. It is the main barrier of uniform silt deposition in the beel. So, it is important to dredge the khals by mechanical dredger, or manual re-excavation program is needed after four months.

There always arises a problem about disposing of the dredged spoil. It would be better to store the dredged spoil in the remote portion of the beel where sedimentation is less. With dredging of khals in the beel, the net sediment deposition pattern inside the tidal basin after one, three and four years are shown in Figures 5.9 and 5.10. Comparison with Figures 5.7 and 5.8 shows an improvement in deposition pattern when dredging is performed.

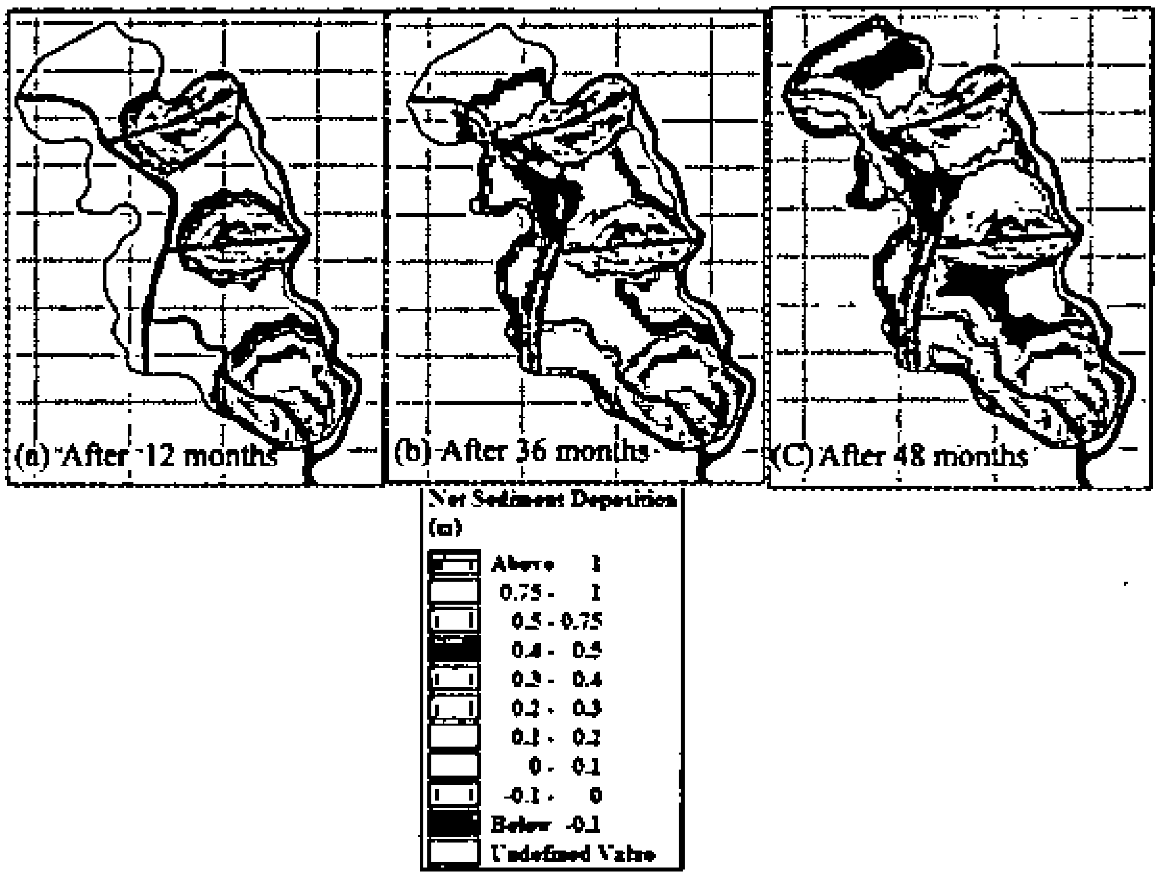


Figure 5.9: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-1 of East Beel Khuksia.

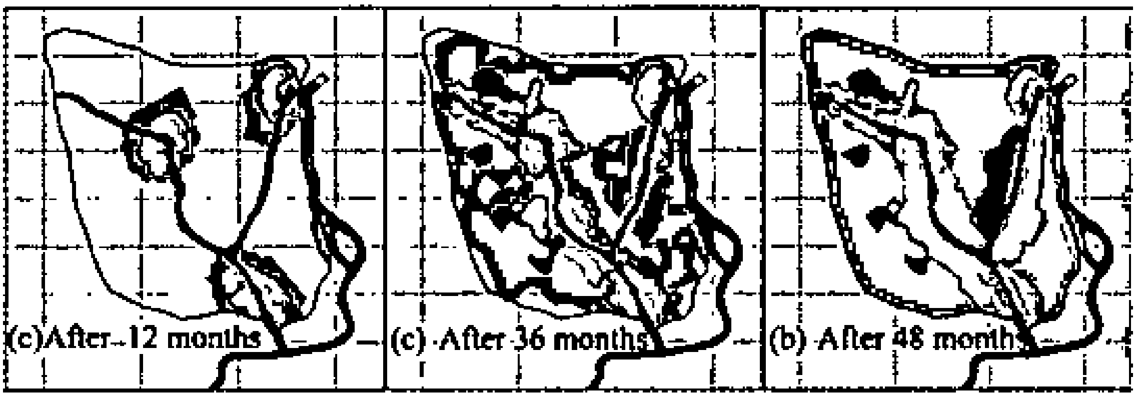


Figure 5.10: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-1 of Beel Kapalia.

Option-2:

In option-2 the predicted net deposition pattern inside the tidal basin after 3 months, and after 6 months are given in Figures 5.11 and 5.12 for East Beel Khuksia and Beel Kapalia, respectively. It is clear that re-excavation or dredging is required in the khals of the tidal basin after four months for uniform sedimentation inside the basin in option-2 also.

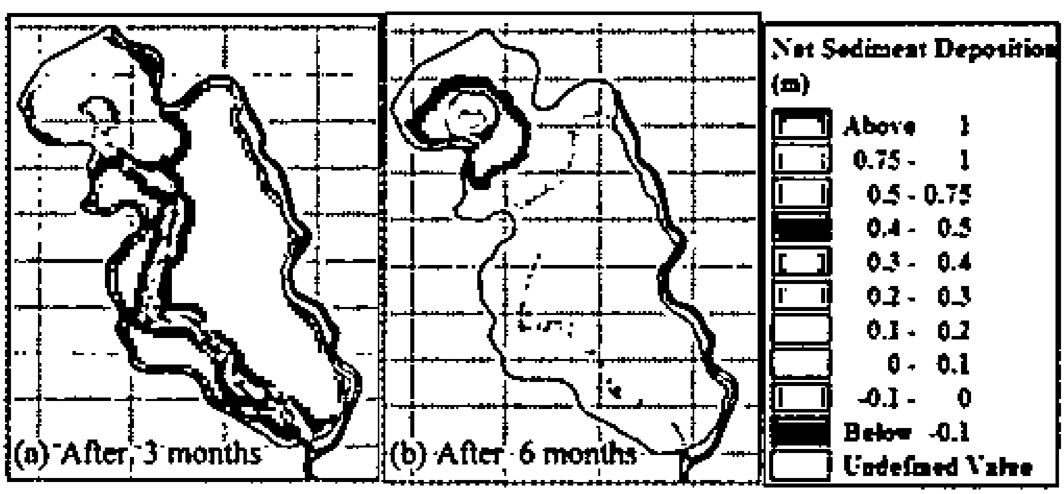


Figure 5.11: Predicted net deposition pattern inside the tidal basin for Option-2 of East Beel Khuksia.

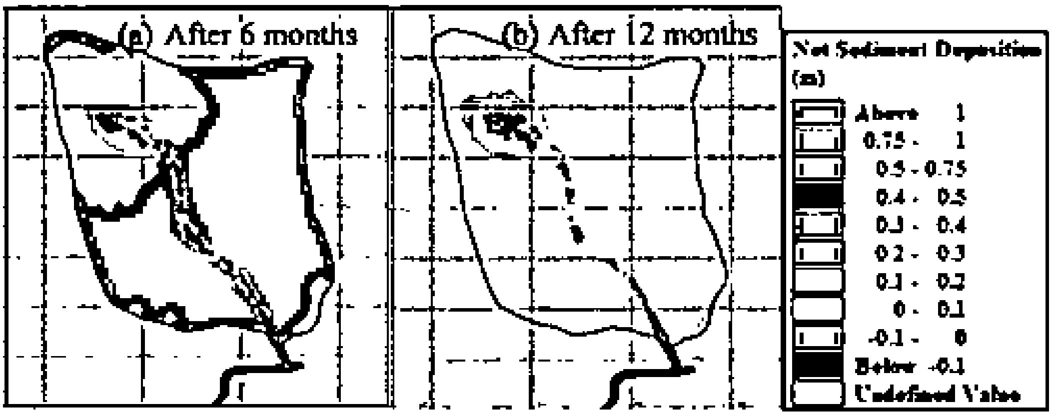


Figure 5.12: Predicted net deposition pattern inside the tidal basin for Option-2 of Beel Kapalia.

After dredging of khals, predicted net deposition pattern inside the tidal basin inside the tidal basin for Option-2 after 6 months, 12 months, 18 months, 24 months, 30months, 36 months, 42 months, and 48 months are shown in Figures 5.13 and 5.14 for East Beel Khuksia and Beel Kapalia, respectively. Improved pattern of sedimentation is observed when dredging is performed.

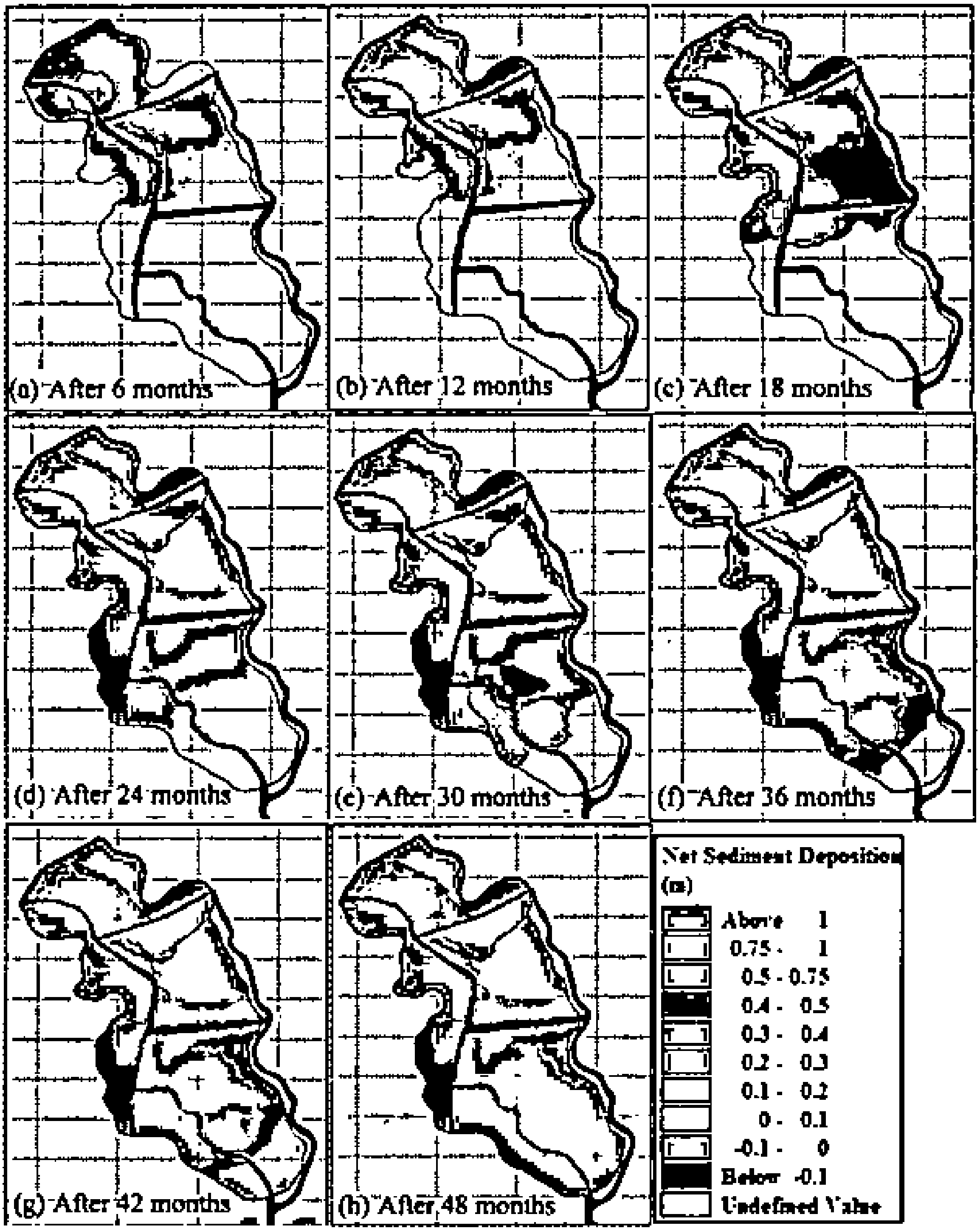


Figure 5.13: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-2 of East Beel Khuksia.

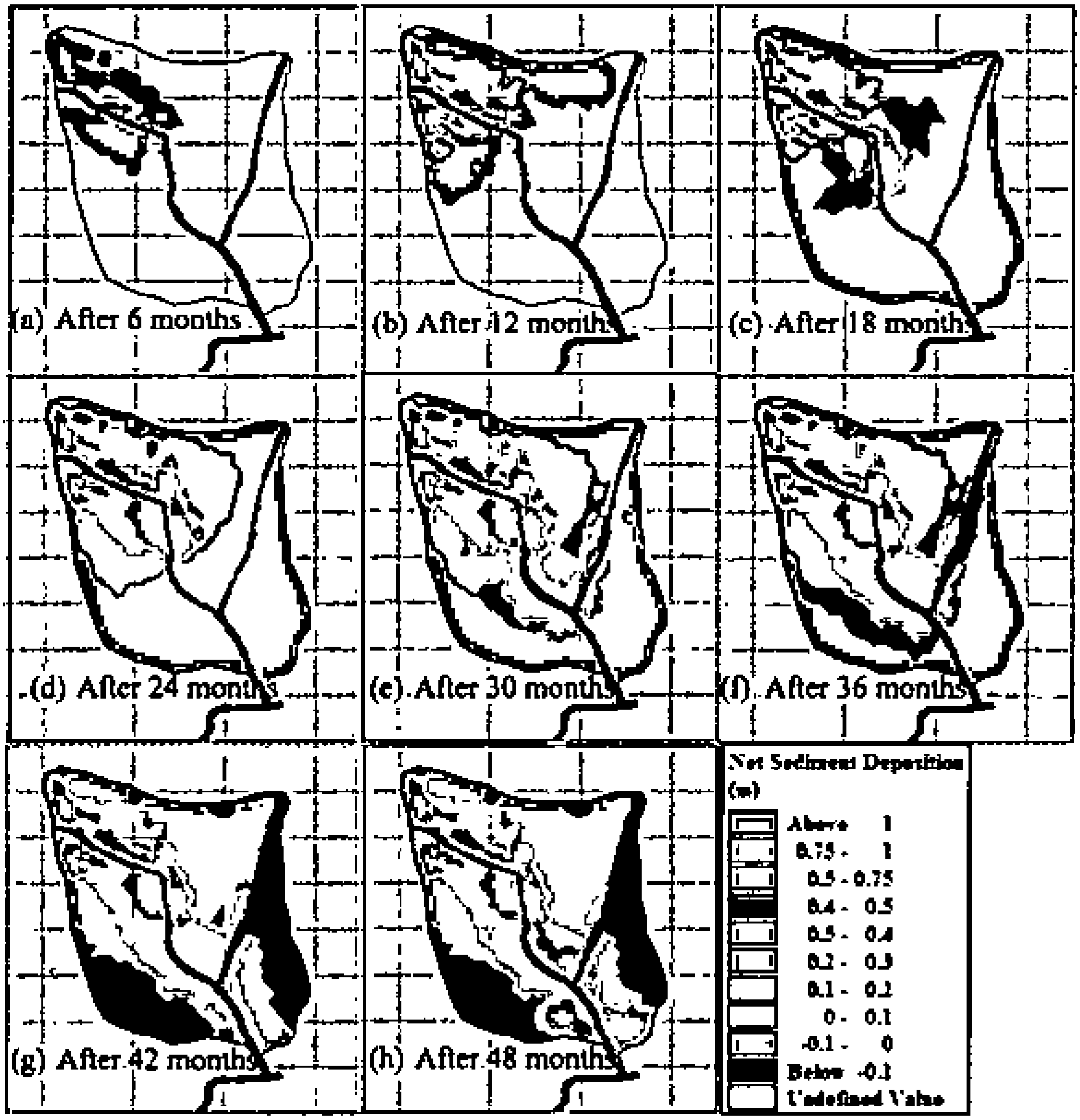


Figure 5.14: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-2 of Beel Kapalia.

Option-3:

In Option-3, predicted net deposition pattern inside the tidal basin for option-3 after 3 months and 6 months are shown in Figures 5.15 and 5.16 for East Beel Khuksia and Beel Kapalia, respectively. It is clear that re-excavation or dredging is also required in the khals of the tidal basin after four months for uniform sedimentation inside the basin in Option-3.

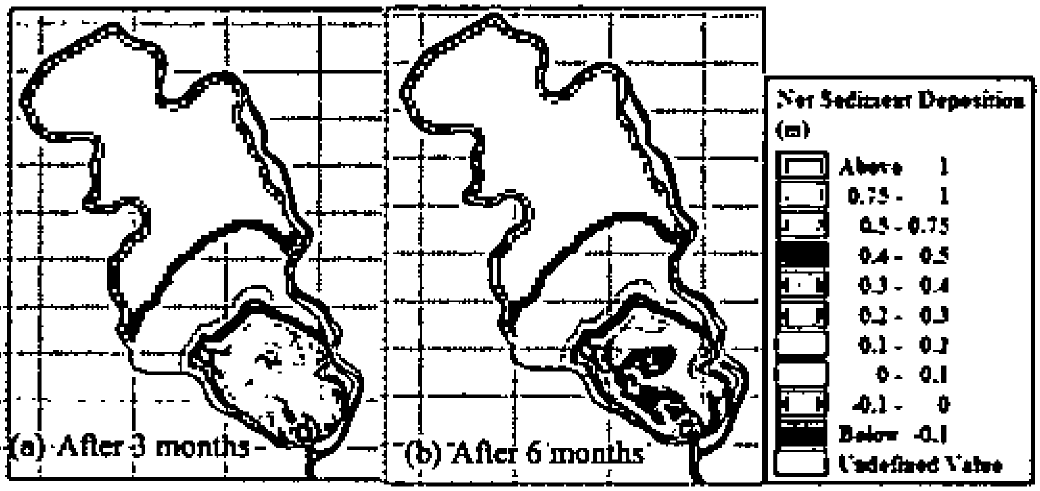


Figure 5.15: Predicted net deposition pattern inside the tidal basin for Option-3 of East Beel Khuksia.

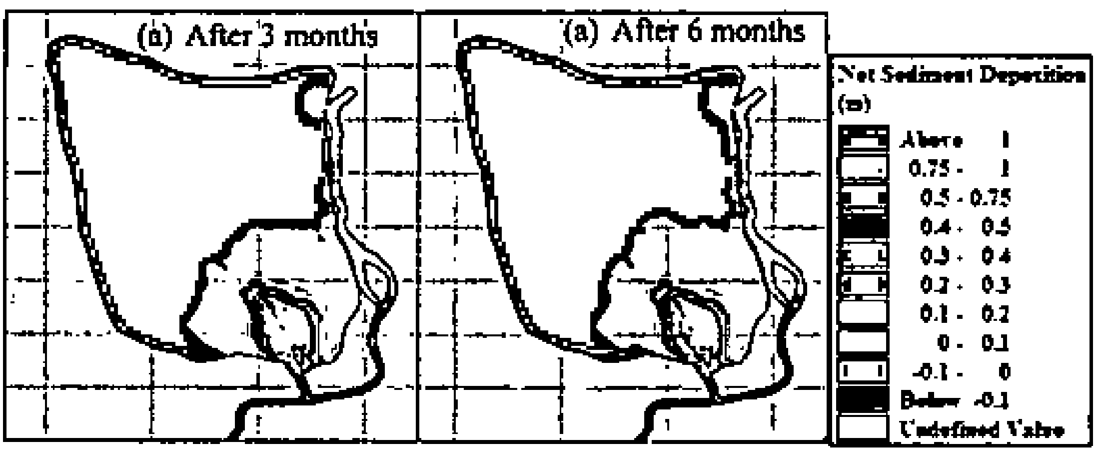


Figure 5.16: Predicted net deposition pattern inside the tidal basin for Option-3 of Beel Kapalia.

After dredging of khals, predicted net deposition pattern inside the tidal basin for Option-3 after 6 months, 12 months, 18 months, 24 months, 30months, 36 months, 42 months, and 48 months are shown in Figures 5.17 and 5.18 for East Beel Khuksia and Beel Kapalia, respectively. An improved sedimentation pattern is observed when dredging is performed.

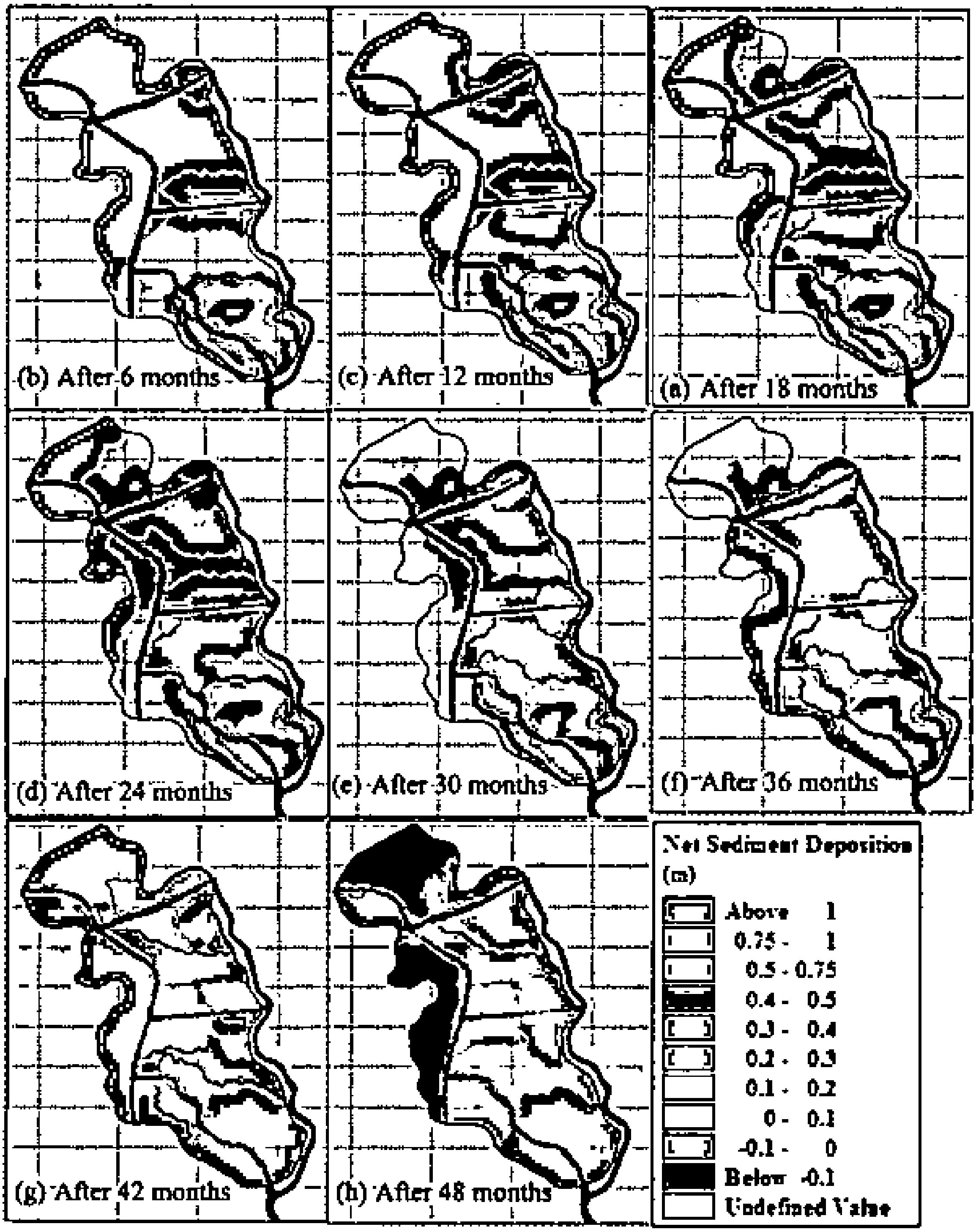


Figure 5.17: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-3 of East Beel Khuksia.

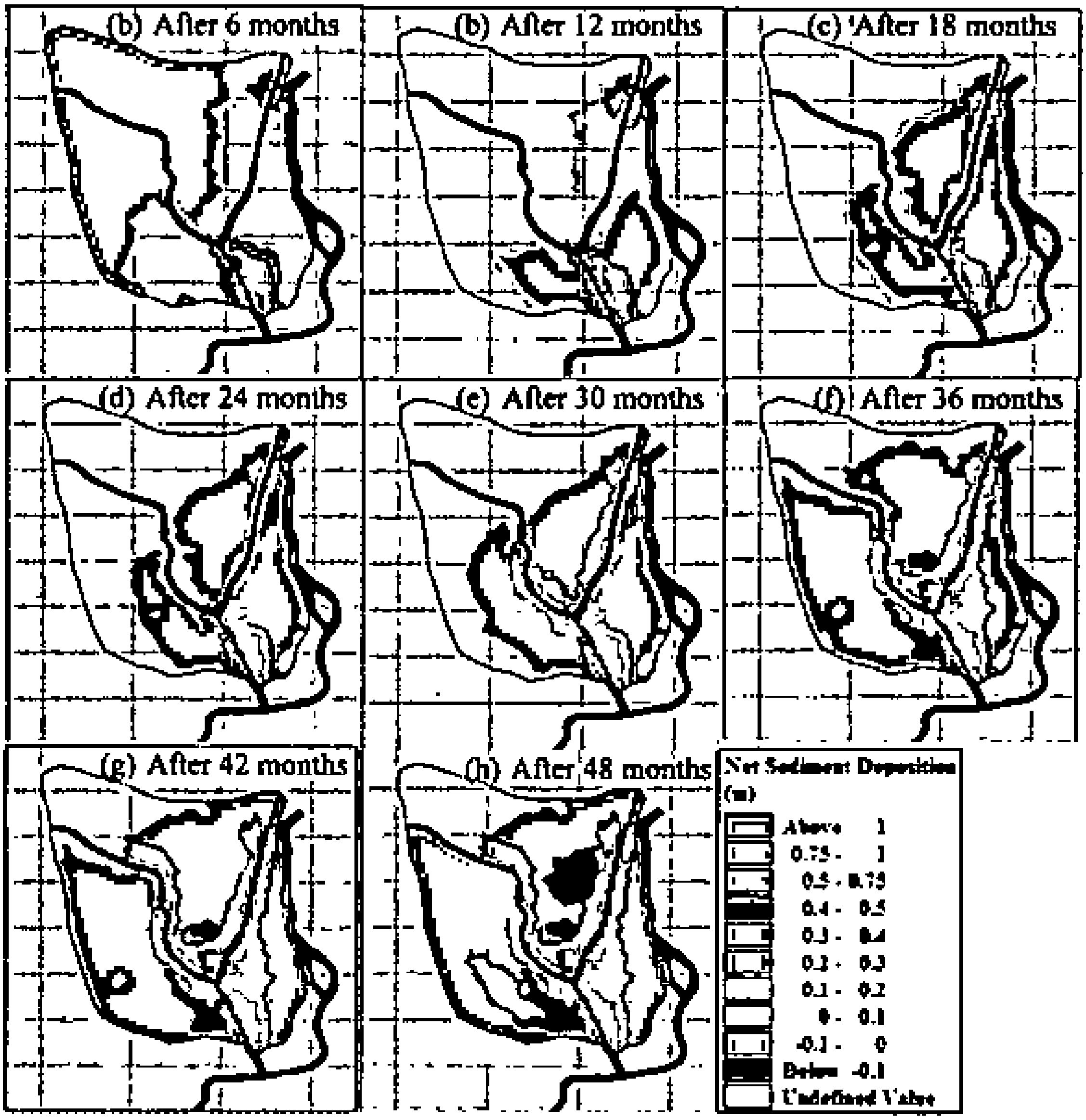


Figure 5.18: Predicted net deposition pattern inside the tidal basin with dredging of khals for Option-3 of Beel Kapalia.

