TECHNICAL FEASIBILITY OF SEDIMENT MANAGEMENT OPTIONS OF BEEL BARUNA IN JESSORE AREA

A Project Submitted

by

Md. Monirul Islam

(Roll No. 100616004 P)

In partial fulfillment of the requirements for the degree of

Master of Engineering in Water Resources Engineering

DEPARTMENT OF WATER RESOURCES ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DHAKA-1000, BANGLADESH

September, 2011

CERTIFICATE OF APPROVAL

We hereby recommended that the M. Engg. Project work submitted by Md. Monirul Islam, Roll no. 100616004 P, Sesson- October, 2006 entitled "**Technical Feasibility of Sediment Management Options of Beel Baruna in Jessore Area**" has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Water Resources on September 26, 2011.

____

Dr. Umme Kulsum Navera — Chairman (Supervisor)
Professor and Head
Department of Water Resources Engineering,
BUET, Dhaka.

____

Dr. M. Fazlul Bari — Member
Professor
Department of Water Resources Engineering,
BUET, Dhaka.

____

Dr. M. Shah Alam Khan — Member
Professor and Director
Institute of Water and Flood Management
BUET, Dhaka.

DECLARATION

This is hereby certified that this project work entitled "Technical Feasibility of Sediment Management Options of Beel Baruna in Jessore Area" has been done by me under supervision of Dr. Umme Kulsum Navera, Professor and Head of the Department of Water Resources Engineering (WRE), Bangladesh University of Engineering and Technology (BUET), Dhaka. I do declare that this project work or any part of it has not been accepted elsewhere for the award of any degree or dimloma from any other institutions.

Md. Monirul Islam
Signature of the Candidate

ABSTRACT

Raising of low lying land inside the beel and maintaining proper drainage capacity of river are the two main objectives of Tidal River Management (TRM) process. But it was observed that sedimentation inside the beels were not uniformly distributed in the previous and current TRM practices in Beel Kedaria and East Beel Khuksia due to technical and operational problems/limitations during TRM process. In the present practice of TRM operation, a link canal is constructed to connect the beel with the river. This results in sediment deposition at the mouth of the link canal, preventing further sedimentation inside the wider area of beel.

In this study sediment management options for uniform sediment deposition in tidal basins have been identified in consideration of existing problems of current TRM practices through review of literature, related reports, studies and better sedimentation inside the beel. Three options for sediment management inside the tidal basins have been identified. In Option-1, existing khal is connected with the river by constructing one link canal and allowing sedimentation in the beel. In Option-2, beel is divided into three compartments by constructing embankment around the compartment and allowing sedimentation in the compartments one after another. In Option-3, embankments are constructed along both banks of the main khal through the beel and cutting the embankment part by part gradually from upstream to downstream. Technical feasibility of these options have been assessed by a cohesive sediment transport model using MIKE21 FM modelling system.

Deposition volume in Beel Baruna in Jessore district for the three options have been assessed. The total deposition volume after four years operation for Option-1, Option-2 and Option-3 are 2.28, 2.97 and 3.12 million m^3, respectively, in the beel area. Provision of dredging or manual re-excavation has been considered for all of the three options. It has been found that the maximum sediment deposition occurs in Option-3 and the minimum sediment deposition occurs for Option-1. Level of deposition for different options have been analyzed and found that deposition is more uniform in Option-3. The total construction costs of four years operation for different options also have been estimated. The minimum cost is required for Option-3. From the study it has been found that Option-3 is prefered in the study area.

ACKNOWLEDGEMENT

The author would like to mention with gratitude Almighty Allah’s continual kindness without which no work would reach its goal. The author is highly grateful and obliged to his honorable supervisor, Dr. Umme Kulsum Navera, Professor and Head, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka, for her continuous guidance, constant support, supervision, inspiration, advice, infinite patience and enthusiastic encouragement throughout this research work.

The author would like to express gratitude to the members of the Board of Examination namely Dr. M Fazlul Bari, Professor, Department of WRE and Dr. M. Shah Alam Khan, Professor and Director, IWFM for their contribution in various ways for completing this study report.

The author is highly gratitude to Dr. Md. Monowar Hossain, Executive Director, Institute of Water Modelling, for allowing him to work in IWM office and providing him all types of logistic support includmig data. 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 its study.

The author expresses his highly indebted to Md. Mobassarul Hasan, Associate Specialist, Coast, Port and Estuary Management Division, IWM, for his cordial cooperation 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.

I am deeply indebted to my wife Jannatul Mawa for her continuous encouragement and inspiration during the whole project works. Special acknowledgement is due to author’s parents and family members for their well wishes, prayers, encouragement and inspiration during the period of work.

Finally, the author likes to express his sincere gratitude to all other teachers and members of the Water Resources Engineering Department, BUET, for their cooperation and help in the successful completion of the work.

Table of Contents

List of Figures

Figure No		Page No.
Figure 5.4.6	Schematization of Beel Baruna for Option-3 with no embankment	45
Figure 5.6.1	Simulated deposition pattern inside the tidal basin after first for Option-1	46
Figure 5.6.2	Simulated deposition pattern inside the tidal basin after second year for Option-1	47
Figure 5.6.3	Simulated deposition pattern inside the tidal basin after third year for Option-1	47
Figure 5.6.4	Simulated deposition pattern inside the tidal basin after fourth year for Option-1	48
Figure 5.6.5	Simulated deposition pattern inside the Compartment-A after 16 month operation for Option-2.	49
Figure 5.6.6	Simulated deposition pattern inside the Compartment-A and B after 32 month Operation for Option-2	49
Figure 5.6.7	Simulated deposition pattern inside the Compartment-A, B and C after 48 month operation for Option-2	50
Figure 5.6.8	Simulated deposition pattern inside the tidal basin after first year with embankment length of 3800 m for Option-3	50
Figure 5.6.9	Simulated deposition pattern inside the tidal basin after second year with embankment length of 2800 m for Option-3	51
Figure 5.6.10	Simulated deposition pattern inside the tidal basin after third year with embankment length of 1800 m for Option-3	51
Figure 5.6.11	Simulated deposition pattern inside the tidal basin after fourth year with no embankment for Option-3	52
Figure 5.8.1	Deposited area plot for Option-1	54
Figure 5.8.2	Deposited area plot for Option-2	54
Figure 5.8.3	Deposited area plot for Option-3	55

List of Tables

List of Abbreviation

BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
EGIS	Environmental and Geographic Information Services
GOB	Government of Bangladesh
HD	Hydrodynamic
IWM	Institute of Water Modelling
KJDRP	Khulna-Jessore Drainage Rehaliatation Project
LGI	Local Government Institution
MT	Mud Transport
PWD	Public Works Department
SSC	Suspended Sediment Concentration
SWMC	Surface Water Modelling Centre
SMEC	Snowy Mountain Engineering Corporation Limited
TB	Tidal Basin
TRM	Tidal River Management
WMA	Water Management Association
WMG	Water Management Group

Chapter 1
INTRODUCTION

1.1 General

Bangladesh is a land of rivers. Most of the rivers in Bangladesh are part of the great Ganges-Brahmmaputra-Meghna River systems. In the southwest region of Bangladesh, a large number of tidal rivers flow which are characterized by erosion and sedimentation and discharge in the Bay of Bengal. Most of the rivers of this region have been silted up. As a result the areas have been suffering drainage congestion and water logging problems for quite a long time. To solve this problem Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was implemented. After implementation of the KJDRP, the prevailing drainage congestion and water logging problems were partially solved by introducing a popular concept based on Tidal River Management (TRM). But unsatisfactory and non uniform sedimentation inside the beels during TRM operations resulted in people's unwillingness to allow their land for TRM operation. Now proper and functional sediment management options have become a key requirement to make TRM successful in the area.

1.2 Background of the Study

The southwest region of Bangladesh is characterized by numerous morphologically active tidal rivers which form the main drainage network for coastal polders and low-lying beels. The entire river system of the region is vulnerable to excessive sedimentation by the incoming silts from the downstream sea with high tide, especially during the dry season (IWM, 2010). The sedimentation effects of similar river and floodplain interventions were described by Sarker (2004).

After implementation of coastal polders in the early 70s, the rivers in this part of Bangladesh gradually started to silt up. Moreover, decrease of flushing fresh water flow from the upstream rivers accelerate sedimentation in the area. The presence of polders restricts the natural tidal flows and prevents sedimentation on low-lying lands. This caused sedimentation in the peripheral rivers of the polders and reduced drainage capacity. As a result, the areas inside the polders have been suffering from water logging and drainage congestion problems for quite a long periods. To solve these long-standing water logging problems, the KJDRP was implemented during 1994-2002 by BWDB (IWM, 2010).

Later, a popular concept based water management practice, known as TRM, was adopted. In TRM process, natural movement of tidal water into a beel is allowed and the beel functions as a tidal basin. During flood tide, tidal flow carrying sediments enter the tidal basin and the sediments are deposited due to reduction of current speed in a wider beel area. During ebb tide the tidal water flows out of the beel with reduced sediment load and erodes the river bed by hydraulic dredging. Thus, the adequate drainage capacity of a tidal river is maintained naturally (IWM, 2009). After implementation of the KJDRP, the prevailing drainage congestion and water logging problems were partially solved and agricultural, social and economic benefits were achieved (SMEC, 2002).

TRM concept was practiced in Beel Bhaina and Beel Kedaria during 1998-2001 and 2002-2005, respectively. Beel Bhaina tidal basin was closed in 2001 after sedimentation inside the tidal basin. But in the case of Beel Kedaria tidal basin, sedimentation inside the beel was not satisfactory as desired by the land owners. For this reason, Beel Kedaria tidal basin had to be closed in 2005 due to cultivation of Boro crop inside the tidal basin. This closure of tidal basin resulted in severe siltation in the Teka-Hari River system during March-May 2005 and the entire Teka-Hari River lost its drainage capacity remarkably within 3 to 4 months. This morphological change of Teka-Hari River system caused severe water logging in the Bhabodah and adjoining areas (IWM, 2007). Later on, operation of East Beel Khuksia for TRM was started in 2006 and it has been functioning till to-date (IWM, 2010). Monitoring results of Beel Kedaria and East Beel Khukshia TRM process show that sedimentation inside the tidal basins are not uniform and people are not satisfied of allowing their land for TRM operation (IWM, 2007).

So, the areas require further attention for unsatisfactory and non-uniform sedimentation inside the beels during TRM. Unsatisfactory and non-uniform sedimentation ultimately causes conflicts among farmers, fishermen and landowners during TRM. Sediment management is the most challenging and important technical aspect 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 and they can cultivate more crops. But monitoring results of previous and present TRM practices 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 (Amir, 2010). Thus, a functional sediment management plan is required for successful TRM practices in future.

The study area consists a large number of beels which are very potential for TRM process. A sequential operation for TRM process is needed for long term solution of drainage congestion in the area (IWM, 2010). As dredging of river is an expensive operation, it can not be a long term solution for the area. The areas require a technically feasible solution for long term removal of drainage congestion problem with managing sedimentation.

In present TRM process, usually one or two link canals are constructed that connect the beel with the river. In this process, sediment deposition occurs mostly near the mouth of link canal, it obstructs spreading of sediment in the wider beel area and creates a non-uniform sedimentation. Non-uniform sedimentation causes uneven land development and people's unwillingness to give up their land for 3 or 4 years. To solve this problem, a better functional technique for uniform and effective sedimentation inside the beel is essential which can relieve long term drainage congestion and water logging problem from the study area with improvement of social and environmental conditions.

1.3 Objectives of the Study

The objectives of the study were:

1. To identify and analyze the causes behind the problems with sediment management practices in the coastal polders.

2. To determine different technically feasible options for uniform sediment deposition in Beel Baruna tidal basin by using a sediment transport model.

1.4 Scope and Limitations

This study has identified sediment management options for uniform sediment deposition in tidal basins in the southwest region of Bangladesh. Technical feasibility of those options have been verified by a cohesive sediment transport model using MIKE21 FM modelling system in a selected beel. The best option has been selected after analysis of the results from option simulations and estimates of construction cost.

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. Stakeholder consultation could not be carried out due to time and resource constraints.

1.5 Organization of the Thesis

The thesis consists of six chapters. The contents of the chapters are as follows:

Chapter 1 provides detailed background information, objectives and scope.

Chapter 2 gives a review of relevant literature. It contains definition and concepts of tidal basins, history of TRM, causes of water logging and sedimentation in the study area, performance and lesson learnt from previous studies and tidal basins under TRM.

Chapter 3 describes methodology followed in the present study. The standard procedure that followed in this work is presented with relevant references here. The method of analysis is also included in this chapter.

Chapter 4 contains detailed information of the study area including geographical location, water resources, climate, tidal and sediment characteristics.

Chapter 5 contains results and discussions of the present study. Results and discussions describe identification and finalization of sediment management Options for uniform deposition in the study beel. It also contains estimates of construction cost for TRM operation for the selected Options.

Chapter 6 contains conclusions and recommendations of the study. The major findings of the study are shown in this chapter.

The thesis also includes 6 Appendices contain bathymetry and schematization of sediment transport model of Beel Baruna (Appendix-A), water level and discharge hydrograph (Appendix-B), long section and cross section of Hari-Teligati-Gengrail River beds (Appendix-C), suspended sediment concentration data of rivers (Appendix-D), general description of numerical model (Appendix-E), detail cost estimate for Beel Baruna TRM (Appendix-F).

Chapter 2
REVIEW OF LITERATURE

2.1 General

A large number of beels and low-lying areas exist in the study area and most them have no connection with rivers. Due to disconnection of the beels with river, tidal water can not enter into beels resulting sedimentation on the river beds and causing water logging and drainage congestion problems in the study area. This chapter describes relevant literature, causes of water logging and performance of previous and present TRM practices in the study area.

2.2 Beel and Tidal Basin

A Beel is a natural depression which may vary in size from a few to thousand hectares. Normally, beels are formed by inundation of low lying lands during flooding, where some water gets trapped even after flood waters recede back from the flood plains. Beels may also be caused by filling up of low lying areas during rains, specially during the monsoon season.

There are different causes for the formation of beels. 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 normally the land between two rivers remain low-lying. Such a low-lying land is known as a beel (Amir, 2010).

A Tidal Basin is also a depressed low-lying area adjacent to the tidal rivers carrying sediment. In the study area, a large number of potential tidal basin exist which can be very useful to manage the tidal rivers of the study area carrying huge sediment (Figure 2.2.1). Due to existence of coastal polder in the study area, major beels and low-lying areas have no link with the river. For this reason tidal flow of river carrying sediment cannot spread inside the beel/basin especially in the dry season.

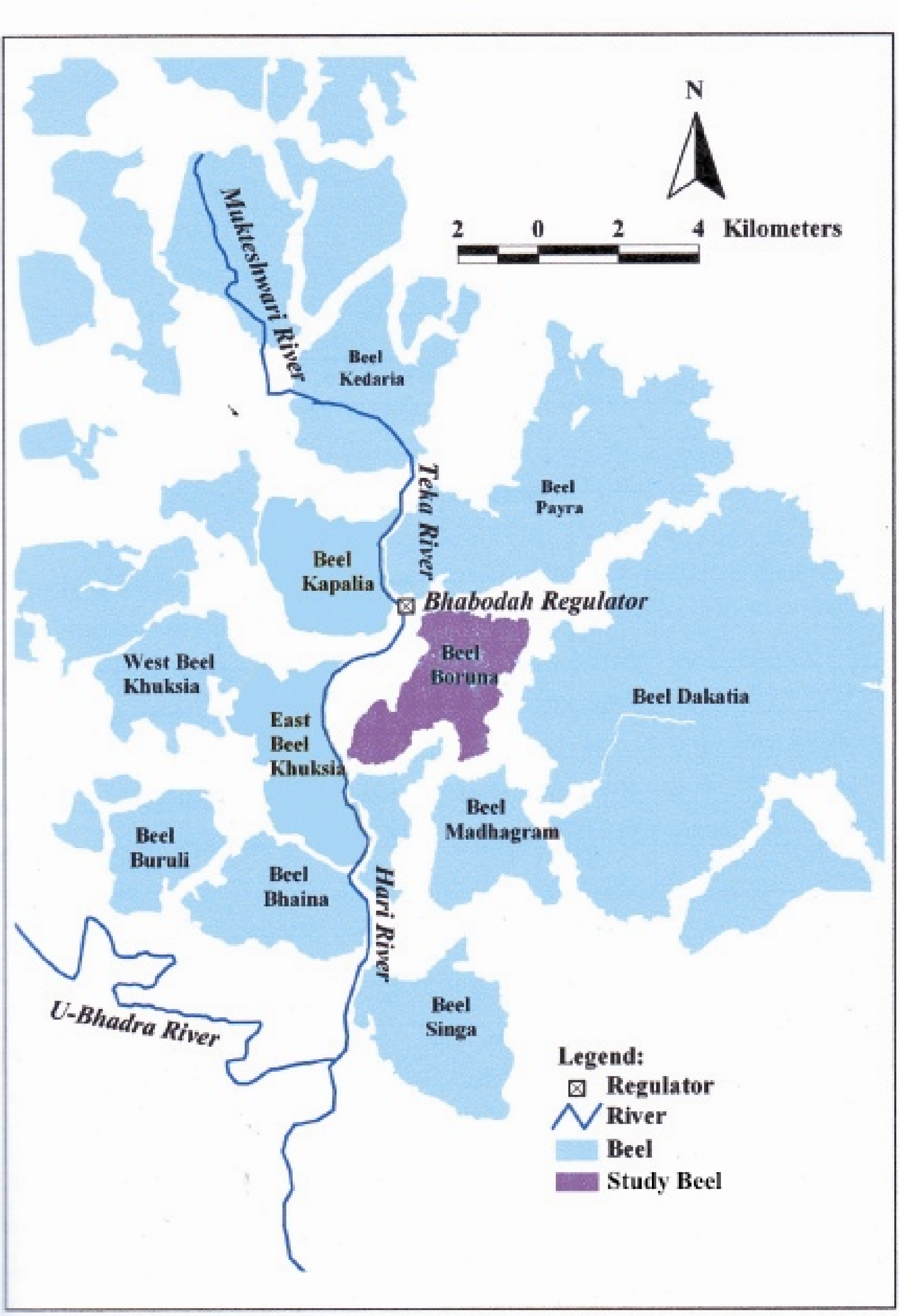

Figure 2.2.1: Beels in the study area (Source: IWM, 2007)

The concept of the sediment management in the 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 (Figure 2.2.2). Peter Conover Hains, an engineering officer in the U. S. Army, oversaw the design and construction.

The basin is designed to release 250 million gallons of water captured at 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, remain close to store incoming water and to block the flow of water for sedimentation in the basin. When the tide begins to ebb, the outlet gates open with the channel and the inlet gates remain close. Silt build up in the channel 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 (Green, 1974).

Figure 2.2.2: Protomac River Tidal Basin (Source: Internet)

2.3 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 volume of 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) 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 in the form:

According to O'Brien, 1931

$$A_c = C.P^n \qquad (2.3.1)$$

Where, Ac = minimum inlet cross-sectional area in the equilibrium condition, C = an empirically determined coefficient, P = tidal prism in Mm^3 and n = an exponent usually slightly less than unity.

This type of analysis was carried out for the Hari River. With a view to establish 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 relationship was found between cross-sectional area and tidal prism expressed by the following equation (IWM, 2007):

$$A_c = 43.42P^{0.9985} \qquad (2.3.2)$$

Where, P = mean tidal prism in Mm^3

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 2.3.1.

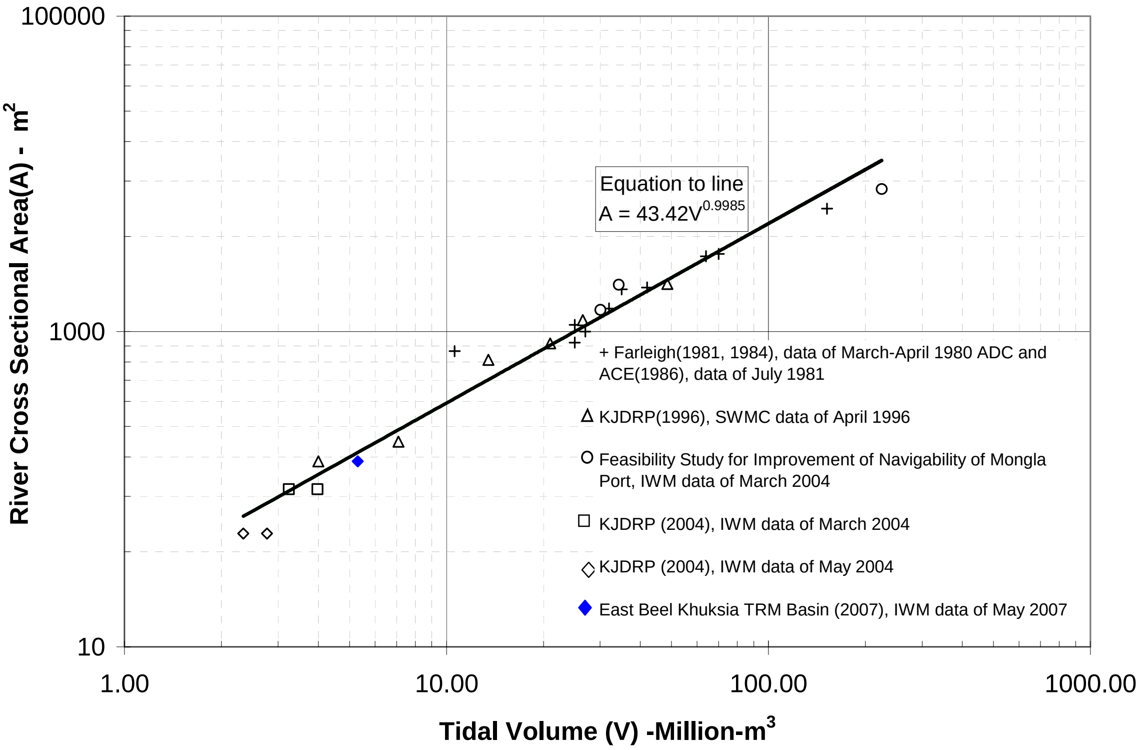

Figure 2.3.1: O'Brien equilibrium relationship updated with recent data

(Source: IWM, 2007)

According to O'Brien's equilibrium relationship developed for southwest region, the generated tidal volume of Hari River at Ranai under changed morphological condition is sufficient to maintain the required drainage capacity of the river.

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 increasing 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 deposition of sediment in the dredged river reach. This process stops when the equilibrium profile has been restored.

2.4 Historical Developments of Coastal Polders

In the study area, crop failure due to saline water inundation and monsoon flooding was common. Since 17th century, Zamindars/Landlords temporarily constructed low dikes and wooden sluice gates around the area to protect the arable land from above hazards. In the rainy season, farmers exchanged saline water of their fields with river water when it became almost sweet. Sweet water normally washed away the salinity from the land. Thus they got good harvest of paddy as well as varieties of fish. Due to this traditional practice, there was a balance between sedimentation and subsidence of the area. Thus, the environment, eco-system and bio-system evolved in the coastal area were in equilibrium. As the dikes were not sufficiently high and strong, the problem of crop failure still existed. Opening of sluice gates were not enough and gates were weak. These were temporary structures and need to be repaired every year. After abolition of Zamindars/ Landlords system, the maintenance of these structures became disrupted. As a result, the problem related to land-water management became serious and crop failure occurred frequently. In 1959, to solve this problem, a big program of construction and maintenance of permanent polders was undertaken by the government. The main objectives were to protect the arable lands from tidal inundation and flooding, and to achieve more crop production (SMEC, 2002). Thus construction of coastal polders were established.

The polders were 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).The creation of polders greatly complicated the existing drainage network, which comprised a very large number of tidal creeks and rivers of all sizes, resulting in substantial decrease in the total tidal volume accompanied by an increase in tidal range. After more than a decade of high productivity, drainage congestion began to affect the northernmost polders from the 1980s (DHI, 1993).

2.5 Tidal River Management in the Study Area

Tidal river management (TRM) involves taking full advantage of the natural tide movements in rivers. During flood tide, tide waters transporting sediments are allowed to enter into low-lying areas (tidal beels) where the sediments are deposited. During ebb tide the tidal water flows out of the beels with a greatly reduced sediment load and erodes the river bed. Thus, the adequate drainage capacity of a tidal river is maintained naturally. The natural movement of the flood and ebb tides along the downstream river ensures that it maintains a satisfactory hydraulic capacity to transport drainage water from the upstream area during and after the monsoon period (IWM, 2007).

By implementing TRM in the study area more and more waterlogged area 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. 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).

2.6 Origin of River Sediment in the Study Area

Usually sedimentation from the upstream area of a river occurs due to change of land use, 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. But in the case of the study area, upstream areas are very flat and excessive erosion is very small (SMEC, 1997a).

From the 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 in tidal flows. This movement of sediment is also confirmed by the field measurements of sediment concentrations and tidal flows by SWMC (June 1996 and October1996) and other measurement programs. In the study 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).

2.7 Causes of Water Logging and Siltation Problem in the Study Area

Due to polderization in the study area, no water is able to enter into the tidal flat. Sedimentation takes place on the channel bed, causing very rapid deposition on the channel bed and no or very limited sedimentation on the tidal flat. These processes upraise the rive bed higher than the adjacent tidal flats, effects of which ultimately cause inundation in tidal flats and drainage congestion. This is the main cause of water logging and siltation problems in this region (SMEC, 1997).

Coastal Polders constructed in the study area without considering the morphodynamics, geological conditions and tectonic of the area. The land and water management of each geologic and geomorphic unit is different from other units. Moreover, the morphodynamics of the boundary zone of two or more units is very complex. During construction of the polders, authority did not consider these units. Due to overlapped polders, morphodynamics become very complex. Ultimately, it causes different types of problems such as water logging, siltation, etc. (SMEC, 2002).

In the study area, the Matabhanga and the Gorai rivers are the main distributaries of the Padma river. About 160 years ago, the Matabhanga River began to silt up at its mouth and now completely silted up. Due to siltation of this river, all its distributaries are now receiving practically no water from upstream region (Kumar, Chitra, Bhairab, Kabadak, Nabaganga, etc.). Only the Kumar river is receiving very little water in the rainy season. Similarly, the mouth of the Gorai river, about 140-150 years before, began to silt up. Later due to construction of the Gorai railway bridge near Kushtia city, the rate of siltation increased tremendously . Now this river is receiving almost no water in the dry season. Moreover, construction of Farakka Barrage on the Ganges river caused a sudden decrease of flow below the Ganges river known as the Padma river and its distributaries. Just after withdrawal of the Ganges water by Farakka Barrage in 1976, the rate of siltation on river beds increased tremendously specially, in the Ganges tidal plain (Sarker, 2004).

Recently, the communication networks of the study area developed tremendously. Most of the roads are in east-west direction whereas the regional slope and drainage directions are in the north-south direction. So, east-west roads are obstructing the natural drainage and are enhancing drainage problem in this region.

Mismanagement of sluice gates and willful misuse of land and water by the influential people are also important causes of water logging. For example, each tidal channel has its own catchment area and if anyone closes it for pisci-culture, it will cause inundation to its upstream and make conflict of shrimp farming and paddy cultivation (CEGIS, 2002c).

2.8 Initiatives to Solve Water Logging Caused by the Coastal Polders

Fifteen years after the construction of the coastal embankments, water logging began to emerge in the polders of upper part of this region. The people of the waterlogged area initially thought water logging to be a temporary problem and petitioned the authority to solve it. Gradually, however, with the realization of its severity, solving water logging became a people’s demand. As the authority paid no heed to their grievances, people themselves took the initiative to organize and mobilize the community and devise plans for solving the problem. From their own experience and observation, people could identify the polders as the main cause for water logging and began to present their reasoned arguments for breaching or cutting away polders to allow unrestricted tidal flows for solving the problem. Their logic was that if tidal flows can be made free, the navigability of the rivers will be restored, the beels will be free from water logging, alluvial’s will accumulate inside the beels and as a result the bed level of beels will rise. The first manifestation of this logic was seen in September, 1990, when the polder of Beel Dakatia was breached at four places (EGIS, 2001).

Through one of the four cuts made in the embankment, Beel Dakatia was again connected with the river Hamkura (Figure 2.8.1). Through regular tidal actions and the accumulation of alluvial, the land formation process of the beel resumed. The experience has proved that if people take initiatives to face their problems, they can expose the faults of any large engineering work that concerns their lives and livelihood.

The success in draining out water of Beel Dakatia encouraged people of adjacent waterlogged areas. They organized themselves and formed committees at different levels and took initiative to turn their waterlogged land into agricultural land again. Madhukhalir beel and Patra beel are examples of such collective efforts. But, these efforts could not achieve desired results at every stage because of a lack of proper organizational structure, planning and sediment management.

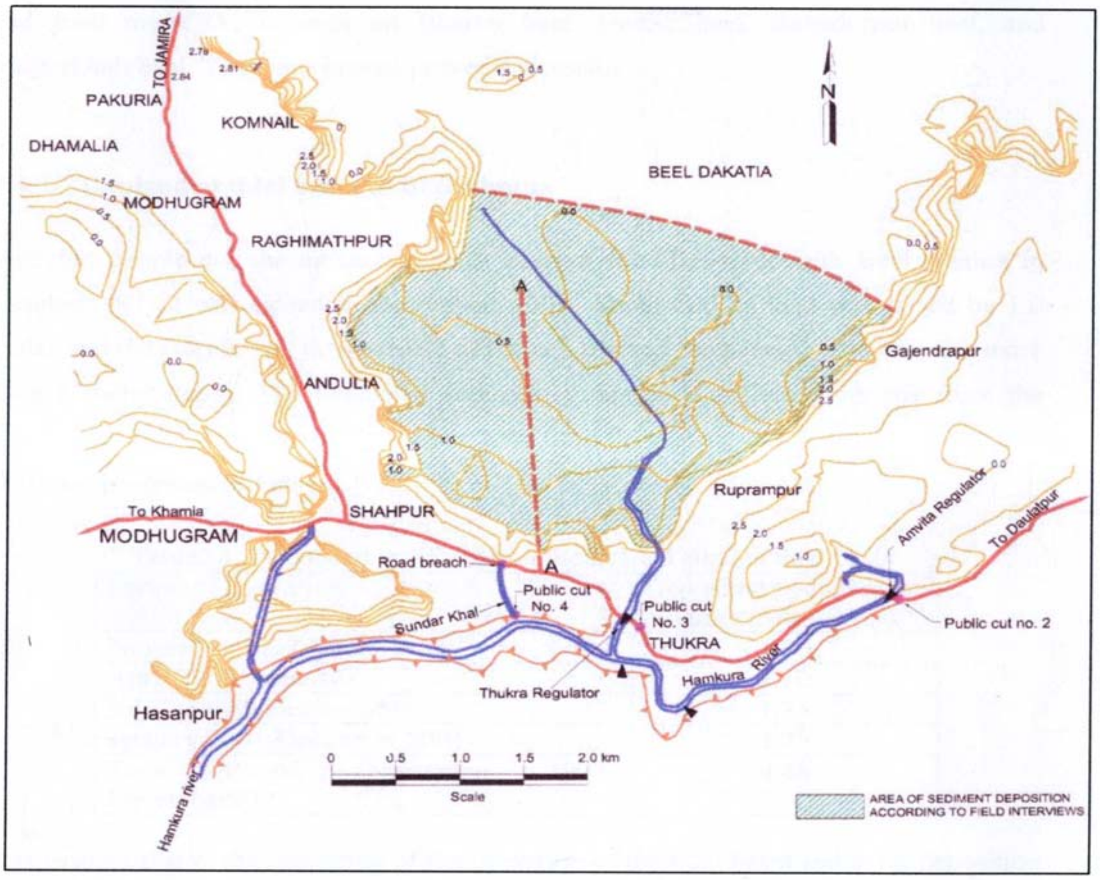

Figure 2.8.1: Public Cuts in Beel Dakatia (Source: IWM, 2002)

However, the initiatives and innovativeness of people drew attention of the policy makers and donor agencies and they began taking people's involvement in solving the problem of water logging quite seriously.

In the mean time, Bhabadaha (Jessore zone) area started to experience widespread water logging. The people of the area organized themselves to solve the problem. They removed the accumulated silt in front of the Bhabadaha sluice gates every year with their own hands and opened a narrow drainage channel. Thus, every year, they retrieved some land for agricultural production (CEGIS, 2002).

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 some 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 (EGIS, 2001).

When the coastal Embankment was implemented, all the tidal flood plains were enclosed with in 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 (Amir, 2010).

2.9 Institutionalization of Tidal River Management

The people of the area should be involved from the onset and included in the planning and design future activities. Such involvement will necessitate the development of an institutional framework that would be able to encourage and co-ordinate participation of the local people and their organizations (formal and informal). At the same time, it will be necessary to maintain effective linkages with other government agencies at the various tiers-in particular, the local government structure at the bottom, and the NGOs operating in the project areas. Given the experience and modus operandi of the project area, this will be a rather difficult task. The remainder of this section first gives an overview of the organization of the project. It subsequently presents suggestions that have been made to support an institutional framework and the participation of the local population. Finally, it makes an assessment of the institutional “manageability” of the different options (EGIS, 1998). For successful TRM practices in the study area institutionalization has a great importance.

2.10 Previous Experiences of Tidal River Management

2.10.1 Tidal River Management in Beel Kedaria

Beel Kedaria Tidal Basin started its operation on 31 January 2002. Monitoring results for Beel Kedaria tidal basin shows 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 (Figure 2.10.1) 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 2.10.1 that the drainage capacity was also higher compared to the design one during the operation of Beel Kedaria.

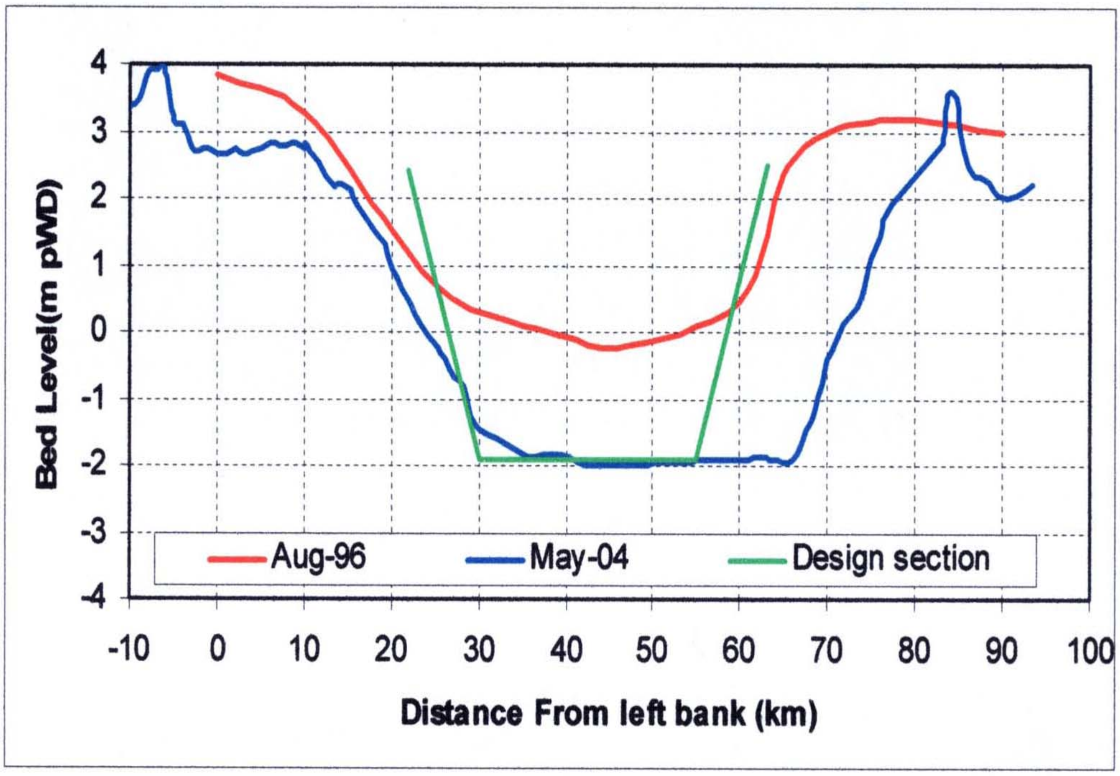

Figure: 2.10.1: Stability of drainage capacity of the Hari river at Ranai during the operation of Beel Kedaria Tidal Basin (Source: IWM, 2005)

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 2.10.3). Sediment deposition near the opening of Beel Kedaria Tidal Basin is about lm higher compared to other areas.

But during the dry season of 2005, the Beel Kedaria Tidal Basin could not be operated due to cultivation of Boro crop on a portion of land inside the tidal basin by the land owners. Land owners of the beel closed the Bhabodah regulator and there was no tidal movement into the Beel Kedaria Tidal Basin. Due to this discontinuation of TRM, severe siltation took place in the Teka-Hari River system during February-April 2005 (Figure 2.10.2).

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

Figure: 2.10.2: Siltation on river bed and water logging problem (Source: IWM, 2007)

2.10.2 Tidal River Management in Beel Bhaina

Beel Bhaina started as a tidal basin from 29 october 1997, and continued upto 8 December 2001. Monitoring result of Beel Bhaina shows that its 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 (Figure 2.2.1) in downstream of East Beel Khukshia.

