Ministry of Water Resources

Bangladesh Water Development Board

Coastal Embankment Improvement Project, Phase-I (CEIP-I)

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

FINAL INCEPTION REPORT

January 2019

DHI
Deltares Enabling Delta Life
IWM Water Environment & Climate
Columbia University

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

Project Management Unit
Coastal Embankment Improvement Project, Phase-I (CEIP-I)
House No.15, 4tn Floor, Road
No.24(CNW) Gulshan, Dhaka-1212

Date: 30 January 2019

Att: Engr. Md. Habibur Rahman, Chief Engineer & Project Director

Dear Sir,

Submission of Final Inception Report

We are pleased to submit herewith the Final Inception Report of the project known as *"Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone, (Sustainable Polders Adapted to Coastal Dynamics)"*.

We are submitting 20 copies of the Report today. The preparation of this report took longer than we had planned because of the time take to respond to the many written comments and observations we received until a week ago. The report has been finalized incorporating the comments and suggestions received on the draft inception report from BWDB and other organizations.

We hope you find this report satisfactory and look forward to being able to carry the work plan forward to a fruitful conclusion.

Thank you,

Yours sincerely,

Dr Ranjit Galappatti
DHI Team Leader

Copies: Engr. Md. Mahfuzur Rahman, Director General, BWDB
Engr. KM Anwar Hossain, Additional Director General (Planning), BWDB

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ACRONYMS AND ABBREVIATIONS

ADCP- Acoustic Doppler Current Profiler

BDP2100- Bangladesh Delta Plan 2100

BIWTA- Bangladesh Inland Water Transport Authority

BMD- Bangladesh Meteorological Department

BoB- Bay of Bengal

BWDB- Bangladesh Water Development Board

CBA- Coast Benefit Analysis

CCP- Chittagong Coastal Plain

CDMP-Comprehensive Disaster Management Program

CDSP- Char Development Settlement Project

CEA- Cost Effectiveness Analysis

CEGIS- Centre for Environmental and Geographic Information Services

CEIP- Coastal Embankment Improvement Project

CEP- Coastal Embankment Project

CERP-Coastal Embankment Rehabilitation Project

CPA- Chittagong Port Authority

CPP-Cyclone Protection Project

CSPS-Cyclone Shelter Preparatory Study

DDM- Department of Disaster Management

DEM- Digital Elevation Model

DOE- Department of Environment

EDP- Estuary Development Program

FAP- Flood Action Plan

FM- Flexible Mesh

GBM- Ganges Brahmaputra Meghna

GCM- General Circulation Model

GIS- Geographical Information System

GTPE- Ganges Tidal Plain East

GTPW- Ganges Tidal Plain West

HD- Hydrodynamic

InSAR- Interferometric Synthetic Aperture Radar

IPCC- Intergovernmental Panel for Climate Change

IPSWAM- Integrated Planning for Sustainable Water Management

IWM- Institute of Water Modelling

LCC- Life Cycle Costs

LGED- Local Government Engineering Department

LGI- local Government Institute

LRP- Land Reclamation Project

MCA- Multi Criteria Analysis

MES- Meghna Estuary Study

MoWR- Ministry of Water Resources

MPA- Mongla Port Authority

NAM - Nedbor Afstromnings Model

PPMM- Participatory Polder Management Model

RCP- Representative Concentration Pathways

RTK- Real-Time Kinematic

SET-MH- Surface Elevation Tables – Marker Horizons

SLR- Sea Level Rise

SOB- Survey of Bangladesh

SSC- Suspended Sediment Concentration

SWRM- South West Region Model

TBM- Temporary Bench Mark

ToR- Terms of Reference

WARPO- Water Resources Planning Organization

WL - Water Level

1 INTRODUCTION

1.1 Background

Bangladesh is situated at the confluence of three great trans-Himalayan rivers the Ganges, the Brahmaputra or Jamuna, and the Meghna which forms the Bengal (or GBM) Delta. While over 90 percent of the catchment of the GBM system lies outside of Bangladesh, more than 200 rivers and tributaries and distributaries of the GBM system drain through the country via a constantly changing network of channels, tidal inlets and creeks, forming the most active large deltas on the planet. The coastal land mass is formed by the interaction of large volumes of sediment laden water with the moderate to high tides of the Bay of Bengal. Figure 1.1 shows the tidal limits in the Bengal Delta.

Land in the coastal zone is built up by the deposition of river sediments among the mangroves in one of the largest mangrove forests in the world. The deposits of sand, silt, clay and peat form the land mass which despite subsidence due to continuous consolidation of layers many kilometres deep, is kept just below the level of the highest tides by the continuing deposition of sediments that are trapped among the mangroves.

The coastal zone of Bangladesh spans over 710 km of coastline and is subject to multiple threats. Sixty- two percent of the coastal land has an elevation less than 3 meters above mean see level. With a sediment supply of 1 billion tons per year, this is the delta with the largest sediment supply in the world. This leads to accretion of the land area in the coastal zone (5-10 km^2/year, mainly in the Meghna Estuary). It has been observed that the land subsidence rate may vary from place to place due to anthropogenic factors such as drainage and ground water extraction as well as the properties and depth of underlying strata. On top of this there are tectonic plate movements in the deepest strata that give rise to other changes in ground level.

The coastal lands, being subject to regular flooding by saline water during high tides, could not be used for normal agricultural production in a country with a very high demand for land. The Coastal Embankment Project (CEP) was initiated in the 1950s and 1960s to build polders surrounded by embankments preventing the spilling of saline water onto the land at high tides. These embankments were built along the larger rivers and across the smaller rivers and creeks which then formed the drainage system within each polder and connected to the peripheral rivers via appropriately sized flap gate regulators, that open at low tide to let the drainage water out.

The Coastal Embankment Project made possible the reclamation of large tracts of land for agriculture from 1960 onwards. Polder building proceeded continuously until today. We now have 1.2 million hectares reclaimed in 139 active polders in the coastal zone of Bangladesh (see Figure 1.2)

In over half century of its existence, a number of challenges have surfaced that threaten the long-term safety and even the very existence of the polder system as a viable and sustainable resource. These are:

- Sea level rise and changes in precipitation and water discharge due to climate change
- Threats of damming and diversion to the delivery of river sediments from upstream
- Subsidence of lands)except where it has been allowed to be rebuilt by tidal flooding(and structures founded on existing land
- Drainage congestion due to accumulation of silt in some peripheral waterways around the polders
- Changes in tidal hydrodynamics and related river erosion and siltation in the peripheral rivers of polders
- Increasing vulnerability to cyclones and storm surges

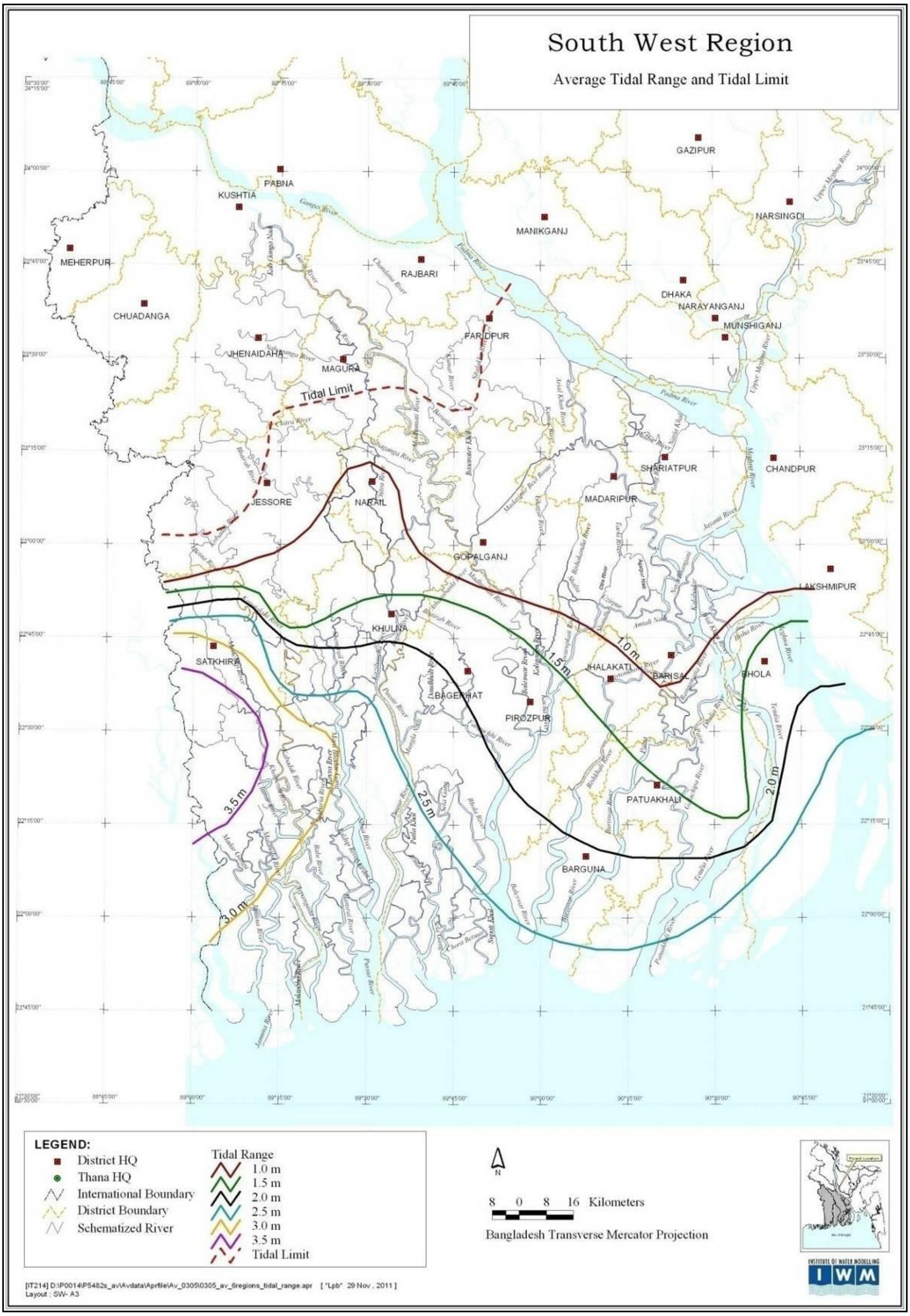


Figure 1.1 Average Tidal Range and tidal Limit in the South-West Region of Bangladesh.

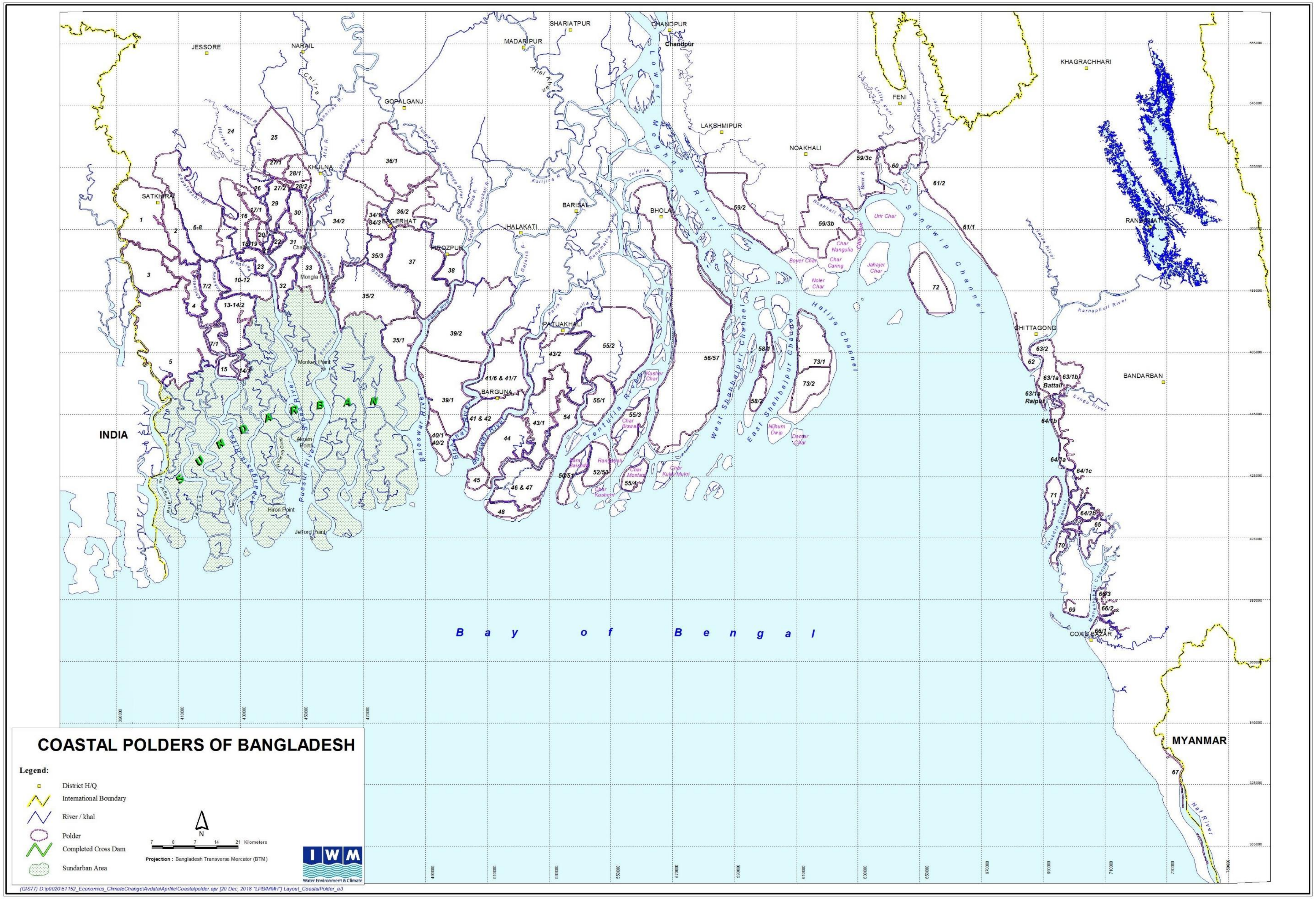


Figure 1.2 Coastal Polders of Bangladesh

The disasters resulting from two major cyclones Sidr (2007) and Aila (2009) and the unexpectedly high value of the damages caused by these, provoked the World Bank and the Government of Bangladesh to initiate the Coastal Embankment Improvement Programme (CEIP-1) which was to redesign and rebuild the entire polder system, in several phases, to resist the long term challenges of climate change and other natural phenomena such as

- Storm Surges, wind and wave attack
- Sea level rise
- Land subsidence
- Changing tidal hydrodynamics and channel network system
- Long term challenges to drainage
- Increasing threats from cyclones and storm surges
- Maintenance and management failures

The objectives of CEIP-1 were:

- *Increase the area protected in selected polders from tidal flooding and frequent storm surges, which are expected to worsen due to climate change and relative sea-level rise*
- *Improve agricultural production by reducing saline water intrusion in selected polders; and*
- *Improve the Government of Bangladesh's capacity to respond promptly and effectively to an eligible crisis or emergency*

The implementation of the first 17 polders of CEIP-1 (see Figure 1.2) brought into stark relief several shortcomings and gaps in our knowledge and understanding of many of the physical phenomena that govern major processes in and the evolution of the Bengal Delta. Recognition of these lacunae resulted in the inclusion of this research study as a component project to support the phased Coastal Embankment Improvement Programme which was to bring in massive investments over many decades.

1.2 Objectives of this Study

Create a framework for polder design, based on understanding of the long term and large-scale dynamics of the delta and on sustainable polder concepts. These polders should offer their inhabitants a safe environment to live in and sufficient opportunities for their livelihood. Among other issues, land use (agriculture including cropping pattern and adaptation of new varieties of cultivars that are emerging through research, aquaculture, housing, urbanization, etc.), management of drainage congestion through control over ground level, sedimentation balance inside and outside the polder, and salinity in rivers and groundwater, are the key parameters in coming to these concepts, taking climate change into account

Present an overview of values of relevant parameters at locations in the polder area, now and in the future, as boundary conditions for polder design and management

Develop a long-term investment plan for implementation of the proposed design and management improvements leading to integrated water resources management, targeting sustainable development goals.

Build the analytical foundation and technical capacity of BWDB and other stake holders including local communities, as appropriate, to engage in science driven decisions on floods, storm surges and drought hazards in the coastal region of Bangladesh;

To quote the Terms of Reference, a further objective could be added: *"The vision is also to expand the* ***analytical capacity and data driven decision making*** *into an "ecosystem" in which professionals cooperate, and exchange knowledge and information in a community of practice, using* ***a common infrastructure (of knowledge and data)****, to be housed in* ***BWDB and other*** *organizations* ***would have access to the data system****. Starting with the researchers directly* *involved in the coastal area and the polders, the future extension will be to bring on board the whole coastal belt and the Bangladesh water management community".*

1.3 Signing of Contract and Mobilisation

The contract was signed between the Bangladesh Water Development Board and the Joint Venture of DHI, Denmark and Stichting Deltares of the Netherlands in association with subconsultants, Institute of Water Modelling, Bangladesh, University of Colorado, Boulder, USA and Columbia University, USA on 4th October 2018, to provide consultancy services for the study titled "Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)" under the CEIP.

The project was made effective on 15th October 2018 and therefore this Inception Report is to be submitted on or before 15 January 2019. The Team Leader was mobilised on 28 October 2018 and preparations were made to field the first set of consultants at the time the Draft Inception Report is submitted in preparation for the Inception Workshop.

A detailed description of the start-up activities is given in Chapter 2. The project office was selected and leased out for the full project duration from 1st December 2018. Candidates for office Manager and other staff positions were interviewed and suitable persons selected and appointed. The office infrastructure including cabling for the computer network have been procured and installed. The computers and peripherals, and other office equipment and furniture have also been purchased and commissioned.

New regulatory safeguards that have become applicable to the opening of bank accounts by foreign entities caused delays in opening project bank accounts and obtaining bank guarantees from local banks. Consequently, there have been some delays is mobilising the advance payments necessary to facilitate rapid deployment of the project infrastructure. The work was not delayed because IWM was instrumental in alleviating some of the problems caused by these delays.

1.4 Objectives of the Inception Report

The inception phase is meant to review the overall approach of the program and to align strengths and capacities between consultant and MoWR/BWDB to come to a common view on its implementation.

Through the Inception Report the Consultant will clarify the agreed ToR and propose a suitable and practicable methodology, as well as the necessary staffing and other resources to achieve the desired objectives. The proposed work will carry out the development of relevant new knowledge while maintaining focus is on how to ensure the concept of sustainable polders will be achieved; while maintaining a coherent relationship between the various physical processes that take place concurrently in the coastal zone of the delta.

The Inception Report must present a viable work plan and staffing schedule which is broadly in line with the original proposal. However, some adjustments will be necessary keeping in mind the original proposal was for a far longer project and negotiations have lasted for about three years. The timing of fieldwork which is largely dependent upon the seasons, will require some difficult adjustments.

1.5 Contents of the Inception Report

The Inception Report comprises 10 Chapters. The first three introductory chapters describes the project background and the need for this study.

Table 1.1 Navigating this Inception Report

Comp. No.	Activities in ToR	References in Inception Report	Page No
1	Inception report (Finalization of methodology and Work Plan)	Ch.4-9 & 10	35-74 & 75
2	Detailed literature review and its summery and lessons learnt	Art 4.1	35
3	Development of input datasets for models of the long-term physical processes	Art 4.2	38
4	Modelling of the long-term physical processes in the coastal zone	Art 4.3	43
	a) Morphology	Art 4.3.1, Art 4.3.2	49 & 51
	b) Subsidence	Art 4.3.3	52
	c) Meteorology	Art 4.3.4	53
	d) Effect of climate change on Water levels, salinity and Storm surge	Art 4.3.5	53
5	Finalizing of approach for reconstruction of the polder at different coastal zones including their phasing and construction program	Chapter 5	55
	a) Reconstruction of the polder at different coastal zone including their phasing and construction program	Art 5.1	55
	b) Coherence and overall picture delta	Art 5.2	56
6	Updating of design parameters and specifications for planning & design works; review of approaches for management of polders with active participation of beneficiaries and stake holders;	Chapter 6	59
	6.1) Updating of design parameters and specifications for construction works	Art 6.1	59
	6.2) Review of approaches for management of polders with emphasis on active participation of beneficiaries and local stakeholders	Art 6.2	59
	6.3) Setting up a performance monitoring mechanism	Art 6.3	61
7	Investment plan for the entire CEIP	Chapter 7	63
8	Action plan for Capacity Building of professionals and stakeholders in planning, design, construction supervision and management of the polders, as appropriate	Chapter 8	67
9	Outreach and communication strategy	Chapter 9	73
	9.1) Outreach program	Art 9.1	73
	9.2) Communication Strategy	Art 9.2	74

Chapter 4 describes all the activities being undertaken in the study to produce the required outputs as summarised in Chapter 10.1. The modelling activities that form the backbone of this study requires much more detailed elucidation. Therefore, the detailed description of the planned modelling work is moved to Appendix A which will offer a comprehensive description of the modelling effort.

The way in which the greater understanding of delta processes that was gained though the activities described in Chapter 4, is to be used to develop the polder re-construction strategy, is described in Chapter 5. This chapter will also discuss the way the coherence of the study findings with the overall delta dynamics will be investigated.

Chapter 6 describes how the study outcomes and the results of stakeholder consultations will be used to update of design parameters and specifications for construction works. Improved methods for management of polders with stakeholder and beneficiary participation will also be integrated into the design process. Recommendations will be made for a performance monitoring mechanism.

Chapter 7 describes the steps to be taken to prepare a development plan for the entire polder system. The capacity building action plan for professionals and stakeholders is described in Chapter 8. The outreach programme and communication strategies aimed at explaining the objectives of this study to both associated professionals and stakeholders are discussed in Chapter 9.

Chapter 10 summarises the project deliverables and graphically shows the work programme and proposed manning schedule of the project.

1.6 Inception Workshop and Follow-up

The Draft Inception Report was presented at the Inception Workshop held on Wednesday, 09 January 2019, at CIRDAP International Conference Center in ‘Chameli House’, 17 Topkhana Road, Dhaka-1000. Mr. Kabir Bin Anwar, Hon’ble Secretary, Ministry of Water Resources was the Chief Guest and Engr. Md. Mahfuzur Rahman, Director General of BWDB presided.

In addition to the lively plenary discussion, several sets of written observations were received in the Project Director’s office in the following weeks. The project team also met with the Director General and his staff to discuss the Draft Inception Report on 16 January 2019.

Appendix D of this report presents the minutes of the meeting with the DG on 16th January and a Comment of Response Matrix summarising the observations received by the Project Director’s office. The responses tabulated in this matrix have all been incorporated in this Final Inception Report.

2 MOBILISATION AND START-UP ACTIVITIES

2.1 Setting Up Office in Dhaka and Mobilising Experts:

The project office is situated at Flat #3/B, House #4, Road #23/A Block B, Banani, Dhaka-1213. The office was fully equipped and functional on 14th December 2018.

2.2 Kick-Off Meetings with Project Director and other Officials

The Team Leader mobilised on 28th October 2018, and accompanied by Mr Zahirul Haque Khan, Deputy Team Leader, met with the Project Director, Eng. Md. Habibur Rahman, for an introductory meeting on 29th October.

The Consultant's Project Manager was also present at an initial kick-off meeting at the Project Director´s Office on 9th November 2018 Present at this meeting were

Engr. Md. Mahfuzur Rahman, Director General, BWDB (Chair)

Engr. Md. Delwar Hossain, Additional Director General, BWDB

Mr A.K.M. Bodrudozza, Procurement Specialist, BDWB

Dr Kim Wium Olesen, Project Manager, DHI

Dr Ranjit Galappatti, Team Leader, DHI

Mr Zahirul Haque Khan, Deputy Team leader, IWM

A brief presentation of the project was made, followed by detailed discussions focussing on the expectations of the client regarding the project deliverables and capacity building at BWDB and associated agencies. It was agreed that there was no need to convene a separate kick-off meeting for officials of the Ministry and that the team should move directly into the Inception Phase.

2.3 Review of Scope of Work

The scope of work has been broken down into 9 components as shown in Table 2.1. These components, though of unequal size in terms of the resources necessary to carry them out, are nevertheless essential for the successful outcome of the project.

This sub-section examines how the scope of work would deliver results that would make it possible to achieve the broad objectives listed in Section 1.2 of this report. Component No 2 represents how the state of current knowledge relevant to the objectives of the study is reviewed and understood in relation to our present understanding of problems relating to economic and environmental sustainability of the coastal zone as well as the types of data we need for designing effective and safe coastal embankment systems. Component 2 would also help identify and highlight data gaps that need to be addressed if we are to create designs and polder management systems that address present needs as well as those that arise from longer term changes that are likely to occur as a result of how the delta evolves under the influence of natural geological processes, climate change and developments in the upper catchments in the major river systems feeding the delta.

Table 2.1: The Components of the Scope of Work

Component-1:	Inception report (Finalization of methodology and Work Plan)
Component-2:	Detailed Literature Review and its Summary and Lessons Learnt;
Component-3:	Development of input datasets for models of the long-term physical processes
Component-4:	Modelling of the long-term physical processes in the coastal zone;
Component-5:	Finalization of approach for reconstruction of the Polder at different coastal zones including their phasing and construction program;
Component-6:	Updating of design parameters and specifications for planning & design works; review of approaches for management of polders with active participation of beneficiaries and stake holders;
Component-7:	Investment plan for the entire CEIP;
Component-8:	Action plan for Capacity Building of concerned professionals and relevant stake holders in planning, design and management of the polders.
Component-9:	Outreach and communication strategy

Component 3 deals with the collection and assembly of data necessary to set up these models, and to calibrate and validate them before using them to simulate the full range of possible scenarios. This preparatory phase is essential for providing the basis for the modelling efforts. The data collected are to be quality checked and added to the BWDB database that would already have been quality assured. The resulting comprehensive database would be installed at the BWDB, at the conclusion of the project.

There are several types of data that are not routinely collected by the BWDB or BIWTA – particularly those relevant to the macro-scale processes. New techniques introduced by this project must be "naturalised" and institutionalised within Bangladesh either at BWDB or at another other suitable institution, with a mandate to continue collecting such data into the future. It is necessary that all data are analysed, and quality checked and validated before they are entered into the database.

Component 4 describes a complex set of interlinked tools for modelling the long-term processes in the coastal zone. It has been accepted that a range of modelling tools, some already available, some yet to be developed, should be used to predict the future short, medium and long-term development of the delta, under many possible climate and development scenarios.

These modelling tools are to investigate the macro-, meso- and micro-scale behaviour of the system and parts of the system as shown in Figure 4.12 in Chapter 4.

These models will simulate processes in different length and time scales as follows:

- Macro-scale：sediment balance sheet GBM delta．Models on this scale are necessary to get a good understanding on how the system functions as a whole, and to estimate the impact of climate change and anthropogenic works in a general context, in the longer term．
- Meso-scale：local river and estuary dynamics．This scale will highlight meandering and other dynamics of main estuarine branches, translating the macro scale findings into relevant impacts at the level of groups of polders．There will be several meso-scale models covering different parts of the coastal zone
- Micro-scale：water-logging and polder management．This scale is necessary to provide a detailed and local reference of（future）boundary conditions for dedicated polder design and management．

It must be kept in mind that the macro scale model addresses the sediment balance in the entire delta and how the delta responds to upstream developments in the basin and to downstream changes within the Bay of Bengal, land subsidence due to consolidation and/or tectonic movements, and sea level rise. These changes have also to be taken into account when modelling the smaller scale phenomena.

Recent discussions in the greater water resources community have raised issues that are not dealt with explicitly by the terms of reference: Among these are the problem of longer term prediction of river bank erosion risks to embankment safety which has to be further addressed. The other is the need for detailed feasibility studies of land reclamation in the Meghna Estuary via the use of judiciously positioned cross-dams.

Components 5 and 6 are directly related to using the new knowledge and understanding gained in Components 1 to 4, to fine-tune the approach to planning, design and management of the polders to be responsive to the challenges of climate change in consultation with all beneficiaries and stakeholders. Experience with the CEIP-1 implementation has taught us that unforeseen threat of bank erosion that could threaten even a recently planned (aligned) and designed embankment giving rise to additional expenditure. The results of meso-scale modelling studies are expected to contribute to further improving the knowledge and understanding of bank erosion towards making the planning of river erosion protection measures more reliable.

Component 7 calls on the project to devise an investment plan to for the Coastal Embankment Improvement Programme covering the existing 139+ polders and coastal zone development keeping within the requirements of socio-economic and environmental feasibility and the development objectives of the government of Bangladesh. Due consideration will be given to Bangladesh Delta Plan 2100 in the preparation of this investment plan.

The plans developed by this 30 months' study must not be cast in stone. They must remain flexible and adaptable to changes in the external environment – much of which will be beyond the control of a single nation. It is necessary to update the predictions at regular intervals into the future indefinitely. The work begun by this project must therefore continue indefinitely.

Component 8 will thus become the most important component of this project. The capacity of the professionals, mainly within the BWDB, to continue and improve on the work of this project has to be established by a well-focused training programme. However, this alone is not sufficient. There must be an institutional framework to sustain this work in years to come. Thus capacity, once built up, must be sustained and nurtured beyond the life of the project. The history of development aid is littered with examples of where "technology transfer" has been frittered away being allowed to decay in an institutional vacuum. On the other hand, there are a few remarkable success stories too. Capacity building plan will be prepared in consultation with the Project Director and policy makers of BWDB.

Component 9 deals with outreach and communications. This recognises the importance that this scientific study should not be carried out in an ivory tower. The stakeholders and beneficiaries must be taken into our confidence about the fact that the final objective is sustainable development of the coastal zone. It is necessary to disseminate and explain the results of the study at several interim stages of the work. The team of consultants would need the support of the BWDB and the district administration in the field, the university community and the NGO community in reaching out to the beneficiaries and stakeholders.

2.4 Meeting with Stakeholders

Consultation with various cross sections of the people is essential for better planning of improvement measures. People are to be meaningfully consulted at the initial stage of the project to obtain their knowledge and experience about the baseline information, potential impacts and improvement measures. In this project, Consultation and Participation will be an interactive process wherein the consultants, project owner, policy makers, beneficiaries and local stakeholders listen to each other and discuss their views and concerns in the project planning and design process. Meaningful consultations are to be made for disseminating the project activities, methods, deliverables including investment plan for the coastal zone.

The project team will visit selected areas within the coastal zone for intensive consultation with stakeholders. Participants will be drawn from the cross sections of the population to represent various social groups and interest groups such as LGI (Local Government Institutions), LGED, DOF, DAE, DOE and NGOs. Local BWDB personnel will also be consulted. People’s concerns, needs and aspirations will be elicited through group discussions on physical, environmental, social and economic issues. The discussions will be supplemented by professional observations made by the multi-disciplinary team members comprising national and international experts. Consultants will organise a number of national stakeholder consultation workshops and one international meeting during the course of the study.

2.5 Field Visits

2.5.1 Introduction

Minimal field visits were undertaken during the inception period because of the lack of time and the fact that almost the entire team had recent field experience among the polders while engaged in other recent projects dealing with physical processes, environmental problems and livelihoods in the coastal zone. The following pages gives a photographic summary of many of the problems encountered in the polder areas. The visit made by members of the team to Aricha, the confluence of the Ganges and the Jamuna in January 2019 is also recorded. Some photographs of field visits are presented below:

Photo-1: Settlements Built on the Sibsa embankment in Polder 32

Photo-2: Damage by Cyclone Sidr on Polder 35/1 on Baleswar River

Photo-3: River Siltation: Hari river in Jessore district, 2016

Photo-4: River Erosion of Polder 29, 2016

Photo-5: Drainage Congestion in Mosihati School (Polder-24) during September 2016

Photo-6: GPS measurements of Subsidence

Photo-7: River bank protection by sand fill Geo-bags

Photo-8: Receding of water level in the Brahmaputra River during January 2019

2.5.2 Field Visit to Bhola Island

Participants

1) Md. Zahirul Haque Khan, Deputy Team Leader
2) Shume Akhter Coastal and Estuarine Morphological Modelling Specialist,
3) Md. Raqubul Hasib, Salinity Specialist

Areas Visited

A field visit was conducted in Polder 56/57 in Char Fasson Upazilla of Bhola district during 20-24 January 2019. The objective was to visit the erosion vulnerable areas, ongoing protective measures and discuss with officials and the local community. Areas visited included river erosion along the eastern shoreline of Bhola Island and severe erosion on the left bank of Tentulia river and the right bank of Lower Meghna river (see Figure 2.1).

The team visited the erosion vulnerable area at Baburhat and Bakshi Bazar along the left bank of Tentulia river. It was observed that, the Ferry Ghat and metal road were engulfed into the river at Baburhat. The river bank erosion is severe for a long stretch of the river. Many acres of land had been devoured by the river over the last 3 to 5 years. Photo 9 shows the erosion vulnerable area at Baburhat along the left bank of the Tentulia river.

The team then visited the erosion vulnerable area along the right bank of the Lower-Meghna river at Lord Hardinge village under Char Fasson Upazilla. The river is eroding the eastern shoreline over a long stretch. The main flow is along the river bank and depth of water is substantial in accordance with the views of the local community. There is a submerged bar at the eastern side of the erodible bank (see photo 9) that has confined the channel close to the shoreline and caused higher near bank velocity.

BWDB has already started to protect the land against river erosion through revetment. Photo 11 shows the CC blocks made at site for placement at layers on land.

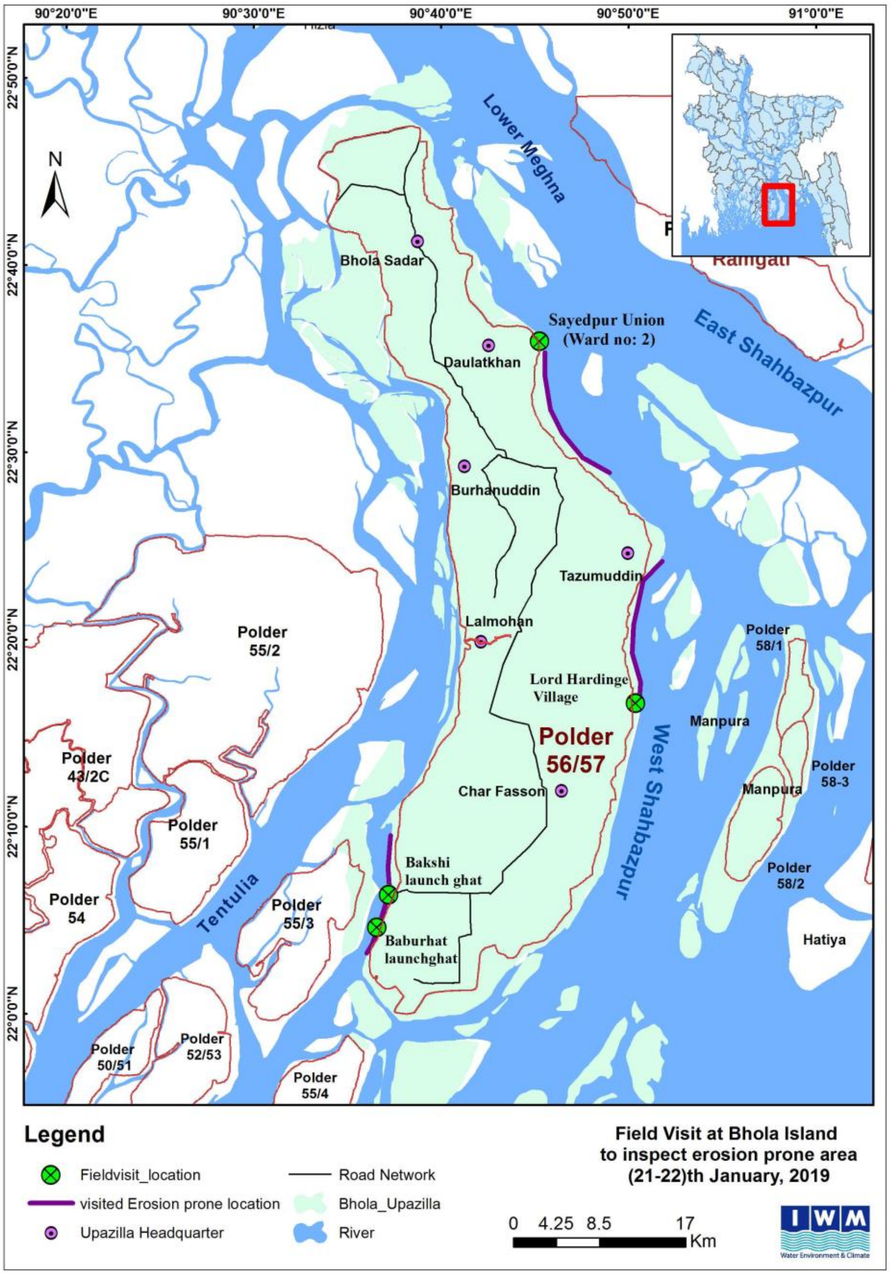


Figure 2.1 Location Map of field visit.

Photo 9: River bank erosion at Baburhat, Tentulia River

Photo 10: *River erosion at the eastern shoreline at Char Fasson of Bhola Island. Photo 11: CC block for erosion mitigation.*

The team visited the eroded area at Saidpur Union under Daulatkhan Upazila． It was observed that there is no setback distance of the embankment, which were eroded over the years． Photo 12 shows the polder（56/57）strengthening of embankment at east coast, Daulatkhan, Bhola Island． Photos 13 shows several photographs of bank erosion and geo–bag protection．

Photo-12: Strengthening of embankment to avoid overtopping during cyclone

Photo-13: Sand-filled geo-bag at Daulatkhan

3 UNDERSTANDING THE PROJECT

3.1 Introduction

The Government’s commitment to develop a safe and habitable coastal zone can be dated back to the mid-1960s. Compelled by the call for intensive rice cultivation during the green revolution, the government constructed a series of embankments and polders in order to provide tidal flood protection for coastal population; thereby enabling intensification of crop production and agricultural growth As described in Section 1.1, the coastal embankment projects put in place regulators and other structures to control water intake and drainage of polder areas with the primary objective of improving agricultural productivity.

The coastal embankment system brought immediate benefits to the people living in low lying areas. The system was originally designed to protect the low-lying land against inundation from the high spring tides, in monsoon-months, that occur twice a month during new moon and full moon, that may last over three or four days

The large-scale construction of polders has had a significant impact on tidal dynamics in the coastal zone. While previously, the flood tide which carried a large suspended sediment load was allowed to spread over the land at high tides and deposit this sediment load, now this tide is confined between embankments and forced to transport the sediment load farther into the delta. At the same time the high-water level was increased while the total volume (cubature)of the tide during a cycle was reduced. Consequently, the flow velocities were lower than they were before the construction of the polders, reducing the sediment carrying capacity of the flow at both flood tide and ebb tide. The consequence was the deposition of some sediment in the channels, thereby reducing cross sectional area of the channel to compensate for the reduction of flow velocities.

Siltation of some peripheral rivers surrounding polders has caused many polders to suffer from water logging, resulting in severe environmental, social and economic damage. Poor maintenance and inadequate management of the polders have also contributed to internal drainage congestion and heavy external siltation.

When the polders were initially constructed, attention was not given to storm surges that could over-top the polder, and at times breach embankments, resulting in submergence, crop destruction and human casualties. Recovery from such disasters had been slow, taking two on more seasons to return the polder to its former productivity, even after the breaches had been repaired. Recent cyclones, that occurred in 2007 (Sidr) and in 2009(Aila), had brought substantial damage to the embankments and threatened the integrity of the coastal polders. These two cyclones have focussed attention on the extent of economic damage inflicted on the population and raised awareness that much worse is to come because of sea level rise and increased cyclonic activity due to climate change and other natural processes taking place in the region.

While the fact that deposition of sediments during regular tidal inundation in the coastal zone was responsible for maintaining or even gradually building up the ground levels was universally known in the water resources community, the restoration of damages caused to the embankment system following many severe storms had been carried out until very recently without recognising the fact that the very system of level bench mark pillars being used had been subject to subsidence over the many decades they had existed.

It has even been questioned whether the polder concept, as it is practiced now, will provide a durable and sustainable solution for protection of the coastal belt against saline intrusion, tidal flooding, storm surges, and maintain production level in agriculture sector. Water logging inside the polders specially in the south-west region as the bed of peripheral rivers have silted up is another serious morphological challenge. Many polders, even though well protected from flooding by saline water, benefited by the possibility of letting in water (flushing) from the peripheral rivers seasonally when fresh water was available. Sea level rise and reductions in upstream flows would diminish this possibility.

3.2 The Need for the Project

Every one of the natural phenomena described above has long been individually studied and understood. The way in which climate change and other man-made changes will affect these processes in the future and how the processes interact with each other in making the coastal zone difficult to manage for the benefit of the population, is less well understood. Some phenomena, such as land subsidence (and rarely in places, up-thrust), have yet to be monitored and mapped throughout the entire coastal zone. Similarly, the rates of sedimentation on land in the unprotected areas such as the Sundarbans must be known if we are to quantify how much of the potential sediment deposits are being kept out by the embankment system and what proportion is left in the Bay of Bengal and what proportion is contributing to the siltation of river channels.

To complicate matters further, estimating the long-term impacts of climate change will remain a work in progress for the foreseeable future. So are the changes brought about by physical interventions in the major river systems that form the upper catchment of the delta, mainly outside the boundaries of Bangladesh.

This study will make a comprehensive and integrated study of all the processes that affect the environment of the coastal zone. It will re-examine the bases of long held assumptions about these processes, particularly in the light of climate change and an over-dependence on the historical record. While the project will make long-term predictions based on current knowledge, it will remain aware of how these predictions can change as new knowledge (data) becomes available. The methods and techniques used in this study have to be assimilated within the BWDB and related agencies so that the studies/tools/models are updated at regular intervals as new data becomes available, well beyond the life of this project.