5.5 Comparison of Simulation Results of Two Beels

5.5.1 Net deposition volume

Comparison of net deposition volume in East Beel Khuksia and Beel Kapalia for the three options is given in Figure 5.19 and Figure 5.20. Net deposited volume increased after dredging of the khals. So, for uniform silt deposition inside the tidal basin dredging of khals inside the beel is required within two to three months. It is also seen that maximum net deposition occurred for Option-2 and minimum net deposition occurred for Option-3 in both beels. Besides, net deposition volume is higher in East Beel Khuksia than Beel Kapalia because East Beel Khuksia is located at the downstream of the Hari river.

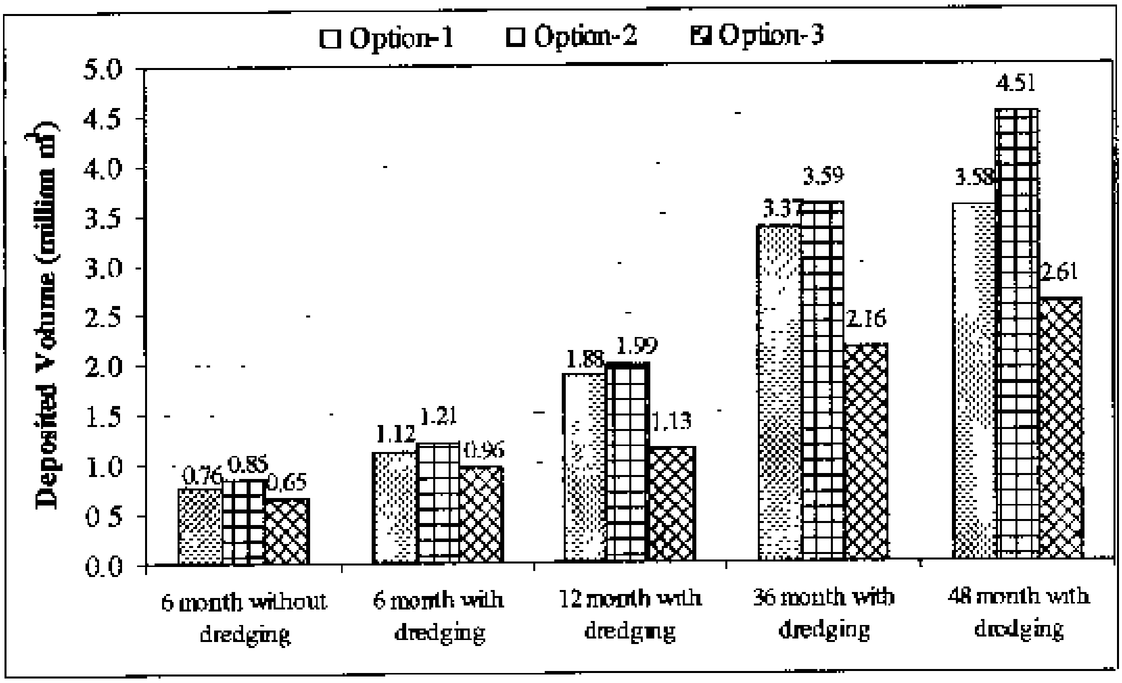


Figure 5.19. Net deposition volume at different options for East Beel Khuksia.

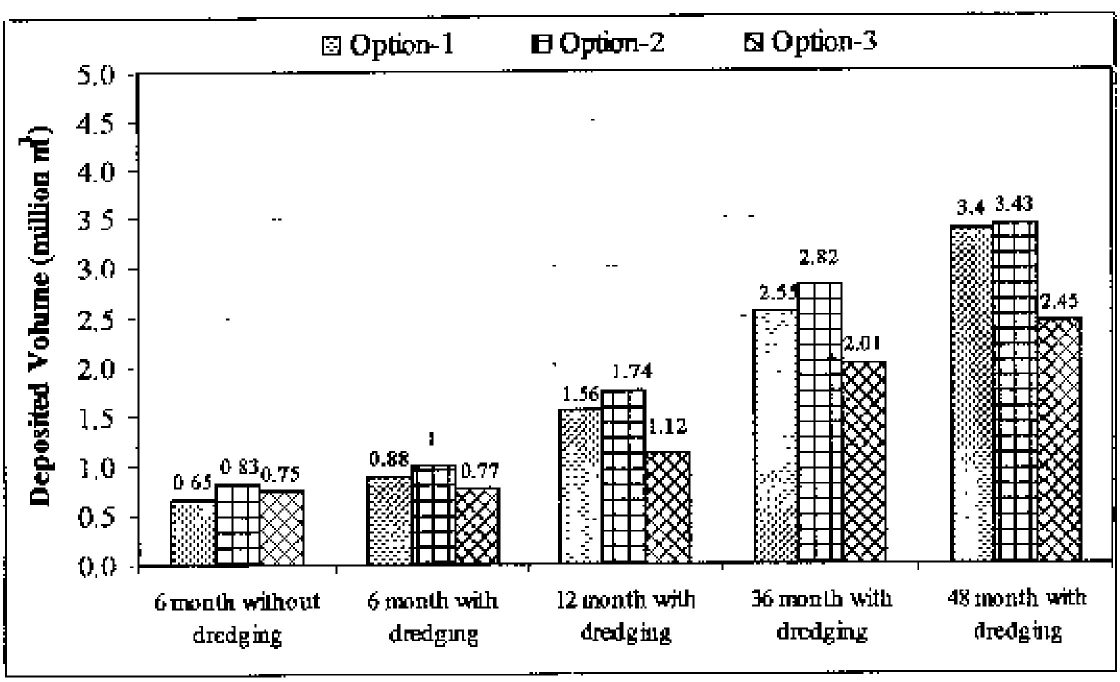


Figure 5.20: Net deposition volume at different options for Beel Kapalia.

5.5.2 Deposition area

From the simulated results six plots (Figures 5.21 to 5.26) of deposited area versus time have been prepared for each option in both beels. The plots are prepared for three level of deposition: net deposition greater than 0.5 m, net deposition greater than 1.0m and net deposition greater than 1.5 m. It is seen that maximum and minimum net deposition occurred for Option-2 and Option-3, respectively.

Figures 5.21 and 5.22 for Option-1 and Option-2 in East Beel Khuksia show that for deposition depth greater than 1.0 m and 1.5 m, sediment deposition does not increase significantly after almost 36 months. But further deposition will occur under 48 months in areas where the net deposition depth is greater than 0.5m. In Option-3, all areas where the net depositiou depth is grearer than 0.5 m, 1.0 m and 1.5 m, continue to increase even after 48 months. Similar situations have been observed from Figures 5.24 to 5.26 for Beel Kapalia.

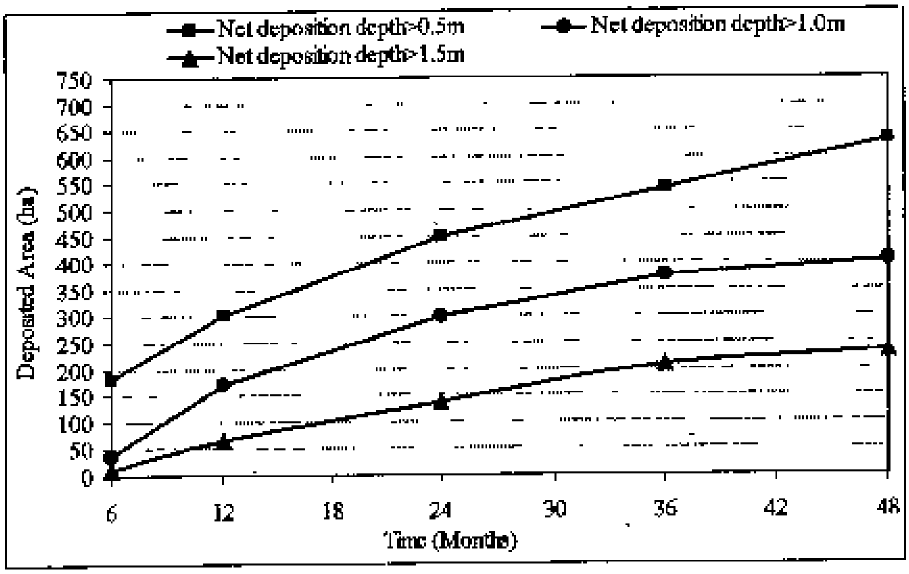


Figure 5.21. Deposited area plot for Option-1 of East Beel Khuksia.

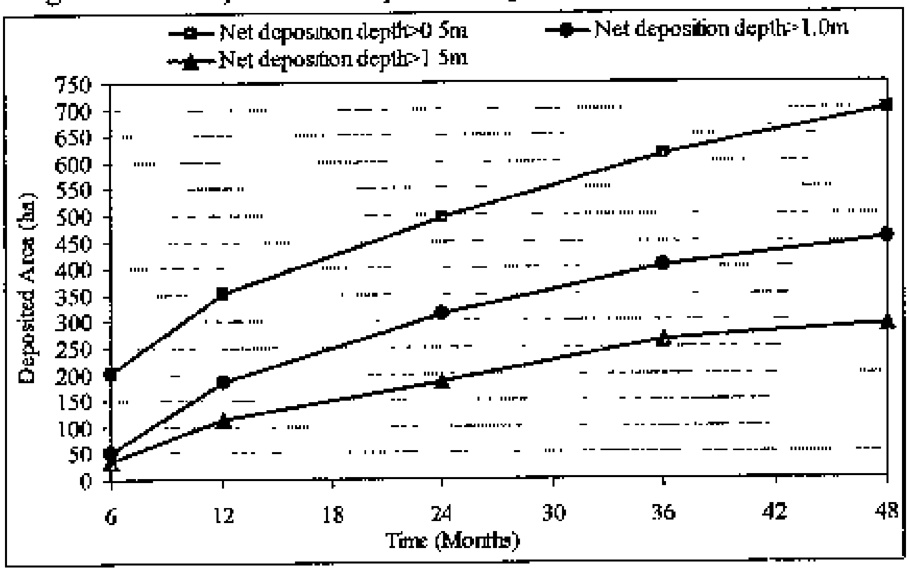


Figure 5.22: Deposited area plot for Option-2 of East Beel Khuksia.

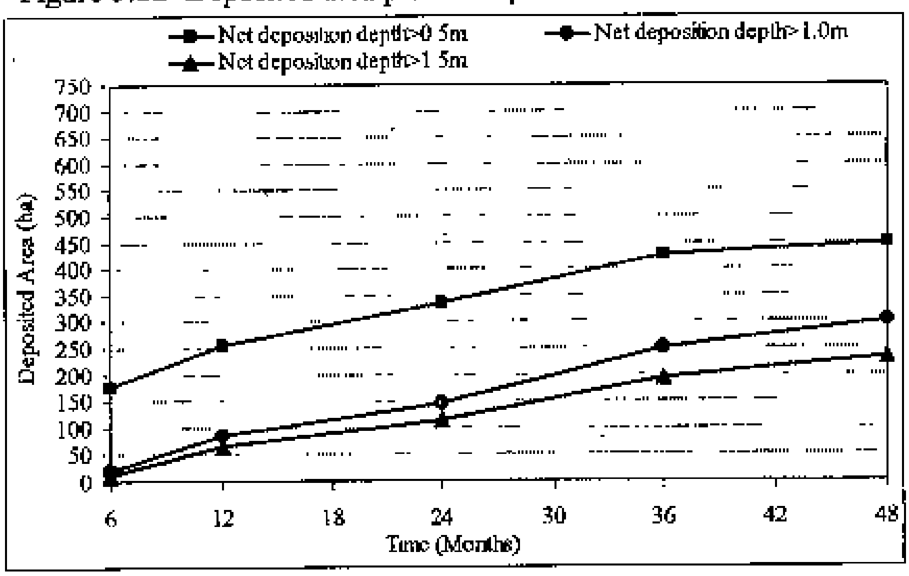


Figure 5.23: Deposited area plot for Option-3 of East Beel Khuksia.

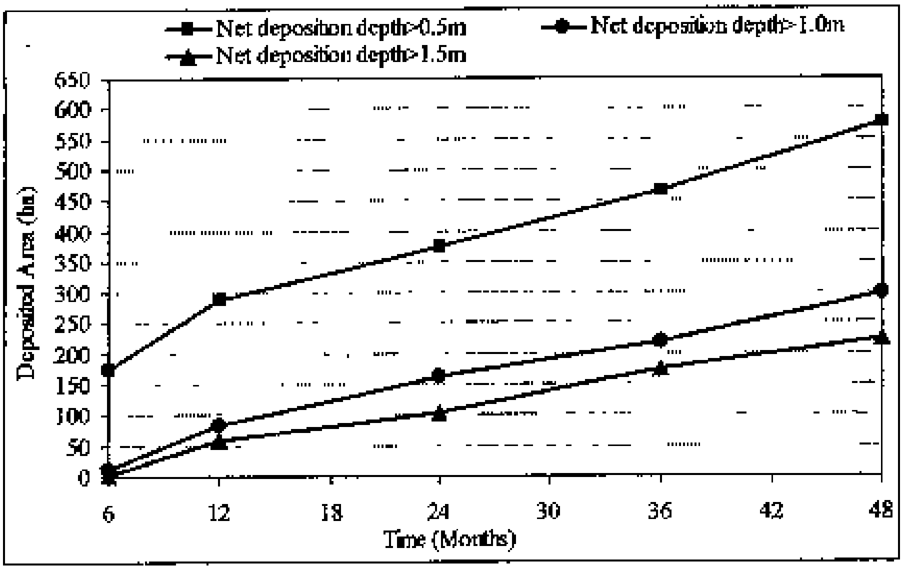


Figure 5.24: Deposited area plot for Option-1 of Beel Kapalia.

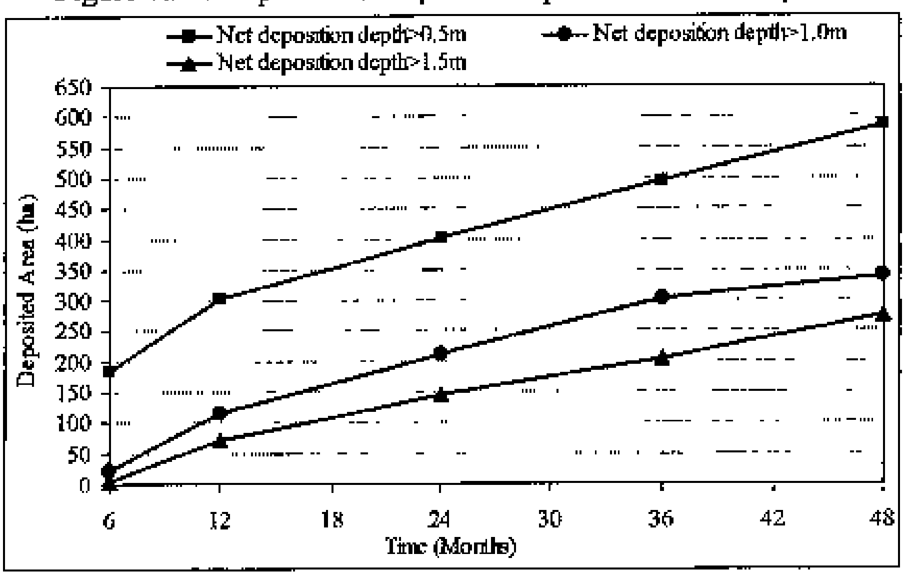


Figure 5.25: Deposited area plot for Option-2 of Beel Kapalia

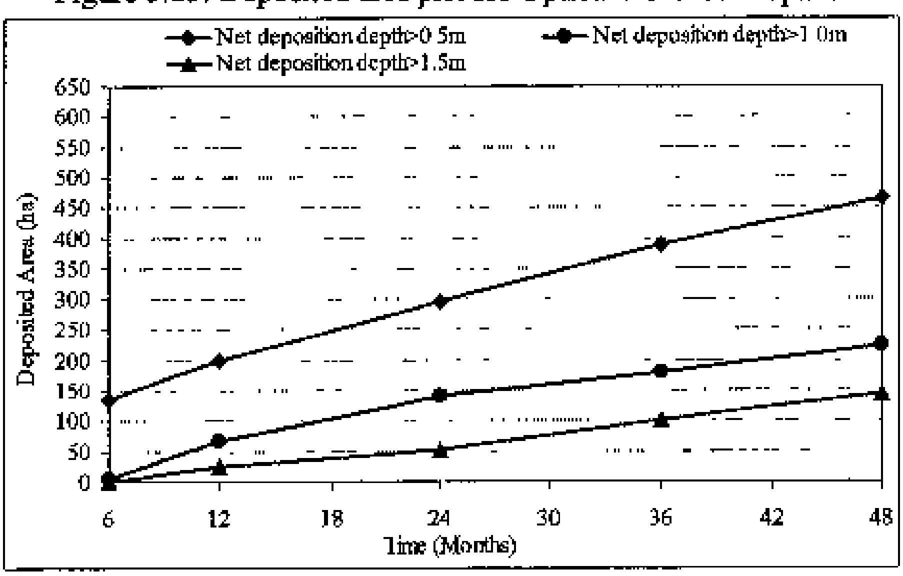


Figure 5.26: Deposited area plot for Option-3 of Beel Kapalia

5.5.3 Different levels of deposition

From the simulated results six plots (Figure 5.27 to 5.32) of percentage of deposited volume above a specific elevation have been prepared for each option in both beels. All plots are prepared for deposition after 6 months, 1year, 2 years, 3 years and 4 years with dredging of khals. It is seen that maximum and minimum deposition occurred for Option-2 and Option-3, respectively.

5.6 Cost for Different Options

Much civil works are needed for the operation of tidal basins under TRM operation. Construction of peripheral embankment is essential to protect the homestead and crop lands from flooding In Beel Kapalia, link canal will disrupt the present communication in the Bhabodah area. As such, one single span 40 m steel Bailey bridge to be laid over cast-in-situ pile supported abutments is proposed for construction to maintain the existing communication link in the area. At the end of the operation of tidal basin the canal will be closed by closure dam after removing the Bailey bridge. Besides this a 37 m long seasonal earthen cross dam is also required to be constructed on Hari river at upstream of the off-take of the link canal to divert total tidal flow of the Hari river to the tidal basin and to stop intrusion of sediment laden water at upstream during operation of the tidal basin Dredging or re-excavation of khals is needed for uniform silt deposition in the tidal basin. Besides, compensation is required for the land owner of the beel.

5.6.1 Basis of cost estimation

The cost is based on rates of current Schedule of Rates of Jessore O & M Circle enforced from August, 2008. The rates of major items are shown in Table 5.3.

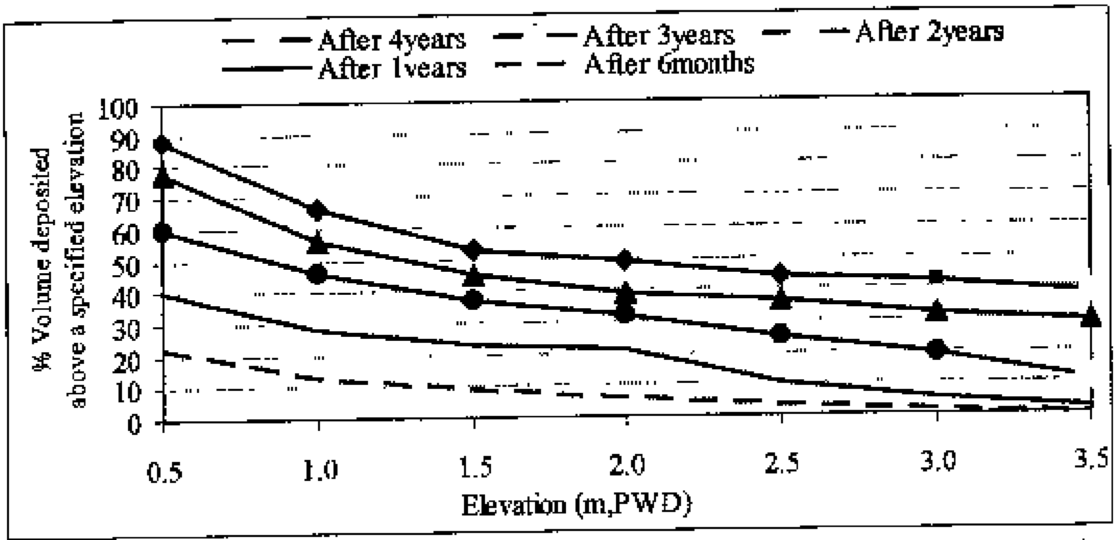


Figure 5.27 Deposited volume above different elevations for Option-1 of East Beel Khuksia.

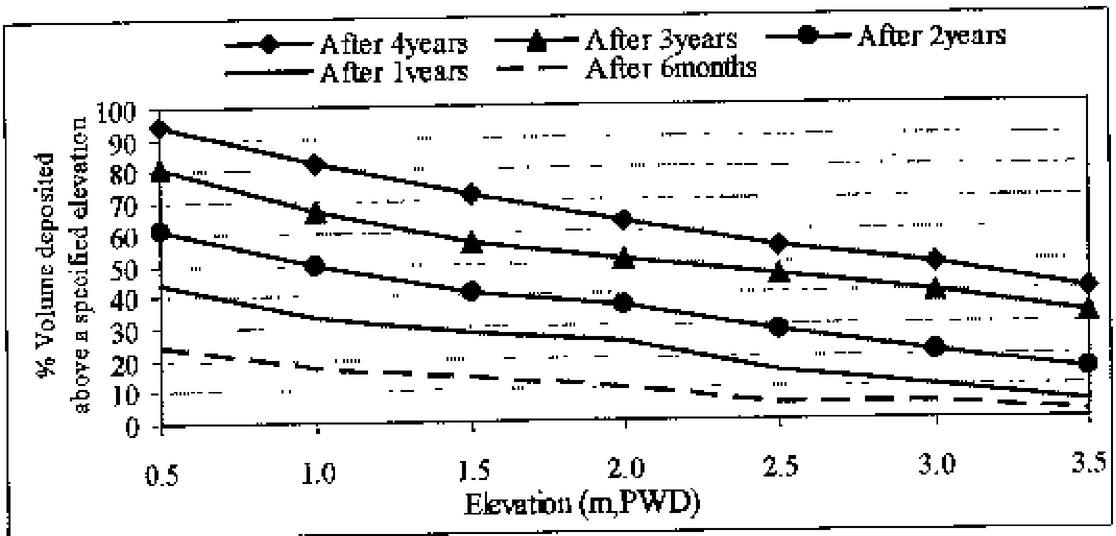


Figure 5.28: Deposited volume above different elevations for Option-2 of East Beel Khuksia.

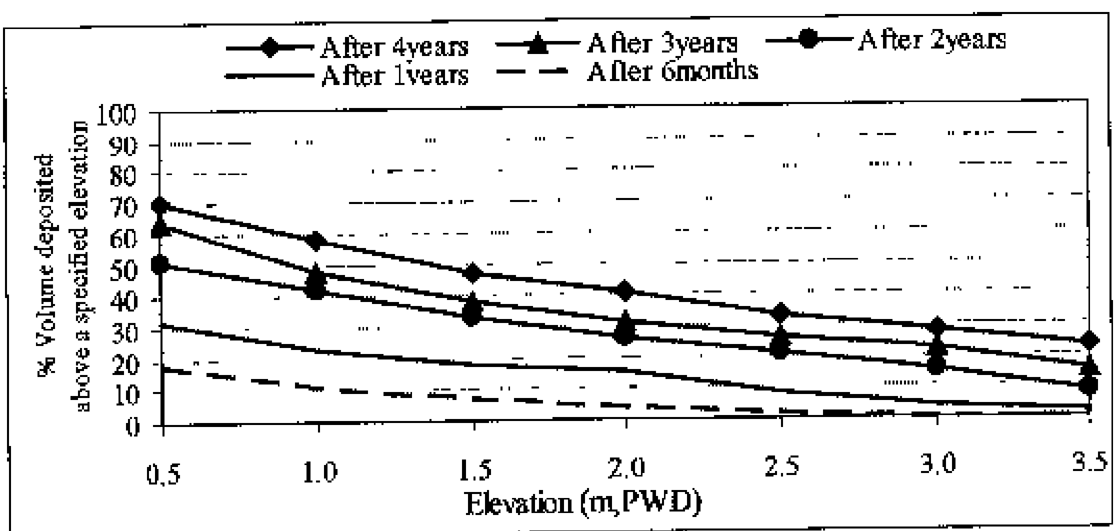


Figure 5.29. Deposited volume above different elevations for Option-3 of East Beel Khuksia.

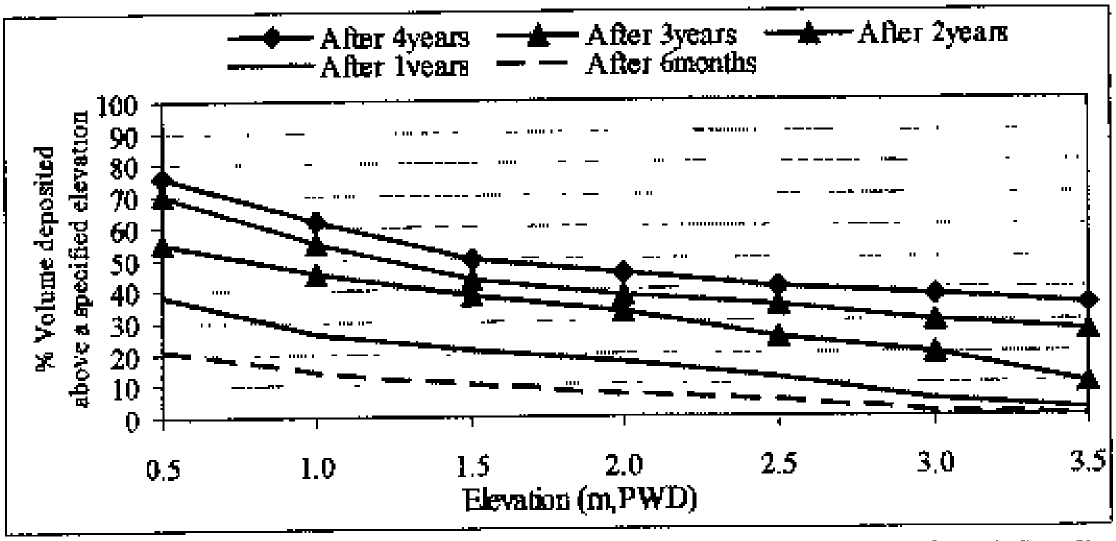


Figure 5.30: Deposited volume above different elevations for Option-1 of Beel Kapalia.