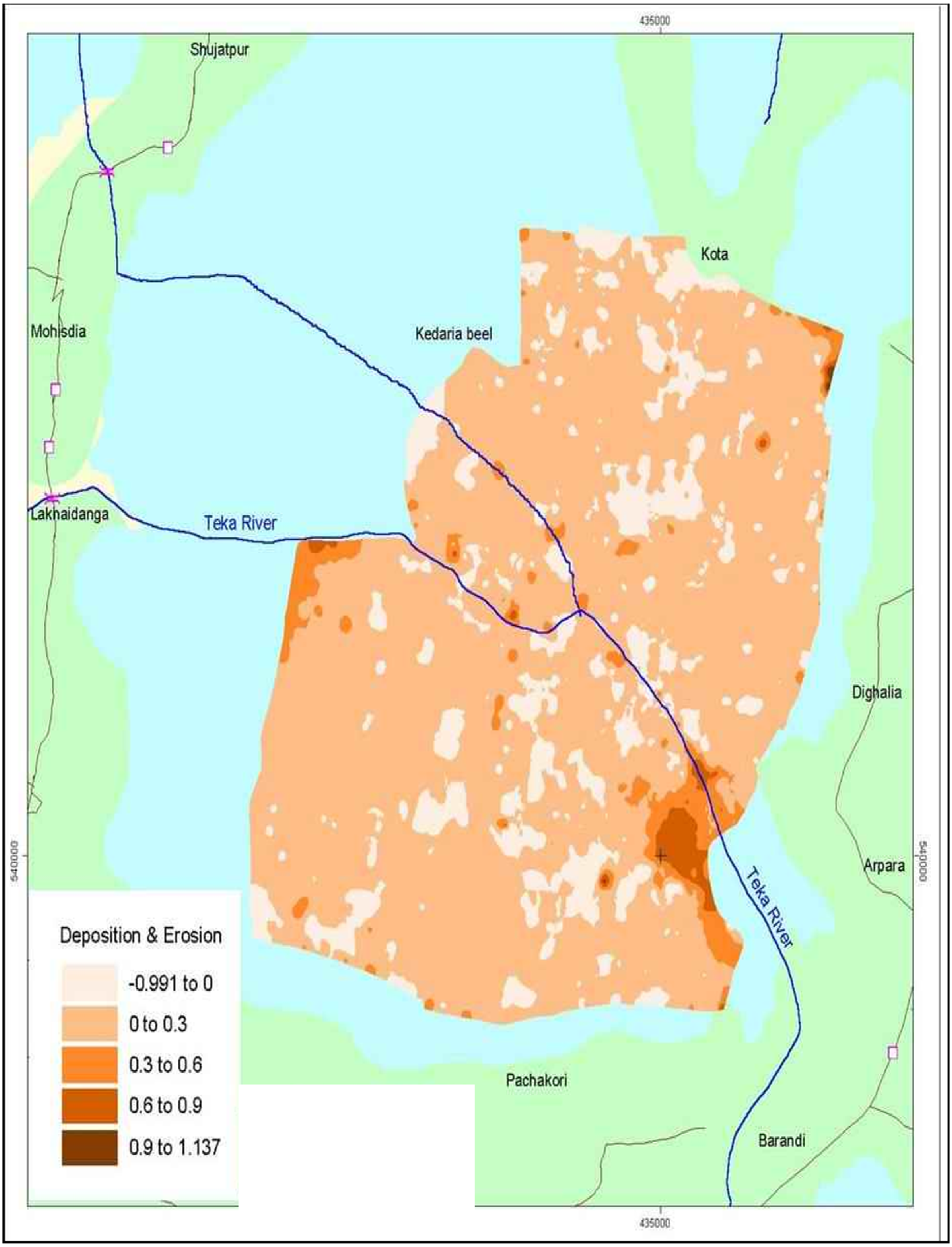

Figure: 2.10.3: Map showing deposition and erosion in the Beel Kedaria Tidal Basin between March 2002 and May 2004 (Source: IWM, 2005)

The tidal range in the location of Beel Bhaina was more than 1.0 meter, as 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, location and proper selection of beel is very important for successful TRM.

2.10.3 Tidal River Management in East Beel Khukshia

Operation of TRM in East Beel Khukshia started from December 2006 and continues till to date. River bed scouring and sedimentation in the beel is satisfactory. A cross section of Hari river at Ranai before TRM and after implementation of 5.5 month TRM operation is shown in the figure 2.10.4.

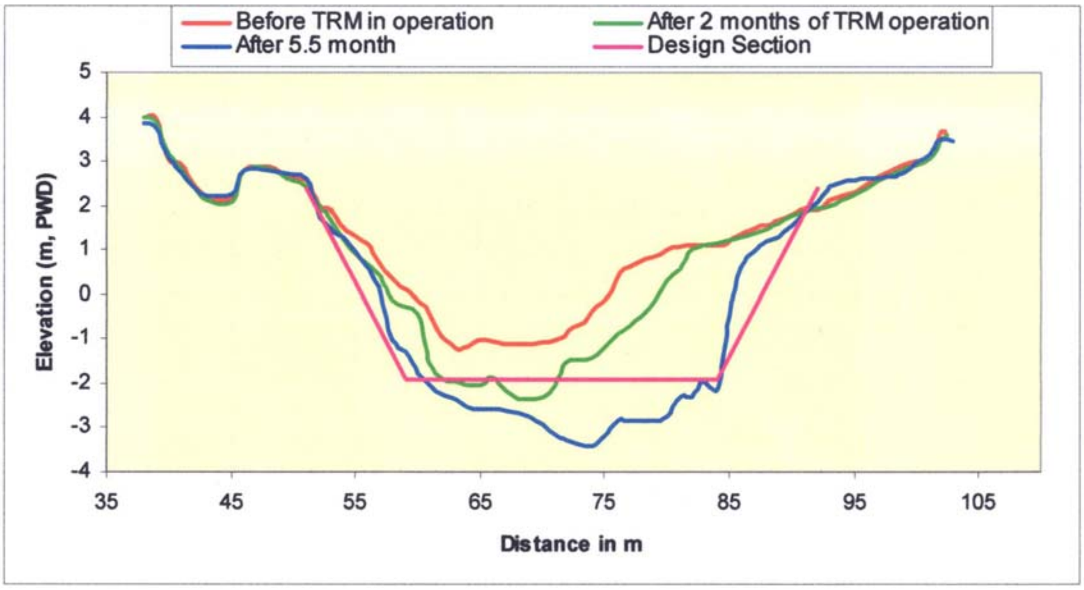

Figure: 2.10.4: Comparison of cross section of the Hari River at Ranai after 5 month of TRM operation (Source: IWM, 2007)

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 remarkably 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 (Figure 2.10.4).

Deposition of sediment in the tidal basin is an important issue as it determines the life time of the tidal basin as well as development of land for agricultural production. Figure 2.10.5 show deposition and erosion in the East Beel Khuksia tidal basin between February and may 2007. It is apparent that deposition occurred mostly nearest to the cut point.

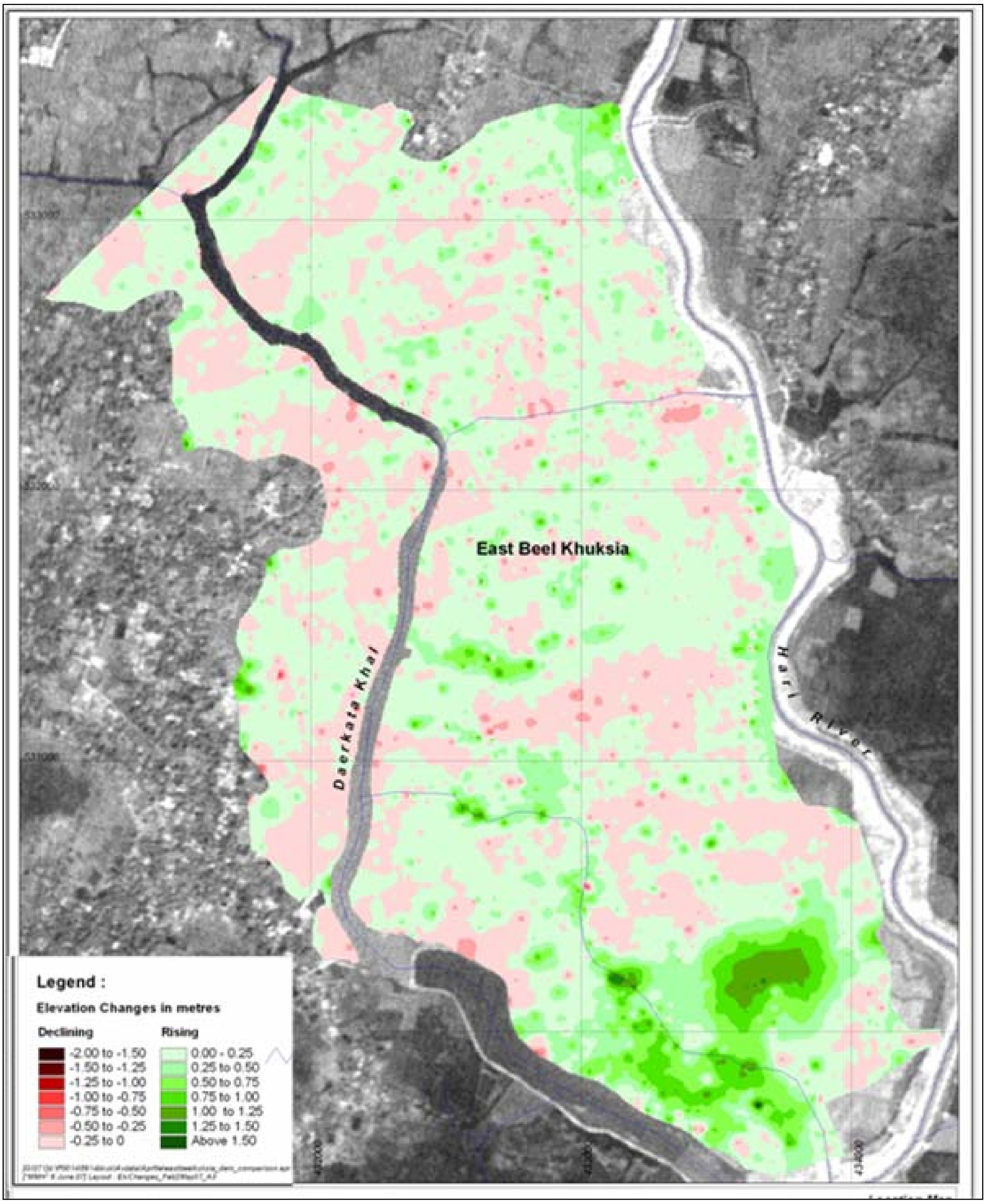

Figure: 2.10.5: Map showing deposition and erosion in the East Beel Khukshia Tidal Basin between February and May 2007 (Source: IWM, 2007)

2.11 Previous Studies

Amir (2010), conducted a study on socially acceptable and technically feasible sediment management options in East Beel Khuksia which is located parallel and opposite bank of Beel Baruna. Study was conducted using numerical modeling and participatory field research tools. Options of that study were selected using participatory rural appraisal techniques with participation of local people of the study area. Options selected of that study are given below:

Option-0 : Current sediment management practices.

Option-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.

Option-2: Embankments are constructed along both banks of main khals through the beel and thereby allow sedimentation by cutting the embankment part by part gradually from upstream to downstream.

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.

From model results of that study for different options for East Beel Khukshia, Option-2 was preferred for the study area.

2.12 Lessons Learnt from Previous Tidal River Management Practices

Sediment management inside the beel and maintaining proper drainage capacity of the river through operation of a beel by TRM is the main objective in the study area. To do this, previous TRM experience is very important for future TRM attempt in the study area.

It is seen from the previous TRM practices that almost all cases sediment deposition mostly occurred at the mouth of the tidal basin. Moreover it is observed that sediment deposition is very non-uniform throughout the whole basin. This non uniform sedimentation makes people unwillingness to allow their land for basin operation for long time (normally 3-4 years). So, the main objective was not attained by the TRM practice for the lack of technical effectiveness during operation. Thus, uniform sedimentation in the TRM basin becomes essential aspect for effective TRM in the study area. As present TRM practices have some limitation for uniform sedimentation throughout the beel, i.e. better sediment management option is required for TRM operation in the study area. Besides, institutionalization of TRM is required, because social conflicts among various groups like farmers, fisherman, landowners, etc., and institutional conflicts among government agencies, water management group (WMG), water management association (WMA) and local government institutions (LGIs) have made the TRM practices unsuccessful (CEGIS, 2002c).

2.13 Summary

In this chapter relevant literatures related to the study work have been included. Previous history of construction of coastal polder, sedimentation, drainage congestion and different aspects of Tidal River Management (TRM) in the southwest region have been discussed extensively. Drainage congestion due to sedimentation and long-term solution by TRM for the study area have been incorporated to give a brief outlook on the matter. Previous and existing TRM process have been shown using satellite images, hydrographic plots and photographs. Situation has been discussed to give significant idea and knowledge for proper sediment management in the study area. Previous relevant studies in the study area also have been discussed. This extensive review of literature will be helpful to understand the subject matter of this project work.

Chapter 3
METHODOLOGY

3.1 General

The key question for the study was identified through literature review, related reports and papers. Conceptual and methodological frameworks for the study were prepared before execution of the research. The methodologies followed in the study can be categorized in following steps:

1. Selection of beel for the study.
2. Secondary data collection and processing.
3. Identification of sediment management options.
4. Development of sediment transport model to find a technically feasible sediment management option for uniform sediment deposition in the study beel during TRM operation.

3.2 Selection of Beel for the Study

Beel selection process for the study was mainly involved extensive review of related reports, papers, secondary data and literature. It is one of the major component of the study. Beel selection criteria mainly depends on its location and operable area of tidal basin. In consideration of these two criteria, Beel Baruna is a very potential beel for TRM (IWM, 2010). Beel Baruna is located just downstream of Bhabadah regulator and upstream of East Beel Khukshia. It is situated almost parallel and in the opposite bank of East Beel Khukshia. Beel selection was also guided by a set of criteria devised in line with the objectives of the study and considerations of availability of secondary data. Total area of Beel Baruna is 715 ha (IWM, 2010). Based on the review of previous and present practices and analyses of existing problems of TRM practices, some options has been developed. Then these options are verified with the help of a numerical model to find the best and effective option for uniform sediment deposition in the study beel.

3.3 Secondary Data Collection and Processing

Secondary data for the study 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.

1. Institute of Water Modelling (IWM).
2. Bangladesh Water Development Board (BWDB).
3. Center for Environmental and Geographic Information Services (CEGIS).

3.3.1 Topographic Data of the Beel

To develop the cohesive sediment transport model for the study, the existing bottom topography data of Beel Baruna were collected from Institute of Water Modelling (IWM). After simulation of model the assessment of sedimentation in the basin and its distribution pattern over the whole basin in respect to base condition has been found. The generated bathymetry of Beel Baruna is presented in Appendix-A (Figure A-1).

3.3.2 Water Level and Discharge

Water level and discharge data were collected from IWM and were used to produce boundary and calibration of hydrodynamic model. Inventory of collected water level and discharge data are presented in the Table 3.3.1. Quality of data has been assured by visual checking and plotting hydrograph. All water level and discharge data plots are given in Appendix-B (Figure B-1 to B-7).

3.3.3 Cross Section and Bathymetric Data of River

Cross section data is required to generate the bathymetry of the model. Extensive bathymetric survey data of March 2008 have been collected from IWM. Bathymetric data used in the study were surveyed in March 2008 under the project titled " Mathematical Modelling Study for Planning and Design of Beel Kapalia Tidal Basin,". Inventory of cross section data are presented in the Table 3.3.2. Long profile of bed level and some plots of cross sections are given in Appendix-C (Figure C-1 to C-46).

Table 3.3.1: Inventory of water level and discharge data

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

(Source: IWM, 2009)

Table 3.3.2: 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

(Source: IWM, 2009)

3.3.4 Tidal Volume

Tidal range inside the Beel Baruna tidal basin, generated tidal volume and required tidal volume for sustainability of Hari river is given in the Table 3.3.3.

Table 3.3.3: Tidal Volume of Beel Baruna

Name of Beel	Tidal Range (m)	Generated Tidal Volume (Mm^3)	Required Tidal Volume (Mm^3)
Beel Baruna	0.27	2.5	2.0

(Source: IWM, 2010)

3.3.5 Sediment Data

Suspended sediment concentration data is required to develop boundary of the cohesive sediment transport model and for calibration of the model. Hourly suspended sediment samples were collected from IWM for one tidal cycle (13 hours) at different locations in the rivers of the study area. An inventory of suspended sediment concentration data is presented in Table 3.3.4. All sediment concentration data are given in Appendix-D (Table D-1 to D-7). Developed time series sediment concentration file for the model were linked to calibrate and simulate the model.

Table 3.3.4: Inventory of suspended sediment concentration data

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

3.4 Identification of Sediment Management Options

The options have been selected on review of related reports, studies, in consideration of existing problems of present TRM practices and better sedimentation inside the beel. Selection of options has also been included in consideration of almost all possible types of sedimentation arrangement for the beel. Three options have been selected for sediment management inside the beel during TRM operation. In Option-1, one link has been constructed to connect the beel with the river. This process has been considered to know the sedimentation in the present TRM condition. In Option-2 sedimentation is allowed in the divided compartment of the beel one after another. In this option divided three compartments has been connected with three different link canals according to location of compartments. When one compartment has been allowed for sedimentation, other compartments have been remain closed. Thus this option has been selected to fill up the beel by different link canals. In Option-3 an embankment has been constructed along both banks of main khal in the beel. Then a link canal has been constructed to connect with the river. In this process sedimentation has been allowed by cutting the embankment part by part, gradually from upstream to downstream. Thus this option has been selected to fill up the beel from upstream distance area to near the mouth of link canal.

3.5 Assessment of Volume of Sediment

Assessment of volume of sediment deposition is required to know the effective functions of different options during TRM operation. To asses the volume of sediment, a sediment transport model has been developed with the help of MIKE21 FM Modelling system. After development of sediment transport model, it has been simulated for the identified options to find better option for sediment management and uniform deposition of the beel. Volume of sediment deposition has been assessed from the change of bed topography from base condition.

3.6 Development of Sediment Transport Model by MIKE21 Flow Model FM

In order to know the sedimentation inside the beel, a two dimensional sediment transport model has been developed using MIKE21 FM Modeling system and duly calibrated. At first hydrodynamic model has been developed, then the developed hydrodynamic model has been coupled with sediment transport model. As the sediments are cohesive in nature (average grain size less than 0.063 mm), a cohesive sediment transport model has been developed. 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 implies information on water levels and currents from the hydrodynamic module to calculate the sediment transport. A general description of the numerical model is attached in Appendix-E.

Depositing material always enters the top bed layer. Deposition of weak or strong flocks 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 position 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/m2 and 0.05 N/m2 respectively.

Dispersion in tidal river is expected to be higher than in non-tidal river. Empirical dispersion formulation is used where dispersion coefficient 5 m2/s is applied depending on the current speed and water depth.

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 (IWM, 2009). The numerical model has been developed integrating the main Hari-Teligati-Gengrail river system and Beel Baruna tidal basin. Model has been calibrated with the observed data of Hari River and simulated for the identified options. Sedimentation inside the tidal basin has been assessed from the simulation results of cohesive sediment transport model for the identified options.

Topographic data of beel baruna has been used to develop the bathymetry of Beel Baruna for the model. Generated bathymetry of Beel Baruna is given in Appendix-A (Figure A-1). Water level and discharge time series data have been used in Hydrodynamic (HD) Module to set boundary condition and calibration of the model. Water level and discharge hydrographs are given in Appendix-B (Figure B1-B-7). Cross section and bathymetric data of river have been used to develop bathymetry of the river. Graphical presentation of cross section and bathymetric data are given in Appendix-C (Figure C1-C45). Suspended sediment concentration data of river are required to develop boundary and calibration of the cohesive sediment transport model. Time series data of suspended sediment concentration have been used in Mud Transport (MT) Module to set boundary condition and calibration of the model. Hourly suspended sediment concentration data for one tidal cycle (13 hours) at different locations in the rivers of the study area are given in Appendix-D (Table D1-D7).

3.6.1 Boundary Condition

Sediment concentration in the tide-dominated rivers is not dependent on the supply from the upstream. Rather it is controlled from downstream (EGIS, 2002). The downstream Mud Transport (MT) model boundary has been defined by measured suspended sediment concentration and the upstream boundary has been defined by constant sediment concentration. Upstream and downstream boundary for the Hydrodynamic (HD) model has been defined by measured discharge and water levels respectively.

3.7 Summary

In this chapter the procedure to select beel for the study, secondary data collection and processing, identification of sediment management options, development of sediment transport model and assessment of volume of sediment inside the beel are discussed. Standard procedures as described were followed to determine these parameters.

Chapter 4
STUDY AREA

4.1 Location

The study area is located in between Latitudes 22° 49’40.3”N and 23° 6’27.1” N and Longitudes 89° 13’32.46” E and 89° 26’15.43” E. The study area is in the southwestern region of Bangladesh under Jessore and Khulna districts. A location map for the study area is shown in Figure 4.1.1.

4.2 Water Resources

4.2.1 Surface Water

The main sources of the surface water in the study area are rivers, khals and wetlands. Surface water resources are available in the hydrological region throughout the monsoon .The runoff during the months of January to April is negligible and thus the salinity level in the tidal reaches of rivers in the study area increase during this period.

Rivers

The area is mainly drained by a number of north-south flowing rivers. Most of the rivers are tidal in nature. These north-south rivers are interconnected by east-west rivers. In this region, flows of these east-west rivers are very important for the complete circulation of tide all over the tidal flat. In the rainy season, water becomes fresh to slightly salty and in the dry season, it becomes salty. Most of the river waters carry appreciable amount of suspended load.

The inland rivers represent the remaining channels of the old spill or regional rivers, which have lost their connection to the oldest boundary river. The inland and regional rivers run into tidal rivers or estuaries. The flow regimes are driven by high, variable sediment laden flows.

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 main outlet for the drainage of the Bhabodah area. These river systems are deteriorating rapidly due to siltation and causing drainage congestion in the study areas. The rivers of the study area are shown in figure 4.1.1.

Khals

There are several khals in the study area which role important part for draining of the study area. But most of these khals are dead due to sedimentation on the bed. 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 consists of huge numbers of beels which are very important for biodiversity, such as freshwater fish and birds. The beels including study beel are shown in the figure 4.1.1. Such beels and wetlands cover about 45% of the study area. Area of beels in the study area varies from 50 ha to 1200 ha. Beel Baruna is located just downstream of Bhobidaha regulator. Area of Beel Baruna is 715 ha (IWM, 2010).

4.2.2 Groundwater

There is a saline-freshwater interface in the groundwater. Groundwater development may cause movement of the saline front inland. So study is required to develop irrigation water availability from ground water in the study area. However, groundwater are abstracted in some areas for irrigation.

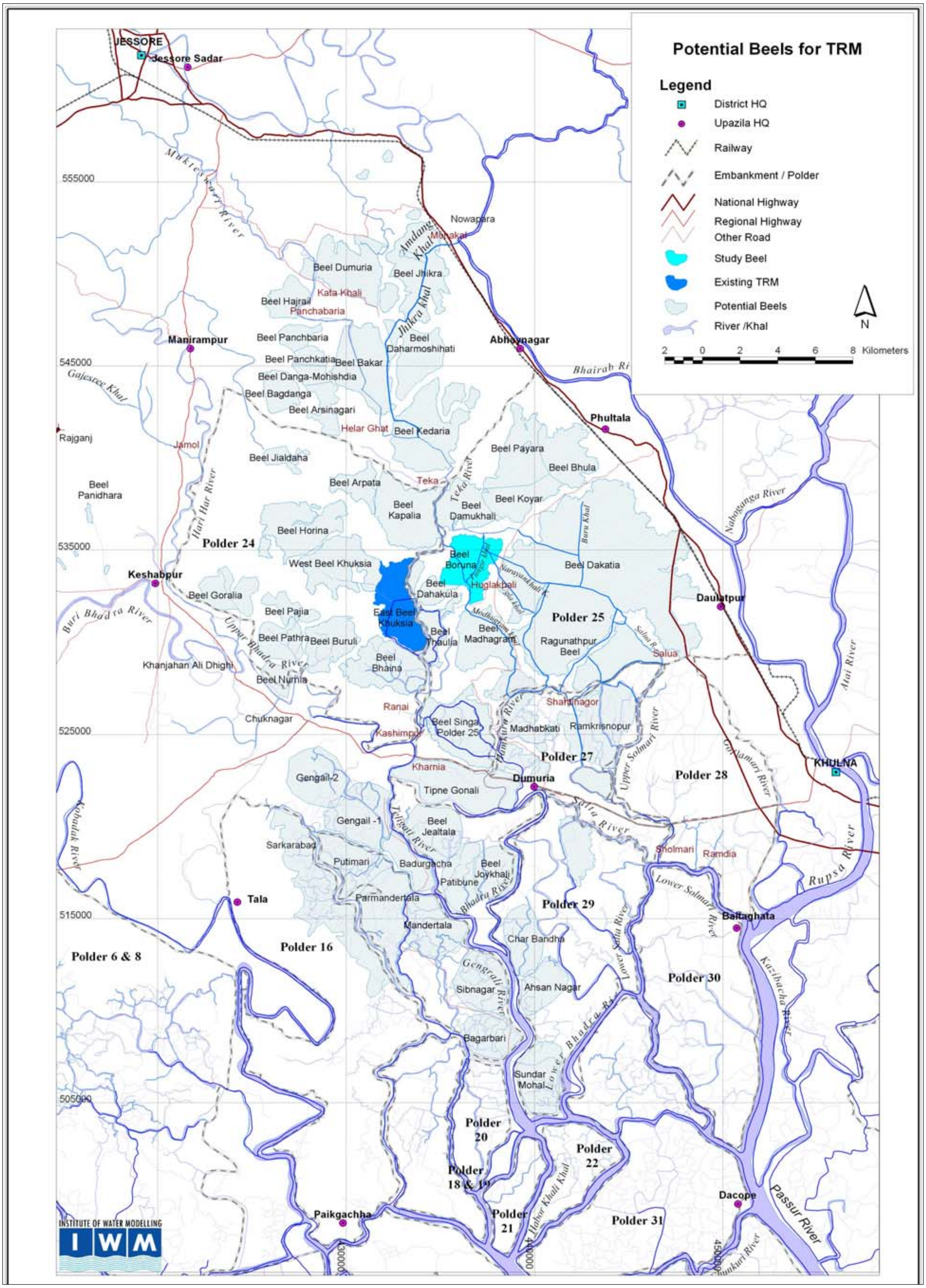

Figure: 4.1.1: Location Map of the study area (Source: IWM, 2010)

4.3 Physical Characteristics of the Area

The study area is mainly tidal floodplain and 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 reagion. 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.

4.4 Climate

The study area has a typical monsoon climate with a warm and 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 2,000 mm of which approximately 70% occurs during the monsoon season. The area has a relative humidity which 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 can fall to 8°C in January.

The climate is favorable for various agricultural activities throughout the year (CEGIS, 2002a). The maximum, minimum and average temperature for monthly and annual, relative humidity, wind speed, sunshine, evaporation and rainfall are shown in Table 4.4.1.

4.5 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 4.5.1.

Table 4.4.1: Climate data from 1960-2002 at station Keshobpur (Station Code 936)

Month	Mean Monthly Temperature (^{0}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	32.9	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, 2007)

4.6 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 for the Hari river at Ranai 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 analysed to know the maximum sediment concentration in spring tide. All suspended sediment concentration data are given in Appendix-D from table D-1 to D-7.

Table 4.5.1: 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

4.7 Summary

In this chapter geographical location, water resources and physical characteristics of the study area have been described. In addition to this climate, tidal and sediment characteristics of the study area have been illustrated in this chapter. Thus, this chapter provides the basis for selecting the area for the study.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 General

The location, area and topography of Beel Baruna is suitable for tidal river management and ensuring drainage capacity of Hari River (IWM, 2010). Beel Baruna is located at the opposite bank and upstream of East Beel Khukshia and immediately downstream of Bhabodah regulator. Bottom topography of Beel Baruna varies from 2.75m PWD to (-) 1.0 m PWD.

This chapter includes model set up, model calibration, selection of sediment management options, options simulation and analysis of results from selected option simulations. It also includes estimates of construction cost for TRM operation for the selected options.

5.2 Model Set Up

In order to know the sedimentation inside the beel, a two dimensional sediment transport model has been developed using MIKE21 FM Modelling system and duly calibrated. The numerical model has been developed integrating the main Hari-Teligati-Gengrail river system and the Beel Baruna tidal basin. Model has been calibrated with the available observed data of Hari River. First, hydrodynamic model for the system has been developed, then the developed hydrodynamic model is coupled with sediment transport model. As the sediments are cohesive in nature, a cohesive sediment transport model is developed. Model has been calibrated against suspended sediment concentrations using settling velocity, bed roughness height, critical bed shear stresses, dispersion coefficient and concentration at the open boundaries.

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/m2 and 0.05 N/m2 respectively.

Empirical dispersion formulation is used where dispersion coefficient 5 m2/s is applied depending on the current speed and water depth. The Dispersion coefficient according to DHI Water and Environment User Manual is:

$$D=K_2.\Delta x.u \qquad (5.2.1)$$

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

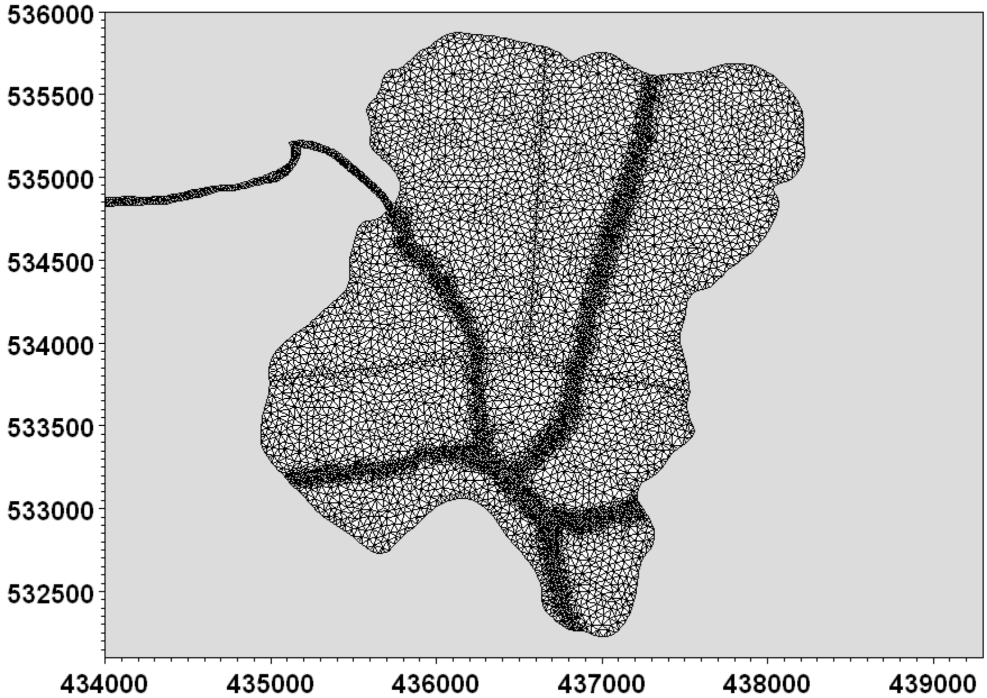

Figure 5.2.1: Schematization of sediment transport model of Beel Baruna

Figure 5.2.1 shows a schematization of sediment transport model of Beel Baruna with triangular cells.

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 10 ppt. As salinity level in most of the location of the study area is less than 10 ppt, influence of salinity has been ignored (IWM, 2009).

The downstream Mud Transport (MT) model boundary has been defined by measured suspended sediment concentration and the upstream boundary has been defined by constant sediment concentration. Upstream and downstream boundary for Hydrodynamic (HD) model has been defined by measured discharge and water levels.

5.3 Model Calibration

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 for the study was limited. However, comparison of observed and simulated discharge and sediment concentration data are shown in Figure 5.3.1 and 5.3.2 indicating that a reasonable calibration has been achieved with limited available data.

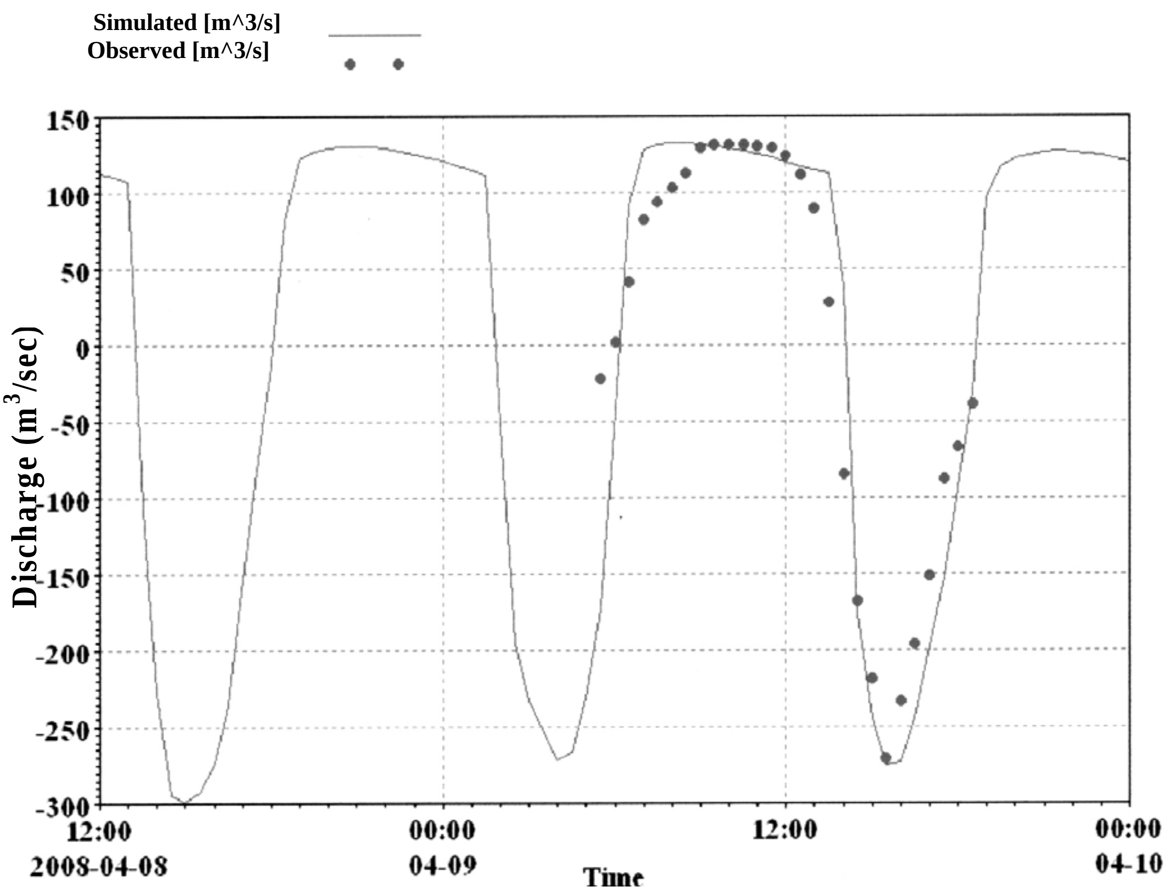

Figure 5.3.1: Observed and simulated discharge in the Hari River near Dierkatakhali link canal of East Beel Khukshia

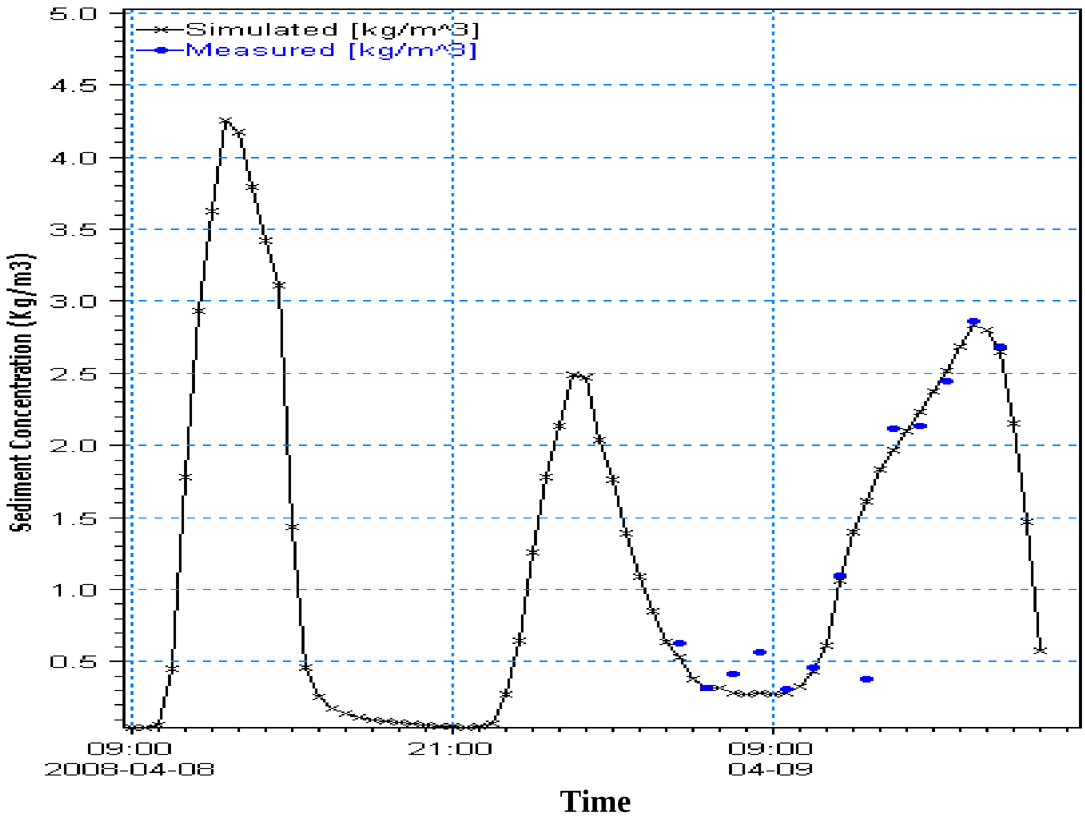

Figure 5.3.2: Observed and simulated suspended sediment concentration in the Hari River near Dierkatakhali link canal of East Beel Khukshia

5.4 Sediment Management Options

The options for uniform sedimentation have been selected in consideration of existing problems of present TRM practices, local people demand collected from previous reports and thesis papers. Selection of options has also been included in consideration of almost all possible types of sedimentation arrangement for the beel. In Option-1, one link canal has been constructed to connect the beel with the river. This process has been considered to know the sedimentation in the present TRM condition. In Option-2 sedimentation is allowed in the divided compartment of the beel one after another. In this option divided three compartments has been connected with three different link canals according to location of compartments. When one compartment has been allowed for sedimentation, other compartments have been remain closed. Thus this option has been selected to fill up the beel by different link canals. In Option-3 an embankment has been constructed along both banks of main khal in the beel. Then a link canal has been constructed to connect with the river. In this process sedimentation has been allowed by cutting the embankment part by part, gradually from upstream to downstream. Thus this option has been selected to fill up the beel from upstream area to downstream. The options are summarized in Table 5.4.1:

Table 5.4.1: Different Options for sediment management in the tidal basin

Options	Description
1	Current sediment management practices.
2	The beel has been divided into three compartments by constructing embankment around the compartment and one compartment has been connected to river at a time by constructing an artificial link canal in between the river and that compartment i.e. allowing sedimentation in the compartments one after another.
3	Embankments have been constructed along both banks of main khal through the beel and thereby allow sedimentation by cutting the embankment part by part from upstream to downstream.

Dredging of Canal:

Initial and maintenance dredging are important components in all of the Options under consideration. Before TRM operation the critical silted stretches of the river needs to be de-silted by capital dredging and manual excavations is required to link and improve the existing drainage condition. Otherwise TRM will not be fully effective. It is known from the present TRM practices that after 3 or 4 months most of the natural khals inside the tidal basin are silted up, if no manual re-excavation or mechanical dredging activities have taken place. Without dredging sedimentation will take place in the khal and the silt cannot spread out in the wider area. So, it is important to dredge the khals by mechanical dredger, or manual re-excavation program is needed after three or four months according to field condition. The dredged spoil may be store in the remote portion of the beel where sedimentation is less. For Option-1 and Option-3, link beel has been connected along Noimuddir Khal (length=750 m) alignment and for Option-2 link canal has been connected along Noimuddir Khal alignment for compartment A, along Deakula Khal (length=1660 m) alignment for compartment B and along Tungir Khal (length=2000 m) alignment for compartment C.