The long-term monitoring, research and analysis project has been designed based on stakeholder consultation workshops with active and meaningful participation of representatives of BWDB, BUET, DU, BRAC university, BIWTA, IWM, CEGIS, TU Delft, Netherland, University of Colorado, Boulder and Columbia University of USA. The Bengal Delta is one of the largest and most complex Deltas in the world, understanding the delta process at the present time and in the future is important for appropriate planning and design of coastal polders and any other infrastructure. National and international experts have identified a number of key issues and emphasized the need to find solutions to these issues, for which a long-term research and monitoring programme is required. The key issues are the morphological changes in the peripheral rivers of polders, the development of the Meghna Estuary, the process of land subsidence in the polders and river systems, sedimentation processes in peripheral rivers that results in water-logging and navigation problems, salinity problems, increasing with climate change, integrated water management practices in the polders, need to collect bio-physical, environmental and socio-economic data for each polder, GIS based database development and capacity building of BWDB professionals.

It is well understood the drainage problems in the polder system are due to several factors:

a) The lack of sediment previously supplied to the land by natural tidal flooding has resulted in a relative lowering of land level inside the polder due to subsidence and tidal-range amplification.

b) Altering of the intertidal landscape and river discharge has driven changes in regional tidal hydrodynamics and an ongoing reorganization the tidal-channel network.

c) This eventually led to increased drainage difficulties encountered in low lying polders, which are also subject to subsidence.

d) This is further exacerbated by sea level rise and increased storm surges, and more extreme local rainfall.

The rationale behind the new polder improvement concepts is that the drainage conditions in the polder could be sustainably improved by addressing several of these reasons in parallel and taking full account of the aspects that are beyond our control.

The idea of “sustainable polders” in the coastal zone of the GBM delta is not completely new but there have been no concrete quantifiable options for interventions until now. In the Netherlands some ideas exist on ‘polder warping’ where sediment (and salt water) are allowed into the polder for some years after which, on the raised bottom, agriculture is carried out. In fact, this wheel does not have to be invented here; the necessary elements of knowledge are present around the world.

Sediment management will be an important issue, where both subsidence of the polder soil and sedimentation in the peripheral rivers is to be reduced, either in a natural or artificial way. “Natural” does not mean without technical means: an intelligent system of gates, to be opened or closed at will, can play an important role to manage the sediment balance. “Artificial” means actively taking up sediment with mechanical (dredging) equipment.

There is an immense requirement of important of bio-physical, environmental and socio- economic data necessary for each polder, as well as for the whole coastal area, tidal river system for characterizing the polders, assessing present and future problems and planning and design of polder improvement works in times of climate change.

There is insufficient knowledge about sediment transport within the estuaries, sediment sources, sediment distribution into the river system and sediment budget. Sediment and tidal dynamics are important driving forces for river and costal erosion, land reclamation, delta development. The knowledge on sediment dynamics, distribution, erosion deposition process and sediment management at present and future under climate change, land use changes and proposed interventions in the upstream reaches of the Ganges-Brahmaputra river systems are essential.

Field campaigns have been designed under this project to measure sediment transport, monitor and analyse to generate data and knowledge on sediment dynamics, sediment deposition and erosion.

There is a possibly a lack of appreciation of the multiple causes of embankment failures that have occured in the past. Storm surge attack and overtopping, wave attack and river bank erosion have all combined with incidences of poor construction, lack of maintenance and the absence of vigilant monitoring and preparedness have all contributed to these failures. There is also a lack of awareness that it is not always economic to protect against the lowest probability scenarios and that rare failures do occur even in the best designed systems. The need to recover quickly from such disasters is also a feature of a resilient system. Two-dimensional storm-surge models, including the effects of future sea level rise, and wave propagation will be implemented and used to assess the impact of future storm events. These assessments may provide the basis for the design of future resilient polders.

There is a need of investment plan based on scientific analysis, environment and socio-economic considerations with long-term perspective to implement in phases, so that donors and the Government of Bangladesh could fund on-going development and improvement in the coastal zone.

3.3 Objectives of the Consultancy Services

The Terms of Reference lists the objectives of this study as follows：

a. Create a framework for polder design, based on understanding of the long term and large–scale dynamics of the delta and on sustainable polder concepts. These polders should offer their inhabitants a safe environment to live in and sufficient opportunities for their livelihood. Among other issues, land use（agriculture including cropping patterns and adaptation of new varieties of cultivars that are emerging through research, aquaculture, housing, urbanization, etc）, management of drainage congestion through control over ground level, sedimentation balance inside and outside the polder, and salinity in rivers and groundwater, are the key parameters in coming to these concepts, taking climate change into account

b. Present an overview of values of relevant parameters at locations in the polder area, now and in the future, as boundary conditions for polder design and management
c. Develop a long-term investment plan for implementation of the proposed design and management improvements leading to integrated water resources management, targeting sustainable development goals.
d. Build the analytical foundation and technical capacity of BWDB and other stake holders including local communities, as appropriate, to engage in science driven decisions on floods, storm surges and drought hazards in the coastal region of Bangladesh;

The objective (a) involves the consideration of a large number of complex processes that have to be understood and quantified in order to make a useful and practical framework for designing sustainable solutions for providing safe livelihoods for the population within the coastal zone. The solutions require a much more diverse and broad-based approach than the initial study of physical processes undertaken in first phases of the project. The design of each polder must take into account, in addition to the initial study of physical processes, its individual characteristics in terms of its hydrological setting, land use, vulnerabilities to natural disasters and socio-economic situation. This will make it necessary to have detailed consultations within the community and with water management organisations.

There are insufficient resources or time available to make the studies necessary to finalised detailed designs for each of the 122 polders. Therefore, the conceptual designs for each polder will be carried out using their broad characteristics, their morphodynamic setting, taking into account the lessons learnt from the detailed design of 17 polders in an earlier phase of the project, to the extent necessary to group them and rank them for phased intervention

The vision of the scope of work is also to expand the analytical capacity and data driven decision making into an “ecosystem” in which professionals cooperate, and exchange knowledge and information in a community of practice, using a common infrastructure (of knowledge and data), to be housed in BWDB and other organizations would have access to the data system. Starting with the researchers directly involved in the coastal area and the polders, the future extension will be to bring onboard the whole coastal belt and the Bangladesh water management community.

Beside geography and community, the third dimension in this movement is quality. With one of the most complicated deltas in the world, understanding and application of this knowledge is of paramount importance. Activities described in this ToR should be carried out in Bangladesh in cooperation with BWDB and related agencies ("training on the job"). Among the deliverables in the ToR, will be workshops and training as elements of capacity building and an explicit indication of future steps for further improvement.

3.4 Project Management Challenges

This ambitious project was originally conceived as a research study to fill in gaps in knowledge and understanding of physical phenomena that control the active processes in the Bengal Delta. It was also supposed to create knowledge that would assist the Coastal Embankment Improvement Programme (CEIP) to create designs that can withstand all the forces that have to be resisted by the Embankment System including the additional impacts of climate change.

The polder concept was expected to evolve towards a sustainable model that would face the uncertainties of climate change and other environmental challenges that could arise, the introduction of designs that could be adapted from time to time to meet changing environmental conditions. It was anticipated that new solutions, based on innovative thinking would be tested and introduced to improve sustainability.

The original team selected for this study comprised 30 international specialists from 2 international consulting firms from Europe, 2 major Universities from the United States of America and 26 domestic specialists from the Institute of Water Modelling in Bangladesh to carry out a very complex study over a duration of 54 months. This study was later curtailed to a period of 30 months without significant reductions in the scope of work. Managing the very diverse team of international consultants within a compressed time scale would present severe challenges that would require re-scheduling of staff inputs and field work as indicated in this Inception Report.

Due to the large size and complexity of the delta system, repeated sampling and collecting observations over time and location are required to capture the system's natural patterns and variability. These constraints will require significant time and manpower to collect the appropriate data needed to develop well-validated models of the delta system behaviour under various scenarios of natural and anthropogenic change. In particular, observations of subsidence and sedimentation will take a minimum of several years to develop precise rates. Observations of water discharge, tidal transport, and sediment exchange will be required at many locations across the coastal zone at timescales of spring-neap tidal cycles, wet-dry seasonal cycles, interannual variability, and under storm surge conditions. Major progress toward these goals will nevertheless be achieved in the 30 months of the project. The lack of time available to carry out two additional seasons of field surveys is a major constraint to obtaining more accuracy with the new types of data being collected by this study.

The project activities connected with developing innovative approaches to polder management, planning and design were planned for late in the life of the project, because they could not be carried out optimally until a more complete understanding of all delta processes could be reached using the results of the scheduled detailed modelling activities. However, as it is necessary to canvass the opinions of stakeholders regarding the future development of their livelihoods and their attitude to how their polders are best managed, two consultative workshops will be conducted in Khulna and Barisal for the edification of the study team. There will be several consultative workshops towards the end of the study period held to discuss proposals for polder improvement.

4 SCOPE OF WORK FOR CONSULTANCY SERVICES

4.1 Literature Review and Summary

4.1.1 Documentation including Summary

Various development plans and strategies have been developed, studies were carried out and many important projects were implemented in the past to address various aspects of coastal zone management including construction of polders and effective land and water management. Reports and documentation from these activities have been published and are available in different organizations and institutions. The coastal belt is considered to be the most vulnerable area of Bangladesh to adverse impacts of climate change. The risks due to climate change are cyclones and storm surges, river bank erosion and vulnerability of islands and chars, sea level rise, salinity intrusion, floods, droughts, drainage congestion, coastal erosion etc. Climate change issues may have been addressed in many reports. We will review all the previous studies and reports to extract relevant knowledge and understanding. This review will be published in a report.

BWDB does not have a central library. Some of its departments particularly the planning departments hold libraries where documents of their own completed projects are generally kept. Consultant visited the library of Director Planning-1 BWDB, and from their readily available list, some relevant documents in limited numbers have been detected. Simultaneously, Consultants have identified the availability of some documents at the libraries of IWM and WARPO. The identified documents are mostly on coastal studies including plan, policies and strategies for coastal development. At IWM, 88 relevant documents (reports, technical notes, etc.) have been identified which are categorized in Table 4.1. Similarly, 51 documents are identified at the WARPO library that are summarized in Table 4.2.

Table 4.1 The Number of Relevant Documents Identified in IWM

SL No.	**Subject Area**	**Numbers**
1	River & Water Management	29
2	Flood control, drainage and erosion management	19
3	Feasibility studies on coastal development/ improvement and estuary development studies	16
4	Studies on Climate change issues	11
5	National Water Plan and Coastal zone policies	5
6	Studies on Coastal embankment and Polders	5
8	Others	3
Total Number of Documents		88

Table 4.2 The Number of Relevant Documents Identified at WARPO

SL No.	Subject area	Numbers
1	River & Water Management	29
2	Flood control, drainage and erosion management	11
3	Feasibility studies on coastal development/ improvement and estuary development studies	5
4	Coastal zone policy and summary of Flood Action Plan studies (FAP)	4
5	Others	2
Total Number of Documents		51

4.1.2 Lessons Learnt

The lessons learned from reviewing all the previous studies will be summarised in the annotated literature review report. The coastal zone is divided into 4 subzones with distinct environmental characteristics, see Figure 4.1. The boundaries of the coastal zone are shown here.

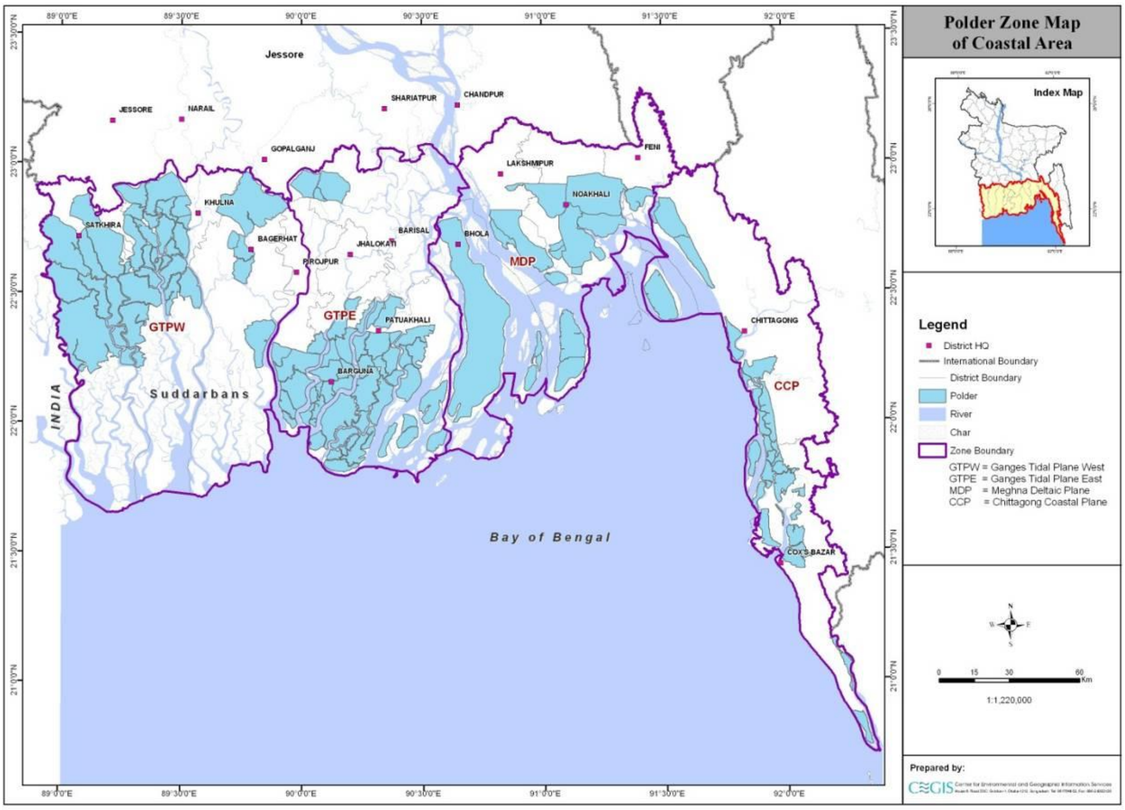


Figure 4.1 This is Environmental Subdivisions of the Coastal Zone

They are: GTPW: Ganges Tidal Plain West; GTPE: Ganges Tidal Plain East; MDP: Meghna Deltaic Plain; CCP: Chittagong Coastal Plain. These subzones are controlled by their connectivity to the major rivers to the north and the large estuaries that bring them under the influence of the Bay of Bengal. In the case of the subzone GTPE which is linked strongly to the Ganges/Padma in the north as well as to the Meghna in the east, makes this zone almost free of salinity and of the strong flood tides that carry a huge silt load into the western part of the delta. The GTPW on the other hand is the most interesting as well as the most difficult to manage among the four subzones. The area was once fed by Ganges right bank distributaries such as the Mathabanga, Kobadak and the Gorai. Now, only the Gorai is active, though not providing significant flows in the dry season. Many polders built in this subzone, exhibit many negative features that threaten their long-term ability to support their populations, viz water-logging and drainage congestion and salination triggered by siltation of peripheral rivers. This problem is so severe that some rivers are completely moribund. Restoring these rivers by dredging would only be temporary unless the mechanism that caused the siltation is dealt with. Regenerating the tidal flow by opening up selected polders or beels to tidal flooding has been found to be beneficial in desilting some river channels.

Storm surges, propagating into the delta, are constricted by the polder system which raises the maximum water levels. The cumulative impact of increasing the density of polder building, thereby constricting the pathways available for the storm surge to travel upstream, have not always been taken into account. Neither has the impact of continuing subsidence of all the embankments and structures over time.

Failure of embankments during storms had not always been as the result of overtopping. There have been many failures due to undermining of the toes of the embankment due to riverbank erosion, as well as because that some embankments were not properly constructed nor maintained. It is now clear that embankments and drainage structures, however well they are designed and constructed, require continuous monitoring and maintenance to ensure a long and effective life. This requires the cooperation of all stakeholders and this must be planned for at the outset.

4.1.3 Initial Considerations for Sustainability

The long-term survival of the polder systems has been a subject of discussion among professionals in the field for more than 3 decades. The flow mechanisms that caused severe siltation of some channels and drainage congestion have been increasingly well understood and quantified over the years. Although we now have a greater appreciation of the (cumulative) impact of polder construction on not only the tidal dynamics in the delta, but also the propagation of storm surges within the river network we have not fully understood the way in which sediments are brought in an circulated within the complex network of tidal channels. Although the nature of land subsidence has been known, we did not fully appreciate, until recently, the impact it had on the safety of the polder system. Advent of climate change with increase in sea levels and more intense and frequent storm surges has exacerbated all threats to sustainability of the polder system.

Searches for more “natural” management solutions to the problem of channel siltation and land subsidence has led to some possible devices such “tidal river management” (TRM) that has enabled temporary relief to be provided with the cooperation of the polder population. This type of solution is not applicable everywhere. It is now established that the vulnerability of polders is variable, as are the measures required for providing relief. The management of a given polder or system of polders requires study of hydraulic and sedimentation processes in relation to alternative land uses. This requires consultation with the resident population. Such consultations will be successful because there will be an outreach programme that could explain alternatives to the stakeholders.

4.2 Input Datasets for Modelling (Component 3)

4.2.1 Introduction and Background

Data collection is an integral part of this study and it is required for characterising baseline hydrological, morphological, environment and social conditions of the study area as well as detailed modelling study. ToR stipulates that modelling is carried out for physical process at macro, meso and micro scales, which requires substantial data for model set-up, calibration and validation. Data are available in different organizations such as BWDB, BIWTA, BMD, CPA, MPA, LGED and other organizations, available data are to be collected from these organizations. However, field survey plans have been made to collect the required data on bathymetry, sediment, water flow, tide, subsidence and aquifer characteristics applying state-of-art survey technology and equipment. A geo-database will be developed for the coastal zone containing physical, environmental and social data of each polder.

In addition to data collection and processing, there will be a focus on improving organizational capacity and technical capacity to improve quantity and quality of data collection. During the survey campaign participation of professionals of BWDB will be ensured. Quality assurance and quality checking are prerequisite to use the data for modelling and analysis.

4.2.2 Availalble Data Inventory

A truly massive volume data has been gathered from many sources and organised within the IWM database during the 33 continuous years of its existence as a project and then an institution dedicated to modelling water resources in Bangladesh and the region. The data coverage is summarised in Figure 4.2. The actual list of data is tabulated and shown in Appendix C of this report.

The project would develop a GIS based National Coastal Polder Database (and Management Information System) which would be transferred to the BWDB at the closure of the project. Much of the data identified in Appendix C would be included in this database together with new data and new data types gathered by the project.

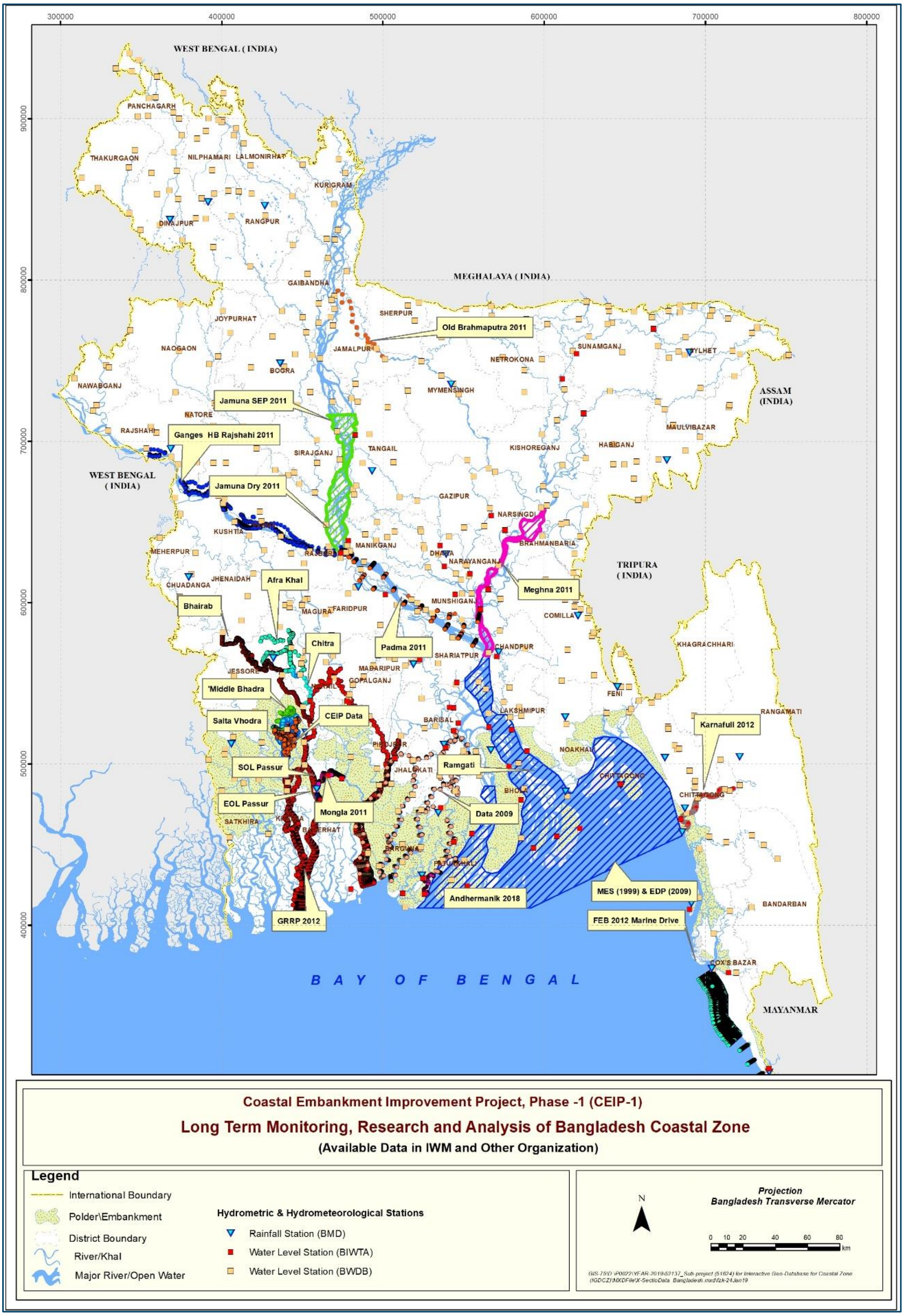


Figure 4.2 The Coverage Map of Existing Data

4.2.3 Collection of New Data

In accordance with the Terms of Reference the following hydrological, morphological and hydrogeological data are to be collected under this study;

- Water Level Observation
- Bathymetry Survey
- Current Profiling and Discharge Observation by ADCP
- Suspended Sediment Sampling
- Turbidity measurements
- Bed Material Sampling
- Salinity observations
- Aquifer characteristics
- Satellite images

In addition to the above, collection of data on land subsidence and flood plain sedimentation are described in Section 4.3 of this report and in Appendix A.

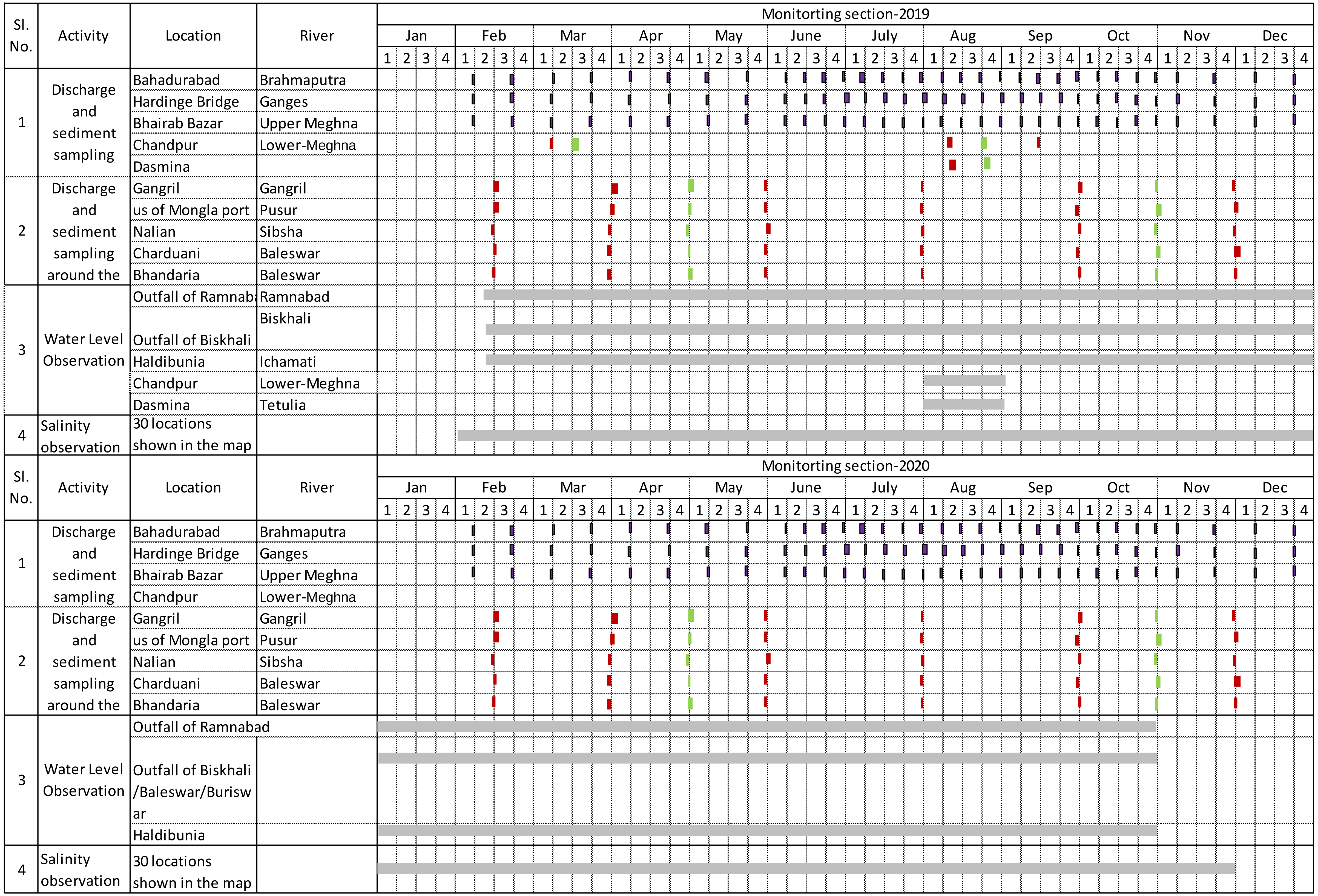
The Table 4.3 presents the data type, location and the frequency of data collection.

It has been agreed that additional field investigations should be carried out to track the westward movement of sediments emerging form the Meghna Estuary to enable us to determine what proportion (if any) of these sediments are reworked by the tides back into the more western estuaries such as the Pussur-Sibsa system. This is an important factor that could drive a part of the sedimentation processes in the Southwest Region and further improve our understanding of the sediment balance in the delta. These measurements are not included in the main terms of reference and additional resources will need to be sought from the contingency funds. Proposals for carrying out this work will be presented to the Project Director in the near future.

Field survey locations are shown in the Figure 4.3.

Table 4.3 Proposed locations of different types of data collection

Discharge, Sediment sampling , Water Level & Salinity Observation Schedule (2019-2020)



Monitorting section-2019

Sl. No.	Activity	Location	River
1	Discharge and sediment sampling	Bahadurabad	Brahmaputra
		Hardinge Bridge	Ganges
		Bhairab Bazar	Upper Meghna
		Chandpur	Lower-Meghna
		Dasmina	
2	Discharge and sediment sampling around the	Gangril	Gangril
		us of Mongla port	Pusur
		Nalian	Sibsha
		Charduani	Baleswar
		Bhandaria	Baleswar
3	Water Level Observation	Outfall of Ramnab	Ramnabad
		Outfall of Biskhali	Biskhali
		Haldibunia	Ichamati
		Chandpur	Lower-Meghna
		Dasmina	Tetulia
4	Salinity observation	30 locations shown in the map	

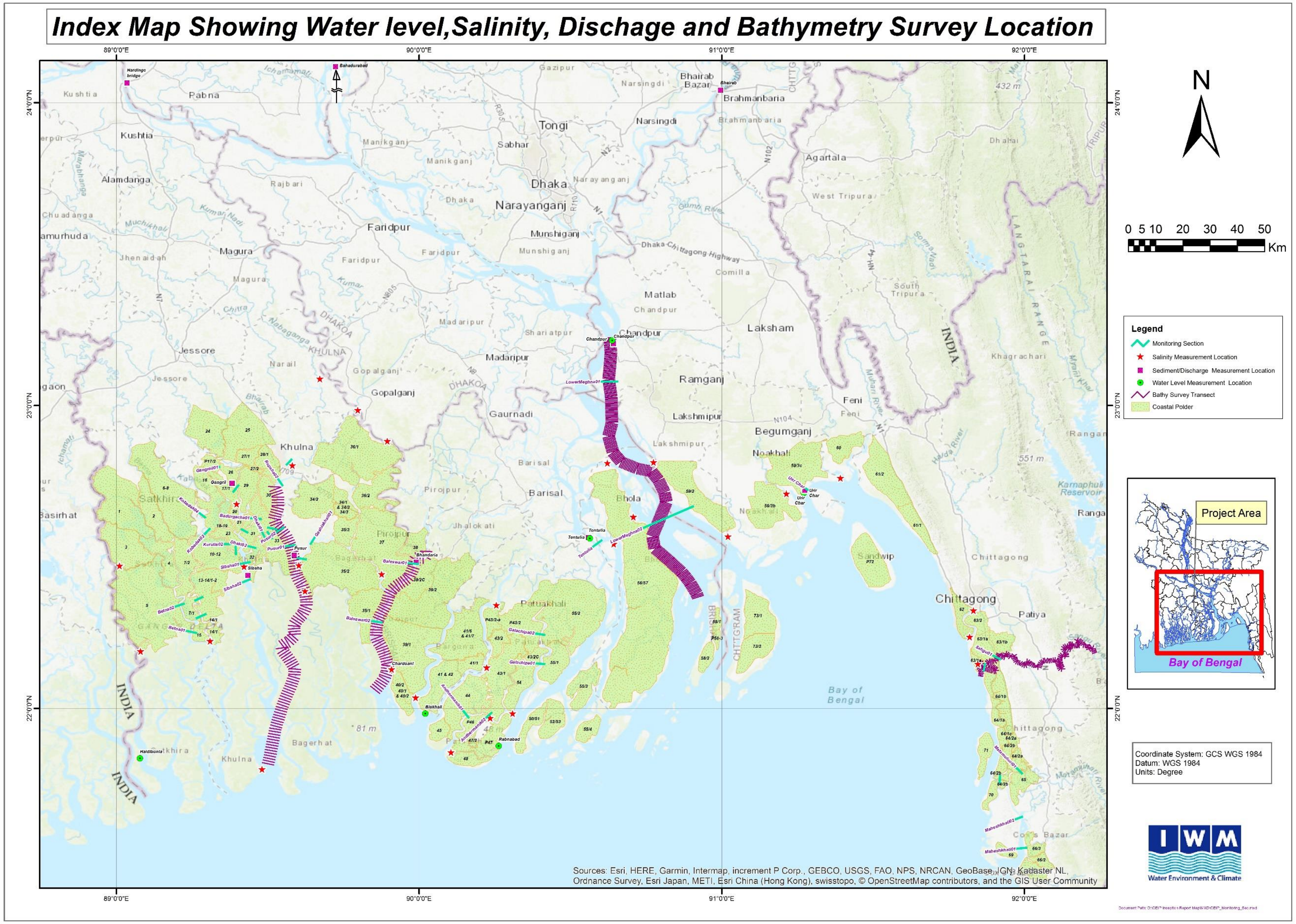
Monitorting section-2020

Sl. No.	Activity	Location	River
1	Discharge and sediment sampling	Bahadurabad	Brahmaputra
		Hardinge Bridge	Ganges
		Bhairab Bazar	Upper Meghna
		Chandpur	Lower-Meghna
2	Discharge and sediment sampling around the	Gangril	Gangril
		us of Mongla port	Pusur
		Nalian	Sibsha
		Charduani	Baleswar
		Bhandaria	Baleswar
3	Water Level Observation	Outfall of Ramnabad	
		Outfall of Biskhali /Baleswar/Burisw ar	
		Haldibunia	
4	Salinity observation	30 locations shown in the map	

🟪 Non tidal discharge observation/sediment sampling

🟥 Tidal discharge (spring)observation/sediment sampling

🟩 Tidal discharge (neap) observation/sediment sampling



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Figure 4.3 Map showing the survey locations

4.2.4 Methods of Data Collection

The detailed survey methodology is given below:

a) Control Point Arrangements

Figure 4.4: RTK GPS survey

Control point arrangement is necessary to conduct the bathymetric survey including shore area and water level observation. Nearest available Bench marks surrounding the study area established by Survey of Bangladesh (SOB) will be used as reference. The Control Points will be connected by fly levelling from the available nearby SOB bench mark. In addition, RTK online survey would be carried out to check the consistency. RTK-GPS with dual frequency/carrier phase measurement can provide vertical accuracy of ±2cm within a range of 10km from the base.

The SOB bench marks were set up in 2002-2003 and have been subject to subsidence and seasonal vertical motions ranging from 5-6 cm near the Jamuna to 1-2 cm near the coast. This must be taken into account. Figure 4.4 shows RTK GPS survey.

We will be reoccupying the sites to estimate subsidence, correcting for the seasonal signal. After that, we can make estimates of the vertical position of the benchmarks. We also have a set continuous GPS (8 after we install the new ones) that can be used at tie points accurate to ±<1cm. They are not RTK, so data must be post processed.

b) Water Level Observation

Water level data will be recorded for 1.5 years at 3 locations – one is at the outfall of Rabnabad Channel, one is at the downstream meeting point of Payra, Bishkhali and Baleswar and remaining one is at the Haldibunia forest camp (latitude 21o50’5” and Longitude 89o4’39”) . Moreover, 4 water level gauges will be installed for 4 months period (2 months for dry season and 2 months for monsoon). In addition, 3 water level gauge will be installed along the lower Meghna during the period of bathymetry survey. The data will be collected at 15 minutes interval by installing pressure cell as well as by installing staff gauges for cross checking. The gauge reading will be taken by gauge readers and as well as automatic recoded by pressure cell. The gauges will be connected from a nearest TBM connected from the existing SOB Benchmark by the RTK survey and level flying. In case of Haldibunia forest camp (western coast of Bangladesh), the gauge will be connected from the existing SOB BM (GPS-150) at Haldibunia, for which only ellipsoidal height is available and orthometric height can be found by using the available GEOID model in SOB. The sensor readings are downloaded time to time as well during the data collection period. Water level gauge & Pressure Cell are shown in Figure 4.5. Figure 4.6 shows a sample of WL recording.

Figure 4.5 Water level gauge & Pressure Cell

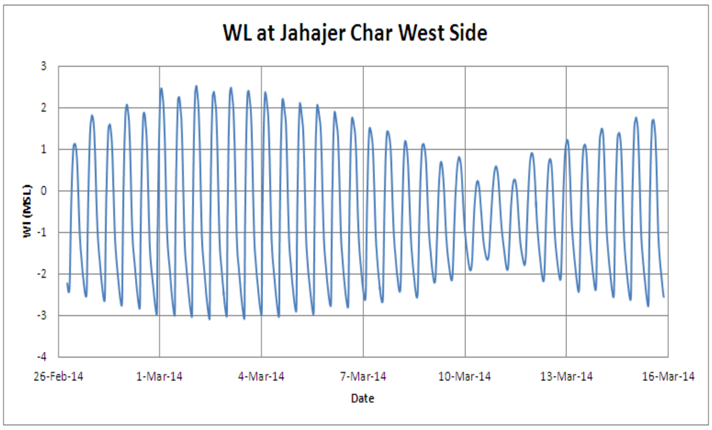


Figure 4.6 Sample of WL Recording

c) Cross-section Survey/Bathymetric Survey

Bathymetry survey will be conducted on the Lower Meghna at 500m intervals for 100 km length starting from Chandpur to Tajumuddin, at Sangu at 500m intervals for 70 km, at Pussur at 1000m for 112 km and at Baleswar at 1000m intervals for 60 km. The cross section will be extended up to high bank and covering all shallow chars. A total of 1550 km transect length of 101 nos. transect line survey will be carried out at Lower Meghna. Whereas, the bathymetric survey will also be conducted over 70 km length of the Sangu River @ 500m intervals.

Survey will be done by using Digital Echo-sounder and DGPS (shown in Figure 4.7). However, the shallower char, bank line will be surveyed manually using level and handheld GPS. Calibration of the Echosounder will be carried out daily before and after the measurements with the help of a bar check or by a measuring staff. A notebook computer with Trimble Hydro Pro software will be used to interface the instruments. The Hydro Pro Navigation software guides the survey boat on the desired transects. The data will be recorded at 1 second interval at 1-2m interval depending on the speed of survey vessel. However, the data recording spacing can be setup as desired. The horizontal accuracy is about ±1.0m whereas the vertical accuracy is ±0.05m. The survey data is stored in tabular

Figure 4.7 Bathymetric Survey

format on an MS Access database during survey by the software. The Nav Edit module of the software compiles depth of water column and position of sounding with time. The depth and position data can be viewed both graphically and in tabular form in the software. The erroneous data is removed by checking the sections during processing. The depth data is then converted to reduced level by deducting depth from water level. The edited data is then exported into ASCII format from the Nav-edit module of Hydro-Pro software. Finally, the contour map will be presented along with features in suitable scale as per requirement of the client. Bathymetric Survey and Data processing work is shown in Figure 4.8.

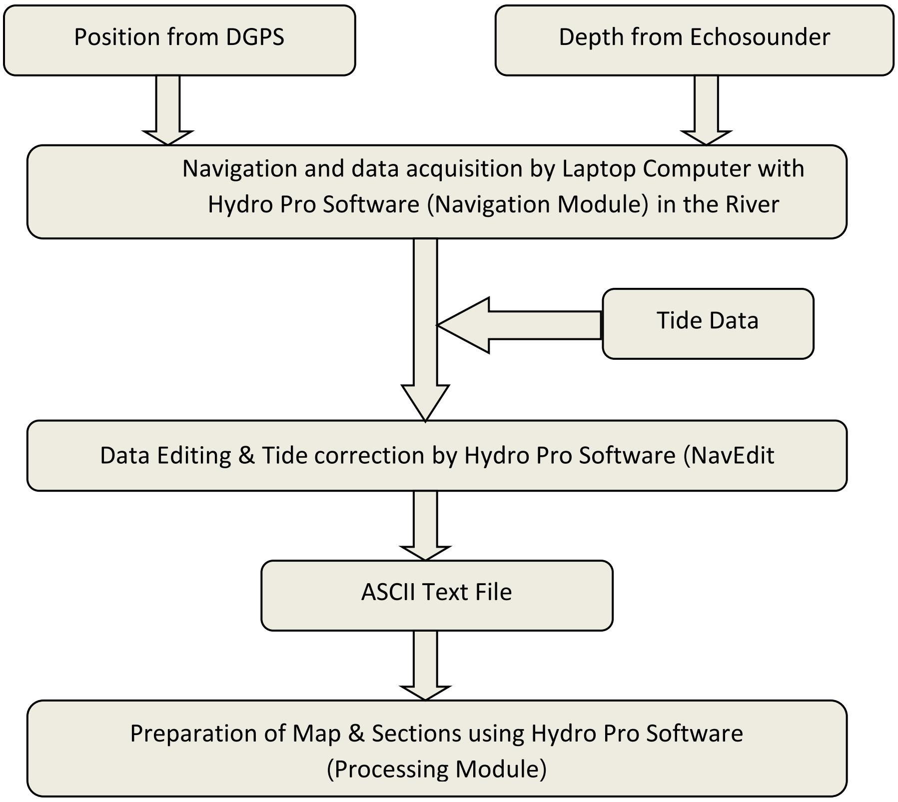


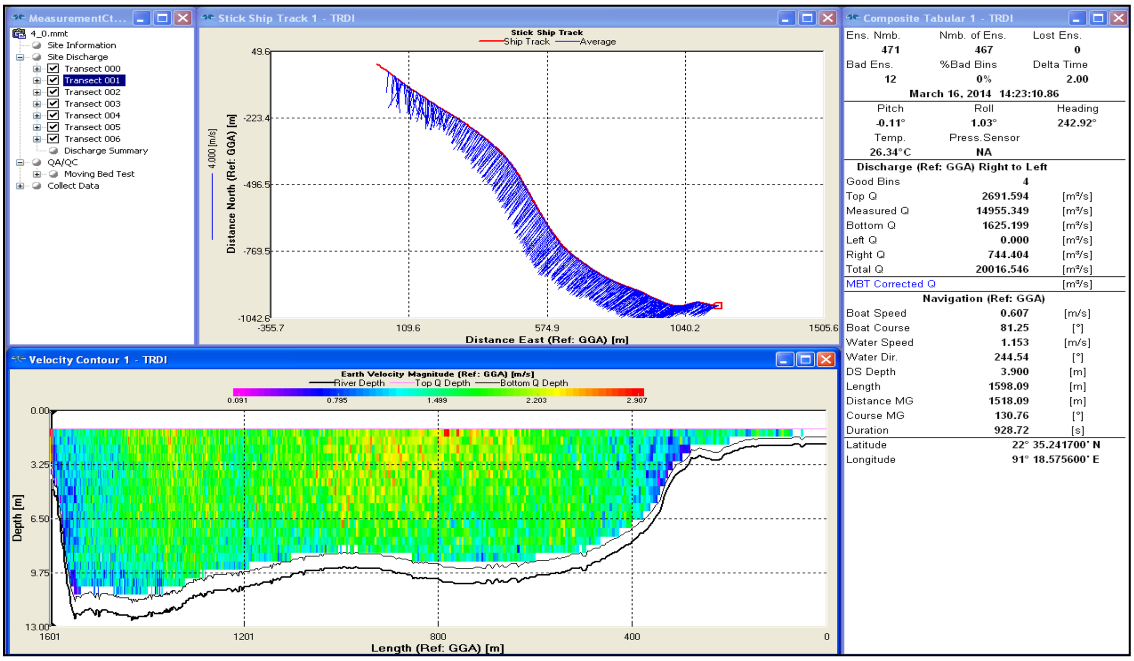
Figure 4.8 Bathymetric Survey and Data processing work

d) Discharge/Velocity Profiling

Discharge/ velocity observations will be made on the Jamuna (at Bahadurabad), Ganges (at Hardinge Bridge), Upper Meghna (at Bhairab) once in a week during monsoon and once a month during dry season. The observation will be made for one and half years along with the BWDB observation schedule. In the Upper Meghna (Bhairab), tidal discharge observation will be made during the dry season. In the Lower Meghna (Chandpur), a total of 5 number tidal discharge observation will be made of which 3 number (2 spring and 1 neap) will be measured during monsoon and 2 no. (1 neap and 1 spring) during dry season. In addition, tidal discharge observation will be made at the 5 locations- Gangrail, Pusur (u/s of Mongla Port), Shibsa (Nalian), Baleswar (Charduani) and Baleswar (Bhandaria) covering one spring in every two months and one neap in every season (six month). As such, a total of 60 discharge observations will be conducted in these 5 locations during the one and half year. The observation will be made for 13 hours and the interval between successive measurements will be 1 hour or half hour based on the requiring time to cross the river. Sediment sampling and turbidity observation will be made during the all discharge observations.