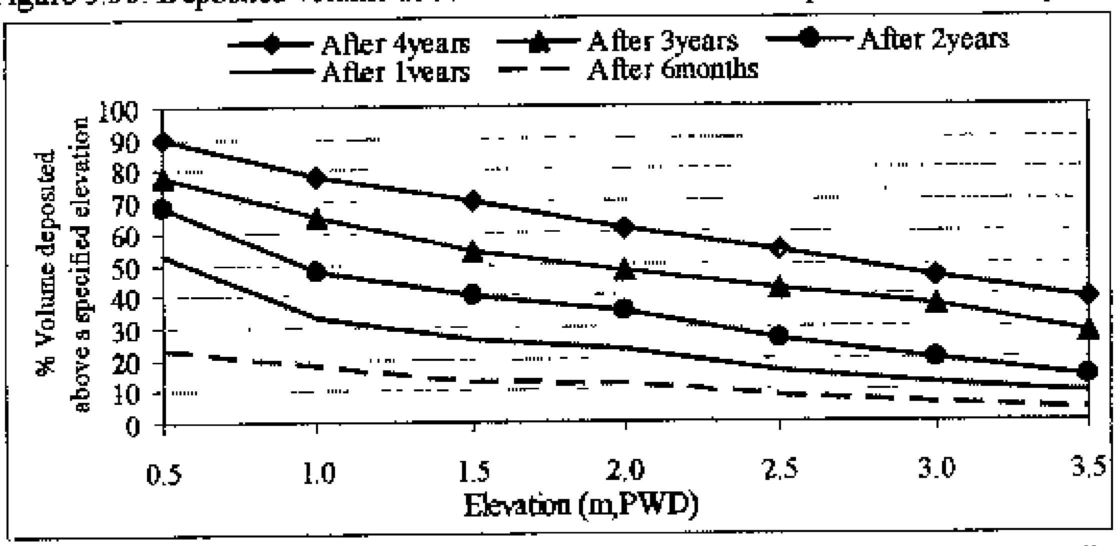


Figure 5.31: Deposited volume above different elevations for Option-2 of Beel Kapalia.

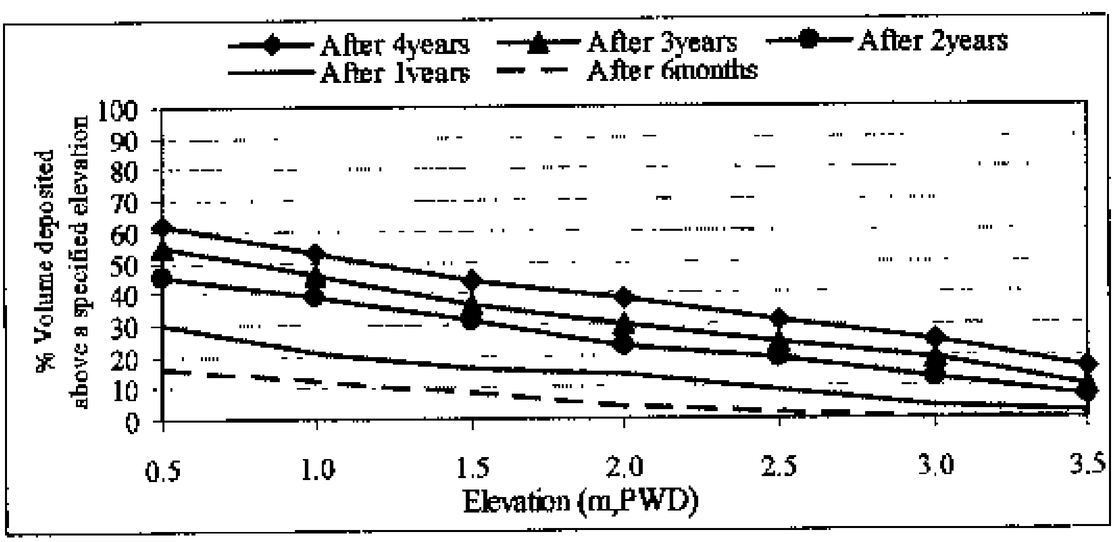


Figure 5.32: Deposited volume above different elevations for Option-3 of Beel Kapalia.

Table 5.3: Rates of major items of works.

Sl. No.	Item	Unit	Rate (Taka)
1	Earth work in excavation or re-excavation in channel/river in all kind of soil as per design with all leads and lifts and placing the spoil earth for construction of embankment/ring bundh/cofferdam	m^3	103.43
2	Earth work by manual labour for construction of embankment road (4m height)	m^3	69.83
3	Earth work by carried earth for construction of cross bundh (300 m to 1.0 km)	m^3	131.96
5	Mechanical dredging	m^3	140.00
6	Compensation for land per year	ha	33393.80
7	Drainage outlet (0 9 m diameter pipe sluice)	each	450000.00
8	Bailey Bridge (40 m)	each	6000000.00

5.6.2 Cost calculation and comparison

The indicative costs of all the works and activities essential for TRM operation have been considered to find out the total cost of the options for the East Beel Khuksia and Beel Kapalia. The total estimated cost of the three options for the two Beels are given in Figure 5 33. The detailed cost estimations for each beel are given in Appendix-G.

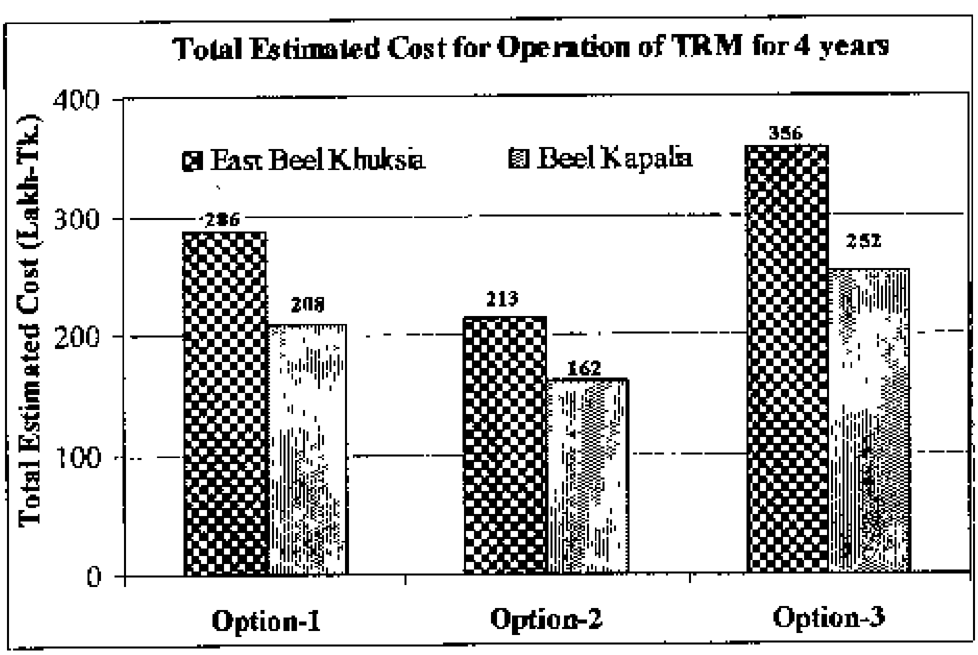


Figure 5.33 · Total estimated cost for the three options in the two beels.

5.7 Stakeholder Consultation for Option Selection

Stakeholder consultation was carried out to finalize the acceptable option(s) for sediment management inside the tidal basin. Discussion was held with different groups including farmers, fisher folks, day laborers and traders. Technical feasibility and economic analysis were presented in the discussion. People allow their land to be used for tidal basin operation hoping that the land will rise after a certain period. But their previous experience from Beel Kedaria and East Beel Khuksia was not good because sedimentation inside these two beel is not uniform. In Option-1 and Option-2 the sedimentation pattern inside the tidal basin is uniform. However, at least 2 million m^3 tidal prism is required for sustainability of the Hari river. If the area of the tidal basin is more, then tidal prism will in crease. In Option-1 the area of the tidal basin is one-third of its original area. Most of the stakeholders opine that in Option-1, minimum tidal prism will not attain. But in Option-2 the area of the tidal basin is not minimized. So in this option, there is no question for the generation of required tidal prism. In option-3, the sedimentation pattern is not uniform. After detailed discussions and consideration of different aspects of sediment management including the cost estimates for different options, it is apparent that Option-2 is acceptable by most stakeholders in the area.

From the simulation results it is observed that for uniform sedimentation inside the tidal basin dredging of the khals inside the tidal basin is essential after four months. Most of the stakeholders opine that re-excavation or dredging of khals inside the tidal basin should be done with the participation of the local stakeholders. The dredged soil should be stored in the remote portion of the beel where sedimentation is less.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

TRM is an eco-technological concept designed to solve the water-logging problem while improving the environment Uniformly raising the land inside a beel and maintaining proper drainage capacity of the river are the two main objectives of TRM. From field visits and monitoring results it is observed that sedimentation inside the beel is not uniform in Beel Kedaria and East Beel Khuksia. This happened due to the lack of social and technical limitations during TRM operation.

In this study sediment management options for uniform silt deposition in the tidal basins have been identified. Three options for sediment management have been identified through FGDs and consultation with the local stakeholders. In Option-1, each beel is divided into three compartments separated by embankment around the compartment and allowing sedimentation in the compartments one after another. In Option-2, embankments are constructed along both banks of the main khals through the beel and sedimentation in the basin is allowed by cutting the embankment part by part gradually from upstream to downstream. In Option-3, all existing khals are connected with the river at the same time by constructing link canals, i.e allowing sedimentation in the whole basin at the same time. Technical feasibility of these options has been assessed by a cohesive sediment transport model using MIKE21 FM modeling system.

In Option-1, after one year without dredging of khals and with dredging of khals, the net sediment deposition volumes are 1.63 and 1.88 million m^3 respectively in East Beel Khuksia, and 1.02 and 1 56 million m^3 respectively in Beel Kapalia. Simulation results indicate that if dredged the khals after four months, more sediment is deposited. Besides, more uniform sedimem deposition is observed inside the tidal basin after dredging of khals. Net deposition volume is higher in East Beel Khuksia than in Beel Kapalia because East Beel Khuksia is located at the downstream of the Hari river. Similar results were obtained for the other two options.

The net deposition volume after 4years in the Option-1, Option-2 and Option-3 are 3.58, 4.51 and 2.61 million m^3 respectively in East Beel Khuksia and 3.40, 3.43 and 2.45 million m^3 respectively in Beel Kapalia. Maximum deposition was observed for Option-2.

The total estimated cost for the three options are Tk. 28,58,48,912 , Tk. 21,34,55,375 and Tk. 35,58,37,393 respectively in East Beel Khuksia and Tk. 20,79,89,120 , Tk. 16,16,72,991 and Tk. 25,21,70,405 respectively in Beel Kapalia. This indicates that minimum cost is required for implementing TRM in Option-2 in both beel.

Stakeholder consultation was carried out to finalize the acceptable option(s) for sediment management inside the tidal basin. Discussion was held with different groups including farmers, fisher folks, day labours and traders. Technical feasibility and economic analysis of these options were considered during these discussions. After detailed discussions and consideration of different aspects of sediment management, it appears that Option-2 is preferred by most stakeholders in the area.

6.2 Recommendations

Based on the present study, the following recommendations are made:

- To calibrate and verify the numerical model, more detailed observed data of siltation inside the tidal basin is required. Long term sediment concentration measurement programs may be undertaken to support similar studied in future.
- To assess the effectiveness of TRM operation in terms of sedimentation inside a tidal basin, accurate measurement of sedimentation is essential. From direct field measurement it is possible to quantify the sedimentation volume. This will also help to investigate the sediment distribntion over the entire basin area

- Due to time constraints the model has been used for simulation for a period of four years. Further simulation may be carried out to determine the actually required life time of a tidal basin.
- Parts of the beel away from the khals were not raised. In those parts new canals may be constructed. The technical feasibility of this can be assessed by using the present cohesive sediment transport model.
- Similar studies may be carried out in other areas of the coastal region to investigate the regional variability.

REFERENCES

Williams, C. A (1819), History of the Rivers in the Gangetic Delta, Bengal Secretariat Press, Calcuta.

CEGIS (2002), Monitoring and Integration of the Environmental and Socio-economic Impacts of Implementing the Tidal River Management Option to Solve the Problem of Drainage congestion in KJDRP Area, Final Report, Part A: Monitoring, Khulna-Jessore Drainage Rehabilitation Project, Bangladesh Water Development Board.

CEGIS (2002a), Monitoring and Integration of the Environmental and Socio-economic Impacts of Implementing the Tidal River Management Option to Solve the Problem of Drainage congestion in KJDRP Area, Final Report, Part B: MIS, Khulna-Jessore Drainage Rehabilitation Project, Bangladesh Water Development Board.

CEGIS (2002b), Monitoring and Integration of the Environmental and Socio-economic Impacts of Implementing the Tidal River Management Option to Solve the Problem of Drainage congestion in KJDRP Area, Final Report, Part C: IWRM Plan, Khulna-Jessore Drainage Rehabilitation Project, Bangladesh Water Development Board.

CEGIS (2002c), Monitoring and Integration of the Environmental and Socio-economic Impacts of Implementing the Tidal River Management Option to Solve the Problem of Drainage congestion in KJDRP Area, Final Report, Part D: WMA-O&M Plan, Khulna-Jessore Drainage Rehabilitation Project, Bangladesh Water Development Board.

Chambers, R. (2002). Participatory workshops, A source book of 21 sets of ideas and activities, London, Earthscan Publications Ltd.

Choudhury, S.U. and Khan, Z.H. (2007), Case studies for Sustainable Drainage Improvement under Tidal River Management in Khulna Jessore area, International Conference on Water & Flood Management (ICWFM-2007), 12-14 March 2007, Dhaka, Bangladesh.

Coleman, J.M. (1968), Brahmaputra River Channel Processes and Sedimentation, International Journal of Geotectonics and Geologyand Physics of the Interior of the Earth. Vol. 3,pp.132–145.

DHI Water and Environment (2007), MIKE 21 FLOW MODULE, Mud Transport Module User's Guide, Danish Hydraulic Institute.

EGIS (1998), Environmental Impact Assessment and Social Impact Assessment of Khulna-Jessore Drainage Rehabilitation Project, Final Report, Water Resources Planning Organization.

Green, S. (1974), Mills Admits Being Present during Tidal Basin Scuffle (http://www.washingtonpost.com/wp-srv/local/longterm/tours/scandal/tidalbas.htm), Washington Post, Retrieved 2009-04-05.

IWM (2009), Mathematical Modelling Study for Planning and Design of Beel Kapalia Tidal Basin, Final Report, Bangladesh Water Development Board.

IWM (2007), Monitoring the Effects of Beel Khuksia TRM Basin and Dredging of Hari River for Drainage Improvement of Bhabodah Area, Final Report, Bangladesh Water Development Board.

IWM (2005), Monitoring of Hydrological and Hydraulic Parameters on Tidal River Management under KJDRP Area, Final Report, Bangladesh Water Development Board.

IWM (2002), Special Monitoring of Rivers and Tidal Basins for Tidal River Management, Final Report (Volume 1: Main Report), Bangladesh Water Development Board.

O'Brien, M.P. (1931), Estuary Tidal Prism Relater to Entrance Areas, Civil Engineering, Vol.1, No. 8, p 738.

O'Brien, M.P. (1969), Equilibrium Flow Areas of Inlets on Sandy Coasts, Proc ASCE, Journal, waterways and Harbours Div., Vol.95, No. WWI, p 43-52.

Rahman, R. (2008), Investigation into Replicability of Good Practices in Flood Management, Final Report, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology.

Sarker, M.H. (2004), "Impact of Upstream Human Interventions on the Morphology of the Ganges-Gorai System", The Ganges Water Diversion: Environmental Effects and Implications, M.M. Qader Mirza (ed.), Water Science and Technology Library Book Series, Springer Netherlands, Vol. 49, pp. 49-80.

SMEC (2002), Khulna Jessore Drainage Rehabilitation Project, Project Completion Report (Final), Bangladesh Water Development Board.

SMEC (1997), Khulna-Jessore Drainage Rehabilitation Project, Feasibility Study Report for Overall Drainage Plan, Bangladesh Water Development Board.

SMEC (1997a), Khulna-Jessore Drainage Rehabilitation Project, Sediment and River Morphology Study, Bangladesh Water Development Board.

Haskoning and Associates (1993), Second Coastal Embankment Rehabilitation Project, Volume 1: Executive Summary and Main Report, Bangladesh water Development Board.

APPENDIX A
Checklist for Focus Group Discussion

Socio-Technical Assessment of Sediment Management Options in Tidal Basins in Southwestern Bangladesh

1. Occupation group:

2. Number of Participants:

3. Name of the Participants:

   i)
   ii)
   iii)
   iv)
   v)
   vi)
   vii)
   viii)

4. Location of FGD:.......................................Village.......................................

   Union...................................Upazilla..................................District: Jessore

5. What should be the options for uniform sediment deposition into tidal basin?

6. Is compensation is required or not?

7. If compensation is required what should be the rate and mechanism

8. What are the obstacles against uniform sediment deposition inside the tidal basin?

9. Is there any conflict between farmers and fishermen?

10. What should be the probable alternative jobs opportunity for the landless and fishermen?

APPENDIX B

DEM and Area Elevation Curve of East Beel Khuksia and Beel Kapalia

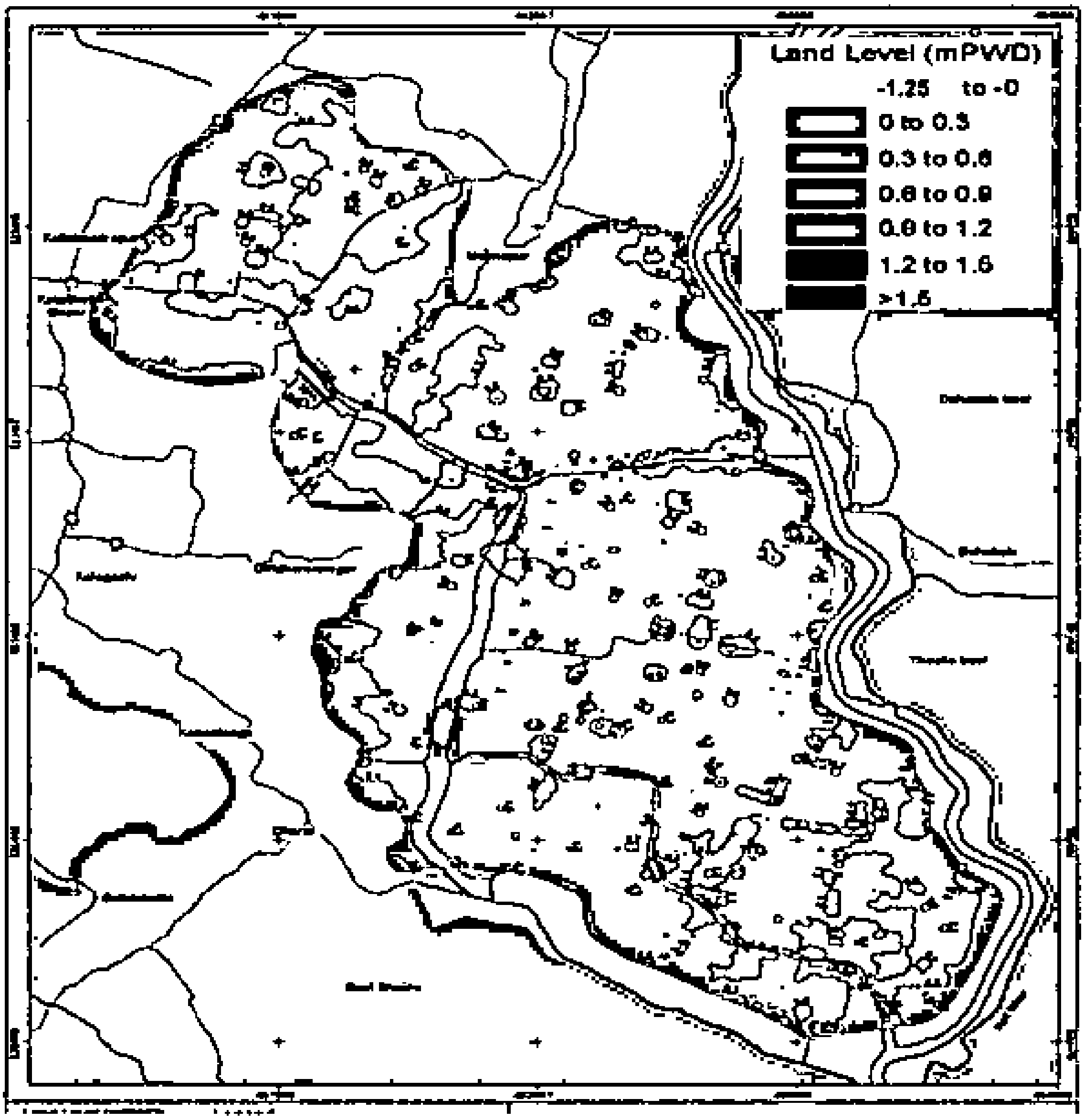


Figure B-1: Bottom Topography of East Beel Khuksia.

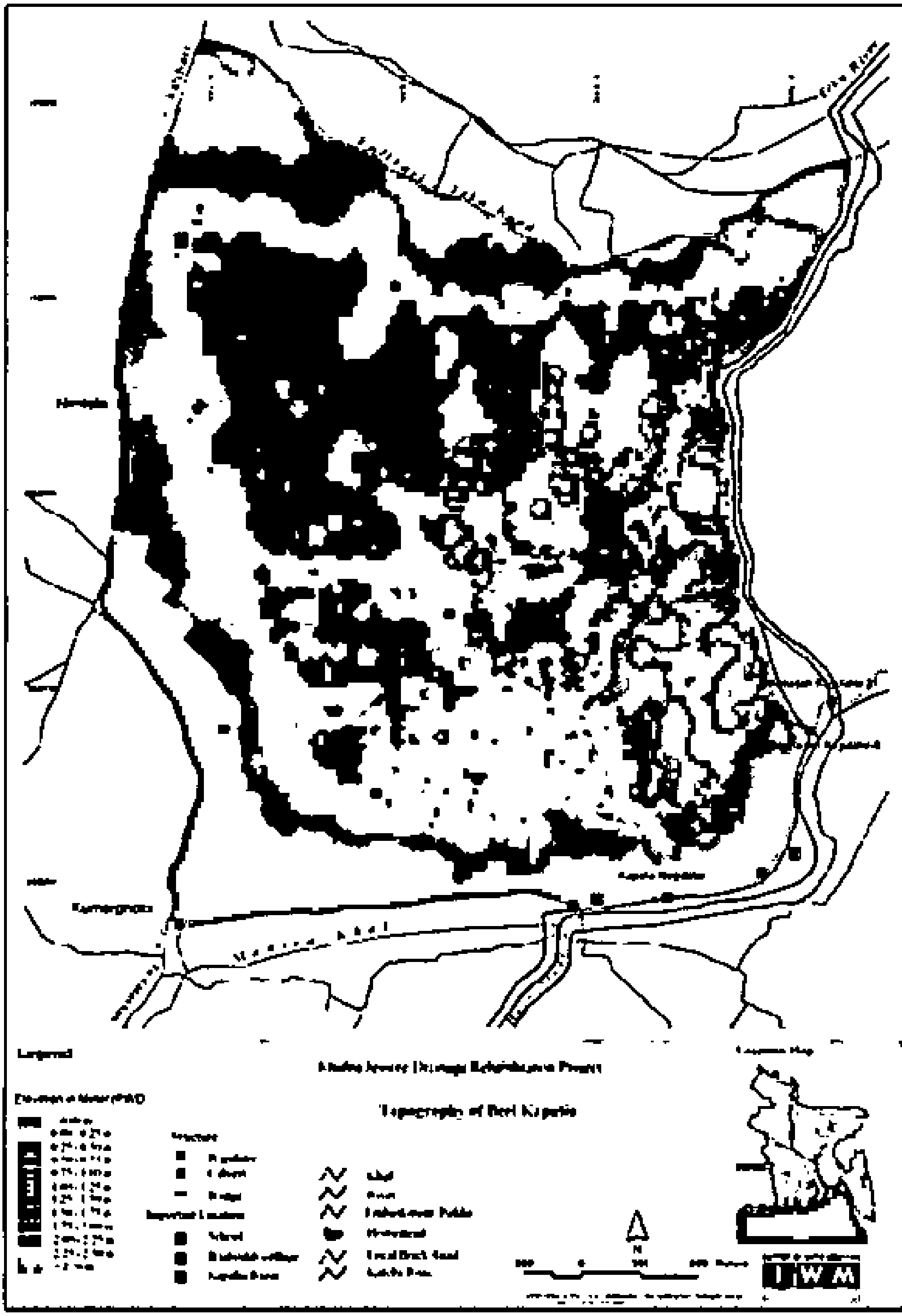


Figure B-2: Bottom topography of Beel Kapalia.

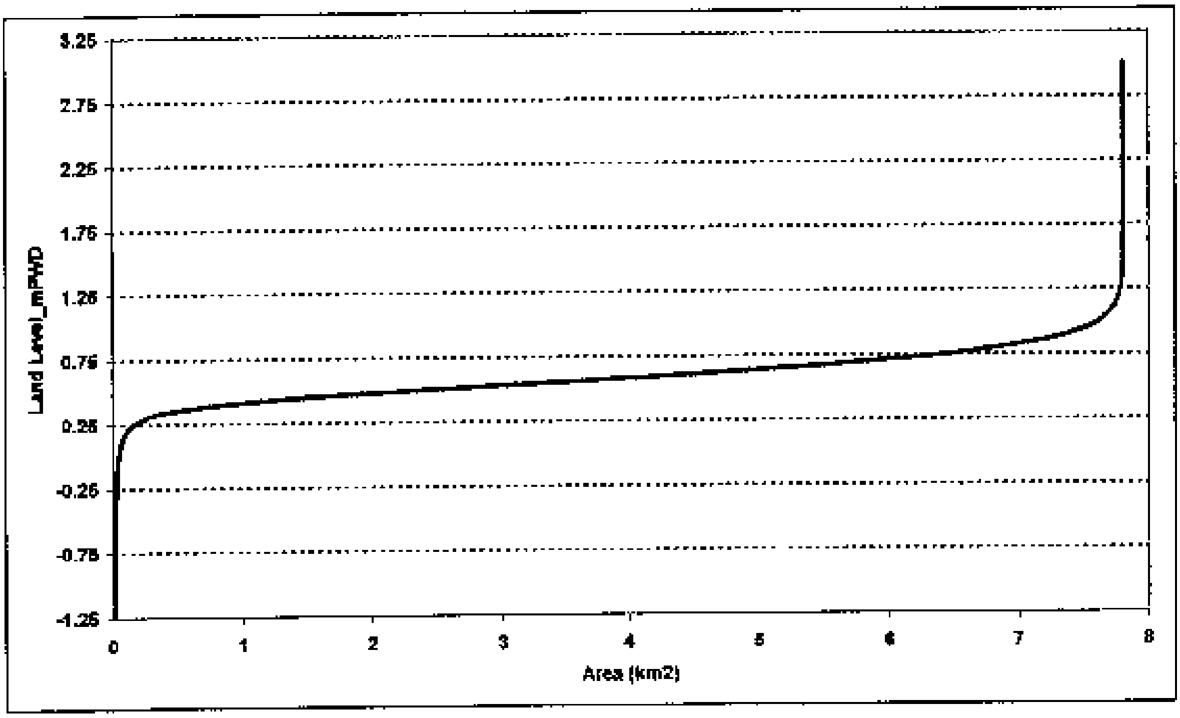


Figure B-3: Area-elevation curve of East Beel Khuksia.