Option-1:

Option-1 has been selected to know the sedimentation in current TRM practices as to compare with the other selected options. In this Option, at first location of link canal has been constructed to connect the beel with the Hari river river. Figure 5.4.1 shows the schematization for Option-1 for Beel Baruna.

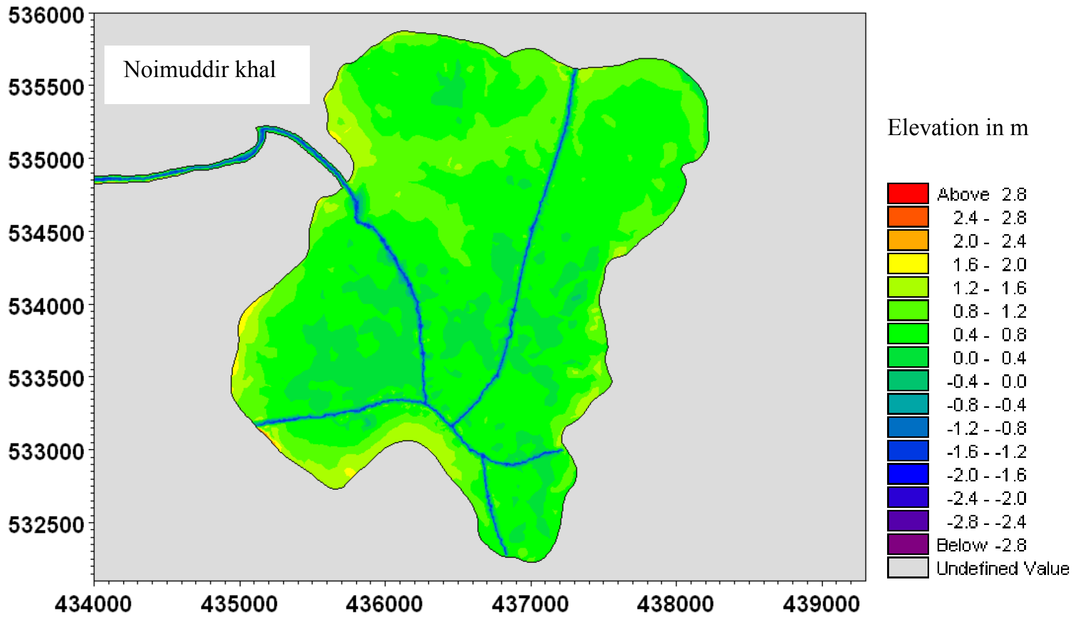

Figure 5.4.1: Schematization of Beel Baruna for Option-1

Option-2:

In Option-2, beel has been divided into three compartments by constructing embankment around the compartment. Then compartments have been connected with the river one after another by constructing link canals. In this process when sedimentation in one compartment has been allowed, only that compartment has been connected with the river, other compartments have remain been disconnected with the river. In this way all the three compartments have been filled up one after another. The compartments have been devised considering three criteria: area of the compartment, existence of khal for using link khal and land topography of the beel. The areas of the compartments have been calculated 211 ha, 258 ha and 246 ha for compartment A, B and C respectively. For this Option, Noimuddir Khal has been used as a link canal for compartment A, Deakula Khal has been used as a link canal for compartment B and Tungir Khal has been used as a link canal for compartment C. Figure 5.4.2 shows the schematization for compartment A, B and C with artificial link canals.

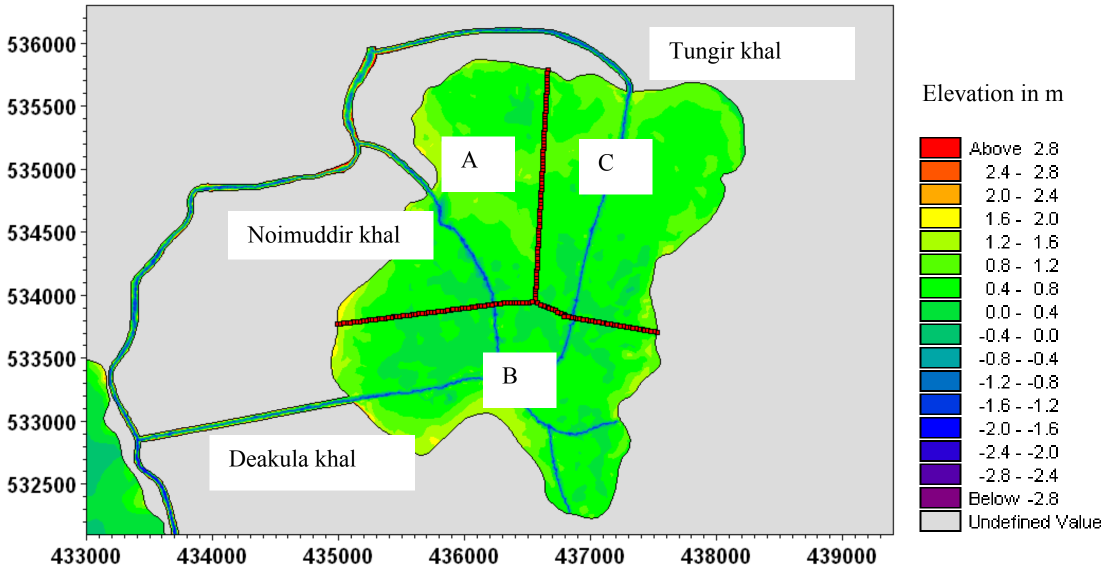

Figure 5.4.2: Schematization of Beel Baruna for Option-2

Option-3:

In Option-3, embankment has been constructed along both banks of main khal in the beel. Link canal has been constructed along Noimuddir khal (Figure 5.4.3, 5.4.4, 5.4.5 and 5.4.6).

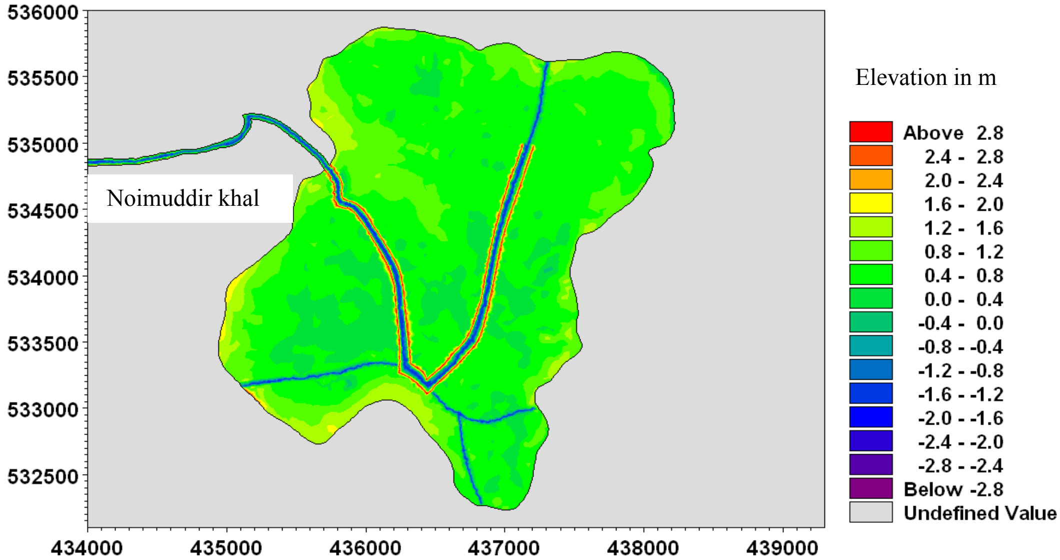

Figure 5.4.3: Schematization of Beel Baruna with 3800 m embankment for Option-3

In this process sedimentation has been allowed by cutting bank rising embankment part by part, gradually from upstream to downstream. Step by step construction of embankment with schematization for Option-3 are shown in Figure 5.4.3, 5.4.4, 5.4.5 and 5.4.6.

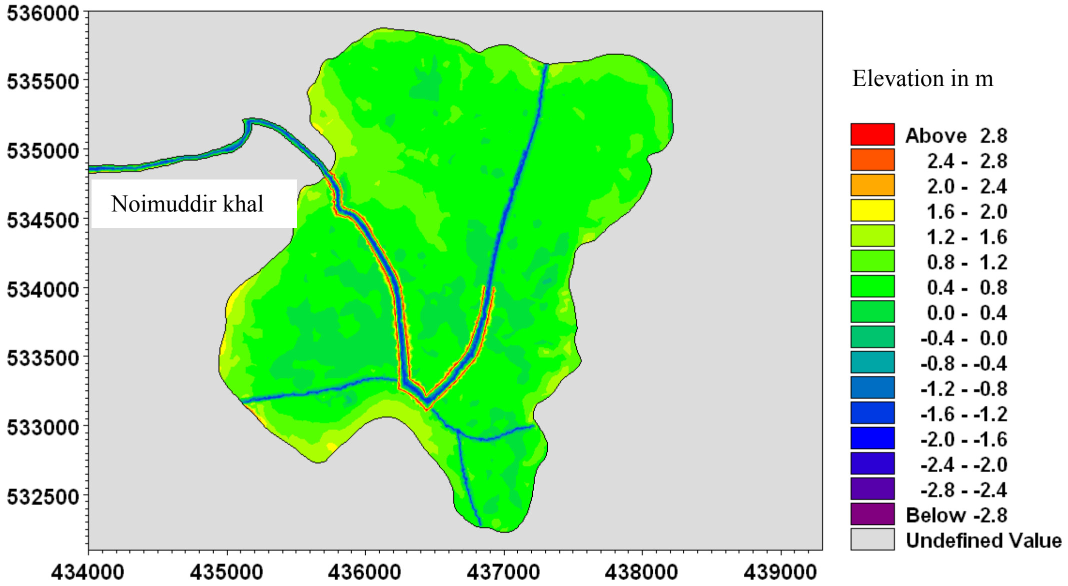

Figure 5.4.4: Schematization of Beel Baruna with 2800 m embankment for Option-3

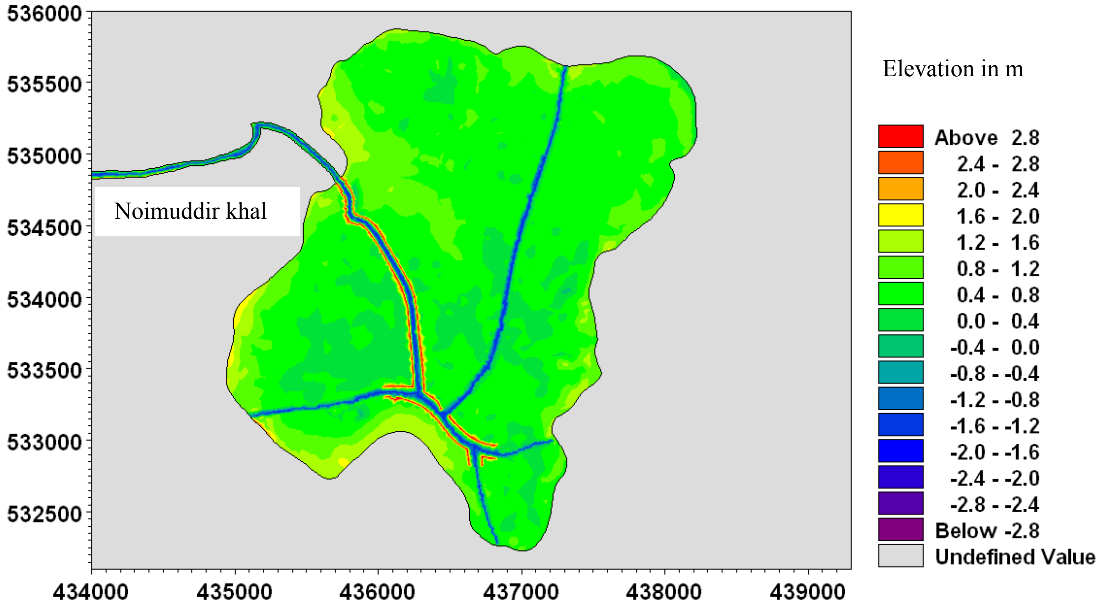

Figure 5.4.5: Schematization of Beel Baruna for Option-3 with 1800 m embankment

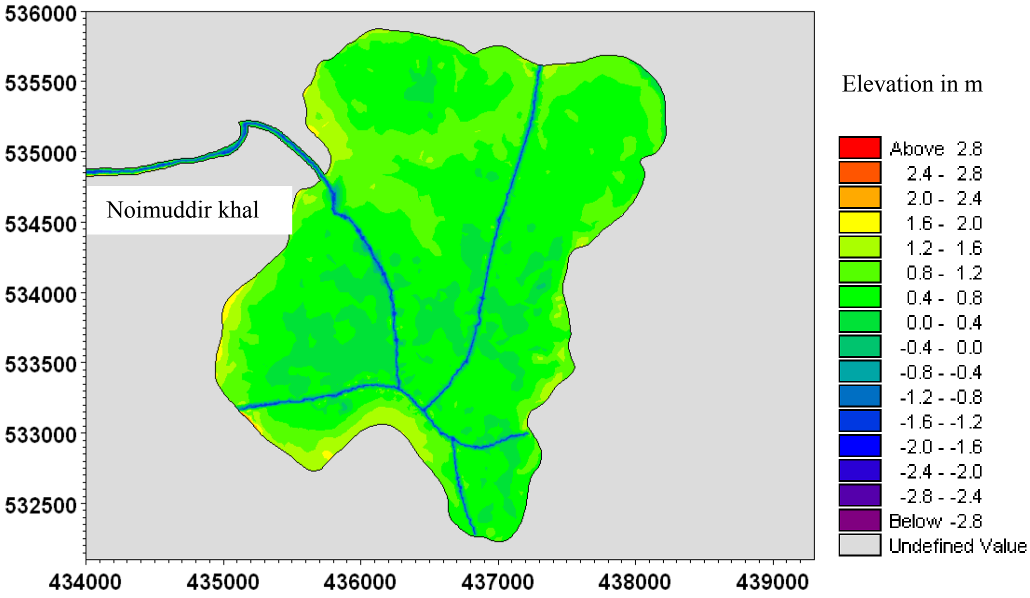

Figure 5.4.6: Schematization of Beel Baruna for Option-3 with no embankment

Bank rising embankment has been constructed considering bottom topography, location of canal and length of canal as to distribute sediment uniformly. To do this, first step embankment has been constructed for a length of 3800 m and sedimentation has been allowed for the first year. Then the embankment has been removed for 1000 m and sedimentation has been allowed for the second year. Similarly in the third year the length of the embankment has been become as 1800 m and there was no embankment in the fourth year. Finally sedimentation in the last year has been occurred as no embankment condition.

5.5 Option Simulations

Options selected for the study have been analyzed for their technical feasibility using MIKE 21 cohesive sediment transport model developed by DHI. To set the Options with the model, the size of the grid has been used very fine. For all the options, total bed thickness change due to deposition in the beel have been calculated. Detailed analysis of results from option simulations of Beel Baruna are given in the following section.

5.6 Analysis of Results from Option Simulations of Beel Baruna

After set up and calibration of the model, it has been simulated for the selected three options to find the most feasible option for sediment management and uniform deposition of the beel. 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. For this reason simulation has been done for the dry season as major sedimentation occurs in this season. Similarly, simulation for the next year has been done with the updated bed level of the previous year. Thus, total deposition inside the beel has been found for four years. Detailed analysis of results from option simulations of Beel Baruna are described below:

Option-1

Figure 5.6.1, 5.6.2, 5.6.3 and 5.6.4 show simulated result for Option-1 after first year, second year, third year and fourth year. In the simulated figures for Option-1, sediment deposition pattern and thickness of deposited sediment on bed of Beel Baruna are shown. Sediment deposition has been calculated from the change of bed topography from base condition.

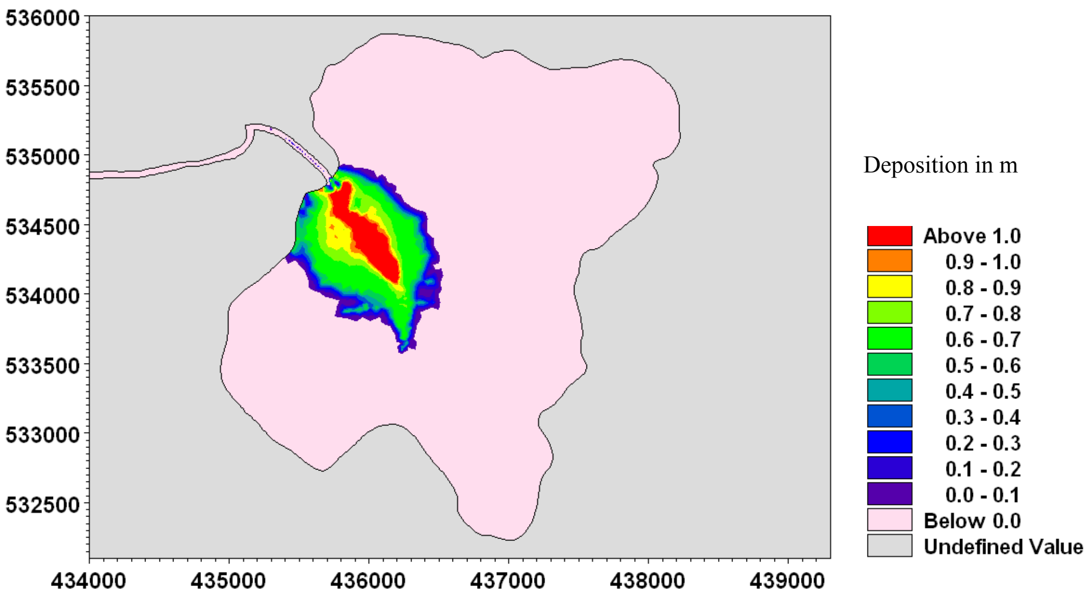

Figure 5.6.1: Simulated deposition pattern inside the tidal basin after first year for Option-1

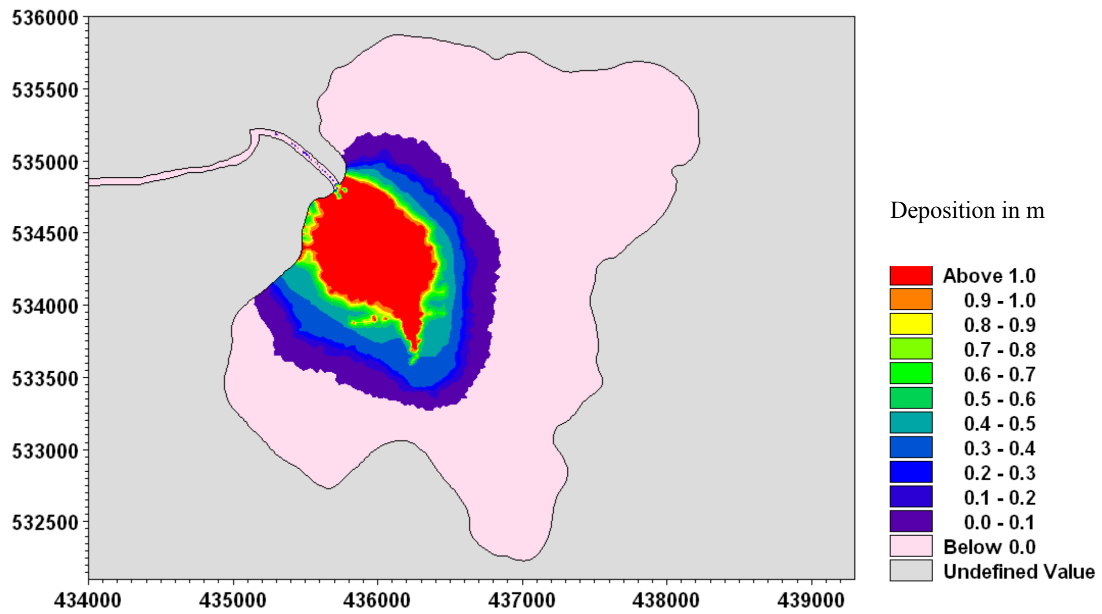

Figure 5.6.2: Simulated deposition pattern inside the tidal basin after second year for Option-1

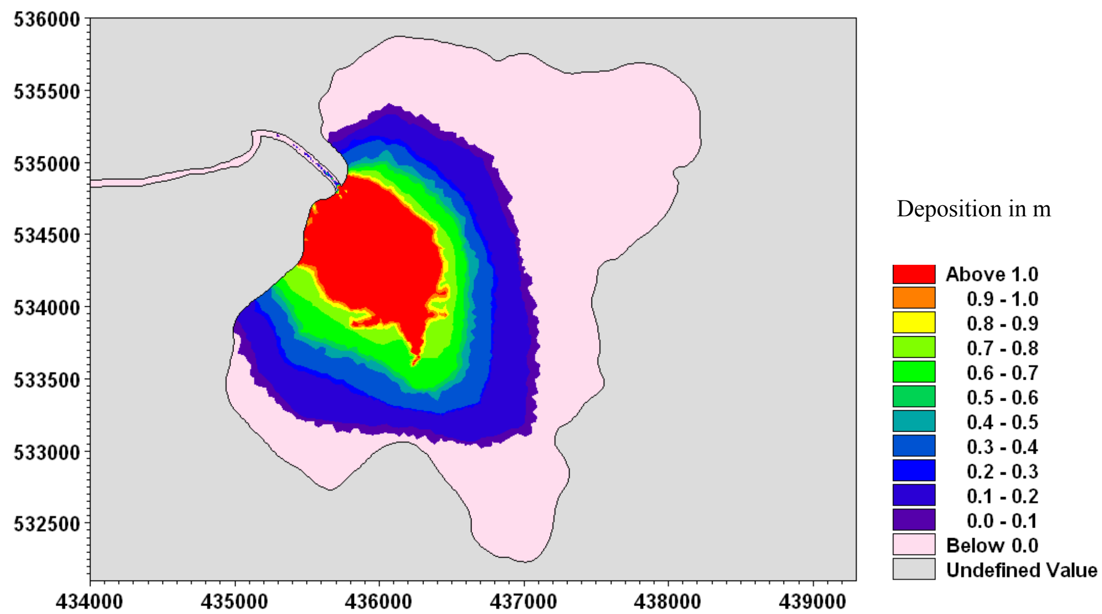

Figure 5.6.3: Simulated deposition pattern inside the tidal basin after third year for Option-1

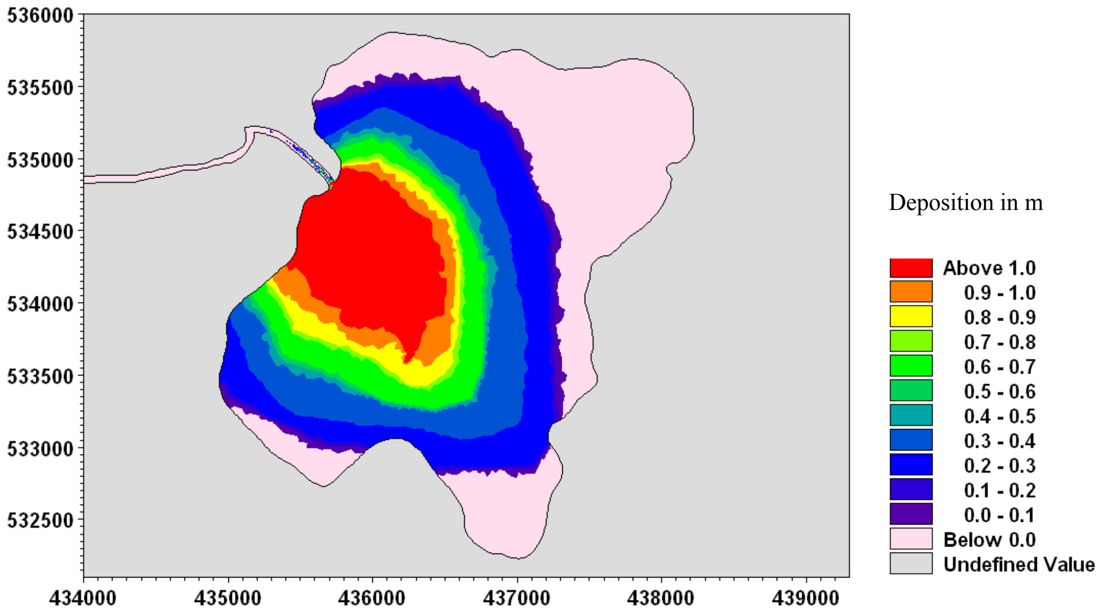

Figure 5.6.4: Simulated deposition pattern inside the tidal basin after fourth year for Option-1

From the above simulated results shown in the Figures 5.6.1, 5.6.2, 5.6.3 and 5.6.4, it is seen that most sedimentation takes place at the mouth and near the mouth of the link canal. Thus in this way silt cannot spread out in the areas far away from the link canal. Figures 5.6.1, 5.6.2, 5.6.3 and 5.6.4 also indicate a non-uniform sedimentation in the basin. Calculated deposition volume after first, second, third and fourth year for Option-1 are given in Table 5.7.1.

Option-2:

The cohesive sediment transport model has been simulated for each compartments one after another. Simulation has been done for compartment A for first step (upto 1 year 4 month or 16 month), then compartment B for second step (from 17 month to 32 month), then compartment C for third step (from 33 month to 48 month). Figure 5.6.5, 5.6.6 and 5.6.7 show the sediment deposition pattern and thickness of deposited sediment on bed of Beel Baruna for compartments A, B and C respectively. Sediment deposition has been calculated from the change of bed topography from base condition. Thus total sediment deposition after 4 years or 48 months in compartments A, B and C have been found. Calculated total sediment deposition for the three compartments for Option-2 are given in Table 5.7.1.

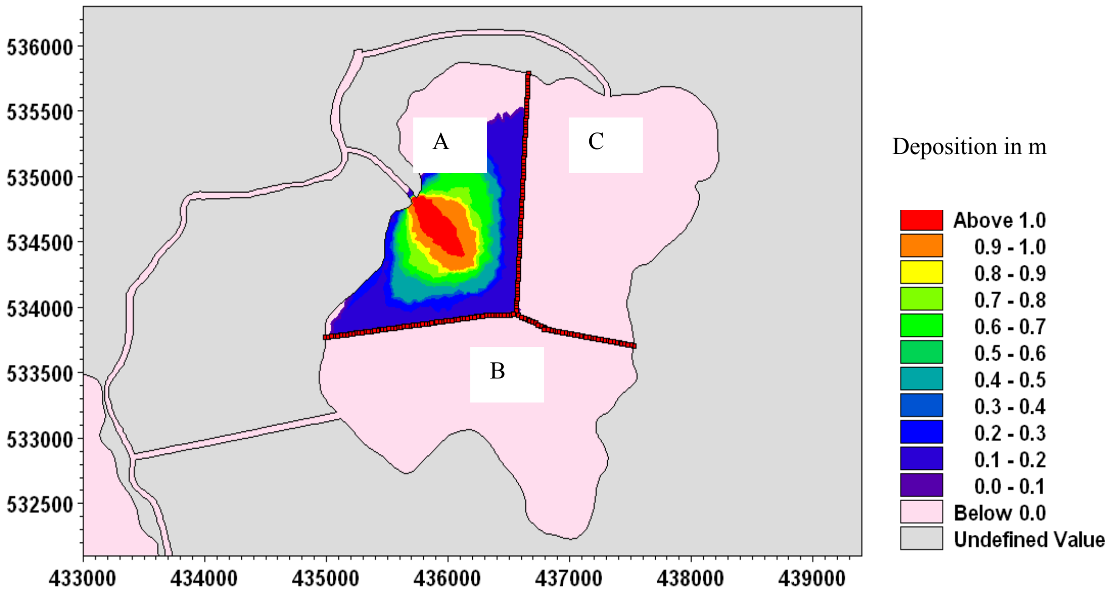

Figure 5.6.5: Simulated deposition pattern inside the Compartment-A after 16 month operation for Option-2. When Compartment-A is in operation (from 0-16 month), Compartment-B and Compartment-C are remain closed

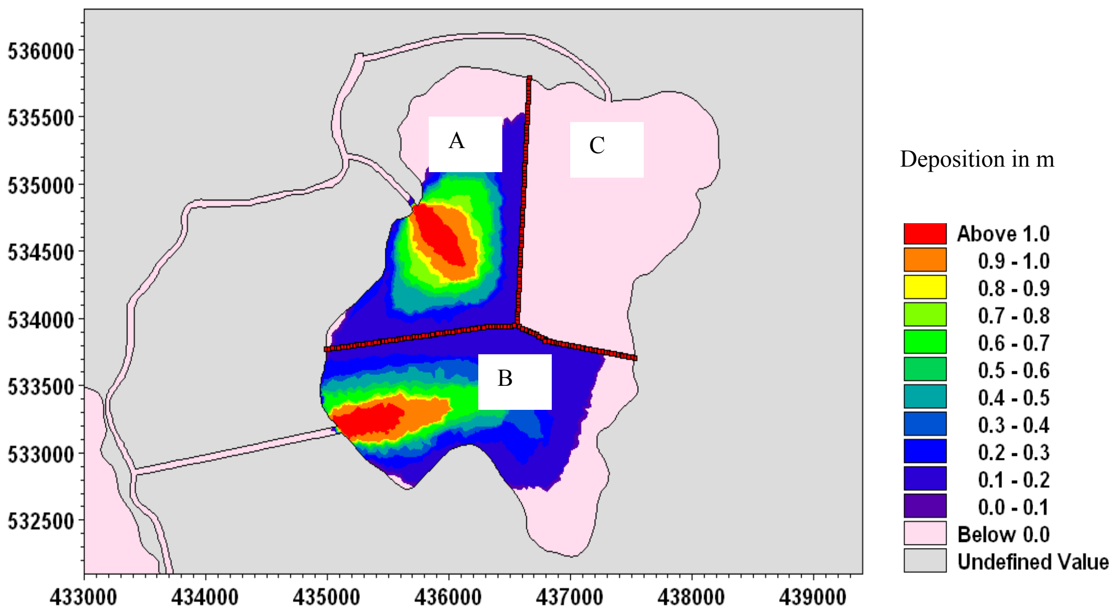

Figure 5.6.6: Simulated deposition pattern inside the Compartment-A and B after 32 month operation for Option-2. When Compartment-B is in operation (from 17-32 month), Compartments-A and Compartment-C are remain closed

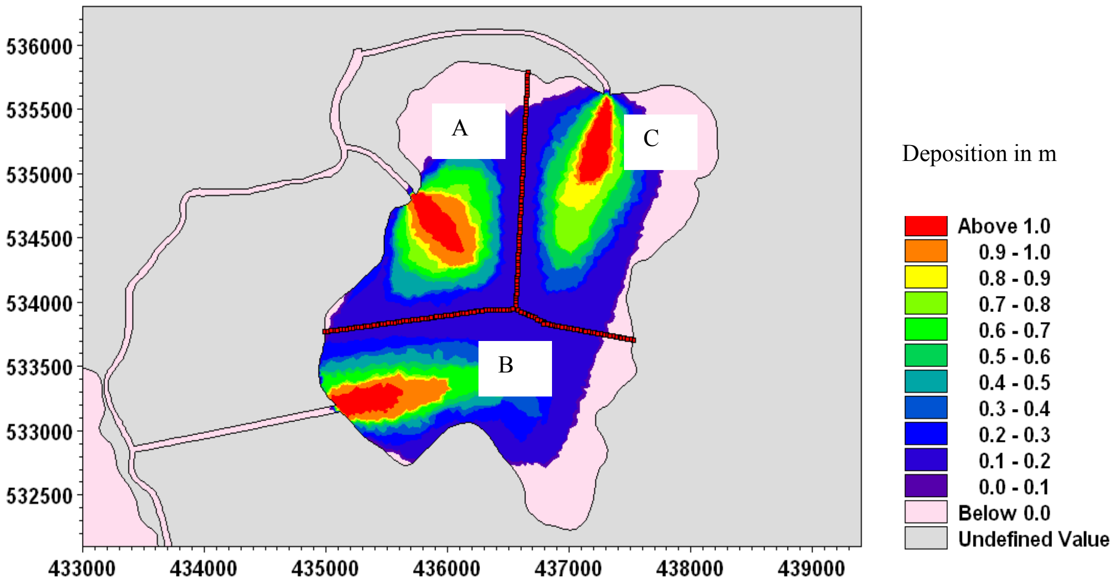

Figure 5.6.7: Simulated deposition pattern inside the Compartment-A, B and C after 48 month operation for Option-2. When Compartment-C is in operation (from 33-48 month), Compartments-A and Compartment-B are remain closed

Option-3

The cohesive sediment transport model has been simulated with bank raising embankment of length 3800 m, 2800 m, 1800 m and for no embankment.

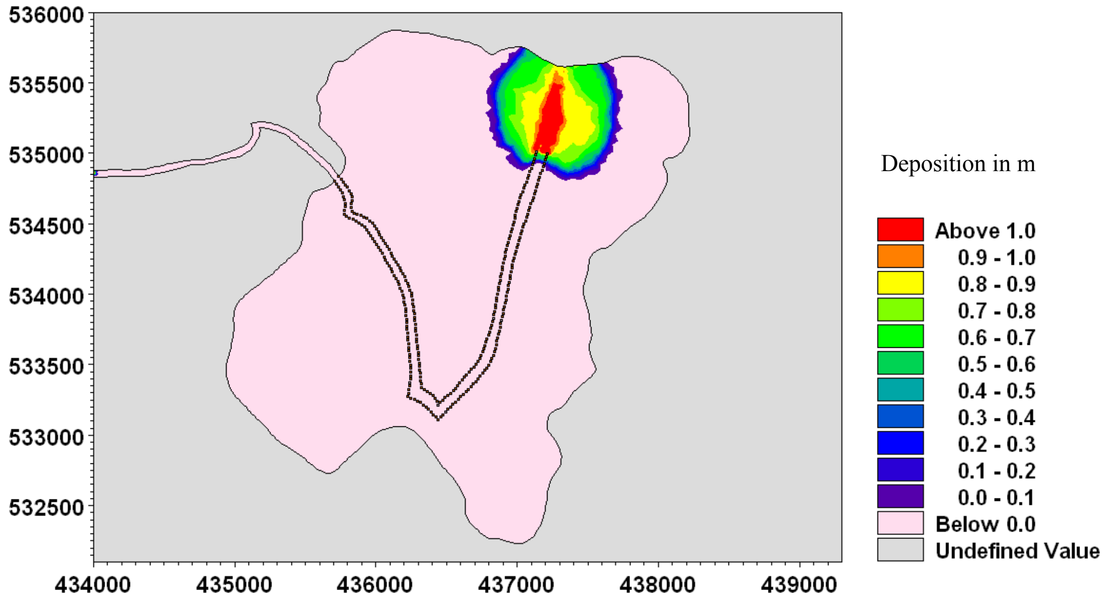

Figure 5.6.8: Simulated deposition pattern inside the tidal basin after first year with embankment length of 3800 m for Option-3

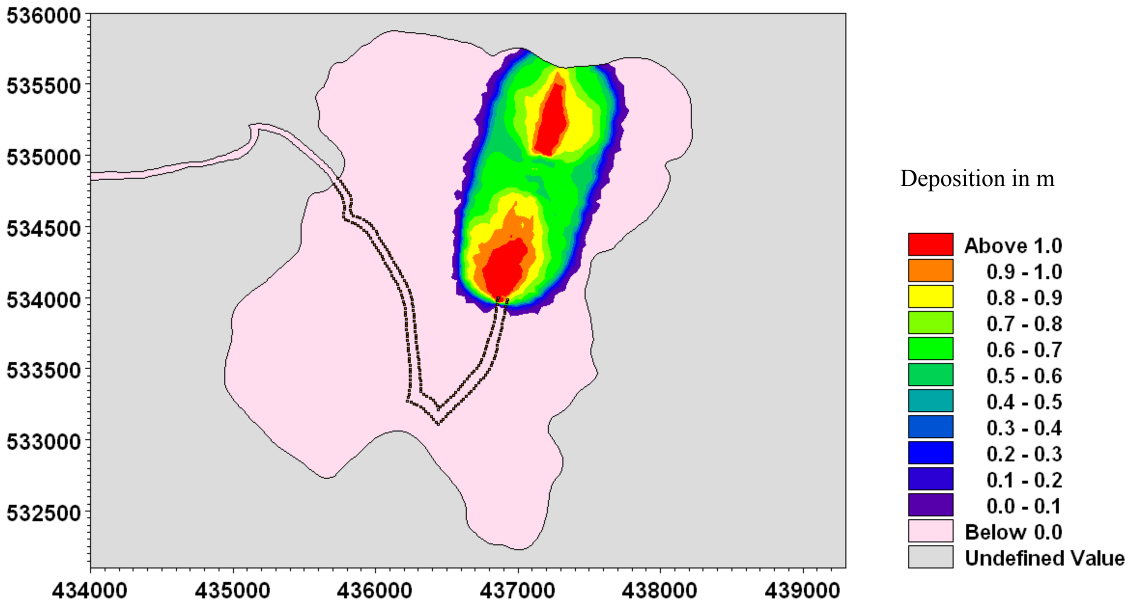

Figure 5.6.9: Simulated deposition pattern inside the tidal basin after second year with embankment length of 2800 m for Option-3

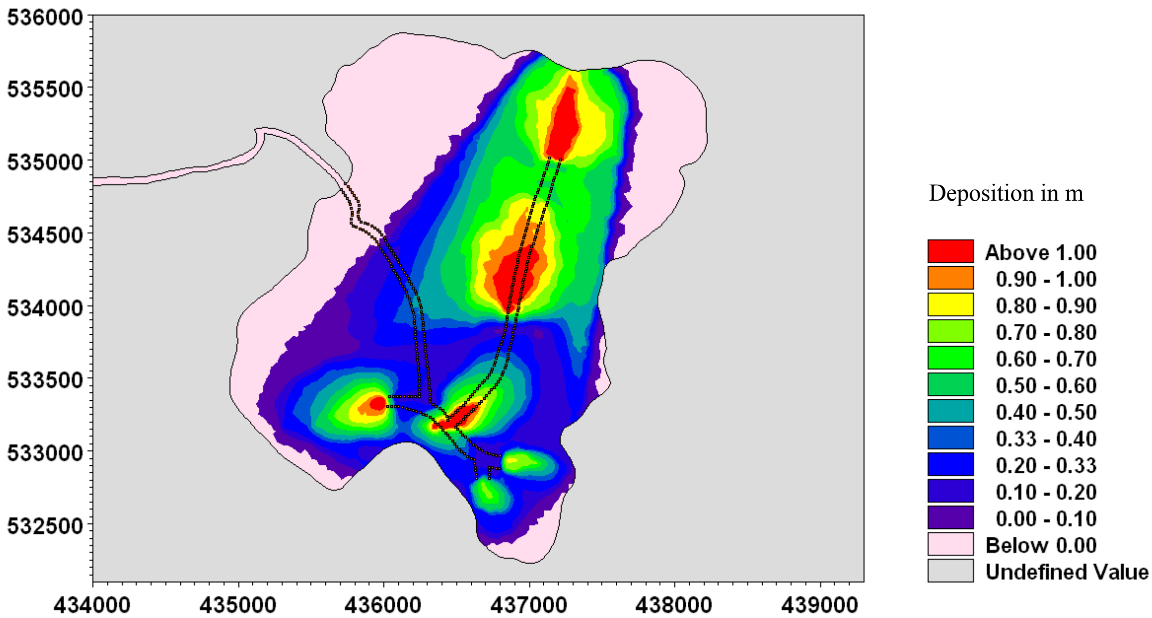

Figure 5.6.10: Simulated deposition pattern inside the tidal basin after third year with embankment length of 1800 m for Option-3

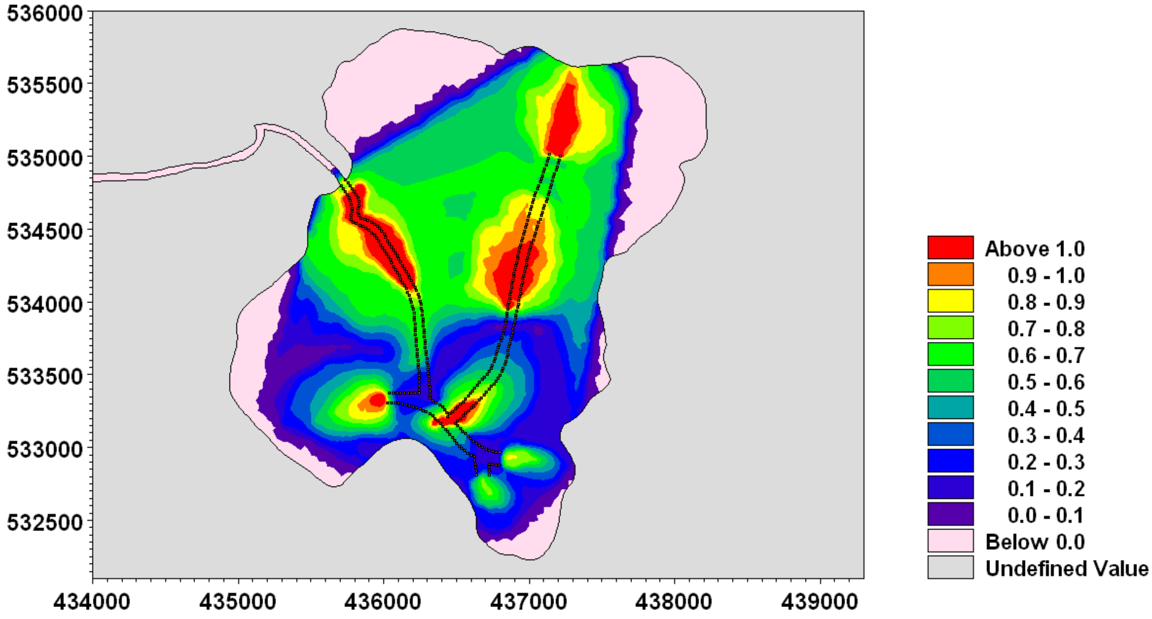

Figure 5.6.11: Simulated deposition pattern inside the tidal basin after fourth year with no embankment condition for Option-3

Simulation has been done for 3800 m embankment for the first year, 2800 m embankment for the second year, 1800 m embankment for the third year and no embankment for the fourth year. Figure 5.6.8, 5.6.9, 5.6.10 and 5.6.11 show the sediment deposition pattern and thickness of deposited sediment on bed of Beel Baruna after first, second, third and fourth year respectively. It is seen from figure 5.6.11 after fourth year simulation that sediment spreads comparatively uniform and almost the whole area of the beel. Calculated total sediment deposition for Option-3 are given in Table 5.7.1.