RD Instruments River Ray 600 Khz /Workhorse Rio Grande 600 KHz ADCP will be deployed for the measurement. Discharge observation by River Ray is presented in Figure 4.9. The velocity profiling range is from 2m depth up to 45m depth. The measurement will be made following WinRiver User Guide supplied by the manufacturer of the instrument. The instrument is capable of measuring velocity without anchoring at measuring locations (moving boat condition). It measures flow velocity at each ensemble across the whole river. At each ensemble, velocity will be measured at 50 cm intervals along the water column. Thus, a series of velocity data will be recorded along the whole transect line. The interval between consecutive ensembles will be around 3 seconds depending on the configuration and depth of the river. The software estimates the discharge of unmeasured areas (the top of instrument face, near bottom part and at edges). The river flow is calculated online by the WinRiver Software by adding discharge of each ensemble as it moves along the transect line. Sample discharge data processing is shown in Figure 4.10.

Figure 4.9 Discharge observation by River Ray



Ens. Nmb.	Nmb. of Ens.	Lost Ens.
471	467	0
Bad Ens.	%Bad Bins	Delta Time
12	0%	2.00

March 16, 2014 14:23:10.86

Pitch	Roll	Heading
-0.11°	1.03°	242.92°
Temp.	Press.Sensor	
26.34°C	NA	

Discharge (Ref: GGA) Right to Left

Good Bins	4	
Top Q	2691.594	[m³/s]
Measured Q	14955.349	[m³/s]
Bottom Q	1625.199	[m³/s]
Left Q	0.000	[m³/s]
Right Q	744.404	[m³/s]
Total Q	20016.546	[m³/s]
MBT Corrected Q		[m³/s]

Navigation (Ref: GGA)

Boat Speed	0.607	[m/s]
Boat Course	81.25	[°]
Water Speed	1.153	[m/s]
Water Dir.	244.54	[°]
DS Depth	3.900	[m]
Length	1598.09	[m]
Distance MG	1518.09	[m]
Course MG	130.76	[°]
Duration	928.72	[s]
Latitude	22° 35.241700' N	
Longitude	91° 18.575600' E	

Figure 4.10 Sample discharge data

e) Suspended Sediment Concentration

The suspended sediment samples will be collected during the all discharge observation. In case of a non-tidal rivers like the Brahmaputra, Ganges and the Upper Meghna sediment sampling will be made on 10 verticals during the discharge observation together with the BWDB scheduled discharge measurement team. In case of tidal discharge, sampling will be done for 13 hours during morning to evening. Samples will be collected once every hour to show the time variation. The samplings for total concentration will be taken from 1 vertical along the defined location. At each vertical, samples will be collected from 0.2, 0.6 and 0.8 times the total depth from the surface. The sediment sampling will be made using pump-bottle technique. The water is withdrawn using JABSCO Pump operated by AC motor that has uniform speed and is operated by a generator. The pump is connected with a tube of required length. The tube is attached with a fish (normally used with traditional current meter) and lowered from a winch at the desired depth. The initial water pumped from the tube is allowed to drain before the sampling is made for total concentration. The samples will be tested for total concentration at IWM laboratory, Dhaka using filtration technique.

f) Bed Material

The bed sampling will be made at each discharge location of different rivers. 6 bed samples will be collected from each discharge measurement cross-section. As such, a total of 54 samples will be collected from 9 discharge locations.

The sampler consists of cupped jaws that close to trap a sample of bed material. Closure of the jaws is obtained either by a pull on an auxiliary line or by an automatic spring arrangement. Grab bucket sampler is shown in Figure 4.11 The grain size distributions of bed materials are usually estimated by sieve analysis. In the case of most cohesion less soils (gravel, sand and silt), distribution of grain size could be determined by sieve analysis. Cohesive soils (clay) cannot be separated by sieve analysis into size categories because no practical sieve can be made with openings so small; instead, particle size may be determined by observing settling velocities of the particles in the water mixture. Sieving through a 63 microns sieve separates samples for grain size analysis. The portion above 63 microns is analysed by dry sieving and the portion below 63 microns is analysed by observing settling velocity of the sediments in Andreasen Settling Tube.

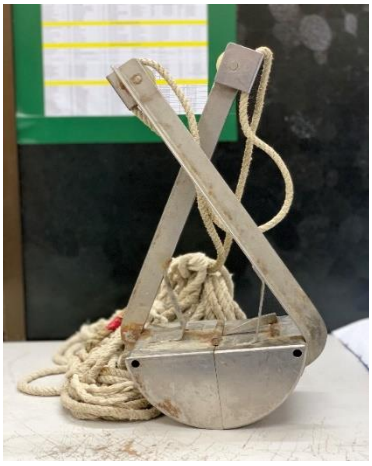


Figure 4.11: Van Veen Grab

g) Grain size Distribution Analysis for Suspended Sediment

Analysis for Grain size distribution will be done once in each season (six months) for each discharge observation location. 1 sample will be collected for each time of sampling for each location. For each sample, minimum 40 litre water sample will be collected depending sediment concentration. The samples will be brought to IWM Laboratory for analysis. The samples will be passed through # 63 sieve to separate finer and coarser particles. The coarser part will be dried in the oven and analysed using dry sieving and the portion below 63 microns is analysed by observing settling velocity of the sediments in Andreasen Settling Tube.

The laser particle size analyser at Dhaka University that can measure grain size distribution from 2 microns to 2 mm. Measurements, particularly for the fine grain part can be done much more efficiently there.

h) Salinity Profile

The salinity will be observed at 20 locations surrounding the study area. Sampling will be made in every alternate day at the 20 locations through engaging a sample collector. In addition, Salinity profiles will be measured simultaneously by using the Salinometer or CTD Sensors during the discharge observation.

4.3 Modelling Long Term Physical Processes in the Coastal Zone

4.3.1 Macro, meso and micro scale models

The long-term morphological development of the Ganges, Brahmaputra and Meghna Delta will have deciding influence on the sustainability of the polders in the Bangladesh Coastal Zone. Generally, deltas are widely accepted to be shaped by tides, waves and sediment input by the source rivers. All of these driving processes are strongly influenced by "change drivers" such as climate change and basin development/ anthropogenic activities in the basin. An additional change driver in the Bangladesh Delta is the significant land subsidence that takes place without being compensated by natural sedimentation due to the embankments encircling the polders.

The time scales associated with the driving processes and the change drivers range from hours (tides) to decades (climate change). Similar, the morphological responses encompass a large range of spatial scales, viz. from thousands of kilometres (e.g. basin scale) to a few meters (e.g. internal polder drainage and siltation of peripheral rivers). Making long term predictions for this system is therefore particularly challenging and will be based on using a cascade of process-based morphodynamic models to understand and predict long-term (~25-50-100y) morphodynamic development, see Figure 4.12.

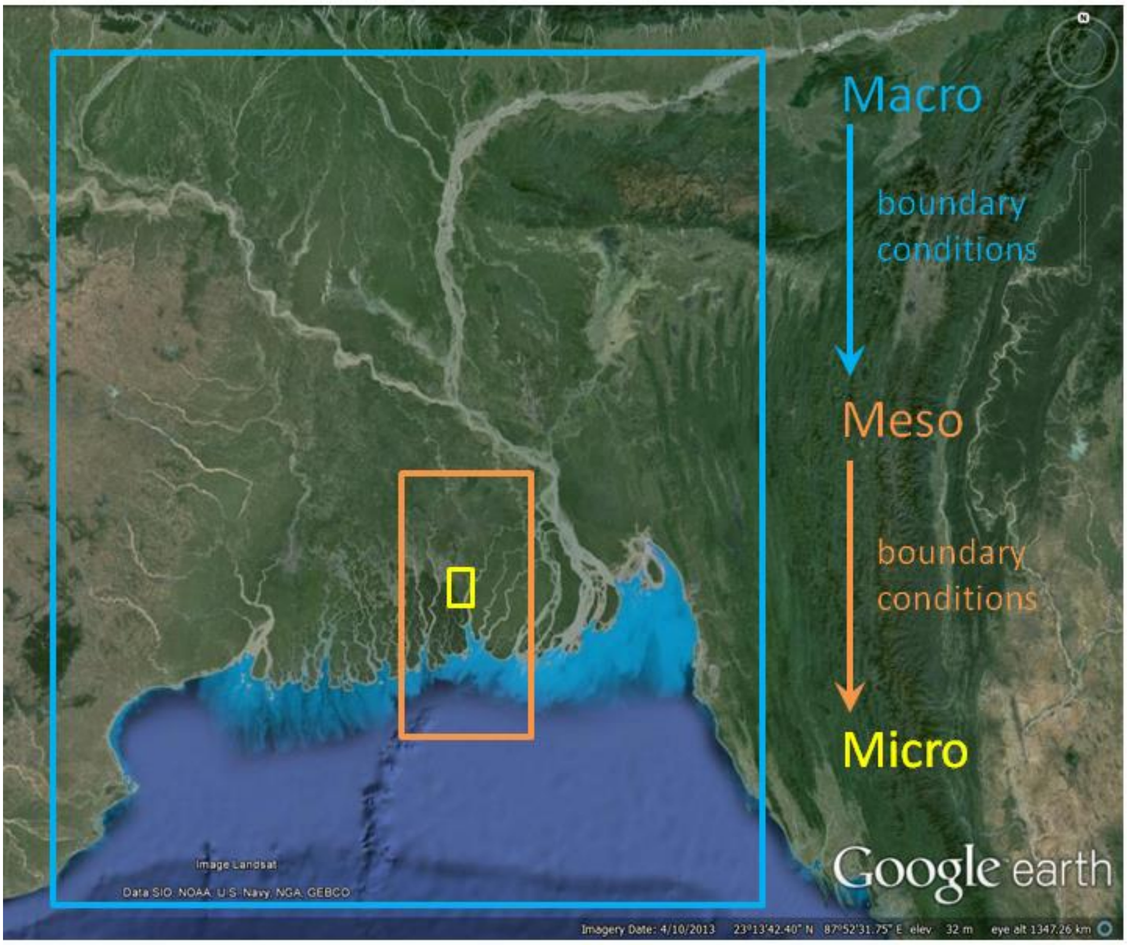


Figure 4.12: A model cascade starting from the larger system in blue and finally focussing on an individual polder in the yellow rectangle.

The cascade of models will consider three different spatial and temporal viz.:

- Macro-scale: sediment balance sheet GBM delta. This scale is necessary to get a good understanding on how the system functions as a whole, and to estimate the impact of climate change and anthropogenic works in a general context.
- Meso-scale: local river and estuary dynamics. This scale will highlight meandering and other dynamics of main estuarine branches and how they respond to major changes in tidal volumes, translating the macro scale findings into relevant impacts on local polder level.
- Micro-scale: water-logging and polder management. This scale is necessary to provide a detailed and local reference of (future) boundary conditions for dedicated polder design and management. While polder drainage can be addressed individually polder by polder,

This multi-scale modelling approach allows a low-resolution, macro-scale model to supply boundary conditions for higher resolution, meso-scale models on the scale of an individual river or groups of rivers, in its turn providing boundary conditions for highest-resolution, micro-scale models on a polder level. From macro to micro, spatial resolution will be increased and model process descriptions will become more specific allowing for a more detailed model analysis. Table 4.4 represents the Multiple Application of Different Model Scales.

The boundaries of the meso-scale models could overlap with the downstream section in the macro scale model depending on the phenomena being investigated and the boundary conditions that have to be supplied to the different microscale models being used for different purposes.

Table 4.4 The Multiple Application of Different Model Scales

Scale	Coverage	Application
Macro	Whole GBM Basin Major Rivers in Bangladesh	Long Term Sediment Balance Sediment Redistribution
Meso	Variable including overlap with Macro scale, several models (3D,2D and 1D)	River morphology and stability, meandering and bank erosion, tide and wave propagation, storm surge dynamics, long term and medium term
Micro	Individual Polders, interconnected polders and peripheral rivers	Polder flooding and drainage, water logging, water quality, tidal river management, sediment management, salinity control, bank erosion, and tidal dynamics

The macro-scale modelling will focus on 1) predicting changes to sediment input and water flows from the basin; and 2) understanding of the sediment dynamics of the GBM delta.

The impact of proposed major hydro power and irrigation projects – particularly in the Brahmaputra Basin outside Bangladesh, but also the Indian River Interlinkage project cannot be ignored. There are several large, steep tributaries carrying relatively high flows and sediment loads feeding the Brahmaputra River in Assam. All these tributaries have proposals for power stations generating thousands of megawatts – already under consideration. The impact of flow regulation and the trapping of coarse sediment might take a long time (>50 years) to propagate into the delta. The trapping of finer sediments (wash load) could affect the balance of the finer fractions that participate in the processes within the coastal zone. This latter impact could be felt within one year in the meso-scale morphological processes.

This task will include long-term modelling (time scale up to 100 years from present) to describe changes in sediment transport patterns and morphology, including changes in water and sediment supplies. The model needs calibration by hydrodynamic parameters (river flow, water level), suspended sediment concentration and bed level changes throughout the GBM delta. Based on this validated model we will include morphodynamic development applying morphological acceleration techniques to limit computational time (e.g., morphological factor, morphological hydrograph and morphological tide). We will use the process-model, with the topographic and bathymetric constraints to model multiple scenarios including sea level rise, subsidence, varying landward sediment supply and river flow, as well as polder construction scenarios and major hydro power projects.

The meso-scale modelling will focus on the understanding of the dynamics of the river branches and estuaries in the coastal zone of the GBM delta, channel switching and bank erosion both in the fluvial-dominated parts of the delta as well as in the tidally-influenced river delta. This assessment should also account for future changes (time scales of 25, 50 and 100 years from present). The macro-scale will be used to derive appropriate boundary conditions for the meso-scale modelling. The output from these models should provide useful information for polder management (i.e., modelling drainage and irrigation inside the polders, and external threats such as wave attack and river bank erosion).

Unexpectedly high levels of bank erosion have already been encountered in the execution CEIP-1. This matter was highlighted in the recently held Inception Workshop and therefore it is proposed that a special Meso-Scale study of “Bank Erosion Hindcasting” is undertaken to analyse the bank erosion processes that have taken place in the large tidal estuaries in the last 20 or more years in areas already been subject to in which large and often intensive data collection programmes have been mounted for various projects. Improved guidelines for predicting medium term bank erosion will emerge from this study.

The analysis at meso-scale will also be used as input for the micro-scale modelling and analysis. The objective will be the understanding of waterlogging in the polder and tidal river systems. This will inform the development of measures to reduce waterlogging and the restoration of natural sedimentation processes within polder areas adjacent to tidal rivers. The present practice of tidal river management by BWDB for drainage and sediment management will be reviewed and improved for allowing sediment in the polders for counteracting the subsidence and sea level rise as well as to restore the tidal prism in the rivers for proper drainage conveyance.

The cascade of models where one level of models takes boundary conditions from the next level would ideally require that first the macro-scale modelling would have to be carried out, then meso-scale and finally micro-scale modelling. However, with the rather compressed implementation schedule (the project was originally designed with a 54 months implementation period and is now 30 months) this is not possible, hence preliminary boundary conditions will have to be used for the meso- scale model development and as better information become available the model simulations will have to be updated.(e.g. GBM Basin model) and meso-scale (e.g. Bay of Bengal and South-West Regional Model) will be used to generate the preliminary boundary conditions. Micro-scale models analysing polder drainage will proceed directly using the South West Region model.

4.3.2 Morphology (Component 4-A)

The predicting morphological change in the three scales Macro, Meso and Micro – require differing modelling approaches on different spatial and temporal scales. Tracking these changes requires that we have a full understanding of sediment sources, their composition, their mode of transport in relation to flow regime and their re-distribution in the fluvial system. The fact that the interface between the flow and the riverbed and banks are also sources and/or sinks of sediments affecting the overall sediment balance complicates our ability to predict morphological change. The multi-scale approach discussed above makes it possible to find a way through this maze of complexity in our approach to the problem.

The basis for this approach is explained in the previous section. Further descriptions are given in Appendix A.

Land Reclamation

Land accretion and erosion in the Meghna Estuary and adjacent areas are continuous and gradual natural process. The annual sediment transport to the Bay of Bengal has been estimated to be about 1.1 billion tons through the Lower Meghna River. At present 9.0km² land rises each year in the Meghna Estuary due to natural accretion. Bangladesh is a land hungry country. It is a proven truth that an engineering intervention is required in order to accelerate the rate of land accretion

There have been a large number of studies about the Meghna Estuary, studying the potential of land reclamation from the sea and use them mainly for agricultural purposes. The success of the two existing cross dams has encouraged the government to construct new cross dam(s)in this area. The Meghna Estuary Study (MES), the Estuary Development Program (EDP) and the Land Reclamation Project (LRP) were carried out to assess the potential for additional land reclamation in the Meghna Estuary. Based on the LRP and the MES findings, the BWDB Task Force made a priority list of 19 potential cross dam sites with the objective to accelerate the natural processes of land accretion. The EDP study recommended three potential cross dam sites at the Sandwip-Urir Char-Noakhali zone. Among them, the cross dam connecting Urir Char and Noakhali main is to be taken up first. Bangladesh Delta Plan 2100 also emphasized the need of land reclamation and outlined a framework for land reclamation.

The subject of land reclamation is outside the scope of the present Terms of Reference. However, the Project Director of CEIP-1, Mr. Habibur Rahman emphasized the need for studies that would support the land reclamation plans of the Government, during an interaction meeting with the consultant. Given tools being developed and deployed by the Consultant in this study, it would not be difficult to include the morphological and drainage studies necessary within a technical investigation for preparing a land reclamation plan for such a project. The main objective of such a technical study, although it is not an explicit part of the present study, would be to support Bangladesh Water Development Board (BWDB) with the preparation of a cross dam project.

While this is a logical extension of the skills and capabilities being developed in the present project, additional resources would need to be sought if this major task is to be added on to the current work plan. Such a study would involve desk studies, surveys and field investigations, technical and model studies, feasibility studies, detailed designs and environmental and social impact studies. followed by monitoring and evaluation.

4.3.3 Subsidence (Component 4-B)

Subsidence affects all deltas worldwide. It originates from a wide variety of processes including lithospheric cooling, faulting, isostatic loading by tectonic motions and the weight of the sediments, compaction and dewatering of sediments, and oxidation of organic matter (e.g., Steckler et al., 1988). Subsidence lowers the elevation of the land and thus constitutes a risk for sustainability of polders over time. Different processes act over different time frames; while some processes such as lithospheric cooling act over millions of years, others such as sediment dewatering will react to changes in sedimentation rates over times of years to decades. It is thus critically important to understand the rates of the different components in order to predict patterns of subsidence rates over 25, 50 and 100 year periods. Furthermore, it is critical to evaluate the net effects of the combination of subsidence, sea level rise, sedimentation (including lateral migration of rivers) on polders to evaluate their sustainability and potential for elevation and land loss or gain

In order to understand the rate and distribution of subsidence across the study area, we propose several different types of measurements. For the long-term rates, we propose to drill and analysis samples from tube wells that focus on subsidence rates and environmental changes in the study area. For short-term direct measurements, we will employ a combination of GPS measurements, surface elevation tables – marker horizons (SET-MH) and Interferometric synthetic aperture radar (InSAR). We will co-locate GPS and SET-MH systems so that the data can then be used to separate shallow compaction from deeper components of subsidence. These detailed point measurements will be supplemented with InSAR, which provides lower resolution measurements with broad spatial coverage, and a campaign GPS survey. The latter will reoccupy benchmarks installed by the SoB and JICA in 2002-2003. These ~60 sites will provide a regional view of subsidence over the last 16 years.

The basis for this approach and further descriptions of the field plans are explained in more detail in Appendix A.

4.3.4 Meteorology (Component 4-C)

In order to assess the development of the entire delta as a basis to derive new conceptual designs for sustainable polders, it is crucial to have a good understanding of current and future trends in meteorological conditions. Additionally, the development of socio-economic activities inside the polders, are strictly dependent on these conditions. As an example, it has repeatedly been reported that rainfall figures are changing, such as more "erratic" rainfall and a possible shift from four to three seasons (monsoon and post monsoon are more or less one) as the monsoon period is delayed but lengthened. These changes have a direct impact on the development of agriculture production in the polders.

The objectives of this component are to 1) Identify current trends in rainfall, temperature, in Bangladesh and in the different zones of the coastal area and in cyclone frequency and intensity, 2) Estimate future changes in rainfall, temperature and cyclone frequency & intensity considering climate change.

As part of this task, statistical analysis of past observation for different meteorological parameters will be carried out. Additionally, the use of Global Circulation Models (GCM) will be used to extrapolate these observations towards the future.

The output from this Activity will serve as Input to Component 4A (“Morphology on Macro-, Meso- and Microscale”), 5A (“Programme for Polder Reconstruction in Different Coastal Zones”), and 6.1 (“Updating Design Parameters and Specifications for Construction Works”). More details on the analysis carried out under this component are provided in Appendix A.

4.3.5 Effect of Climate Change on Water Levels, Salinity and Storm Surge (Component 4-D)

The potential impacts of climate change on coastal regions include progressive inundation from the combined effect of precipitation increase and sea level rise, overtopping and damages of polders due to increased height of cyclonic storm surge and wind waves, loss of wetlands, and increased salinity from saltwater intrusion. Sea level rise and changes in river discharges is likely to cause the extent of the tidal zone and the salinity intrusion to extend landward compared with the present condition. In times of climate change higher tidal water levels in the river and more rainfall runoff in the polder will decrease the opportunity to drain water from the polders to the rivers through regulators under gravity.

Therefore, it is important to quantify the change in water levels due to climate change.

The salinity distribution in the estuary is a balance between saline water arriving with the incoming tide and the freshwater flow from the river system upstream. Already today saline intrusion is exacerbated by reduced dry season flow in some of the important distributaries of the Ganges River. Sea level rise and changing river flows caused by climate change and continued development in the catchment are likely to increase this problem. On the other hand, the implementation of the Ganges Barrage Project would have the opposite effect.

In the Bay of Bengal, the tidal current has a typical speed of 1-2m/s, which creates a nearly constant and very high production of turbulent kinetic energy close to the sea bed. This is the most important reason for the well-mixed salinity conditions in the estuary. The yearly variation in the river discharges creates a yearly variation in the horizontal salinity distribution in the Bay of Bengal. In the inner part of the bay the salinity typically varies from below 5 per mil in August to 20 per mil in March-April. The salinity in the central part of the Bay of Bengal remains around 34 per mil. With the well mixed conditions in the bay the salinity distribution can be modelled with a depth integrated two-dimensional model (as shown in Figure 4.13).

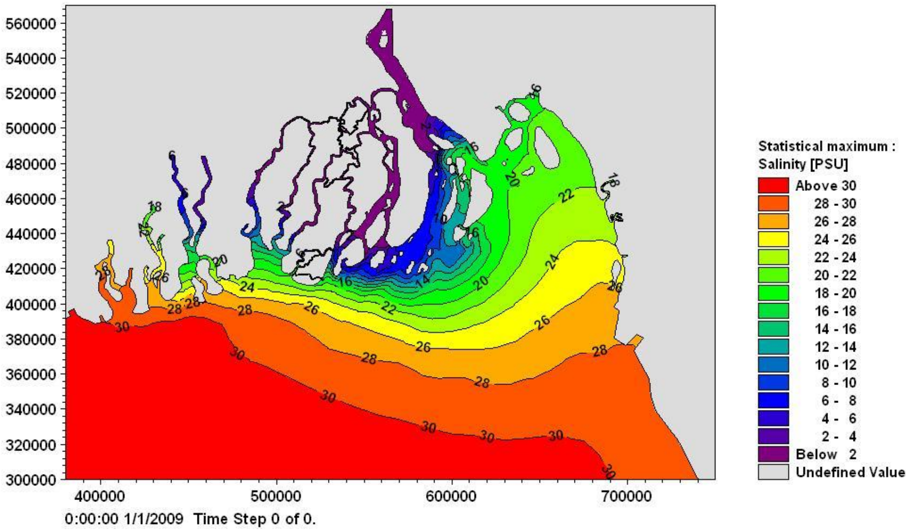


Figure 4.13: Simulated salinity distribution in the Bay of Bengal.

The objectives of Component 4-D are the following:

- To have an overview of extreme water levels due to storm surges and cyclones
- To have an overview of tidal water levels and salinity in the river, estuary and groundwater system in the coastal zone at present and in the future
- To devise scenarios and strategies to optimize salinity levels in the coastal zone

The objectives will be reached through modelling using the numerical hydraulic models developed under the previous phase of the CEIP-I project as well as other models available to the Consultant and further developed as part of this project.

The following models have been developed and are operational at IWM:

- The South West Region Model (SWRM) using two separate modules of the MIKE 11 modelling system: rainfall-runoff modelling (MIKE11-NAM) and hydrodynamic modelling (MIKE11-HD)
- The Bay of Bengal model (BoB) using the two-dimensional hydrodynamic model MIKE21 FM
- The South West Regional Salinity Model, which is based on the advection-dispersion (AD) module of MIKE11 that is coupled with the hydrodynamic (HD) module
- A wind generation tool which can calculate wind and pressure fields on the basis of cyclone data

Impacts of climate change on the open model boundary conditions in the form of sea level rise and discharge levels will be estimated and the models will be used to predict future changes in tides, surges and salinity distribution. Meteorology, describing changes in cyclone frequency and intensity due to climate change, will be used as forcing to the hydraulic modelling.

5 A Programme for Polder Reconstruction in Different Coastal Zones

5.1 A phased programme for reconstruction in different zones (5-A)

The purpose of this research study is to use the knowledge and understanding reached by previous projects, and the additional knowledge in and understanding reached through the research and monitoring study, to create better and more sustainable polder systems. The most relevant project would be the CEIP-1 project which is currently rehabilitating and strengthening 17 polders mainly in the southwestern zone. These 17 polders are distributed over an area that is spread over a range of environmental zones (except the Chittagong Coastal Plain) requiring different management strategies.

The objective of the CEIP is to “Improve” all 122 remaining polders, in a phased programme, based on the application of design concepts developed during this study and design of the 17-polder programme. The optimal polder concepts will depend on many criteria such as the conditions in the peripheral rivers, the land use and drainage system within the polders, exposure to storm surges and waves and the socio-economic conditions of the polder population. The design of a polder entails not only the physical design of facilities but also rules for operation and management of the gates, and maintenance of the drainage system and the embankment.

Activities

a) Make an inventory of the present situation in 139 polders in general and details of 17 polders under CEIP-I with regards to; land use, population, economic activities, social organization, infrastructure, functioning of flood protection and water management system

b) List the boundary conditions for each polder, based on available data and outcomes of the research of Component 4A to 4D, including influence of climate change

c) Make a match between the promising polder options from the Inception phase and the outcomes of activity 1 and 2. Where necessary, the work on the polder concepts of the Inception phase is extended to come to realistic options

d) Establish designs for 3 to 5 polders as a pilot program considering climate change, subsidence, possible land heights, land use, economic activities, infrastructure needed for water management and water management policy, drinking water facilities (especially in salt water conditions) for long term stability.

e) Development of new and additional polders as may be considered necessary. If found beneficial, hydraulically, some polders may be lumped together to create a bigger polder;

f) Make a cost estimate for the redesign of the polders and estimate the benefits and beneficiaries in the new situation

Deliverables

a) Technical Report on Long-term Polder Improvement measures and Polder Development Plan

b) Conceptual design of polder improvement measures of 17 polders under CEIP-I with consideration of existing improvements with a description of; opportunities for livelihood, spatial planning, water management and operation, subsidence, raising of low-lying area and future climate change scenarios.

c) Report for each of the 3-5 polders with a description of;

- Present situation
- Boundary conditions (scenarios)
- Matching with polder options
- Establish conceptual design, including management plan
- Costs and benefits

5.2 Coherence and Overview of the Entire Delta (5-B)

5.2.1 Objectives

The main objective of this component is to summarize the main findings of the study with the aim to explore possibilities to optimize the system (with respect to economical, physical and societal aspects and possibly by large scale interventions) and define research efforts in support of reaching the optimization.

This can be subdivided into three separate objectives:

- Obtain an overall picture of the delta dynamics in the future;
- Obtain a picture of (the need for) possible large-scale interventions in the coastal zone of the delta to reach optimal living conditions;
- Improve knowledge on the effects of physical processes and the interactions between them and obtain an indication where more research is wanted.

5.2.2 Context

In achieving these objectives we will consider the relevant and significant projects which are already under way. These projects include

- The Payra Port project, and the related transport infrastructure of highways and railways, and Padma Bridge;
- Ganges Barrage, a high priority project under the current five-year plan and essential for improved water resources management of south west region;
- The BLUE GOLD Project, for internal management of 26 polders towards becoming viable units of production;
- Bangladesh Delta Plan 2100, which deals with 19 themes including coastal zone and coastal polders;
- Multi-hazard modelling and mapping, another project of Department of Disaster Management (DDM) which is nearly complete;
- Brahmaputra barrage, also an important future project for water resources management in the basin and coastal area of Bangladesh;
- Water Management Knowledge and Innovation Program that is three-year program focusing on various innovations in managing polders in southern coastal region of Bangladesh.

The work of this component has major relevance to every one of the related projects listed above. The choices made within this component will also be influenced by having an intimate knowledge of the experiences of these related projects. This is most important in scenario development. It is therefore necessary that we establish and maintain close interactive links with these projects from the very inception of the project. We will need to communicate with these projects concerning their progress and ours. Relevant results from their and our projects will be exchanged as soon as possible. Within our project we will interact with the other components (and their (key) experts) already in an early stage of the project to create awareness of this (quite conclusive) component and to prioritize scenario development in favour of this component. We need to build on knowledge acquired by other components of the projects, and the choices we are going to make can have influence on the other components.

5.2.3 Activities

a) Describe the interdependencies and mutual effects in detail, also based on the outcome of the studies in Component 2 (Detailed Literature Review and its Summary of Lessons Learnt), Component 3 (Development of input datasets for modelling the physical processes) and Component 4 (Modelling of the Long-Term Physical Processes in the Coastal Zone of Bangladesh).

In consultation with national and international experts we will explore and make inventories on possible interdependencies between economical, physical and societal aspects on macro, meso and micro level in the early stage of the project. Preferably, this will result in a matrix of economical, physical and societal indicators pointing to relationships between these. We will seek support from Bangladesh societal bodies for this matrix. This matrix will be used as basis for activity 2.

An important issue here is the relation between the socio-economical system and the physical system, see Figure 5.1for a first impression. Note that the physical system is divided into two parts: the outside part which cannot be influenced by interferences within the delta and the delta part which interacts with the socio-economical system within the delta.

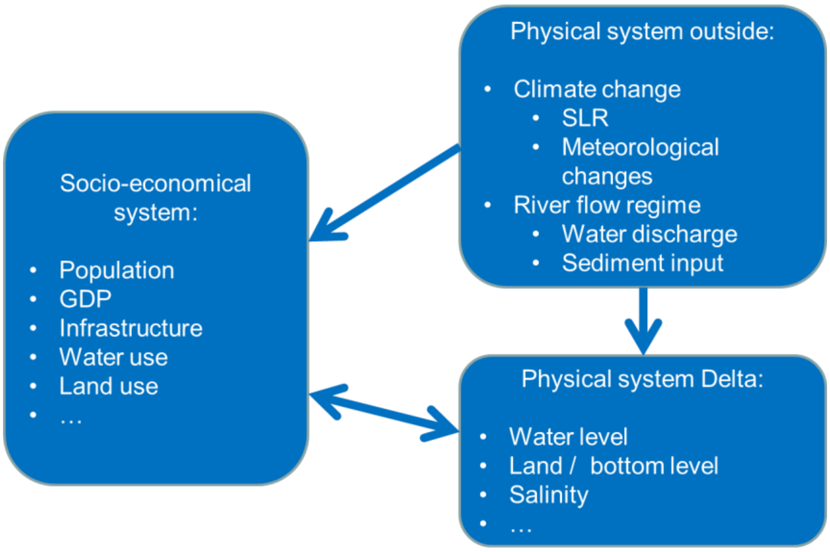


Figure 5.1 This is an indication of the relation between the socio-economical and physical systems. Each of the boxes will need to be completed and specified, and the interdependencies & mutual effects between the elements in the three boxes will be described in detail in this activity.

b) Quantify these for the future (the same 25, 50 and 100 year horizons to be used but more as a framework than as exact figure) and indicate possible consequences for the boundary conditions for the polders (water levels, salinity, erosion and sedimentation patterns, subsidence, etc.)

Based on the (economical, physical and societal) indicator matrix derived under activity 1 we will substantiate indicator relationships for the different scenarios and address qualitatively the consequences for the polder boundary conditions. Use will be made of the results from Components 3 and 4 to project the future developments for the various scenarios. Note that the outcome of activity 3 described below will need to be considered.

c) Based on the results of activity 2, component 5A (polder design) and the possibilities to influence the salinity situation in the delta (activity 4 in component 4D), investigate the need or desirability of large scale changes in the coastal zone (river diversions, damming river mouths, etc.).

The analysis described under activities 1 and 2 will point to critical (economical, physical and societal) indicator relationships for different scenarios. The product is a 'visual' explicitly addressing bottleneck of the system. We will qualitatively describe potential large-scale interventions to mitigate and optimize the system based on a workshop with (key) experts and national stakeholder during the final phases of the project. In addition, we will explore knowledge gaps and research needs required to address potential solutions adequately.

Given the ample fluvial supply of water and sediment to the delta, many of the problems in the delta (flooding, erosion, siltation, water logging, salinity intrusion, and drought & water scarcity) can potentially be solved by improving the distribution of water and sediment in space and time. The presence of many estuaries (outlets to the sea) seems to provide opportunities for redistributing the fresh water and sediment from the rivers spatially within the delta. However, the low-lying and flat land limits the possibilities of redistributing water temporally by measures within the delta, although the proposal for the Ganges Barrage is still under consideration.

6 Design Parameters, Construction & Management Practices and Monitoring

6.1 Updating Design Parameters and Specifications for Construction Works

Using the current design manual of the BWDB as a starting point, recommendations will be made for improvements and expansion of the manual into additional areas. However, as suggested in the following paragraphs the recommendations will mainly focus on the planning, monitoring and operational approach.

When examining the failure of dykes and embankment, the causes determined would more likely point to failures of planning and quality control during construction, rather than in the actual design process. When structures are designed for a pre-determined return period, a very occasional exceedance of the design condition could lead to failure. Very often the very long time it takes for a breached polder to be brought back to full productivity points to a lack of preparedness, both operationally and in the original planning of the design. Failure of river bank monitoring and the inability to take emergency protective measures have resulted in many disasters. Thus, it is important to evaluate failures holistically with their relationship to planning strategies, monitoring and management issues. Such an approach would lead to a more effective method of improving the safety of designs.

While the research carried out by this project will provide more accurate evaluation of design parameters, the structures being designed have to face continual changes in the natural environment arising from climate change and other natural phenomena such as subsidence. The designs adopted at any particular time would necessarily have to trade off the additional cost of a long design life against savings made if one uses a short time horizon. The trajectory of climate change effects is not entirely predictable depending on international agreements on climate change. Thus, there is case to be made for innovative approaches that create adaptable designs that can be enhanced if and when necessary. This type of thinking requires the evolution of environmental changes is continuously monitored the longer-term predictions are regularly updated.

The process of updating design parameters should not only depend on the in-house expertise within the consultancy team and in the BWDB, but also make use of the experience and expertise found in sister projects in the Coastal Zone such as the Coast Embankment Improvement Project, The Delta Plan, and others. It is proposed that a varied team of professional drawn from the major government agencies and the construction and consultancy sectors are invited to volunteer their services to participate in this evaluation

6.2 Approaches for Management of Polders with Stakeholder and Beneficiary Participation

6.2.1 Objectives

The goal of this component is to develop a Participatory Polder Management Model (PPMM) for Bangladesh. With a range of interests (such as agriculture, fishery, aquaculture, flood, tidal protection and so on) in the polders, this model aims to address them for the optimum benefit of all. This can be achieved only through active participation of different stakeholders and beneficiaries.

6.2.2 Context

One of the major causes of failure of dykes in the polders in Bangladesh have been identified as lack of maintenance or poor maintenance. Insufficient or non-existent institutional mechanisms for maintenance and management of embankments and associated structures are one of the major reasons for this. Part of the cause elevating this is lack of active engagement from local stakeholders and beneficiaries. The projects such as Integrated Planning for Sustainable Water Management (IPSWAM), Blue Gold, community centred interventions in the Char Development Settlement Project (CDSP), and Water Management Knowledge and Innovation Program have already implemented participatory management models. PPMM will build upon the lessons learnt and best practices from these examples and other related fields for sustainable polder management.

6.2.3 Activities

To develop the PPMM, our approach will be carried out in three phases: i) analysis of the historic and current management situation; ii) development of a participatory management model and iii) initial testing for participatory polder management model.

a) Analysis phase

Within this phase, both the best practices and lessons learnt from past experiences of embankment management (and failure) will be analysed. This will be done through literature review and interviewing key informants. To further understand the local condition, Focus group discussions (FGDs) and meetings will be organized in the polder areas to obtain primary field data and to engage the stakeholders from the start. The objectives of these FGDs and meeting will be i) to understand the reasons of failure of participation of local stakeholders and beneficiaries in polder management in the past ii) identify key factors that can enhance their engagement and iii) understand their vision for an ideal participatory polder management model. We will use MOTA-model (Motivations to act or not to act, Opportunities and Threats and Ability to act) (Ho Long, 2013) for understanding the reasons for non-participatory behaviour of actors to find the key factors of change.

b) Participatory Polder Management Model Development

Based on the results from the analysis phase, participatory polder management model development will be initiated. From component 4, insight of long-term physical processes will also be vital input for this model since it will give better understanding of the impacts of physical evolvement of delta on the economic and societal aspects of the polder. In addition, the analysis of the effects of climate change on different processes in delta (component 4D) and overview of future scenarios will be crucial to integrate in PPMM; because this will make the model more robust and applicable for the gradually changing polders.

The results from Component 5 (finalization of approach for reconstruction of the polder) and 6.2 will be fed into one another, so that the new concepts of polder design are more participatory. We will also analyse the roles of stakeholders and beneficiaries in sustainable investment plan for the polder management. For this, we will share ideas and outcomes with component 7.

Following are some of the considerations we will draw on for the development of PPMM:

It will be aligned with the Bangladesh Delta Plan 2100 (BDP2100) that emphasizes on integrated delta management;

The roles of local level authorities and groups such as water management associations and water management groups in polder management will be highlighted. For example in participatory monitoring, polder asset management, influencing decision making and decision making;

Horizontal learning where the stakeholders from one polder can share their experiences regarding the participatory polder management with the stakeholders of another polder will be stressed. This will facilitate that the polders can benefit from the lessons learnt and best practices from one another than through top to bottom approach;

The interest of the stakeholders and beneficiaries in different polders range from increase in crop production and agricultural growth, protection from flooding, storm surge, fisheries, and aquaculture and so on. Given these differences, this model will be integrated but generic; so that with limited modifications, the model can be applied to other polders in the coastal region of Bangladesh.

The indicators for monitoring and evaluation framework for the model will also be identified in this phase. These indicators will be identified and/or checked with the stakeholders. PPMM will emphasize on engagement of local stakeholders and beneficiaries in both design of the model itself and its implementation. We will organize workshops with stakeholders and beneficiaries to discuss and evaluate alternative model concepts in order to arrive at a feasible and sustainable PPMM.

c) Initial Testing Participatory Polder Management

Once the PPMM is developed, the model will be piloted in a selected polder during the project duration. A list of selection criteria will be developed for selecting the pilot polder. This selection will be done in close consultation with the BWDB and relevant stakeholders. Piloting the model will give an initial understanding on the feasibility of the model. After the pilot phase, the model will be monitored and evaluated using the identified indicators. Based on the experiences and outcomes during the pilot case, we might identify further needs for improvements in the model. These lessons learnt will be used to further refine the model that can be used for upscaling in other polders.

This component will follow the workplan given below:

Activities	Month																										
List of activities by phase	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Analysis phase																											
Literature review on the historic polder management	▨	▨						🟥																			
Stakeholder consultation (FGD)				▨																							
Participatory polder management model development																											
Development of the model						▨	▨	▨	▨	▨																	
Consultation with the stakeholders									▨		▨																
Refining of the model																						▨	▨	▨	▨	▨	
Finalisation of the model																											🟥
Final report on Participatory polder management model																											🟥
Pilot testing for participatry polder management model																											
Selection of the polder										▨	▨																
Consultation with local stakeholders in the polder Meeting, FGD												▨	▨	▨	▨	▨	▨	▨	▨								
Implementation of the model															▨	▨	▨	▨	▨								
Monitoring and evaluation																		▨	▨	▨	▨						

Figure 6.1 Workplan for Participatory Polder Management

6.3 Setting up a Performance Monitoring Mechanism (6.3)

Performance monitoring has to be a part of a formal structure to ensure that it is effective and reliable. The participatory monitoring group must be fully conversant with the overall goal of the development activity, in this case the construction of a sustainable polder, and be armed with a clear set of performance targets and indicators on which to base their responses. These targets and indicators will be developed in consultation with stakeholder groups from with the monitoring groups are selected. The targets developed for any polder or group of similar polders should be varied according to climatic, and environmental factors and land use practices.