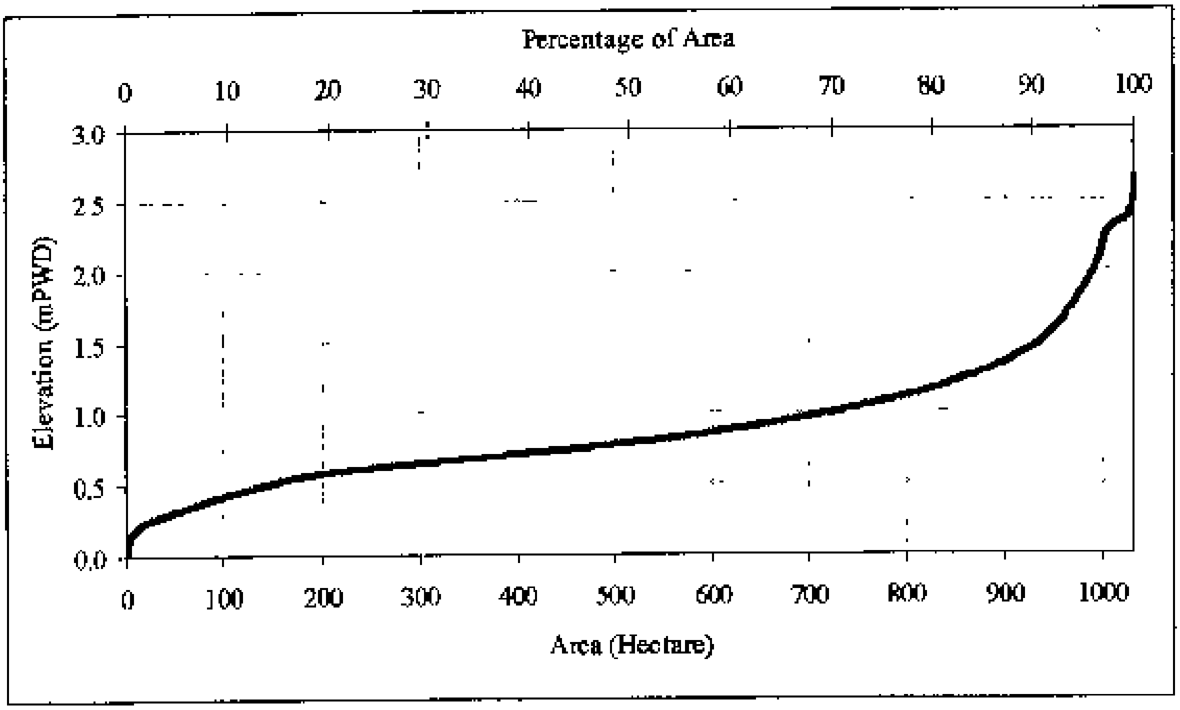


Figure B-4: Area-elevation curve of Beel Kapalia.

APPENDIX C

Water Level and Discharge

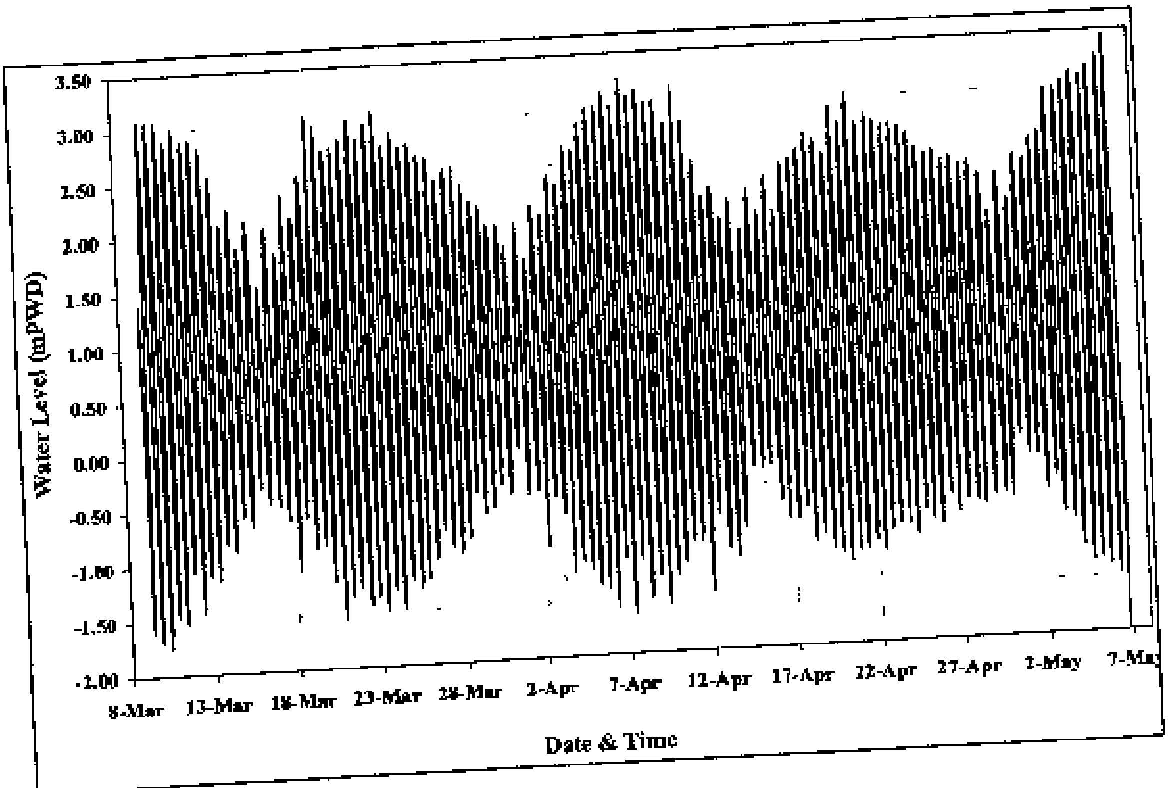
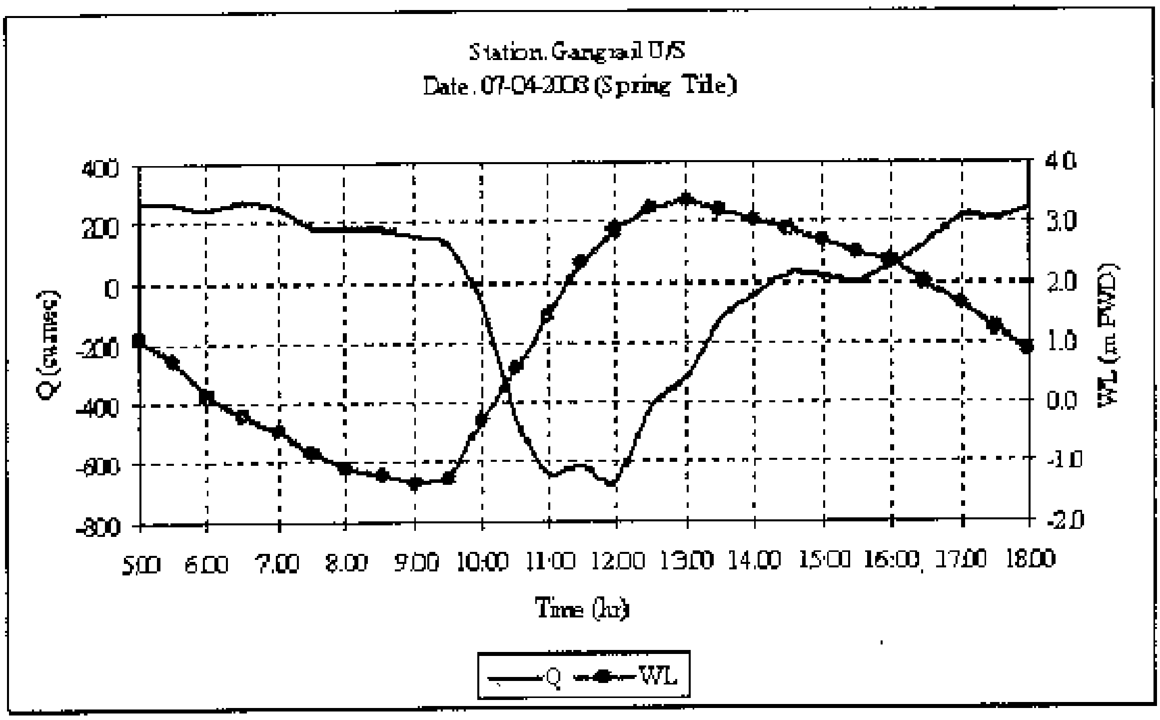


Figure C-1: Water Level hydrograph at Kanchan Nagar in the Gengrail River.



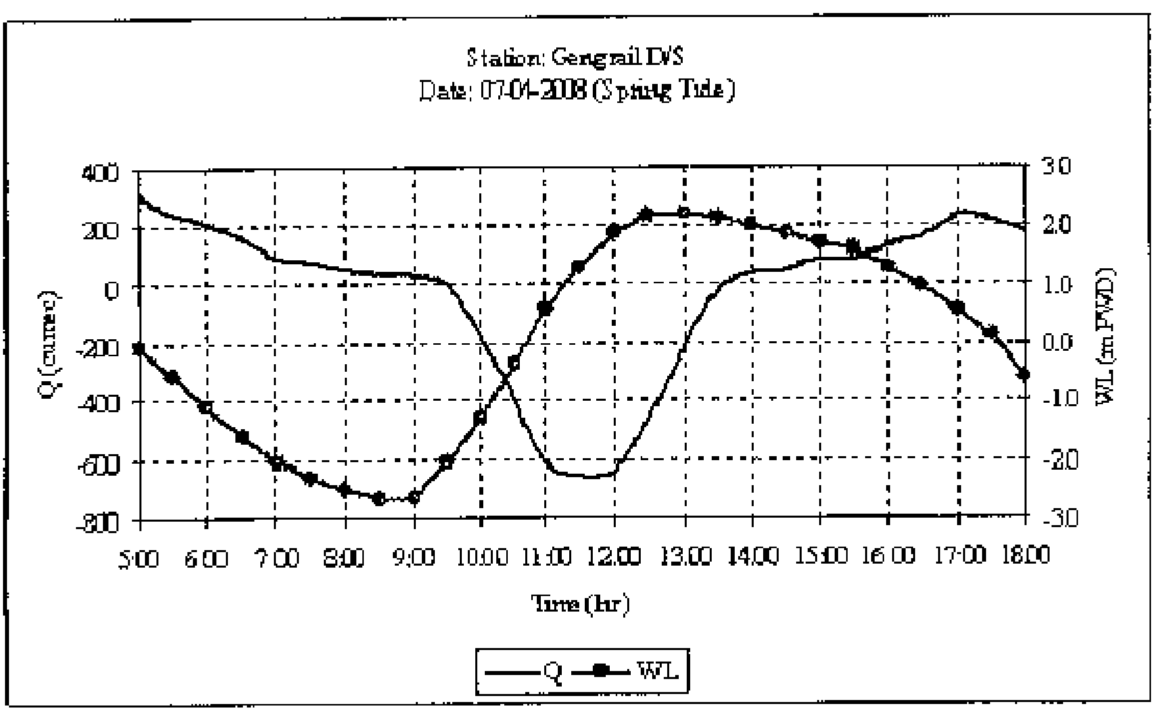
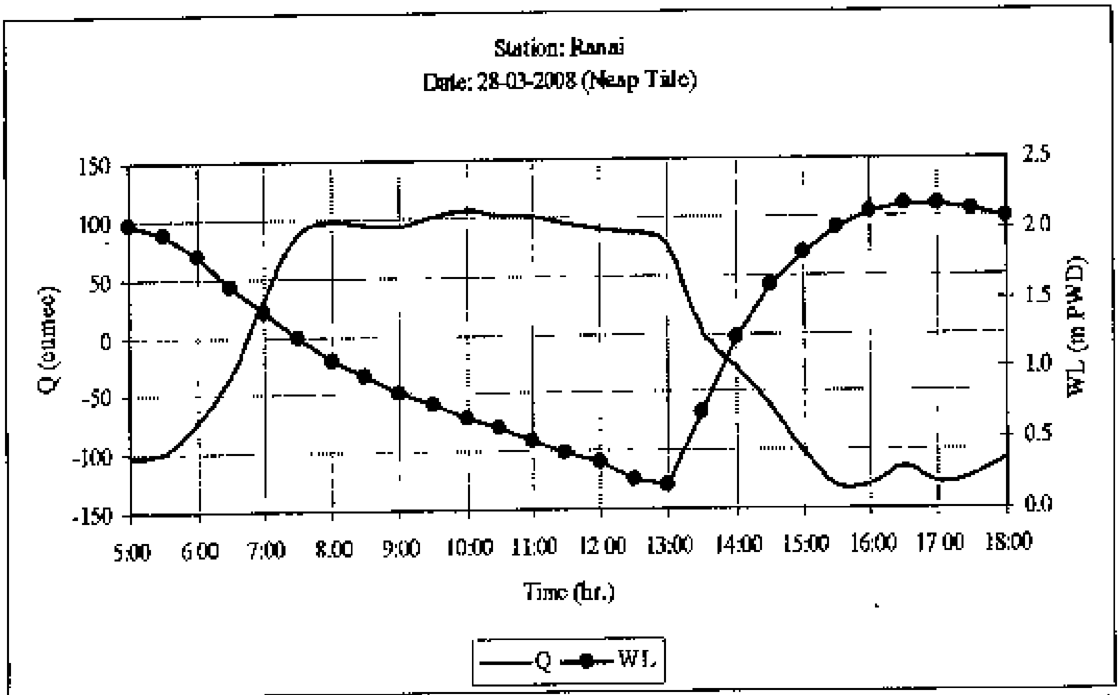


Figure C-2: Water Level and Discharge profile in the Gengrail river.



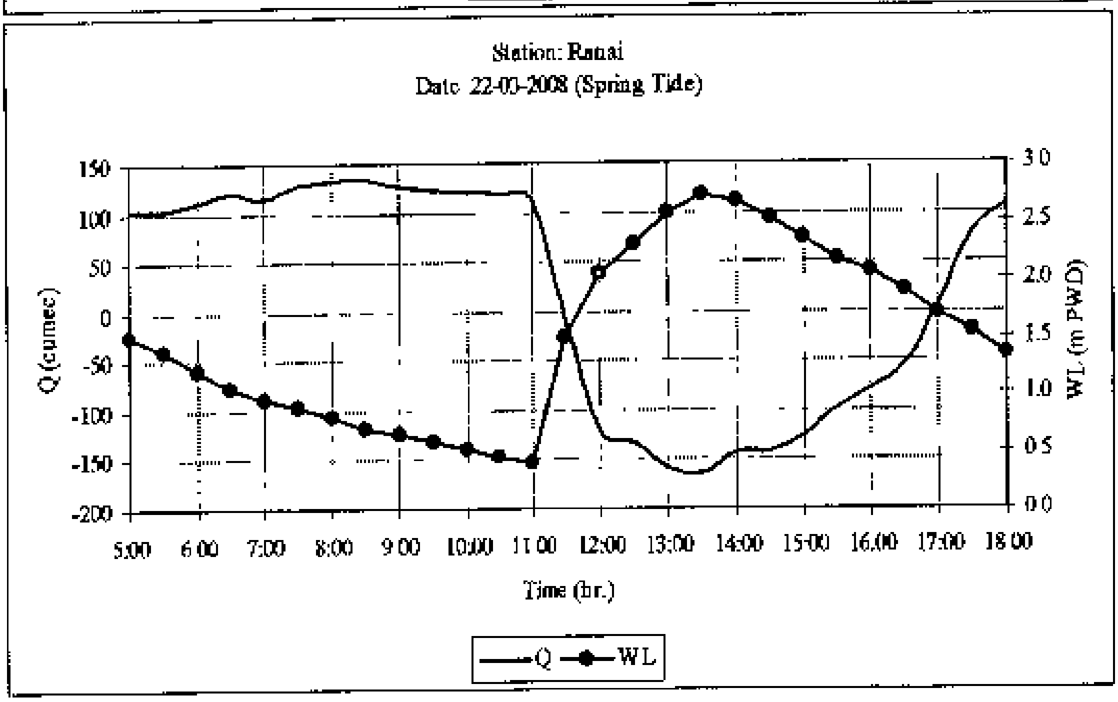
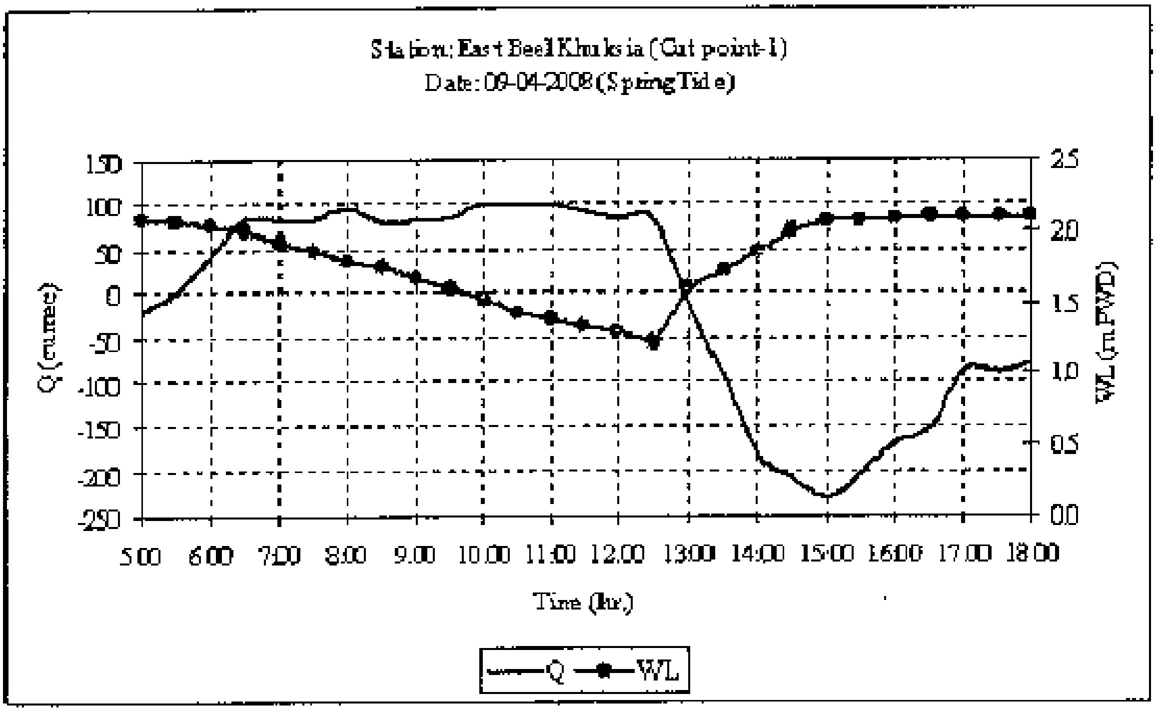


Figure C-3: Water Level and Discharge profile at Ranai in the Hari river



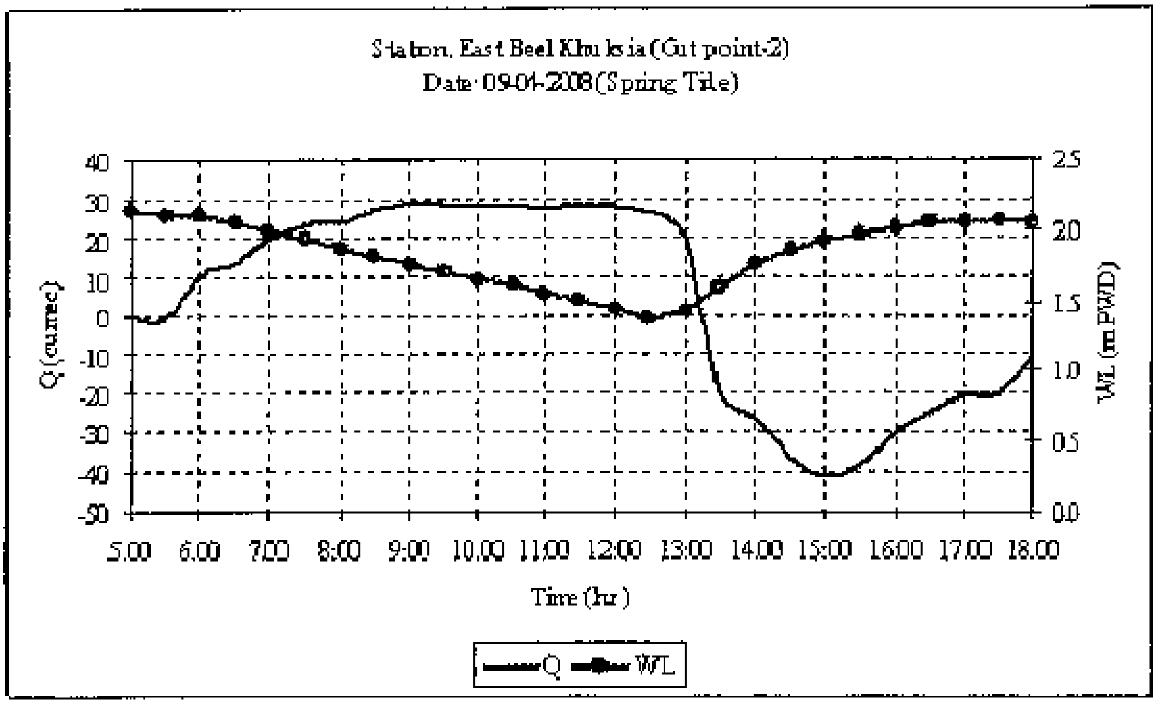
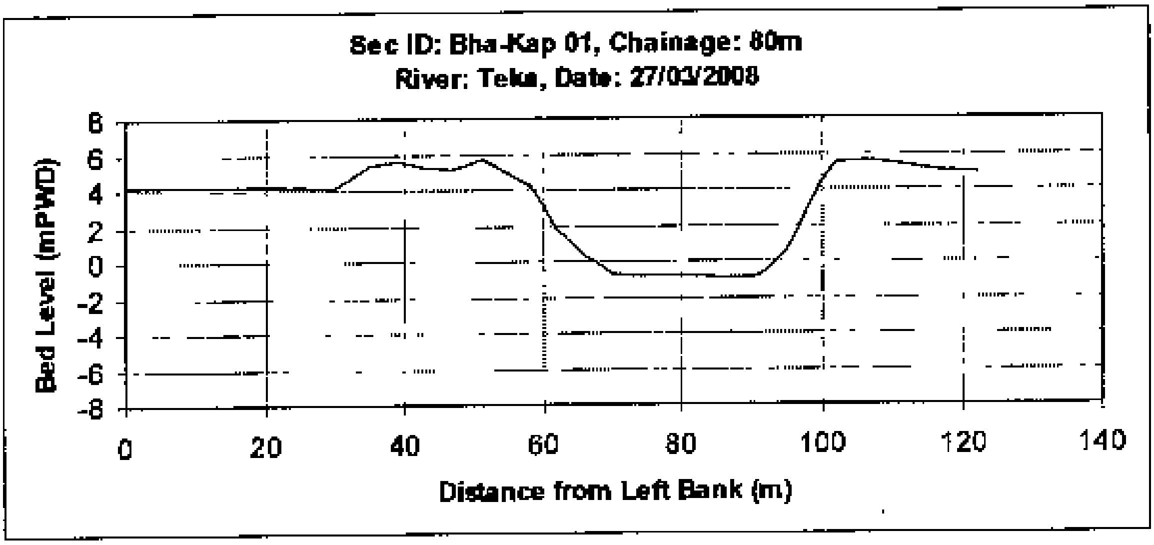
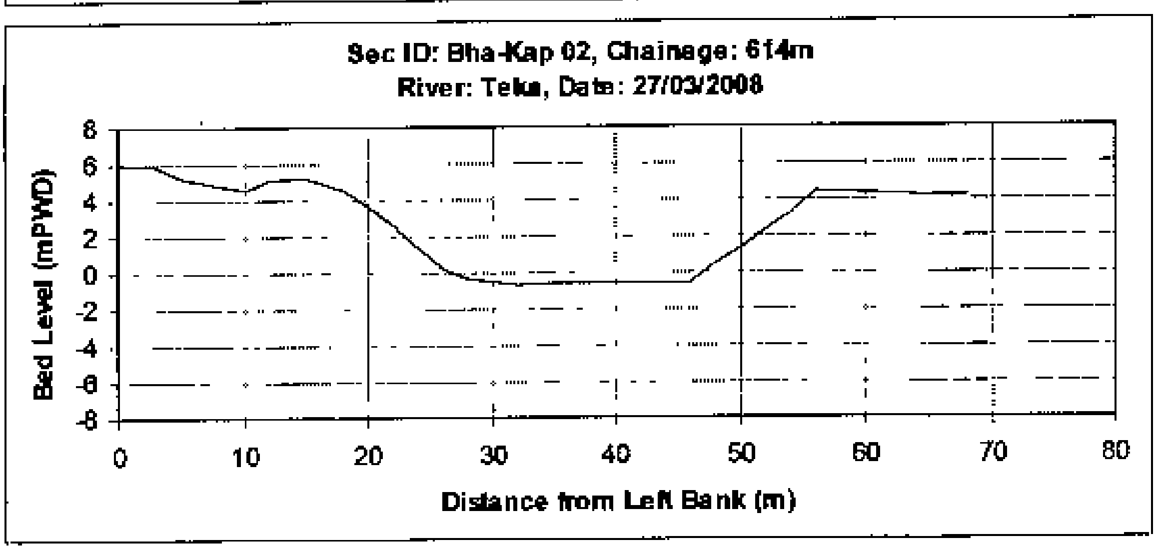


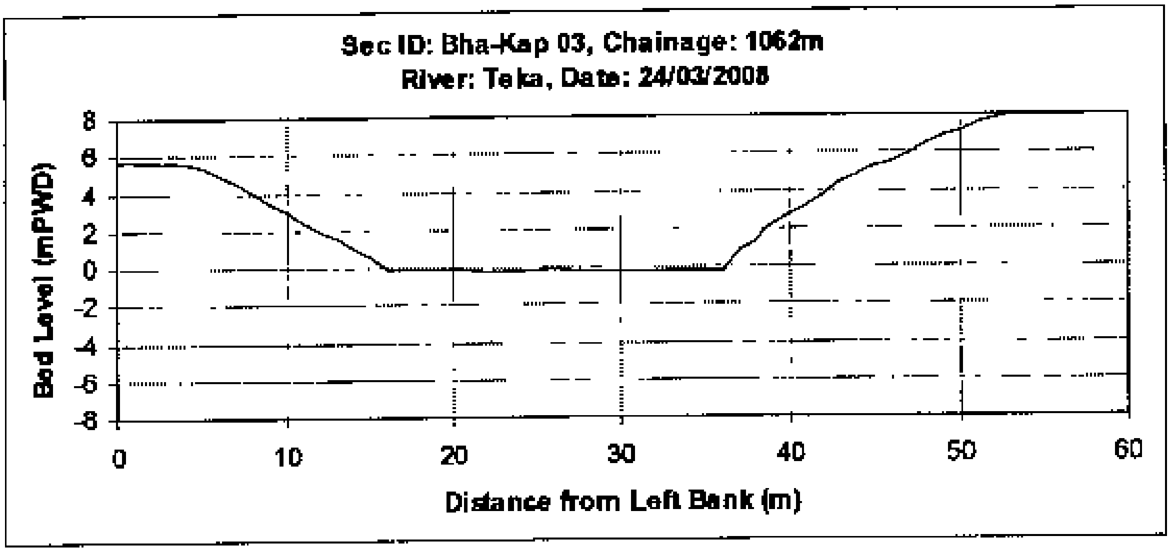
Figure C-4. Water Level and Discharge profile at link canal in the East Beel Khuksia tidal basin in the Hari river.