5.7 Deposition Volume

Deposition volume for Beel Baruna tidal basin after options simulation for the selected three options have been calculated according to change of bed thickness from the base condition. Provision of dredging is considered for all of options. Estimated deposition volume for Option-1, Option-2 and Option-3 are shown in Table 5.7.1.

Table 5.7.1: Deposited volume for the selected three options

Option	Deposition Volume in Mm^3			
1	After 12 months	After 24 months	After 36 months	After 48 months
	0.68	1.22	1.76	2.28
2	After 16 months in Compartment-A	From 17-32 months in Compartment-B	From 33-48 months in Compartment-C	After 48 months in Compartments-A, B & C
	0.82	1.11	1.04	2.97
3	After 12 months	After 24 months	After 36 months	After 48 months
	0.52	1.26	2.42	3.12

5.8 Deposition Area

From the simulated results and deposition of sediment, three plots of deposited area versus time have been prepared for the three options. The plots are prepared for three level of deposition: net deposition greater than 0.50 m, net deposition greater than 0.80 m and net deposition greater than 1.0 m. Figure 5.8.1, 5.8.2 and 5.8.3 show time versus deposition area plots for Option-1, Option-2 and Option-3 respectively. It is seen from the plots that maximum deposition area (610 ha) covers for Option-3 and minimum deposition area (485 ha) covers for Option-1.

Plots for Option-3 in Figure 5.8.3 shows that for deposition depth greater than 0.80 m and 1.0 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 0.5 m. In Option-1, all areas where the net deposition depth is greater than 0.5 m, 0.80 m and 1.0 m, continue to increase even after 48 months.

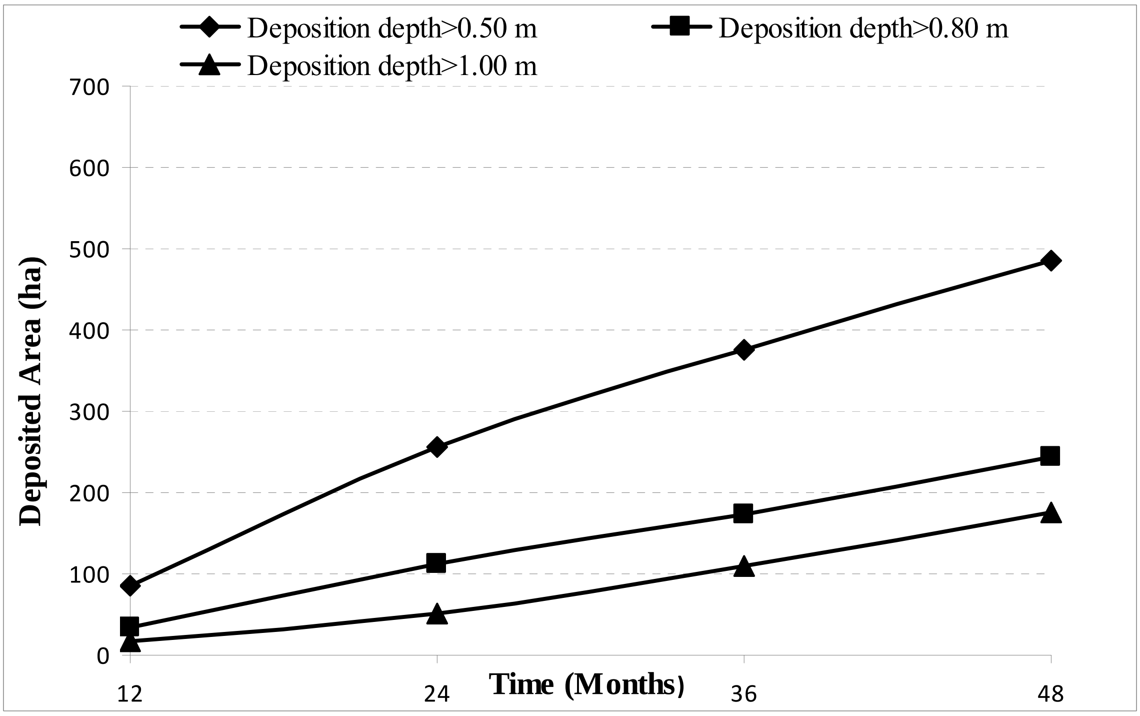

Figure 5.8.1: Deposited area plot for Option-1

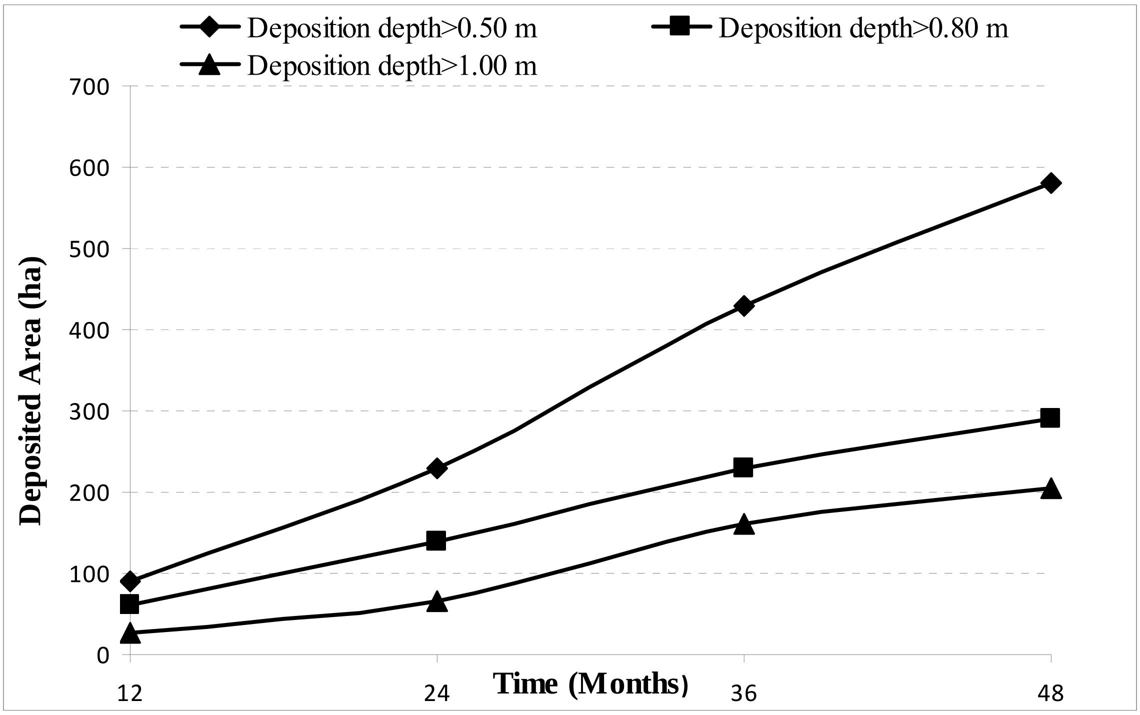

Figure 5.8.2: Deposited area plot for Option-2

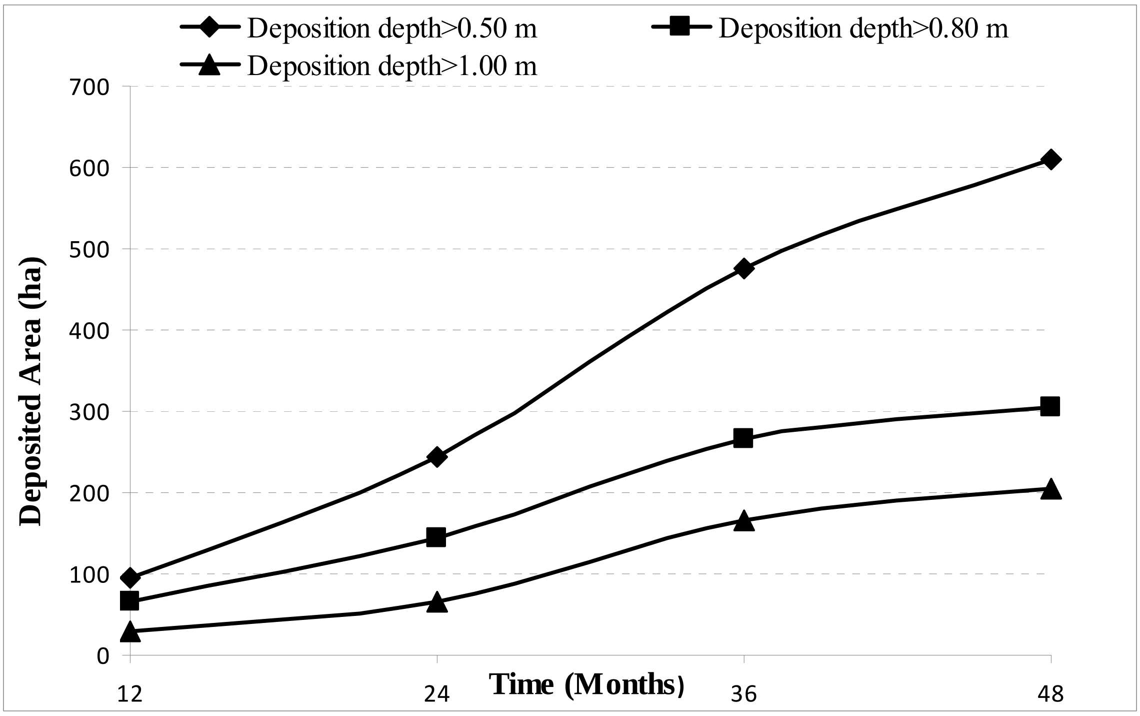

Figure 5.8.3: Deposited area plot for Option-3

5.9 Cost for Different Options

Huge civil works are needed for the operation of tidal basin under TRM operations. Construction of peripheral embankment is essential to protect the homestead and crop lands from flooding. In addition some drainage outlets are required for the purpose of local drainage. Besides, a 35 m long seasonal earthen cross dam is also required on Hari river at upstream of the tidal basin to divert total tidal flow of the river to the tidal basin and to stop intrusion of tidal water at upstream during operation of the tidal basin. Dredging or re-excavation of khals is needed for uniform and effective silt deposition in the tidal basin. Besides, compensation is required for the land owner of the beel for four years.

5.9.1 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 5.9.1.

Table 5.9.1: Rates of the major items of work

S1.	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	m^3	103.43
2	Earth work by manual labour for construction of embankment road (4 m 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
4	Mechanical dredging	m^3	140.00
5	Compensation for land per year	ha	33,592.00
6	Drainage outlet (0.9 m diameter pipe sluice)	each	4,50,000.00

5.9.2 Cost Calculation and Comparison

The indicative costs of all of the works and activities essential for TRM operation have been considered to find out the total cost of the three options for Beel Baruna Tidal Basin. The total estimated cost of the three options for the study beel are given in Table 5.9.2. The detailed cost estimations for Beel Baruna TRM are given in Appendix-F.

Table 5.9.2: Total estimated costs for the selected options

Name of Beel	Options	Total Estimated Cost (Taka)
Beel Baruna	1	2,37,603,700.00
	2	1,99,917,000.00
	3	1,61,956,700.00

5.10 Summary

In this chapter model set up and calibration have been discussed. Selection of three options for uniform sedimentation and simulation of the options have been discussed. Analysis of results from option simulations for different options and estimation of deposition volume have been done. Graphical representation of time versus deposition area for different options have been discussed to identify better option for uniform sedimentation in the tidal basin. Cost for different options for TRM operation and comparison of the costs also have been discussed. Standard procedures were followed to analyze and calculate all of the results for different options of TRM.

Chapter 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 General

The techniques of Tidal River Management (TRM) is a popular and proven process to solve water logging problems in the tidal river area having low lying beels or tidal basins. It is an effective process and has been applied in the KJDRP project in southwest zone of our country. Uniformly raising the land inside a beel and maintaining proper drainage capacity of the river are the two main objectives of TRM. But in the present TRM practices, it is observed that sedimentation inside the beel is not uniform. This has been happened mainly due to technical problems and operational limitations during TRM process. To solve this problem of present TRM practices, three options for sediment deposition in the tidal basins have been identified. Option-1, is the existing practice of TRM operation. In this practice, one link canal is constructed that connect the beel with the river. In Option-2, beel is divided into three compartments separated by embankment around the compartment and allowing sedimentation in the compartments one after another. In Option-3, embankments are constructed along both banks of the main khal through the beel and sedimentation in the basin is allowed by cutting the embankment part by part gradually from upstream to downstream. The selected options have been simulated with the help of MIKE21 FM sediment transport model to find better option for uniform deposition for the study beel.

6.2 Conclusions of the Study

The major findings of this study are stated as follows:

1. Sediment deposition inside the beel is not uniform in the present TRM practices.

2. In the present TRM practices, non uniform sedimentation inside the beel make people unwilling to allow their land for TRM operation.

3. Sediment deposition volume after four years operation in Option-1, Option-2 and Option-3 are 2.28, 2.97, 3.12 million m^3 respectively. Maximum deposition is

observed in Option-3 and minimum deposition is observed in Option-1 for the study beel.

4. Deposition area covers after four years operation in Option-1, Option-2 and Option-3 are 485 ha, 580 ha and 610 ha respectively. Maximum deposition area covers for Option-3 and minimum deposition area covers for Option-1. For deposition depth greater than 0.80 m and 1.0 m, sediment deposition does not increase significantly after almost three years in Option-3. But in Option-1, all areas where the net deposition depth is greater than 0.5 m, 0.80 m and 1.0 m, continue to increase even after four years. Sediment deposition is more uniform in Option-3.

5. Construction cost for four years TRM operation in Option-1, Option-2 and Option-3 are Tk. 2,37,603,700, Tk. 1,99,917,000 and Tk. 1,61,956,700 respectively. This indicates that minimum cost is required for implementing TRM in Option-3.

So, in technical consideration, it appears that Option-3 is preferred in the area.

6.3 Recommendations of the Study

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

1. In Option-2, generated tidal volume will be less than that of for the other two options, as the beel is divided into compartments having less basin area. Thus comparatively less natural hydraulic dredging will occur in the Hari River during TRM operation in Option-2.

2. For effective and uniform deposition in the TRM basin, dredging or manual re-excavation as required must be maintained for every options.

3. Long term observed data's of suspended sediment concentration are required for better calibration of numerical model and for better results.

REFERENCES

Amir, M.S.I.I. (2010), “Socio-Technical Assessment of Sediment Management Options in Tidal Basins in Southwestern Bangladesh”, M. Sc. Thesis, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology.

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.

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

DHI (1993), “MIKE 11, User’s Manual”, Danish Hydraulic Institute.

EGIS (2001), “Environmental and Social Management Plan (ESMP) for TBA in the Hari River System under KJDRP”.

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 2011-08-12.

IWM (2010), “Feasibility Study and Detailed Engineering Design for Long Term Solution of Drainage Problems in the Bhabodah Area”, Final Report, Bangladesh Water Development Board.

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”, Proc ASCE, Journal, Civil Engineering Div., 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.

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

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

APPENDIX A: BATHYMETRY AND SEDIMENT TRANSPORT MODEL OF BEEL BARUNA

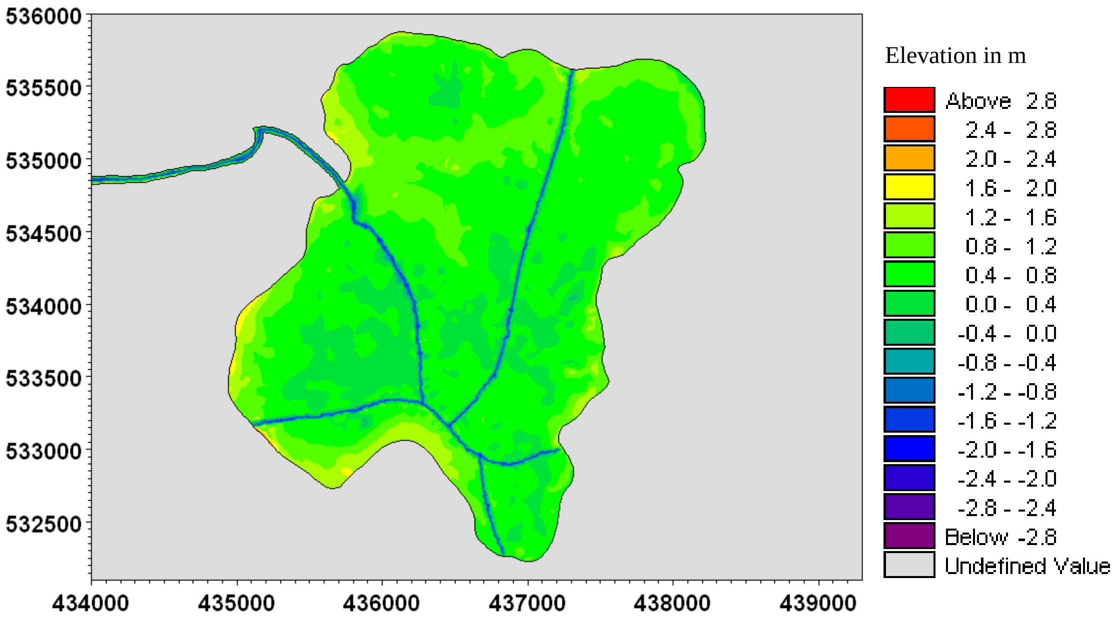

Figure A-1: Bathymetry of Beel Baruna

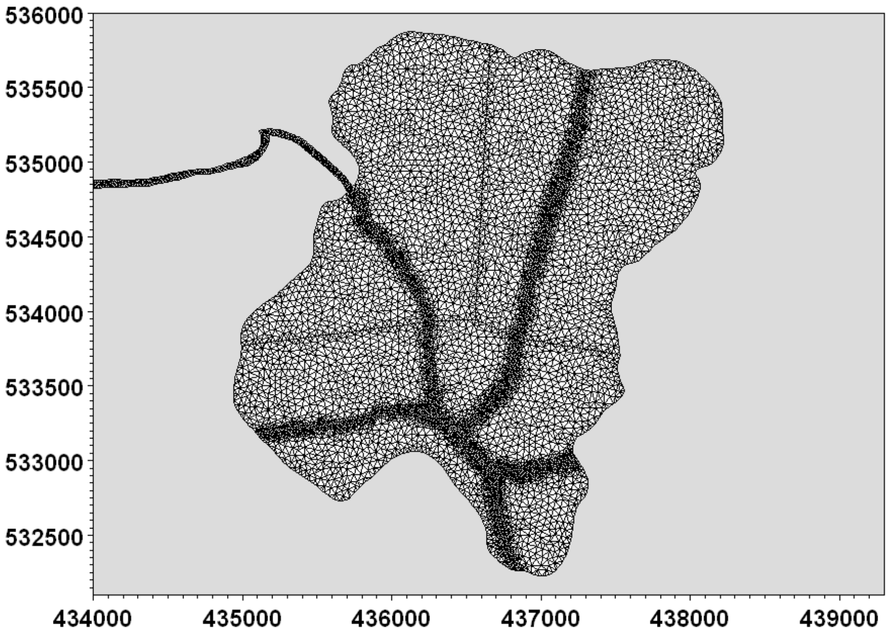

Figure A-2: Schematization of sediment transport model of Beel Baruna

APPENDIX B: WATER LEVEL AND DISCHARGE HYDROGRAPH

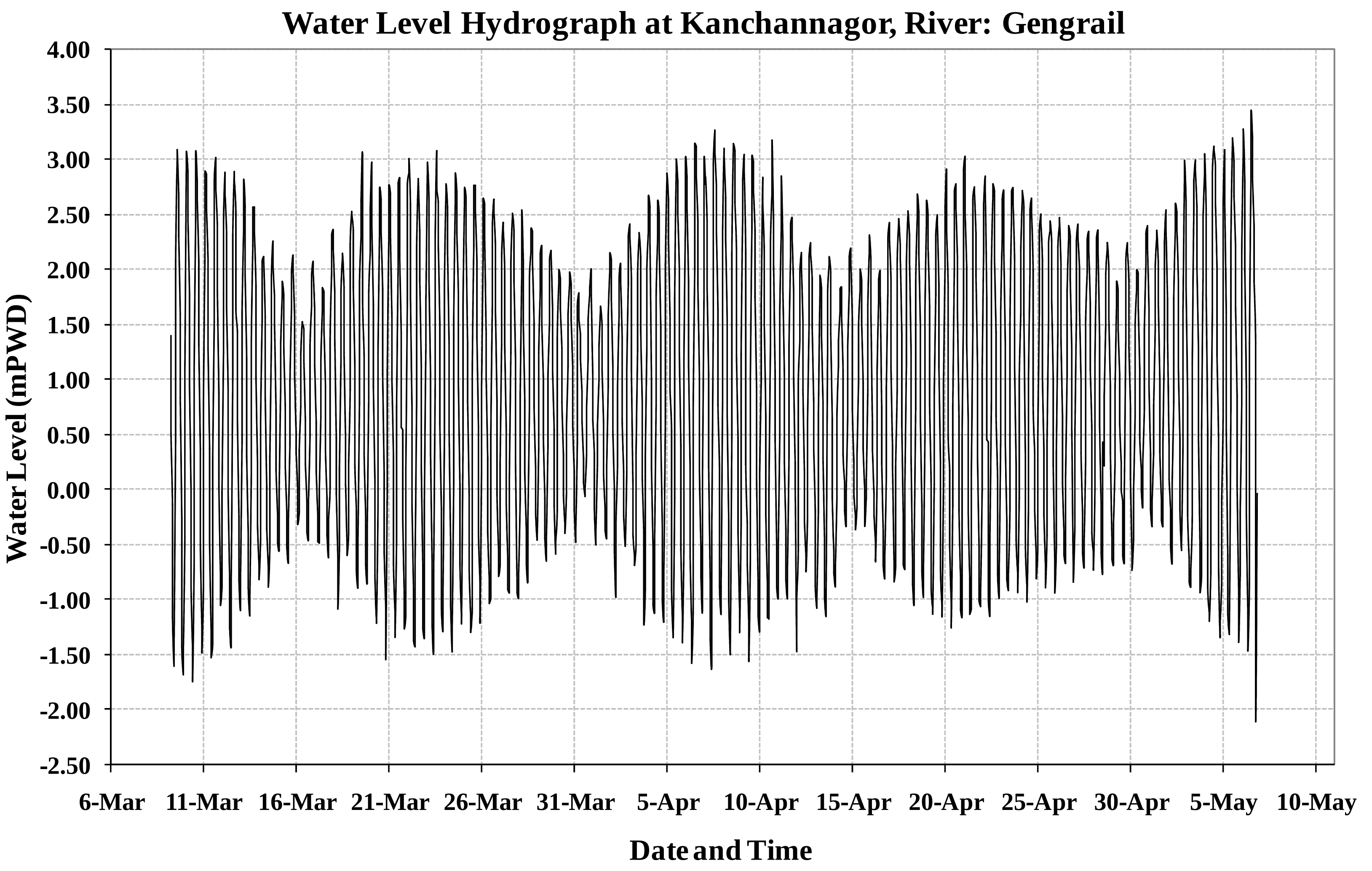

Figure B-1: Water Level Hydrograph of Gengrail River at Kanchannagar

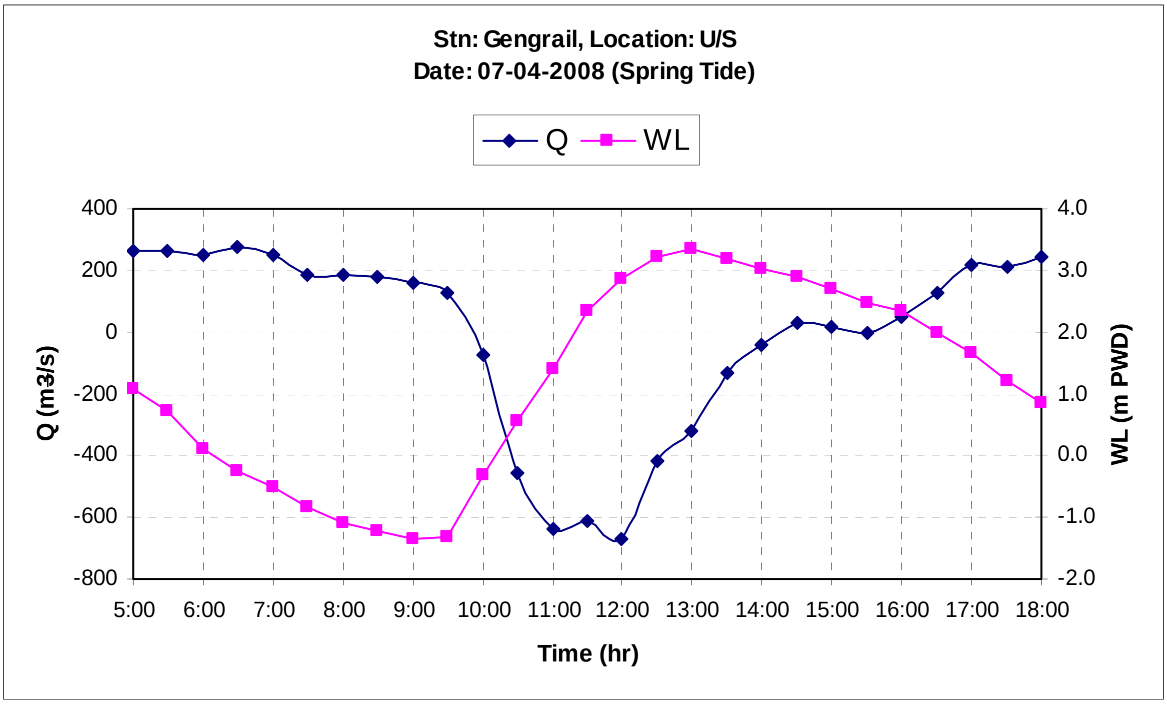

Figure B-2: Water Level and Discharge Hydrograph of Gengrail River at Kanchannagar at upstream

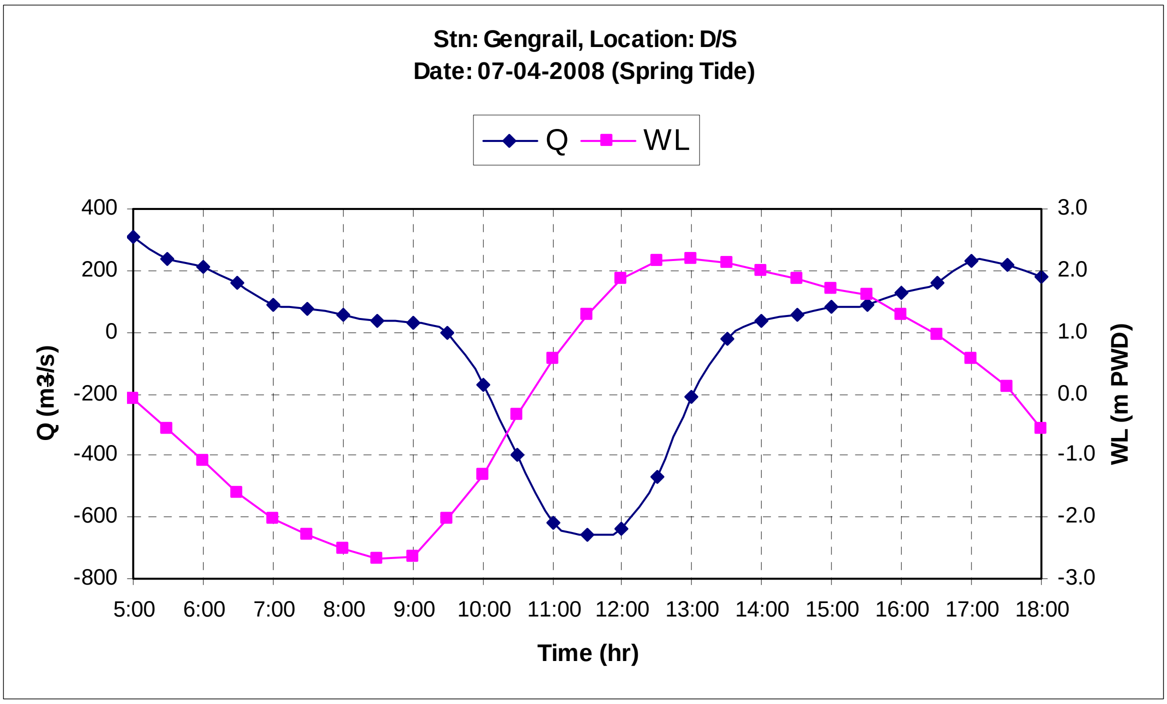

Figure B-3: Water Level and Discharge Hydrograph of Gengrail River at Kanchannagar at downstream