Maintenance and routine operations are expected to be carried by beneficiaries either directly or through a mechanism at their cost. Records kept of his activity have also to be monitored.   In polders requiring major repair works or some re-modelling for better performance, the capital expenditure will have to be covered by the government. The performance monitoring mechanism will alert the concerned responsible authority to take necessary steps. An annual review will also assist the managers responsible for effective as well as smooth functioning of the polders.

Recent trends and changes in land use must, if found to be acceptable, be included in the goals and targets being set up. There may be separate goals, targets and indicators for each of the polders.

The setting up of the Performance Monitoring mechanism could be initiated as soon as soon as the participatory polder management model for each polder is finalised.

7 Investment Plan for the Entire CEIP

7.1 Economic assessment and investment plan

The main objective of the project is to devise a plan to re-build, in an orderly fashion, the remaining 122 polders not yet taken up under CEIP. The polders, being too many to be taken up at once, will have to be prioritised and taken up in phases. The construction of polders was primarily to make the land available for agriculture and habitation. Depending on its location with respect to the coastline and the major river upstream river system, the polders were initially designed to protect the land from river flooding and overtopping by storm surge. In addition, the impacts of the polder system on the tidal regime caused major siltation problems in some rivers progressively leading to drainage congestion and waterlogging. Next to these primary objectives the project aims to increase the agricultural production within the polders and to increase the knowledge of Bangladesh counterpart staff through capacity building.

This will result in a wide array of potential investments that will be proposed for implementation. In order to select the investments that will have the largest impact on the stated objectives, while meeting the criteria set by the different stakeholders, a process of evaluation is proposed in order to arrive at a preferred implementation strategy. The Participatory Polder Management Model (PPMM) as explained in chapter 6 will play an important role in this process to assess the objectives as set by the different stakeholders. It is possible that investments can have an opposing impact on objectives within certain specific geographical locations, while serving overall project goals.   This will also have a close connection to other relevant developments and (investment) plans (e.g. Bangladesh Delta Plan 2100, Blue Gold, Water Management Knowledge and Innovation Program, Payra Port Project, etc.).

The specific objective of component 7 “Investment Plan for the entire CEIP” is to develop a programmatic investment plan to sustainably improve the resilience of communities in 139 polders. To this end the project has developed the following activities;

a) Develop a macro-level multi-phased investment plan for the construction for the selected polder improvement measures based on priorities agreed with the client

b) Develop an investment plan for long term management of the polders and their effective operation

c) Develop a plan for potential financing and technical collaboration with the international community

In order to be able to draft this investment plan, the project should develop efficient and effective measures and arrive at an overall cost efficient strategy. In order to achieve this the investments proposed during the design process will be evaluated according to the steps as outlined in Figure 7.1.

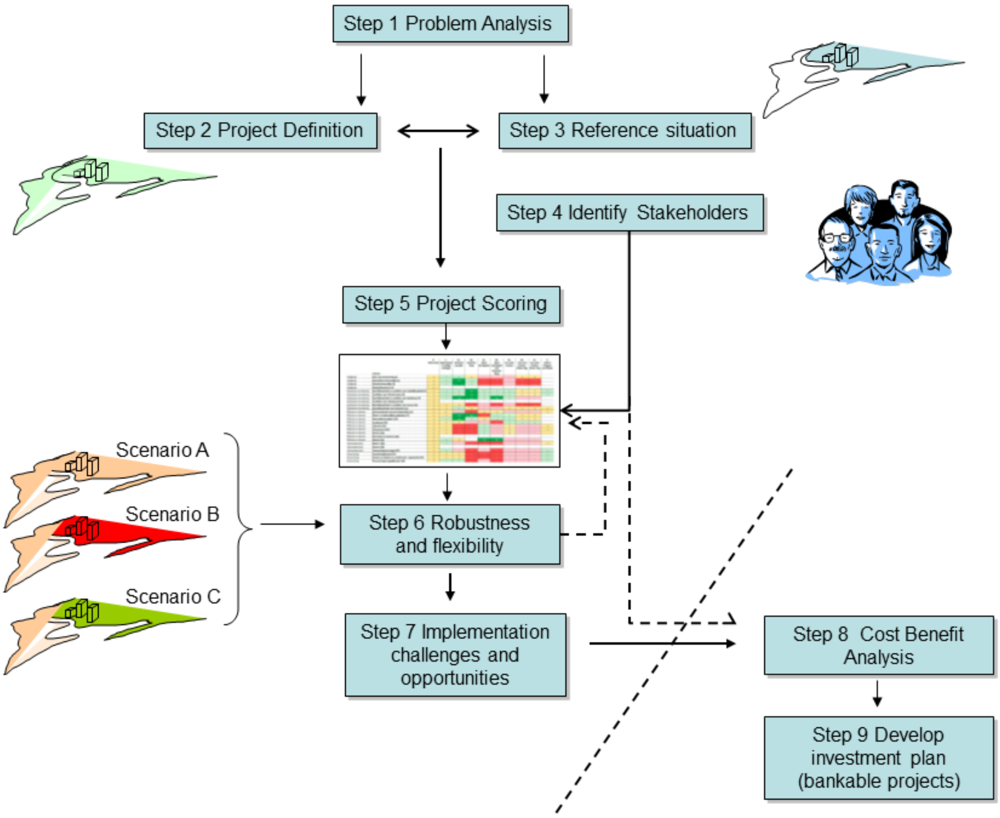


Figure 7.1 Steps to arrive at a viable implementation and fundraising plan

In this economic evaluation process these outlined steps should be followed in order to have a clear understanding of the project objectives, stakeholder preferences and possible external developments (e.g. climate change, land use alternatives, socio-economic developments) to assess the economic performance under different external condition. Only when insight is gained in the different specific measures and project alternatives, the economic rationale of the overall implementation strategy can be demonstrated. The economic evaluation will include a sensitivity analysis that will test the robustness and flexibility of the proposed measures under different external scenarios, as well as insight into the distributional effects of the different (economic) benefits from the project to the different stakeholders. Furthermore, possible (indirect) impacts of the investments will be assessed, e.g. Possible positive effects related to an optimal sediment management/use on agriculture and life quality within the polders.

These proposed steps are necessary in order to arrive at a plan that outlines an implementation strategy that is economically viable and supported by all stakeholders. Furthermore, it should present the separate projects of the overall policy as bankable projects, including a prioritisation of the different projects over time in an overall investment plan, while safeguarding equitable distribution of project benefits over the different stakeholders.

Chapter 9.1 of this report describes a number of workshops used for stakeholder consultations to be conducted during the project. The last 5 workshops (Nos 7 to 11) These workshops support the selection of final polder groupings and implementation programme.

7.2 Timing

In order to arrive at an investment plan that will meet an adequate level of economic return, while meeting a wide array of stakeholder preferences, it is important that the stakeholder preferences and economic rationale of potential measures are evaluated from the onset of the design process. In Table 7.1 a listing of possible evaluation tools for different stages in the design process is presented. Next to the different economic evaluations, it is important to keep stakeholders involved (e.g. through MCA) in the design process of the policy alternatives, in order to attain commitment from the stakeholders and achieve sustainability of the policy.

Table 7.1: Appropriate economic evaluation tools for different stage in project design

Planning stage	Short description, level of detail of design	Appropriate economic tools
Project assessment, project objectives	Quantification of (economic) challenges and opportunities, first idea of which type of measures could be suggested within the project.	Assessment of autonomous developments, definition of reference situation/scenario
Measures, design building blocks	First assessment of efficiency of measures/building blocks on policy objective and possible co-benefits. First indication of costs. First assessment of relevant stakeholders for measures	Life Cycle Costs (LCC) of measures. Cost Effectiveness Analysis (CEA), based on effect on policy objective(s). Multi Criteria Analysis (MCA), to take into consideration stakeholder preferences.
Preliminary design	Combination of building block/measures into preliminary project alternatives or strategies, through combining measures with high CEA or important co-benefits.	“quick-scan” CBA, or CBA on general benefits transfer principles (e.g. not considering specific local context like actual demand or local market prices), MCA to check alternative implementation policies against stakeholder preferences.
Draft design	Based on quick-scan CBA definition of project alternatives that meet policy objectives and achieve varying levels of co-benefits. Selection of preferred implementation alternative.	CBA, either economic, financial or both. Based on location specific data and a detailed cost calculation. Possibly including financing arrangements, including the identification of stakeholders receiving benefits or paying costs. Could draft a Business Case (BC) to identify financial gains for stakeholders. Will result in a preferred alternative based on policy preferences, and (possibly) economic evaluation, which will be selected to be developed into a detailed design.
Detailed design	Design that will be used to implement the project	Detailed cost calculation. Financing arrangements. Normally no further economic assessment will take place.

Although the economic analysis will focus on the steps 3, 5, 6, 8 and 9, involvement in all the design steps is necessary in order to assess economic impact of design alternatives and illustrate possible economic implementation, trade-offs, challenges and opportunities resulting from different implementation scenarios and external developments and distributional effects for the different stakeholders. Step 8, cost benefit analysis, is an important step, as the design of bankable projects is a prerequisite for the overall investment plan. Although the steps are presented as a linear process, several iterative loops can be required based on project development in which changes in project layout can result in significant changes in costs and/or achievements, which in turn can influence (socio-)economic performance. Without a CBA with a significant positive score, it will be difficult to get a project funded, implemented and operated sustainably. It is therefore essential that from the start design alternatives are assessed on their economic performance, in order to avoid needless design efforts in inadequately (economically) performing measures.

In the CBA an analysis will be made between the costs for interventions and the benefits from these interventions. The benefits of the proposed measures will be assessed against their achievement towards overall policy objectives. Costing of measures will be based on direct costs (investments, operation and maintenance and financing costs). Costs will be based on preliminary designs for the different measures and will be conducted based on typical costs for construction works and materials (e.g. steel, concrete, earth works, etc.).

A first preliminary project scoring of proposals for measures can be based on a preliminary CBA or a cost effectiveness analysis (CEA). A CEA will be used if monetary benefits for measures will be difficult to assess in the early stages of a proposal. In this case a CEA will be made on the basis of effect of the project towards the identified policy objectives like hectares of polder created or protected or land prepared for agriculture or human settlement. Later on in the process proposals will be subject to a more detailed CBA and the robustness and flexibility of the proposals under different scenarios, e.g. climate change scenarios or socio-economic development scenarios.

This activity will result in an investment plan describing a phased polder improvement roadmap and required budget. It will include a plan for long term management of the polders, including the expansion of monitoring systems, and the required maintenance and operations cost.

Develop a plan for fundraising and technical collaboration with the international community

As a final step all project will be incorporated into an overall investment and fundraising plan. In the plan the project will be bundled and characterised according to a set of criteria that will be agreed upon with the relevant stakeholders and institutions. This plan will be of adequate quality to serve as a basis for decision making by potential financers. For the validation of these proposals, collaboration will be sought with the international community and alignment with the strategies as set out in the Bangladesh Delta Plan 2100. The results of this activity will be incorporated in an execution plan including financing and fundraising strategies and plans, and a technical collaboration plan. There are many possible sources of funding including multilateral and bilateral donors and the Green Climate Fund.

Furthermore, as the contribution of this component to the objective of capacity building, all techniques that will be used during the project in the different stages will be explained and handed over to local experts and counterpart staff. Training sessions will be organised to explain the importance of different steps and methodology for data collection and analysis.

8 Action Plan for Capacity Building among Professionals and Stakeholders as appropriate to their respective Roles

8.1 Main Objectives and Approach

To build the capacity of the BWDB and related agencies/institute responsible for designing and managing the built as well as the natural environment in coastal zone of Bangladesh and strengthen the university level curriculum in water resources/coastal engineering and management.

The content below has been, in the main extracted from the Terms of Reference. The section on Sustainability has been added as the means of ensuring long term impact of the improved capacity.

8.2 On the Job Training

The Research Team shall provide training on the job for the technical and scientific counterpart staff on a regular basis, by carrying out the activities in the ToR in Bangladesh in cooperation with the counterpart staff or by giving specialized trainings. The training on the job will include – at minimum – the quality assurance / quality checking of data, the statistical analysis of trends in data, the development and calibration of new models, and the use of new techniques and analyses

Provide on the job training to technical and relevant government counterparts on a regular basis and conduct a number of specialized training courses. The training on the job will include but not limited to;

a) Feasibility study of alternative plans including mutli- criteria analysis

b) Quality assurance / quality checking of data

c) Statistical analysis of trends in data

d) Development and calibration of models

e) Design of polder improvements and the development of management plans

f) Development of investment plans and financing strategies

g) On the job technical training plan on each of the topics described above

h) Report detailing the results of the on-the-job training, list of participants and measure of success

On-the-job training requires that all professionals assigned to each of the tasks follow through as full-time participants in the process, from beginning to the evaluation of the success of the assignment. It is necessary that the government engineers who are usually assigned to the task are committed to a full-time engagement – usually lasting several months. During this assignment deficiencies, (if any) in their technical backgrounds, will be remedied the project scientific staff. Those showing special aptitude for the work should be chosen for further training overseas.

8.3 In-House Training Courses

In addition to the formal training courses being organised, the Research Team will organise one or two-day specialist training courses for the members of project team engaged in routine tasks in the project office. These courses will be conducted by individual members of the International Team on topics that would broaden the background knowledge of the counterpart staff. A list of topics will be selected and announced in advance during the year, to fit in with the timing of the individual expert's deployment in Bangladesh and will not entail additional cost to the project. A tentative list is given in Table 8.1 below.

Table 8.1 List of Possible Lecture Topics

Name Expert	Topic for Lecture or Seminar
Prof. Zheng Bing Wang	Long-term morphodynamic modelling for tidal regions
Dr. Bas van Maren	Impact of human interventions on estuarine fine sediment dynamics
Mr. Reinier Schrijvershof	Morphological modelling in D-Flow FM
Mr. Mark de Bel	Economic and Financial Cost-Benefit Analysis
Dr Mick van der Wegen	Estuarine morphodynamics under sea level rise : do we drown or not?
Dr Alessio Giardino	Multi-hazard risk assessment in view of climate change
Prof Dano Roelvink	Approaches to modelling coastal evolution in the context of global change
Ms Shristi Vaidya	Tools and methods for stakeholder engagement. Applications and examples
Dr Ferdinand Diermanse	Flood risk analysis in a changing climate
Dr Soren Tjerry	Morphological Modelling of Braided Rivers
Dr Steven Goodbred	Field Observations of Tidal Mass Transport and Channel Behavior on the Lower Bengal Delta
Dr Steven Goodbred	Holocene Evolution of the Bengal Delta - Lessons for the Modern
Dr Michael Steckler	Tectonics and Earthquake Hazard in Bangladesh
Dr Irina Overeem	Hydrotrend: Empirical Basin Model for Future Water & Sediment Fluxes (Half day Seminar)
Dr Bo Brahtz Christensen	Impact of Waves on Sediment Transport
Dr Kim Wium Olesen	Modelling Bed Topography on River Bends

8.4 Overseas Training

8.4.1 Formal Training Overseas

The overseas training budget allows for approximately 60 person-months of overseas training.

original budget a number of 20 participants was mentioned as a starting point. However, further detailed discussion of the practicalities of using the services of the trainees within the project, on their return to Bangladesh, 3 groups would go at different times to follow targeted courses.

Second, a ‘one size fits all’ approach might not be the best solution, as existing skill sets vary and so do the jobs the participants return to. A further detailing of the best combination of courses to provide will be after meeting with a number of BWDB staff eligible for this training.

Third, taking this approach one step further, it was realized that a good way to institutionalize the knowledge transfer from this project to BWDB would be to work towards a Dredging and Morphology Forecasting Centre, along the lines of the Flood Forecasting and Warning Centre, where BWDB staff could independently run simulations and provide the link between research (by IWM and other consultants) and BWDB practice. Staff to carry out such a mission would need to have more in-depth training and hands-on practice with the complex models, something that could be achieved through MSc studies that can be carried out within this project period and which contain a 6-month research phase that would be spent working with these models in the framework of the current Long-Term Monitoring and Research project. Each full MSc study would then be seen as an accumulation of 3 to 4 individual training programmes. Furthermore, the consensus in the meeting was that it would be best if approximately 4 months of the MSc research would be spent in the project office in Dhaka.

Conclusions

a) A differentiated approach is needed as it is difficult and undesirable to send one group of 20 staff to the same training

b) A promising option is to send two groups of 6-7 to separate trainings and 2 staff for full MSc programme, where 4 months of the research phase will be carried out in Dhaka

c) Participants of today’s meeting agree that it would be beneficial for the embedding of the knowledge transfer to work towards a Dredging and Morphology Prediction Centre along the lines of the Flood Forecasting and Warning Centre.

d) The Project Team will meet with the BWDB staff concerned this week, tentatively Wednesday 16/1, or early next week.

8.4.2 Study Tours Overseas

Expanding the horizons of senior BWDB Engineers and policy makers through overseas study tours and visits to similar agencies in foreign countries will be arranged from time to time.

8.5 Curriculum Development

It is intended that through collaboration with academic institutions and professional bodies, the curriculum in water resources/coastal engineering and management in Universities in Bangladesh will be strengthened to help develop a solid scientific cadre in the country

The Research Team shall organize International workshop on understanding the dynamical processes I,n the coastal zone of Bangladesh, including morphology, subsidence, meteorological changes due to climate change, salinity intrusion, water levels, and the effect on polder management and design

Teach the teacher: students at universities are the future members of the Bangladeshi water community. New and advanced techniques used in the execution of this ToR should be taught at universities. Develop new curriculum materials in cooperation with academic institutions and professional bodies

8.6 Long Term Sustainability and Institutional Setting

It is necessary to quote the following from the published project objectives related to capacity building:

The vision is also to expand the analytical capacity and data driven decision making into an "ecosystem" in which professionals cooperate, and exchange knowledge and information in a community of practice, using a common infrastructure, to be housed in BWDB and other organization would have access to data system. Starting with the researchers directly involved in the coastal area and the polders, the future extension will be to bring onboard the whole coastal belt and the Bangladesh water management community.

Beside geography and community involved, a third dimension in this movement is quality. With one of the most complicated deltas in the world, understanding and application of this knowledge is of paramount importance. Activities described in this ToR should be carried out in Bangladesh in cooperation with BWDB and related agencies ("training on the job"). Among the deliverables in the ToR, will be workshops and training as elements of capacity building and an explicit indication of future steps for further improvement.

These laudable objectives are usually difficult to attain within the administrative environment of a very large government agency. Training alone will not ensure that the new knowledge and technology that was absorbed through this project will become a part of the fabric of the institution.

The career objectives of an able officer working in the BWDB would be to do good work while aspiring to climb the promotional ladder within the mainstream of the organisation (Executive Engineer > Superintending Engineer > Chief Engineer > ADG > DG etc), following a promotional path that requires them to abandon, at some stage, the scientific career requiring special skills and duties.

It is necessary that some of the officers following the regular path in the organization should have had some experience of the special skills required for this work so that they can appreciate the necessity of having the benefit of these skills in the planning and design activities of the future. It is also necessary to ensure a rewarding career path for those who have the special aptitudes and skills to follow the research route.

Many institutions do not have a special scientific cadre, with their own career path, set aside for such individuals. In many countries (including Bangladesh, e.g. IWM) have resorted to creating new institutions to house such specialist individuals. There are pros and cons regarding the efficacy of such a model. This is not the time to debate the issue.

Let is just be said that it is necessary to create a specialist scientific cadre who will carry on the work on this project well into the future. It is also necessary that there is a healthy exchange of personnel between the elite scientific institution and the regular hierarchy to ensure mutual confidence in the conclusions drawn by their studies.

8.7 Action Plan

The most effective method of capacity building will the on-the-job training, which if planned and executed properly has proved to be very successful. The number of participants might be small or moderate. Assuming that they have a sound basic education, their success depends principally on motivation and aptitude and continuous engagement with the work of the group they are assigned to. Intermittent engagement will not be useful in generating a group of professionals capable of continuing the type of work to make it possible to ensure sustainability of the scientific effort beyond the life time of the project. Those who gain the expertise and skill to carry on, would thrive is an institutional framework is created for developing careers within a specialised scientific cadre. A period of scientific apprenticeship will prepare some of the trainees to receive overseas training.

It might be useful to have a number of trainees to receive intermittent engagement but up to the point where they develop an appreciation of the usefulness of good research in supporting the planning and design effort within the mainstream organisation. Study tours would benefit. The planning of overseas study tours.

The development of an action plan to maximise the long-term utility of the capacity building programme must include some work on the institutional development either within or alongside the BWDB to create a career path for the special scientific cadre created by this project.

9 Strategy Towards Transparency and Accountability

9.1 Outreach Programme

The outreach programme will comprise several workshops, focus group discussions and community consultations where a selected group of stakeholders will interact with the client with the Consultant acting as interlocutor. These workshops will endeavour to keep the client and stakeholder groups well informed. Table 9.1 shows the summary of workshops to be held.

a) Upon finalizing the Inception Phase: to discuss polder problems, work plan and proposed basin approaches

b) At the end of data collection phase (9 months after inception): to discuss extent of existing data, identify gaps and propose improvement methods

c) At the end of the main modelling phase (24 months): to discuss the findings of the analyses and its implications

d) At the end of development of design and implementation phase: to discuss the effectiveness of the selected interventions and their social, environmental and economic implications

e) At the end of the development of investment plan phase: to select the most promising alternatives and discuss risk reduction investment strategy

f) Consultants shall actively participate in the workshops, in their development, in the discussions and in drafting the conclusions. The composition of the participating group at the Workshops will vary according to the subject matter being discussed

Table 9.1 Summary of Workshops to be held

no	**Workshop Name**	**Date**	**Location**	***Description* / Participants**
1	Inception Workshop	09 Jan 2019	Dhaka	*Workplan and Schedule* / Senior Officials and WR Community
2	Polder Design Concepts 1 (Brainstorming)	Feb 2019	Khulna	*Polder solutions* / BWDB Planning, Coastal Field Divisions, WMO and CBOs, CEGIS, Selected Academics,
3	Polder Design Concepts 2 (Brainstorming)	Mar 2019	Barisal	*Polder solutions 7* BWDB Planning, Coastal Field Divisions, WMO and CBOs, CEGIS, Selected Academics,
4	Coastal Database	Aug 2019	Dhaka	*Introduce the New BWDB Database, its functionality etc* /BWDB, SoB, BIWTA, WARPO, CEGIS
5	International Modelling Workshop	Oct 2020	Dhaka	*Two-day Workshop Expert level discussion of modelling results /* National and International Modelling Experts to discuss the modelling work done by the project
6	Final Polder Concept Review	Dec 2020	Dhaka	Present Selected Polder Interventions and Design concepts to be reviewed and agreed by Technical Stakeholders

no	Workshop Name	Date	Location	*Description* / Participants
7, 8, 9, 10	Stakeholder Review (4 workshops)	2019, 2020	Coastal Zone	Presenting the findings of the study and proposed investment plan to non-specialist stakeholders
11	Investment Plan	2021	Dhaka	Final Discussion of the final investment plan (at pre-feasibility level) including implementation priorities

9.2 Communication Strategy

Communication strategy is mainly to communicate the results of the project and benefit-cost analysis through a series of stakeholder workshops. Communication materials such as brochures, animations, flyers, reports etc. will be prepared for communicate the proposed improvement. Table 9.2 shows the communication strategy.

Table 9.2 Communication Strategy

Activity	Activities and Timing	Start Month	End Month
9-2-1	Upload and store all collected and generated data	1	30
9-2-2	Share all analysis and results from the study with shareholders	1	30
9-2-3	Communicate the results of the project and benefit-cost analysis through a series of stakeholder workshops.	24	30
Deliverables		**Month**	
All datasets stored in database of BWDB for use in a variety of ministries, with illustrative material Communication materials such as brochures, animations etc. that will help communicate the proposed improvements		30	

10 Project Workplan

10.1 Project Deliverables

The project Deliverables are tabulated in Table 10.1

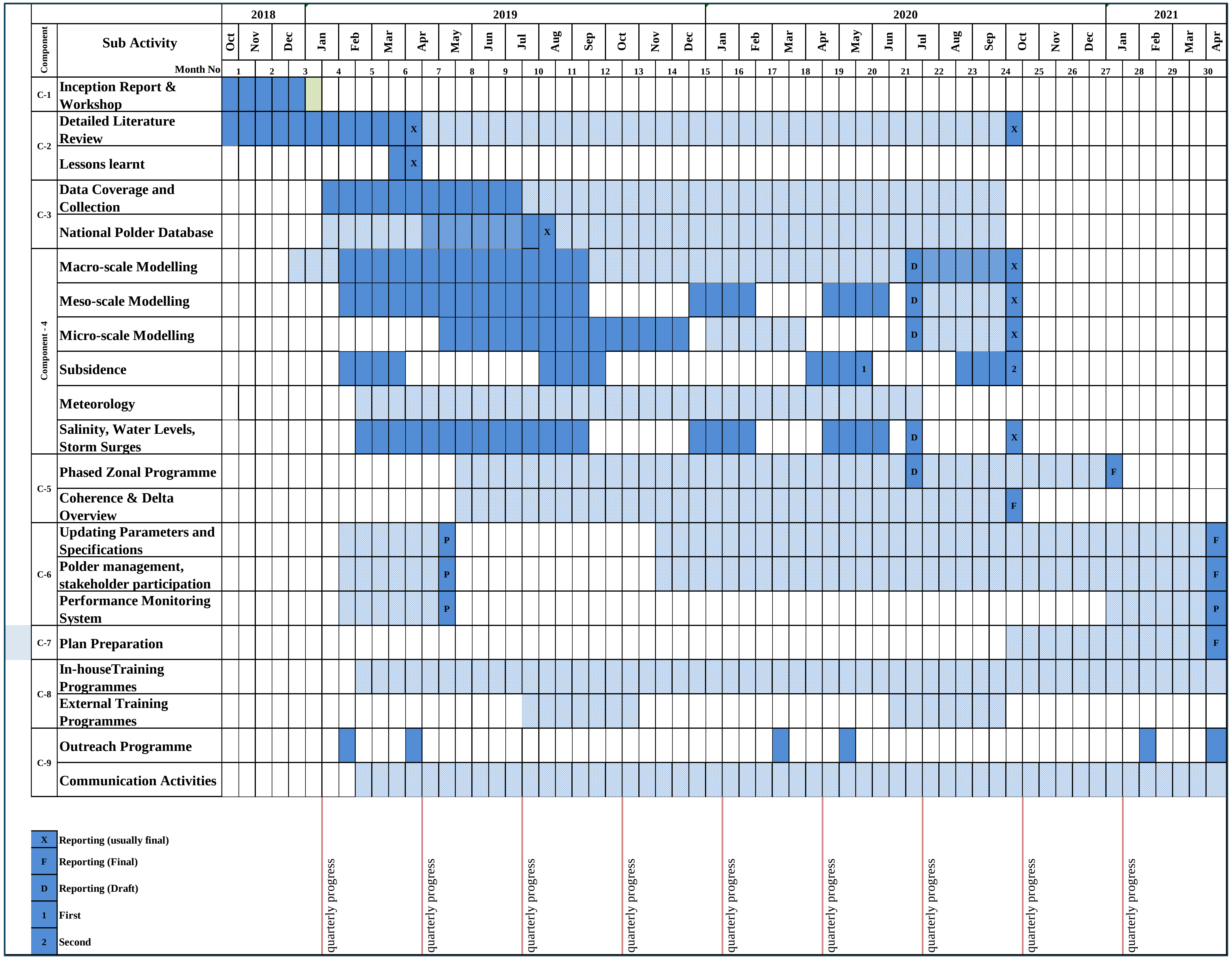
Table 10.1 Deliverables

Delivery	**Description**	**Output/Report**	**Month**
D-1	Inception	Inception Workshop Inception Report (Workplan etc	0 - 3
D-2	Literature	Literature Inventory & Annotated Review	0 - 6
		Literature Review Summary Report & Lessons Learnt	7 - 24
		Lessons Learnt	12
D-3	Data	Data Report , Inventory, quality checks etc	3 - 9
		Database Design Report	3 - 9
		GIS based maps GIS Based Database	3 - 9
		Supply of model boundary data (various)	3 - 9
		Technical Report on Data Analysis and Validation	10 - 12
		Technical Report on Improving Data collection	10 - 12
D-4A-1	Macro	Macro-scale Georeferenced morphological field data	15
		Technical Report on Macroscale modelling and Results	24 & 30
		Current Morphological Processes and Trends	15
		Long Term Morphological Processes and Trends	24
		Transfer Model to BWDB with training	30
D-4A-2	Meso	Meso scale data and modelling data (several models)	12 - 24
		Reports & Interpretation	24 - 30
		Bank Erosion Modelling Report	24 - 30
		Long Term Morphological Processes and Trends	24
		Transfer Models to BWDB with training	30
		Meso-scale field data and timeseries	24
		Technical Report on Mesoscale modelling and Results	24

Delivery	Description	Output/Report	Month
		Medium & Longterm Morphology Erosion Hindcasting Modelling Reports Storm Surge and Wave Propagation Modelling Transfer Models to BWDB with training	30 24 - 30 12 - 20 30
D-4A-3	micro	Polder Drainage Data Reports Drainage Design Reports Morphological Polder Management Transfer Models to BWDB with training	14 20 12 - 24 30
D-4B	subsidence	Subsidence Geospatial Datasets Detailed Technical Report	18 24
D-4C	Meteorology	Technical report on current trends etc Geospatial Datasets	18 20
D-4D	Climate change effects	Geospatial Datasets for h/L water, salinity etc Geospatial Datasets for Groundwater Salinity Tidal & Salinity Curves Exceedance Frequencies Extreme storm surges water levels Detailed Technical Report	24 24 24 24 24 24
D-5A	Polder Development Plan	Polder Development Plan Improvements to 17 Polders Report for Each of 3-5 polders (full feasibility) Draft Report on initial 4 polders Final Report on 17 polders	30 21 - 30 21 4 - 21 217
D-5B	Data	Coherence with Respect to Overall Delta	24
D-6.1	Updated Parameters	Updated Design Parameters and Specifications Detailed Delivery plan	30 6
D-6.2	Polder Management	Polder Management Plan Detailed Delivery plan	30 6

Delivery	Description	Output/Report	Month
D-6.3	Polder Management	Performance Monitoring Mechanism Detailed Delivery plan	24 - 30 30
D-7	Data	Investment Plan of Entire CEIP	24 - 30
D-8	Macro	Action Plan for Capacity Building In-country on-the-job technical training Training Report with List of Participants International Workshop Teach the Teacher (Curriculum development)	6 0 - 24 27 27 18
D-9.1	Outreach programme	Workshops Workshops Report	12, 16, 24, 27 24, 27
D-9.2	Communication Strategy	Transfer all Datasets to BWDB Prepare Communications Materials	18 - 20 20 - 24

10.2 Activity Schedule



		2018					2019																								2020																								2021						
Component	Sub Activity	Oct	Nov		Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr
	Month No	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20		21		22		23		24		25		26		27		28		29		30	
C-1	Inception Report & Workshop	■	■	■	■	■	🟩																																																						
C-2	Detailed Literature Review	■	■	■	■	■	■	■	■	■	■	■	X	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	X												
	Lessons learnt											■	X																																																
C-3	Data Coverage and Collection							■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨													
	National Polder Database							▨	▨	▨	▨	▨	▨	▩	▩	▩	▩	▩	▩	■	X	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨													
Component - 4	Macro-scale Modelling					▨	▨	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	D	▩	▩	▩	▩	▩	X												
	Meso-scale Modelling								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							■	■	■	■					■	■	■	■		D	▨	▨	▨	▨	▨	X												
	Micro-scale Modelling														■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨	▨	▨	▨	▨	▨							D	▨	▨	▨	▨	▨	X												
	Subsidence								■	■	■	■										■	■	■	■														■	■	■	1						■	■	■	2												
	Meteorology									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨																		
	Salinity, Water Levels, Storm Surges									■	■	■	■	■	■	■	■	■	■	■	■	■	■							■	■	■	■					■	■	■	■		D						X												
C-5	Phased Zonal Programme															▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	D	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	F						
	Coherence & Delta Overview															▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	F												
C-6	Updating Parameters and Specifications								▨	▨	▨	▨	▨	▨	P													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	F
	Polder management, stakeholder participation								▨	▨	▨	▨	▨	▨	P													▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	F
	Performance Monitoring System								▨	▨	▨	▨	▨	▨	P																																									▨	▨	▨	▨	▨	▨	P
C-7	Plan Preparation																																																▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	F
C-8	In-houseTraining Programmes									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	External Training Programmes																			▨	▨	▨	▨	▨	▨	▨																	▨	▨	▨	▨	▨	▨	▨													
C-9	Outreach Programme								■					■																							■				■																				■				■
	Communication Activities									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
								quarterly progress							quarterly progress											quarterly progress					quarterly progress						quarterly progress							quarterly progress						quarterly progress								quarterly progress				

X Reporting (usually final)
F Reporting (Final)
D Reporting (Draft)
1 First
2 Second

Figure 10.1: Activity Schedule

10.3 Manning Schedule

No.	Name	Months since Project Commencement on 14 October 2018																														
		Position		1,2, 3,	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Totals
IK-1	Dr. Ranjit Galappatti	Team Leader	Home																													0.00
			Field	2.50	1.00	1.00		1.00	1.00		1.00	1.00		1.00	1.00		1.00	1.00		1.00	1.00	0.50	1.00	1.00		1.00	1.00		1.00	1.00	1.00	22.00
IK-2	Prof. Zheng Wang	River and Estuarine Morphologist	Home		0.50			0.50		0.50				0.35			0.50			0.50			0.50			0.45				0.50		4.30
			Field			0.50							0.50			0.50			0.50			0.50			0.50				0.75		0.25	4.00
IK-3	Prof. Dano Roelvink	River and Coastal & Estuarine Morphological Modeler	Home			0.50	0.50		0.50	0.50		0.50		0.50	0.50		0.50				0.50					0.50				0.40		5.40
			Field		0.50			0.75			0.75					0.75				0.75					0.50						0.30	4.30
IK-4	Dr. Marcel Marchand	Integrated Coastal Zone and Polder Management Expert	Home								0.50					0.50							0.50									1.50
			Field			0.75		0.75						0.75				1.00			1.00			0.75			0.75			0.75	0.50	7.00
IK-5	Dr. Bo Brahtz Christensen	Coastal and Estuarine Morphologist	Home			0.25			0.10			0.25				0.25				0.25				0.25						0.25		1.60
			Field		0.50				0.75				0.75				0.50				0.75				0.75						0.50	4.50
IK-6	Dr. Søren Tjerry	Tidal River and Sediment Management Specialist	Home		0.25	0.25	0.25			0.30	0.25	0.25		0.25	0.50							0.25	0.25	0.25	0.25							3.30
			Field					0.50	0.50				1.00	1.00	0.75	1.00	1.00	1.00	1.00												0.25	8.00
IK-7	Dr. Irina Overeem	Macro Scale Delta Morphologist	Home		0.50			0.50						0.50							0.50		0.50					0.50				3.00
			Field		0.50		0.50				0.50				0.50			0.50								0.50					0.50	3.50
IK-8	Dr. Steve Goodbred	Large Scale Delta Morphologist/Geologist	Home							1.00	1.00	0.50										1.00	1.00	0.50								5.00
			Field		0.33				1.00							0.50					1.00					0.33		0.50				3.67
IK-9	Dr. Michael Steckler	Subsidence Expert/Geo-Morphologist	Home			0.25	0.25	0.25	0.25					0.50	0.50		0.50	0.50	0.50	0.50	0.50						0.50	0.50	0.50	0.50		6.50
			Field		1.00								1.00			1.00										0.50					0.50	4.00
INK-10	Mr. Henrik Rene Jensen	Storm Surge and Wave Specialist	Home		0.10																0.10				0.10							0.30
			Field						0.70				0.75				0.50				0.50				0.75						0.50	3.70
INK-11	Dr. Alessio Giardino	Climate Change Risk Assessment and Adaptation	Home		0.25	0.25		0.25		0.25		0.25				0.25					0.25				0.25				0.15	0.15		2.30
			Field		0.75		0.75				0.75				0.75				0.75				0.75				0.75				0.65	5.90
INK-12	Mr. Mark de Bel	Economist	Home				0.25			0.25			0.25			0.25				0.25			0.25			0.25			0.25	0.25		2.25
			Field					0.50			0.75							0.75			0.75				0.75			0.75			0.50	4.75
INK-13	Dr Flemming Jacobsen	Salinity Specialist Surface water	Home																													0.00
			Field																		0.50				0.50							1.00
INK-14	Dr. Christopher Small	Remote Sensing Expert	Home				0.50	0.50	0.50	0.50	0.50	0.50																				3.00
			Field		1.00	1.00																										2.00
INK-15	Dr. Kim Wium Olesen	River Morphologist	Home			0.20	0.20		0.10			0.10		0.10		0.10		0.10						0.10		0.13						1.13
			Field		0.25			0.40	0.20				0.40		0.40		0.40		0.40			0.50			0.50		0.52				1.00	4.97
INK-16	Dr. Mick van der Wegen	Capacity Building and Estuarine Modelling	Home		0.25	0.25		0.25	0.50	0.25	0.25	0.25		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		0.25					0.25		5.00
			Field				0.50						0.50																			1.00
INK-17	Dr. Bas van Maren	Fine sediment Modelling	Home		0.25		0.25			0.25			0.25			0.25		0.25		0.25					0.25							2.00
			Field			0.75			0.50			0.75			0.75				0.75				0.50									4.00
INK-18	Mr. Toine Vergroesen	Polder Design	Home			0.25					0.25								0.25					0.25			0.25			0.25		1.50
			Field																			0.75						0.75				1.50
INK-19	Dr Stephanie Higgins	Remote Sensing Image Analysis Expert	Home									0.90	0.90				0.50															2.30
			Field								0.20																					0.20
INK-21	Dr. Torsten Jacobsen	Salinity Specialist Groundwater	Home																													0.00
			Field													0.75			0.75												0.50	2.00
INK-24	Dr. Kimberley Rogers	Macro Scale Delta Morphology and Socio Economics	Home					1.00														1.00									1.00	3.00
			Field		0.50										0.50													0.50				1.50
INK-25	Dr. Carol Wilson	SET Compaction Meters and Polder/TRM Impacts	Home			0.25								0.25						0.50										0.25		1.25
			Field		0.75								0.75						0.50										0.75			2.75
INK-26	Dr. Richard Rip Hale	Tidal Hydrodynamics and Sediment Mass Flux	Home																													0.00
			Field					0.50																								0.50
INK-27	Dr. Rolf Deigaard	Coastal Morphologist	Home																													0.00
			Field																													0.00
INK-28	Dr. Ferdinand Diermanse	Statistical Analysis of Meteorological Data	Home			0.25		0.25			0.25			0.25																		1.00
			Field				0.50			0.50																						1.00
INK-29	Dr. Deepak Vatvani	Coastal Flooding and Storm Surge Expert	Home																													0.00
			Field																													0.00
INK-30	Dr. Monica Altamirano	Investment Plans and PPP Specialist	Home																													0.00
			Field																													0.00
INK-31	Mr. Reinier Schrijvershof	Morphodynamics Modelling Expert	Home				0.25			0.25			0.25						0.25													1.00
			Field			0.75			0.75			0.75			0.75																	3.00
INK-32	Dr. Kasper Kærgård	Coastal and Estuarine Modeller	Home									0.25						0.50						0.25								1.00
			Field										0.75								0.50				0.75							2.00
INK-33	Dr. Jordan Adams	Macroscale delta modeler	Home		1.00	1.00				1.00	1.00					1.00	1.00	0.50		1.00	1.00		0.50			1.00	1.00		1.00		0.50	12.50
			Field					0.50						0.50	0.50								0.50								0.50	2.50
NK-34	As per technical proposal	IWM Key and Non-Key	Home																													0.00
			Field																													0.00

Figure 10.2 Manning Schedule (international experts)