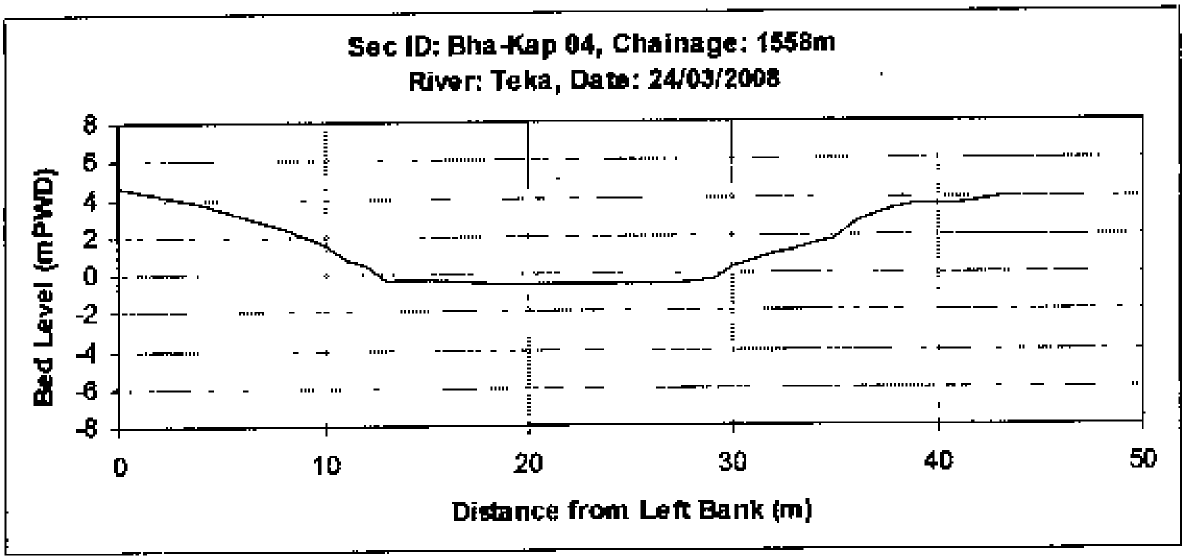
APPENDIX D

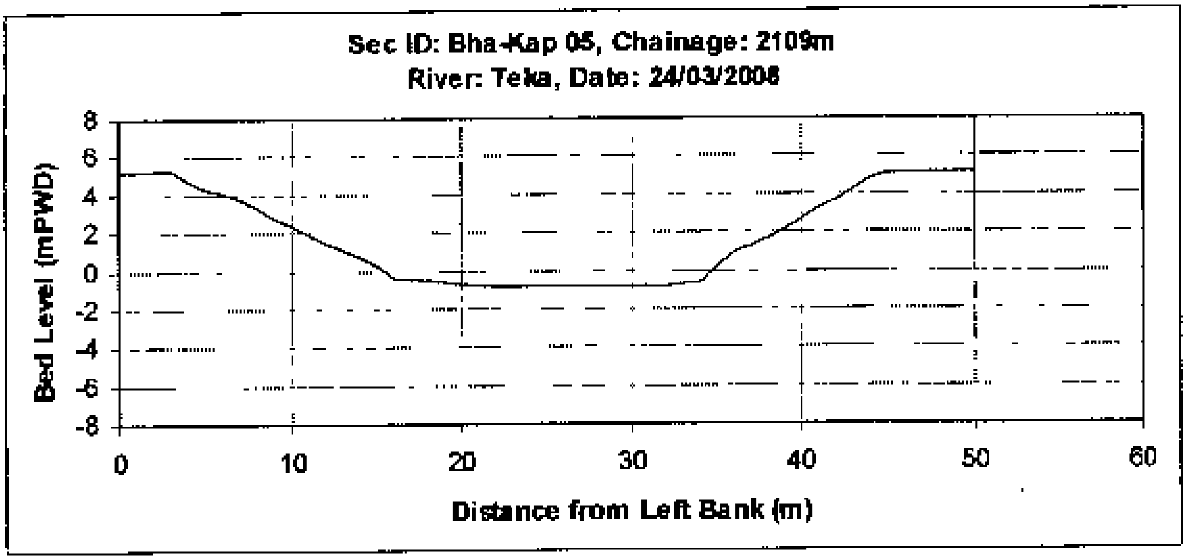
Cross sections of Rivers

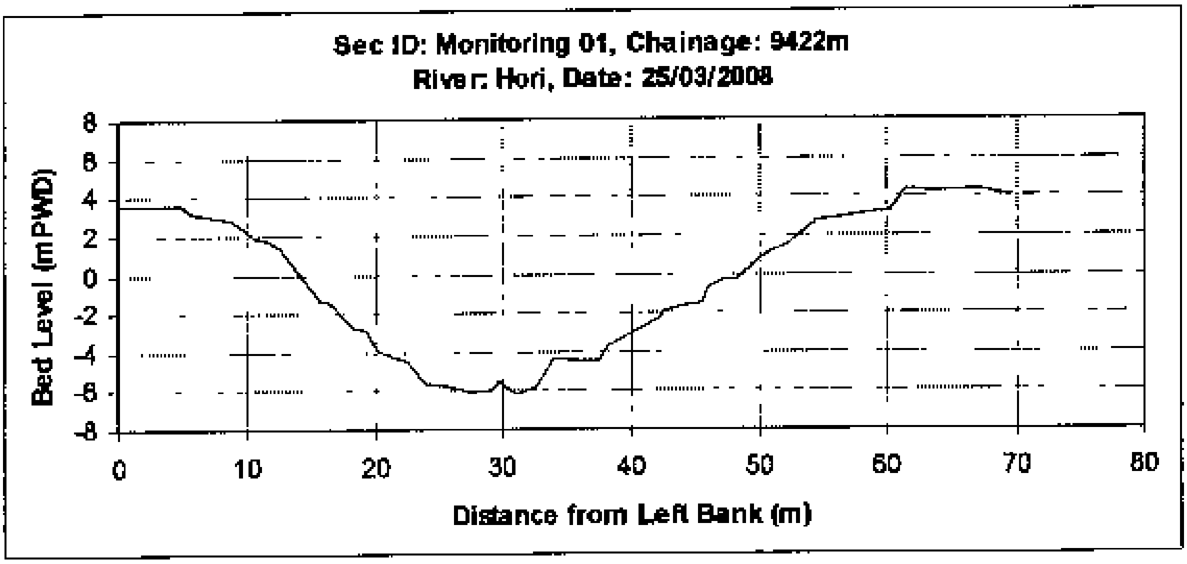


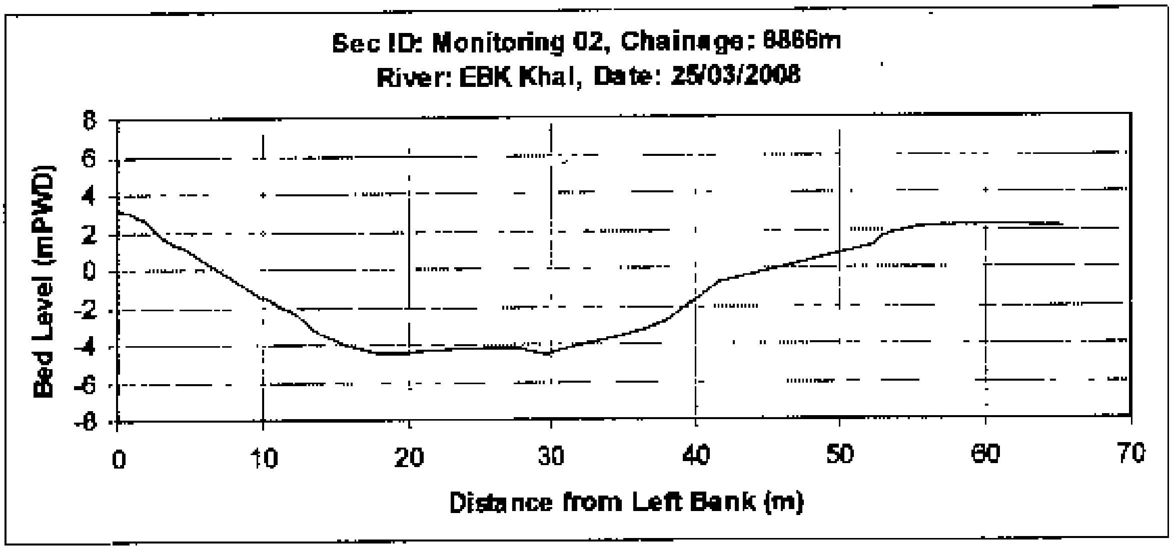


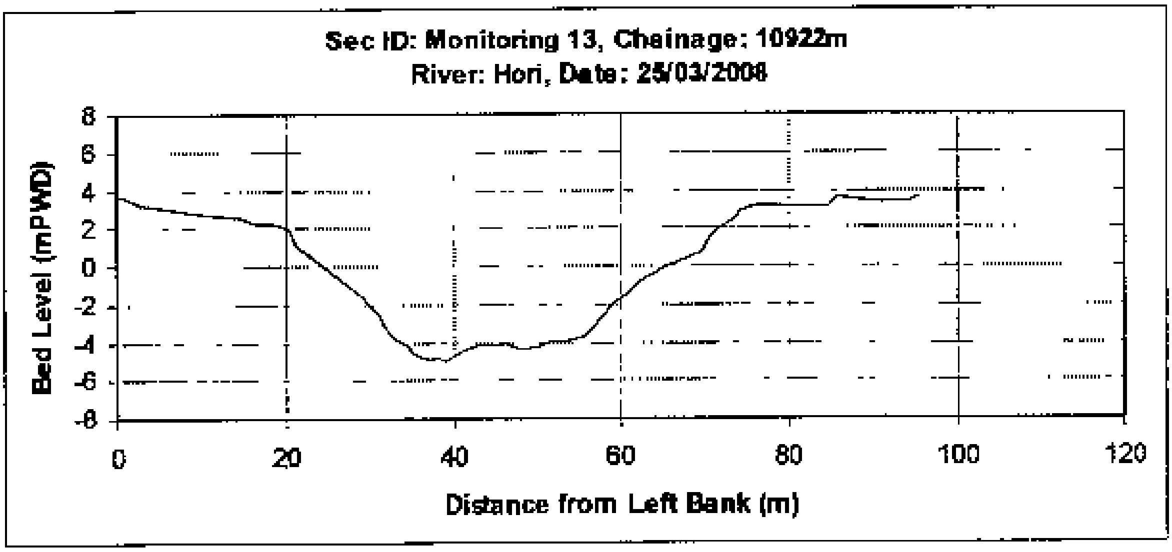

Sec ID: Bha-Kap 03, Chainage: 1062m
River: Teka, Date: 24/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
Distance from Left Bank (m)

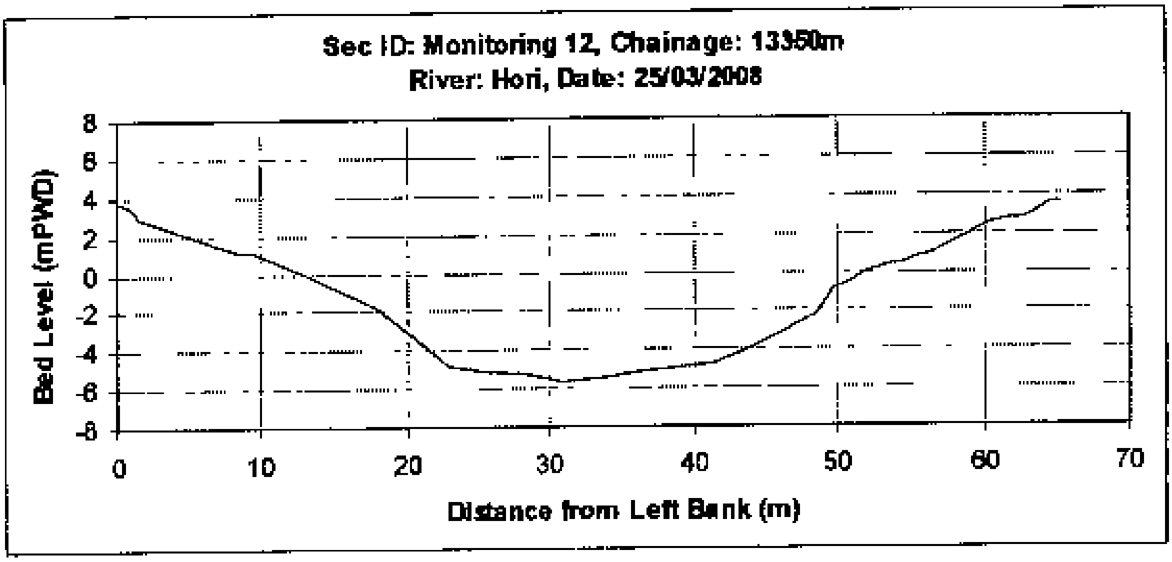

Sec ID: Bha-Kap 04, Chainage: 1558m
River: Teka, Date: 24/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
Distance from Left Bank (m)

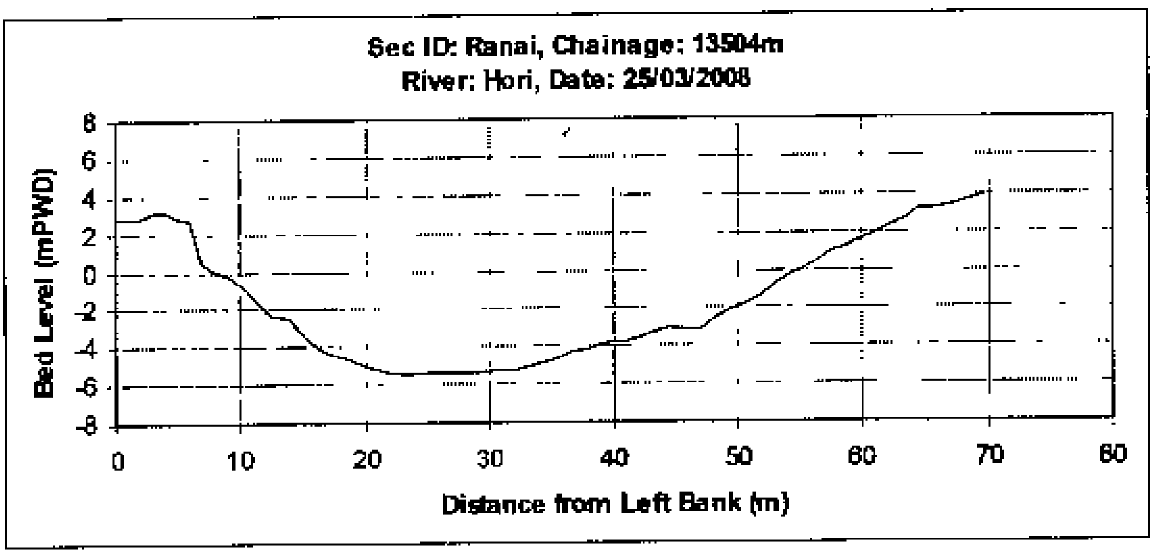

Sec ID: Bha-Kap 05, Chainage: 2109m
River: Teka, Date: 24/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
Distance from Left Bank (m)

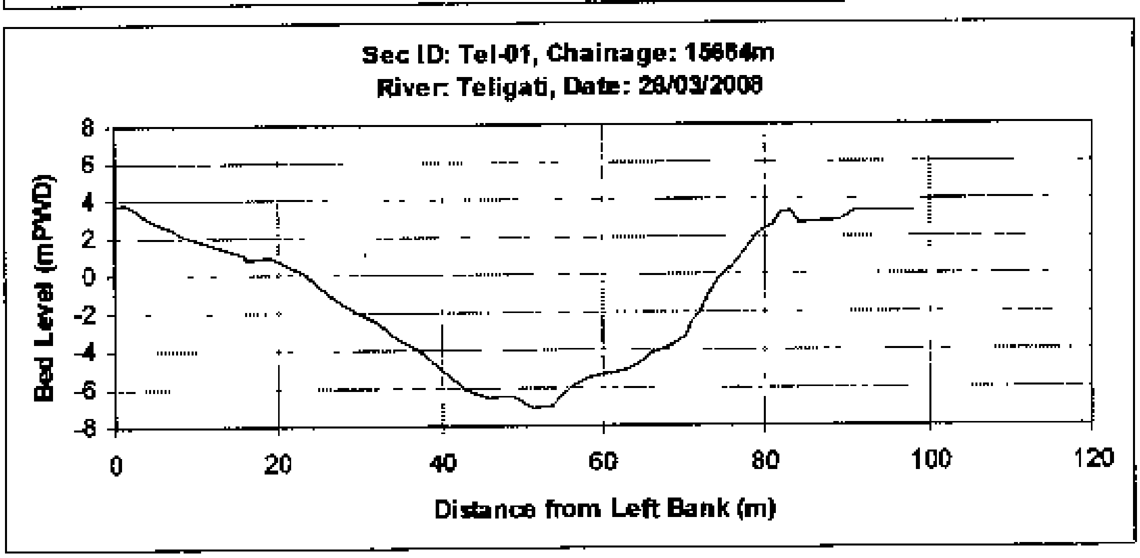

Sec ID: Monitoring 01, Chainage: 9422m
River: Hori, Date: 25/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
80
Distance from Left Bank (m)

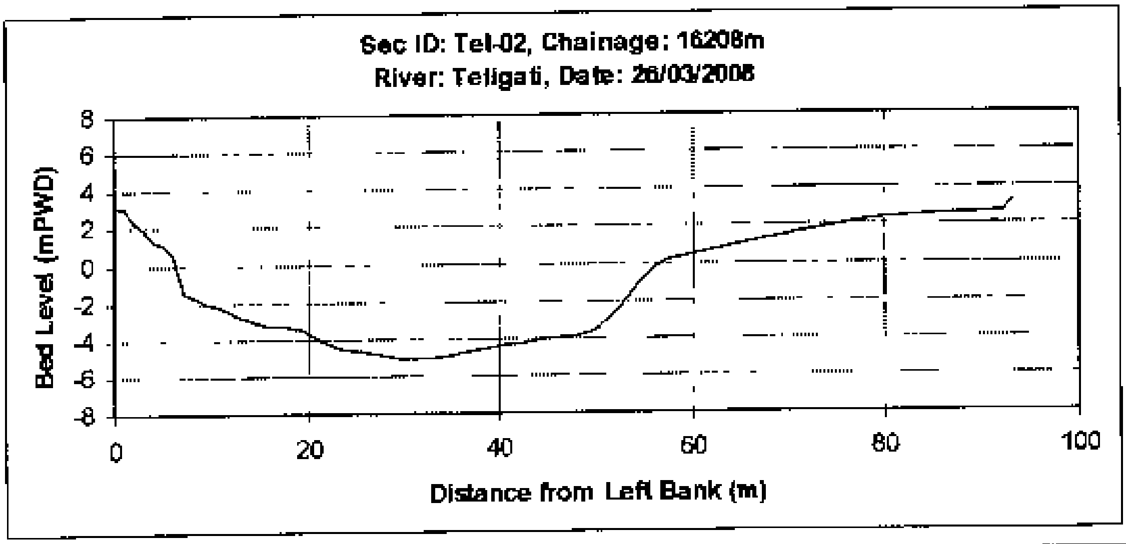

Sec ID: Monitoring 02, Chainage: 8866m
River: EBK Khal, Date: 25/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
Distance from Left Bank (m)

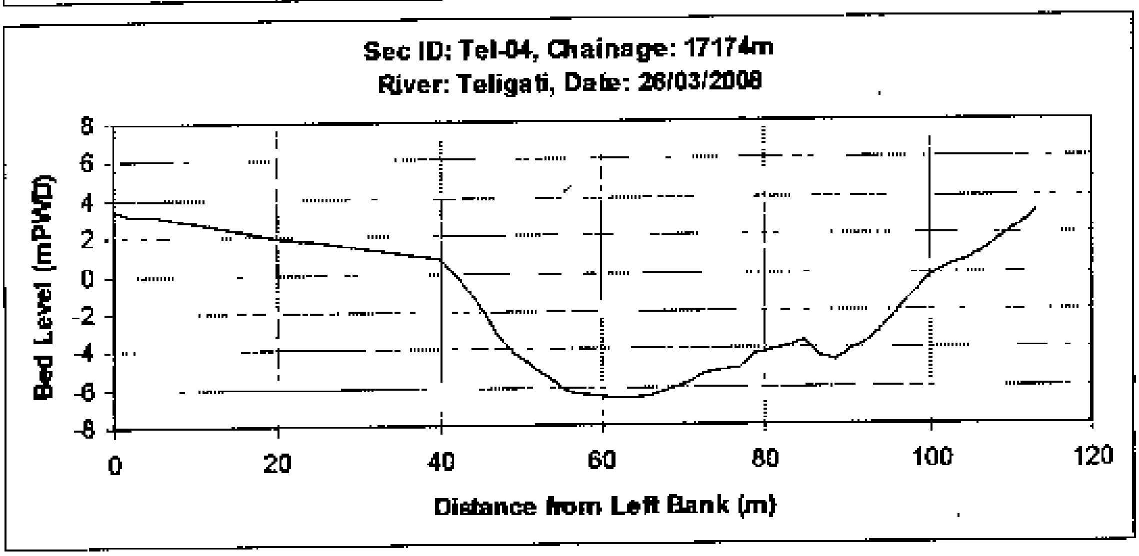

Sec ID: Monitoring 13, Chainage: 10922m
River: Hori, Date: 25/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

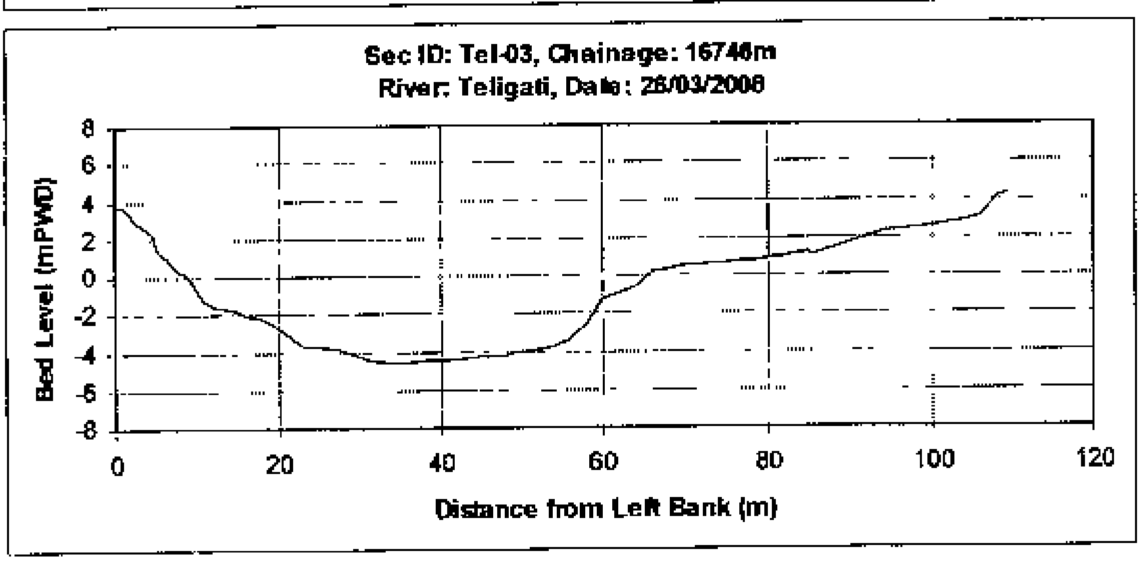

Sec ID: Monitoring 12, Chainage: 13350m
River: Hori, Date: 25/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
Distance from Left Bank (m)

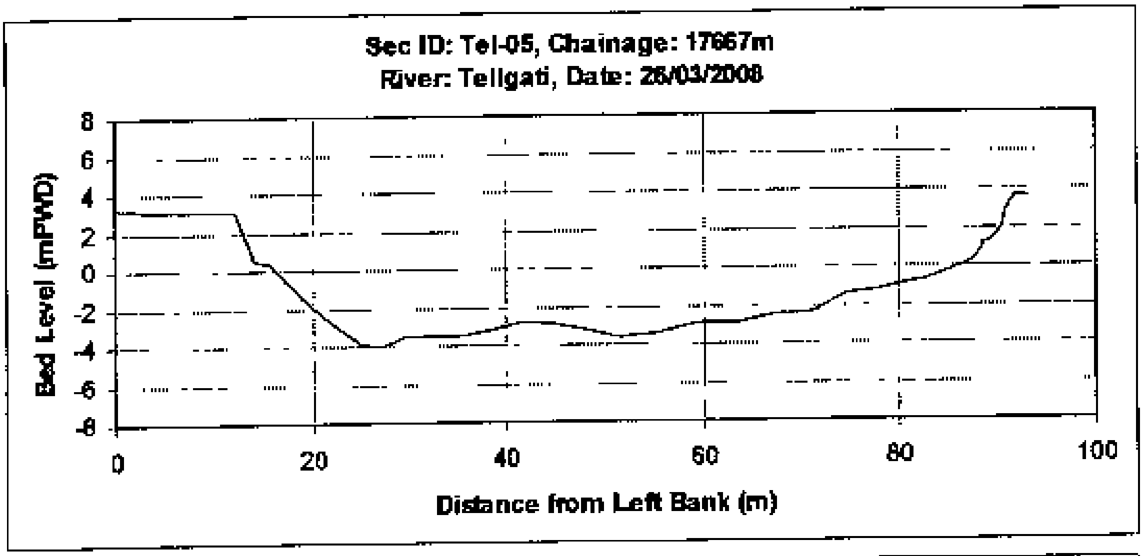

Sec ID: Ranai, Chainage: 13504m
River: Hori, Date: 25/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
10
20
30
40
50
60
70
80
Distance from Left Bank (m)

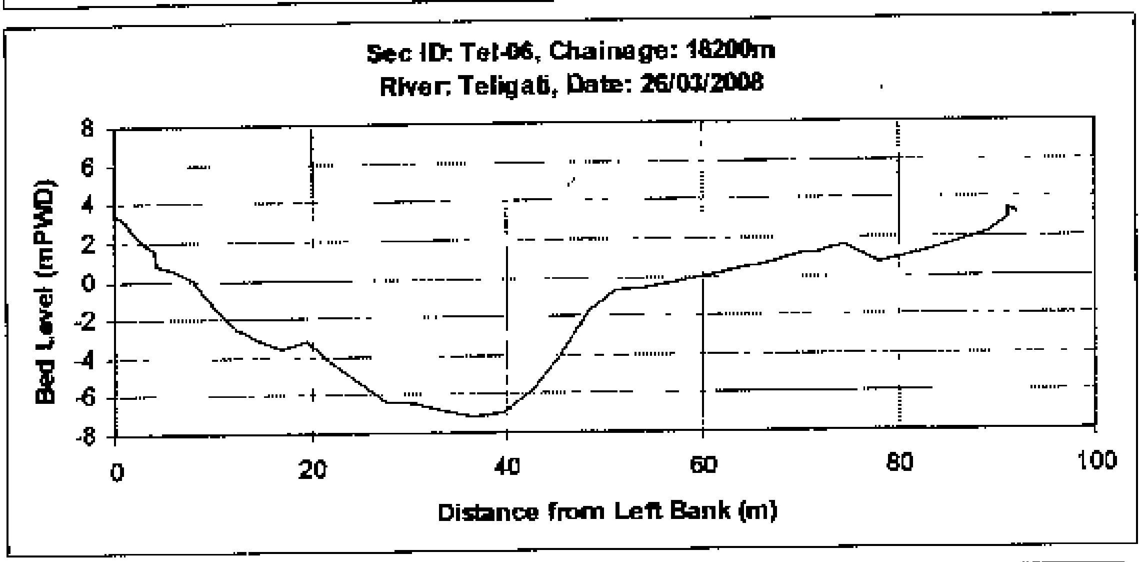

Sec ID: Tel-01, Chainage: 15664m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