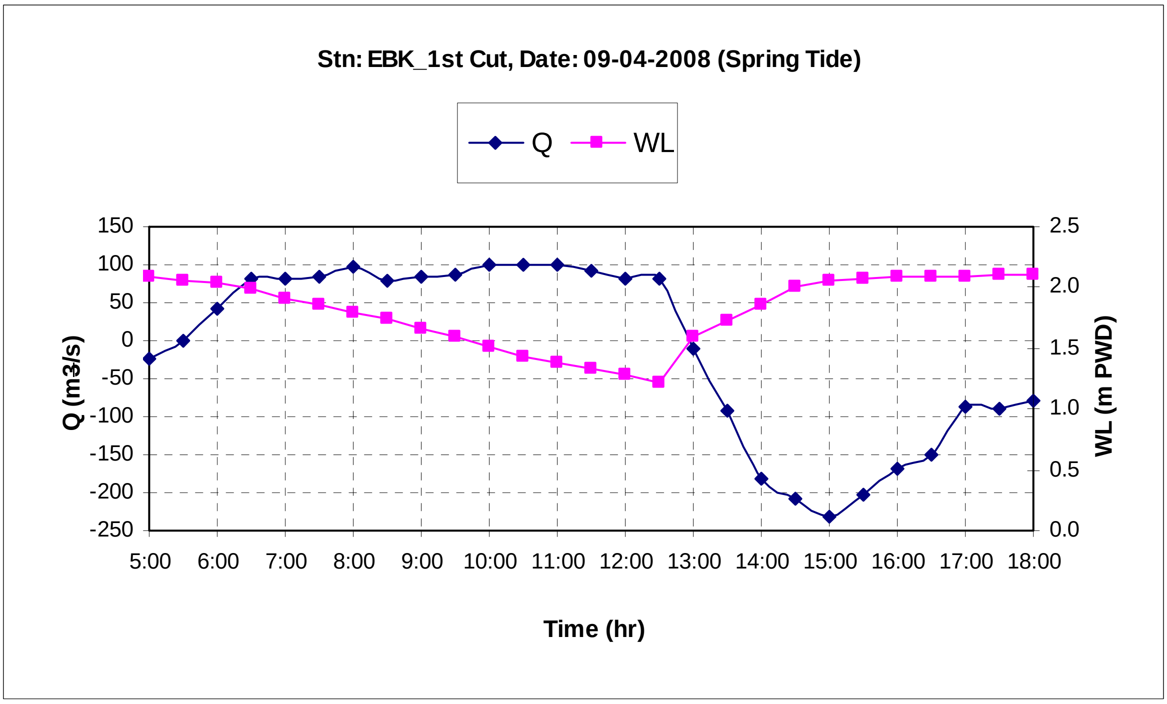

Figure B-4: Water Level and Discharge Hydrograph of EBK 1st Cut

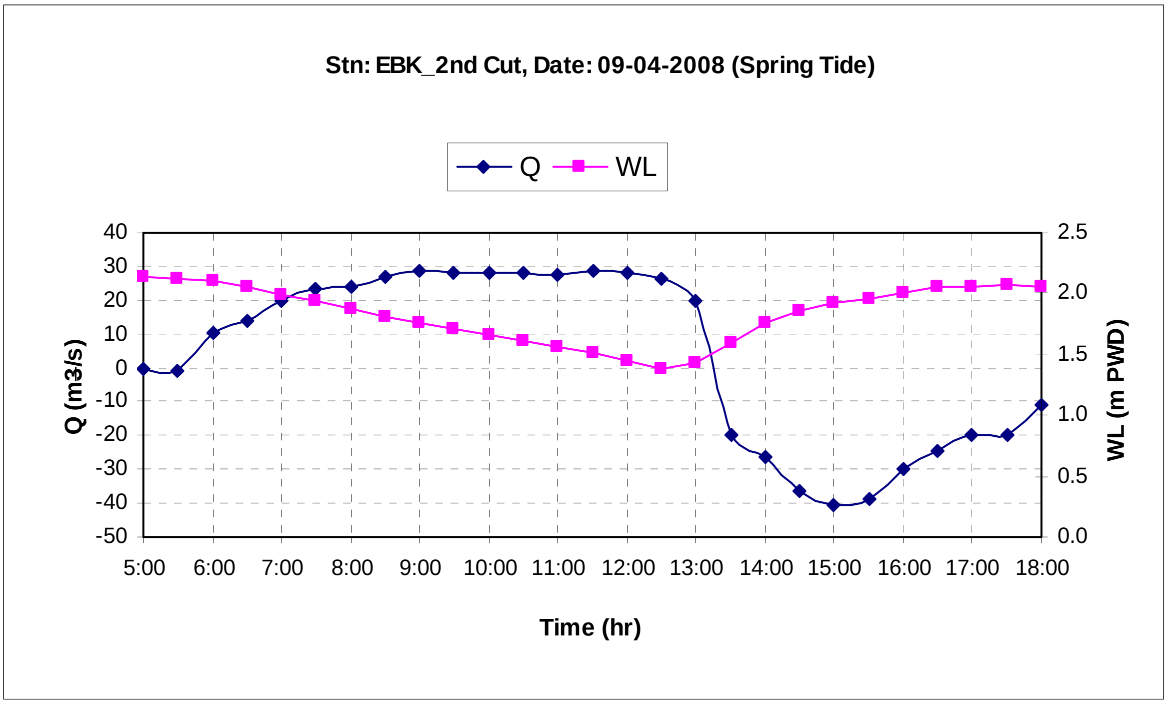

Figure B-5: Water Level and Discharge Hydrograph of EBK 2nd Cut

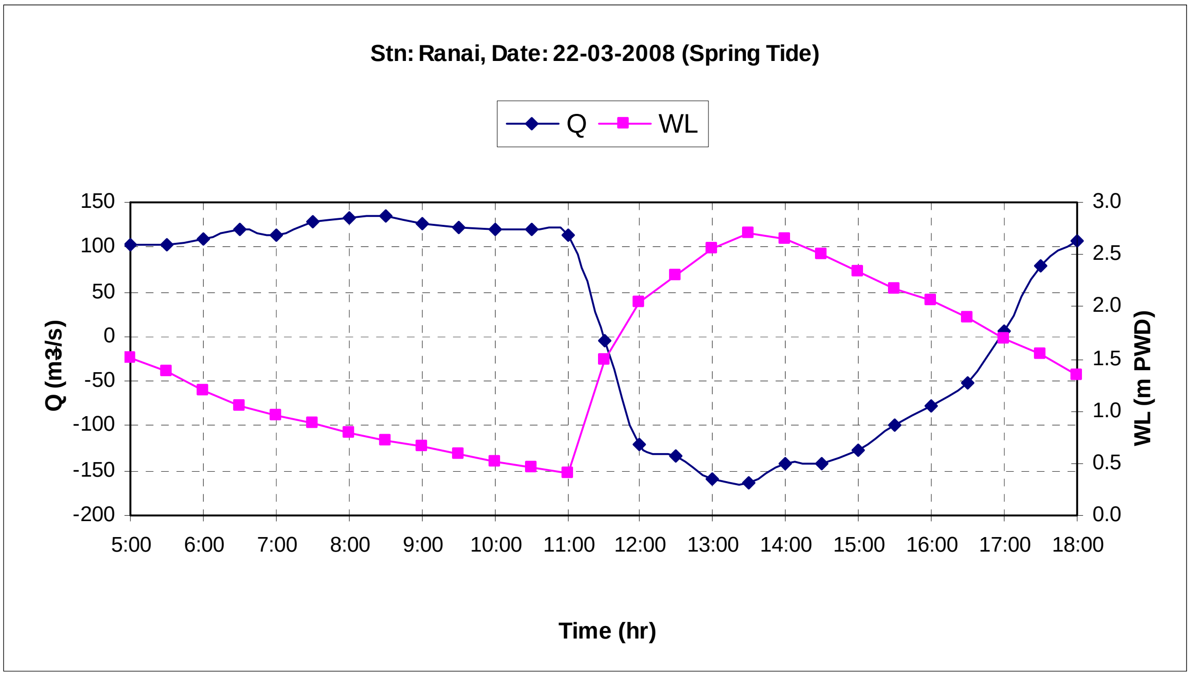

Figure B-6: Water Level and Discharge Hydrograph of Hari River at Ranai

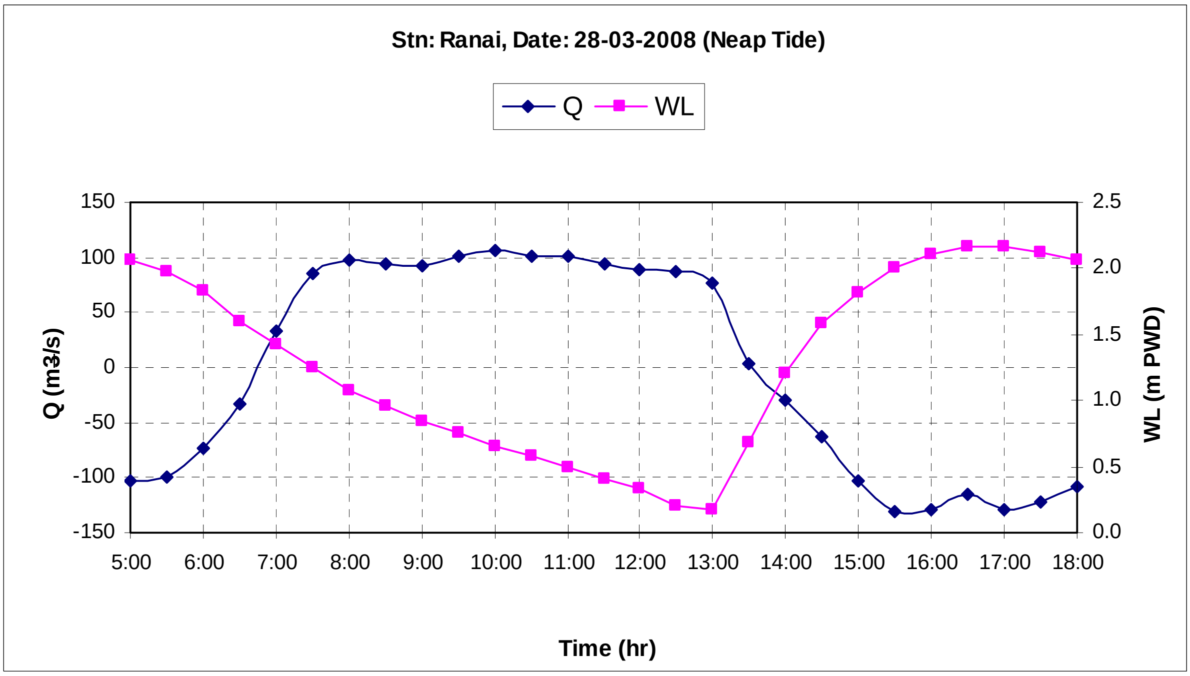

Figure B-7: Water Level and Discharge Hydrograph of Hari River at Ranai

APPENDIX C: LONG SECTION AND CROSS SECTION OF RIVER

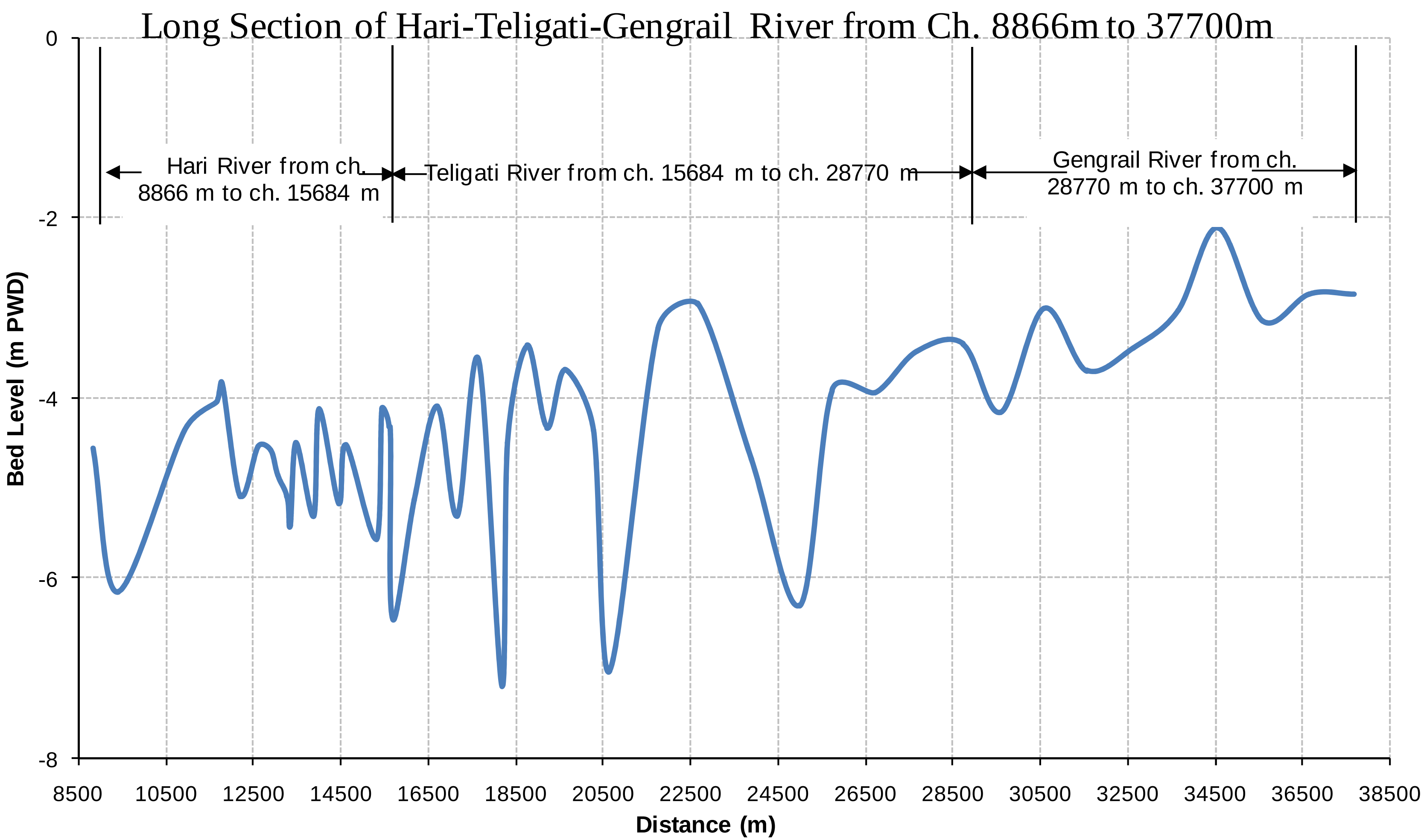

Figure C-1: Long Section of Hari-Teligati-Gengrail River

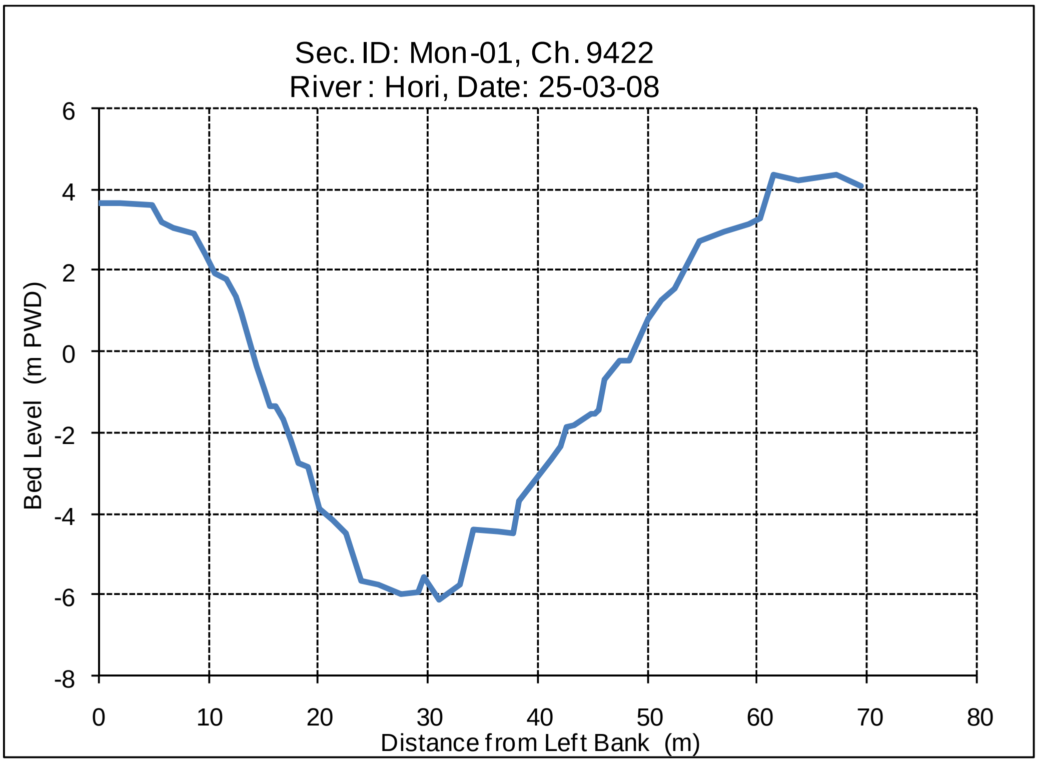

Figure C-2: Cross Section of Hari River at Ch. 9422 m

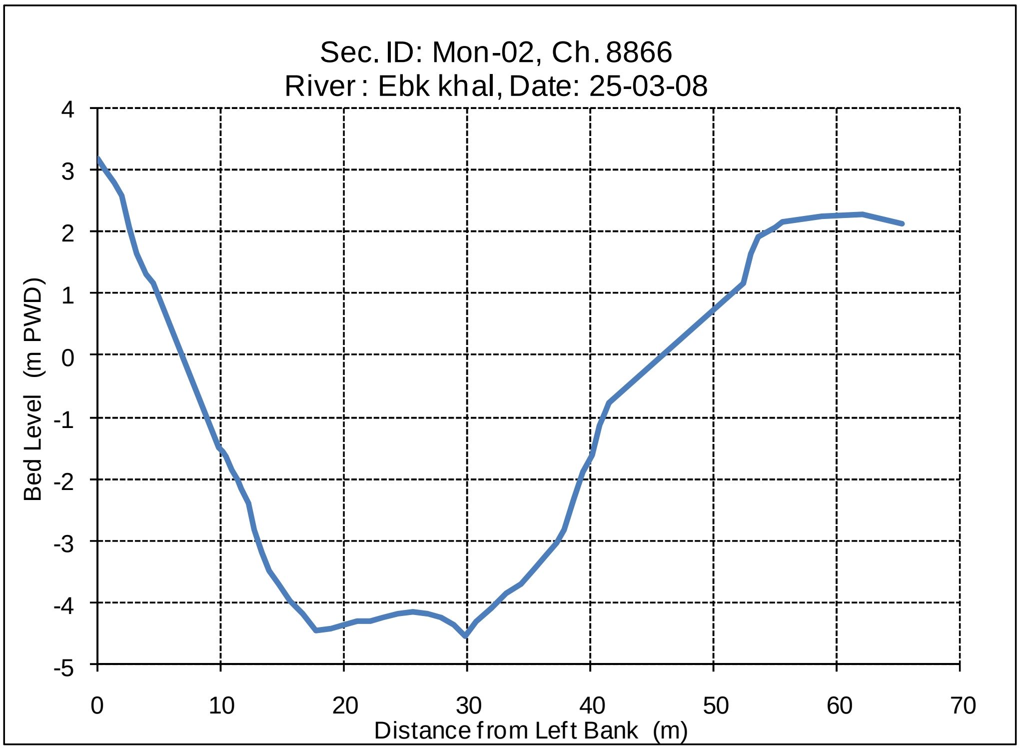

Figure C-3: Cross Section of Hari River at Ch. 8866 m

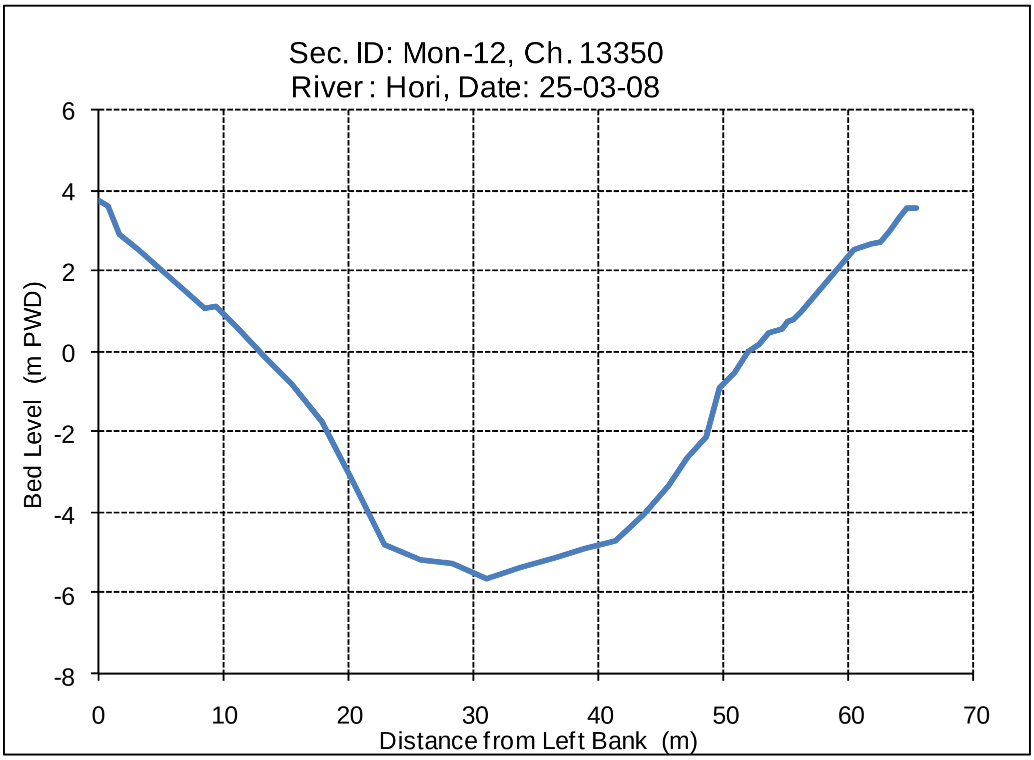

Figure C-4: Cross Section of Hari River at Ch. 13350 m

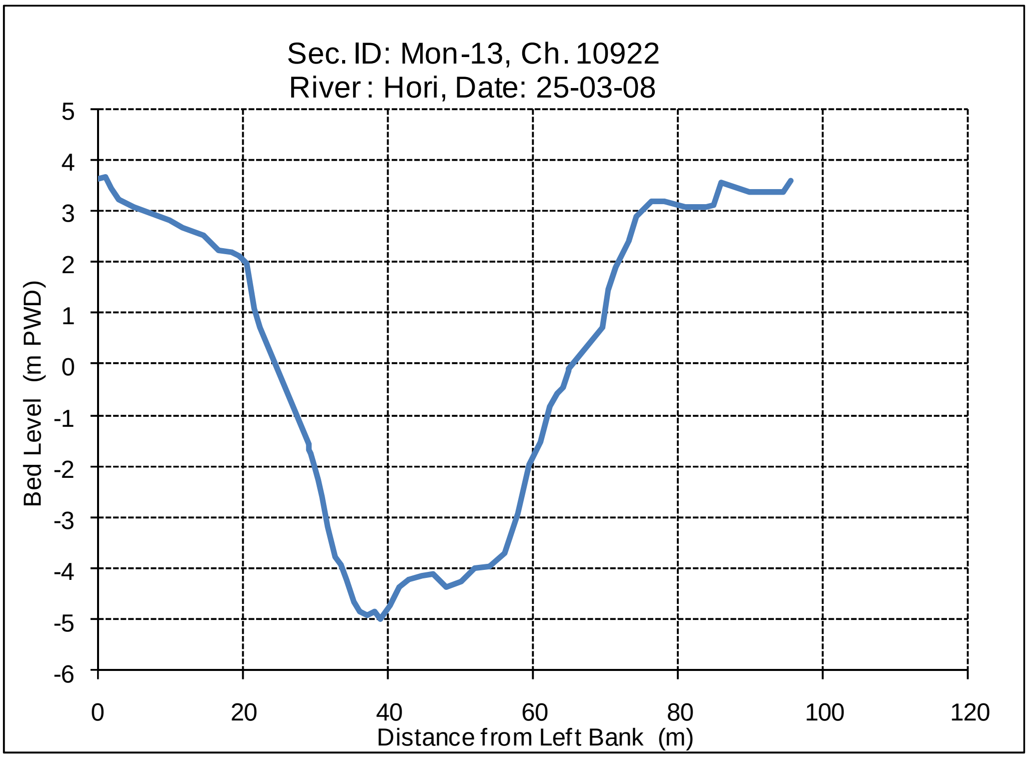

Figure C-5: Cross Section of Hari River at Ch. 10922 m

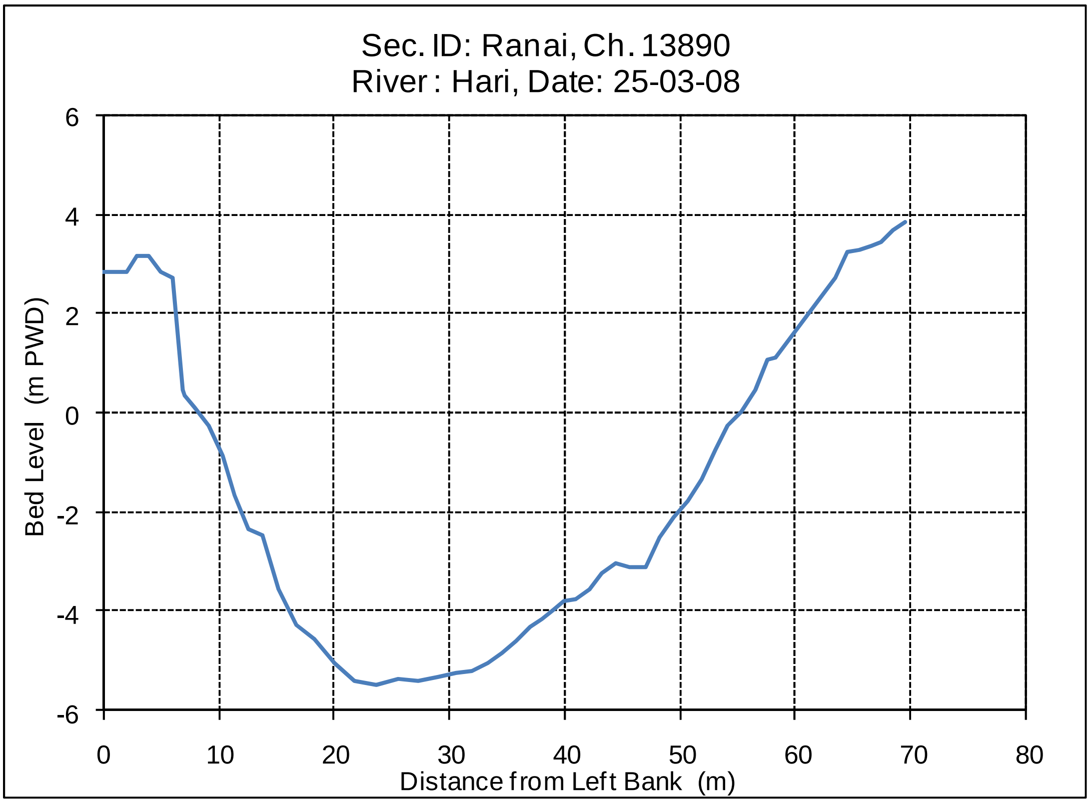

Figure C-6: Cross Section of Hari River at Ch. 13890 m

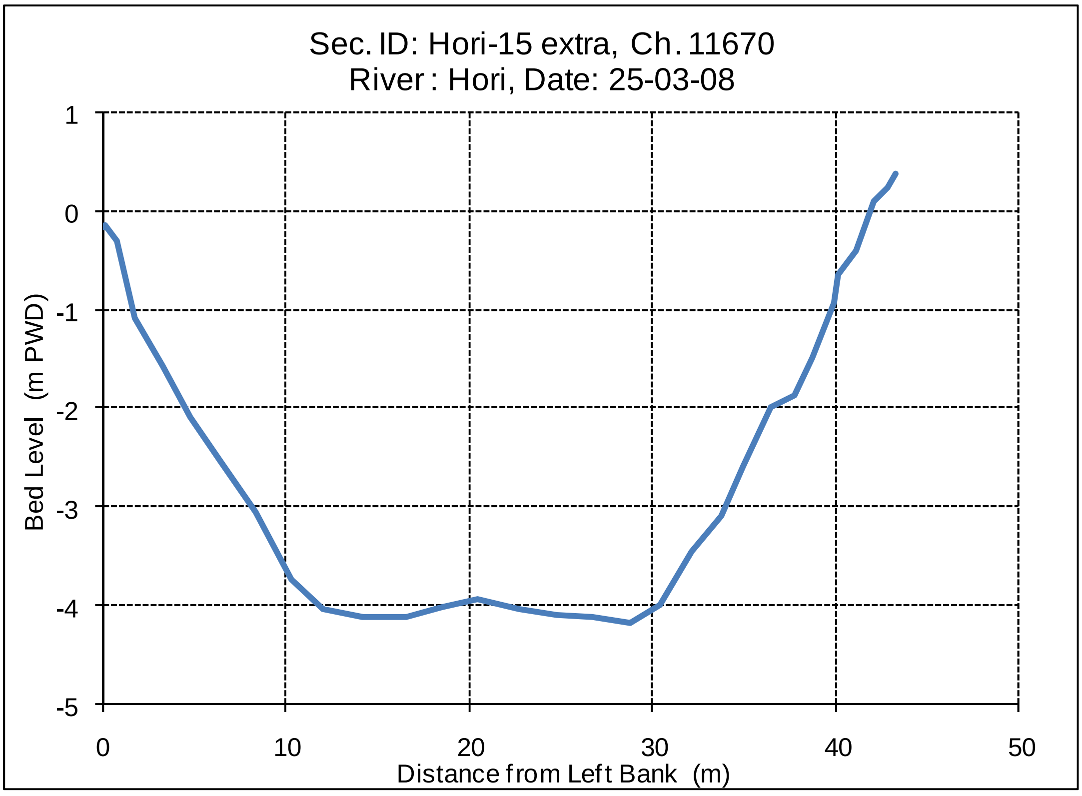

Figure C-7: Cross Section of Hari River at Ch. 11670 m

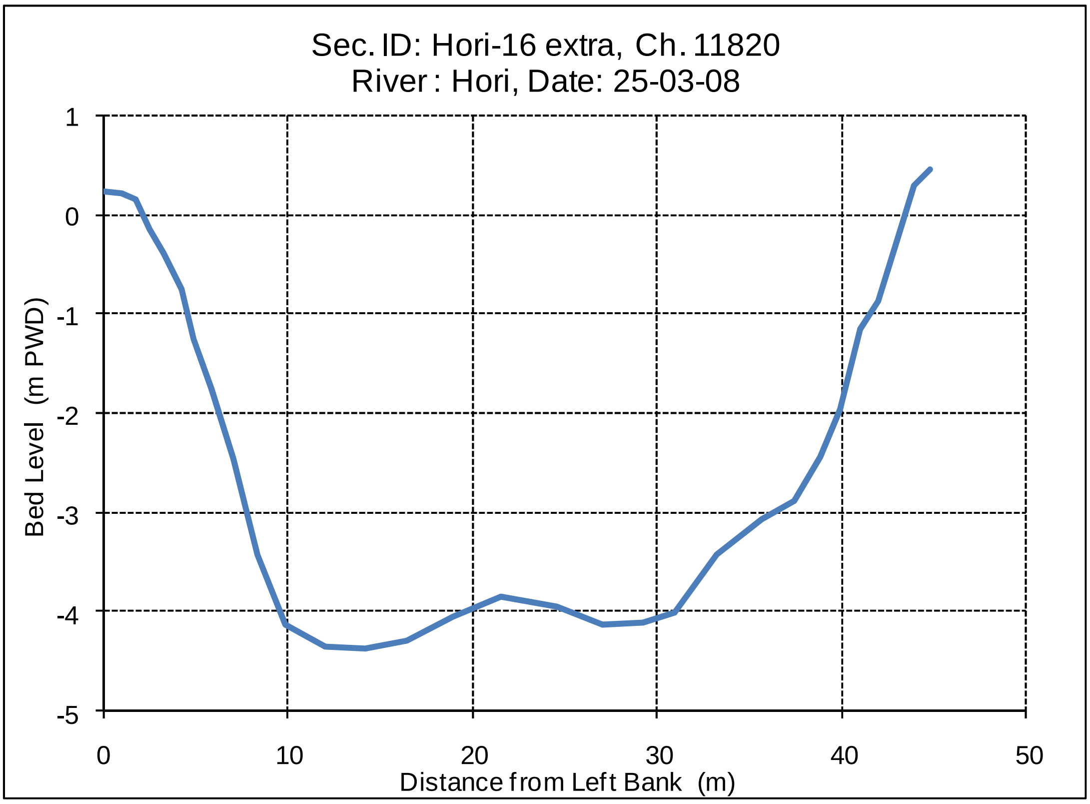

Figure C-8: Cross Section of Hari River at Ch. 11820 m

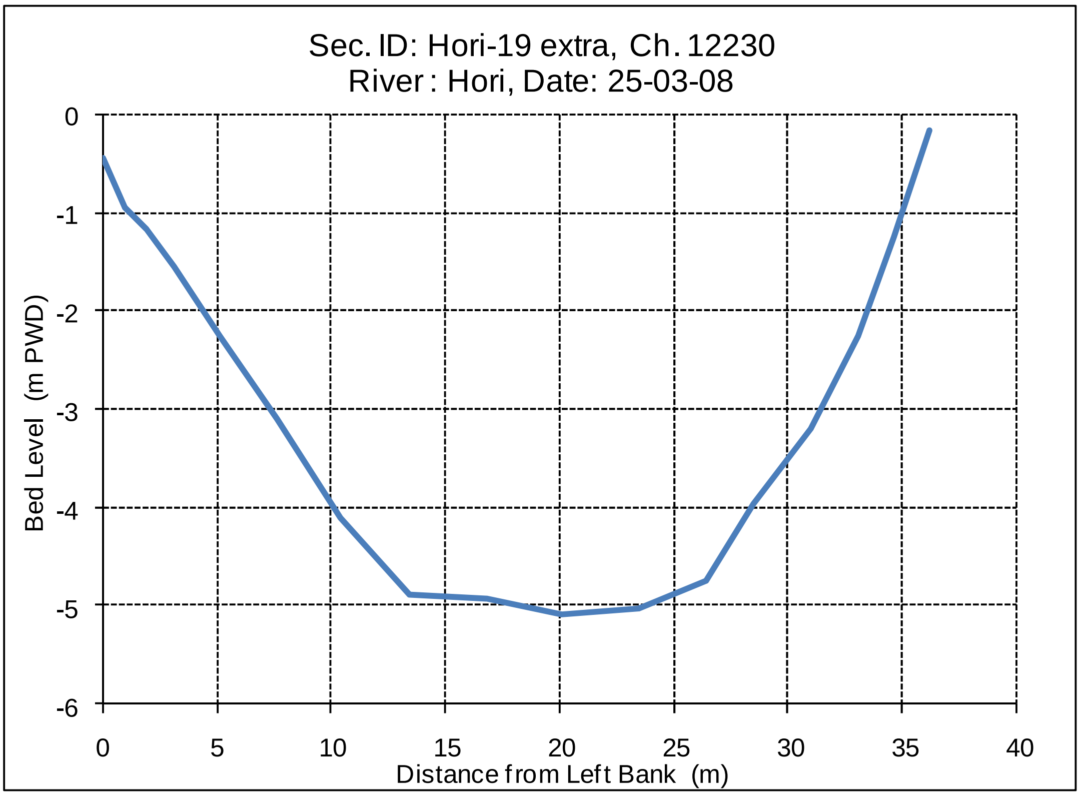

Figure C-9: Cross Section of Hari River at Ch. 12230 m

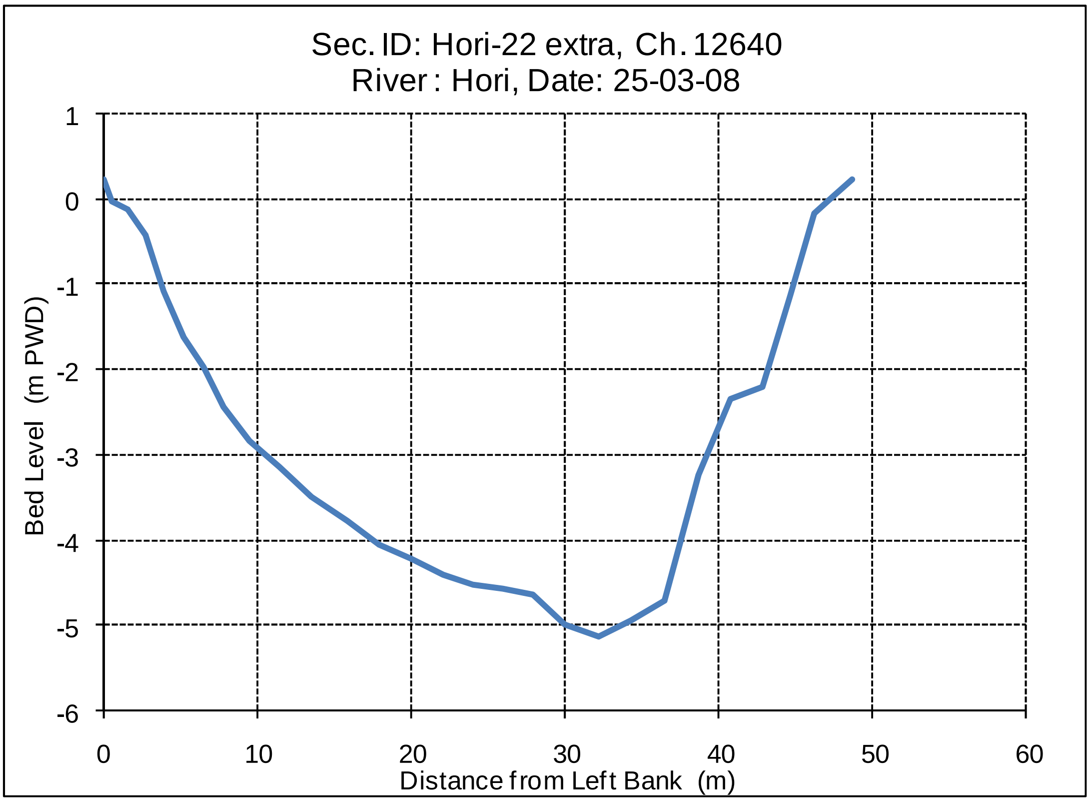

Figure C-10: Cross Section of Hari River at Ch. 12640 m

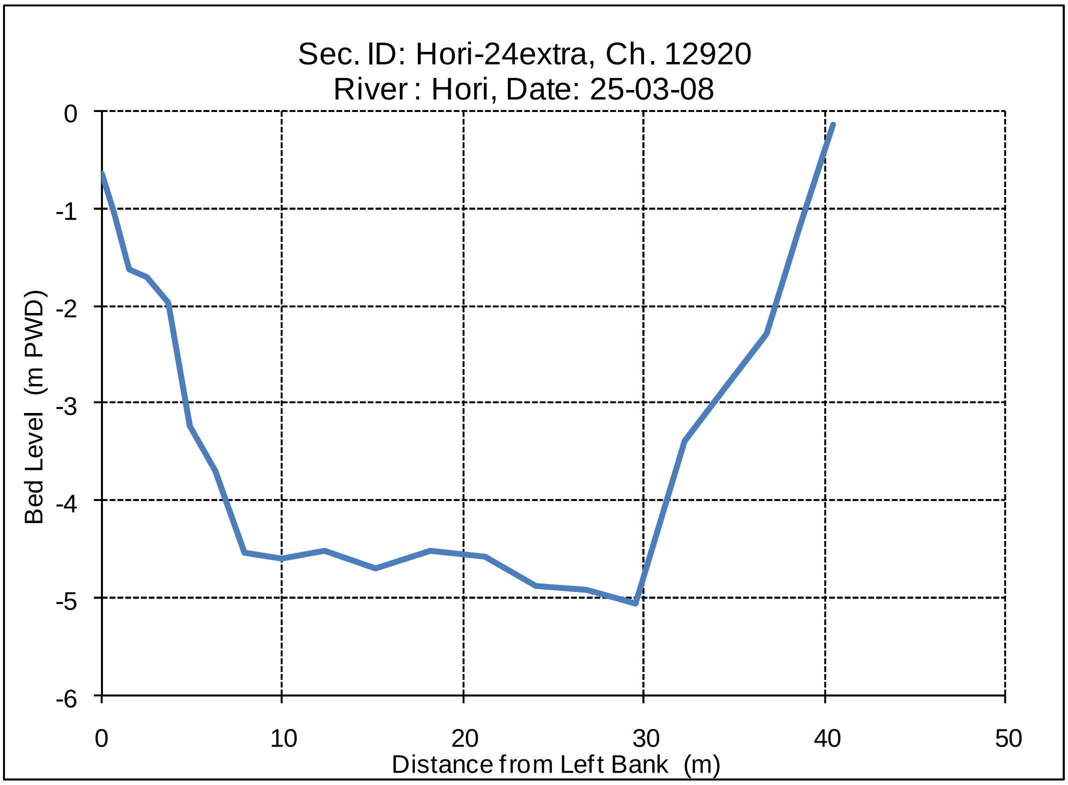

Figure C-11: Cross Section of Hari River at Ch. 12920 m

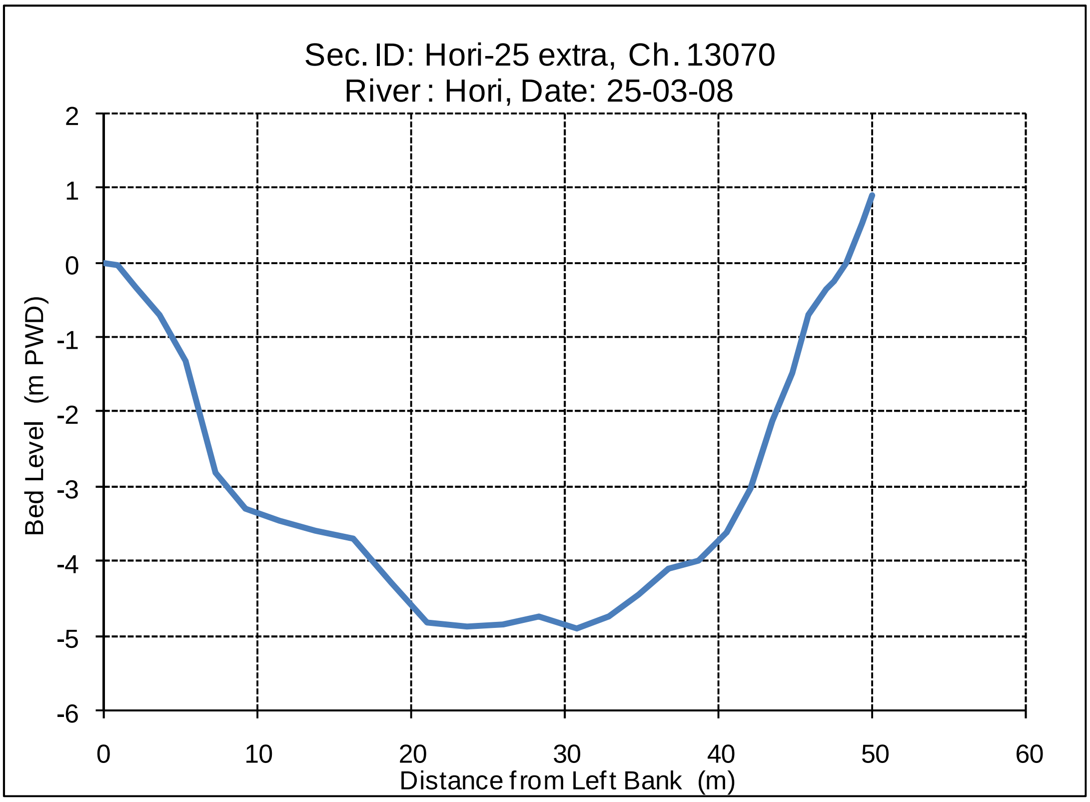

Figure C-12: Cross Section of Hari River at Ch. 13070 m

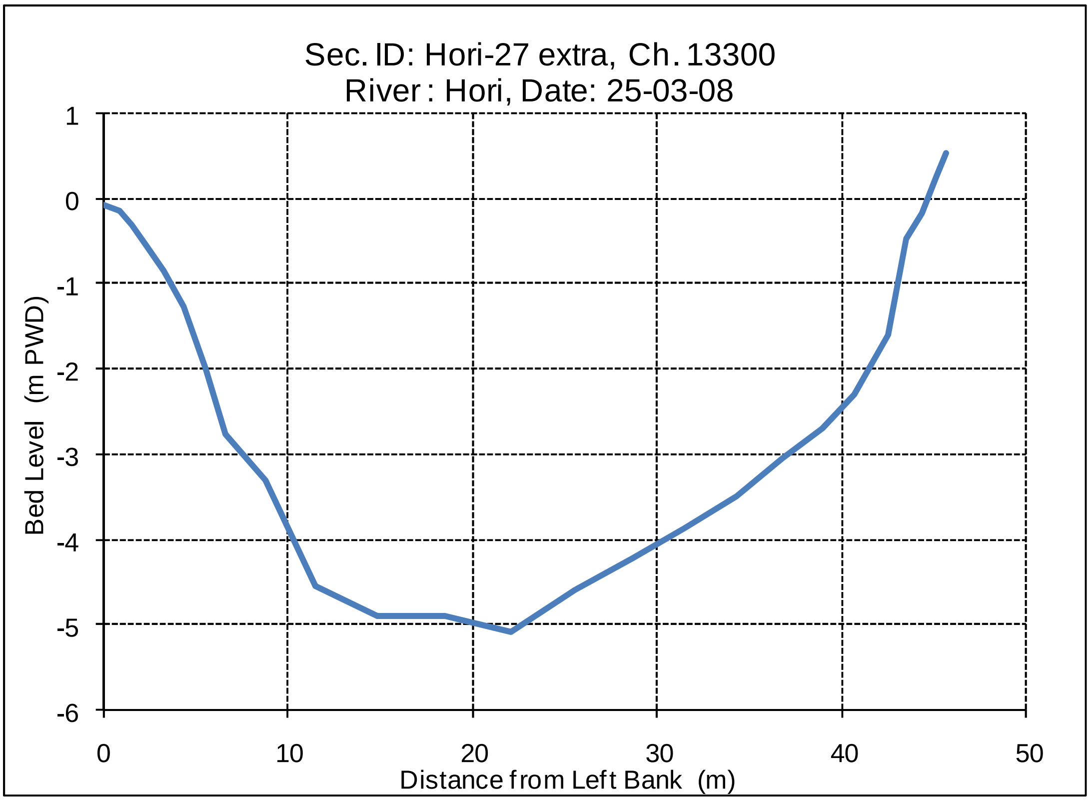

Figure C-13: Cross Section of Hari River at Ch. 13300 m

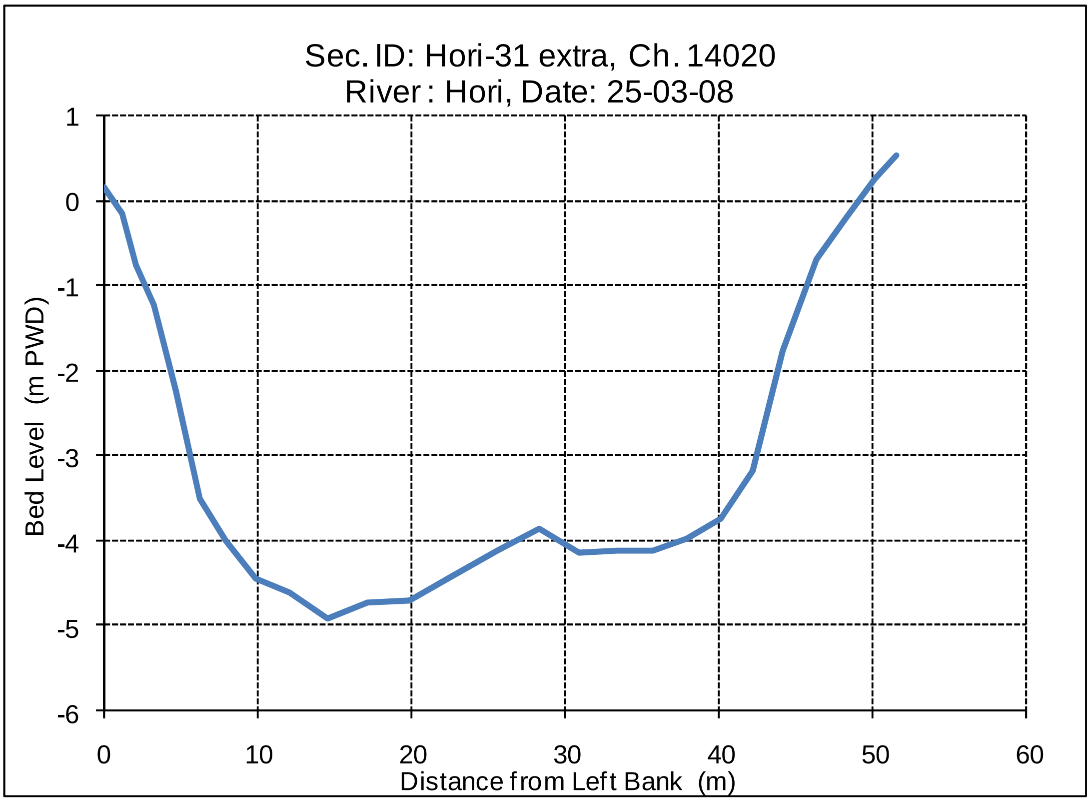

Figure C-14: Cross Section of Hari River at Ch. 14020 m

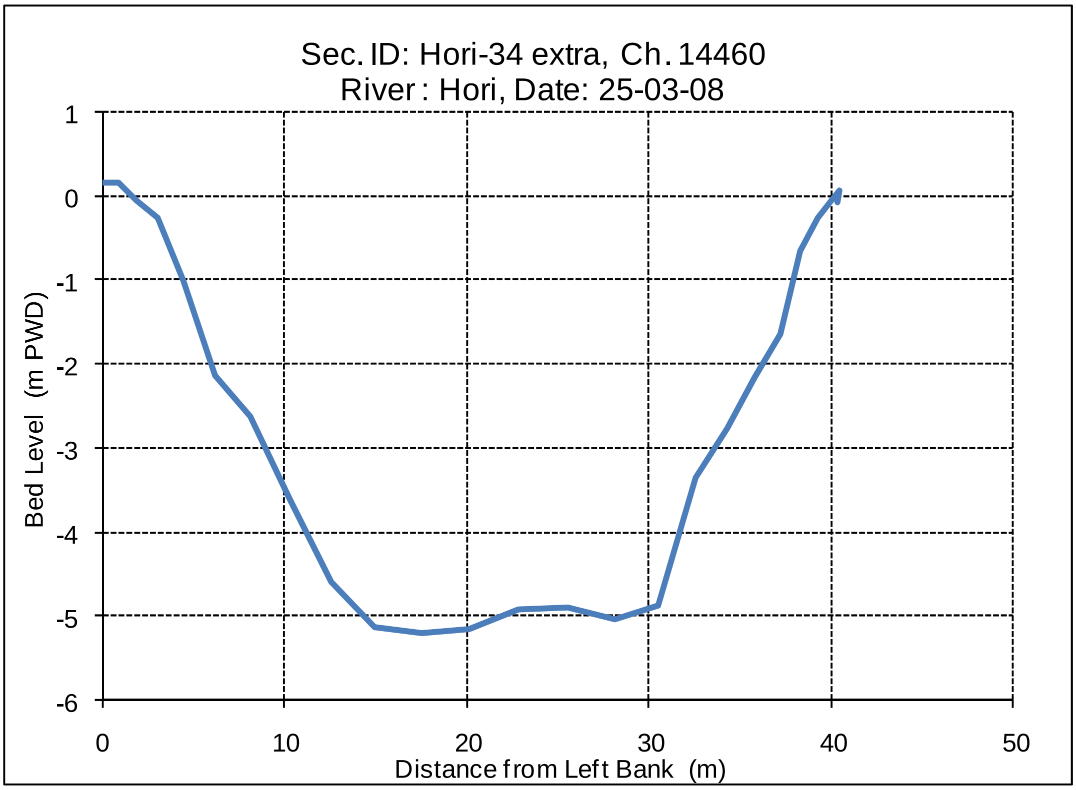

Figure C-15: Cross Section of Hari River at Ch. 14460 m

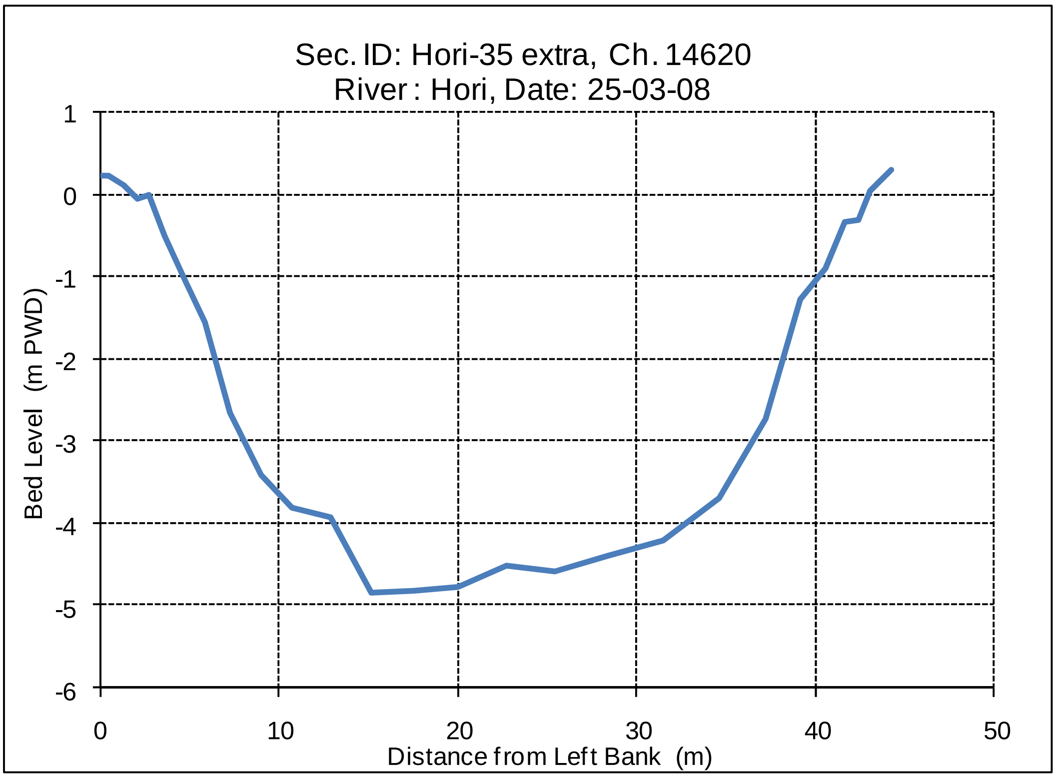

Figure C-16: Cross Section of Hari River at Ch. 14620 m

Figure C-17: Cross Section of Hari River at Ch. 15320 m

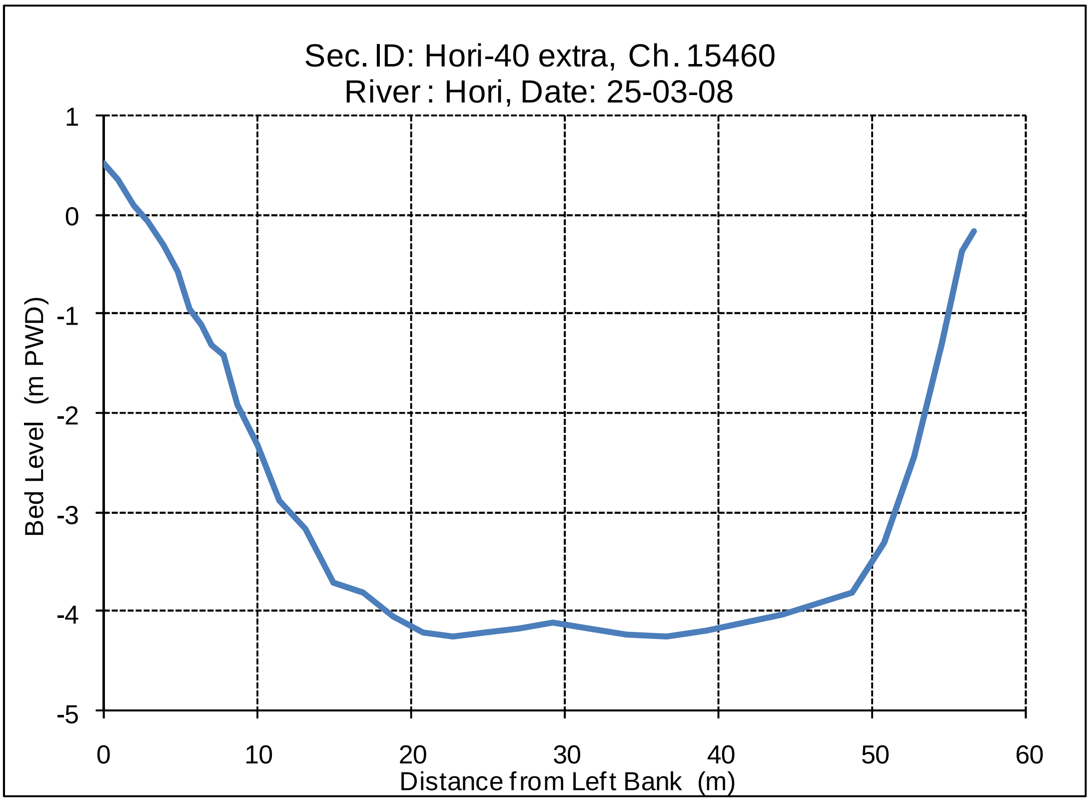

Figure C-18: Cross Section of Hari River at Ch. 15460 m

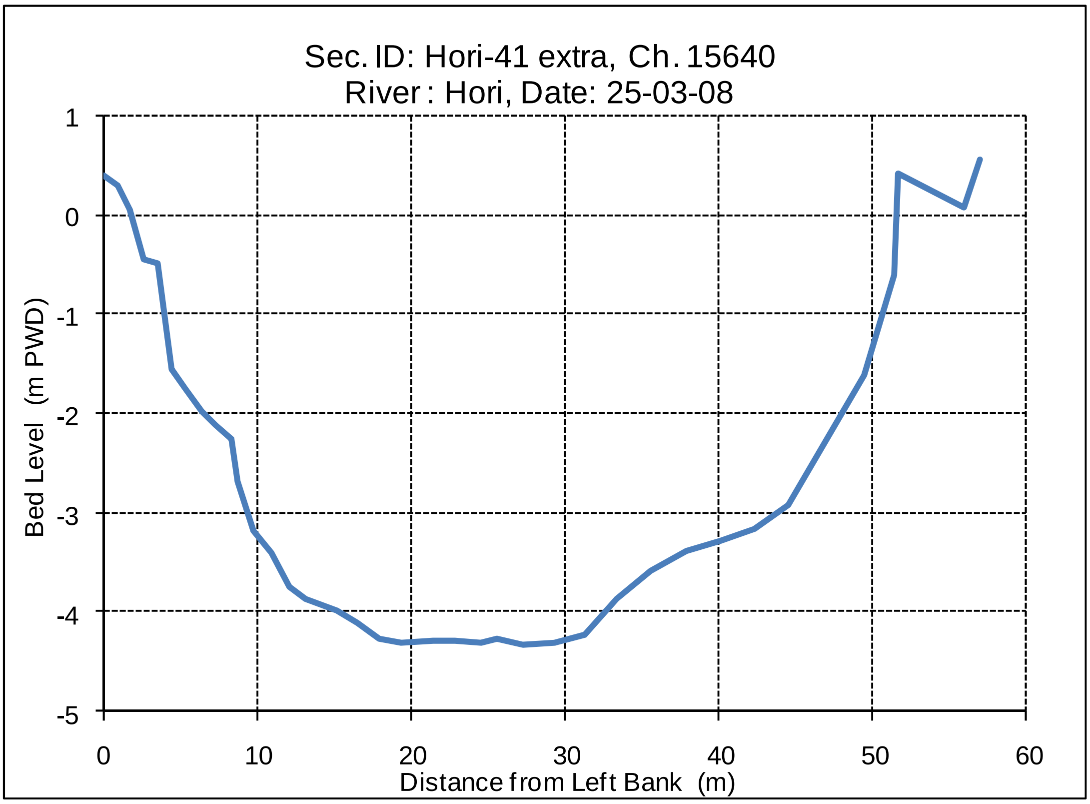

Figure C-19: Cross Section of Hari River at Ch. 15640 m

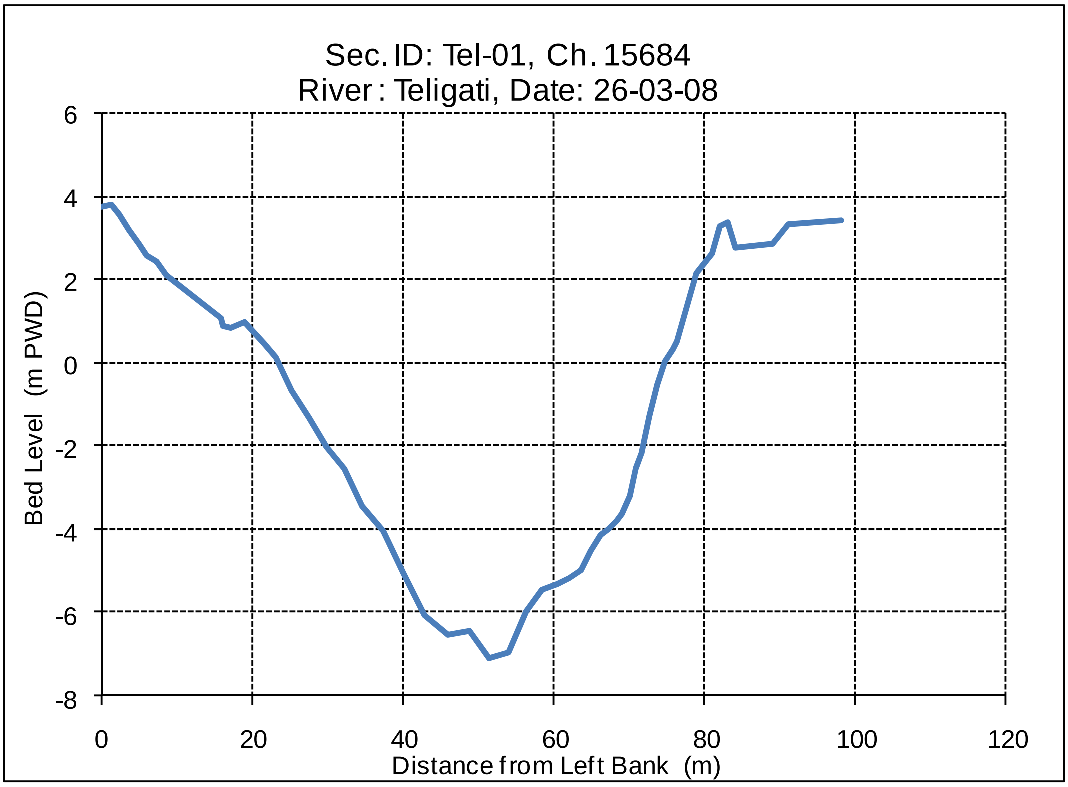

Figure C-20: Cross Section of Teligati River at Ch. 15684 m

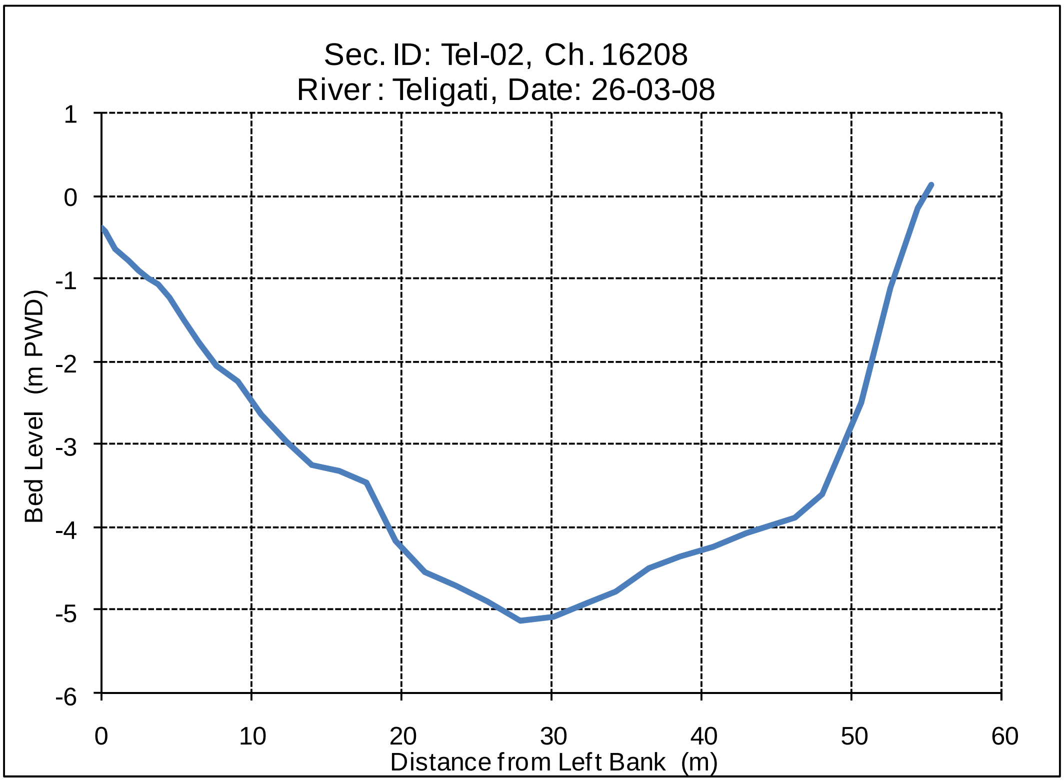

Figure C-21: Cross Section of Teligati River at Ch. 16208 m

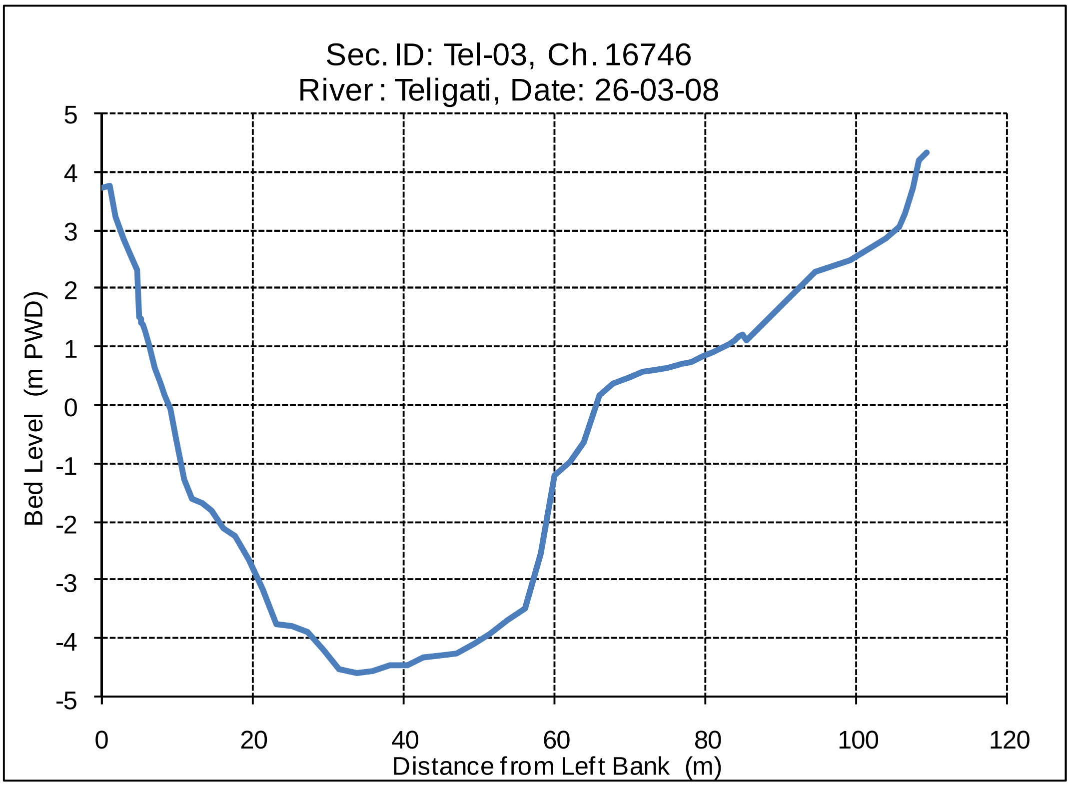

Figure C-22: Cross Section of Teligati River at Ch. 16746 m

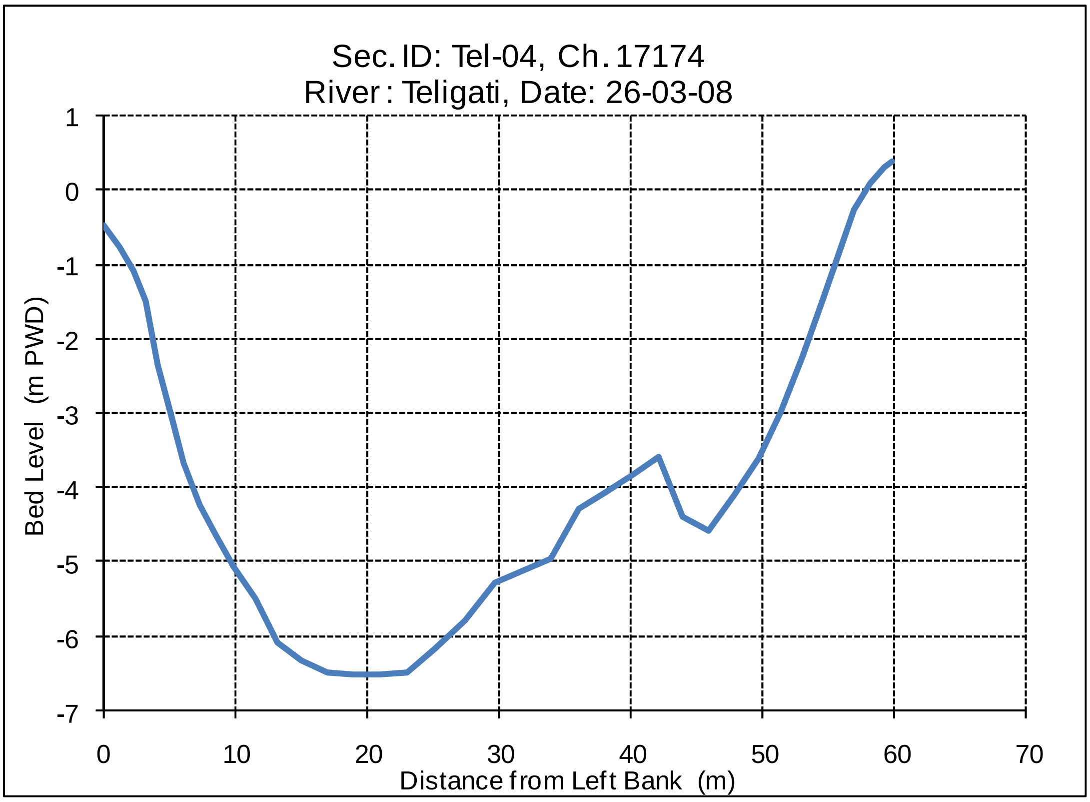

Figure C-23: Cross Section of Teligati River at Ch. 17174 m

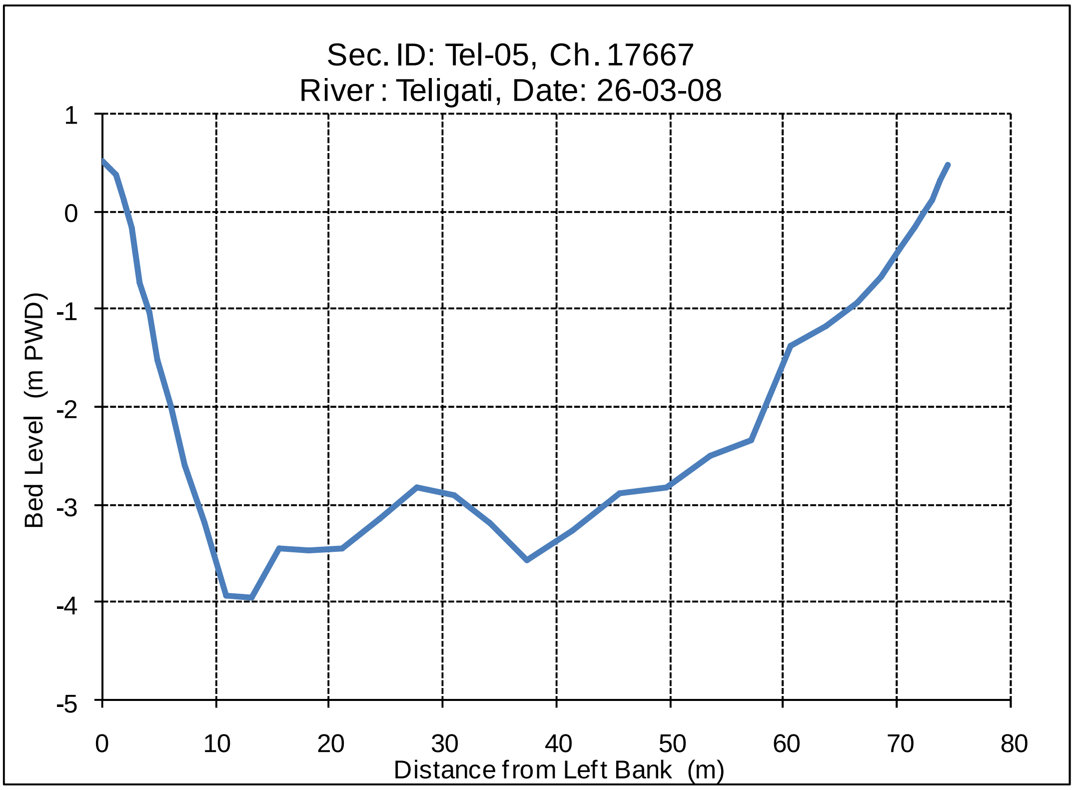

Figure C-24: Cross Section of Teligati River at Ch. 17667 m

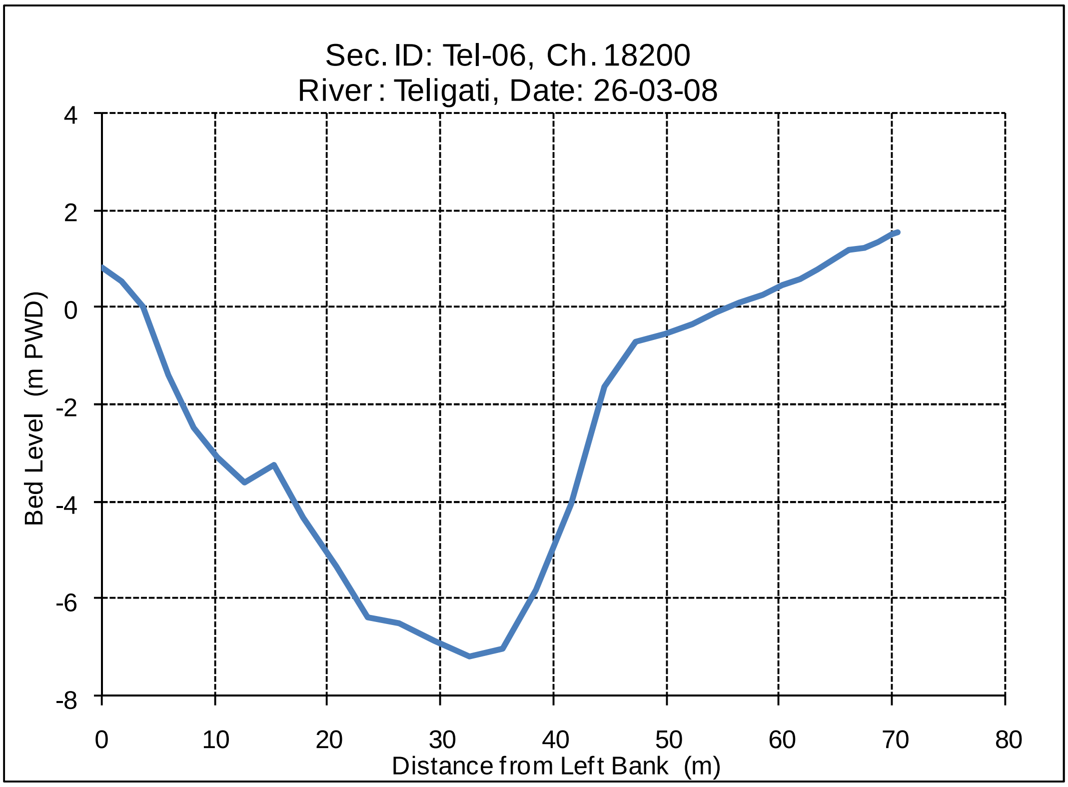

Figure C-25: Cross Section of Teligati River at Ch. 18200 m

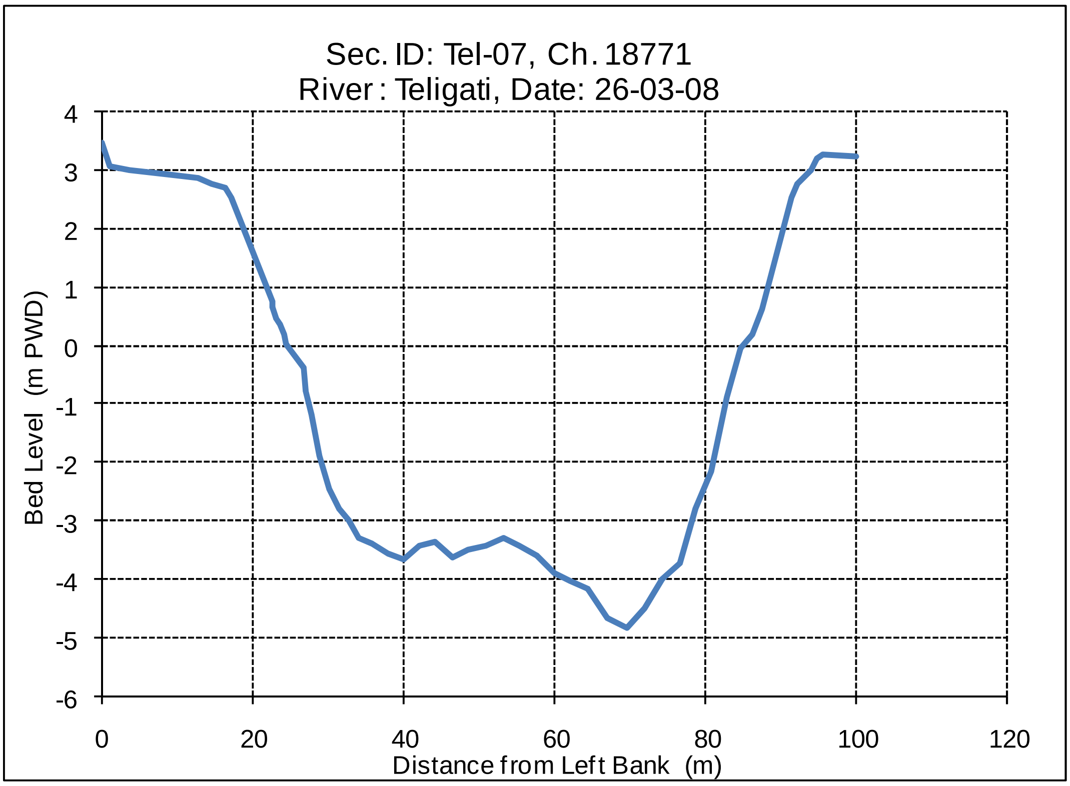

Figure C-26: Cross Section of Teligati River at Ch. 18771 m

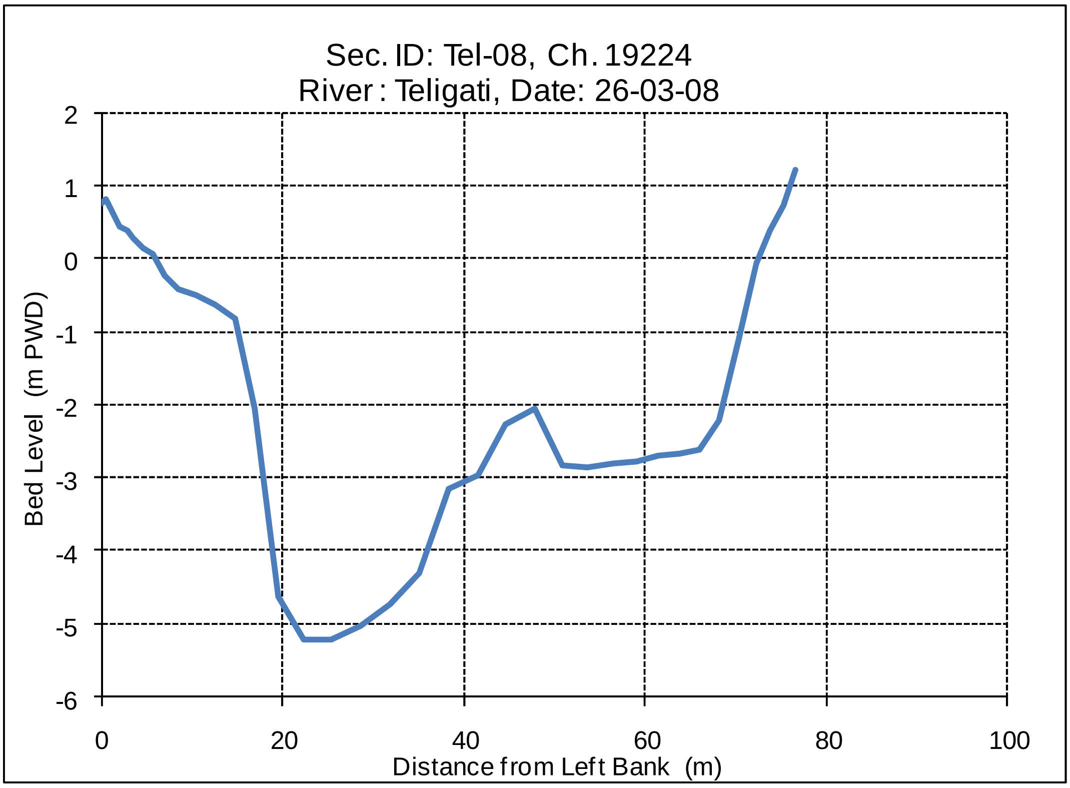

Figure C-27: Cross Section of Teligati River at Ch. 19224 m

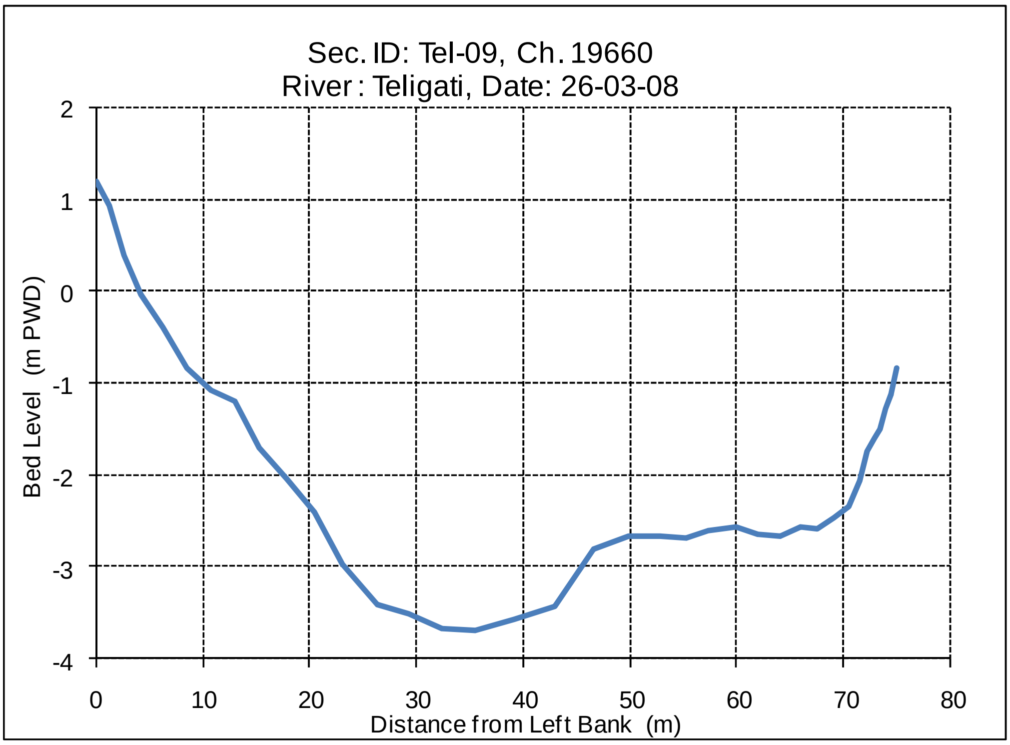

Figure C-28: Cross Section of Teligati River at Ch. 19660 m

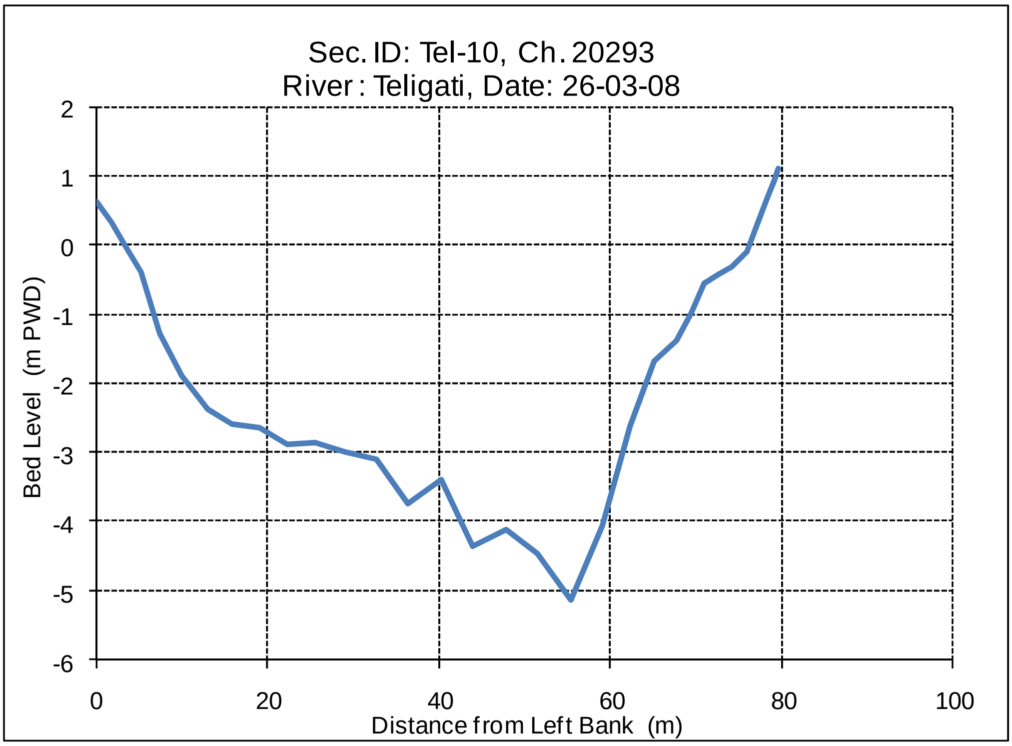

Figure C-29: Cross Section of Teligati River at Ch. 20293 m

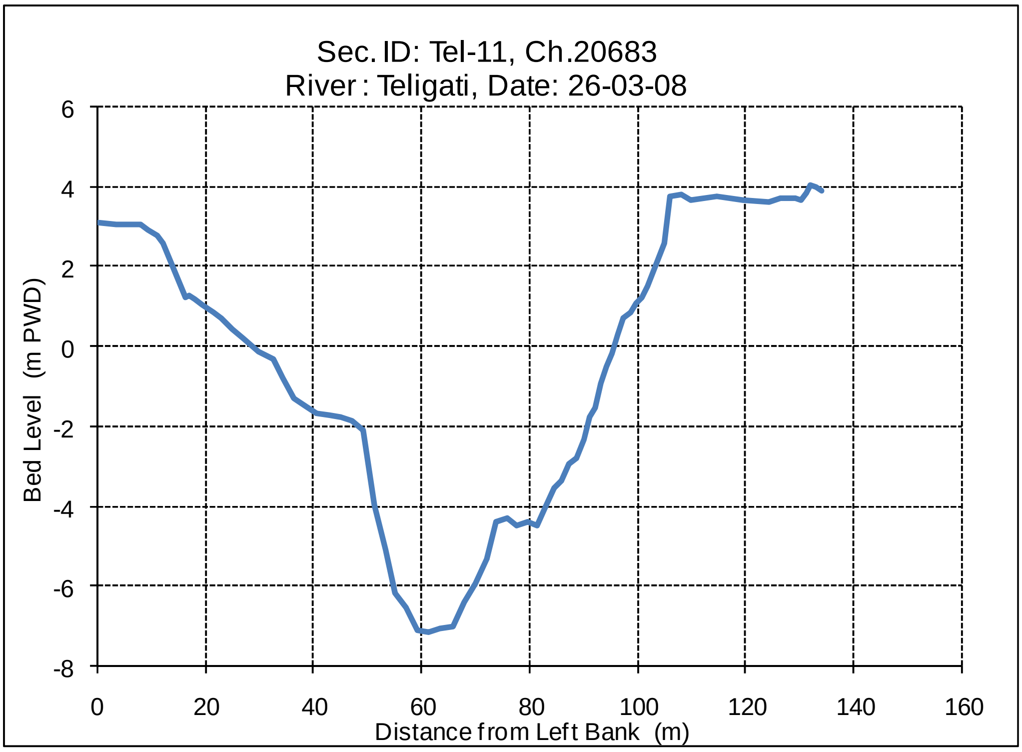

Figure C-30: Cross Section of Teligati River at Ch. 20683 m

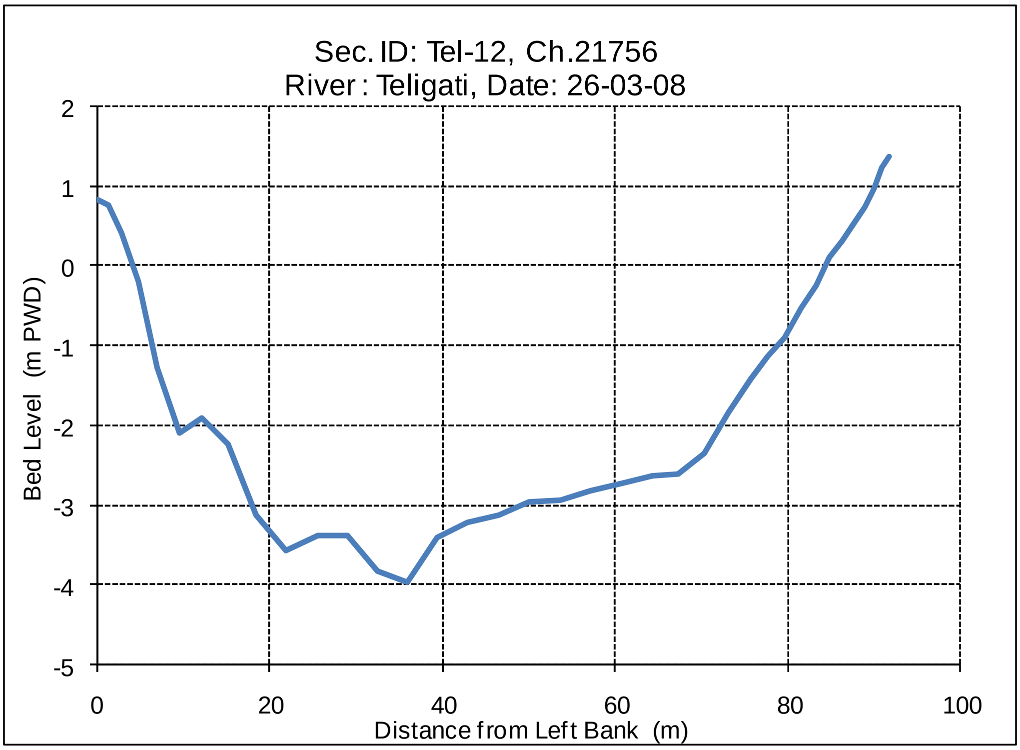

Figure C-31: Cross Section of Teligati River at Ch. 21756 m

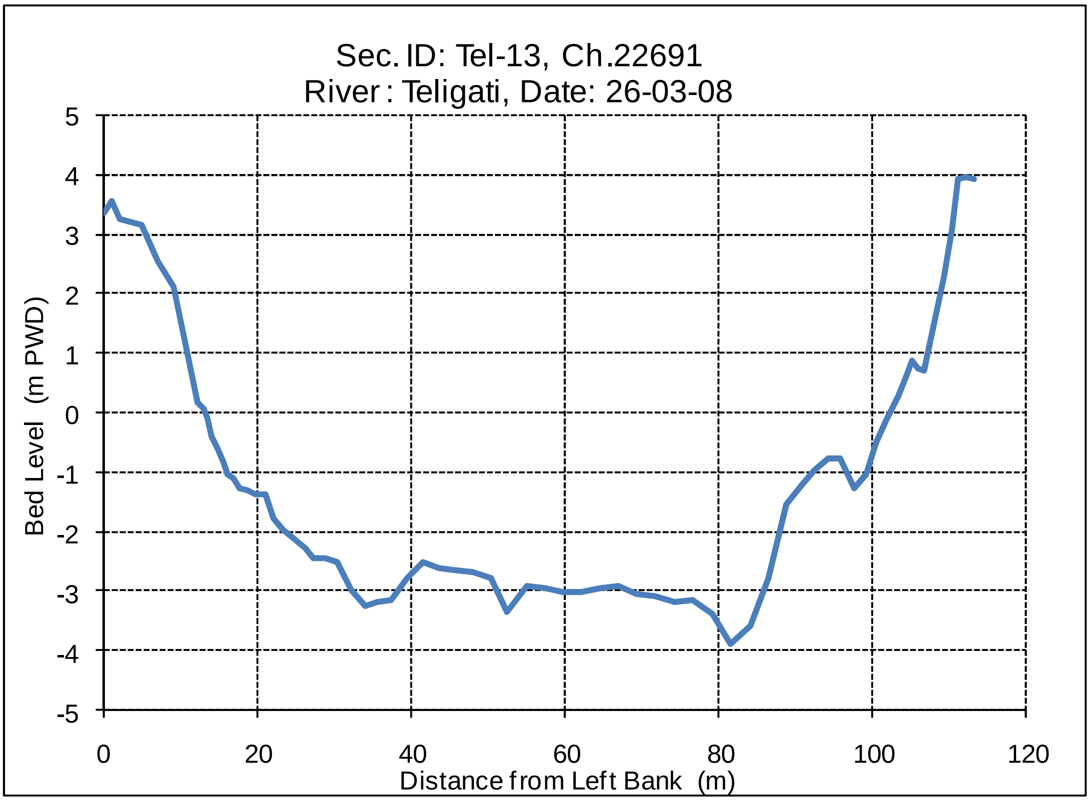

Figure C-32: Cross Section of Teligati River at Ch. 22691 m

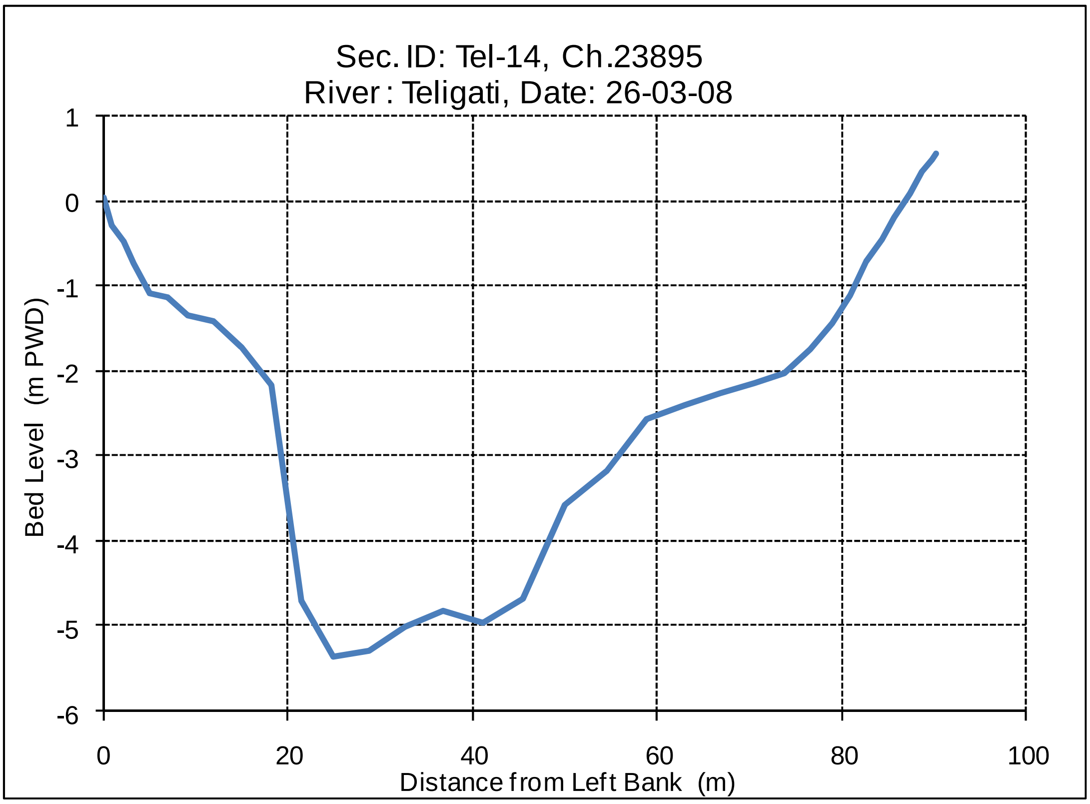

Figure C-33: Cross Section of Teligati River at Ch. 23895 m

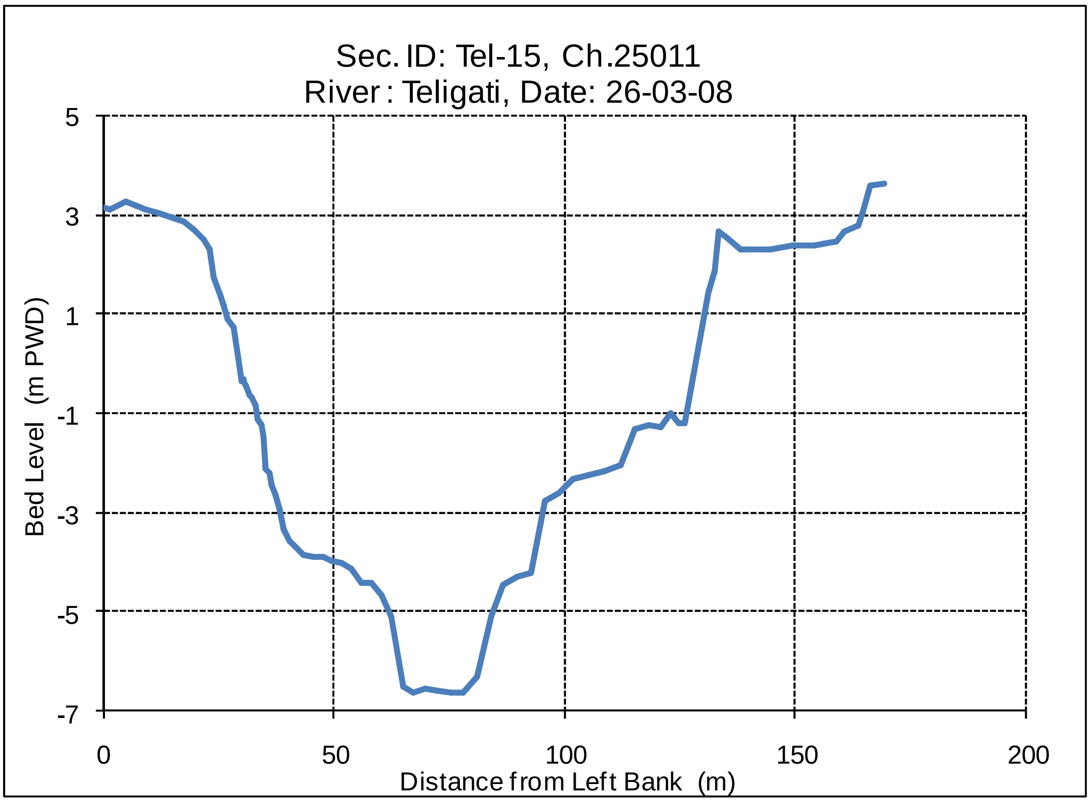

Figure C-34: Cross Section of Teligati River at Ch. 25011 m

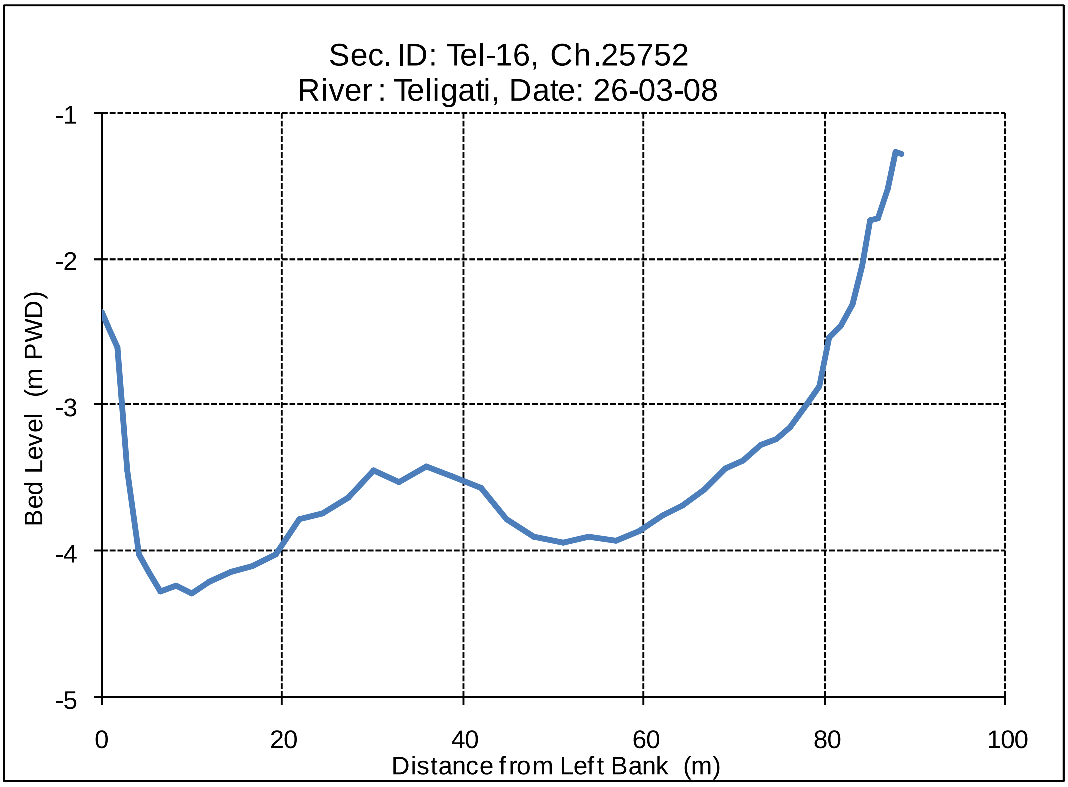

Figure C-35: Cross Section of Teligati River at Ch. 25752 m

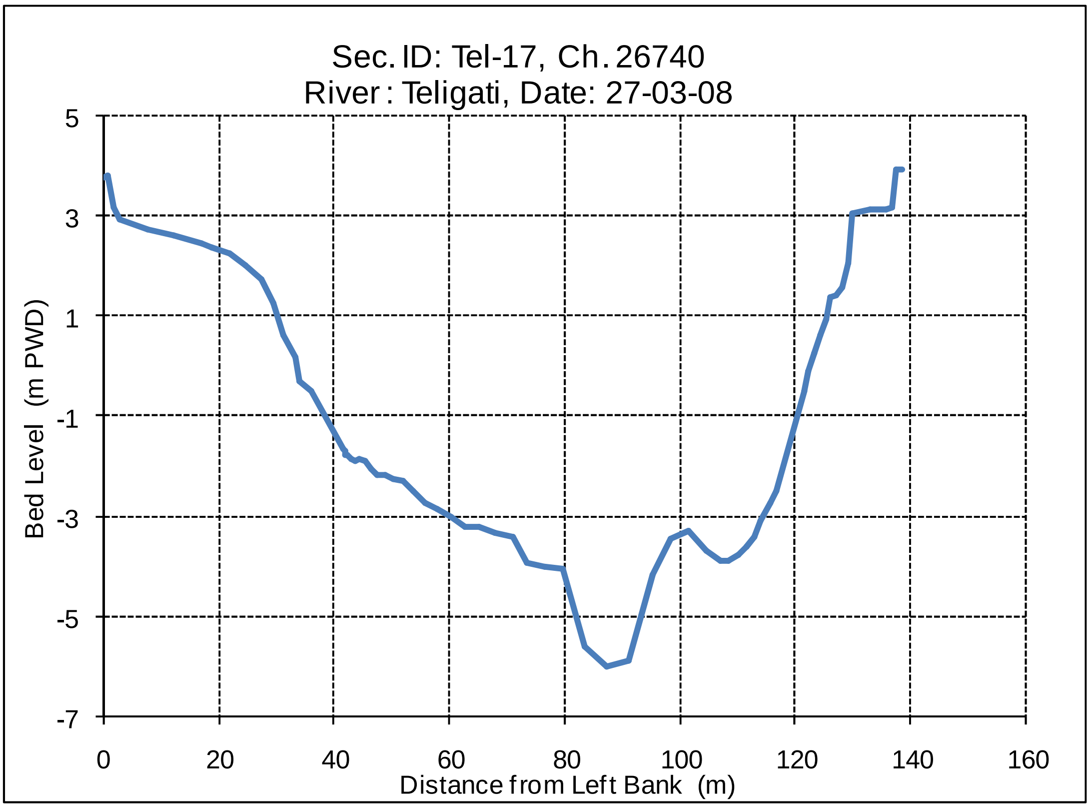

Figure C-36: Cross Section of Teligati River at Ch. 26740 m

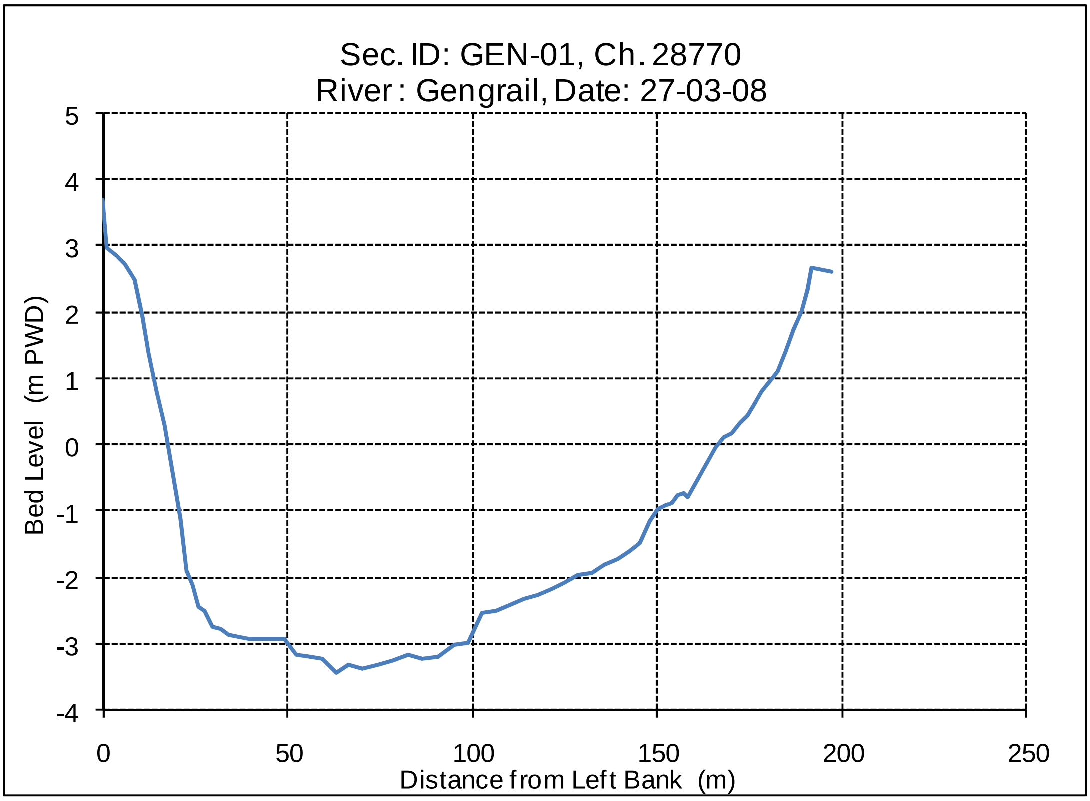

Figure C-37: Cross Section of Gengrail River at Ch. 28770 m

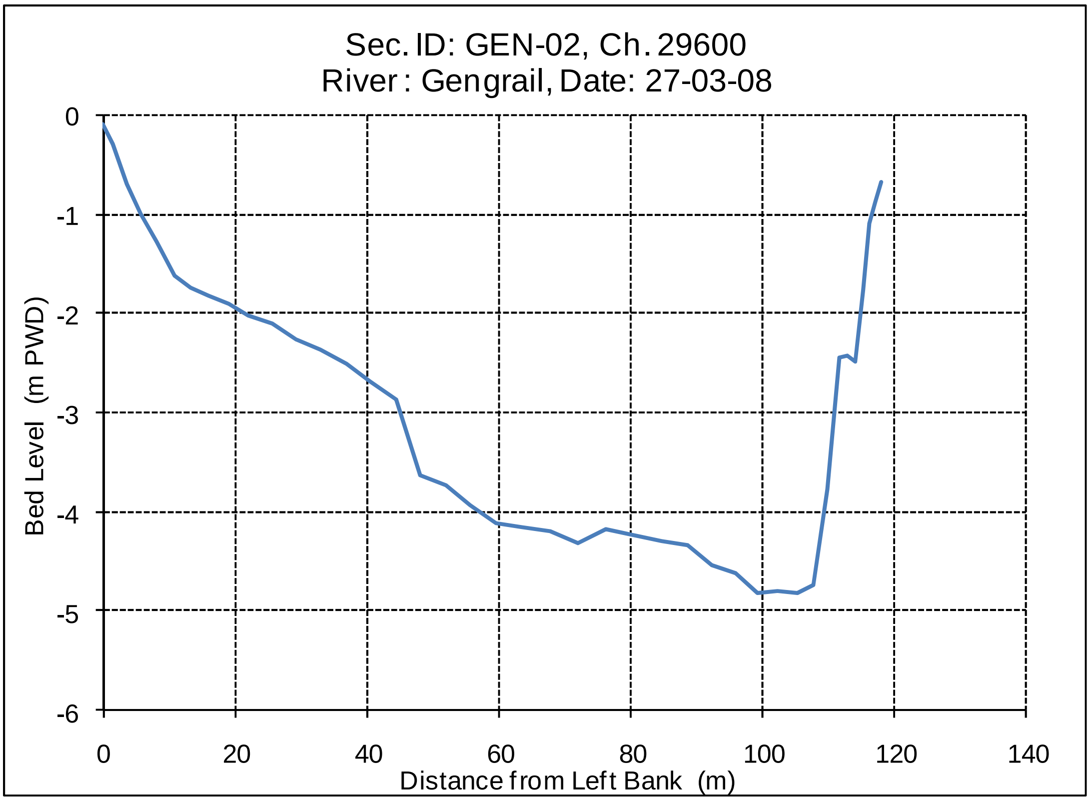

Figure C-38: Cross Section of Gengrail River at Ch. 29600 m

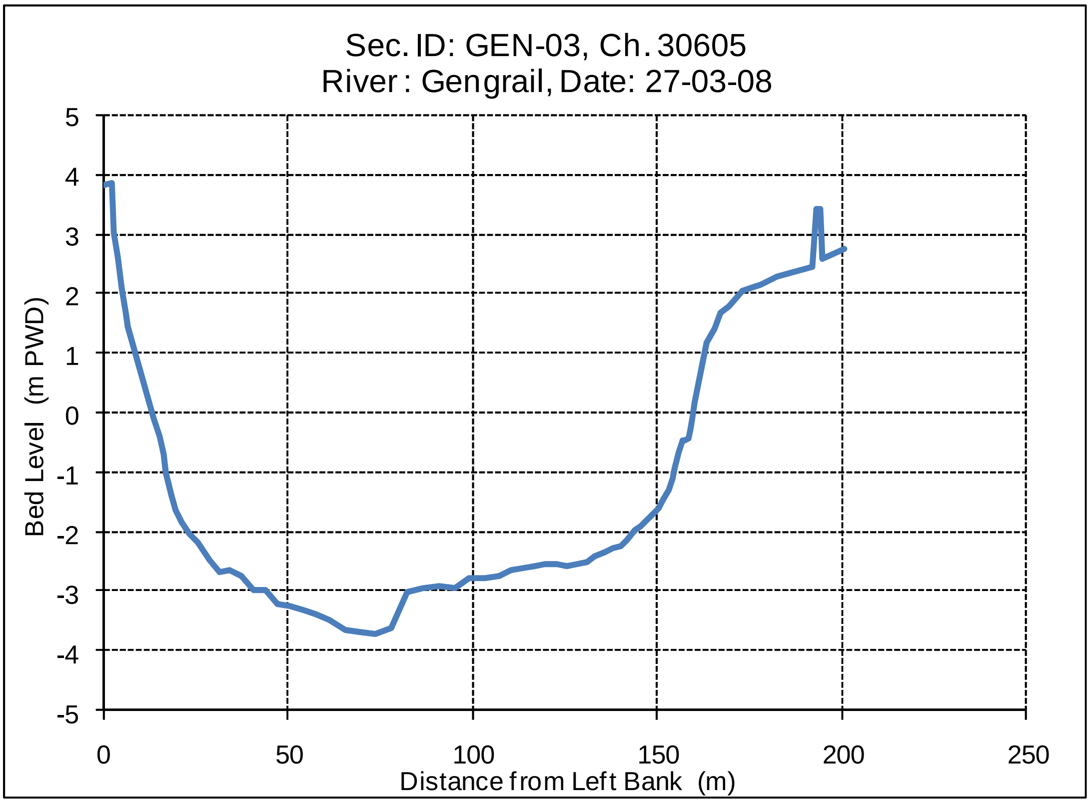

Figure C-39: Cross Section of Gengrail River at Ch. 30605 m

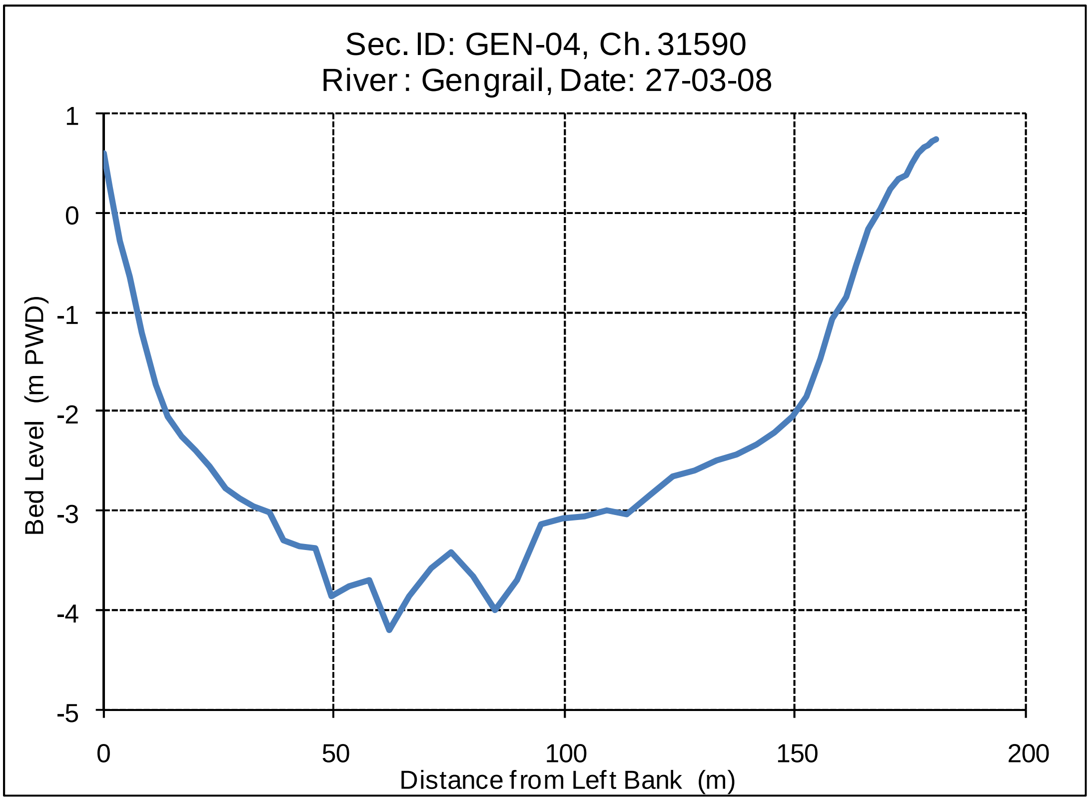

Figure C-40: Cross Section of Gengrail River at Ch. 31590 m

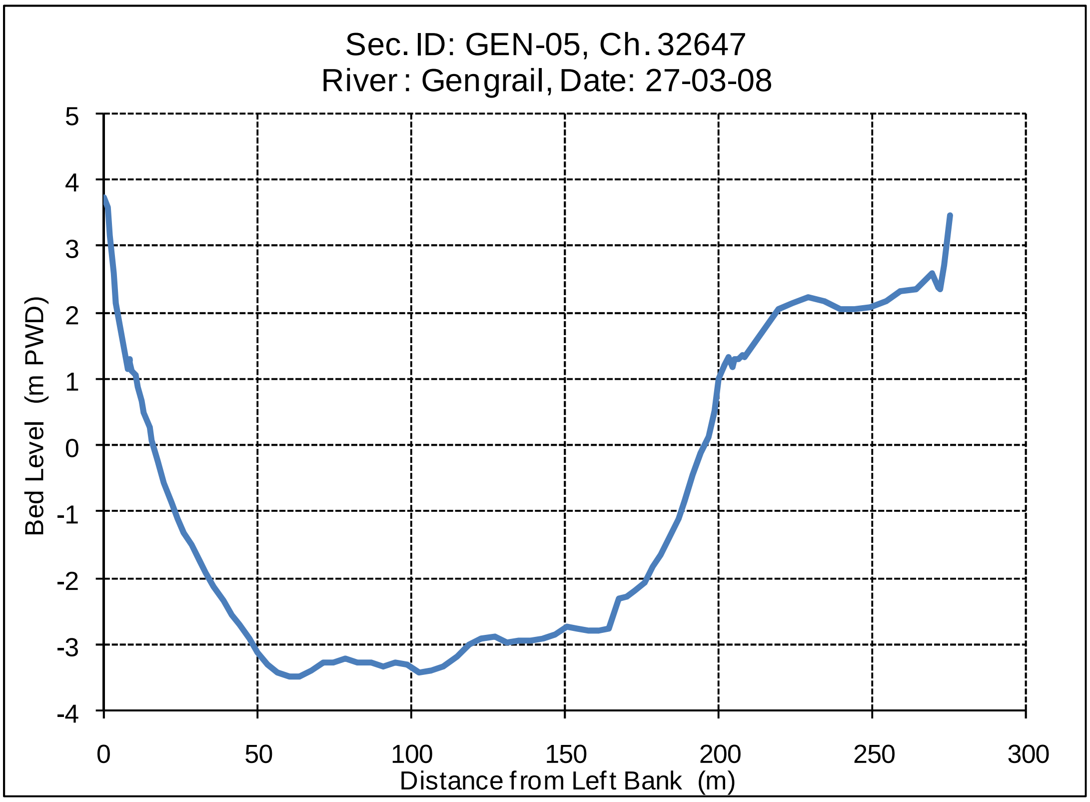

Figure C-41: Cross Section of Gengrail River at Ch. 32647 m

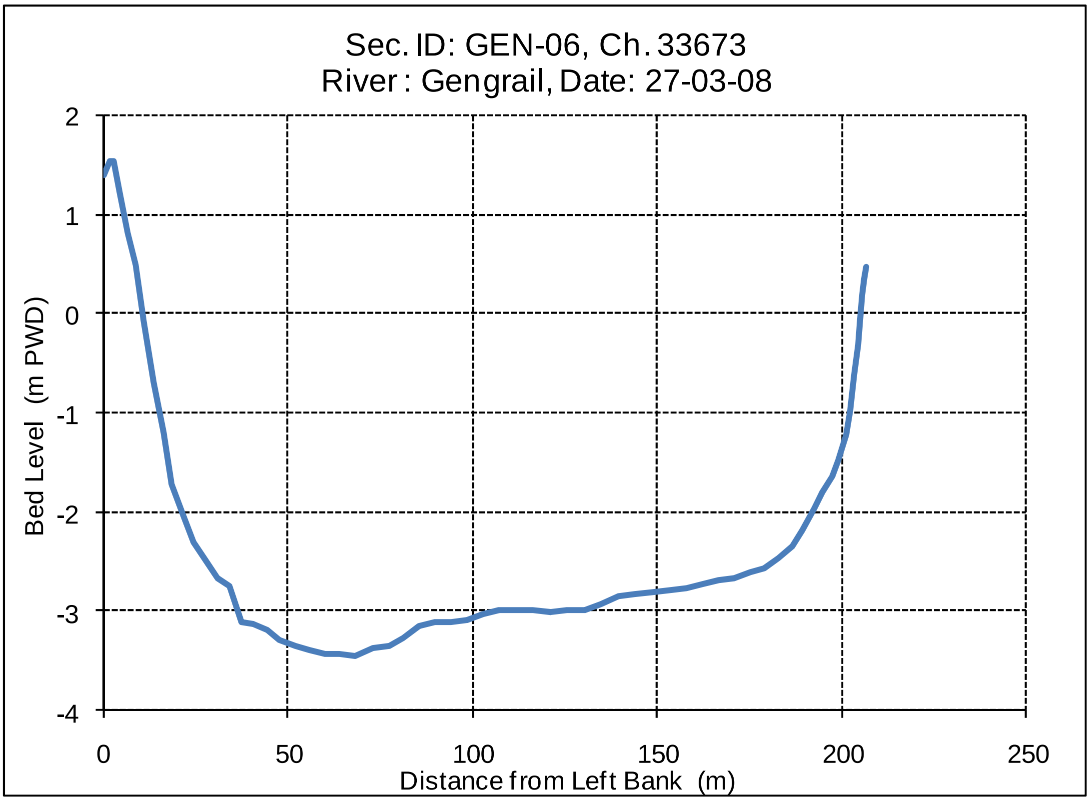

Figure C-42: Cross Section of Gengrail River at Ch. 33673 m

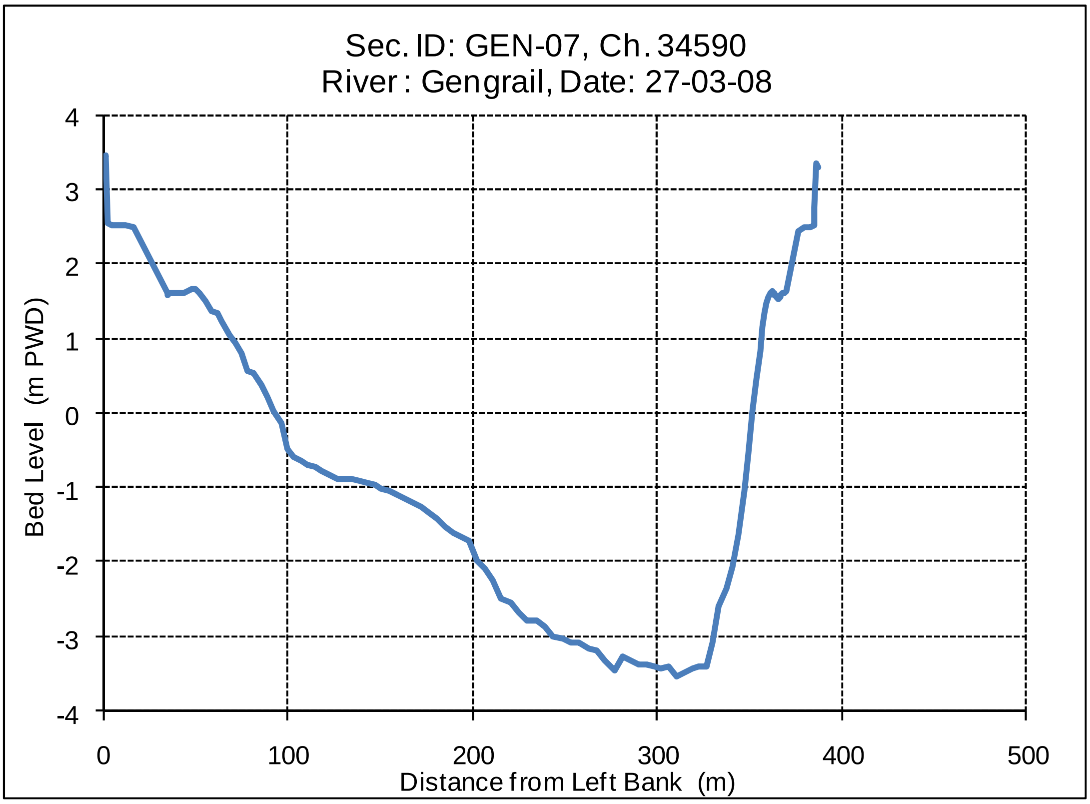

Figure C-43: Cross Section of Gengrail River at Ch. 34590 m

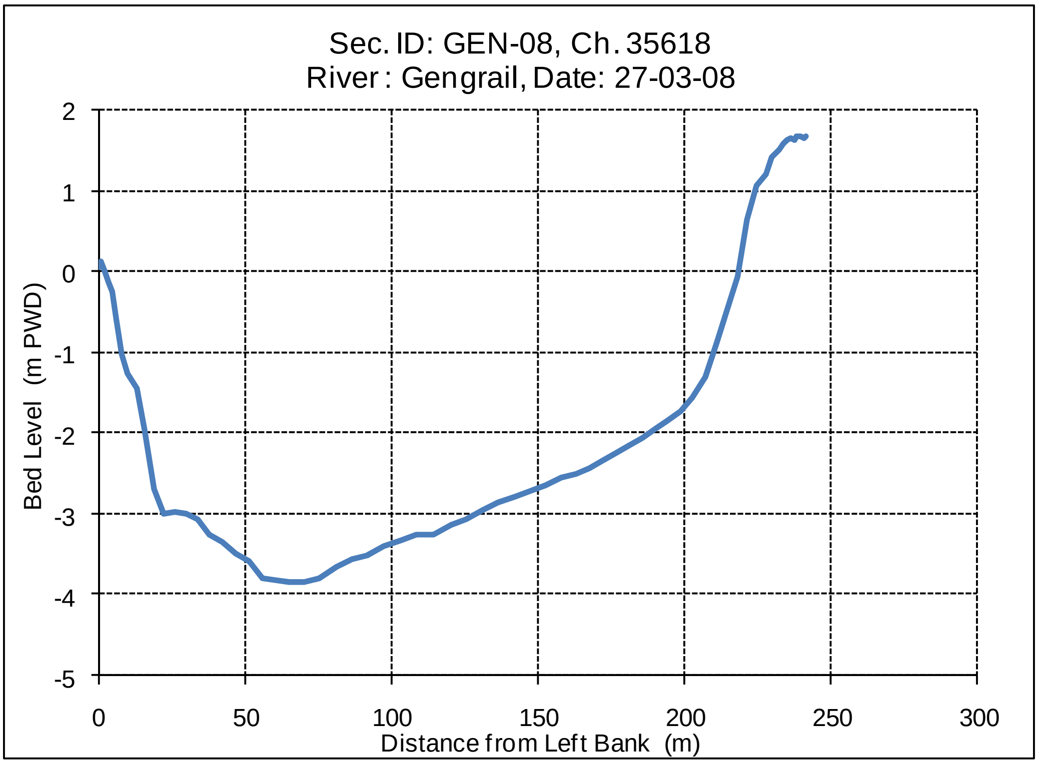

Figure C-44: Cross Section of Gengrail River at Ch. 35618 m

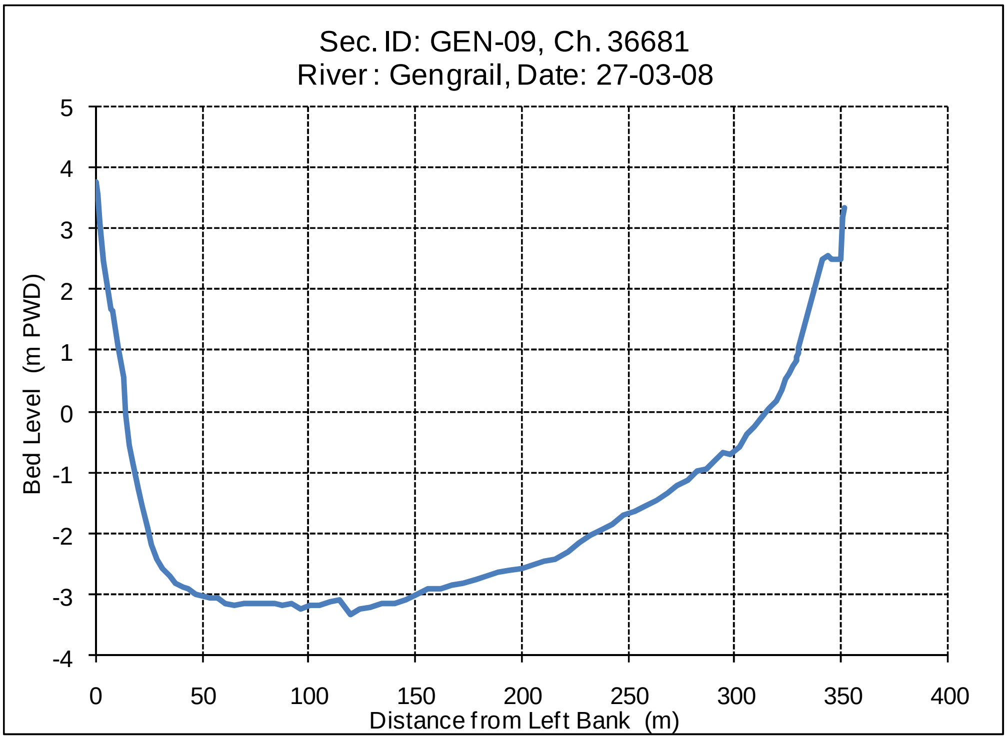

Figure C-45: Cross Section of Gengrail River at Ch. 36681 m

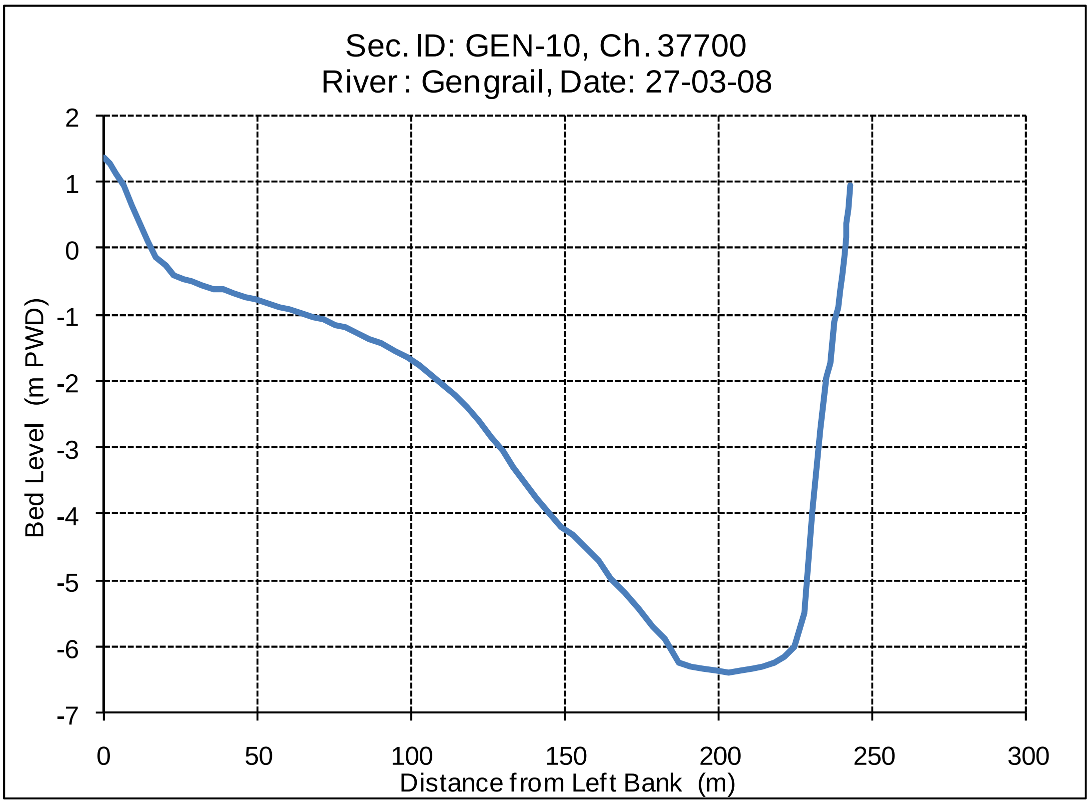

Figure C-46: Cross Section of Gengrail River at Ch. 37700 m

APPENDIX D: SUSPENDED SEDIMENT CONCENTRATION DATA

Table D-1: Suspended Sediment Sample Data of East Beel Khukshia at 1st Cut

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : East BeeL Khukshia
STATION : 1 st cut
VERTICAL NO. : V1
POSITION : 433811.8 E 529395 N
OBSERVATION DATE : 09/04/2008

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	828.48
		0.2d	246	0.0854	0.2107	0.1253	509.45
7:00	6.07	0.8d	244	0.0828	0.1575	0.0747	306.18
		0.2d	250	0.0827	0.1625	0.0798	319.24
8:00	5.95	0.8d	250	0.0829	0.2042	0.1213	485.29
		0.2d	242	0.0827	0.1715	0.0888	366.99
9:00	5.82	0.8d	238	0.0829	0.2620	0.1791	752.73
		0.2d	240	0.0830	0.1909	0.1079	449.66
10:00	5.68	0.8d	246	0.0830	0.1616	0.0786	319.55
		0.2d	246	0.0830	0.1564	0.0734	298.41
11:00	5.55	0.8d	246	0.0830	0.2730	0.1900	772.58
		0.2d	248	0.0828	0.1496	0.0668	269.38
12:00	5.45	0.8d	242	0.0828	0.4036	0.3208	1326.28
		0.2d	240	0.0822	0.3114	0.2292	955.34