No.	Name	Expert's input (in person/month) per each Deliverable (listed in TECH-5)																				Total time-input (in Months)		
		Position		D-1	D-2	D-3	D-4A-1	D-4A-2	D-4A-3	D-4B	D-4C	D-4D	D-5A	D-5B	D-6.1	D-6.2	D-6.3	D-7	D-8	D-9.1	D-9.2	Home	Field	Total
NK-34	Zahirul Haque Khan	Deputy Team Leader	*[Home]*	1.14	1.14	2.28	0.76	0.76	1.14	0.57	0.57	0.57	1.71	1.14	0.86	0.57	0.57	0.87	0.57	1.14	1.14	17.5		23.0
			[Field]	0.39	0.39	0.39	0.20	0.20	0.39	0.20	0.20	0.20	0.57	0.39	0.30	0.20	0.20	0.30	0.20	0.39	0.39		5.5	
NK-35	Sarwat Jahan	River Morphological Modeler	*[Home]*	1.00	1.00	1.00	2.00	4.00	5.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	0.00	23.0		25.0
			[Field]	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		2.0	
NK-36	Mohammad Ziaur Rahman	Coastal and Estuarine Morphological Modelling Specialist	*[Home]*	0.38	0.38	1.88	2.25	3.00	5.25	0.38	2.25	0.00	0.00	2.25	0.75	0.75	0.75	0.00	0.38	0.38	0.00	21.0		28.0
			[Field]	0.13	0.13	0.63	0.75	1.00	1.75	0.13	0.75	0.00	0.00	0.75	0.25	0.25	0.25	0.00	0.12	0.12	0.00		7.0	
NK-37	Emaduddin Ahmed	Integrated Coastal Zone and Water Resource	*[Home]*	2.41	2.41	1.07	1.07	1.07	1.07	1.07	1.60	0.80	2.41	0.80	0.80	0.80	0.80	3.22	0.80	1.60	0.70	24.5		30.0
			[Field]	0.27	0.80	0.27	0.27	0.27	0.00	0.00	0.56	0.27	0.27	0.27	0.27	0.27	0.27	1.17	0.27	0.00	0.00		5.5	
NK-38	Dr. Faruq Ahmed Mohiuddin, PEng.	Tidal River Morphologist	*[Home]*	1.50	1.50	0.75	1.50	3.00	3.00	0.75	1.00	0.00	2.25	0.75	0.75	1.00	0.75	1.50	1.00	0.75	0.25	22.0		28.0
			[Field]	0.50	0.50	0.25	0.50	1.00	1.00	0.25	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.50	0.00	0.25	0.00		6.0	
NK-39	Md. Saiful Islam	Storm Surge and Wave Modelling Specialist	*[Home]*	0.00	1.00	4.00	0.00	0.00	0.00	0.00	2.00	4.50	1.00	0.00	3.00	2.00	0.00	0.00	1.50	1.00	0.00	20.0		24.0
			[Field]	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	1.00	0.00	0.00	0.00	0.50	0.00	0.00		4.0	
NK-40	Abu Saleh Khan*	Long-term Polder Management Specialist	*[Home]*	1.50	1.50	1.50	0.50	1.00	1.00	1.00	2.50	1.50	2.50	1.50	1.25	2.25	1.25	0.75	0.50	0.50	0.50	23.0		28.0
			[Field]	0.50	0.50	0.50	0.00	0.25	0.25	0.25	0.00	0.50	0.50	0.50	0.25	0.50	0.25	0.25	0.00	0.00	0.00		5.0	
NK-41	Tarek Bin Hossain	Sediment Management Specialist	*[Home]*	1.60	1.60	1.60	1.60	2.40	2.40	1.60	0.00	0.00	1.60	1.60	0.90	1.60	1.60	1.20	0.40	0.40	0.40	22.5		30.0
			[Field]	0.50	0.50	0.50	0.50	0.80	0.80	0.50	0.00	0.00	0.50	0.50	0.30	0.50	0.50	0.40	0.30	0.20	0.20		7.5	
NK-42	Md. Mahbubur Rahman	Database Development Specialist	*[Home]*	0.50	0.50	11.00	5.50	0.00	0.00	0.00	3.00	1.50	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.50	0.50	25.0		28.0
			[Field]	0.00	0.00	1.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		3.0	
NK-43	Md. Anowar Saadat	River Morphological Modeler	*[Home]*	0.50	0.50	1.50	3.00	6.00	6.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.50	0.00	21.0		24.0
			[Field]	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		3.0	
NK-44	Shume Akhter	Coastal and Estuarine Morphological Modelling Specialist	*[Home]*	0.00	2.00	3.00	3.00	5.00	5.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	22.0		24.0
			[Field]	0.00	0.00	0.50	0.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		2.0	
NK-45	Abdus Salam Sikder	Geo-Morphologist	*[Home]*	0.40	1.60	1.60	4.80	4.80	1.60	4.00	0.00	0.00	0.00	1.20	0.40	0.00	0.40	0.00	0.90	0.40	0.40	22.5		30.0
			[Field]	0.15	0.54	0.54	1.60	1.60	0.54	1.30	0.00	0.00	0.00	0.40	0.15	0.00	0.15	0.00	0.27	0.13	0.13		7.5	
NK-46	Md. Tarikul Islam	Groundwater Specialist	*[Home]*	0.38	1.50	3.00	0.00	0.00	0.00	0.38	1.50	9.00	0.00	0.00	0.00	1.50	1.50	0.00	1.50	0.38	0.38	21.0		28.0
			[Field]	0.13	0.50	1.00	0.00	0.00	0.00	0.13	0.50	3.00	0.00	0.00	0.00	0.50	0.50	0.00	0.50	0.13	0.13		7.0	
NK-47	Md. Zahid Hasan Siddiquee	Remote Sensing Specialist	*[Home]*	0.00	0.00	9.63	3.50	3.50	1.75	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.88	0.00	21.0		24.0
			[Field]	0.00	0.00	1.38	0.50	0.50	0.25	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13	0.00		3.0	
NK-48	Md. Raqubul Hasib	Salinity Specialist	*[Home]*	0.00	1.67	2.50	0.00	0.00	0.00	0.00	2.50	11.67	0.00	0.00	0.00	0.00	0.42	0.00	0.83	0.42	0.00	20.0		24.0
			[Field]	0.00	0.33	0.50	0.00	0.00	0.00	0.00	0.50	2.33	0.00	0.00	0.00	0.00	0.08	0.00	0.17	0.08	0.00		4.0	
NK-49	Fouzia Khanam	GIS Specialist	*[Home]*	0.95	0.00	6.65	3.80	3.80	0.00	0.95	0.95	0.95	0.00	0.00	0.00	0.00	0.00	0.48	0.48	0.00	0.00	19.0		20.0
			[Field]	0.05	0.00	0.35	0.20	0.20	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00		1.0	
NK-50	Rubayet Alam	Large Scale Delta Morphologist	*[Home]*	0.00	1.50	0.75	5.25	5.25	1.50	1.50	0.00	0.00	1.50	1.50	0.00	0.00	1.50	0.00	0.00	0.38	0.38	21.0		28.0
			[Field]	0.00	0.50	0.25	1.75	1.75	0.50	0.50	0.00	0.00	0.50	0.50	0.00	0.00	0.50	0.00	0.00	0.13	0.13		7.0	
NK-51	Farhana Akhter Kamal	Macro Scale Delta Morphologist	*[Home]*	0.00	2.00	1.50	10.00	3.00	0.00	3.00	0.00	0.00	0.00	2.00	0.00	0.00	1.00	0.00	0.00	0.50	0.00	23.0		28.0
			[Field]	0.00	0.00	0.50	2.00	1.00	0.00	0.75	0.00	0.00	0.00	0.50	0.00	0.00	0.25	0.00	0.00	0.00	0.00		5.0	
NK-52	Md. Aminul Islam	Economist	*[Home]*	0.45	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.20	0.00	0.45	0.00	9.0		10.0
			[Field]	0.05	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.05	0.00		1.0	
NK-53	Sheikh Muhammad Abdur Rashid	Environmentalist	*[Home]*	0.25	1.00	0.00	0.00	0.00	0.00	0.00	1.50	0.50	0.50	0.00	0.00	1.25	1.50	0.50	0.50	0.25	0.25	8.0		12.0
			[Field]	0.25	0.50	0.00	0.00	0.00	0.00	0.00	0.50	0.50	0.25	0.00	0.00	0.50	0.50	0.25	0.25	0.25	0.25		4.0	
NK-54	Md. Mustafizur Rahman	Sociologist and Industrial Specialist	*[Home]*	0.27	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.00	3.82	0.00	0.00	0.27	0.27	0.27	6.0		11.0
			[Field]	0.23	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	3.18	0.00	0.00	0.23	0.23	0.23		5.0	
NK-55	Md. Rafiqul Islam	Communication and Out-reach Specialist	*[Home]*	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	4.00	6.0		7.0
			[Field]	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.50		1.0	
NK-56	Md. Anwar Hossain Bhuiyan	Hydraulic Structure Design Specialist	*[Home]*	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	5.00	0.00	0.75	0.25	0.25	0.38	0.00	11.0		14.0
			[Field]	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.25	0.00	0.25	0.13	0.13	0.13	0.00		3.0	
NK-57	Pankaj Kumar Maitra	Survey and Monitoring Specialist	*[Home]*	0.67	0.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.0		12.0
			[Field]	1.33	0.00	6.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		8.0	
NK-58	A. B. M. Anwar Haider	Survey and Monitoring Specialist	*[Home]*	0.00	0.50	6.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	7.0		17.0
			[Field]	0.00	0.67	8.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00		10.0	
NK-59	Shaikh Nahiduzzaman	Climate Change Monitoring Specialist	*[Home]*	0.00	0.88	0.00	0.00	0.00	0.00	0.00	2.63	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.00	7.0		8.0
			[Field]	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.38	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00		1.0	
NK-60	Tarun Kanti Magumder	Basin Modelling Specialist	*[Home]*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	4.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	12.0		13.0
			[Field]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.30	0.00	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.00		1.0	

Figure 10.3 Manning Schedule (national experts)

APPENDICES

APPENDIX A – MODELLING OF THE LONG TERM PHYSICAL PROCESSES IN THE COASTAL ZONE OF BANGLADESH

A Modelling of the long-term physical processes in the coastal zone of Bangladesh

A.1 Morphology

A.1.1 Morphology on a Macro Scale

A.1.1.1 Objectives

The main objectives are the following:

- To derive and validate a sediment budget for the GBM Delta, covering largest part of Bangladesh in coarse resolution (both 1D and coarse 2D unstructured grid models).
- To assess the gross morphodynamic trends on timescales of decades
- To assess the large-scale distribution of sediment fractions
- To assess large-scale fine sediment fluxes along the coast, explaining pathways of sediment from Meghna to Sundarbans, under influence of wind, waves and density driven circulations
- To apply the validated sediment budget models under scenarios of changing flow boundary conditions (river, ocean) and climate change and land use adaptation, in order to provide gross bed level changes and boundary conditions to meso-scale models.

A.1.1.2 Approach

A.1.1.2.1 General Approach

To derive a GBMD wide sediment budget, we propose a well-evaluated, numerical, process-based approach using the Delft3D FM software, which integrates 1D and 2D (and 3D) meshes for hydrodynamics, sediment transports and morphodynamics. This allows for a physics-based analysis of governing processes including multiple scale interactions. In addition, the approach has high flexibility. It is easy to adjust process descriptions, grid resolution and domain extent. The model covers the GBMD, essentially covering Bangladesh.

In first instance we will focus on deriving a 1D model covering major rivers and floodplains. In second instance we will extend this model to 2D, albeit with a coarser resolution (~ 200m – 1km).

The 1D model will provide information on sediment distribution and cross-sectionally averaged morphodynamic processes. This model is ideal to carry out sensitivity analysis on sediment characteristics, roughness values and different hydrographs. Results of the 1D model include a preliminary sediment budget under different hydrograph and SLR scenarios and the results will make explicit characteristic morphodynamic adaptation scales, evolutionary time scales and possible equilibrium conditions.

The 2D model will apply settings derived by the 1D model. Additionally, this 2D model includes processes like bank erosion, braiding and meandering, for the larger branches. The 2D model can grow “organically” –stepwise approach- from the 1D model.

A.1.1.2.2 Existing Models

Delft3D FM (and similar software packages such as the MIKE suite) have proven skills in predicting hydrodynamics, sediment dynamics and morphodynamics on a high resolution grid.

Process-based models of the GBMD do exist, albeit that most models are MIKE based. These are, amongst others, the GBM Basin model (hydrological catchment model), Bay of Bengal Model (BOBM, covering the Bay of Bengal and large part of the GBMD and used as basis for wave, salinity intrusion and storm surge modelling) and 1D models like the General Model, the Super model, or the National flood model (NAM & HD) or regional models like the South West Region Model. Existing MIKE-Delft3D conversion algorithms will be used to develop large scale Delft3D FM models. Additionally, the experience using Delft3D for long-term morphodynamic simulations within the MorphoFlood project will be used and lessons learned from this will be applied (e.g., need to include floodplains in predictions, necessity to let the sediment distribution spin up before starting morphology, morphodynamic upscaling strategies).

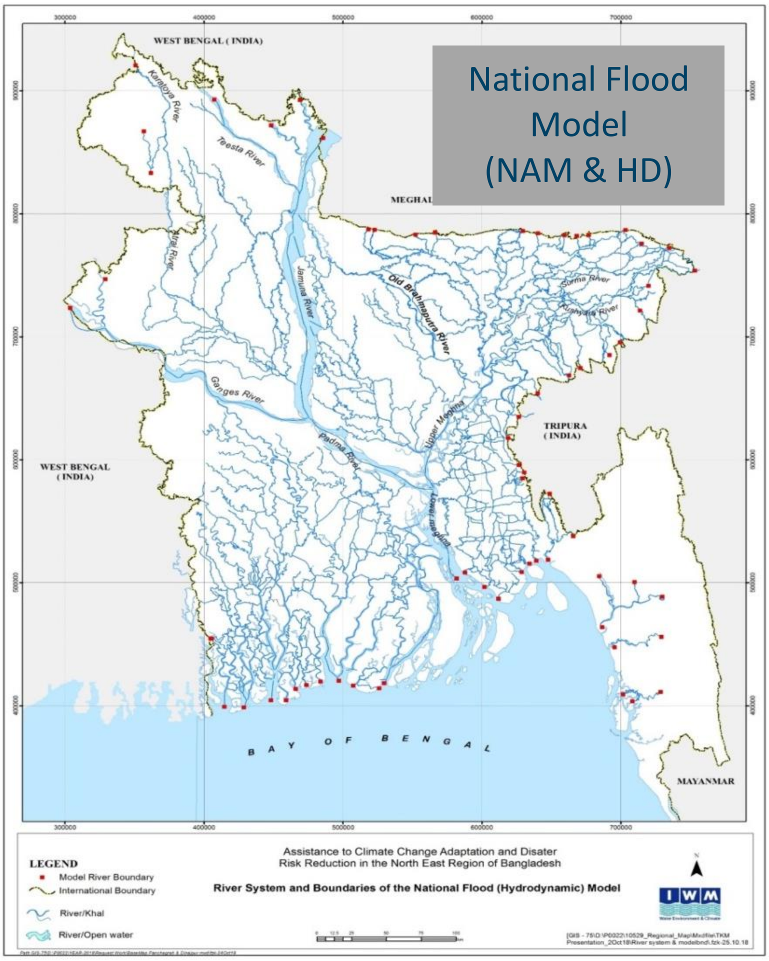


Figure A- 1: National flood model

A.1.1.2.3 Activities

We will apply a proven process-based morphodynamic model, i.e., the open source Delft3D FM to derive a sediment budget for the GBM Delta. This software includes coupling with waves and sediment transport formulations and is, able to include morphodynamics. For the macro scale we will apply a relatively coarse grid (~ km) allowing for large time steps. We will cover a relatively large domain to the extent of Bangladesh. An important aspect will be an assessment of associated uncertainty levels (e.g. due to limited data availability, limited process descriptions or numerical approximations) regarding the model outcome. Additionally, the behaviour of different sediment fractions (sand, silt, mud) will be explored

1. As a first step we will start from a very coarse approach and develop the ‘branch model’. This implies the setup of a 1D FM model describing the main tributaries (Ganges, Brahmaputra, Meghna and 2-4 other major branches), by channels and floodplains.
    a. Select best 1D model for conversion
    b. Convert existing 1D MIKE model into Delft3D FM
    c. Hydrodynamic calibration and validation
    d. Calibration and validation of sediment concentrations and transports
    e. Morphodynamic runs of 1 hydrograph (1 year).
    f. Morphodynamic scenario runs including SLR and future hydrographs and sediment supply scenarios and scenarios of extreme events (river flow and cyclones). Scenarios also include tectonics and subsidence. This leads to 25, 50 and 100 year predictions of the GBM Delta sediment budget and morphodynamics
2. The second step develops a coarse resolution (~200m-1 km) 2D model, ‘coarse area model’ including all important branches and processes necessary to connect to the meso scale modelling efforts. Model parameter settings of the 1D ‘branch model’ will be taken as starting point. This FM model will be based on existing Mike and Delft3D models covering the GBMD. Delft3D FM integrates 1D and 2D meshes so that this 2D model can grow stepwise from the 1D branch model possibly leaving parts of the model in 1D. The 2DH model will be able to represent wind- and tide-driven flows along the coast of Bangladesh and the resulting transport of fine sediments, under the influence of wave stirring.
    a. Select best 2D model for conversion
    b. Convert existing 2D Mike model into Delft3D FM
    c. Investigate most suitable grid design (combination triangles/curvilinear sections; triangles only; automatic quadtree refinement)
    d. Hydrodynamic calibration and validation
    e. Calibration and validation of sediment concentrations and transports
    f. Morphodynamic calibration runs of single hydrograph (1 year) and characteristic hydrographs covering several years, up to decades. Comparison with satellite imagery.
    g. Morphodynamic scenario runs including SLR and future hydrographs and sediment supply scenarios

Data needed

Both the 1D and 2D model need data as input and for calibration/validation. Partly (especially with respect to hydrodynamics) these data are available in existing MIKE models. Sediment budget data are available from literature. With respect to long-term trends and morphodynamics the following data are needed, as much as they are available:

- Historic data on river flow and sediment supply at Bangladesh boundaries;
- Data for hydrodynamic/sedimentological model calibration/validation (water levels, flows, SSC) within the model domain (ie Bangladesh);
- Sediment characteristics/composition of sediment input and bathymetry in the model domain (ie Bangladesh);
- All bathymetry data collected over the past decades, whether in national or local projects, should be made available and brought together in order to estimate long-term trends over ~20 km stretches of rivers and estuaries and their variability.
- Surface sediment concentration patterns from satellite imagery must be collected and ground-truthed with available surface sediment sampling

Boundary conditions and input reduction

For the long-term simulations we will need to schematize the boundary conditions representing the forcing from the sea and from the upstream rivers varying on various time scales. The forcing from the rivers shows a clear seasonal variation. The forcing from the sea includes tidal and spring-neap variations in addition to a clear seasonal, monsoon-driven variation and sea-level rise with a very long time-scale. It is challenging to schematise all these variations with the different time scales in the morphodynamic modelling using the Morfac (MF) acceleration technique. Two alternative approaches will be considered: (1) schematize the yearly discharge curve into a period equal to 1 year/MF in combination with schematized morphological tide; (2) Mormerge approach based on different discharge levels in combination with spring-neap phases. For prediction runs synthetic timeseries of river discharges will be required.

Connection to aggregated modelling

The results of the Delft FM model will be used for supporting the set up and calibration of the reduced complexity models (/aggregated models), e.g. the HydroTrend and AquaTellUs models mentioned in Approach C. We will also investigate the possibility and desirability in setting up an aggregated morphodynamic model for the GBMD based on model concept a la the ASMITA model. The aggregated models can be used in combination with the Delft FM model for efficiently simulating the future scenarios.

A.1.1.2.4 Deliverable

The software newly developed under this project with all source code and accompanying technical document with detailed explanation of the methodology and assumptions. The delivered models include

- the coarse 1D ‘branch model’ describing roughly the yearly sediment budget and distribution and morphodynamic behaviour of the system;
- the coarse 2D ‘area model’ describing in more detail sediment dynamics and morphodynamics as well as the impact of scenarios after 25, 50 and 100 years

A.1.2 Morphology on a Meso Scale

A.1.2.1 Objectives

The main objective of this component is to address the morphodynamic behaviour of estuaries and river branches in the GBM coastal zone and to estimate future changes under different scenarios. The meso scale modelling is the typical scale to address the morphodynamic impact on waves, salt intrusion, river bed levels near polders and associated suspended sediment concentrations. In addition, the meso scale is suitable for addressing local 3D effects such as density driven flows on sediment transport pathways. Apart from reproducing current conditions for model validation, the time span involved concerns conditions after 25, 50 and 100 years.

A.1.2.2 Approach

A.1.2.2.1 General Approaches

The meso scale model connects macro scale to micro scale. The macro scale model will provide boundary conditions (such as tidal dynamics, river flow, sediment and salinity concentrations) for the meso scale, whereas the meso scale model provides boundary conditions for polder scale micro models. It must also be mentioned that meso scales models, in addition to being the bridge between macro scale and micro scale models do in themselves provide results directly useful for many purposes.

In the initial workshop (in the first three months), key experts will determine and select key micro polder areas together with BWDB. Meso scale model domains will be defined based on the micro scale selection. It may be possible that we have to define different meso scale model domains covering different (groups) of key polders.

The meso scale puts extra challenges to a number of processes that may require parameterization to keep models efficient. These processes include waves, density currents by salt/fresh water interactions, or mangrove growth. Wave action will need to be included to account for the along shore transports eg at the coast in the Sundarbans. Density driven flows may significantly impact on the landward transport of fine sediments, especially in environments or during time periods of low river flow. Apart from influencing the roughness values, mangroves will impact on sediment deposition patterns. In addition, growth or decline of mangrove belts will impact on morphodynamics and prevailing SSC. Are these mangrove belts able to cope with SLR?

A.1.2.2.2 Existing Models

The mesoscale model domains already exist, both by MIKE and D3D. We propose to further develop both models. In this way the project benefits from a parallel modelling effort that enhances sensitivity analysis and can confirm model results, while estimating at the same time sensitivities due to differences in in numerical scheme, approach and processes. We believe that the parallel approach will make the outcome of the modelling effort stronger and better documented. These meso scale models will have to be optimised to serve outcome for the microscale and to receive boundary conditions from the macro scale.

Recently developed mangroves growth models in Python and Matlab interact with waves models like SWAN and Xbeach and Delft3D FM. This cascade of models is able to predict the growth of mangrove vegetation on a morphodynamically evolving bed, including SLR scenarios.

In addition, reduced complexity models are available to validate and complement our numerical approach. For example, Shorelines schematises long-shore sediment transport and morphology of coastlines by wave action, Asmita is able to rapidly assess sea level rise impacts along estuarine tributaries. Finally more detailed models exist that can help parametrizing mesoscale sub-grid processes. An example is Mflat that describes detailed transect processes of mud dynamics on intertidal flats and the effect of sea level rise.

A.1.2.2.3 Activities

1) Area selection - Selection of meso scale areas based on definition of micro scale focus

2) Setup and Calibration – Setup, calibrate and validate the model with field measurements and remote sensing data

3) Governing processes - Quantify river, tide and storm surge flooding and associated sedimentation rates in the natural and human-impacted coastal zone

4) Past interventions - Assess the effects of past interventions such as polderization in the coastal area on tidal prism, amplitude, morphological conditions

5) Scenario runs - Study future changes in the morphological processes based on possible scenarios coming from the macro scale approach such as (but not limited to) possible dam construction, probable natural, sea level rise, etc and interpret these changes in terms of drainage and irrigation in polders, and erosion of embankments.

6) Output - Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and for possible scenarios 25, 50 and 100 years from now, for various seasons and circumstances (average river flow, extreme discharge, average tide, extreme spring tide, storm surges and cyclone). These geospatial datasets should include full meta-data and be stored and archived in Data base of BWDB.

7) Reporting - Technical report with description and explanation of geospatial analysis of erosion and sedimentation in the coastal zone at present and for 25, 50 &100 years from present, including description of relevant seasonal variations, sediment distribution and budget, used models, indication of more and less likely scenarios, and full metadata. The Research shall indicate what the consequences of future scenarios are for drainage and irrigation in the polders, and for erosion of the embankments.

Data needed

The data need is equal to the macro scale data need defined in previous sections. In addition, we need data on alongshore sediment transport rates, density currents in selected estuarine tributaries as well as associated sediment transports.

A.1.2.2.4 Deliverable

1) The available models will be further upgraded &updated under this project and accompanying technical report with detailed explanation of the methodology and assumptions

2) Geospatial datasets of erosion and sedimentation in the coastal zone at present for various seasons and circumstances if relevant (average river flow, extreme discharge, average tide, extreme spring tide, storm surges and cyclone). These geospatial datasets should include full meta-data and be stored and archived in Data base of BWDB.

3) Geospatial datasets of erosion and sedimentation in the coastal zone for possible scenarios 25, 50 and 100 years from now, for various seasons and circumstances if relevant (average river flow, extreme discharge, average tide, extreme spring tide, storm surges, cyclone). These geospatial datasets should include full meta-data and be stored and archived in Data base of BWDB.

4) Technical report with description and explanation of geospatial analysis of erosion and sedimentation in the coastal zone at present and for 25, 50 &100 years from present, including description of relevant seasonal variations, sediment distribution and budget, used models, indication of more and less likely scenarios, and full metadata. The research shall indicate what the consequences of future scenarios are for drainage and irrigation in the polders, and for erosion of the embankments.

A.1.3 Morphology on a Micro Scale

A.1.3.1 Objectives

The key reason for water logging in the polders is elevation loss over time from preclusion of sediment deposition, combined with siltation of the peripheral rivers which makes drainage difficult. The polders are designed to be drained through sluice gates by gravity (“flap gates”), i.e. when the water level inside the polder is higher than outside then the sluice gates open and discharge drainage water into the peripheral rivers. The construction of the polders has greatly reduced the tidal volume, the flow velocities in the peripheral rivers therefore decreases (unless they carry a significant through-flow) and the size of the peripheral rivers decrease significantly though siltation (Alam, 1996; Wilson et al., 2017). As a result, the ability to drain polders at low tidal levels variation diminishes (i.e., polder elevation becomes lower than the channel bed elevation), and especially low tide levels increases preventing effective drainage of the polders. This drainage congestion problem is greatly exacerbated by subsidence of the land inside the polders and sea level rise, which decreases the window for gravity drainage of the polders and thus contributes to water logging in the polders.

The key objective of this activity is to understand the dynamics of water-logging in the polder and tidal river system and develop measures to reduce water-logging in combination with restoring natural sedimentation processes within polder areas and adjacent tidal rivers. The key objective of this activity is to understand the dynamics of water-logging in the polder and tidal river system and develop measures to reduce water-logging in combination with restoring natural sedimentation processes within polder areas and adjacent tidal rivers.

A.1.3.2 Approach

A.1.3.2.1 General Approach

With the key objective being to understand the water logging in the polders the overall approach is to setup a mathematical model of selected polders and its peripheral rivers1. A classical modelling approach will be applied where the model will be setup based on data representing the existing situation and subsequently calibrated and verified on observed data that are relevant for the issues the model will be used to analyze. This means data representing the present drainage and flooding conditions as well as siltation in peripheral rivers. Subsequently, the model will be used to represent future conditions with sea level rise due to climate changes and changed topography due to continued subsidence as well as to study a large number of “what-if scenarios”.

The scenarios will include already tested management strategies such as Tidal River Management2 as well as alternative operation of existing drainage structures, introduction of new drainage structures (including pumps) etc.

Indicators that are suitable for comparison and ranking of scenarios will be defined and evaluated based on the simulation results. The indicators can be used to rank the scenarios through e.g. a Multi Criteria Analyses (MCA). MCA is an excellent tool to engage stakeholders in prioritization of various options and this can thus feed into Component 6 activities that will involve active participation of beneficiaries and stake holders for review of approaches for management of polders.

According to ToR an available and proven mathematical model should be used for the analyses. Mike 11 has already been used extensively for this type of modelling as part of CEIP-1 (see next

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[1] Often it was found to be more convenient to connect the polder (or several polders simultaneously) to the full Regional Model to avoiding the complicated procedure of cutting up the Regional Model and extracting many water level and discharge boundary time series to serve as boundaries.

[2] TRM is basically to breach a part of the embankment around the polder to enhance natural sedimentation within the polder area and to increase the tidal volume so tidal flow increases in the peripheral rivers and (partly restores) the cross-section by eroding the deposited silt.

section). It may be beneficial to include some elements of the model in 2D, hence a combined 1D & 2D model based on MIKE 21FM and MIKE 11 (MIKE Flood) will be used. The polders will be selected in consultation with the Client and based on data availability, assessment of its representativeness and relevance, etc.

A.1.3.2.2 Existing Models

As part of CEIP-1 drainage improvements have been studied for 17 polders. For all of these polders local drainage models have been established that includes the local drainage network inside the polders (the khals), polder infrastructure such as roads and culverts and the polder drainage structures to the peripheral rivers. Sample output of a model for Polder 32 is shown in the figure below (from CEIP-1 – full title).

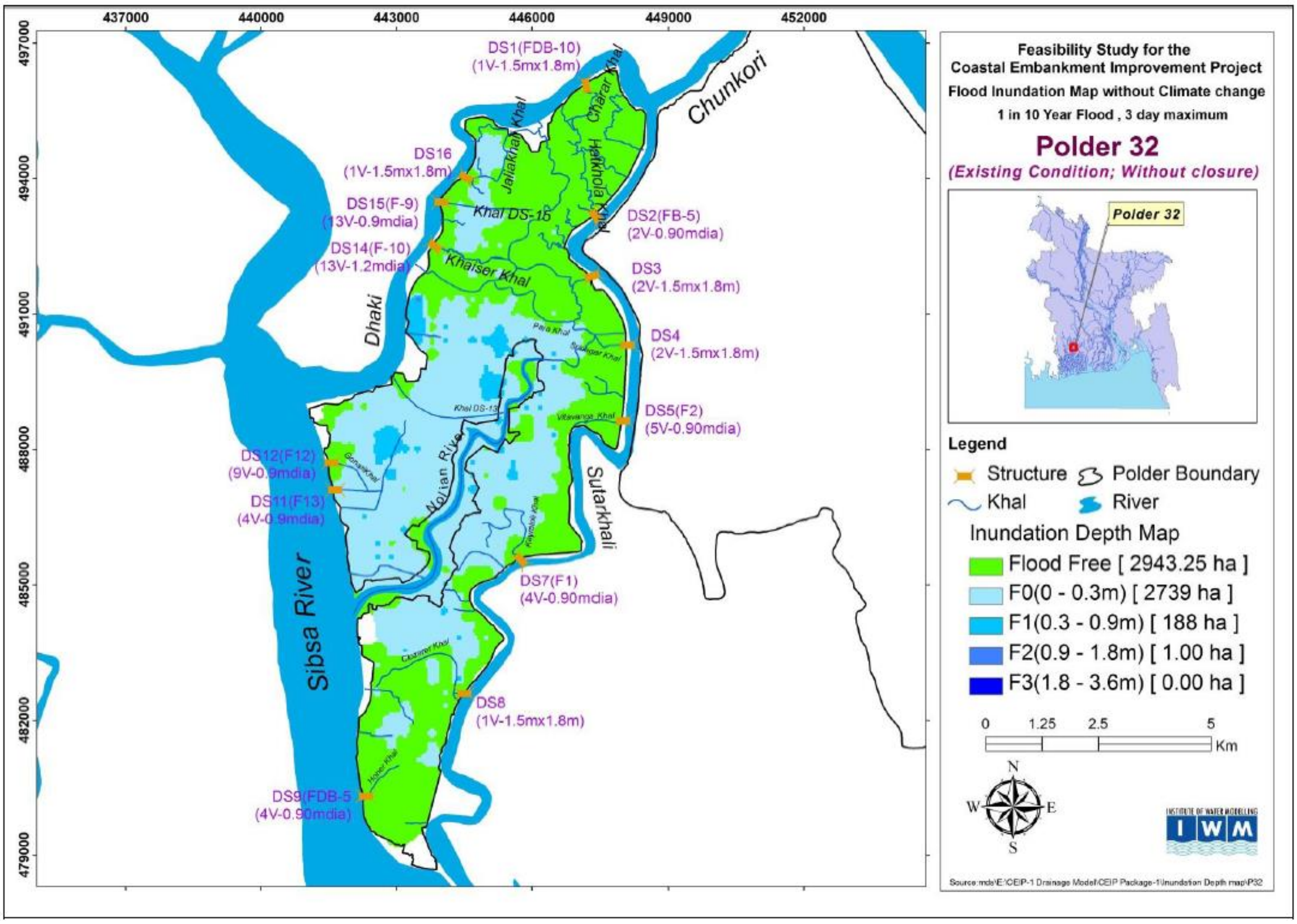
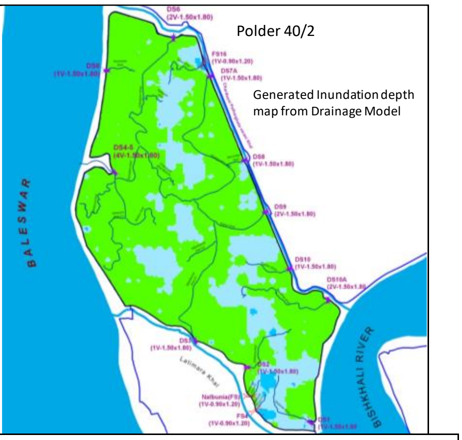


Figure A- 2: This is Inundation map showing the depth of 3-days duration and land class under existing condition of Polder 32.

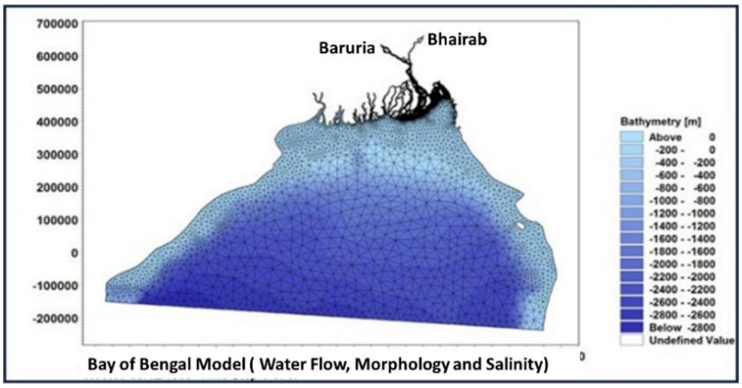
Table A- 1: Available Polder models

About 17 polders (Polder 14/1, 15,16, 17/1, 17/2, 23, 32, 33, 34/3, 35/1, 35/3, 39/2C, 40/2, 41/1, 43/2C, 47/2, 48) drainage modelling were carried out in CEIP project. MIKE 11 modelling system are used to develop the drainage model.



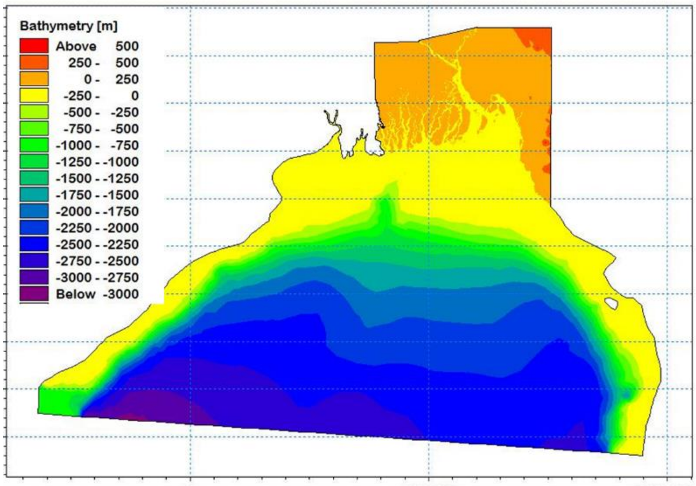
Sl No	Polder No.	Components of the polder model	Applications
1	P-1	included all drainage khals, drainage regulators, peripheral rivers, culverts information	Simulations of Drainage Improvement Option, providing hydraulic parameters for designing the regulators and dredging of peripheral rivers, preparation of flood depth maps of Polders.
2	P-2		
3	P-6/8 & 6/8 Extn.		
4	P-14/1		
5	P15		
6	P16		
7	P17/1		
8	P17/2		
9	P23		
10	P30		
11	P32		
12	P33		
13	P34/3		
14	P35/1		
15	P35/3		
16	P36/1		
17	P40/2		
18	P41/1		
19	P43/2C		
20	P47/2		
21	P48		

Table A- 2: Available River and Bay of Bengal Models

Available Model in IWM	**Description of the Model**
Bay of Bengal Model (BoBM)	Water Flow Model (Hydrodynamic Model): The available Bay of Bengal model covers the whole coastline of Bangladesh. The modelling system used for the development of Bay of Bengal Model is the MIKE21 FM, which is based on an unstructured flexible mesh consisting of linear triangular elements. The mesh enables to increase the resolution of grid around Islands, along coastline and other area of interest. It uses Finite Volume method for discretization of the flow and transport equations. The upstream end of the model is extended up to non-tidal zone and the downstream end of the model area extends upto 16^0 Latitude in the Bay of Bengal. Three open boundaries are defined in the model, two in the north in the Upper Meghna river at Bhairab and in the Padma river at Baruria. Another one is in the south in the Southern Bay of Bengal at 16^o latitude. The maximum depth along the southern open boundary of the model area is more than 2000 m. The northern/ upstream boundaries measured discharge and southern boundary is tidal boundary generated from Global Tide Model. Bathymetric data have been collected from different sources and used for the generation of bathymetry. C-map provides the bathymetry data in the deep sea. In the estuary, different rivers and other areas available recent surveyed bathymetry data has been used. The water flow model generates time series water level, tide, water flow, velocity distribution in the whole model domain for different period.  Morphological Model: The domain of the morphological model is same as for water flow model. The cohesive sediment transport module is linked to the hydrodynamic module and they run in parallel. The governing equation for sediment transport is solved on the same mesh and applies information on water levels and currents from the hydrodynamic module to calculate the sediment transport. One layer describes the sea bed in the sediment transport model. In the upstream boundary on the Lower Meghna River, time-series suspended sediment concentration have been applied based on previous measurements. Zero sediment concentration has been assumed at the south boundary. Initial sediment concentration in the Meghna Estuary is generated based on the field measurement during different study. 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 to run the model is often scattered and limited. This means that the results of the morphologic simulations must be interpreted with care. Two Dimensional Salinity Model: To model the salinity variation in the estuary it is very important to have a well calibrated hydrodynamic model. The hydrodynamic model describes the transport and advection of the salinity. The existing Bay of Bengal model has been further updated by incorporating new upstream boundaries. There are seventeen (17) open boundaries in the upstream side of the model. Flow from

calibrated and validated southwest and eastern hilly regional model has been used at all these boundaries. This model has been calibrated against flow and salinity data.

Storm Surge Model: The existing Bay of Bengal Model (Water Flow Model) has been applied in this study for storm surge modelling. The storm surge model is the combination of Cyclone and Hydrodynamic models. The description of a cyclone is based on a few parameters related to the pressure field, which is imposed to the water surface and a wind field which is acting as a drag force on the water body through a wind shear stress description. The pressure field creates a local level setup close to the eye up to one metre only. Whereas the wind shear contributes more to the surge giving a level setup on the right side of the eye and a level set down on the left side. To generate the wind field, Holland Single Vortex theory has been applied. For simulating the storm surge and associated flooding, Bay of Bengal model based on MIKE21FM hydrodynamic modelling system has been adopted. In the hydrodynamic model simulations meteorological forcing due to the cyclone has been given by applying wind and pressure fields derived from the analytical cyclone model. The MIKE 21FM modelling system includes dynamic simulation of flooding and drying processes, which are very important for a realistic simulation of flooding in the coastal area and inundation

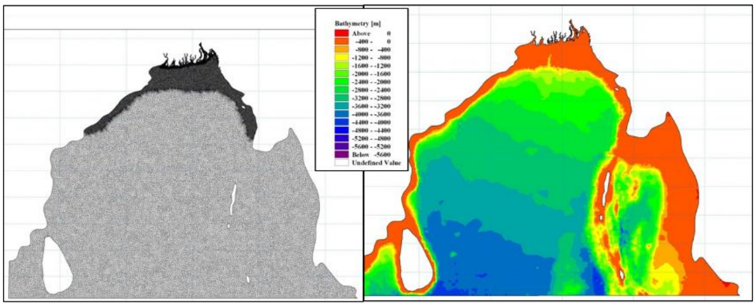


Model Domain for Storm Surge Modelling

Wave Model: Cyclonic wave fields across the coast for 19 severe cyclones as well as for normal monsoon condition has been modelled. Spectral Wave module has been applied for development of the wave model for Bay of Bengal. MIKE 21 SW is a new generation spectral wind-wave model based on an unstructured flexible mesh. The model simulates the growth, decay and transformation of wind generated waves and swells in the offshore and coastal areas.

Flexible mesh used for the Bay of Bengal model has been further

updated for wave simulation. The model domain has been extended further. Finer resolution has been used in deep sea. Cyclonic wave generated from cyclonic wind and cyclonic wind originated far away from the Bangladesh coast. Considering generation locations of nineteen severe cyclones, the model domain for cyclonic wave simulation extended up to 4^0 latitude. For normal wave simulation the model is same as for water flow model but finer resolution has been applied both for deep sea and shallow area.



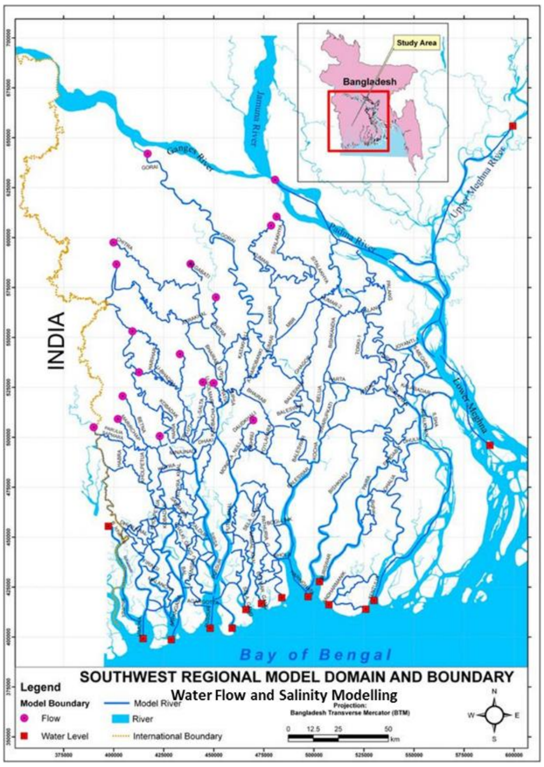
Model Domain for Cyclonic Wave

South West Regional Model

Water Flow/ Hydrodynamic Model: The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary. This regional model (SWRM) is one of the six regional models of Bangladesh developed at IWM. It is basically a river network model, which has been developed, calibrated and validated and continuously updated for the last 25 years at IWM. The SWRM is based on MIKE11 modelling system.

The MIKE 11 hydrodynamic (HD) module solves an implicit, finite difference scheme to compute unsteady flows in rivers and estuaries. The module can describe sub-critical as well as supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). Advanced computational modules are included for description of flow over hydraulic structures, including possibilities to describe structure operation. The formulations can be applied to looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable for vertically homogeneous flow conditions extending from steep river flows to tidally influenced estuaries. The system has been used in numerous engineering studies around the world.

The SWRM is bounded on the north by the Ganges and the Padma River, on the east by the Lower Meghna and Shahabazpur River, on the west by the Indian border and on the south by the Bay of Bengal. The regional model covers approximately 37,330 km2 area and the length of rivers/channels is around 5,600 km. Most of the rivers of the southwest area of Bangladesh are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow during dry season, but act as tidal channels for tides originating in the Bay of Bengal.