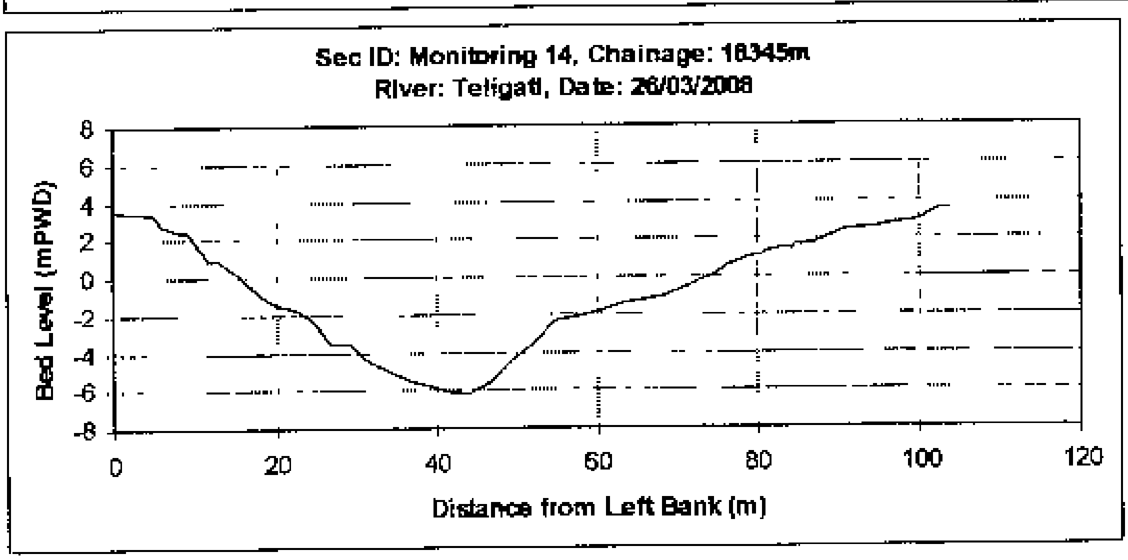

Sec ID: Tel-02, Chainage: 16208m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
Distance from Left Bank (m)

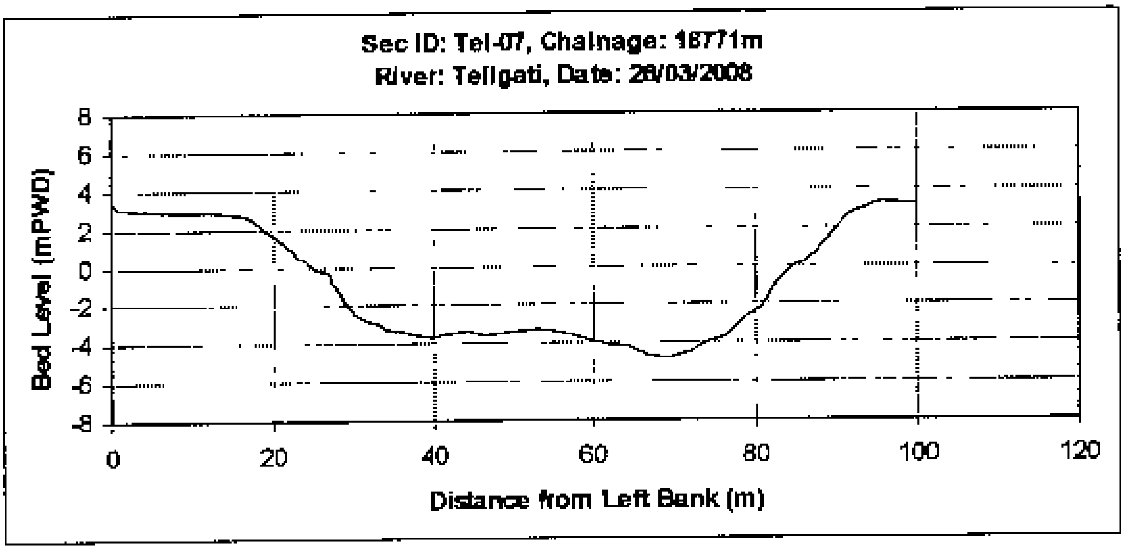

Sec ID: Tel-04, Chainage: 17174m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)


Sec ID: Tel-03, Chainage: 16746m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

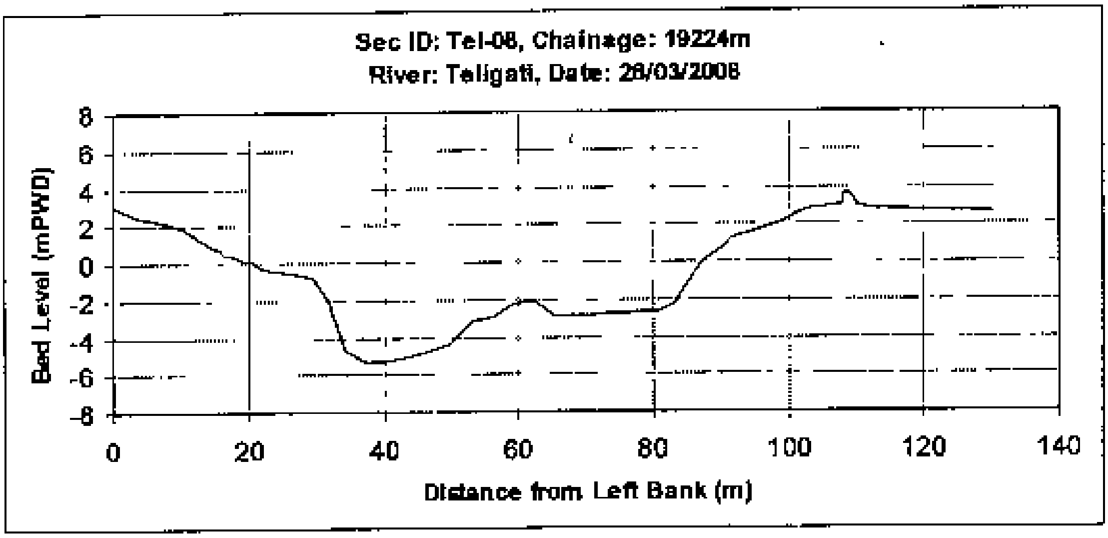

Sec ID: Tel-05, Chainage: 17667m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
Distance from Left Bank (m)


Sec ID: Tel-06, Chainage: 18200m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
Distance from Left Bank (m)

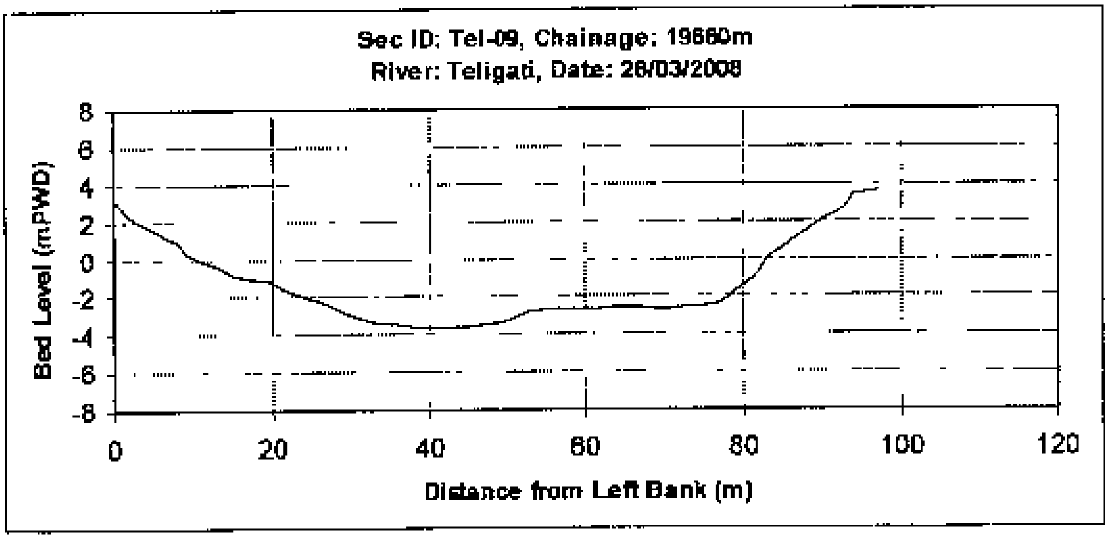

Sec ID: Monitoring 14, Chainage: 18345m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)



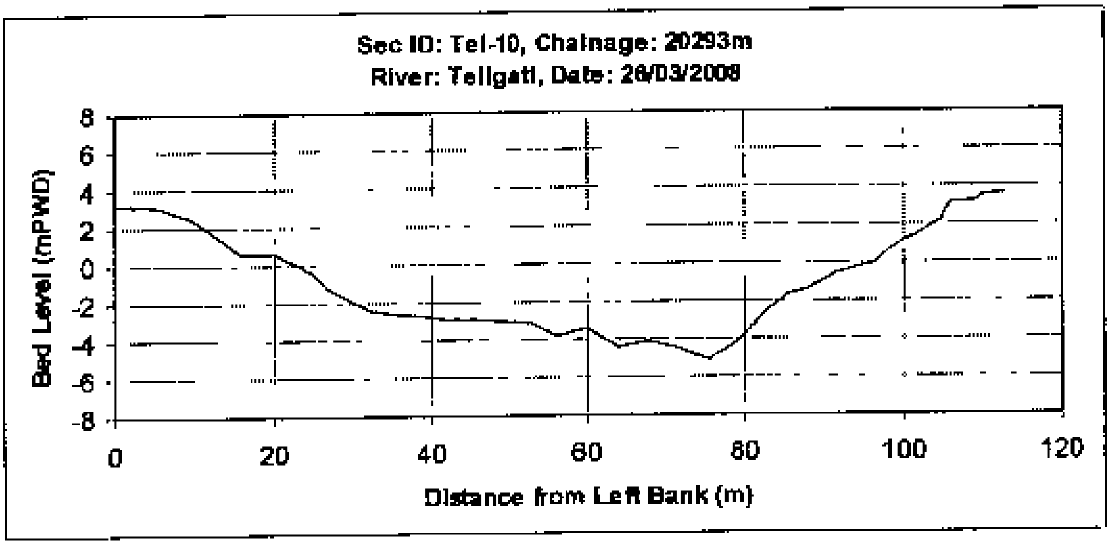
Sec ID: Tel-07, Chainage: 18771m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

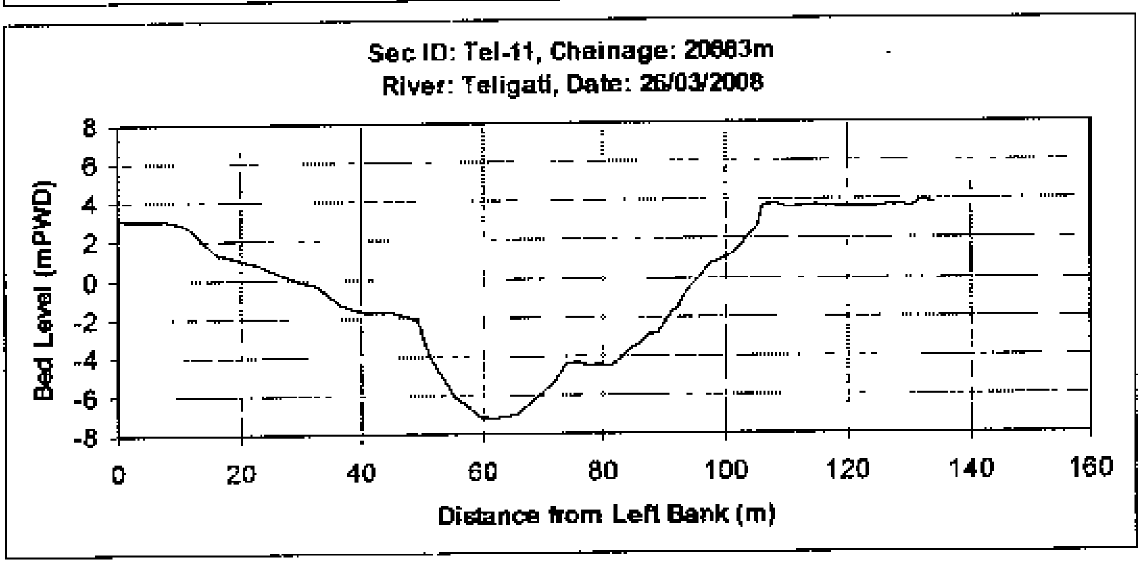


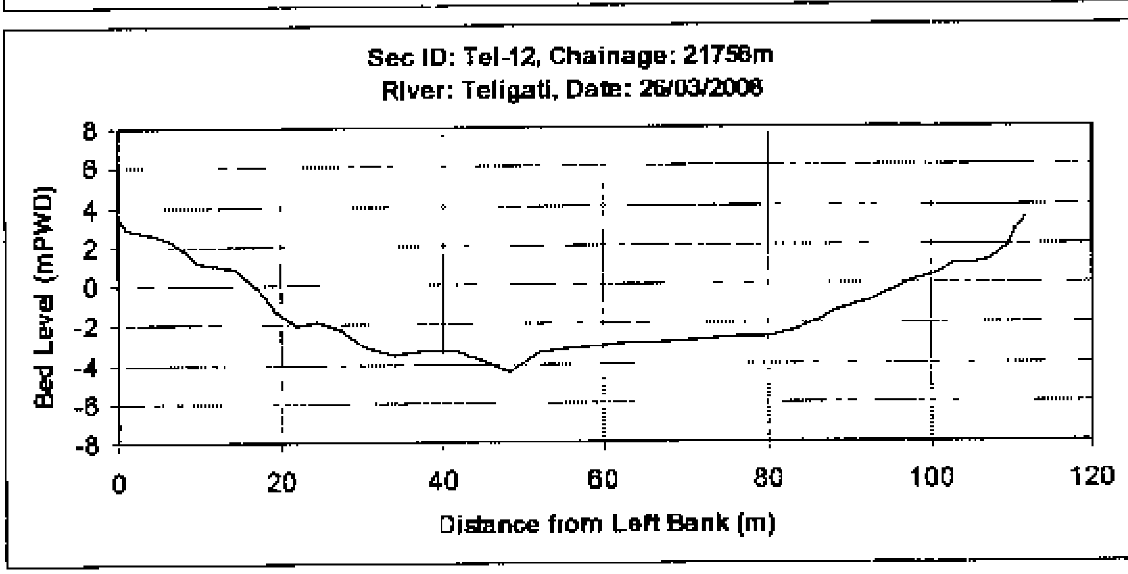
Sec ID: Tel-08, Chainage: 19224m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
Distance from Left Bank (m)

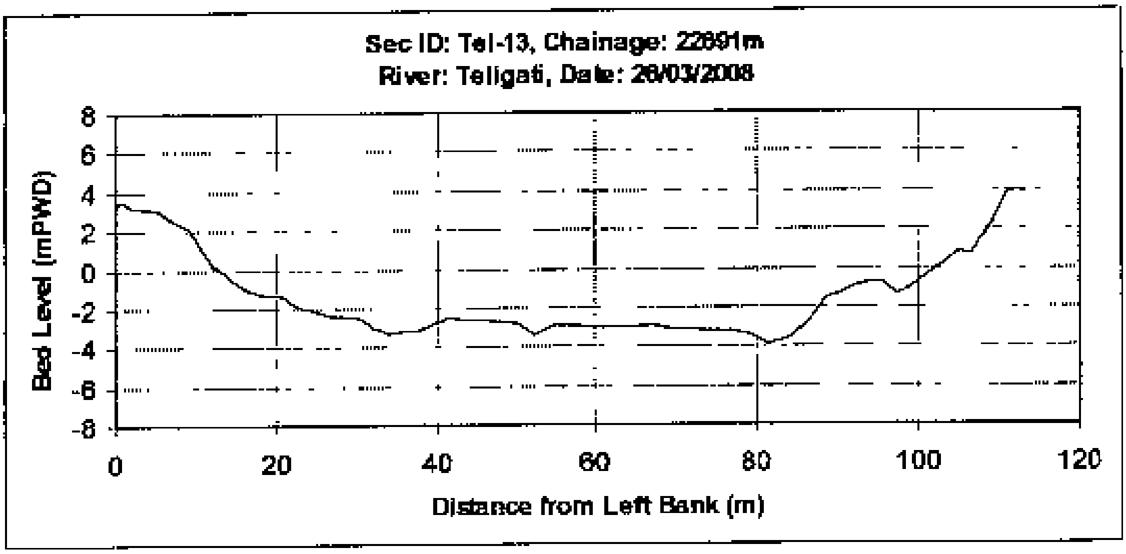


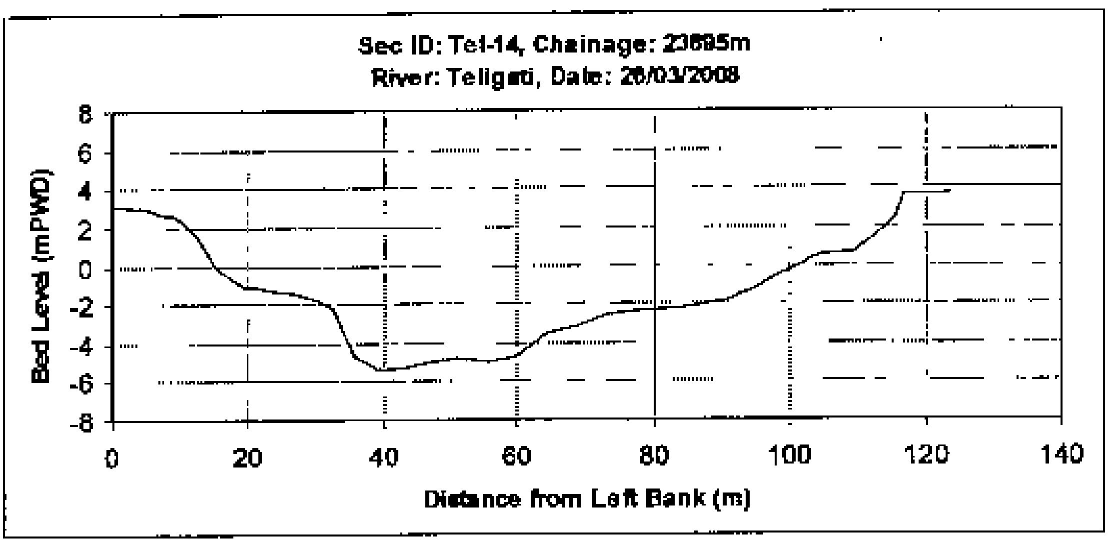
Sec ID: Tel-09, Chainage: 19660m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

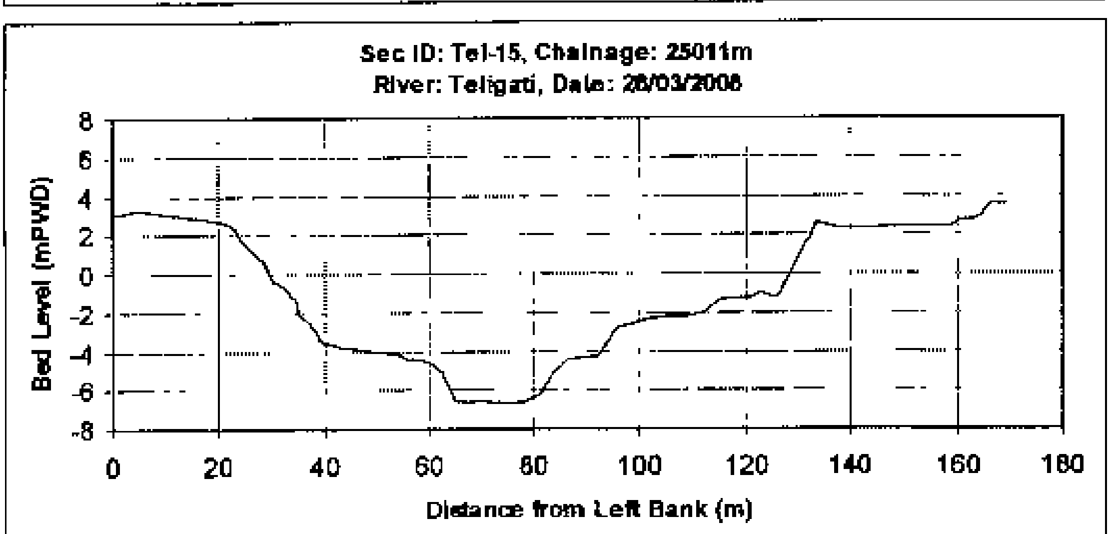

Sec ID: Tel-10, Chainage: 20293m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

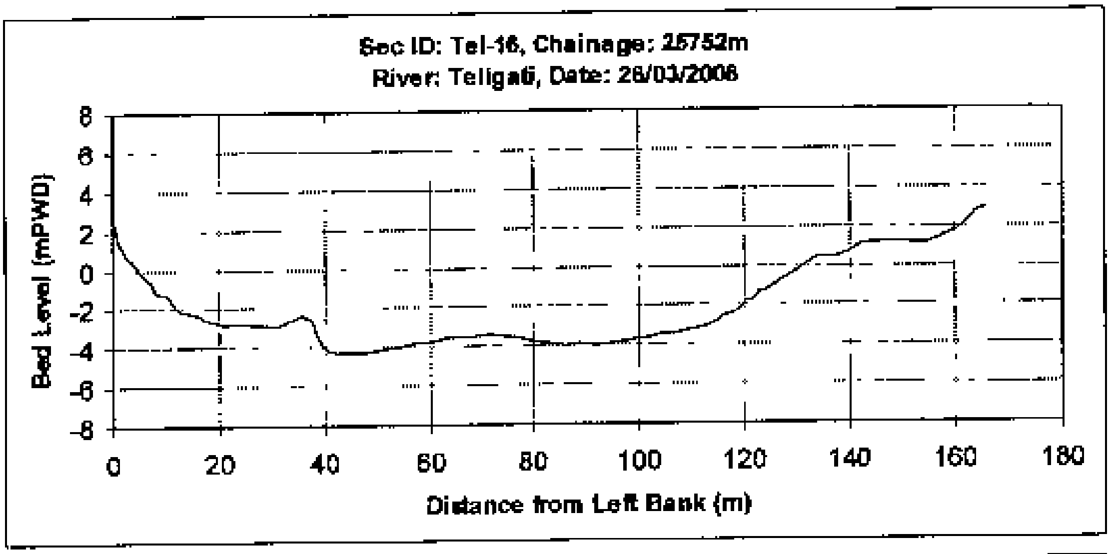

Sec ID: Tel-11, Chainage: 20883m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
Distance from Left Bank (m)


Sec ID: Tel-12, Chainage: 21758m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)

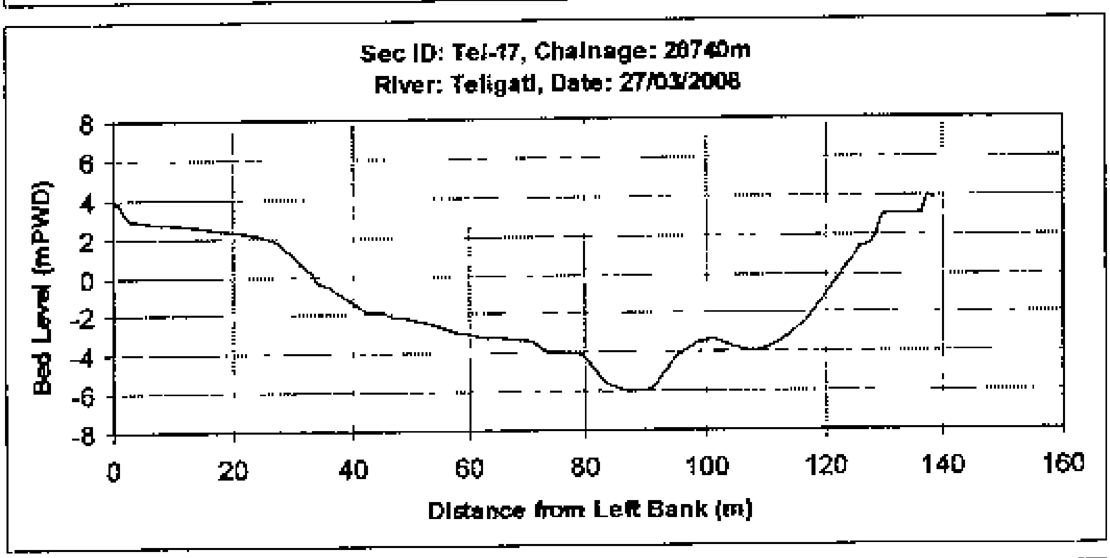

Sec ID: Tel-13, Chainage: 22891m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
Distance from Left Bank (m)


Sec ID: Tel-14, Chainage: 23685m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
Distance from Left Bank (m)

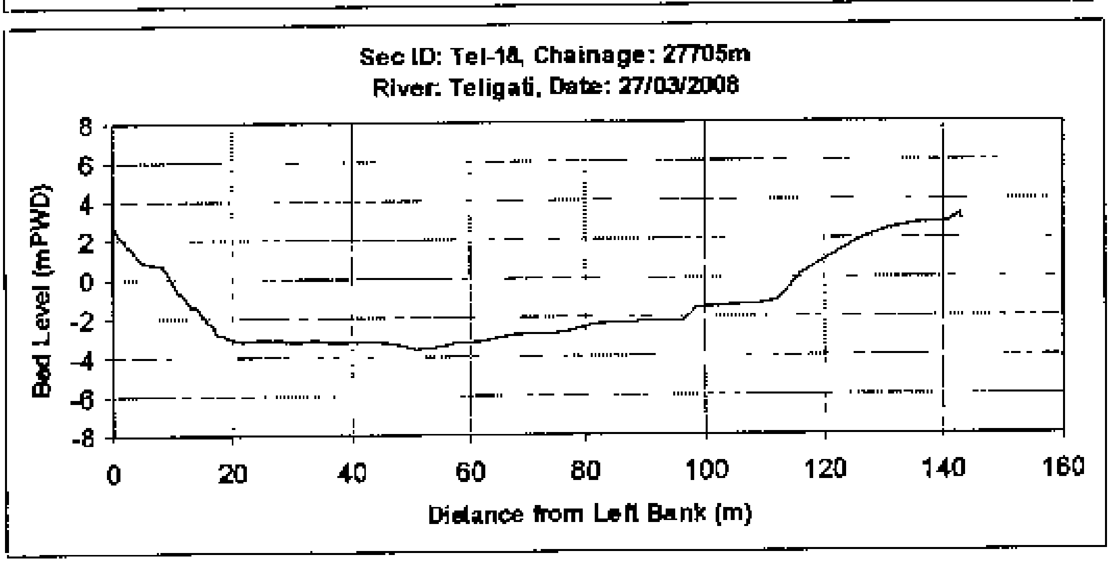

Sec ID: Tel-15, Chainage: 25011m
River: Teligati, Date: 28/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
180
Distance from Left Bank (m)



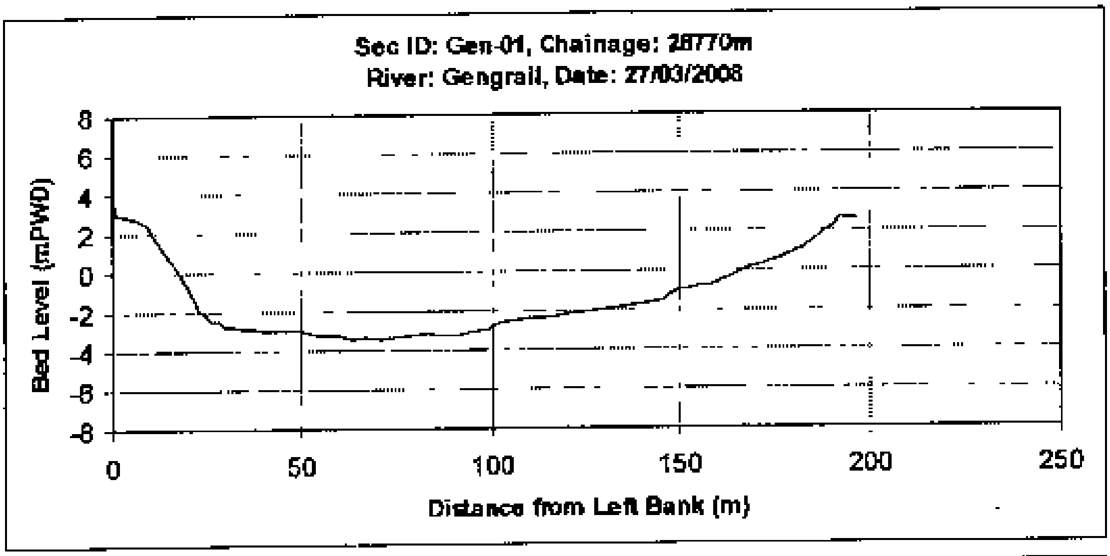
Sec ID: Tel-16, Chainage: 25752m
River: Teligati, Date: 26/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
180
Distance from Left Bank (m)