13:00	5.76	0.8d	240	0.0826	0.2086	0.1260	525.10
		0.2d	246	0.0827	0.1540	0.0713	289.87
14:00	6.03	0.8d	244	0.0829	0.8698	0.7869	3228.93
		0.2d	242	0.0824	0.4330	0.3506	1449.55
15:00	6.23	0.8d	236	0.0829	0.7094	0.6265	2657.32
		0.2d	238	0.0828	0.5149	0.4321	1816.79
16:00	6.25	0.8d	240	0.0826	0.8165	0.7339	3061.45
		0.2d	242	0.0825	0.5832	0.5007	2070.62
17:00	6.27	0.8d	242	0.0827	0.8724	0.7897	3267.25
		0.2d	240	0.0825	0.7115	0.6290	2623.43
18:00	6.28	0.8d	240	0.0827	0.8540	0.7713	3217.65
		0.2d	242	0.0826	0.6545	0.5719	2365.33

Table D-2: Suspended Sediment Sample Data of East Beel Khukshia at 2nd Cut

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : East BeeL Khukshia
STATION : 2nd cut
VERTICAL NO. : V1
POSITION : 433739.2 E 531718.4 N
OBSERVATION DATE : 09/04/2008

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	118.60
		0.2d	240	0.0834	0.1070	0.0236	98.34
7:00	2.35	0.8d	240	0.0835	0.1058	0.0223	92.92
		0.2d	246	0.0834	0.1019	0.0185	75.21
8:00	2.25	0.8d	246	0.0836	0.1022	0.0186	75.61
		0.2d	238	0.0835	0.0993	0.0158	66.39
9:00	2.06	0.8d	236	0.0837	0.1098	0.0261	110.60
		0.2d	240	0.0842	0.1032	0.0190	79.17
10:00	1.90	0.8d	240	0.0837	0.1115	0.0278	115.84
		0.2d	240	0.0836	0.0963	0.0127	52.92
11:00	1.85	0.8d	242	0.0837	0.1209	0.0372	153.73
		0.2d	244	0.0838	0.1066	0.0228	93.45
12:00	1.77	0.8d	244	0.0839	0.1630	0.0791	324.22
		0.2d	246	0.0841	0.1445	0.0604	245.55
13:00	1.75	0.8d	240	0.0839	0.1276	0.0437	182.10
		0.2d	244	0.0834	0.1275	0.0441	180.75
14:00	1.98	0.8d	244	0.0841	0.1763	0.0922	377.92
		0.2d	246	0.0839	0.1526	0.0687	279.30
15:00	2.15	0.8d	244	0.0838	0.3664	0.2826	1158.70
		0.2d	240	0.0840	0.2899	0.2059	858.19
16:00	2.25	0.8d	240	0.0840	0.5722	0.4882	2035.73
		0.2d	246	0.0838	0.2979	0.2141	870.61
17:00	2.35	0.8d	242	0.0840	0.2770	0.1930	797.76
		0.2d	242	0.0839	0.2925	0.2086	862.26
18:00	2.40	0.8d	246	0.0840	0.2836	0.1996	811.63
		0.2d	240	0.0840	0.2648	0.1808	753.55

Table D-3: Suspended Sediment Sample Data of Gengrail River at Kanchannagar

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : Gengrail
STATION : Kanchannagar
VERTICAL NO. : V1
POSITION : 438538 E, 507343N
OBSERVATION DATE : 10/03/2008

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	0.3676	1471.22
		0.2d	250	0.0845	0.3393	0.2548	1019.59
5:00	6.24	0.8d	250	0.0842	0.2360	0.1518	607.34
		0.2d	250	0.0845	0.1460	0.0615	246.02
6:00	5.39	0.8d	250	0.0848	0.5305	0.4457	1784.00
		0.2d	250	0.0847	0.6011	0.5164	2067.21
7:00	4.49	0.8d	250	0.0846	0.6560	0.5714	2287.57
		0.2d	250	0.0848	0.5449	0.4601	1841.68
8:00	3.62	0.8d	250	0.0847	1.3024	1.2177	4879.77
		0.2d	250	0.0845	0.8301	0.7456	2985.76
9:00	3.07	0.8d	250	0.0847	1.8031	1.7184	6891.48
		0.2d	250	0.0846	1.6656	1.5810	6339.13
10:00	2.81	0.8d	250	0.0845	1.8766	1.7921	7187.84
		0.2d	250	0.0845	1.7195	1.6350	6556.18
11:00	3.87	0.8d	250	0.0845	1.4224	1.3379	5362.43
		0.2d	250	0.0848	0.7351	0.6503	2603.76
12:00	5.61	0.8d	250	0.0847	1.0393	0.9546	3823.91
		0.2d	250	0.0845	0.7572	0.6727	2693.54
13:00	6.97	0.8d	250	0.0845	0.8143	0.7298	2922.42
		0.2d	250	0.0842	0.5828	0.4986	1995.90
14:00	7.59	0.8d	250	0.0844	0.6965	0.6121	2450.66
		0.2d	250	0.0841	0.6433	0.5592	2238.69
15:00	7.43	0.8d	250	0.0847	0.6502	0.5655	2263.93
		0.2d	250	0.0845	0.5387	0.4542	1818.05
16:00	7.14	0.8d	250	0.0845	0.6233	0.5388	2156.95
		0.2d	250	0.0846	0.5470	0.4624	1850.89

Table D-4: Suspended Sediment Sample Data of Gengrail River at Kanchannagar

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : **Gengrail**
STATION : **Kanchannagar**
VERTICAL NO. : **V1**
POSITION : **438538 E 507343 N**
OBSERVATION DATE : **12/03/2008**

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	1974.05
		0.2d	240	0.0813	0.3699	0.2886	1203.05
5:00	6.85	0.8d	238	0.0809	0.5392	0.4583	1927.03
		0.2d	250	0.0811	0.1597	0.0786	314.44
6:00	6.17	0.8d	250	0.0809	0.3103	0.2294	917.92
		0.2d	242	0.0800	0.1470	0.0670	276.89
7:00	5.42	0.8d	246	0.0801	0.4939	0.4138	1683.18
		0.2d	244	0.0800	0.2024	0.1224	501.73
8:00	4.51	0.8d	238	0.0797	0.9229	0.8432	3547.60
		0.2d	250	0.0800	0.5637	0.4837	1936.21
9:00	3.73	0.8d	242	0.0801	1.5232	1.4431	5976.67
		0.2d	242	0.0802	0.9779	0.8977	3714.70
10:00	3.27	0.8d	240	0.0804	1.9485	1.8681	7806.68
		0.2d	246	0.0803	2.0430	1.9627	8002.55
11:00	2.51	0.8d	246	0.0831	1.6700	1.5869	6466.55
		0.2d	250	0.0825	1.0482	0.9657	3868.44
12:00	3.45	0.8d	250	0.0806	0.8109	0.7303	2924.42
		0.2d	250	0.0808	0.4898	0.4090	1637.01
13:00	4.92	0.8d	248	0.0808	0.9121	0.8313	3356.26
		0.2d	246	0.0809	0.7305	0.6496	2643.28
14:00	6.23	0.8d	248	0.0807	0.6363	0.5556	2242.22
		0.2d	244	0.0808	0.4248	0.3440	1410.59
15:00	6.79	0.8d	242	0.0808	0.4660	0.3852	1592.69
		0.2d	248	0.0809	0.3907	0.3098	1249.78
16:00	6.72	0.8d	250	0.0810	0.4272	0.3462	1385.52
		0.2d	250	0.0812	0.3310	0.2498	999.58

Table D-5: Suspended Sediment Sample Data of Gengrail River at Kanchannagar

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : Gengrail
STATION : Kanchannagar
VERTICAL NO. : V1
POSITION : 438538 E 507343 N
OBSERVATION DATE : 15/03/2008

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	2687.12
		0.2d	250	0.0812	0.2704	0.1892	757.02
4:00	6.42	0.8d	250	0.0843	0.5757	0.4914	1967.06
		0.2d	250	0.0844	0.3337	0.2493	997.58
5:00	6.84	0.8d	250	0.0845	0.5260	0.4415	1767.18
		0.2d	250	0.0846	0.2290	0.1444	577.73
6:00	7.02	0.8d	250	0.0848	0.2792	0.1944	777.83
		0.2d	250	0.0848	0.2366	0.1518	607.34
7:00	6.84	0.8d	250	0.0845	0.3371	0.2526	1010.79
		0.2d	250	0.0849	0.1399	0.0550	220.02
8:00	6.38	0.8d	250	0.0849	0.2769	0.1920	768.22
		0.2d	248	0.0849	0.1297	0.0448	180.66
9:00	5.82	0.8d	232	0.0848	0.1649	0.0801	345.30
		0.2d	250	0.0849	0.1910	0.1061	424.47
10:00	5.26	0.8d	246	0.0850	0.2227	0.1377	559.87
		0.2d	248	0.0847	0.2199	0.1352	545.27
11:00	4.86	0.8d	250	0.0850	0.4244	0.3394	1358.30
		0.2d	238	0.0848	0.3462	0.2614	1098.77
12:00	4.54	0.8d	232	0.0848	0.5831	0.4983	2149.59
		0.2d	250	0.0853	0.4807	0.3954	1582.54
13:00	4.40	0.8d	250	0.0853	0.6460	0.5607	2244.70
		0.2d	250	0.0850	0.3509	0.2659	1064.03
14:00	4.80	0.8d	250	0.0850	0.4460	0.3610	1444.79
		0.2d	250	0.0848	0.2536	0.1688	675.37