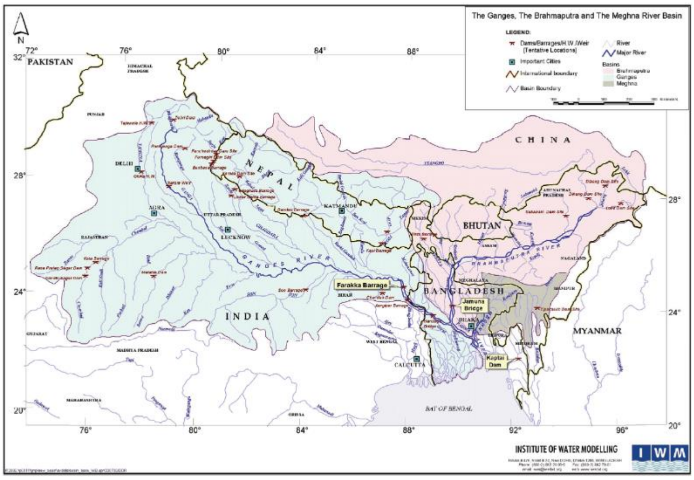


One Dimensional Salinity Model: MIKE 11 advection-dispersion (AD) module computes the salt transport in a river system. The module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material, i.e. the advection-dispersion equation. The module requires output from the hydrodynamic module, in time and space, in terms of discharge and water level, cross-sectional area and hydraulic radius. The advection-dispersion equation is solved numerically using an implicit finite difference scheme, which, in principle, is unconditionally stable and has negligible numerical dispersion.

GBM Basin model

Geographic extent of GBM (Ganges Brahmaputra and Meghna) Basin

The Ganges-Brahmaputra-Meghna (GBM) river basin distributed between India (64 percent), China (18 percent), Nepal (9 percent), Bangladesh (7 percent) and Bhutan (3 percent). Nepal is located entirely in the Ganges river basin and Bhutan is located entirely in the Brahmaputra river basin. The GBM river system is considered to be one transboundary river basin. Three major rivers of this system have distinct characteristics and flow through very different regions.



The headwaters of both the Ganges River and the Brahmaputra River originate in the Himalayan mountain range in China. The Ganges River flows southwest into India and then turns southeast, being joined by many tributaries. After flowing into Bangladesh, the Ganges, Brahmaputra and Meghna rivers join and flow into the Bay of Bengal as the Meghna River. The Brahmaputra river (known as Yalung Zangbo in China) flows east through the southern area of China, then flows south into eastern India, turns southwest, then enters Bangladesh (where it is also called Jamuna) before merging with the Ganges and Meghna rivers. The tributaries of the Meghna River originate in the mountains of eastern India (the main one called Barak), flow southwest and join. The Meghna River flows southwest and joins the Ganges and Brahmaputra rivers before flowing into the Bay of Bengal (McEwen, 2008). These three individual river is big, each of them also has tributaries that are important by themselves in social, economic and political terms, as well as for water availability and use. Many of these tributaries are also of a transboundary nature (Biswas, after 2006). The GBM river system is the third largest freshwater outlet to the world’s oceans, being exceeded only by the Amazon and the Congo River systems (Chowdhury and Ward, 2004).

GBM Basin model

The GBM basin model covers the Ganges, the Brahmaputra and the Meghna Basin and their important tributaries. It was originally developed at FFWC, BWDB in 2005 and the latest development was carried out by IWM. The model is developed based on MIKE BASIN, the GIS based water resource modelling package developed by DHI Water & Environment. At this stage, the model includes 133 sub-catchments, out of which 79 are in the Ganges basin, 47 in the Brahmaputra basin and the remaining seven are in the Meghna Basin. Area included in the Ganges, Brahmaputra and Meghna Basin is 979,503 sq. km, 520,663 sq.km and 26,567 sq. km, respectively.

The model includes snow melt feature in the snow fed catchments of Hindu-Kush Himalaya region. Since the glacier melt component is still under development, it will be incorporated future. Lumped features of the water retention and control structures (reservoirs and dams) within India are incorporated in the model. The diversion of water through Bhagirathi and the Hooghly River is not added in the model.

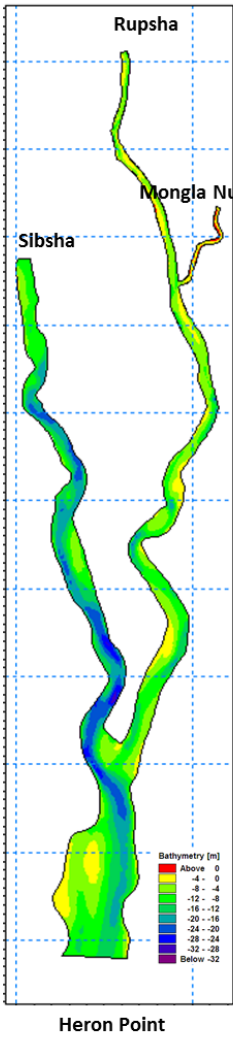
The model is calibrated at outlet stations such as Hardinge Bridge on the Ganges and Bahadurabad on the Brahmaputra inside Bangladesh. The performance of the model could not be tested within India due to non-availability of measured data.

Pussur-Sibsa River Model

The mathematical modelling tool applied for Pussur-Sibsa river system was MIKE 21 FM (Flexible Mesh), a two dimensional modelling system of DHI Water•Environment•Health based on flexible mesh approach. The morphological models for Pussur-Sibsa river system were developed by IWM to assess the change in river morphology under base and Climate Change. The Model has been updated with the recent bathymetry data which has been collected year 2011 under the GRRP study.

The Pussur-Sibsa model has two upstream boundaries and one downstream boundary. Upstream boundaries were collected from calibrated and validated South West Regional Model and measured water level of Hiron Point was used as downstream boundary.

As the bed sediments are non-cohesive in nature in the river systems, non-cohesive sediment transport models were developed for the river systems. Sand Transport module of MIKE 21 FM was used for the development of sediment transport/morphological model. The ST Module calculates sand transport rates on a flexible mesh (unstructured grid) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) together with information about the characteristics of the bed material.

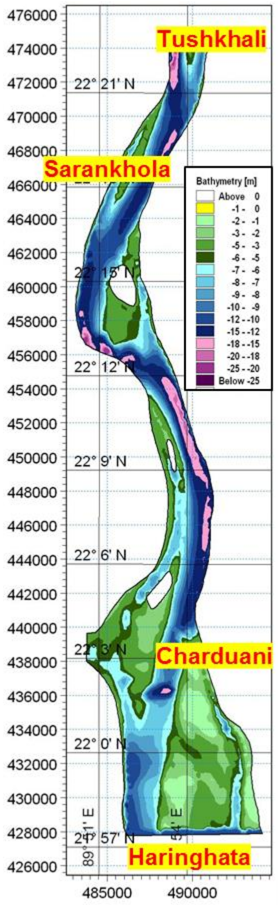


Baleswar River Model

The morphological models for Baleswar river system were developed by IWM to assess the change in river morphology under base and Climate Change. The Model has been updated with the recent bathymetry data which has been collected year 2011 under the GRRP study.

The Baleswar River model has one upstream boundary which was collected from calibrated and validated Southwest Regional Model and one downstream boundary which was collected from calibrated and validated Bay of Bengal Model.

The sediments are non-cohesive in nature in the river system, non-cohesive sediment transport models were developed for the river system. Sand Transport module of MIKE 21 FM was used for the development of sediment transport/morphological model. The ST Module calculates sand transport rates on a flexible mesh (unstructured grid) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) together with information about the characteristics of the bed material. The sediment transport model was also calibrated make it more reliable for further use. The models were calibrated against suspended sediment concentration both in the Baleswar river system.

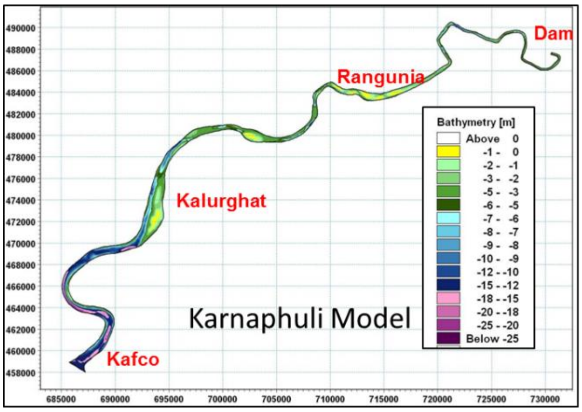


Karnaphuli River Model

The modelling system used for the development Karnaphuli two dimensional Model is MIKE21 FM, which is based on an unstructured flexible mesh consisting of quadrilateral and triangular elements. The mesh enables to increase the resolution of grid at and around the area of interest.

The model has two open Boundaries. Flow of Kaptai Release has been used as upstream boundary whereas water level data of Khal no -18 used as downstream boundary. The two-dimensional Karnaphuli model has been updated with recent bathymetric chart data.

The two-dimensional hydrodynamic and morphological models of Karnaphuli River system were developed to assess the erosion-sedimentation pattern in the Karnaphuli River. As the bed sediments are non-cohesive in nature both in the upstream (kaptai) and downstream (kafco), non-cohesive sediment transport models were developed under this project for both the river systems. The MIKE 21 Flow Model FM, Sand Transport was used to develop the sediment transport/morphological model. It is the module for the calculation of sediment transport capacity and related initial rates of bed level changes for non-cohesive sediment (sand) due to currents or combined waves-currents.



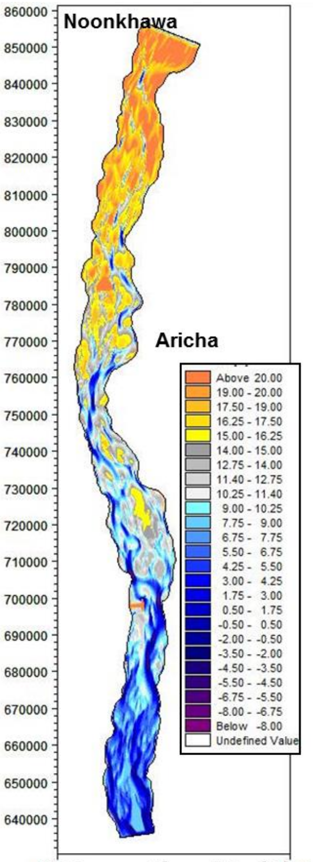
Jamuna River Model

The total length of Jamuna River is almost 240km that starting from Noonkhawa and ends at Aricha. In the Bangladesh reach, it has a major right-bank tributary: the Teesta and two left bank distributaries: the Old Brahmaputra River and the Dhaleswari River. The whole model has been hydro-dynamically and morphologically calibrated against the year of 2011.

The curvilinear grid has been generated based on the bankline surveyed in post-monsoon of 2011. The grid has the dimension of 550 grid points along the river and 127 grid points across the river, i.e. 69850 grid points in total. The grid has land boundaries as well. The model simulates the hydrodynamic and morphological parameters in every computational grid point. The bathymetry of the model has been prepared based on data from the IWM bathymetric survey carried out during post-monsoon 2011.

The two-dimensional model has one upstream discharge boundary and one downstream water level boundary. The boundary conditions have been established from observed data and one-dimensional model simulation results for the year of 2011.

The hydrodynamic calibration mainly involves adjustment of two important hydrodynamic parameters namely eddy viscosity and bed resistance (Chezy). The sediment transport model domain is compared with the observed sediment discharge data. The calibration of the morphological model requires mainly specification of sediment grain size, suitable sediment transport predictor and alluvial roughness.



Jamuna River Model

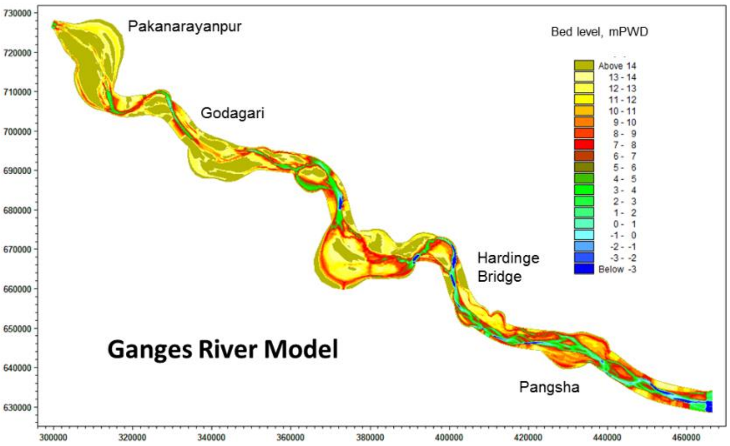
Ganges River Model

The total length of Ganges River is almost 170 km that enters into Bangladesh through Pakanarayanpur of Chapai Nawabganj district and ends at the confluence of Aricha. To reduce the complexity of model domain, the contributions of the distributaries of this river have been ignored. The whole model of Ganges River has been hydro-dynamically and morphologically calibrated against the year of 2011.

The curvilinear grid has been generated based on the bankline surveyed in post-monsoon of 2011. The grid has the dimension of 569 grid points along the river and 54 grid points across the river, i.e. 30726 grid points in total. The grid has land boundaries as well. The model simulates the hydrodynamic and morphological parameters in every computational grid point. The bathymetry of the model has been prepared based on data from the IWM bathymetric survey carried out during post-monsoon 2011.

The two-dimensional model has one upstream discharge boundary and one downstream water level boundary. Another major distributary Gorai is also added in the calibration boundary. The boundary conditions have been established from observed data and one dimensional model simulation results for the year of 2011.

Hydrodynamic calibration is done with the fixed bed model. Water level calibration has been done at four different locations of Ganges River. The hydrodynamic calibration mainly involves adjustment of two important hydrodynamic parameters namely eddy viscosity and bed resistance (Chezy).



The calibration of the morphological model requires mainly specification of sediment grain size, suitable sediment transport predictor and alluvial roughness. In case of grain size specification, single grain size (d50 =0.15 mm) have been considered that varies spatially. From the experience in dealing with the rivers of Bangladesh in other past studies, it is found that Englund-Hansen sediment predictor provides satisfactory results. The sediment transport in this model domain is compared with the observed sediment discharge data.

Padma River Model

The total length of Padma River is almost 112km that starts from Aricha and ends at the Chandpur. However, only 90km reaches is considered as the model domain. It has only one distributary along the right bank named Arial Khan at

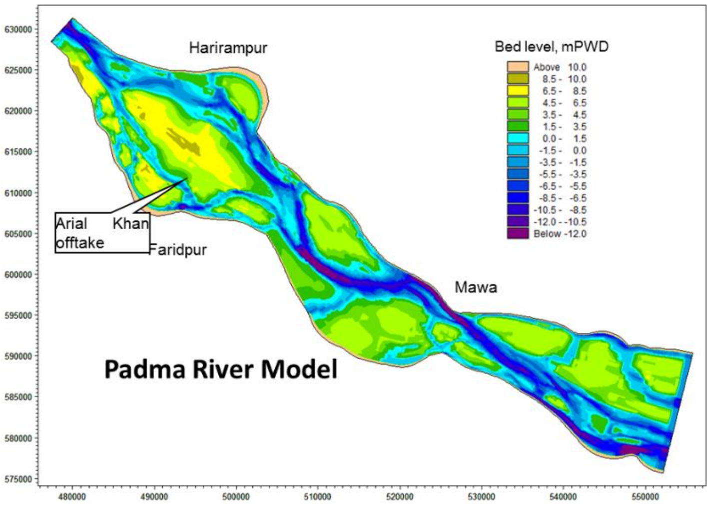
Chowdhury Char. The model has been hydro-dynamically and morphologically calibrated against the year of 2011.

The curvilinear grid has been generated based on the bankline surveyed in post-monsoon of 2011. The grid has the dimension of 366 grid points along the river and 92 grid points across the river, i.e. 33672 grid points in total. The grid has land boundaries as well. The bathymetry of the model has been prepared based on data from the IWM bathymetric survey carried out during post-monsoon 2011.

The two-dimensional model of Padma River has one upstream discharge boundary at Baruria and one downstream water level boundary. The boundary conditions have been established from observed data and one-dimensional model simulation results for the year of 2011.

Hydrodynamic calibration is done with the fixed bed model. Water level calibration has been done at Mawa station in Padma River. The hydrodynamic calibration mainly involves adjustment of two important hydrodynamic parameters namely eddy viscosity and bed resistance (Chezy).

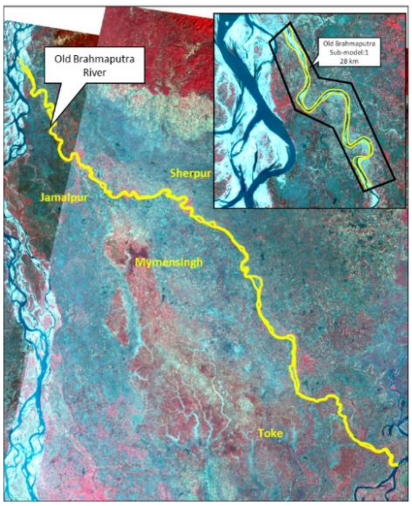
The main purpose of the use of the morphological model is to assess the morphological conditions of the rivers. The calibration of the morphological model requires mainly specification of sediment grain size, suitable sediment transport predictor and alluvial roughness. From the experience in dealing with the rivers of Bangladesh in other past studies, it is found that Van Rijn sediment predictor provides satisfactory results. The sediment transport in this model domain is compared with the observed sediment discharge data.



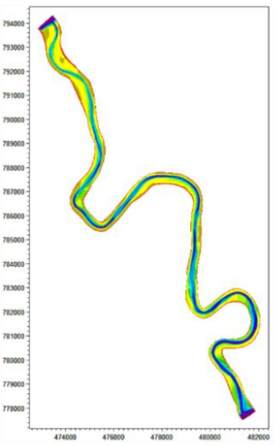
Old Brahmaputra River Model

The total length of Old Brahmaputra River is almost 265km that starts from left bank of Brahmaputra-Jamuna River at Gaibandha district and ends at Upper Meghna River near the Bhairab Bazar. It is quite complicated to develop a single model through MIKE 21C for this whole river. In addition, this river has several tributaries and distributaries which formed into a complex network of river. Hence, this model has been divided into nine sub-models to ease the complexity. Each sub-model has been hydro-dynamically and morphologically calibrated against the year of 2011. The curvilinear grid has been generated based on the bankline surveyed in post-monsoon 2011.

The full model extent of Old Brahmaputra River



Model bathymetry of Old Brahmaputra Sub-model 1



A.1.3.2.3 Activities

The following activities will be carried out:

a) Selection of Polders to be modelled

The Polders to be modelled will be selected in close consultation with BWDB. Issues to be considered are data availability, to which extent the polders are representative, etc. It is suggested to select three polders; one located close to the Bay of Bengal, one of the most upstream polders (with less tidal influence) and an intermediate polder, and possibly a polder subjected to diminishing upstream fresh was flows.

An obvious polder to select is Polder 24 where TRM has been implemented. It seems that pre and post TRM topographical data are available, however, it remains to be investigated whether sufficient data are available for the modelling (see below).

To avoid duplication of efforts it is also suggested to select one or more of the models developed under CEIP-1). The CEIP-1 models will have to be extended with smaller peripheral rivers in order to simulate siltation of these.

b) Identification of data needs and data gaps

The data required for the modelling exercise can be divided into setup data, boundary data and calibration data.

Setup data includes DEM of the polder, dimensions and type of all drainage and flushing structures as well as cross-sections of the peripheral rivers.

Boundary data includes time series of precipitation, the tidal discharge and river flow, tidal water levels, salinity, suspended sediment concentrations, and composition of the sediment in suspension. The time series selected are representative of the design events used in the simulations. The information can be based on either survey data or extracted information from the meso scale model. The meso scale model results will not be available from the start of the project and therefore the existing SW Regional Model will be used to generate boundary conditions that will be update if necessary when the meso scale model is available. Data must as a minimum cover a neap and spring cycle in both the dry and wet season.

Calibration data will be similar to the boundary data but from locations inside the model domain. In addition, a post DEM will be required for simulation of TRM and post siltation cross-sections in the peripheral rivers. If the latter is not available, information on dredging/excavation of the peripheral rivers may be used.

Existing data will be reviewed, and data gaps identified. If feasible, this will lead to a proposal for adjustments to data collection programme

c) Model setup, calibration and validation

A micro model of a polder will include modelling of:

Rainfall-runoff processes to generate local runoff inside the polders. For this purpose the existing rainfall-runoff model of the SW Regional Model-3 will be used.

Water levels and flows through a hydrodynamic model that will include cross-section data of the internal drainage channels and existing water control structures within the polder area including detailed catchments distribution for the internal drainage channels and peripheral river systems for representation of the polder drainage system. All structures will be modelled in 1D, internal drainage channels in either 1D or 2D (as needed) while the peripheral river system will be modelled in 2D only when channel migration and bank erosion become important factors.

Salinity and sediment transport through advection-dispersion modelling which will use the same discretization as the hydro-dynamic component

d) Simulation of Polder Management Strategies

Polder Management Strategies or scenarios have to be tested on various aspects and corresponding “design events” needs to be specified and used for generating boundary conditions for the models:

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[3] If the selected polder is in another region, the corresponding Regional Model will be used.

First of all, the polder drainage system has to demonstrate that it has sufficient drainage capacity. To this end hydro-meteorological design events should be defined. In general, 5-days 10-year rainfall event is considered by BWDB for water management projects. This was also used in CEIP-1 and the same hydrological criteria are proposed to be used here also.

Secondly, the scenarios should be investigated for how siltation in peripheral rivers develops. The time scale for this is larger and it is proposed to test this for a full year to cover both monsoon and dry season flows and corresponding sediment transport conditions. Data representing a typical year will have to be identified.

A.1.3.2.4 Deliverables

The output of "*Morphology on a Micro Scale"* are envisaged to be

a) Once the model has been calibrated and verified the model setup and calibration/verification will be documented in a technical report with detailed explanation of the methodology and assumptions.

A report that describes the pros and cons of the different methodologies to prevent water-logging within the polder and sedimentation of tidal river system including polder subsidence. The report will include meta-data on the models used and measurements, recommendations for polder design including drainage and long-term management plan, and recommendations for pilot area/polder to implement the ideas, such as but not limited to location, methods and measurements

It will also recommend a plan to manage sediment at the downstream stretch of the tidal river and in the polder.

A.2 Subsidence

A.2.1 Objectives

Subsidence affects all deltas worldwide (e.g., Syvitski et al., 2009). It originates from a variety of processes including lithospheric cooling, faulting, isostatic loading by tectonic motions and the weight of the sediments, compaction and dewatering of sediments, and oxidation of organic matter (e.g., Steckler et al., 1988). Subsidence lowers the elevation of the land and thus constitutes a risk for sustainability of polders over time. It is critically important to understand the net effects of the combination of subsidence, sea level rise, sedimentation (including lateral migration of rivers) on polders to evaluate their sustainability.

Published results from Bangladesh suggest both very high rates of up to 18 mm/yr (Syvitski et al., 2009) and low rates of 0-2.5 mm/yr (Sarker et al., 2012). A recent analysis of subsidence rates over the Holocene (last 10,000 years; Grall et al., 2018) revealed a systematic variation of subsidence rates across the delta. In SW Bangladesh subsidence increase from near zero rates landward of the Hinge Zone to 4.5 mm/yr at the southern coast of Bhola Island. However, the work of Grall et al. (2018) had very limited data from our study area and further information is needed to better define long-term subsidence rates. These results indicate that subsidence rates can be even larger than the rates of sea level rise and of critical importance to designing sustainably polders.

On the shorter time scale, there appear to be greater variability in subsidence rates. Fine-grained sediments show greater subsidence rates due to relatively near surface compaction of the Holocene muds. However, the rate and patterns are poorly known. Additional measurements distributed throughout the study area are needed to understand the distribution of subsidence and its relationship to the underlying sediment types.

A.2.2 Approach

A.2.2.1 General Approaches

We propose several different types of measurements to measure the rate and distribution of subsidence across the study area. For the long term rates, we need additional drilling and analysis of tube wells that focus on subsidence rates and environmental changes in the study area. For short-term direct measurements, we need a combination of GPS measurements, surface elevation tables – marker horizons (SET-MH) and Interferometric synthetic aperture radar (InSAR).

Tube well sediment sample analysis, in conjunction with C14 and OSL dates provide a record of the history of sediment accumulation and environmental changes across the field area. This record can be further analysed to obtain long-term subsidence rates. Fixed GPS antennas with advanced processing can provide position estimates to ±2 mm in the horizontal and ±6 mm in the vertical. After years of observations, subsidence rates to ±1 mm/yr can be estimated. SET-MH provide both changes in surface elevation and sediment accumulation rates that can be differenced to obtain subsidence rates relative to the bottom of the monument, a rod driven to the depth of refusal. Co-locating GPS and SET-MH can then be used to separate shallow compaction from deeper components of subsidence. Both GPS and SET-MH provide detailed spot measurements of subsidence. InSAR, in conjunction with GPS to calibrate the images, provide a spatial image of the subsidence in an area.

The combination of multiple methods will provide the best estimate of the rate and distribution of subsidence rates in the region.

A.2.2.2 Existing Work

Brown and Nichols (2015) compiled over 200 measurements of subsidence in the delta. However, by mixing multiple types of measurements with insufficient constraints on the settings of them, they obtains subsidence rates that varied from 44 to -1 mm/y, including broad ranges of values are individual sites. Grall et al. (2018) estimated subsidence rates over the delta using >400 tube wells with almost 200 C14 dates, analyzing the data to separate sediment accumulation, sea level rise and subsidence. However, only a limited amount of data from SW Bangladesh was included in the analysis. We have already established 5 GPS in the field area at Patuakhali (PUST), Khepupara (KHEP), Polder 32 (PD32), Khulna (KHUL and KHL2), and Hiron Point (HRNP). PUST and KHUL were established in 2003, but the old instrumentation only provides intermittent data. KHUL was replaced by KHL2 in 2014. The other stations were installed in 2012.

Four SET-MH were established in 2014 in the vicinity of Polder 32: two within the polder near the village of Shrinagar, and two within the Sundarbans forest. Four more SET-MH were installed in 2015 and 2017 in the Sundarbans and Polder 32, respectively. These monuments have been measured seasonally, and results from this region indicate that elevation gain within the Sundarbans approximates 20 mm/yr, exceeding that of average relative sea-level rise estimates. and more closely following the range of local effective sea-level rise. Corresponding rates of elevation change in the embanked and hydrologically-disconnected poldered landscape (24 mm/yr) also appear to exceed rates of effective sea-level rise, though this may be due to localized sedimentation events near leaky sluice gates. Shallow subsidence measured using these instruments averaged 10.2 ± 5.2 mm/yr in the Sundarbans, and 10.9 ± 10.3 mm/yr within Polder 32 (Bomer et al., submitted). In addition, two new SET-MH were installed in July 2018 at Katka in the Sundarbans, but no measurements have been collected at this site to date. This study will provide more spatial variability, having instruments deployed both within the polder interior as well as outside embankments on river terraces, and in several different regions of coastal Bangladesh.

We also established an optical fibre compaction meter at Bhanderkote, south of Khulna in 2011. We have 5 wells from 20-300 m depth with stretched optical fibres, whose length has been measured weekly. However, dredging of the river at the site in 2015 my have disrupted the fibres. Problems with the computer system for the measurements means measurements have not been made since the dredging. Higgins et al. (2014) analysed 18 scenes from the Japanese ALOS satellite for 2007 to 2011 to provide subsidence rates in the Dhaka-Comilla region. The ALOS satellite uses L-band radar, which is less sensitive to vegetation, which is a major issue limiting InSAR use in Bangladesh, but suffers from orbital drift. The GPS was used to calibrate the interferograms to convert from relative to absolute deformation.

A.2.2.3 Activities

Coring Activities – To better understand how the delta components and its influences define the system’s behaviour, we will reconstruct a detailed and up-to-date history and sediment budget for the delta. The effort will begin with a major stratigraphic database previously collected by Goodbred and Steckler and comprising >400 sediment cores and >15,000 sediment samples from the upper delta and Sylhet basin (green points on Figure). Through the current contract, we will add another 80 cores to the lower deltaplain to develop a completed 3D reconstruction of coastal delta stratigraphy. Sedimentological analyses on these samples, including XRF geochemistry, magnetic susceptibility, laser-diffraction particle size, optically stimulated luminescence and radiocarbon dating, will be used to establish the location of the river channels through time,

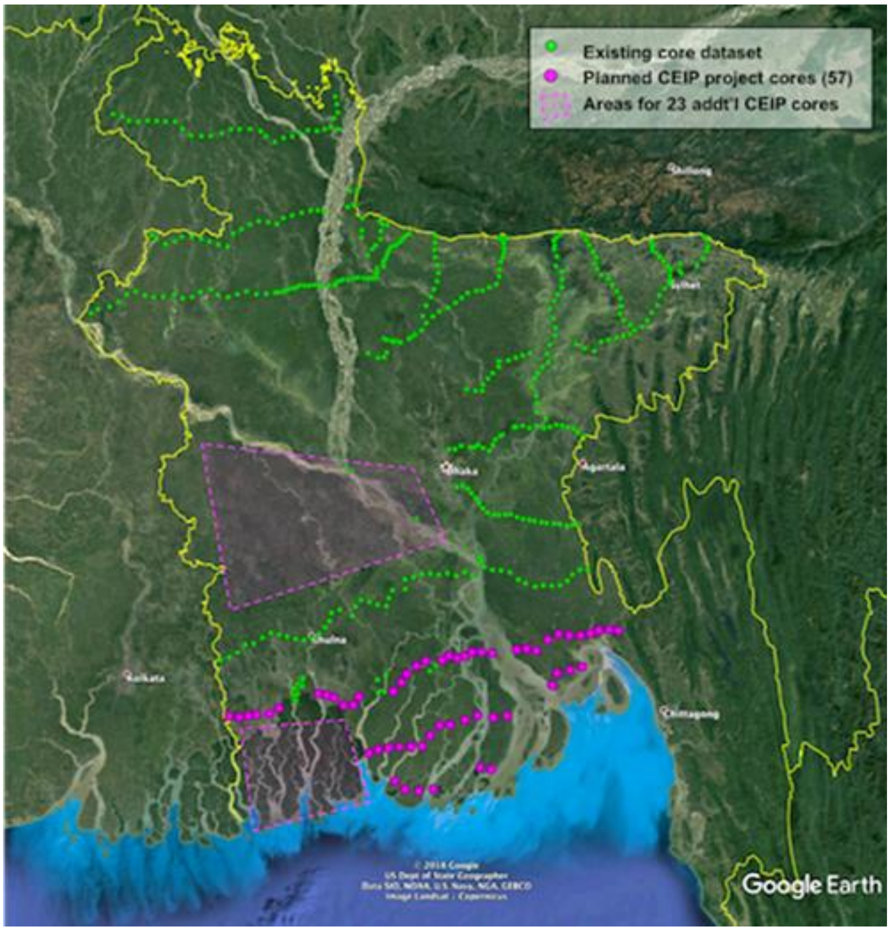


Figure A- 3: Location of >400 Holocene cores collected via the BanglaPIRE study by Goodbred, Steckler, and colleagues (green dots). Location of planned core sites for the World Bank/BWDB CEIP project (magenta dots), and additional areas for further coring as possible. Together these samples and resulting data will be used to develop a comprehensive sediment budget, geologic history, and delta-behavior model for the Bengal basin and Ganges-Brahmaputra River delta.

Sedimentological analyses on these samples, including XRF geochemistry, magnetic susceptibility, laser-diffraction particle size, optically stimulated luminescence and radiocarbon dating, will be used to establish the location of the river channels through time including where and when they have avulsed, and what type and how much sediment they deposit. With new data and technology (e.g., use of strontium concentration as a provenance tracer for each river), the resulting products will be considerably more advanced than the existing geologic history available in the literature. Recent papers from our research group that apply these new approaches include (Goodbred et al., 2014; Pickering et al., 2014; Chamberlain et al., 2017; Sincavage et al., 2018)

The sediment mass balance will be developed from the core database by using conservation-of-mass principles between the riverine source inputs and total sediment volume deposited. The previous and new core data will allow us to develop a more precise budget in time and space. Furthermore, because of our provenance tools, we will provide independent sediment budgets for the Ganges and Brahmaputra rivers, plus other local source inputs from Sylhet and the foldbelt regions.

Elevation and Subsidence using GPS, SET-MH, and InSAR – The number of continuous GPS (cGPS) units to be purchased and deployed in this project was reduced from 7 to 4. However, we have one additional available unit, so we will deploy 5 GPS at four sites. At each site, the GPS will be co-located with SET-MH sites to provide multiple measurements of subsidence (shallow and deep), termed culminating in a subsidence supersite (sensu Allison et al., 2016). We will upgrade the GPS at Patuakhali (PUST), replacing the obsolete receiver and antenna. We will deploy two new GPS at Polder 35/1. One will be installed on the roof of a reinforced concrete building, likely a school, similar to our other GPS for consistency. The other will be mounts on a rod driven to refusal to match the SET-MH installation and provide a direct comparison. The other two sites will be established at Polder 15 and 16 (or possibly Polder 2). In addition, we will install new cellular modems at our existing sites to enable remote downloading of the data.

At the end of the project, subsidence estimates at the new sites will have limited accuracy due to the short length of time. We will improve the estimate by using BWDB water level data to model to seasonal loading, increasing the accuracy. The GPS will also act as reference sites for all other position measurements in the region, improving their accuracy. In order to provide a more robust estimate of subsidence, we will make campaign measurements of the ~60 geodetic benchmarks in the region established by the Survey of Bangladesh (SoB) in conjunction with JICA. These were established in 2002 and thus record over 16 years of subsidence. We will use 4 GPS to measure positions for 3 days at each site and correct both the original and new measurements for the seasonal signal. The cGPS will provide nearby reference stations to increase accuracy. Even if many of the benchmarks are not useable, this campaign measurements will greatly densify the subsidence control points enabling us to determine the pattern of subsidence in the region.

The number of new SET-MH units to be purchased and installed for this project was reduced from 24 to 16. These instruments measure short-term and seasonal elevation change, sediment vertical accretion, and shallow subsidence. Study areas will be co-located with the new GPS installations, as described above. At each study area, two SET-MHs will be installed, one inside the polder of interest, and one outside on the non-embanked river terrace. An additional SET-MH will be installed within the Sundarbans to record sedimentation within the natural tidal delta plain for comparison. New SET-MHs sites will include: i) near the existing GPS at Patuakhali (PUST) (Polder 43), ii) Polder 48, iii) Polder 35/1, iv) Polder 16 or 17/1, v) Polder 14/1 or 15, and vi) at Hiron Point in the Sundarbans near an existing GPS location. For each installation, a stainless steel rod will be driven to the depth of refusal, creating a benchmark on top of which an SET receiver will be installed. These installations will be accomplished using personnel from LSU, Columbia University, IWM, BWDB, and Dhaka University. Trainees will receive instruction on the installation and subsequent measurement and data analysis procedures. Measurements will be taken on a seasonal basis, ideally after the monsoon season (Oct-Nov), and after the dry season (Mar-May). At the end of the project, shallow subsidence estimates at the new sites will have limited accuracy due to the short length of time, however, we can improve the estimates by comparing with the existing SET-MHs already in operation (Polder 32 and Katka).

We will examine the compaction meter at Bhanderkote to determine if it can be fixed. If so, we will restart the weekly measurements made by the local host family. We will visit the site yearly to collect the data and conduct optical levelling between the 5 wells.

A.2.2.4 Deliverable

a. *Literature survey on subsidence in the polder area of the coastal zone, more specific on the (neo) tectonics and compaction*

We will conduct a literature review of all available data on subsidence, compaction and neotectonics of the Bangladesh coastal zone, with careful evaluation of the accuracy of the measurements. The published data will be supplemented by our as yet unpublished data.

b. *Make an inventory of natural and anthropogenic causes of near-surface compaction, estimate its rate and their contribution to the total subsidence in the study area of the coastal zone at present and for over 25, 50 and 100 years.*

We will make an inventory of natural and anthropogenic causes of compaction applicable to SW Bangladesh. We will evaluate the rate of compaction due to these causes and estimate their contribution to the total subsidence in the regions of the polder area of the coastal zone. Information on soil type, drainage practice, natural and anthropogenic causes of compactions will be used to constrain the model. This information will be used to understand the active processes and better project these estimates forward to 25, 50 and 100 years from now.

c. *Use our subsidence measurements to model the subsidence in the field area.*
We will use our measurements of subsidence using GPS geodesy, InSAR, SET-MHs, the KHLC compaction meter, subsidence of historic sites and dated sediment cores to estimate subsidence rate variations over space and time in SW Bangladesh. Measurements will take place over the entire length of the project. We will use these measurements to create a subsidence model to estimate the subsidence rates in the study area and estimated total subsidence for 25, 50 and 100 years from now.

A.3 Meteorology

A.3.1 Objectives

The objectives of this sub component are to 1) Identify current trends in rainfall, temperature, in Bangladesh and in the different zones of the coastal area and in cyclone frequency and intensity, 2) Estimate future changes in rainfall, temperature and cyclone frequency & intensity considering climate change

It has repeatedly been reported that rainfall figures are changing, such as more "erratic" rainfall and a possible shift from four to three seasons (monsoon and post monsoon are more or less one) as the monsoon period is delayed but lengthened. At this moment, there is no significant drought problem in the coastal area but due to changing rainfall figures, this could change when periods without rain lengthen. Statistical processing of data can shed light on these processes.

This component will provide valuable information to be used as input towards new updated conceptual designs of polders (Sub-components 5.A and 6.1).

A.3.2 Approach

A.3.2.1 General Approach

This Component will be sub-divided in three main activities as follow:

- Activity 1 : Assessment of the changes in rainfall patterns, including annual rainfall, monsoon rainfall, and temporal and spatial distributions in the polder area of the coastal zone, based on historical data
- Activity 2: Assess the changes in frequency and intensity of cyclones based on historical data.
- Activity 3: Compute future scenarios for rainfall, temperature and cyclone frequency and intensity for the next 25, 50 and 100 years by downscaling global climate models (Statistical and Dynamic downscaling).

A detail description of the work to be carried out under each activity is provided under Section Existing Work

The effect of global climate change on the frequency and strength of tropical cyclones has been considerably studied in the past often with conflicting results. Large fluctuations in frequency and strength in the past makes this a complicated task and the findings show large variations between different modelling studies (Knutson et. al., 2010). The task is made more complicated by the fact that most Global Climate Models (GCMs) that are being used to determine climate change effects do not have sufficient resolution to allow prediction of Tropical Cyclones. The literature review (Component 2) will therefore include frequencies and strength of tropical cyclones.

Statistics analysis on tropical cyclone, best track data (IBTrACS) database from National Climatic Data Centre, will be performed to confirm the present frequency analysis that is presented in the literature.

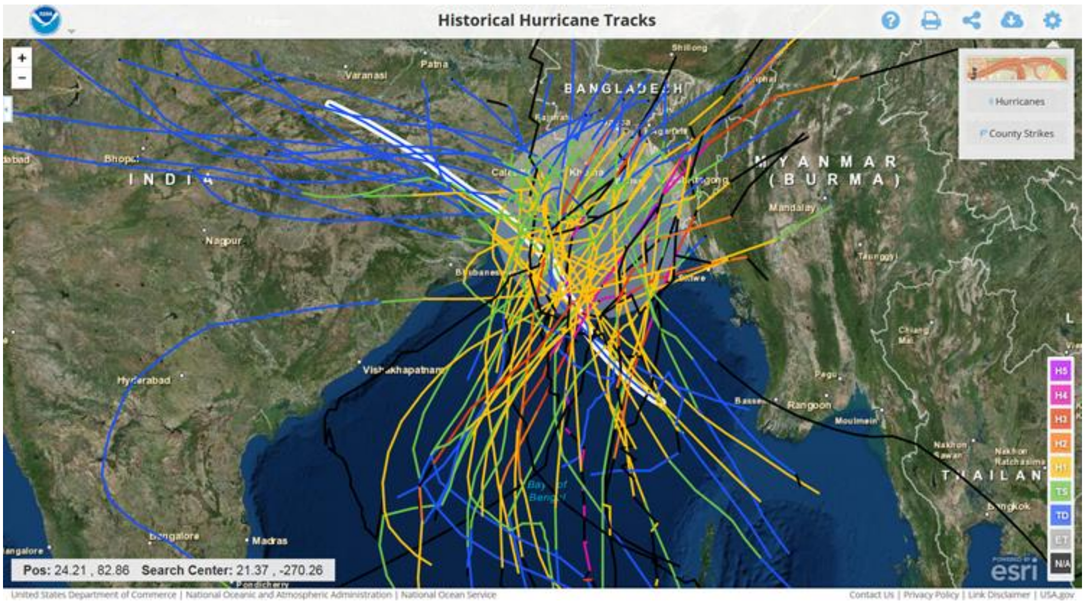


Figure A- 4: Overview of tropical cyclones that has made landfall in or near Bangladesh since 1878 (source: NOAA).

A.3.2.2 Activities

Activity 1: Assessment of the changes in rainfall patterns, including annual rainfall, monsoon rainfall, and temporal and spatial distributions in the polder area of the coastal zone, based on historical data

Key rainfall indicators like annual rainfall, total monsoon rainfall and annual maximum daily rainfall will be derived from historical data sets. Subsequently, four statistical tests for series homogeneity will be applied to these indicators: Pearson’s t-test, Spearman’s rank correlation test, Mann-Kendall’s test and the Wilcoxon-Mann-Whitney test (see text box below for an explanation). These tests will show if observed trends in rainfall are statistically significant.

Furthermore, spatial and temporal correlation of rainfall and changes of these correlations in time will be quantified in order to identify if changes in temporal and spatial distributions in the study area and in the different polders are statistically significant.

Statistical tests explained

Pearson t-test (linear trend test)

The classical Student's t-test evaluates the Pearson correlation coefficient between the values of the annual values and their years of observation. Correlations deviating significantly from zero are indicators for a trend in the data and, hence, indicators for non-homogeneity.

Spearman's rank correlation test

This test is the non-parametric analogue of the Pearson t-test.

The test statistic is Spearman's rank correlation between the annual values and their years of observation.