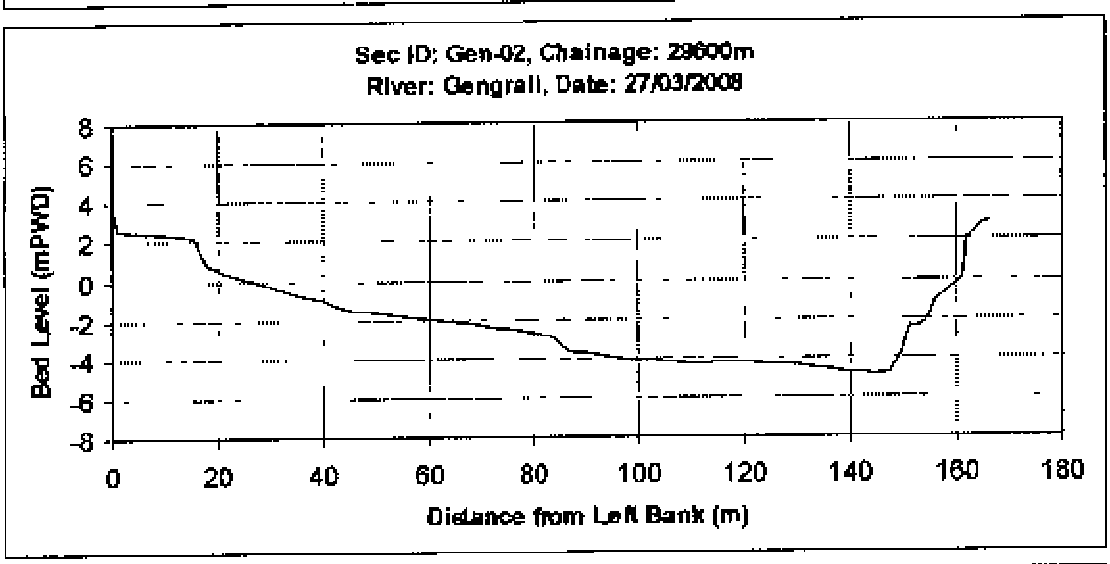


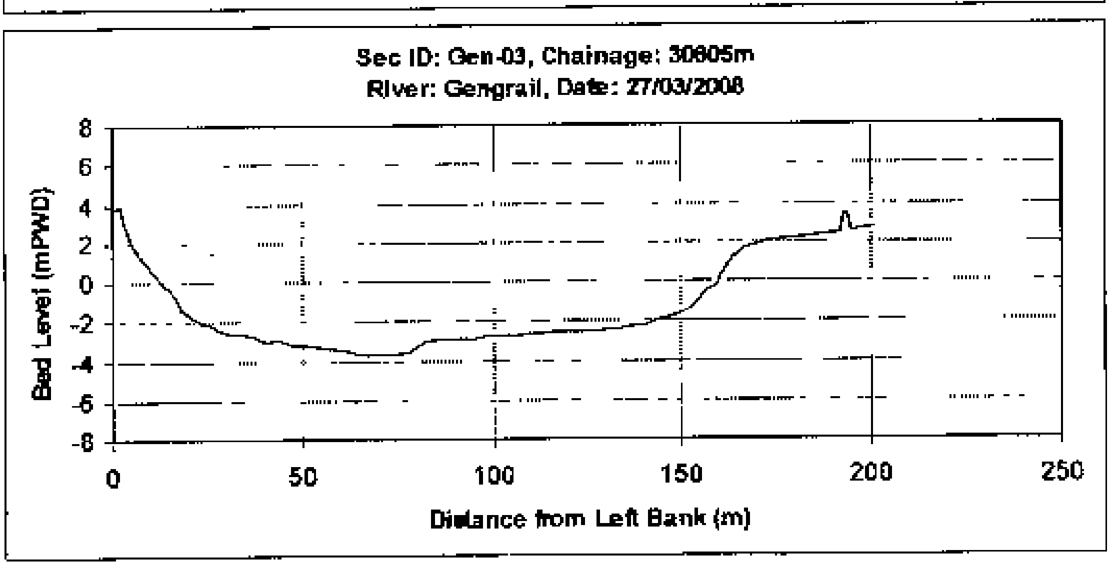
Sec ID: Tel-17, Chainage: 26740m
River: Teligati, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
Distance from Left Bank (m)

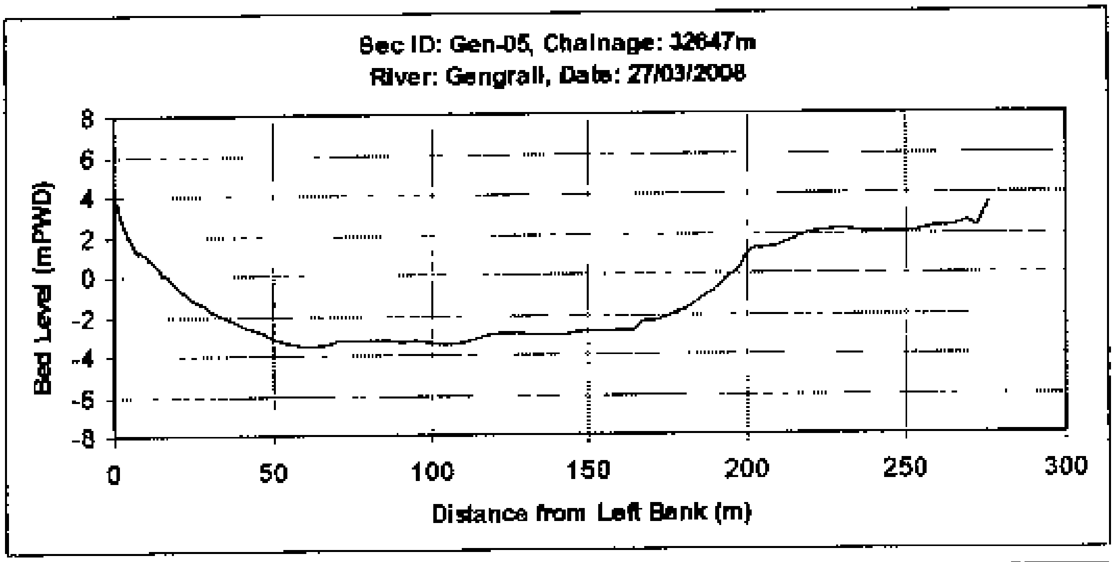


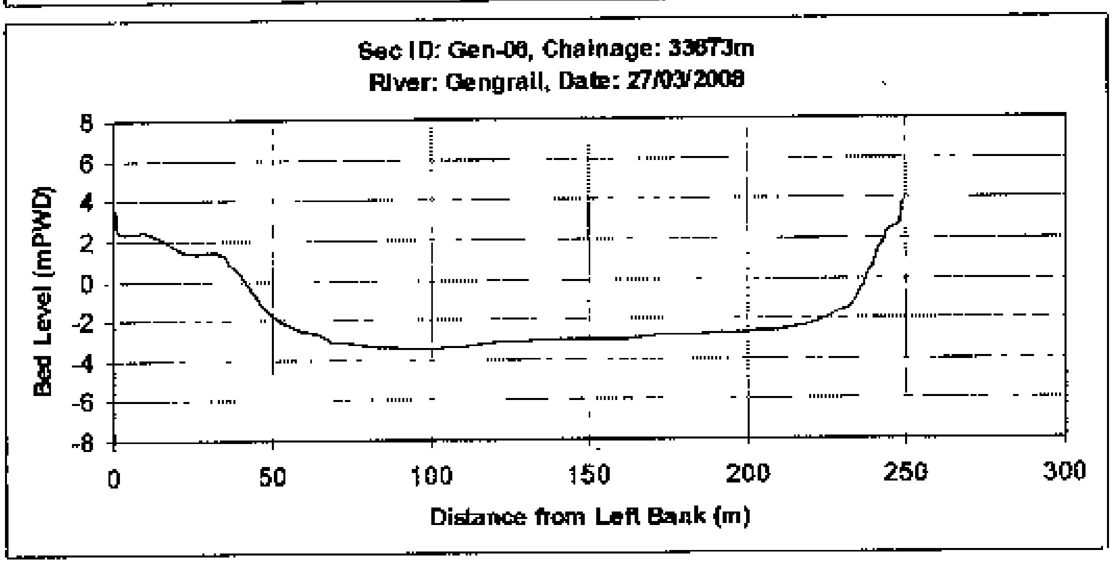
Sec ID: Tel-18, Chainage: 27705m
River: Teligati, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
Distance from Left Bank (m)

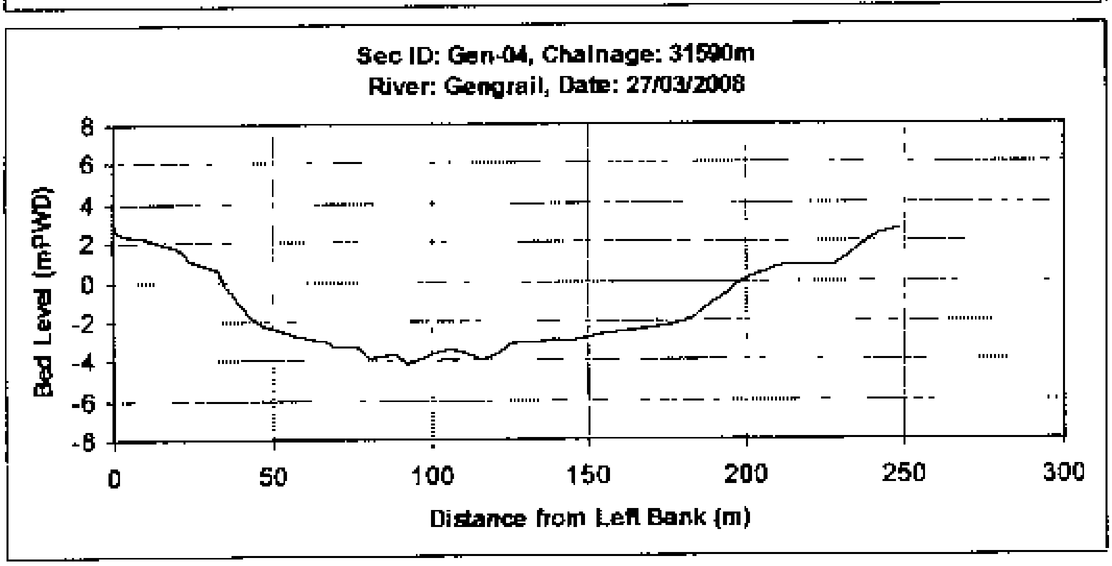

Sec ID: Gen-01, Chainage: 28770m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
Distance from Left Bank (m)

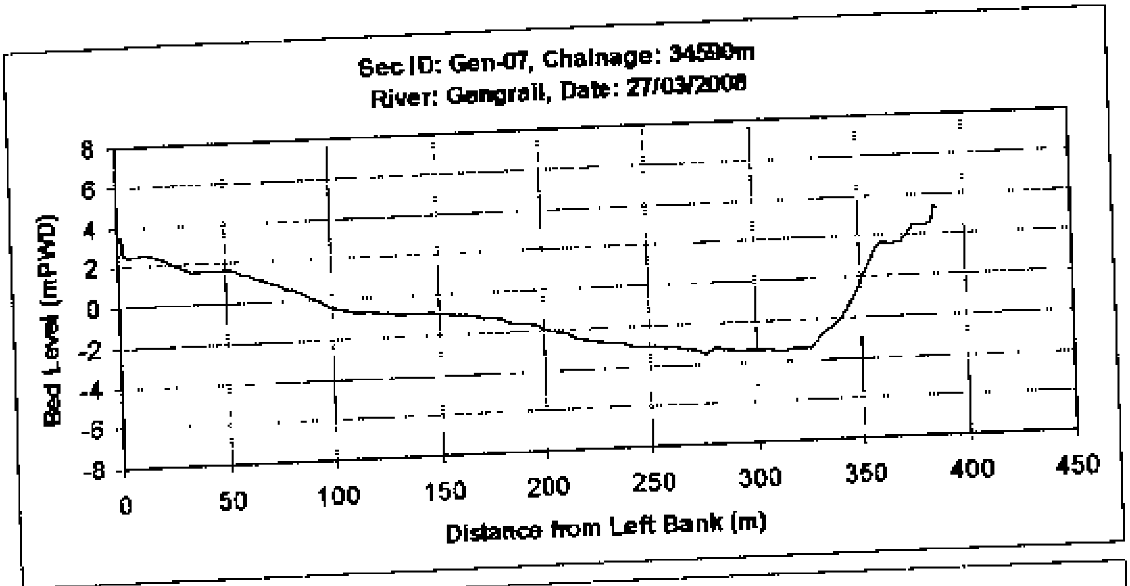

Sec ID: Gen-02, Chainage: 29600m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
20
40
60
80
100
120
140
160
180
Distance from Left Bank (m)

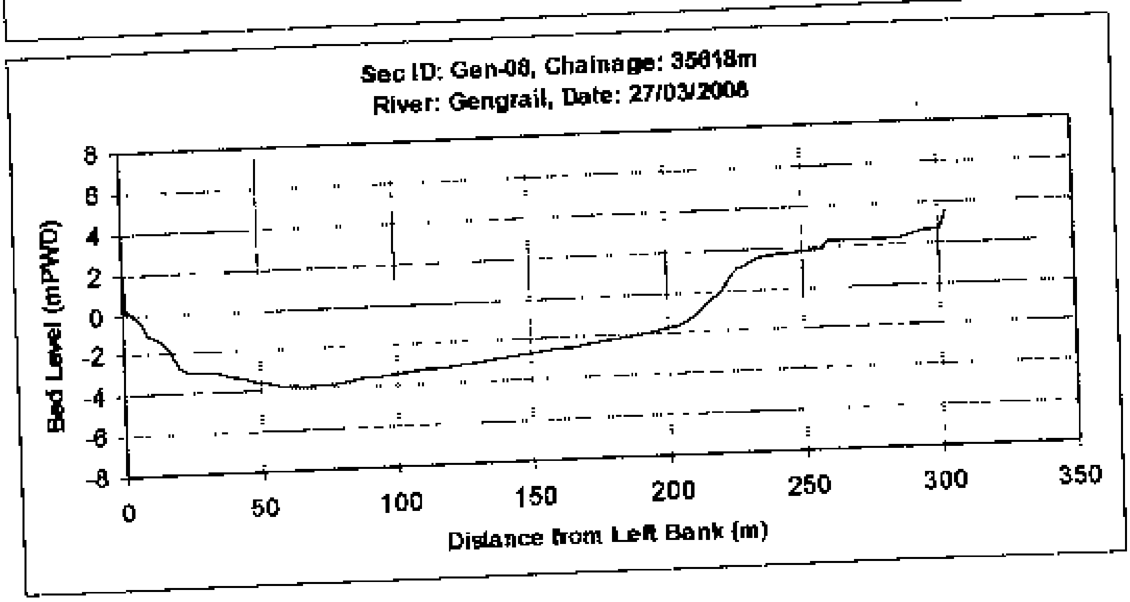

Sec ID: Gen-03, Chainage: 30605m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
Distance from Left Bank (m)

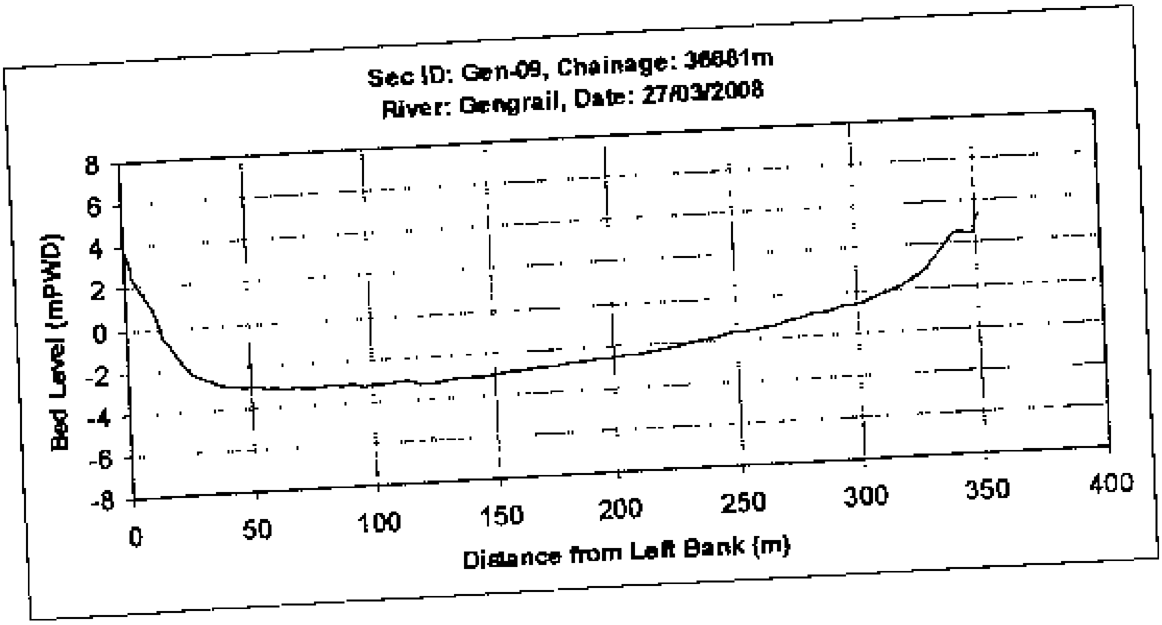

Sec ID: Gen-05, Chainage: 32647m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
Distance from Left Bank (m)

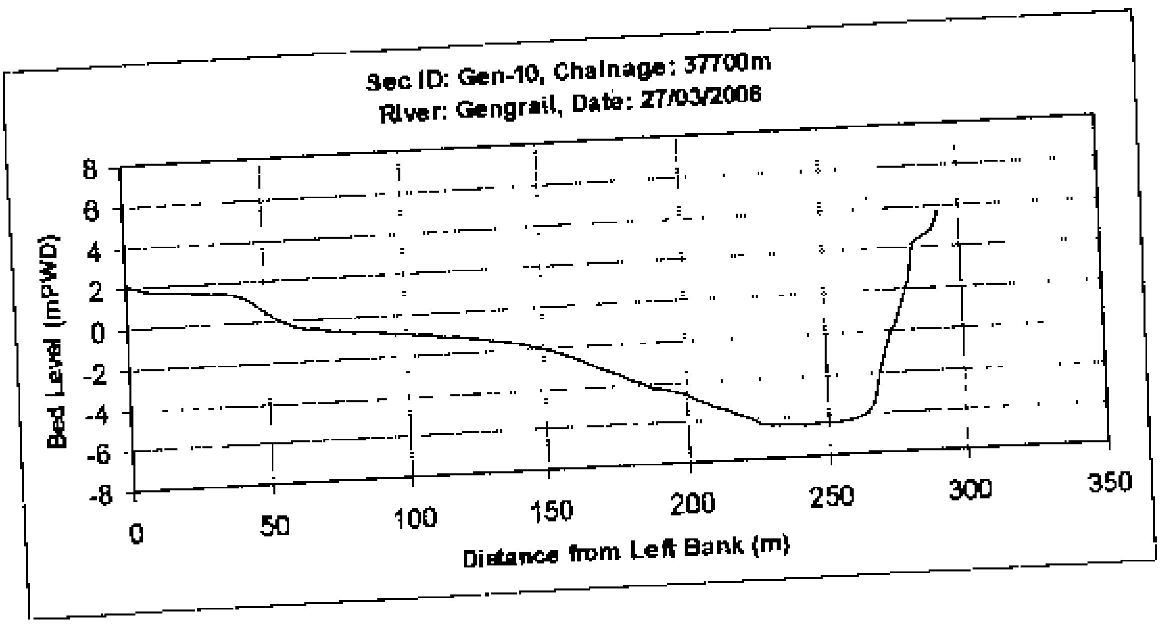

Sec ID: Gen-06, Chainage: 33673m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
Distance from Left Bank (m)


Sec ID: Gen-04, Chainage: 31590m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
Distance from Left Bank (m)


Sec ID: Gen-07, Chainage: 34590m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
350
400
450
Distance from Left Bank (m)


Sec ID: Gen-08, Chainage: 35618m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
350
Distance from Left Bank (m)


Sec ID: Gen-09, Chainage: 36881m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
350
400
Distance from Left Bank (m)


Sec ID: Gen-10, Chainage: 37700m
River: Gengrail, Date: 27/03/2008
Bed Level (mPWD)
8
6
4
2
0
-2
-4
-6
-8
0
50
100
150
200
250
300
350
Distance from Left Bank (m)

APPENDIX E

Suspended Sediment Concentration Data

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	East Beel Khukshia
STATION	:	1 st cut
VERTICAL NO.	:	V1
POSITION	:	433812 E 629395 N
OBSERVATION DATE	:	9-Apr-08

Observation Time	Depth		Sample Volume	Weight			Total Concentration
	Total, d	Sampling		Filter paper	Sample+Filter paper	Sample Dry Wt	
(hrs)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
6.00	6.20	0.8d	248	0.0853	0.2907	0.2054	828.4847
		0.2d	246	0.0854	0.2107	0.1253	509.4475
7.00	6.07	0.8d	244	0.0829	0.1575	0.0747	306.1629
		0.2d	250	0.0827	0.1625	0.0798	319.2385
8.00	5.95	0.8d	250	0.0829	0.2042	0.1213	485.2869
		0.2d	242	0.0827	0.1715	0.0888	366.9930
9.00	5.62	0.8d	239	0.0829	0.2620	0.1791	752.7348
		0.2d	240	0.0830	0.1909	0.1079	449.6596
10:00	5.68	0.8d	246	0.0830	0.1616	0.0786	319.5507
		0.2d	246	0.0830	0.1564	0.0734	298.4076
11:00	5.55	0.8d	246	0.0830	0.2730	0.1900	772.5829
		0.2d	248	0.0828	0.1496	0.0668	269.3822
12.00	5.45	0.8d	242	0.0828	0.4036	0.3208	1326.2833
		0.2d	240	0.0822	0.3114	0.2292	955.3443
13:00	5.76	0.8d	240	0.0826	0.2086	0.1260	525.1040
		0.2d	246	0.0827	0.1540	0.0713	289.8691
14.00	6.03	0.8d	244	0.0829	0.8698	0.7869	3228.9295
		0.2d	242	0.0824	0.4330	0.3506	1449.5528
15.00	6.23	0.8d	236	0.0829	0.7094	0.6265	2657.3230
		0.2d	238	0.0828	0.5149	0.4321	1816.7909
16.00	6.25	0.8d	240	0.0826	0.8165	0.7339	3061.4494
		0.2d	242	0.0825	0.5832	0.5007	2070.6249
17:00	6.27	0.8d	242	0.0827	0.8724	0.7897	3267.2464
		0.2d	240	0.0825	0.7115	0.6290	2623.4279
18.00	6.28	0.8d	240	0.0827	0.8540	0.7713	3217.6522
		0.2d	242	0.0826	0.6545	0.5719	2366.3325

IWM SEDIMENT LABORATORY

Surpended Sediment Sample Analysis

RIVER NAME	:	East Beel Khuksia	
STATION	:	2nd cut	
VERTICAL NO.	:	V1	
POSITION	:	433739 E	531718 N
OBSERVATION DATE	:	9-Apr-08	

Observation Time	Depth		Sample Volume	Weight			Total Concentration
	Total,d	Sampling		Filter paper	Sample+Filter paper	Sample Dry Wt.	
(hrs)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
6 00	2 45	0 8d	242	0.0836	0 1123	0 0287	118 6003
		0 2d	240	0 0834	0.1070	0.0236	98 3070
7 00	2.35	0 8d	240	0 0835	0 1058	0 0223	92.9199
		0 2d	246	0 0834	0.1019	0.0185	75 2054
8 00	2 25	0 8d	246	0 0836	0 1022	0 0186	75 6119
		0 2d	238	0 0835	0 0993	0 0158	66 3862
9 00	2 06	0 8d	236	0 0837	0 1098	0 0261	110.5978
		0.2d	240	0 0842	0 1032	0 0190	79 1690
10 00	1.90	0 8d	240	0.0837	0 1115	0.0278	115 8384
		0 2d	240	0 0836	0 0963	0 0127	52 9177
11:00	1 85	0 8d	242	0 0837	0.1209	0 0372	153.7279
		0.2d	244	0 0839	0 1066	0 0228	93 4459
12 00	1 77	0 8d	244	0 0839	0 1630	0 0791	324 2200
		0,2d	246	0,0841	0 1445	0 0604	245 5512
13 00	1 76	0 8d	240	0 0839	0 1276	0 0437	182 0950
		0.2d	244	0 0834	0 1275	0 0441	180 7500
14:00	1.98	0 8d	244	0 0841	0 1763	0.0922	377 9227
		0 2d	246	0 0839	0.1526	0.0687	279.2977
15:00	2.15	0 8d	244	0 0838	0.3664	0 2826	1158.7031
		0.2d	240	0 0840	0,2899	0.2059	858 1945
16 00	2.25	0 8d	240	0.0840	0 6722	0 4882	2035 7293
		0 2d	246	0 0838	0 2979	0,2141	870 6111
17:00	2 35	0 8d	242	0 0840	0 2770	0.1930	797,7607
		0.2d	242	0 0839	0 2925	0 2086	862.2638
18 00	2.40	0.8d	246	0.0840	0 2836	0,1996	811 6306
		0 2d	240	0 0840	0 2648	0 1808	753 5475

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	Gengrali
STATION	:	Kanchan Nagar
VERTICAL NO.	:	V1
POSITION	:	438538 E 607343 N
OBSERVATION DATE	:	10-Mar-08

Observation Time	Depth		Sample Volume	Weight			Total Concentration
	Total,d	Sampling		Filter paper	Sample+Filter paper	Sample Dry Wt.	
(hrs.)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
4:00	6.09	0.8d	250	0.0845	0.4521	0.3678	1471.2163
		0.2d	250	0.0045	0.3393	0.2548	1019.5921
5:00	6.24	0.8d	250	0.0842	0.2360	0.1518	607.3392
		0.2d	250	0.0845	0.1460	0.0615	246.0228
6:00	5.39	0.8d	250	0.0848	0.5305	0.4457	1784.0002
		0.2d	250	0.0847	0.6011	0.5164	2067.2113
7:00	4.49	0.8d	250	0.0846	0.6560	0.5714	2287.5730
		0.2d	250	0.0848	0.5449	0.4601	1841.6790
8:00	3.62	0.8d	250	0.0847	1.3024	1.2177	4879.7692
		0.2d	250	0.0845	0.8301	0.7456	2986.7603
9:00	3.07	0.8d	250	0.0847	1.8031	1.7184	6891.4752
		0.2d	250	0.0846	1.6656	1.5810	6339.1278
10:00	2.01	0.8d	250	0.0845	1.8766	1.7921	7187.8435
		0.2d	250	0.0845	1.7195	1.6350	6556.1802
11:00	3.87	0.8d	250	0.0845	1.4224	1.3379	5362.4293
		0.2d	250	0.0848	0.7351	0.6503	2603.7558
12:00	5.61	0.8d	250	0.0847	1.0393	0.9546	3823.9099
		0.2d	250	0.0845	0.7572	0.6727	2693.5360
13:00	6.97	0.8d	250	0.0845	0.8143	0.7298	2922.4193
		0.2d	250	0.0842	0.5828	0.4986	1995.9021
14:00	7.59	0.8d	250	0.0844	0.6965	0.6121	2450.6642
		0.2d	250	0.0841	0.6433	0.5592	2238.6896
15:00	7.43	0.8d	250	0.0847	0.6502	0.5655	2263.9325
		0.2d	250	0.0845	0.5387	0.4542	1818.0464
16:00	7.14	0.8d	250	0.0845	0.6233	0.5388	2156.9542
		0.2d	250	0.0846	0.5470	0.4624	1850.8919