15:00	5.44	0.8d	250	0.0847	0.4528	0.3681	1473.22
		0.2d	250	0.0847	0.3310	0.2463	985.57

Table D-6: Suspended Sediment Sample Data of Hari River at Ranai

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : Hari
STATION : Ranai
VERTICAL NO. : V1
POSITION : 433790 E 525575 N
OBSERVATION DATE : 22/03/2008

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	4.97	0.8d	250	0.0847	0.9522	0.8675	3474.55
		0.2d	248	0.0849	0.7670	0.6821	2753.26
7:00	4.72	0.8d	244	0.0847	0.5403	0.4556	1868.53
		0.2d	250	0.0851	0.3999	0.3148	1259.80
8:00	4.58	0.8d	242	0.0850	0.4563	0.3713	1535.19
		0.2d	238	0.0850	0.2933	0.2083	875.50
9:00	4.44	0.8d	242	0.0848	0.3447	0.2599	1074.40
		0.2d	250	0.0847	0.3115	0.2268	907.51
10:00	4.30	0.8d	250	0.0844	0.2825	0.1981	792.64
		0.2d	232	0.0845	0.2425	0.1580	681.21
11:00	4.18	0.8d	240	0.0849	0.3078	0.2229	929.08
		0.2d	244	0.0847	0.2669	0.1822	746.93
12:00	5.82	0.8d	244	0.0846	0.4950	0.4104	1683.04
		0.2d	238	0.0837	0.3275	0.2438	1024.77
13:00	6.34	0.8d	248	0.0836	0.5766	0.4930	1989.40
		0.2d	240	0.0842	0.5146	0.4304	1794.55
14:00	6.44	0.8d	248	0.0843	0.7999	0.7156	2888.63
		0.2d	242	0.0842	0.6942	0.6100	2523.06
15:00	6.11	0.8d	236	0.0833	1.0702	0.9869	4188.39
		0.2d	250	0.0828	0.9044	0.8216	3290.48
16:00	5.83	0.8d	250	0.0836	0.8463	0.7627	3054.32
		0.2d	234	0.0837	0.8742	0.7905	3382.52
17:00	5.47	0.8d	238	0.0843	0.7900	0.7057	2968.45
		0.2d	250	0.0843	0.6670	0.5827	2332.85
18:00	5.11	0.8d	248	0.0843	0.7283	0.6440	2599.32
		0.2d	250	0.0842	0.5384	0.4542	1818.05

Table D-7: Suspended Sediment Sample Data of Hari River at Ranai

IWM SEDIMENT LABORATORY

Suspended Sediment Sample Analysis

RIVER NAME : Hari
STATION : Ranai
VERTICAL NO. : V1
POSITION : 433790 E 525575 N
OBSERVATION DATE : 28/03/2008

Observation Time (hrs.)	Depth Total,d (m)	Depth Sampling (m)	Sample Volume (ml)	Weight Filter paper (gm)	Weight Sample+Filter paper (gm)	Weight Sample Dry Wt. (gm)	Total Concentration (mg/l)
5:00	6.30	0.8d	250	0.0845	0.3350	0.2505	1002.38
		0.2d	250	0.0841	0.3044	0.2203	881.49
6:00	6.07	0.8d	248	0.0847	0.4888	0.4041	1630.44
		0.2d	236	0.0848	0.3453	0.2605	1104.27
7:00	6.69	0.8d	250	0.0849	0.5662	0.4813	1926.60
		0.2d	240	0.0855	0.2334	0.1479	616.39
8:00	5.29	0.8d	228	0.0849	0.3236	0.2387	1047.34
		0.2d	242	0.0859	0.3179	0.2320	959.02
9:00	5.05	0.8d	242	0.0861	0.2247	0.1386	572.85
		0.2d	244	0.0857	0.2231	0.1374	563.23
10:00	4.87	0.8d	246	0.0859	0.3552	0.2693	1095.17
		0.2d	250	0.0860	0.2252	0.1392	556.92
11:00	4.69	0.8d	250	0.0857	0.1959	0.1102	440.87
		0.2d	250	0.0860	0.1891	0.1031	412.46
12:00	4.52	0.8d	244	0.0863	0.1961	0.1098	450.08
		0.2d	246	0.0866	0.1980	0.1114	452.92
13:00	4.40	0.8d	248	0.0867	0.1946	0.1079	435.15
		0.2d	242	0.0866	0.1926	0.1060	438.09
14:00	5.42	0.8d	240	0.0866	0.1790	0.0924	385.06
		0.2d	238	0.0868	0.1250	0.0382	160.51
15:00	6.03	0.8d	250	0.0868	0.1858	0.0990	396.06
		0.2d	250	0.0866	0.1686	0.0820	328.04
16:00	6.32	0.8d	244	0.0871	0.2488	0.1617	662.87
		0.2d	244	0.0872	0.2240	0.1368	560.77
18:00	6.28	0.8d	242	0.0870	0.2314	0.1444	596.83
		0.2d	250	0.0871	0.1836	0.0965	386.06

APPENDIX E: GENERAL DESCRIPTION OF NUMERICAL MODEL

General Description of Numerical Model

MIKE 21 Flow Model FM is based on a flexible mesh approach and it has been developed for applications within oceanographic, coastal and estuarine environments. The system is based on the numerical solution of the two/three dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations and it is closed by a turbulent closure scheme.

The spatial discretization of the primitive equations is performed using a cell-centered finite volume method. The spatial domain is discretized by subdivision of the continuum into non-overlapping element/cells. In the horizontal plane an unstructured grid is used comprising of triangles or quadrilateral element. An approximate Riemann solver is used for computation of the convective fluxes, which makes it possible to handle discontinuous solutions. For the time integration an explicit scheme is used.

The local continuity equation according to DHI Water and Environment User Manual is :

$$\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} + \frac{\delta w}{\delta z} = S \qquad \text{(E-1)}$$

And the two horizontal momentum equations for the x- and y- component, respectively:

$$\frac{\partial u}{\partial t} + \frac{\partial u^2}{\partial x} + \frac{\partial vu}{\partial y} + \frac{\partial wu}{\partial z} = fv - g\frac{\partial \eta}{\partial x} - \frac{1}{\rho_0}\frac{\delta p_a}{\delta x} - \frac{g}{\rho_0}\int_z^n \frac{\delta \rho}{\delta x}\, dz - \frac{1}{\rho_0 h}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) + F_u + \frac{\partial}{\partial z}\left(v_t \frac{\delta u}{\delta z}\right) + u_s S \qquad \text{(E-2)}$$

$$\frac{\partial v}{\partial t} + \frac{\partial v^2}{\partial y} + \frac{\partial uv}{\partial x} + \frac{\partial wv}{\partial z} = -fu - g\frac{\partial \eta}{\partial y} - \frac{1}{\rho_0}\frac{\partial p_a}{\partial y} - \frac{g}{\rho_0}\int_z^n \frac{\delta \rho}{\delta y}\, dz - \frac{1}{\rho_0 h}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) + F_v + \frac{\partial}{\partial z}\left(v_t \frac{\partial v}{\partial z}\right) + v_s S \qquad \text{(E-3)}$$

Where t is the time; x, y and z are the Cartesian co-ordinates; η is the surface elevation; d is the still water depth; $h = \eta + d$ is the total water depth; u, v and w are the velocity components in the x, y and z direction; $f = 2\Omega sin\emptyset$ is the Coriolis parameter (Ω is the angular rate of revolution and $\emptyset$ is the geographic latitude); g is the gravitational acceleration; ρ is the density of water; s_{xx}, s_{xy}, s_{yx} and s_{yy} are components of the radiation stress tensor; v_t is the vertical turbulent (or eddy) viscosity; p_a is the atmospheric pressure; ρ_0 is the reference density of water. S is the magnitude of the discharge due to point sources and (u_s, v_s) is the velocity by which the water is discharged into the ambient water. The horizontal stress terms are described using a gradient-stress relation, which is simplified to:

$$F_u = \frac{\partial}{\partial x}\left(2A\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) \quad \text{(E-4)}$$

$$F_v = \frac{\partial}{\partial x}\left(A\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) + \frac{\partial}{\partial y}\left(2A\frac{\partial v}{\partial y}\right) \quad \text{(E-5)}$$

Where A is the horizontal eddy viscosity.

MIKE 21 Flow Model FM is composed of following modules:

1. Hydrodynamic Module
2. Transport Module
3. ECO Lab/Oil Spill Module
4. Mud Transport Module
5. Sand Transport Module
6. Particle Tracking Module

The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow Model. The hydrodynamic module simulates water level variations and flows in response to a variety of forcing and boundary conditions. The effects and facilities include:

1. bottom shear stress
2. wind shear stress
3. barometric pressure gradients
4. Coriolis force

5. momentum dispersion
6. sources and sinks
7. evaporation
8. flooding and drying
9. wave radiation stresses

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 E-1.

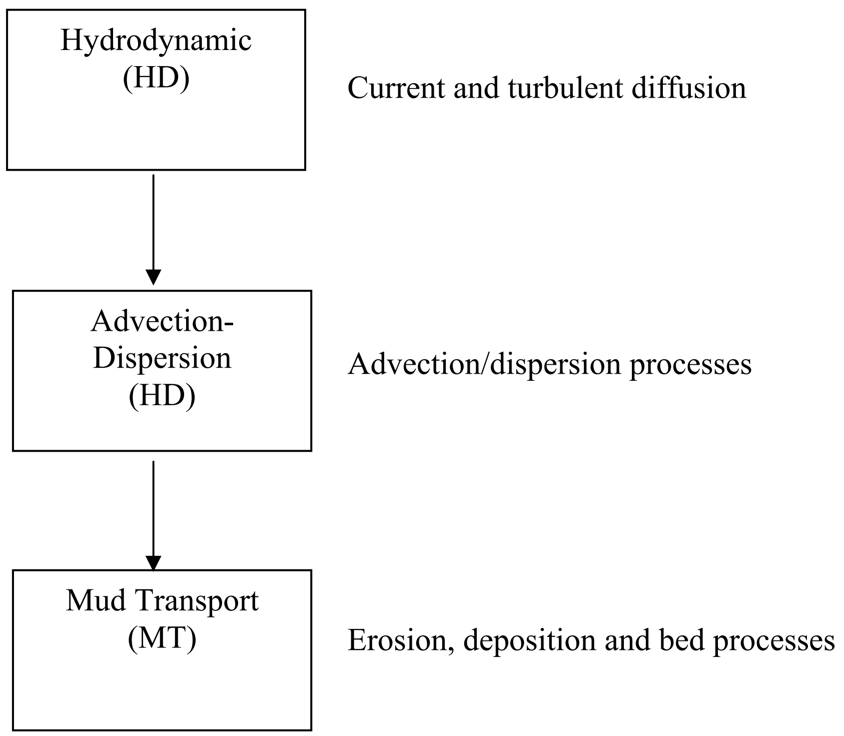

Figure E-1: Data flow and physical processes for MIKE 21 Flow Model FM, Mud Transport calculation (Reference: DHI Water and Environment, User Manual)

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

1. Multiple mud fractions
2. Multiple bed layers
3. Wave-current interaction

4. Flocculation
5. Hindered settling
6. Inclusion of a sand fraction
7. Transition of sediments between layers
8. Simple morphological calculations

The above possibilities cover most cases appropriate for 2D modeling. In case of special application, such as simulating the influence of high sediment concentrations on the water flow through formation of stratification and damping of turbulence, the modeler is referred to 3D modeling. The sediment transport formulations are based on the advection-dispersion calculations in the Hydrodynamic module.

The mud transport (MT) module describes the erosion, transport and deposition of fine-grained material <63 μm (silt and clay) under the action of currents and waves. The mud transport module calculates the resulting transport of cohesive materials based on the flow conditions found in the hydrodynamic calculations. The model is able to simulate the presence of multiple fractions in multiple layers. As well as simulating the presence of fine sand. The module is capable of handling flocculation as well as hindered settling in the water column and sliding and consolidation in the bed.

The Mud Transport module solves the advection-dispersion equation according to DHI Water and Environment User Manual is:

$$\frac{\partial \bar{c}}{\partial t} + u\frac{\partial \bar{c}}{\partial x} + v\frac{\partial \bar{c}}{\partial y} = \frac{1}{h}\frac{\partial}{\partial x}\left(hD_x\frac{\partial \bar{c}}{\partial x}\right) + \frac{1}{h}\frac{\partial}{\partial x}\left(hD_y\frac{\partial \bar{c}}{\partial x}\right) + Q_L C_L\frac{1}{h} - S \qquad \text{(E-6)}$$

Where,

$\bar{c}$ = depth averaged concentration (g/m^3)
u, v = depth averaged flow velocities (m/s)
Dx, Dy =dispersion coefficient (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.

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 modeling, environmental modeling 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 F: DETAIL COST ESTIMATE FOR BEEL BARUNA TRM

Table F-1: Detail cost estimate for Beel Baruna TRM

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		Embankment	Peripheral Embankment around the beel	8750	19.75	172812.50	1.00	m^3	69.83	12067496.88	237603728.08 Say 237603700.00
		Link canal	Total number (2) Mechanical dredging	195	55.15	10754.25	2.00	m^3	140.00	1505595.00	
		Re-excavation	Khals exist in the Beel	5500	52.75	290125	4.00	m^3	103.43	120030515.00	
		Cross-Dam	Every dry season	35	185.50	6492.50	4.00	m^3	131.96	3427001.20	
		Compensation	Per ha of land for 4 years			715	4.00	ha	33592.00	96073120.00	
		Drainage Outlet	0.90 m dia pipe sluice			10	1.00	no	450000.00	4500000.00	
Option-2	Compartment-1	Embankment	Around the compartment	6535	20.60	134621	1.00	m^3	69.83	9400584.43	199917060.91 Say 199917000.00
		Link canal	Mechanical dredging	130	65.55	8522	1.00	m^3	140.00	1193010.00	
		Re-excavation	Khal exists in the compartment	2180	52.76	115017	4.00	m^3	103.43	47584750.50	
		Cross-Dam	Every dry season	35	185.50	6492.50	1.00	m^3	131.96	856750.30	
		Compensation	Per ha of land for 1 year 4 month			211	1.33	ha	33592.00	9426922.96	
		Drainage Outlet	0.90 m dia pipe sluice			4	1.00	no	450000.00	1800000.00	
	Compartment-2	Embankment	Around the compartment	6655	23.69	157657	1.00	m^3	69.83	11009184.82	
		Link canal	Mechanical dredging	130	65.55	8522	1.00	m^3	140.00	1193010.00	
		Re-excavation	Khal exists in the compartment	1650	52.76	87054	4.00	m^3	103.43	36015980.88	
		Cross-Dam	Every dry season	35	185.50	6492.50	1.00	m^3	131.96	856750.30	
		Compensation	Per ha of land for 1 year 4 month			258	1.33	ha	33592.00	11526758.88	
		Drainage Outlet	0.90 m dia pipe sluice			4	1.00	no	450000.00	1800000.00	
	Compartment-3	Embankment	Around the compartment	6605	21.95	144979.75	1.00	m^3	69.83	10123935.94	
		Link canal	Mechanical dredging	100	65.55	6555	1.00	m^3	140.00	917700.00	
		Re-excavation	Khal exists in the compartment	1950	52.76	102882	4.00	m^3	103.43	42564341.04	
		Cross-Dam	Every dry season	35	185.50	6492.50	1.00	m^3	131.96	856750.30	
		Compensation	Per ha of land for 1 year 4 month			246	1.33	ha	33592.00	10990630.56	
		Drainage Outlet	0.90 m dia pipe sluice			4	1.00	no	450000.00	1800000.00	
Option-3		Embankment	Peripheral Embankment around the beel	8750	19.75	172812.50	1.00	m^3	69.83	12067496.88	161956696.25 Say 161956700.00
			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		103.43	39944996.98	
		Cross-Dam	Every dry season	35	185.50	6492.50	4.00	m^3	131.96	3427001.20	
		Compensation	Per ha of land for 4 years			715	4.00	ha	33592.00	96073120.00	
		Drainage Outlet	0.90 m dia pipe sluice			10	1.00	no	450000.00	4500000.00	