Mann-Kendall test

The Mann-Kendall test (Mann, 1945; Kendall, 1975) is a non-parametric significance test for a monotonic trend in a time series. This test compares the ranks for all pairs of annual values. The test statistic τ is the difference between the number of pairs that support a positive trend and the number of pairs that support a negative trend, divided by the standard deviation. If Significant test statistic τ deviates significantly from zero, this indicates non-homogeneity.

Wilcoxon-Mann-Whitney test The Wilcoxon-Mann-Whitney test (Wilcoxon, 1945, Mann and Whitney, 1947) is a non-parametric test for two independent samples. The WMW test can be used for trend analysis by splitting the time series into a first and second half and testing the null hypothesis that the two sub-sets are taken from the same distribution. The test statistic is the sum of the ranks of the elements in each sub-set. Significant differences between the two subsets is an indicator for non-homogeneity.

Activity 2: Assess the changes in frequency and intensity of cyclones based on historical data.

Similar statistical tests for series homogeneity will be applied to observed intensities of historical cyclones in the area around the Bay of Bengal. We will also test for the stationarity of inter-arrival times of cyclones, using the statistical theory of renewal processes, to verify if there is evidence of a statistically significant increase in the frequency of occurrence of cyclones.

The number of cyclones higher than or equal to category 1 that is stored in the NOAA database amounts up to 69, counted from the year 1887 onwards. The coastal area, which lies relatively low, is extremely vulnerable to the storm surges caused by these cyclones.

Activity 3: Compute future scenarios for rainfall, temperature and cyclone frequency and intensity for the next 25, 50 and 100 years by downscaling global climate models (Statistical and Dynamic downscaling).

We will apply a meteorological forcing for future climates, based on Global Circulation Model (GCM) data. As the uncertainty resulting from individual GCMs is large, we will use an ensemble of GCM outputs, as for examples the product obtained from the ISIMIP project (Hempel et al., 2013). The GCM data will be bias corrected to make them comparable with the reference run for current climate conditions. Similar bias corrections have been carried out in the past for the globally available data set EUWATCH (http://www.EUWATCH.org/), see Hempel et al., (2013). The EUWATCH bias correction factors will be adopted here. Alternatively, for tropical cyclones changes in frequency and intensity based on historical data and derived under Activity 2, may be extrapolated towards the future.

A.3.2.3 Deliverable

1. Technical Report describing current trends and future scenarios in rainfall in the polder area of coastal zone for four, coastal regions (including estimation of rainfall distribution over the year) and cyclone frequency and intensity for the next 25, 50 and 100 years from now, including meta-data of the datasets used for the trend analyses and stored and archived in Database of BWDB. The Research Team will include a description of the statistical and downscaling methods used for reproducibility reasons.
2. Geospatial Dataset and archived in Database of BWDB.

Prerequisite of this Task is the information which will become available during literature review (Component 2) and the development of Input datasets for modelling (Component 3). The output from this task will serve as input to sub-components 4A-3, 5A, and 6.1 (update of parameters for design of sustainable polders).

The work will be carried out by the following experts, with the following time distribution:

No.	Name	Position	Months	Time input	
INK-11	Dr. Alessio Giardino	Climate Change Risk Assessment and Adaptation	3 - 12	[Home]	1
				[Field]	1.5
INK-28	Dr. Ferdinand Diermanse	Statistical Analysis of Meteorological Data	3 - 12	[Home]	1.75
				[Field]	0
INK-10	Henrik Rene Jensen	Storm Surge & Wave Specialist	3 - 12	[Home]	0.3
				[Field]	3.7
NK-39	Md Saiful Inslam	Storm Surge &Modelling Wave Specialist	3 - 27	[Home]	20
				[Field]	4.0

The deliverable of this will Component (report + dataset) will become available in Draft Format after Month 9 and as Final Version after month 12.

A.4 The effect of climate change on water levels, salinity intrusion and storm surges

A.4.1 Effect on Water Level

A.4.1.1 Objectives

The objective of this sub-component is to derive scenarios for sea level rise up at 25, 50 and 100 years from now (and/or up to the end of the century) and which can be used as input to assess the medium- and long-term morphological development of the Bangladesh delta (Component 4A), and possible effects on water levels and salinity intrusion (Component 4C and 4D). Additionally, this information will be used to derive innovative concepts for polder design (Component 5A and Component 6.1).

A.4.2 Effect on Saline Intrusion

A.4.2.1 Objectives

The objectives of this task are:

- To establish an overview of tidal water levels and salinity in the river, estuary and groundwater system in the coastal zone at present and in the future
- To devise scenarios and strategies to optimize salinity levels in the coastal zone

A.4.2.2 Approach

A.4.2.2.1 General Approach

The existing South West Regional Salinity Model, already operational at IWM, has been developed to simulate the flow and salinity conditions in the river and estuary system of the delta. Being a one-dimensional model, this is a very effective tool for long term simulations. The South West Regional Salinity Model can be coupled dynamically to the two-dimensional model of the bay to simulate the salinity conditions in the entire area consistently and integrated.

In the river branches gradients in salinity will occur both horizontally and vertically and water stratification may develop. The stratified flows cannot be resolved in a depth integrated model – thus neither in the one-dimensional nor in the two-dimensional models. It is therefore proposed to further develop the South West Regional Salinity Model with a two-dimensional vertical model in the areas where stratification may occur. The MIKE 11 software used for the South West Regional Salinity Model incorporates a full lateral integrated two-dimensional flow description that enables simulation of vertical gradients and stratified flows. The updated South West Regional Salinity Model will thus consist of dynamically coupled 2D horizontal, 2D vertical and 1D model components which will enable resolution of all important processes and accurate modelling results.

A.4.2.2.2 Existing Models

In addition to the models developed and updated as part of the below Task 4.3, Effect on Storm Surges, the following models, already operational at IWM, will be applied for modelling of saline intrusion:

- The South West Regional Salinity Model, which is based on the advection-dispersion (AD) module of MIKE11 that is coupled with the hydrodynamic (HD) module
- The Bay of Bengal Salinity model, which is based on the advection-dispersion (AD) module of MIKE21 that is coupled with the hydrodynamic (HD) module

A.4.2.2.3 Activities

The objectives are reached through the following activities:

Activity 1: Compile available measurements and model results on salinity in the river and estuary system and in the groundwater system of the coastal zone at present and for 25, 50 and 100 years from now. The Research Team will use the changes in storm surges, river discharges and local rainfall, as well as estimations for sea level rise, as input for their salinity models

All available data on salinity in the river and estuary system will be collected and analysed. Based on this a consistent data set covering at least two full hydrological cycles will be compiled. The series will be divided in two and these two subseries will be used for (re-)calibration and verification of the salinity model.

The salinity model will be established by linking the South West Regional Salinity Model with the Bay of Bengal Model (including salinity variations). The river reaches with potential for flow stratification in the present and future conditions will be identified and the corresponding sections of the South West Regional Salinity Model will be updated to simulate the vertical distribution of flow and salinity.

The updated model will be calibrated and verified against the compiled data and the model will subsequently be used to simulate salinity in the river and estuary system for present conditions and for future conditions 25, 50 and 100 years from now.

The approach to assessing potential climate change effects on groundwater salinity is aiming at a model-based risk analysis on a selected polder area. Given future changes in surface water and sea water levels a schematic model will be developed looking at subsurface flow and transport, groundwater pumping, flow and mass flux exchanges between the polder area and surrounding rivers. The polder groundwater salinity intrusion risk model will initially be developed for at transect and possibly extended to a 2-D/3-D model. The polder area will use a DEM including embankments, aquifer layers based on a generalized hydrogeological model, groundwater pumping rates, boundaries of adjacent rivers in terms of water levels and expected river salt concentrations. Datasets of expected future climate changes in precipitation and evapotranspiration will be based on the output of Component 3 and prepared as input for the polder groundwater model. The model will be run for a multiple years simulation period to achieve approximately quasi-steady groundwater salinity concentrations for the 25, 50 and 100 years cases. Outputs from the model include groundwater salinity concentration levels in terms of intervals for the polder which will serve as an indicator of potential adverse impacts from climate change and the risk of unacceptable high concentration levels relative to water supply and irrigation requirements.

It is not deemed feasible to neither rely on empirical models which are too simple to represent the processes affecting groundwater salinity nor to undertake 3D groundwater modelling including salinity transport with a dynamic exchange to surface water for the entire South West region. Given limited data availability, model scale and model performance a geographically restricted and representative area with relatively good quality data should be chosen. Consequently, development in salinity concentrations will be studied with respect to the selected polder and its specific features and layout. It will be possible to closer examine how changes in climate and the surface water regime restricts fresh water resources for water supply and irrigation inside the polder area. The polder drainage system and drainage canal gate operations will be included in evaluation of polder sustainability and identification of measures for climate adaptation. As extensive and detailed groundwater salinity data are likely not available to allow a full calibration results should be interpreted as a trend and relative salinity risk between different alternatives and scenarios.

While the groundwater salinity model will not deliver a full geospatial coverage of the entire model area it will be developed as an efficient tool for testing polder sustainability and evaluating salinity control measures under expected future conditions. Experiences from the selected polder area will serve as a guideline for the remaining polder areas.

Activity 2: Develop reasonable alternatives of redistribution of river water in the delta (more water from the Ganges or Brahmaputra to river branches in the South West) and determine the effect on salinity in the river system, applying the available tested numerical model

A minimum of two reasonable alternatives of redistribution of river water in the delta will be analysed with respect to effects on salinity intrusion in the river system.

It might be important to take into consideration the dramatic improvement in salinity conditions that could be brought about by fresh water diversions from the proposed Ganges Barrage.

A.4.2.2.4 Deliverable

The integrated output of Component-4D, Tasks 4.2 (Effect on Saline Intrusion) and 4.3 (Effect on Storm Surges), are:

1. Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present, and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB.

2. Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be designated by BWDB) at present, and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB.

3. Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated by BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now.

4. Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now.

5. Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges

6. Technical Report with description and explanation of the geospatial datasets of surface and ground water salinity, and the tidal salinity and water level curves, including description of relevant seasonal variations, used models, indication of more and less likely scenarios, and full metadata. The Research Team shall also discuss the effect of at least two relevant options of redistribution of river water in the South West delta on salt intrusion.

A.4.3 Effect on Storm Surges

A.4.3.1 Objectives

The objective of this task is:

- To establish an overview of extreme water levels due to storm surges and cyclones

A.4.3.2 Approach

A.4.3.2.1 General Approach

The objective will be reached through modelling using the numerical hydraulic models developed under the previous phase of the CEIP-I project.

Impacts of climate change on water levels will be modelled by updating presently applied open model boundary conditions to take into account the effect of climate change and using the models to describe future water level conditions of 25, 50 and 100 years events.

A.4.3.2.2 Existing Models

The following models already operational at IWM will be applied:

- The South West Region Model (SWRM) using two separate modules of the MIKE 11 modelling system: rainfall-runoff modelling (MIKE11-NAM) and hydrodynamic modelling (MIKE11-HD)
- The Bay of Bengal model (BoB) using the two-dimensional hydrodynamic model MIKE21 FM
- A wind generation tool which can calculate wind and pressure fields on the basis of cyclone data

The water levels and surges will be modelled using the one-dimensional South West Region Model and the two-dimensional hydrodynamic Bay of Bengal model. The upstream boundary conditions for the models will be predicted on the basis of the one-dimensional rainfall-runoff model (with rainfall input from Component 3C, Meteorology) and the offshore boundary conditions will be determined from predictions of future sea level rise (input from Task 4.1, Effect on Water Level). Extreme cyclone wind developed under Component 3C, Meteorology, describing changes in cyclone frequency and intensity due to climate change, will be used as forcing to the hydraulic modelling.

A.4.3.2.3 Activities

The objectives are reached through the following activities:

Activity 1: Estimate changes in storm surges and discharge levels using the future scenarios on rainfall in the catchment area and cyclone frequency and intensity (coming from Component 3C, Meteorology) as input for computational models

The above listed numerical hydraulic models developed under the previous phase of the CEIP-I project will be applied for this activity.

The models will be updated and verified with new data collected as part of the present study. The models will be applied to simulate present and future river discharges, tides and storm surges on the basis of meteorological data developed under Component 3C, Meteorology. The meteorological events will cover dry and wet season, present and future conditions (25, 50 and 100 years from now) including climate change effects of sea level rise (Task 4.1, Effect on Water Level), intensity of rainfall and cyclones.

Activity 2: *Compile available measurements and model results on tides and water levels, including monsoonal variations, extreme high water due to river discharges and storm surges/cyclones at present and for 25, 50 and 100 years from now. The Research Team will use the changes in storm surges and river discharges, as well as estimations for sea level rise, as input for their hydraulic models*

Under this activity data will be compiled that will form input to the scenario modelling specified under Activity 1. The updated models from Activity 1 will be used to simulate discharge, cyclone, tide and storm surge conditions for present conditions and for future conditions (25, 50 and 100 years events).

The rainfall-runoff model will be forced with present/future rainfall data to simulate river flows. The river flows together with estimates of sea level rise and present/future wind/cyclone conditions will form the input to the Bay of Bengal surge model to simulate present and future surge levels.

Both wet and dry seasons will be considered. The results will be compared with the compiled available measurements.

Developed boundary conditions, cyclone forcing and updated hydraulic models for modelling of water levels, tides and surges will be used as input to Task 4.2, Effect on Saline Intrusion.

A.4.3.2.4 Deliverables

The integrated output of Component-4D, Task 4.2, Effect on Saline Intrusion and Task 4.3, Effect on Storm Surges*,* are:

a) Geospatial datasets of High Water, Low Water and maximum salt intrusion in all river branches for average tide in the wet and dry season at present, and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB.

b) Geospatial datasets of groundwater salinity at 3 relevant levels (in the upper shallow, lower shallow and deeper aquifers, to be designated by BWDB) at present, and at 25, 50 and 100 years from now, including full metadata and stored and archived in Database of BWDB.

c) Tidal and salinity curves for key locations in the coastal zone (about 20, to be designated in consultation with BWDB) in the wet and dry season at present, and at 25, 50 and 100 years from now.

d) Exceedance frequency curves for water levels in the same 20 stations at present, and at 25, 50 and 100 years from now.

e) Define extreme water levels in the polder of coastal zone at 25, 50 and 100 years from now, due to cyclonic storm surges

f) Technical Report with description and explanation of the geospatial datasets of surface and ground water salinity, and the tidal salinity and water level curves, including description of relevant seasonal variations, used models, indication of more and less likely scenarios, and full metadata. The Research Team shall also discuss the effect of at least two relevant options of redistribution of river water in the South West delta on salt intrusion.

APPENDIX B – DEVELOPMENT OF AN INTERACTIVE DATABASE

B Development of an interactive Geo-Database for Coastal Zone

B.1 Introduction

The creation of a comprehensive database covering environmental and socio-economic aspects of the Bangladesh Coastal Zone (and the major river systems that feed it) will be one the important and lasting legacies of this project. This database would include as far as possible all existing data found within the databases of the BWDB and other related agencies, in addition to the vast quantities of data that are to be gathered by this project in the next 27 months. The data included in the database would also be quality labelled and labelled according to sources and methods of collection and processing. The database will remain open to all future data collection. While the data will be geo-referenced and mainly in the domain of water resources, the need to include eco-environmental and socio-economic data are strongly recognized.

The database built by the project will be transferred to the BWDB, who will retain ownership and control access to it; at the close of the project.

B.2 Objectives

To Develop of an Interactive Database System for Research, Monitoring, and Analyses of Bangladesh Coastal Zone towards long term sustainable polder development and management with attention to geo-morphological, environmental, economic and ecological aspects. The database will help in longtime monitoring of polder situation after any project intervention, which include:

- Change of Socio-Economic scenario: Agricultural (Crop Intensity, Crop Production, Agricultural Inputs and cost benefits), rural employments, poverty levels, education and communication facilities etc.
- Status of physical features (polders/embankments, cannel/channels, protective works, Hydraulic Structures etc.
- Land use change
- Hydro-morphological

B.3 The Polder Database

The proposed database will consist of different types of spatial and non-spatial datasets which can be broadly categorized by Physical, Socio-Economic, Hydro-meteorological and Environmental data for polders areas in the coastal region of Bangladesh. These can be outlined as mention below.

- Administrative

  General Admin

  - Division
  - District
  - Upazila
  - Union

BWDB Field Operation

  - Zone
  - Circle
  - Division
  - Sub-Division

- Natural
  - Roads
  - Rivers
  - Wetlands and water bodies
  - Topography
- Communications
  - Roads, Bridge & Culverts
  - Inland waterways
- Environmental
  - Ecology
  - Bio-diversity
  - Forestry
  - Aquatic, Fish (open & Culture)
  - ECA
- Morphological
  - River erosion
  - Coastal Erosion
  - Bathymetry (Coastal and River)
- Hydro-meteorological
  - Surface water level (Tidal & non-tidal)
  - River discharge
  - Ground water levels
  - Borehole lithology
  - Rainfall
  - Evaporation
  - Cyclones
  - Humidity
  - Temperature
- Demographic/Socio-economic
  - Population
  - Literacy
  - Employment
  - Health
  - Livelihood and income
- Agriculture
  - Land use
  - Cropping
  - Irrigation
  - Production

- Interventions
    - Polders
    - Embankments
    - Hydraulic Structures
    - Protective works
    - Canals
    - Settlement
- Impacts/Model Results
    - Flooding and inundation
    - Drought
    - Salinity
    - Subsidence
    - Erosion
- Physiography
    - Physiographic features from AEZ Map
- Soil
    - Soil (land Type)
- Geology
    - Sub-Surface Geology
- Land use
    - Land use, historical changes in land use based on Remote Sensing
- Document Archive
- Metadata

The database will be prepared based on the available data/information

B.4 Data Sources

The possible datasets are the main resources of the proposed IGDCZ database system. The collected data in the Database should be complete, relevance, reliable and up to-date. The above datasets can be collected from primary and secondary sources.

The data which are not available in the secondary sources will need to be collected through primary field survey by the project.

Secondary data refers to data which is collected by some other public and private organizations, NGOs and research institutes in Bangladesh etc. For the proposed IGDCZ database system, most of the data can be obtained from available secondary data sources.

The project is required to identify the data source organizations for the respective data types and will need to be shared through proper channel. The following table lists the tentative data source organizations:

Table B- 1: Tentative Data Source organizations

Sl No	Broad Categories	Broad Categories	Tentative Data Sources
	Administrative	General Admin Division District Upazilla Union	LGED
		BWDB Field Operation Zone Circle Division Sub-Division	BWDB
	Natural	Rivers Wetlands, water bodies & ponds Topography	BWDB, SOB & SPARRSO
	Communications	Roads, Bridge & Culverts Inland Waterways	RHD, BBA & LGED BIWTA
	Environmental	Ecology, Bio-diversity, ECA Forestry Aquatic, Fish (open & Culture)	Department of Environment DoE) Department of Forest Department of Fisheries
	Morphological	River erosion Coastal Erosion Bathymetry (Coastal and River)	BWDB BWDB, Project
	Hydro-meteorological	Surface water level (Tidal & non-tidal) River discharge Ground water levels Borehole lithology Rainfall Evaporation Cyclones Humidity Temperature	BWDB, BMD
	Demographic/Socio-economic	Population Literacy Employment Health Livelihood and income	BBS

Sl No	Broad Categories	Broad Categories	Tentative Data Sources
	Agriculture	Land use Cropping Irrigation Production	BADC
	Interventions	Polders Embankments Hydraulic Structures Protective works Canals Settlement	BWDB, Settlement from SOB topographic Map
	Impacts/Model Results	Flooding and inundation Drought Salinity Subsidence Erosion	BWDB, IWM & Project
	Physiography	Physiography	AEZ map of SRDI
	Geology	Geological Features	Bangladesh Geological Survey
	Land use	Land use, historical changes	From Classified Satellite Imageries (landSat, Sentinel etc.)

B.5 Scope of Work

The scope of works is broadly defined in the following activities:

- Collection of exiting datasets from relevant sources following the quality assurance & quality checking.
- Development of Coastal Polder Information Management Database
- Data dissemination through Web GIS based Interactive Database Portal

B.6 Technology & Software, Hardware Platform

The software platform can be chosen Commercial Proprietary or Open Source System which can be described by the following options:

- **Spatial Data forms:** Shapefiles
- **Database System:** PostgreSQL
- **GIS Server:** GeoServer
- **GIS Desktop:** ArcGIS Desktop/QGIS
- **Web Server:** MS IIS/Apache
- **Web Development Platform** JavaScripts, PHP, Python Scripts, HTM5 or later
- **Mobile Apps:** Android, IOS, Windows

The BWDB head Office has an installed Central Database and a GIS Server Computer in which SiMS-Smart Web GIS based Application is deployed. SiMS-Smart application supports BWDB officials in various purposes mainly for O&M and Progress monitoring of BWDB completed and ongoing projects for South-Eastern Zone of BWDB.

Open source platform has several advantages over the commercial software platform:

- Growing maturity and professionalism of available and developed products.
- Community support (big developers/users base)
- Easy to port: open data and systems
- Maximal Control. Open source software allows extensive configurability and scalability, which means that use can fine-tune the product for exact needs.
- Mostly Linux based software, windows-based software is also available with the same capability.
- No license fees or software maintenance fees
- Hence, we recommend Open Source Software platform for implementing the System

Hence, we recommend Open Source Software platform for implementing the System

Proposed Database Application Architecture

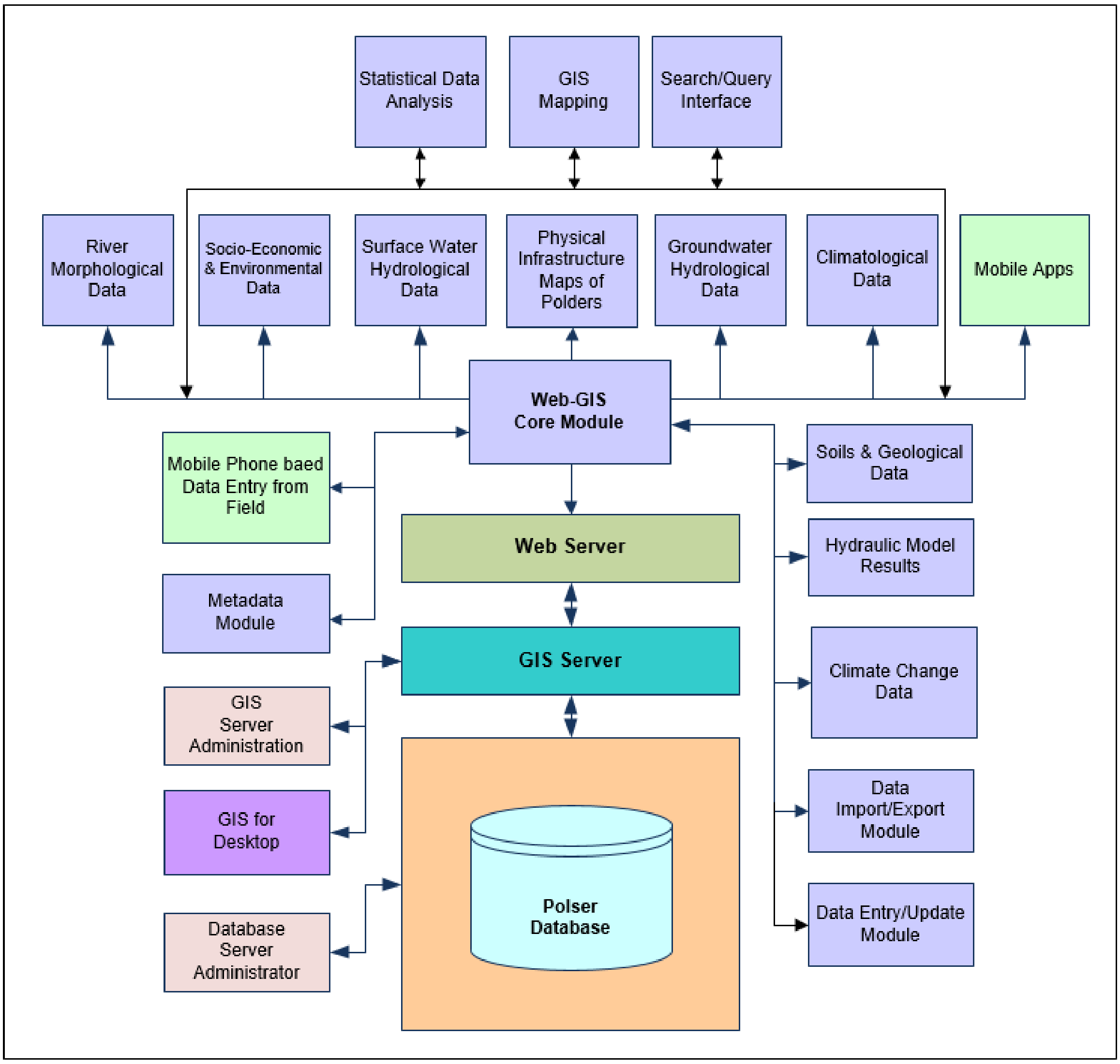


Figure B- 1: System Conceptual Architecture

Table B- 2: Tentative Work Plan

Sl No	Activity/Task	Months																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Mobilization																								
2	Review Existing Systems	▨																							
3	Consultation with Project Team	▨																							
4	Consultation with Projct Client	▨																							
5	Requirement Analysis	▨																							
6	Data Requirements	▨																							
7	Conceptual System Architecture	▨																							
8	Inception Report	▧																							
9	Identification of Data Sources																								
10	Data Collection			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨												
11	Data Review, Validation & data Processing				▨	▨	▨	▨	▨	▨	▨	▨	▨	▨											
12	Preparation of SRS & SDD Report			▧																					
13	Installation of Software Development Platform			▨																					
14	Database Design & Development				▨	▨	▨	▨	▨	▨															
15	Database Implementation										▨	▨	▨	▨	▨	▨	▨	▨	▨						
16	Prototype Development						▨	▨	▨																
17	Prototype Deployment									▧															
18	Full Version Development									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
19	Web GIS Core Module																								
20	Other Module Development													▨	▨	▨	▨	▨	▨						
21	Testing & Debugging											▨	▨	▨	▨	▨	▨	▨	▨	▨					
22	Final Development																			▨					
23	Fully operational version of IGDCZ commissioned																				▧				
24	Training & Technology Transfer																					▨	▨		

APPENDIX C – INVENTORY OF EXISTING DATA

C Inventory of Existing Data

(please refer Figure 4.2 in the Main Report)

Table C- 1: List of Bathymetric Data Available in IWM

Sl. No	Name of the River	Length River Stretch (km)	Interval (m)	No of Cross-section	Remark
1	Haringhata	16	500	32	GRRP-II/2011
2	Pussur	100	1000	100	
3	Sibsa	70	1000	70	
4	Aura Sibsa	20	1000	20	
5	Dhaki	20	1000	20	
6	Sutakhali	30	1000	30	
7	Baleswar	55	1000	55	
8	Kocha	15	500	30	
9	Sarupkathi	15	1000	15	
10	Kaliganga and Madhumati	90	2000	45	
11	Nabaganga, Atai and Rupsa	60	2000	30	
12	Gorai	30	500	60	
13	Betna	48	500	96	IWM/2012
14	Marirchap	38	500	76	
15	Parulia Sapmara	24	500	48	
16	Kholpetua	8	500	16	
17	Jamuna	50	2000	25	GBS/2010-11
18	Padma	128	2000	64	
19	Meghna	26	2000	13	
20	Afrakhal	40	5000	8	
21	Agarpur	15	5000	3	
22	Amanatganj	30	5000	6	
23	Arialkhan	75	5000	15	
24	Badugacha	20	5000	4	
25	Baleshwar	85	5000	17	
26	Bansana	15	5000	3	
27	Betna	105	5000	21	
28	Bhadra	30	5000	6	

Sl. No	Name of the River	Length River Stretch (km)	Interval (m)	No of Cross-section	Remark
29	Bhairab Lower	15	5000	3	
30	Bishnu	30	5000	6	
31	Chitra	45	5000	9	
32	Daudkhali	25	5000	5	
33	Deluti	25	5000	5	
34	Ghagor	30	5000	6	
35	Gobra	10	5000	2	
36	Gashiakhali	30	5000	6	
37	Gunkhali	15	5000	3	
38	Katakhali	5	5000	1	
39	Kazibacha	20	5000	4	
40	Kobadak	70	5000	14	
41	Kaliganga-SW	10	5000	2	
42	Kumar Nadi	45	5000	9	
43	Kumarkhali	15	5000	3	
44	Kumar River	45	5000	9	
45	MBR	35	5000	7	
46	M.G.Canal	10	5000	2	
47	Mongla-Nulia	20	5000	4	
48	Marirchap	30	5000	6	
49	Nalua-Nullah	10	5000	2	
50	Naria	15	5000	3	
51	Nabaganga-M	35	5000	7	
52	Old Pussur	30	5000	6	
53	Otra River	20	5000	4	
54	Palong	35	5000	7	
55	Polyhara	35	5000	7	
56	Pussur	40	5000	8	
57	Rupsa	35	5000	7	
61	Salta-W	10	5000	2	
62	Ganges	60	500	121	2011
63	Gorai	30	50	600	2011
64	Pussur	100	200	440	MP/2011
65	Mongla nala	30	200	150	MP/2011
66	BishKhali	70	2500	28	

Sl. No	Name of the River	Length River Stretch (km)	Interval (m)	No of Cross-section	Remark
67	Burishwar	55	5000	11	FFWC/2009
68	Lohalia	36	2000	18	
69	Baleswar	90	5000	18	
70	Kobadak				IWM/2008-09
71	Tetulia				2017
72	Meghna (Kamal Nagar to Ramgati)	Total length 1260 km	250-500		Ramgati/2012
73	Sandwip-Noakhali-urir char area				IWM/2012-2014-2015
74	Cox's Bazar to Inani	24		228	IWM-Marine Drive/2012-13
75	Karnaphuli River				CPA/2012-14
76	Brahmaputra-Jamuna	240		500	IWM-SRM/2011
77	Ganges-Padma	225		1000	
78	Meghna	50		1000	
79	Old Brahmaputra	265		500	
80	Atrai	245		250	
81	Karnaphuli	50		500	

Table C- 2: List of bathymetric data surveyed under EDP (2009-10) & MES-II (1999-2000)

Sl. No.	**Description of data**	**Period**		**Cruise Number/Data Source**	
		From	**To**		
1	Bay near Sandwip Channel,Lower Meghna	07/04/2009	22/04/2009	EDP-1	MES-II (1999-2000)
2	East Shahabazpur Channel, East of Hatiya	06/05/2009	20/05/2009	EDP-2	
3	Lower Meghna	16/06/2009	25/06/2009	EDP-3	
4	Channel between Sandwip & Jahazer Char	01/07/2009	27/07/2009	EDP-4	
5	Tentulia River	02/10/2009	17/10/2009	EDP-6	
6	West Shahabazpur Channel	08/01/2010	07/02/2010	EDP-7	
7	West Shahabazpur Channel, near Nijhum Dwip	15/02/2010	06/03/2010	EDP-8	
8	Mainka Channel	Oct-09		IWM	
9	Montaz Channel				
10	Bangla Channel				
11	Tentulia-Ilisha Channel	Jan-Feb 2010		IWM	

Table C- 3: Data used for DEM in the coastal area

Sl. No.	**Description of data**	**Period**	**Data Source**
1	All over coastal areas	1991	FINNMAP Land Survey
2	KJDRP area except Beel Kapalia and Beel Khuksia	1997	Khulna Jessore Drainage Rehabilitation Project (KJDRP), surveyed by IWM
3	Beel Kapalia (inside KJDRP)	March 2008	Beel Kapalia, surveyed by IWM
4	Beel Khuksia (inside KJDRP)	February 2004	Beel Khuksia, surveyed by IWM

Table C- 4: Inventory of Historical Water level measurement Stations

Sl	Station Name	River Name	Station ID	Source	Frequency	From	To
1	Abupur	Narayanganj	323	BWDB	3 hr	01-Apr-90	30-Mar-16
2	Afraghat	Bhairab	30	BWDB	3 hr	01-Apr-90	30-Mar-16
3	Amtali	Buriswar	20	BWDB	3 hr	01-Apr-90	30-Mar-16
4	Arpara	Behabati	21	BWDB	3 hr	01-Apr-90	30-Mar-16
5	Athabanki	Maddhumati	105	BWDB	3 hr	01-Apr-90	30-Mar-16
6	Babuganj	Babuganj	316	BWDB	3 hr	01-Apr-90	30-Sep-14
7	Bagerhat	Doratana	1	BWDB	1 hr	07-Apr-90	30-Mar-16
8	Bakerganj	Barisal-Buriswar	18.1	BWDB	3 hr	01-Apr-90	30-Mar-16
9	Bamna	Bishkhali	38	BWDB	3 hr	01-Apr-90	30-Mar-16
10	Barguna	Bishkhali	38.1	BWDB	3 hr	01-Apr-90	30-Sep-15
11	Barisal	Barisal-Buriswar	18	BWDB	3 hr	01-Apr-90	30-Mar-16
12	Baruria Transit	Padma	91.9L	BWDB	3 hr	01-Jan-85	30-Mar-16
13	Basantapur	Ichamati	129	BWDB	1 hr	01-Apr-90	30-Mar-16
14	Benarpota	Betna	24	BWDB	1 hr	03-Apr-90	30-Mar-15
15	Betagi	Bishkhali	37.5	BWDB	3 hr	01-Apr-90	30-Mar-16
16	Bhanga	Kumar	170	BWDB	3 hr	01-Apr-90	30-Mar-16
17	Bhatiapara			BWDB	3 hr	01-Apr-90	30-Dec-08
18	Bhola Kheya ghat			BWDB	3 hr	01-Jan-04	30-Dec-08
19	Bhairab Bazar	Upper Meghna	273	BWDB	3 hr	01-Apr-90	30-Mar-16
20	Chalna	Rupsa-Pasur	243	BWDB	1 hr	01-Apr-90	30-Mar-16
21	Chandpur	Dakatia	IW277	BIWTA	0.5 hr	01-Nov-06	31-Dec-16
22	Chapra	Betna Khal	25	BWDB	3 hr	01-Apr-93	30-Mar-16
23	Chhoto-Bagi			BWDB	1 hr	17-Dec-90	31-Mar-93
24	Chuadanga	Mathabhanga	207	BWDB	1 hr	01-Jan-06	30-Mar-16
25	Chowdhury Char (Chowdhurihat)			BIWTA	1 hr	07-Dec-90	31-Mar-94
26	Daulatkhan	Surma-Meghna	278	BWDB	3 hr	01-Apr-92	30-Sep-14

SI	Station Name	River Name	Station ID	Source	Frequency	From	To
27	Dumuria	Bhadra	28	BWDB	3 hr	01-Apr-93	30-Mar-16
28	Elarchar	Satkhira Khal	254.5	BWDB	2 hr	01-Apr-04	30-May-14
29	Faridpur	Kumar	168	BWDB	3 hr	01-Apr-90	30-Mar-16
30	Garaganj	Kumar	171	BWDB	3 hr	01-Jan-06	30-Mar-16
31	Gazirhat	Nabaganga	219	BWDB	3 hr	01-Apr-90	28-Aug-08
32	Gournadi	Torki	300	BWDB	3 hr	01-Dec-90	30-Mar-16
33	Haridaspur	MB Route	198	BWDB	3 hr	01-Apr-90	30-Mar-16
34	Hatbolia	Mathabhanga	206	BWDB	3 hr	01-Jan-06	30-Mar-16
35	Hizla	Dharmaganj	320	BWDB	3 hr	01-Apr-90	30-Mar-16
36	Insafnagar	Mathabhanga	205.A	BWDB	3 hr	01-Jan-06	30-Mar-16
37	Jhalokati	Bishkhali	37	BWDB	3 hr	01-Jul-98	30-Mar-16
38	Jhikargacha	Kobadak	162	BWDB	3 hr	01-Apr-90	30-Mar-16
39	Jhinaidaha	Nagabganga U	215	BWDB	3 hr	01-Jan-06	30-Mar-16
40	Kabirajpur	Madaripur Beel	193	BWDB	3 hr	01-Apr-90	30-Mar-16
41	Kaikhali	Ichamoti	130	BIWTA	1 hr	01-Apr-90	30-Mar-16
42	Kaitpara	Lohalia	183	BWDB	3 hr	01-Apr-90	31-Mar-03
43	Kala Chandpur	Nabaganga	217	BWDB	3 hr	01-Apr-90	30-May-14
44	Kalaroa	Betna	23	BWDB	3 hr	01-Apr-93	30-May-14
45	Kamarkhali	Gorai	101.5	BWDB	3 hr	01-Jan-06	30-Mar-16
46	Kamarkhali Tran	Gorai	101	BWDB	3 hr	01-Jan-06	30-Mar-16
47	Khathuli	Bhairab Upper	32	BWDB	3 hr	01-Jan-06	30-Mar-16
48	Kazipur	Mathabhanga	205	BWDB	3 hr	01-Jan-06	30-Mar-16
49	Keshabpur	Bhadra	27	BWDB	3 hr	01-Apr-90	30-Mar-16
50	Khatur Magura	Chitra	55	BWDB	3 hr	01-Apr-90	30-Mar-16
51	Khulna	Rupsha	241	BWDB	1 hr	08-Apr-90	30-Mar-16
52	Kobadak Forest Office	Kobadak	165	BWDB	1 hr	01-Apr-90	30-Mar-16
53	Lohagara	Nabaganha U	217 A	BWDB	3 hr	01-Apr-90	30-Mar-16

Sl	Station Name	River Name	Station ID	Source	Frequency	From	To
54	Madaripur	Arialkhan	5	BWDB	3 hr	01-Apr-90	30-Mar-16
55	Mirzaganj	Buriswar	19	BWDB	3 hr	01-Apr-90	30-Apr-10
56	Magura	Nabaganga	216	BWDB	3 hr	01-Jan-06	30-Mar-16
57	Magura Divr	Nabaganga U	216 A	BWDB	3 hr	01-Jan-06	30-Mar-16
58	Mongla	Pussur		(BIWTA MPA GAUGE)	1 hr	01-Apr-90	30-Mar-16
59	Mostafapur	Kumar	190	BWDB	3 hr	01-Apr-90	30-Mar-16
60	Muzurdia	Kumar	169	BWDB	3 hr	01-Jan-06	30-Mar-16
61	Nalianala	Sibsha	259	BWDB	1 hr	01-Apr-90	30-Mar-16
62	Narail	Chitra	56.1	BWDB	3 hr	01-Apr-90	30-Mar-16
63	Nazirpur	Baleswar	107	BWDB	1 hr	01-Apr-91	29-Dec-01
64	Nilkamal			BWDB	3 hr	01-Jan-04	31-Oct-08
65	Paikgacha	Haria	258	BWDB	3 hr	01-Apr-93	30-May-14
66	Patharghata	Bishkhali	39	BWDB	3 hr	01-Apr-91	30-May-14
67	Pirojpur	Baleswar	107	BWDB	3 hr	01-Jan-04	30-Mar-16
68	Protapnagar	Kholpetua	26	BWDB	1 hr	01-Apr-90	30-Mar-16
69	Ratandanga	Chitra	55.1	BWDB	3 hr	01-Apr-90	30-Mar-16
70	Rayenda	Baleswar	107.2	BWDB	3 hr	01-Jan-04	30-Mar-16
71	Shakra	Ichamoti	128	BWDB	1 hr	01-Apr-90	30-Mar-16
72	Sureswar			BWDB	3 hr	01-May-02	30-Dec-08
73	Sutarkhali_Forest Office	Sutarkhali	29	BWDB	3 hr	01-Apr-90	30-Mar-16
74	Swarupkati			BWDB	3 hr	01-Jun-04	30-Dec-08
75	Tajumuddin			BWDB	3 hr	01-Feb-01	31-Mar-02
76	Tala Magura	Kobadak	163	BWDB	3 hr	01-Apr-90	30-Mar-16
77	Tongibari	Rangamatia	288.3	BWDB	3 hr	18-Mar-04	30-May-14
78	Umedpur	Baleswar	136.1	BWDB	3 hr	24-Aug-04	30-Mar-16
79	Uzirpur	Swarupkhati	SW 253A	BWDB	3 hr	01-Apr-90	30-Jul-14

SI	Station Name	River Name	Station ID	Source	Frequency	From	To
80	Dashmina			BWDB	30 min	01-Nov-06	07-Oct-13
81	Galachipa		710	BIWTA	30 min	01-Apr-90	31-Dec-16
82	Bardia		2410	BIWTA	30 min	01-Apr-90	30-Jun-14
83	Chardoani		410	BIWTA	30 min	01-Apr-90	30-Jun-14
84	Chitalkhali		1610	BIWTA	30 min	01-Apr-93	30-Jun-14
85	Khepupara		610	BIWTA	1 hr	01-Jan-88	31-Dec-16
86	Dhulia		820	BIWTA	30 min	01-Apr-90	30-Jun-14
87	Pussur		Pussur		30 min	01-Apr-90	30-Jun-14
88	Hiron Point		IW110		1 hr	01-Jan-77	31-Dec-16
89	Gorai Railway Bridge	Gorai	99	BWDB	3 hr	01-Nov-09	31-Jul-11
90	Tahirpur	Kobadak	161	BWDB	3 hr	01-Nov-09	30-Mar-16
91	Nawhata		261	BWDB	3 hr	01-Nov-09	30-Apr-11
92	Bandarban	Sangu	SW247	BWDB		1965	2016
93	Dohazari	Sangu	SW248	BWDB		1996	2016
94	Banigram	Sangu	SW250	BWDB		1996	2016
95	Lama	Matamuhuri	SW203	BWDB		1996	2016
96	Chiringa	Matamuhuri	SW204	BWDB		1996	2016

Table C- 5: Inventory of Historical Flow measurement Stations

SI	Station Name	River Name	Frequency	From	To
1	Baruria	Padma	Daily	01-Jan-1985	31-Dec-16
2	Gorai Railway Bridge	Gorai	14 days	01-Jan-1985	31-Dec-16
3	Bhairab Bazar	Upped Meghna	Daily	01-Apr-1985	31-Dec-16
4	Kamarkhali	Gorai	14 days	12-Jan-2006	31-Dec-13

Table C- 6: Inventory of Wind & Rainfall measurement Stations of BMD

SI	**Station Name**	**From**	**To**	**From**	**To**
		Wind		**Rainfall**	
1	Dhaka	1953	2018	1966	2018
2	Mymensingh	1948	2018	1966	2018
3	Tangail	1987	2018	1966	2018
4	Faridpur	1948	2018	1966	2018
5	Madaripur	1977	2018	1966	2018
6	Chittagong	1949	2018	1966	2018
7	Sandwip	1966	2018	1966	2018
8	Sitakunda	1977	2018	1966	2018
9	Rangamati	1957	2018	1966	2018
10	Comilla	1948	2018	1966	2018
11	Chandpur	1964	2018	1966	2018
12	M_Court	1951	2018	1966	2018
13	Feni	1973	2018	1966	2018
14	Hatiya	1966	2018	1966	2018
15	Cox's_Bazar	1948	2018	1966	2018
16	Kutubdia	1977	2018	1966	2018
17	Teknaf	1977	2018	1966	2018
18	Sylhet	1956	2018	1966	2018
19	Srimangal	1948	2018	1966	2018
20	Rajshahi	1964	2018	1966	2018
21	Ishurdi	1961	2018	1966	2018
22	Bogra	1948	2018	1966	2018
23	Rangpur	1954	2018	1966	2018
24	Dinajpur	1948	2018	1966	2018
25	Sayedpur	1991	2018	1966	2018
26	Khulna	1948	2018	1966	2018
27	Mongla	1989	2018	1966	2018

Sl	**Station Name**	**From**	**To**	**From**	**To**
		Wind		**Rainfall**	
28	Satkhira	1948	2018	1966	2018
29	Jessore	1948	2018	1966	2018
30	Chuadanga	1989	2018	1966	2018
31	Barisal	1949	2018	1966	2018
32	Patuakhali	1973	2018	1966	2018
33	Khepupara	1974	2018	1966	2018
34	Bhola	1966	2018	1966	2018

APPENDIX D – OBSERVATIONS RECEIVED AFTER INCEPTION WORKSHOP

D Observations Received After Inception Workshop

D.1 Minutes of the meeting on Inception Report of the study titled “Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics) held on 16th January 2019 at the conference room of DG, BWDB)

Minutes of the meeting for finalization on Draft Inception Report of the study titled "Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics) held on 16th January 2019 at the conference room of DG, BWDB

A meeting for finalization on Draft Inception Report with the representatives of DHI-Deltares was held in the Office of the Director General, BWDB, Dhaka in order to revisit the activities, methods and deliverable of the project. The meeting was presided by Md Mahfuzur Rahman, Director General, BWDB. The list of the participants attended the meeting is attached in Annex-I

At the outset of the meeting Mr. Mahfuzur Rahman, DG, BWDB welcomed all the participants and initiated the discussions. He requested consultant to discuss overall understanding of the project. Dr. Ranjit Galappatti, TL of the project stated that detailed understanding of the project has been described in the Inception Report i.e. sediment and drainage management are important issues. Under this project, new modelling tools will be developed and generation of new knowledge is an important task to fill the knowledge gaps such as long-term morphological changes of peripheral rivers under climate change. The new and innovative tools will be applied in future to address the problems and planning the improvement measures. TL said that a detailed investment plan cannot be developed since this is not a feasibility study and project does not have the resources to carry out detailed surveys of 122 polders and any input of financial analyst. PD said that ToR stipulated to prepare an investment plan and BWDB needs it to approach to donors. The Consultant agreed to prepare a development plan for the whole coastal zone.