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	Gengrail	
STATION	:	Kanchan Nagar	
VERTICAL NO.	:	V1	
POSITION	:	436536 E	507343 N
OBSERVATION DATE	:	12-Mar-08	

Observation Time	Depth		Sample Volume	Weight			Total Concentration
	Total, d	Sampling		Filter paper	Sample+Filter paper	Sample Dry Wt.	
(hrs)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
4.00	7.20	0.8d	248	0.0809	0.5701	0.4892	1974.0501
		0.2d	240	0.0813	0.3699	0.2886	1203.0459
5.00	6.65	0.8d	238	0.0809	0.5392	0.4583	1927.0305
		0.2d	250	0.0811	0.1597	0.0786	314.4373
6.00	6.17	0.8d	250	0.0809	0.3103	0.2294	917.9178
		0.2d	242	0.0800	0.1470	0.0670	276.8884
7.00	5.42	0.8d	246	0.0801	0.4939	0.4138	1683.1822
		0.2d	244	0.0800	0.2024	0.1224	501.7343
8.00	4.51	0.8d	238	0.0797	0.9229	0.8432	3547.6000
		0.2d	250	0.0800	0.5637	0.4837	1936.2137
9.00	3.73	0.8d	242	0.0801	1.5232	1.4431	5976.6723
		0.2d	242	0.0802	0.9779	0.8977	3714.7040
10.00	3.27	0.8d	240	0.0804	1.9485	1.8681	7806.6803
		0.2d	246	0.0803	2.0430	1.9627	8002.5409
11:00	2.51	0.8d	246	0.0831	1.6700	1.5869	6466.5643
		0.2d	250	0.0825	1.0482	0.9657	3868.4389
12.00	3.45	0.8d	250	0.0806	0.8109	0.7303	2924.4237
		0.2d	250	0.0808	0.4898	0.4090	1637.0106
13:00	4.92	0.8d	248	0.0808	0.9121	0.8313	3356.2615
		0.2d	246	0.0809	0.7305	0.6496	2643.2844
14:00	6.23	0.8d	248	0.0807	0.6363	0.5556	2242.2182
		0.2d	244	0.0808	0.4248	0.3440	1410.5865
15:00	6.79	0.8d	242	0.0808	0.4660	0.3852	1592.6922
		0.2d	248	0.0809	0.3907	0.3098	1249.7927
16:00	6.72	0.8d	250	0.0810	0.4272	0.3462	1385.5240
		0.2d	250	0.0812	0.3310	0.2498	999.5769

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	Gengrail
STATION	:	Kanchan Nagar
VERTICAL NO.	:	V1
POSITION	:	438536 E 607343 N
OBSERVATION DATE	:	15-Mar-08

Observation Time	Depth		Sample Volume	Weight			Total Concentration
	Total,d	Sampling		Filter paper	Sample+Filter paper	Sample Dry Wt.	
(hrs.)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
3.00	6.00	0.8d	250	0.0810	0.7521	0.6711	2687.1220
		0.2d	250	0.0812	0.2704	0.1892	757.0162
4.00	6.42	0.8d	250	0.0843	0.5757	0.4914	1967.0590
		0.2d	250	0.0844	0.3337	0.2493	997.5754
5.00	6.84	0.8d	250	0.0845	0.5260	0.4415	1767.1777
		0.2d	250	0.0846	0.2290	0.1444	577.7259
6.00	7.02	0.8d	250	0.0848	0.2792	0.1944	777.8282
		0.2d	250	0.0848	0.2366	0.1618	607.3392
7.00	6.64	0.8d	250	0.0845	0.3371	0.2526	1010.7854
		0.2d	250	0.0849	0.1399	0.0550	220.0163
8.00	6.38	0.8d	250	0.0849	0.2769	0.1920	768.2226
		0.2d	248	0.0849	0.1297	0.0448	180.6675
9.00	5.82	0.8d	232	0.0848	0.1649	0.0801	345.3036
		0.2d	250	0.0849	0.1910	0.1061	424.4680
10.00	5.26	0.8d	246	0.0850	0.2227	0.1377	559.0744
		0.2d	248	0.0847	0.2199	0.1352	545.2735
11.00	4.86	0.8d	250	0.0850	0.4244	0.3394	1358.2969
		0.2d	238	0.0848	0.3462	0.2614	1098.7747
12.00	4.54	0.8d	232	0.0848	0.5831	0.4983	2149.5871
		0.2d	250	0.0853	0.4807	0.3954	1582.5445
13.00	4.40	0.8d	250	0.0853	0.6460	0.5607	2244.6998
		0.2d	250	0.0850	0.3509	0.2659	1064.0271
14.00	4.80	0.8d	250	0.0850	0.4460	0.3610	1444.7873
		0.2d	250	0.0848	0.2536	0.1686	675.3721
15.00	5.44	0.8d	250	0.0847	0.4528	0.3681	1473.2186
		0.2d	250	0.0847	0.3310	0.2463	985.5564

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	Hari
STATION	:	Ranai
VERTICAL NO.	:	V1
POSITION	:	433790 E 625575 N
OBSERVATION DATE	:	22-Mar-08

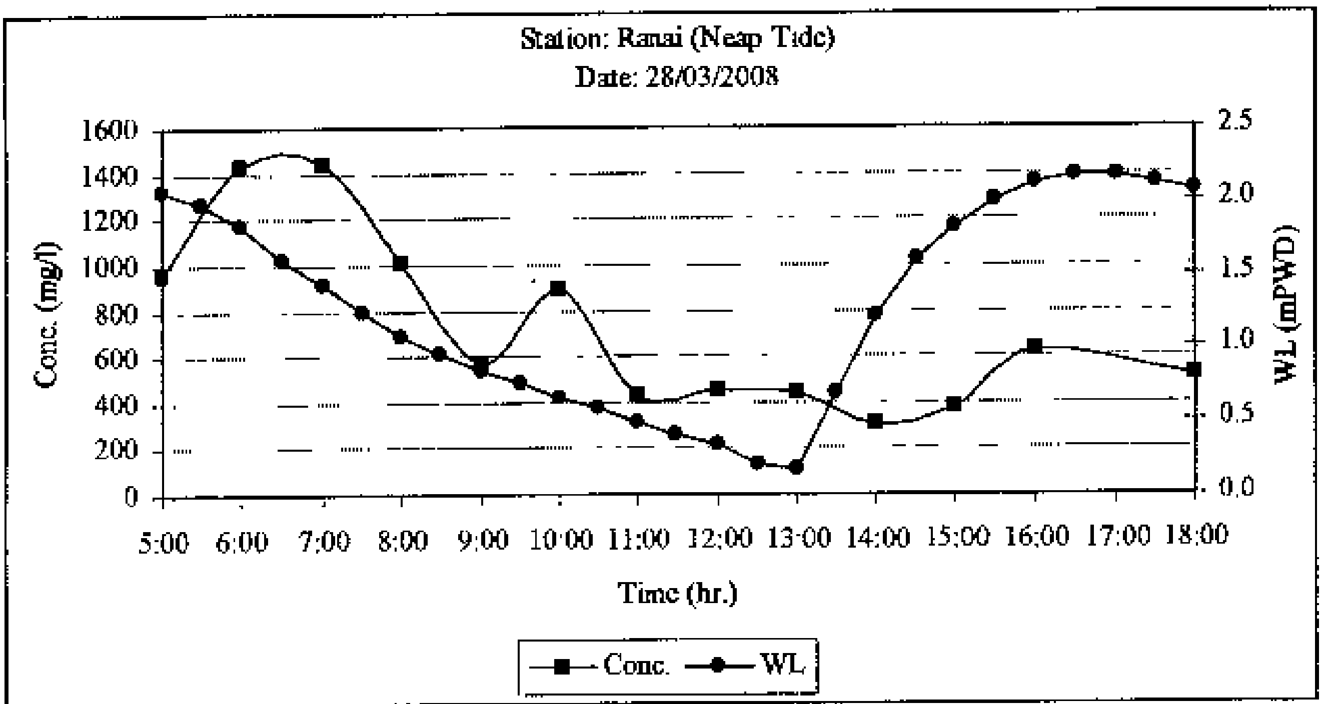
Observation Time	Depth Total,d	Depth Sampling	Sample Volume	Weight Filter paper	Weight Sample+Filter paper	Weight Sample Dry Wt.	Total Concentration
(hrs)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
6:00	4.97	0.8d	250	0.0847	0.9522	0.8675	3474.5497
		0.2d	248	0.0849	0.7670	0.6821	2753.2608
7.00	4.72	0.8d	244	0.0847	0.5403	0.4556	1868.5297
		0.2d	250	0.0851	0.3999	0.3148	1259.7986
8.00	4.58	0.8d	242	0.0850	0.4563	0.3713	1535.1864
		0.2d	238	0.0850	0.2933	0.2083	875.4992
9.00	4.44	0.8d	242	0.0848	0.3447	0.2599	1074.4024
		0.2d	250	0.0847	0.3115	0.2268	907.5107
10:00	4.30	0.8d	250	0.0844	0.2826	0.1981	792.6370
		0.2d	232	0.0845	0.2425	0.1580	681.2095
11:00	4.18	0.8d	240	0.0849	0.3078	0.2229	929.0756
		0.2d	244	0.0847	0.2669	0.1822	746.9318
12.00	5.82	0.8d	244	0.0846	0.4950	0.4104	1683.0954
		0.2d	238	0.0837	0.3275	0.2438	1024.7659
13.00	6.34	0.8d	248	0.0836	0.5766	0.4930	1989.3956
		0.2d	240	0.0842	0.5146	0.4304	1794.5478
14.00	6.44	0.8d	248	0.0843	0.7999	0.7156	2888.6292
		0.2d	242	0.0842	0.6942	0.6100	2523.0611
15.00	6.11	0.8d	236	0.0833	1.0702	0.9869	4183.3891
		0.2d	250	0.0828	0.9044	0.8216	3290.4807
16.00	5.83	0.8d	250	0.0836	0.8463	0.7627	3054.3163
		0.2d	234	0.0837	0.8742	0.7905	3382.5171
17:00	5.47	0.8d	238	0.0843	0.7900	0.7057	2968.4475
		0.2d	250	0.0843	0.6670	0.5827	2332.8519
18.00	5.11	0.8d	248	0.0843	0.7283	0.6440	2599.3213
		0.2d	250	0.0842	0.5384	0.4542	1818.0464

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME	:	Hari	
STATION	:	Ranai	
VERTICAL NO.	:	V1	
POSITION	:	433790 E	626675 N
OBSERVATION DATE	:	28-Mar-08	

Observation Time	Depth Total,d	Depth Sampling	Sample Volume	Weight Filter paper	Weight Sample+Filter paper	Weight Sample Dry Wt	Total Concentration
(hrs)	(m)	(m)	(ml)	(gm)	(gm)	(gm)	(mg/l)
5.00	6.30	0.8d	250	0.0845	0.3350	0.2505	1002.3790
		0.2d	250	0.0841	0.3044	0.2203	881.4931
6.00	6.07	0.8d	240	0.0847	0.4888	0.4041	1630.4380
		0.2d	236	0.0848	0.3453	0.2605	1104.2736
7.00	6.63	0.8d	250	0.0849	0.5662	0.4813	1926.5987
		0.2d	240	0.0855	0.2334	0.1479	616.3933
8.00	5.29	0.8d	228	0.0849	0.3236	0.2387	1047.3436
		0.2d	242	0.0859	0.3179	0.2320	959.0246
9.00	5.05	0.8d	242	0.0861	0.2247	0.1386	572.8511
		0.2d	244	0.0857	0.2231	0.1374	563.2344
10.00	4.87	0.8d	246	0.0859	0.3552	0.2693	1095.1679
		0.2d	250	0.0860	0.2252	0.1392	556.9170
11.00	4.63	0.8d	250	0.0857	0.1959	0.1102	440.8733
		0.2d	250	0.0860	0.1891	0.1031	412.4642
12.00	4.62	0.8d	244	0.0863	0.1961	0.1098	450.0764
		0.2d	246	0.0866	0.1980	0.1114	452.9229
13.00	4.40	0.8d	248	0.0867	0.1946	0.1079	435.1521
		0.2d	242	0.0866	0.1926	0.1060	438.0889
14.00	5.42	0.8d	240	0.0866	0.1790	0.0924	385.0659
		0.2d	236	0.0868	0.1250	0.0382	160.5139
15.00	6.03	0.8d	250	0.0868	0.1858	0.0990	396.0592
		0.2d	250	0.0866	0.1686	0.0820	328.0406
16.00	6.32	0.8d	244	0.0871	0.2488	0.1617	662.8707
		0.2d	244	0.0872	0.2240	0.1368	560.7744
18.00	6.28	0.8d	242	0.0870	0.2314	0.1444	596.8266
		0.2d	250	0.0871	0.1836	0.0965	386.0562



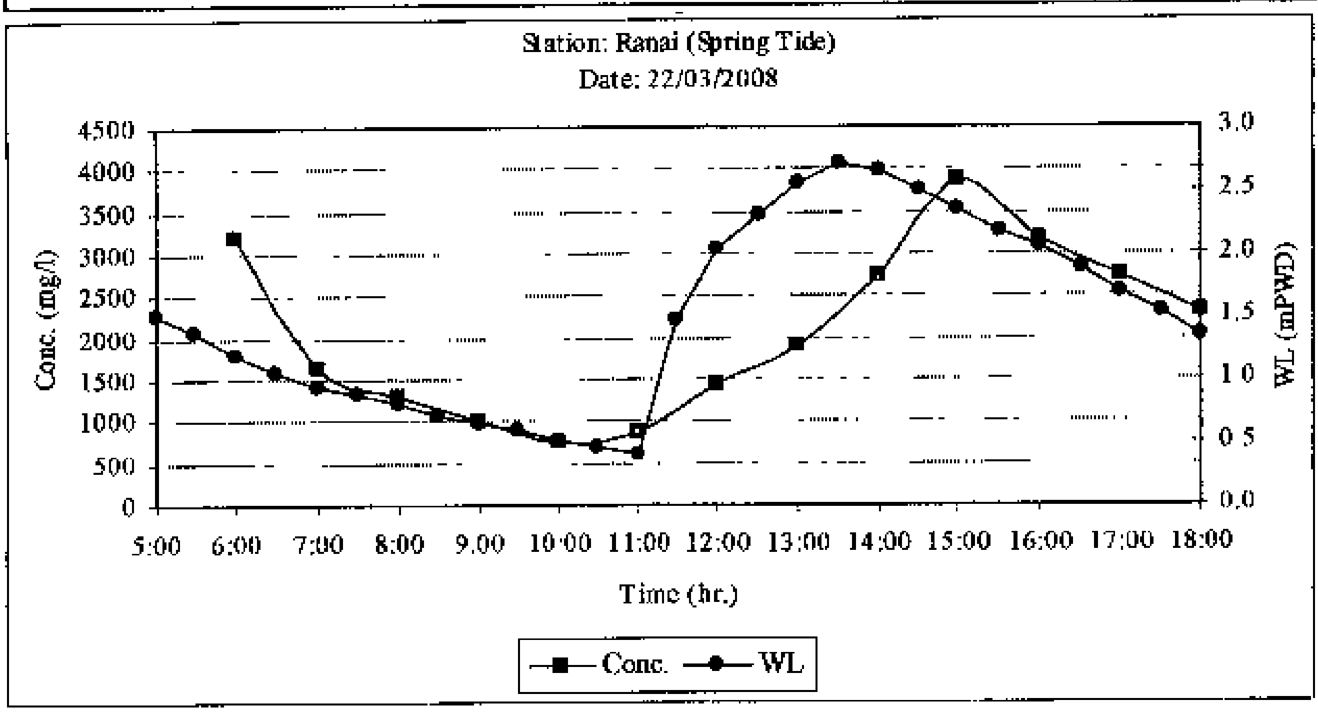


Figure E-1: Sediment profile at Ranai during spring and neap tide.

APPENDIX F

General Description of Numerical Model

Introduction

In order to include the transport and deposition processes of fine-grained material in the modelling system, it is necessary to integrate the description with the advection-diffusion equation caused by the water flow.

MIKE 21 Flow Model FM is based on a flexible mesh approach and has been developed for applications within oceanographic, coastal and estuarine environments. In the case of 2D, the model is depth-integrated. This means that the simulation of the transport of fine-grained material must be averaged over depth and appropriate parameterizations of the sediment processes must be applied.

In the MIKE 21 Flow Model FM , the transport of fine-grained material (mud) has been included in the Mud Transport module (MT), linked to the Hydrodynamic module (HD), as indicated in Figure F-1

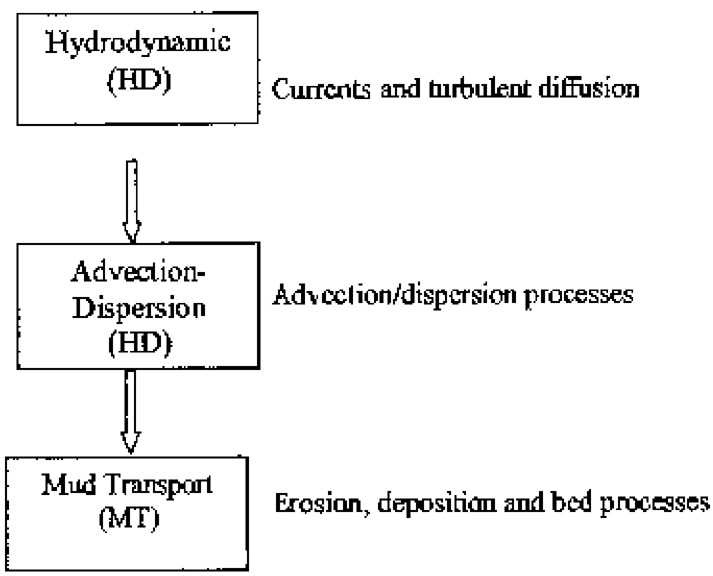


Figure F-1: Data flow and physical processes for MIKE 21 Flow Model FM, Mud Transport calculation.

The processes included in the Mud Transport module are kept as general as possible. The Mud Transport module includes the following processes:

- Multiple mud fractions
- Multiple bed layers
- Wave-current interaction
- Flocculation
- Hindered settling
- Inclusion of a sand fraction
- Transition of sediments between layers
- Simple morphological calculations

The above possibilities cover most cases appropriate for 2D modelling. In case special applications are required such as simulating the influence of high sediment concentrations on the water flow through formation of stratification and damping of turbulence, the modeller is referred to 3D modelling.

Governing Equations

The sediment transport formulations are based on the advection-dispersion calculations in the Hydrodynamic module.

The Mud Transport module solves the advection-dispersion equation.

$$\frac{\partial \bar{c}}{\partial t}+u\frac{\partial \bar{c}}{\partial x}+v\frac{\partial \bar{c}}{\partial y}=\frac{1}{h}\frac{\partial}{\partial x}(hDx\frac{\partial \bar{c}}{\partial x})+\frac{1}{h}\frac{\partial}{\partial x}(hDx\frac{\partial \bar{c}}{\partial x})+Q_L C_L\frac{1}{h}-S \quad \text{(F1)}$$

where,

$\bar{c}$ = depth averaged concentration (g/m^3)
u,v = depth averaged flow velocities (m/s)
D_x,D_y= dispersion coefficients (m^2/s)
H= water depth (m)
S= deposition/erosion term ($g/m^3/s$)
Q_L- source discharge per unit horizontal area ($m^3/s/m^2$)
C_L= concentration of the source discharge (g/m^3)

In cases of multiple sediment fractions, the equation is extended to include several fractions while the deposition and erosion processes are connected to the number of fractions.

Numerical Schemes

The advection-dispersion equation is solved using an explicit, third-order finite difference scheme, known as the ULTIMATE scheme (Leonard, 1991) This scheme is based on the well-known QUICKEST scheme (Leonard, 1979; Ekebjaerg & Justesen, 1991).

This scheme has been described in various papers dealing with turbulence modelling, environmental modelling and other problems involving the advection-dispersion equation. It has several advantages over other schemes especially that it avoids the "wiggle" instability problem associated with central differentiation of the advection terms. At the same time it greatly reduces the numerical damping, which is characteristic of first-order up-winding methods

The scheme itself is a Lax- Wendroff or Leith-like scheme in the sense that it cancels out the truncation error terms due to time differentiation up to a certain order by using the basic equation itself In the case of QUICKEST, truncation error terms up to third-order are cancelled for both space and time derivatives.

The solution of the erosion and the deposition equations are straightforward and do not require special numerical methods.

APPENDIX G

Detailed Cost Estimation for Each Beel

Table G-1: Detailed cost estimation for East Beel Khuksia.

Name of Option	Sub division of Option			Length (m)	Area (m^2)	Quantity	No. of works	Unit	Rate (Tk)	Amount (Tk)	Total Amount (Tk)
Option-1	Compartment-1	Embankment	Around the compartment	7907	23.69	187317	1.00	m^3	69.83	13080334	285848971
		Link canal	Mechanical dredging	50	65.55	3278	1.00	m^3	140.00	458850	
		Re-excavation	Khal present in the compartment	3478	52.76	183409	4.00	m^3	103.43	75917322	
		Cross-Dam	Every dry season	37	225.50	8344	1.00	m^3	131.96	1101008	
		Compensation	Per ha of land for 1 years 4 months			265	1.33	ha	17290.00	6093861	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000	
	Compartment-2	Embankment	Around the compartment	6548	23.69	155122	1.00	m^3	69.83	10832178	
		Link canal	Mechanical dredging	50	65.55	3278	1.00	m^3	140.00	458850	
		Re-excavation	Khal present in the compartment	2747	52.76	144932	4.00	m^3	103.43	59961151	
		Cross-Dam	Every dry season	37	225.50	8344	1.00	m^3	131.96	1101008	
		Compensation	Per ha of land for 1 years 4 months			242	1.33	ha	33592.00	10811921	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000	
	Compartment-3	Embankment	Around the compartment	7071	23.69	167512	1.00	m^3	69.83	11697362	
		Link canal	Mechanical dredging	180	65.55	11799	1.00	m^3	140.00	1651860	
		Re-excavation	Khal present in the compartment	3337	52.76	176060	4.00	m^3	103.43	72839593	
		Cross-Dam	Every dry season	37	225.50	8344	2.00	m^3	131.96	2202017	
		Compensation	Per ha of land for 1 years 4 months			274	1.33	ha	33592.00	12241597	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000	
Option-2		Embankment	Peripheral Embankment around the beel	14910	23.69	353218	1.00	m^3	69.83	24665206	213455375
			Along the both bank of the main khal	5760	23.69	136454	1.00	m^3	69.83	9528611	
		Link canal	Mechanical dredging	180	65.55	11799	1.00	m^3	140.00	1651860	
		Re-excavation	Khals exist in the Beel	2880	52.76	151949	4.00	m^3	103.43	62864258	
		Cross-Dam	Every dry season	37	225.50	8344	4.00	m^3	131.96	4404033	
		Compensation	Per ha of land for 4 years			781	4.00	ha	33592.00	104941408	
		Drainage Outlet	0.9 mm dia pipe sluice			12	1.00	no	450000.00	5400000	
Option-3		Embankment	Peripheral Embankment around the beel	14910	23.69	353218	1.00	m^3	69.83	24665206	355837593
		Link canal	Total number (3),Mechanical dredging	280	65.55	18354	3.00	m^3	140.00	7709690	
		Re-excavation	Khals exist in the Beel	9562	52.76	504491	4.00	m^3	103.43	208718066	
		Cross-Dam	Every dry season	37	225.50	8344	4.00	m^3	131.96	4404033	
		Compensation	Per ha of land for 4 years			781	4.00	ha	33592.00	104941408	
		Drainage Outlet	0.9 mm dia pipe sluice			12	1.00	no	450000.00	5400000	

Table G-1: Detailed cost estimation for Beel Kapalia.

Name of Option	Sub division of Option			Length (m)	Area (m^2)	Quantity	No. of works	Unit	Rate (Tk)	Amount (Tk)	Total Amount (Tk)
Option-1	Compartment-1	Embankment	Around the compartment	6655	23.69	157657	1.00	m^3	69.83	11009194.82	207980170
		Link canal	Mechanical dredging	130	65.55	8522	1.00	m^3	140.00	1193010.00	
		Re-excavation	Khal present in the compartment	1650	52.76	87054	4.00	m^3	103.43	36015980.88	
		Cross-Dam	Every dry season	37	225.50	8344	1.00	m^3	131.96	1101008.26	
		Compensation	Per ha of land for 1years 4 months			254	1.33	ha	17290.00	5840907.80	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000.00	
		Bailey Bridge	About 35m			1	1.00	no	6000000.00	6000000.00	
	Compartment-2	Embankment	Around the compartment	6535	23.69	154814	1.00	m^3	69.83	10810672.09	
		Link canal	Mechanical dredging	130	65.55	8522	1.00	m^3	140.00	1193010.00	
		Re-excavation	Khal present in the compartment	2180	52.76	115017	4.00	m^3	103.43	47584750.50	
		Cross-Dam	Every dry season	37	225.50	8344	1.00	m^3	131.96	1101008.26	
		Compensation	Per ha of land for 1years 4 months			169	1.33	ha	33592.00	7550473.84	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000.00	
		Bailey Bridge	About 35m			1	1.00	no	6000000.00	6000000.00	
	Compartment-3	Embankment	Around the compartment	6653	23.69	157610	1.00	m^3	69.83	11005876.27	
		Link canal	Mechanical dredging	100	65.55	6555	1.00	m^3	140.00	917700.00	
		Re-excavation	Khal present in the compartment	1950	52.76	102882	4.00		103.43	42564341.04	
		Cross-Dam	Every dry season	37	225.50	8344	2.00	m^3	131.96	2202016.52	
		Compensation	Per ha of land for 1years 4 months			235	1.33	ha	33592.00	10499179.60	
		Drainage Outlet	0.9 mm dia pipe sluice			4	1.00	no	450000.00	1800000.00	
Option-2		Embankment	Peripheral Embankment around the beel	11000	23.69	260590	1.00	m^3	69.83	18196999.70	161672991
			Along the both bank of the main khal	2872	23.69	68038	1.00	m^3	69.83	4751071.19	
		Link canal	Mechanical dredging	130	65.55	8522	1.00	m^3	140.00	1193010.00	
		Re-excavation	Khals exist in the Beel	1830	52.76	96551	4.00	m^3	103.43	39944896.98	
		Cross-Dam	Every dry season	37	225.50	8344	4.00	m^3	131.96	4404033.04	
		Compensation	Per ha of land for 4 years			660	4.00	ha	33592.00	88682880.00	
		Drainage Outlet	0.9 mm dia pipe sluice			10	1.00	no	450000.00	4500000.00	
		Bailey Bridge	About 35m			1	1.00	no	6000000.00	6000000.00	
Option-3		Embankment	Peripheral Embankment around the beel	11000	23.69	260590	1.00	m^3	69.83	18196999.70	252170405
		Link canal	Total number (2),Mechanical dredging	230	65.55	15077	2.00	m^3	140.00	4221420.00	
		Re-excavation	Khals exist in the Beel	5780	52.76	304953	4.00	m^3	103.43	126165072.42	
		Cross-Dam	Every dry season	37	225.50	8344	4.00	m^3	131.96	4404033.04	
		Compensation	Per ha of land for 4 years			660	4.00	ha	33592.00	88682880.00	
		Drainage Outlet	0.9 mm dia pipe sluice			10	1.00	no	450000.00	4500000.00	
		Bailey Bridge	About 35m			1	1.00	no	6000000.00	6000000.00	