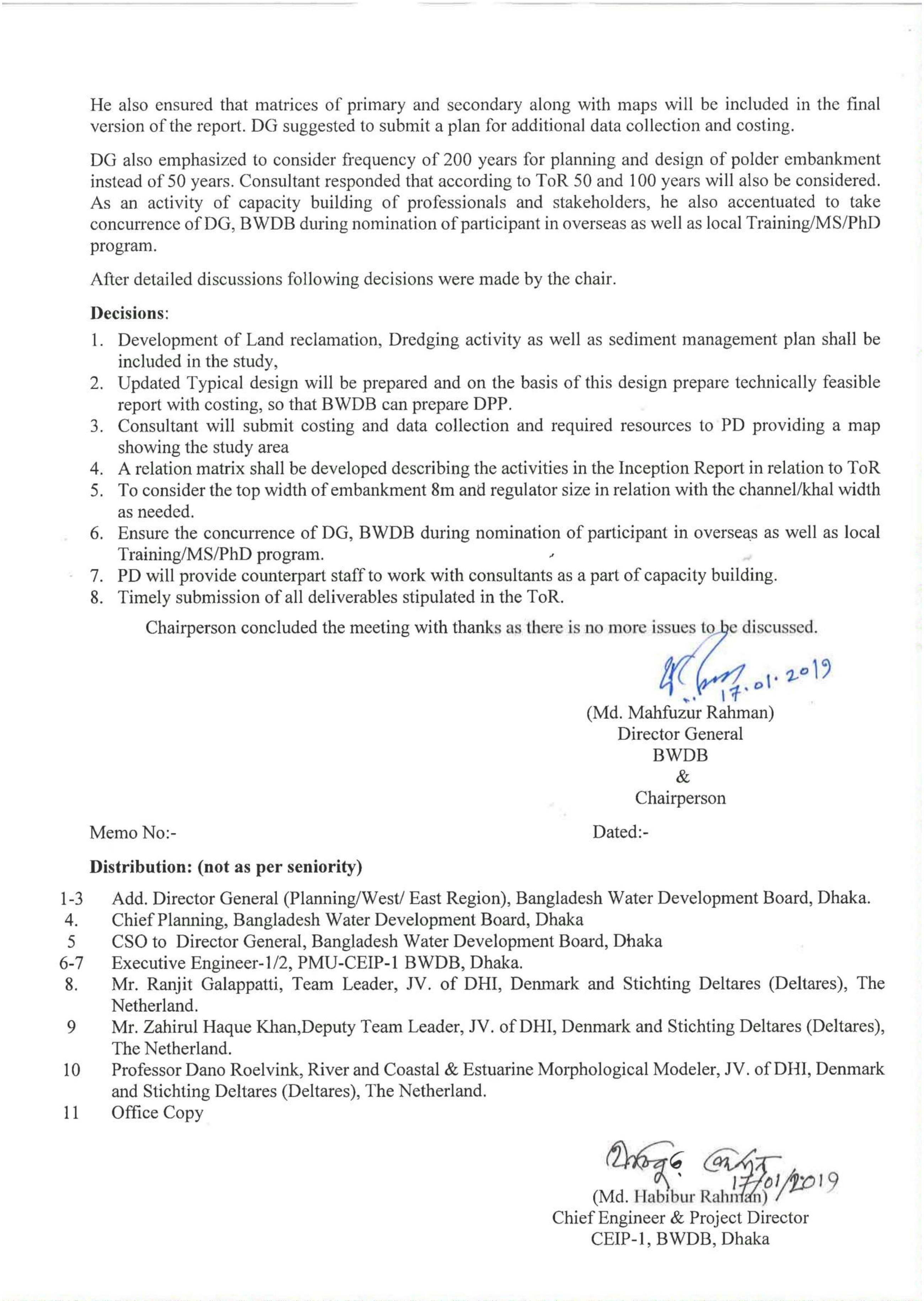
Mr. A.M Aminul Haque, Chief Planning pointed out that there is a need of relation matrix describing the activities stipulated in the ToR and how it is presented in the Inception Report. Consultant agreed to provide it in the final version of the report.

DG emphasized that this research is an applied research for development. He pointed out that consultants should generate new knowledge so that it can be utilised in preparing program for polder improvement and as well as coastal development. He also highlighted to prepare a plan for land reclamation.Consultant argued that land reclamation is beyond the scope of ToR. DG suggested PD to write a letter to JV of DHI, Denmark and Stichting Deltares (Deltares), The Netherland, requesting to include the land reclamation plan. DG suggested consultant to consider 8m top width of the polder embankment in planning the improvement of the polder so that this can be used as road in future.

PD mentioned that in CEIP-1, erosion protection due to wave action and river erosion were not duly considered. This should be considered in the present planning. He also emphasized to revisit the required size of the regulator and it will be larger in accordance with the channel/khal. DG mentioned that 1.5mx1.8 size regulator will not be considered in BWDB in future. That's why he requested to made a Typical Design considering the 8m top width of embankment, land reclamation plan, vent size of the regulator, climate change effect, environmental impact and other criteria that have direct/indirect influence on polders sustainability. One the basis of the prepared design made technically feasible report with costing, so that BWDB can prepare DPP.

Professor Dano Roelvink said that detailed research on erosion will be carried out. PD requested to consider him the Dredging activity as well as sediment management plan during detailed research on erosion. Because Bangladesh government already have been taken the Delta plan to meet up the criteria of SDG as well as to reach the target of Vision 2041. So as an activity of delta plan, in the Report there should be clear plan & activity on Dredging as well as sediment management. Professor Dano Roelvink also requested to provide a counterpart staff to work with consultants as a part of capacity building

PD said that the extent of the study are needs to be defined. He said that development plan should include the phased improvement of all remaining 122 polders. He suggested that data collection plan includes insufficient measurements. Mr. Zahir Deputy Team Leader pointed out that data collection plan is based on ToR and other required data will be collected from secondary sources. There is a need of additional data collection for the study.



He also ensured that matrices of primary and secondary along with maps will be included in the final version of the report. DG suggested to submit a plan for additional data collection and costing.

DG also emphasized to consider frequency of 200 years for planning and design of polder embankment instead of 50 years. Consultant responded that according to ToR 50 and 100 years will also be considered. As an activity of capacity building of professionals and stakeholders, he also accentuated to take concurrence of DG, BWDB during nomination of participant in overseas as well as local Training/MS/PhD program.

After detailed discussions following decisions were made by the chair.

Decisions:

1. Development of Land reclamation, Dredging activity as well as sediment management plan shall be included in the study,
2. Updated Typical design will be prepared and on the basis of this design prepare technically feasible report with costing, so that BWDB can prepare DPP.
3. Consultant will submit costing and data collection and required resources to PD providing a map showing the study area
4. A relation matrix shall be developed describing the activities in the Inception Report in relation to ToR
5. To consider the top width of embankment 8m and regulator size in relation with the channel/khal width as needed.
6. Ensure the concurrence of DG, BWDB during nomination of participant in overseas as well as local Training/MS/PhD program.
7. PD will provide counterpart staff to work with consultants as a part of capacity building.
8. Timely submission of all deliverables stipulated in the ToR.

Chairperson concluded the meeting with thanks as there is no more issues to be discussed.

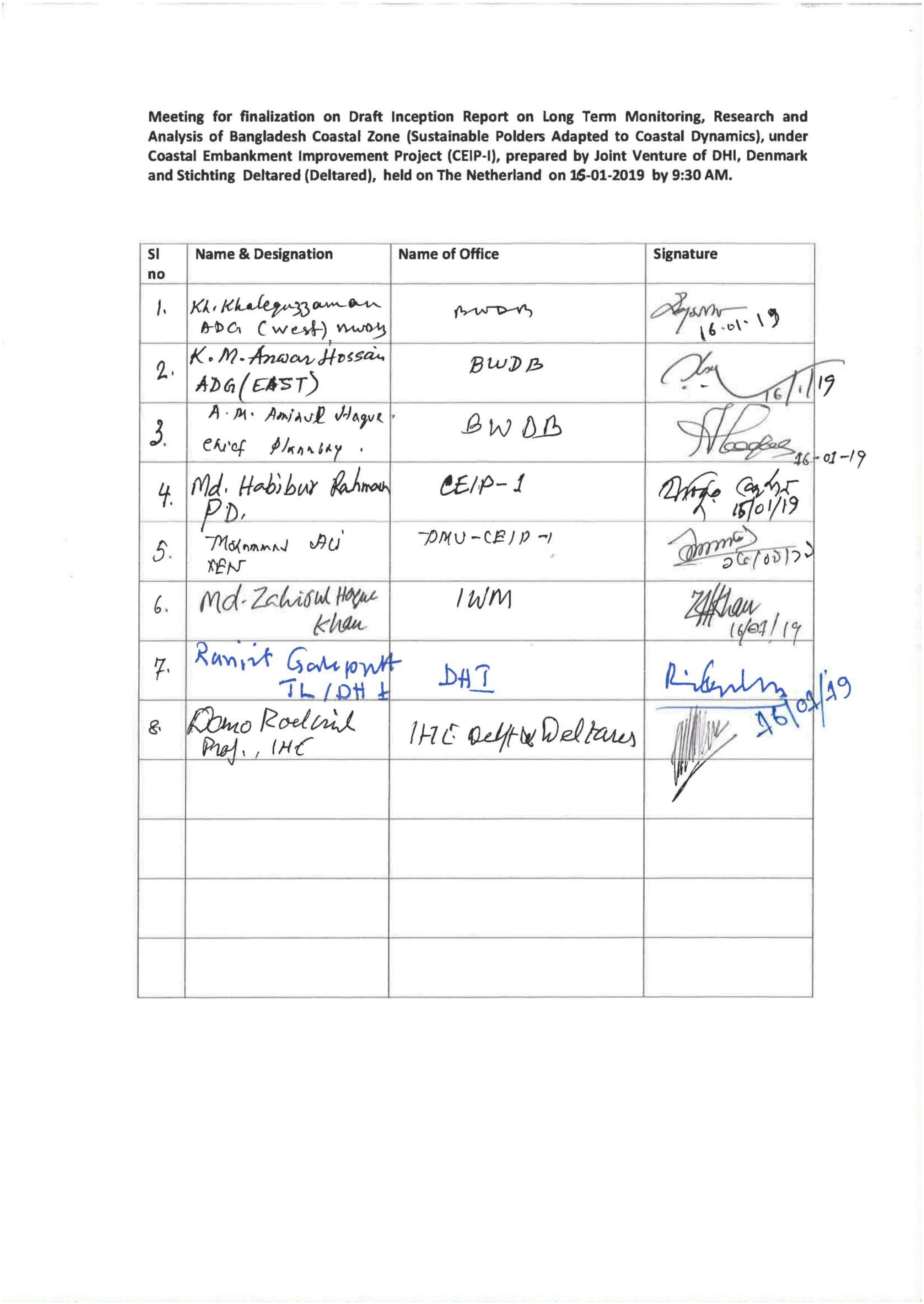
17.01.2019
(Md. Mahfuzur Rahman)
Director General
BWDB
&
Chairperson

Memo No:-　　　　　　　　　　　　　　Dated:-

Distribution: (not as per seniority)

1-3 Add. Director General (Planning/West/ East Region), Bangladesh Water Development Board, Dhaka.
4. Chief Planning, Bangladesh Water Development Board, Dhaka
5 CSO to Director General, Bangladesh Water Development Board, Dhaka
6-7 Executive Engineer-1/2, PMU-CEIP-1 BWDB, Dhaka.
8. Mr. Ranjit Galappatti, Team Leader, JV. of DHI, Denmark and Stichting Deltares (Deltares), The Netherland.
9 Mr. Zahirul Haque Khan,Deputy Team Leader, JV. of DHI, Denmark and Stichting Deltares (Deltares), The Netherland.
10 Professor Dano Roelvink, River and Coastal & Estuarine Morphological Modeler, JV. of DHI, Denmark and Stichting Deltares (Deltares), The Netherland.
11 Office Copy

17/01/2019
(Md. Habibur Rahman)
Chief Engineer & Project Director
CEIP-1, BWDB, Dhaka



Meeting for finalization on Draft Inception Report on Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics), under Coastal Embankment Improvement Project (CEIP-I), prepared by Joint Venture of DHI, Denmark and Stichting Deltared (Deltared), held on The Netherland on 16-01-2019 by 9:30 AM.

Sl no	Name & Designation	Name of Office	Signature
1.	Kh. Khalequzzaman ADG (West) BWDB	BWDB	16-01-19
2.	K. M. Anwar Hossain ADG (EAST)	BWDB	16/1/19
3.	A. M. Aminul Haque. Chief Planning.	BWDB	16-01-19
4.	Md. Habibur Rahman PD.	CEIP-1	16/01/19
5.	Mohammad Ali XEN	PMU-CEIP-1	১৬/০১/১৯
6.	Md. Zahirul Hoque Khan	IWM	16/01/19
7.	Ranjit Galappatti TL/DHI	DHI	16/01/19
8.	Dano Roelvink Prof., IHE	IHE Delft & Deltares	

D.2 Comments and Response Matrix

Observations on the Draft Inception Report received by Project Directors Office with Responses from the Project Team is presented below:

Table D- 1: Comments and Response Matrix on Inception Report of "Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone

Comments of Md. Mahfuzur Rahman, Director General, Bangladesh Water Development Board		
Sl. No.	**Comments**	**Responses from Study Team**
01	**Capacity Building:** In the draft contract there were two PhDs (item no. R-7 A & R-7B) need to be readdressed. One for BWDB and one for IWM meritorious, capable engineers, and these are very much appropriate and essential in capacity building for future onward carrying this study results and planning for the future projects and for handling this issues without the support of the foreign expert consultants involved in the research study. It was the result of long battle between the Consultants & Client's negotiation team. But unfortunately it was cut off latter for unknown reason from the Contract which actually has weakened the effectiveness and sustainability of capacity building. The objective of the capacity building would not be achieved without these components. I therefore, would request to reinstate the two PhDs in the Contract again and involve two meritorious capable engineers who have good results in graduation & Masters as mentioned above.	This statement is true. The suggestions to reinstate the two PhD programs has merit and these programs could be instrumental for capacity building and mainstreaming of the research outputs. The proposal for restoring the PhD Programme must be processed though the PD and the Ministry to obtain the approval of the World Bank.
02	**Item R−23, High Performance Computer:** This cost covers purchase of number crunchers, modern high end computer required for mathematical modeling process. This High−Performance Computer will be purchased by the Consultant installed under CE1P−1 Project Director's Office or in suitable place, used during the project period and handed over to the Client on completion of research study. Capacity building of BWDB Engineers must be with the target that this will be handled, operated & processed aiming to enhance data and future project planning by the BWDB Engineers without the help of the foreign Consultants.	In accordance with the contract 3 High Performance Computers will be purchased and be installed in the project office.BWDB Engineers will have training on handling these computers under on the job−training on meso and micro scale modelling. All these computers will be transferred to BWDB at the end of the project and training on managing these computers will also be provided during transferring process.

Comments of Dr. Mohammad Asad Hussain, Associate Professor, IWFM, BUET		
Sl. No.	**Comments**	**Responses from Study Team**
01	Please consider the impacts of Land Reclamation Activities (cross dam construction) on future polder sedimentation processes. Probably this issue is not included in the ToR but as the consultant will consider many future scenarios (for example: SLR, upstream water and sediment flux, subsidence and extreme events) it will be worth to include the impacts of cross dam construction (especially at the south of Bhola, Char Montaz) which is expected to alter the future sediment flux through the Meghna Estuary towards the south- west coastal region.	Although this proposal is beyond the scope of the ToR, the Project Director has already expressed the importance of this activity. the Consultant will prepare a detailed proposal for possibility of carrying out a full feasibility study of a new land reclamation project taking into consideration the impacts on sedimentation, drainage and long-term sustainability.

Comments from meeting minutes of the meeting held on Draft Inception Report of the Study entitled “Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone（Sustainable Polders Adapted to Coastal Dynamics）”

Venue: Office of Director General, BWDB

Date: 16 January 2019

SL	Comments and Suggestions	Responses
Comments of Director General, BWDB		
1	DG emphasized that this research is an applied research for development. He pointed out that consultants should generate new knowledge so that it can be utilised in preparing program for polder improvement and as well a's coastal development. He also highlighted to prepare a plan for land reclamation. Consultant argued that land reclamation is beyond the scope of ToR. DG suggested PD to write a letter to JV ofDHI, Denmark and Stichting Deltares)Deltares(, The Netherland, requesting to include the land reclamation plan. DG suggested consultant to consider 8m top width of the polder embankment in planning the improvement of the polder so that this can be used as road in future.	Consultant will prepare a detailed proposal considering land reclamation potential, sediment flux, climate change and impact of land reclamation on polder sedimentation. Plan and design of Land reclamation measures. If it is approved by WB then detailed study will be carried out.

SL	Comments and Suggestions	Responses
2	DG mentioned that 1.5mx1.8 size regulator will not be considered in BWDB in future. That's why he requested to made a Typical Design considering the 8m top width of embankment, land reclamation plan, vent size of the regulator, climate change effect, environmental impact and other criteria that have direct/indirect influence on polders sustainability. One the basis of the prepared design made technically feasible report with costing, so that BWDB can prepare DPP.	The size of the structure and crest width of the embankment will be established in consultation with planning and design circles of BWD and in accordance with the suggestions of DG.
3	DG suggested to submit a plan for additional data collection and costing	Consultant will prepare this plan for nearshore surveys and flow and sediment measurement and additional data collection. This plan will be submitted in the last week of February 2019.
4	DG emphasized to consider frequency of 200 years for planning and design of polder embankment instead of 50 years.	
5	As an activity of capacity building of professionals and stakeholders, he also accentuated to take concurrence of DG, BWDB during nomination of participant in overseas as well as local Training/MS/PhD program	Agreed and Suggestions of DG will be followed.
Comments of Project Director, CEIP-I		
1	PD said that ToR stipulated to prepare an investment plan and BWDB needs it to approach to donors.	The Consultant agreed to prepare a development plan for the whole coastal zone
2	PD mentioned that in CEIP-I, erosion protection due to wave action and river erosion were not duly considered. This should be considered in the present planning. He also emphasized to revisit the required size of the regulator and it will be larger in accordance with the channel khal	Erosion modelling for a number of rivers has already been taken up in accordance with the suggestions of PD. Data collection plan has been made and bathymetric survey has already been started. The model set-up is being carried out.
3	PD said that the extent of the study are needs to be defined. He said that development plan should include the phased improvement of all remaining 122 polders. He suggested that data collection plan includes insufficient measurements.	An investment plan will be prepared for all remaining polders)122(as per ToR. Data collection plan proposed is only directed towards the limited studies proposed in the Terms of Referecne. This is already being revisited and includes more data collection is proposed compared to ToR.

SL	Comments and Suggestions	Responses
Comments of Mr. A.M. Aminul Haque, Chief Planning		
1	There is a need of relation matrix describing the activities stipulated in the ToR and how it is presented in the Inception Report	Agreed and provided in the final version of the report. Activities of ToR are reflected in different chapters in the inception report in the inception report.

Comments of Economic Relations Division, Ministry of Finance		
Sl. No.	**Comments**	**Responses from Study Team**
01	No specific field visit was undertaken during the inception report. Rather on the basis of information of 2016 the report was generated. If specific field visit was done more effective report could be generated.	A field visit was made to Aricha and the surrounding area on Janaury 11th 2019. Another Field visit was made to visit Polder 56/57 i.e. Bhola Island from 20th January to 23rd January 2019. Field visit report has been incorporated in final Inception Report at page 22.
02	In case of methods of data collection of water level observation,)page No-38(only 3 locations were selected. If more than 3 locations were taken, more accurate observations could be achieved.	The 3 locations mentioned in the TOR only are shown. A number of water level and discharge station have already been selected to measure discharge and water level to define boundary conditions and calibration and validation of models. In addition to primary data collection available data will also be collected from secondary sources. The new data collection plan is presented in matrices and maps in the final version of the Inception Report in page 40-42 with figure and map.
03	As per project workplan of the inception report)page no- 69(some activaties will take 30 months to implement. But the CEIP -1 Project will be ended by June, 2020. Only 18 months left from now, In that case how this plan will be implemented?	The study period is 30 months in accordance with the ToR. Our work plan reflected the ToR. Request will be made for additional time for the study to the project authority and accordingly DPP of CEIP-1 would be revised.

<table>
<tr><td colspan="3">Comments of from M & E Team on Draft Inception Report,</td></tr>
<tr><td colspan="3">General Comments</td></tr>
<tr><td>Sl. No.</td><td>Comments</td><td>Responses from Study Team</td></tr>
<tr><td>01</td><td>Manning Schedule
National both Key and Non-Key Professional are showing zero.
Provide manning schedule separate both key and non- key professional</td><td>Much appreciated. Some personnel are shown as zero input because they are approved members of the team who could be deployed as and when necessary, with the client’s permission. Manning schedule for expatriate and national experts are provided in final version of the Inception Report at page 79-80.</td></tr>
<tr><td>02</td><td>Provide flow chart to achieve all objectives of long-term monitoring, research and analysis.</td><td>This is a new and innovative research and analysis. Work plan includes all the activities and deliverables sequentially. Activities are outlined based on outputs and deliverables. Separate flow chart is not required.</td></tr>
<tr><td>03</td><td>Describe how to achieve all component)1 to 9(
How to achieve activities of all component step by step
How to provide deliverables to delivery
In component-3: how to do data processing, validation and completion.</td><td>For each component, there is a separate team, data collection plan, methods of analysis and modelling. Standard guidelines of data processing and validation will be followed. All data will be organized in a GIS based database.</td></tr>
<tr><td>04</td><td>Describe how to develop
Development of Coastal Polder Information Management Database,
Data dissemination through Web GIS based Interactive Database Portal,</td><td>This is an important deliverable. The development methods of database is illustrated in Appendix B.</td></tr>
<tr><td colspan="3">Other Comments:</td></tr>
<tr><td>05</td><td>The Draft Inception Report has more or less covered all the aspects regarding Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone, It has generally followed the elements of the ToR but needs some re-arrangements, editing and addition etc.</td><td>Much appreciated your comments and suggestions. We have incorporated it in the revised report..</td></tr>
<tr><td>06</td><td>As there are 9 components of the consultancy services, Chapter 4 should have 9 sections (component wise)</td><td>Agreed.</td></tr>
</table>

07	Content of Chapter 4,5,6,7,8 and 9 may be re-arranged and presented in 2 chapters namely, Chapter 4 Scope of Works for Consultancy Services and Chapter 5 Methodology.	The Inception report has been developed in accordance with the ToR. There are many ways to write it but one should follow the ToR.
08	A Chapter on Methodology containing a flow diagram is suggested for better understanding and emphasizing on the methodology. The Methodology should include all Core Activities; methods of data collection and their analysis and output etc.	Suggestions are much appreciated. We revised the report and it has been improved.
09	A new chapter titled Ò Comments on the ToR’’ may be added.	Agreed. Comments and response matrix is added as an appendix

Specific Comments

Sl.	**Section**	**Comments**	**Responses from Study Team**
1	Contents	In chapter- Methodology, component wise methodology of activities should be presented. However, for detailed information or explanation Appendix may be referred.	
2	Pg. 12 &13; Figs 1.1 &1.2	The title of the figures may be changed as suggested below: Figure 1.1 Average Tidal Range and tidal Limit in the South-West Region of Bangladesh. Figure 1.2 Coastal Polders of the Bangladesh.	Very good suggestions. We have revised the title accordingly in page 12 and 13.
3	Pg.15; Section 1.4: Objectives of the Inception Report	The objectives may revised/ modified as per the ToR.	Objectives is as per ToR in the final version in page 14, section 1.2.
4	Pg. 16; Section 1.5 Contents of the Inception Report	Section 1.5 may be re-written in accordance with the General comments and Specific Comments.	We have rewritten the inception report in accordance with the received comments in page 16

5	Pg. 20; Section 2.5: Field Visits	Field visits are required before finalization of the Report. The Inception Report should contain observations of the Field Visits.	Field visit was made to visit Polder 56/57 i.e. Bhola Island from 20th January to 23rd January 2019. Field visit report has been incorporated in revised Inception Report in page 22 to 28.
6	Pg.28; section 3.3 Objectives of Consultancy Service (points a-d)	Repetition of section 1.2 (points a-d) has been made. Instead of repetition, reference to section 1.2 can be made before the explanation of the points (paragraphs 2,3,4 of section 3.3)	Agreed. It has been revised in page 31.
7	Chapter 4	The Section Titles should be same as that of the ToR.	We followed the ToR.
8	Pg.32; Fig 4.1	The title of the figure may be changed as suggested below: Figure 4.1 Environmental Sub-divisions of the Coastal Zone of Bangladesh	This title is from DELTA PLAN, which has been approved by GOB.
9	Pg.34; Table 4.3 Yearly Monitoring Survey -Row 2, col.2	The word 'At' may be deleted. Spelling of the river passur may please be Checked.	The spelling of river PUSSUR is Pussur.
10	Pg. 36; Table 4.3; D. Water level observation: Row 1 & 2, Column 2	The word 'At' may be deleted.	Agreed
11	Pg. 37; Fig 4.2	The title of the figure may be changed as suggested below: Figure 4.2 Index Map	Your suggestions are much appreciated and changed in page 39, figure 4.3.
12	Pg.38 Fig 4.3	The title of the figure may be changed.	Changed in Page 43, Figure 4.4
13	Pg.39; Fig 4.4, 4.5 and 4.6	The title of the figure may be changed.	Changed in Page 44, Figure 4.5, 4.6 and 4.7.
14	Pg. 44, Fig 4.11	- The title of the figure may be changed. - check the Fig. no at 1st para.	Changed in page 49, Figure 4.12.
15	Pg. 46; Section 4.3.2: Morphology (component 4-A)	It is suggested to mention the 'Objectives' of the Morphological studies in this Section or insert a reference, of the Appendix A (Pg. A1)	Appendix -A, Page 1, Section A.1.1

16	Pg.47; Section 4.3.3: Subsidence (Components 4 -B)	It is suggested to mention the ‘Objectives’ of the Subsidence studies in this Section or insert a reference, of the Appendix A (Pg. A21)	Appendix -A, Page 21, Section A.2.1
17	Pg.52 Section 5.2 Coherence and Overview of the Entire Delta (5-B)	A Sub-section 5.2.4 Deliverables may be added.	Agreed. It is in the final version of the report
18	Pg. 59; Section 7: Economic Assessment and investment plan	Objectives, Activities and deliverables ad per ToR may be added.	Agreed. Deliverables are added.
19	Pg. 59; Fig 7.1	The title of the figure may be changed.	Suggestion is much appreciated and changed in page 64.
20	Pg. 67; Section 9.1 Outreach Programme	‘Objectives may be added	Objectives is in the IR
21	Pg.1; Appendix A, Sub-section A.1.1	-Sub-section title should be ‘Morphology on A Macro Scale’ - The ‘Objectives should be written as per the ToR -Objectives-wise description of the ‘Approach’ should be given in Sub-section A.1.1.2	Please see the Final Inception Report
22	Pg. 2; Appendix A, Sub-section A1.1.2.2: Existing Models; Fig A-1	The title of the figure may be changed.	Do
23	Pg. 3; Appendix A, Section A.1.1.2.3: Activities	The Sub-section may be re-written. The section should elaborate the ‘Activities’ as mentioned in ToR.	Do
24	Pg. 4; Appendix A, Section A.1.1.2.4: Deliverable	The Deliverables should completely match with that of the ToR.	Agreed. Deliverables are added.
25	Pg. 8; Appendix A, Section A1.3.3.3: Existing Models; Fig A-2	The title of the figure may be changed.	Please see the final version of the report
26	Pg. 19; Appendix A, section A1.3.2.3: Activities	An important Activities i.e. ‘Stakeholder Consultation’ as mentioned in the ToR has not been included in the list of Activities. A section on ‘Stakeholder Consultation’ should be added.	Agreed. It is included in the final report.

27	Pg.4; Appendix B, Section B.4; Table B-1	The title of the Table may be changed.	Your suggestion is much appreciated and changed.
28	Pg. 6 & 7; Appendix B, Section B.6; Fig (?), Table B-2	The title of the figure may be changed. Figure number may be inserted. The title of the table may be changed.	do

Comments of Swarna Kazi, Sr. Disaster Risk Management Specialist, The World Bank

Sl. No.	**Comments**	**Responses from Study Team**
01	We would recommended that the big design question of how to get to a more sustainable polder system gets a more prominent role in the entire setup of the program/ activities.	The study was set up to answer even more important design questions related to physical processes which would lead to eventual failure of the designs. These questions have to be settled first. Design of the sustainable polder systems will take place after we have filled some important gaps in our knowledge of how the system will behave in the longer term when we implement user friendly systems against a background of a changing environment.
02	First, the TOR listed that -already as part of the inception phase – several preliminary polder concepts must be created based on brainstorm to start thinking process and generate promising polder concepts at the beginning (see page 45 in the TOR). This activity is not listed and mentioned anymore from what we read in the inception report and/or results of this activity are not reported here. The activity overview starts with the literature review and the polder design starts at component 5 after data collection, modelling activities have been taken place. The good aspect of starting brainstorming of the new polder design concepts right at the beginning is to keep focus on what we want to achieve here and make the polder design leading/central in the entire structure of the program. It will also guide a literature review and the questions to be answered from the literature review and the questions to be answered from the literature specifically, focus the data collection efforts, target the modelling, and so on. Our	We are carrying out consultations among all stakeholders and polder dwellers to ensure that the polder designs are not heavily weighted towards technical convenience and less towards serving the users in a sustainable way. The study team and their colleagues in the BWDB are well aware of every type of engineering solution there is to many problems encountered in the polder system. These consultations will aim at exploring the social, economic and environmental issues that are equally important to the polder communities. Guidance of the stake holders will give rise to other, innovative solutions to the problems of managing polders for the benefit of the population. One would be naïve to believe that a most popular solutions would stand the test of sustainability. The extensive knowledge of physical and environmental processes we will gain through the research component of this study will enable us to evaluate every creative proposal to ensure that these remain viable over an extended period of time. It will also be necessary

	recommendation would be to the consultants to take this into consideration and we would strongly advocate for doing a polder design brainstorm kind of activity at the beginning/inception phase. If not yet scheduled, it may be an idea to convene with experts including people involved in on going CEIP-1 from BWDB etc. in a separate workshop and do this exercise together soon.	to be in a position to explain to the communities why some proposals could turn out to be less beneficial than one thinks in the long run. The team will arrive at a development plan for the remainder of the polder system which will respond to the needs of the polder stakeholders and to the particular hydrological and environmental characteristics of where the polder is situated. This plan would then be put before the stakeholders and the technical experts to obtain approval. Preparation of cost estimates, preliminary feasibility studies etc can only be done at this point. However, a detailed consultation meeting will be conducted on design parameters and design of polders. involving meaningful participation of design offices of BWDB, professionals of CEIP.
03	Second, river bank erosion is a key issue for CEIP_1 for the sustainability of the polder system and has not been systematically investigated in the delta from what we have seen thus far. At page 45 of this inception report. *"It is proposed that a special meso-Scale study of "Bank-Erosion hindcasting" is undertaken to analysis the bank erosion processes that have taken place in the large tidal estuaries in the last 20 or more years in areas already been subjected to in which large and often intensive data collection programmes have been mounted for various projects. New guidelines for predicting medium term bank erosion are expected to emerge this study".* From this quote, it is not entirely clear if the long term monitoring Study will indeed do this bank erosion hindcasting and come up with guidelines for predicting medium term bank erosion (ideally, this is included to scope). A detailed analysis of this including analysis of satellite images, doing meso-scale modelling and also do some forecasting would be very beneficial for the entire thinking about sustainable development of polders in BD delta. It would be good if the inception report can provide clarity what will be done within the scope of the project.	River bank erosion study has already been initiated. Although there is not specific item for this in the TOR, the concept comes easily within the broad coverage of mesoscale modelling activities. This study is essential because satellite image analysis has not been a sufficiently reliable predictor of the river banks that will in the near future (say 5-10 years) be subject to attack. This is essentially an open-ended research study. The quality of the mathematical tools used and the individual reputations within the teams of river morphologists being deployed augurs well. It is proposed that a technical report on this subject be published by the project within 12 months

Comments of Md. Harun ur Rasheed, Superintending Engineer, Design Circle-1, Bangladesh Water Development Board, BWDB		
SL No	**Comments**	**Response**
1	Design criteria shall be fixed in consultation with concern of Design office of BWDB before start of Design work	Design Criteria for designing polder improvement work will be established involving meaningful participation of Design office of BWDB. However, this is a monitoring and research project to fill the knowledge gaps and generating new knowledge for future applications.
2	Approved design is needed for approval of DPP, So, Detail design including Foundation design shall be provided in the study report. Design computation shall also send to Design Office with Drawing. Design shall be vetted from concern Design Circle of BWDB. Cost estimate shall be done accordingly, for smooth implementation of the project	This is not a detailed feasibility study to do detailed design of interventions. There will be an investment plan based on new knowledge and needs of the coastal area. However, some conceptual design will be made in consultation with BWDB.
3	Consultation with Design office must be done before survey work and site selection of structure. Survey work is very important and one of the key element for planning and design. In ECRRP & CEIP-1, many variation occurred during implementation due to survey work. If survey are not done properly, then serious difficulties evolved during implementation. Shifting of location, changing of location, extension of length, Increase or decrease of regulator size etc, evolved during implementation.	This comment is related with detailed feasibility study and irrelevant to the present research work. A detailed data collection plan is given in the final report. Consultants will interact with BWDB counterparts before during and after data collection.
4	In Figure 10.2: Manning Schedule of this Draft Inception Report, there are no Design Engineer, 117 Polders was identified under this project. There are huge Design work. How this work will be performed. Sufficient number of Design Engineer (Junior Design Engineer, Mid-Level Design Engineer & Senior Design Engineer) are needed to perform this huge Design Work. If the Design work are not performed properly, the whole project will be a sick one during implementation.	Input of various professionals are in accordance with ToR. Consultant can't add new input beyond ToR. The ToR
5	In Page 51 of this Draft Inception Report, it was written that "Make an inventory of the present situation in 139 polders". **Comment :** An inventory of all projects of BWDB were done under WMIP and also in many other project. Instead of using those data, why another project for "new inventory" is taken up. This project shall use the inventory of WMIP. Updating of t hat inventory may be done under this project.	Actually an interactive database will be prepared for each polder including physical, environmental and social. We will also consult WMIP inventory as well as other available database.

6	In Page 64 of this Draft Inception Report, it was written that "Provide overseas training mainly of BWDB Engineers on coastal htydraulics, morphology, salinity intrusion, storm surges modelling under changing climate." **Comment:** But there are no training for Hydraulic Design Work, Structural Design Work, Foundation Design Work, Construction work, Construction Management, Maintenance work, Survey work etc. To be familiar with latest Design work & Construction work around the World, BWDB Design Engineers and Field Engineers needs training.	Training disciplines will be selected in consultation with PD.
7	Modalities of On-Job Training is not cleared. Modalities or Methodology of On-Job Training shall be clearly mentioned.	Agreed and will be done in consultation with PD before starting the training.
8	Opening of Sluice or Regulator shall be such that it can be used for navigation and fisheries besides drainage or flushing. So, Design of Sluice or Regulator shall be done accordingly.	Agreed. Design principle and conceptual design will be carried out considering these issues
9	If the top width of design section of khal or river is more than existing section then how this land will be arranged, especially in urban or town area. If it is not clearly mentioned in this report, then during implementation, this excavation work may be abandoned. Necessary cost have to be considered in this respect.	This comment is relevant to detailed feasibility study
10	Dredged material disposal plan" or Excavated earth disposal plan" shall be included in Khal or River Excavation or Dredging work. It include at least size, location of dumping area from the center line of excavation. If it is not clearly mentioned in this report, then during implementation, this excavation work may be subjected to abandon. Necessary cost for disposal have to be considered in this report.	do
11	In excavation of Khal or River, Span & pile cap level of existing bridge shall be addressed.	do

12	In Page 65 of this Draft Inception Report, it was written that " In many countries (including Bangladesh, e.g. IWM) have resorted to creating new institutions to house such specialist individuals". **Comment:** IWM was created for modelling work. But depending only on modelling, IWM cannot survive. For survival, IWM had to shift towards Consultancy service for Feasibility study, Detail Design and Survey work. Although in the organization setup, IWM has no Feasibility study Directorate and Design Directorate. They are providing these services by recruiting consultants on project basis. Similar situation is for CEGIS. Since creation in 1959, BWDB is a self-sufficient organization with the concept of modern "Supply Chain Management". It has Planning wing, Design Wing, Implementation Wing, Maintenance Wing, Hydrology Wing etc. In all wing BWDB has skilled professional with long experience. BWDB has "in-house specialist individuals" in all sectors of a Water Resources Projects.	BWDB is a large Government Institution for planning, design and implementation of water development and management projects in the country. IWM is a small institution compared to BWDB with different mandates. BWDB and IWM are not comparable with each other since mandates are different. IWM is a Trust of Ministry of Water Resources to provide services in the field of Water Modelling, Computational Hydraulics & Allied Sciences for improved integrated Water Resources Management.
13	In page 65 of this Draft Inception Report, it was written that "The career objectives of an able officer working in the BWDB would be to do good work while aspiring to climb the promotional ladder within the mainstream of the organization (Executive Engineer > Superintending Engineer> Chief Engineer> ADG> DG etc), following a promotional path that requires them to abandon, at some stage, the scientific career requiring special skills and duties." **Comment:** This is not true for BWDB. In BWDB, scientific career dose not hampered to climb the promotional ladder. Moreover, in BWDB, there are more to develop professional or scientific career than any other institution or organization in Bangladesh. Only "subjective specific" professional training is needed for the capacity building of BWDB professionals.	Agreed. There are many disciplines in BWDB and one can build his scientific career in any disciplines. BWDB also needs to provide opportunities to build career on state-of art technology water modelling and forecasting of river morphology
14	Before model set up, all boundary condition, criteria etc. shall be discussed with concern. Design Circle & Planning Directorate of BWDB. Accordingly Model shall Run. In all stages of model calibration or validation concern Design Circle & Planning Directorate of BWDB shall be discussed.	Agreed and will be followed in consultation with PD.
15	In Appendix A, it was mentioned that calculation or model will run for 25, 50 and 100 years. But for embankment along Meghna, BWDB criteria is in 200 years. So, calculation or modelling shall be done accordingly.	This frequency will be discussed further during the course of the study. The reliability of 200years is less. Adaptive method will be followed considering long-term analysis.

Attendance Sheet

Inception Workshop

Long Term Monitoring, Research and Analysis of Bangladesh Coastal Zone (Sustainable Polders Adapted to Coastal Dynamics)

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in association with IWM Water Environment & Climate

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