MODELLING THE DRAINAGE SYSTEM OF SELECTED COASTAL POLDERS

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Submitted by

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In partial fulfillment of the requirement for the degree of

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CERTIFICATION OF APPROVAL

The thesis titled "Modelling the Drainage System of Selected Coastal Polders" submitted by Md. Taneem Sarwar, Roll No. 0412162003P, Session: April 2012, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Science in Water Resources Engineering on 24th September 2017.**

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CANDIDATE'S DECLARATION

I do hereby declare that this Thesis work "Modelling the Drainage System of Selected Coastal Polders" has been done by me. Neither of the thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

Signature of the Candidate

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α	Slope angle of the wave front
ε	Sea surface elevation (m).
τ	Bed shear stress
ζ	Breaker parameter
λ_R	Reduction factor due to slope roughness and permeability
λ_B	Reduction factor due to berm
λ_β	Reduction factor due to oblique wave attack
λ_H	Reduction factor due to shallow water
ρ_w & ρ_a	Air and water density respectively (kg /m^3),
Ω	Coriolis parameter
A	Horizontal area of the Mangrove forest
C_w	Wind friction factor
D	Diameter of the trunk
f	Friction factor
h	Water depth (m).
H_s	Significant wave height
g	Acceleration due to gravity (9.81 m^2/s)
k_N	Nikuradses roughness height
L_o	Wave length at deep water
M	Manning number
p and q	Flux in x and y directions respectively (m^3/s/m).
P_a	Atmospheric pressure (kg/m/s^2).
P_c	Central pressure
P_n	Neutral pressure
R	Effective runup
Re	Reynold's number
t	Time (s), x and y (m) are Cartesian Co-ordinate (s).
V_r	Rotational wind speed
W	Wind speed (m/s).

LIST OF ABBREVIATIONS

AOGCM	Atmosphere-Ocean general Circulation Model
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Metrological Department
BoBM	Bay of Bengal Model
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering and Technology
BTM	Bangladesh Transverse Mercator
CEGIS	Center for Environmental and Geographic Information Services
CEIP	Coastal Embankment Improvement Project
CEP	Coastal Embankment Project
CERP	Coastal Embankment Rehabilitation Project
C/S	Country side
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DOE	Department of Environment
D/S	Downstream
GBD	Ganges-Brahmaputra Delta
GBM	Ganga–Brahmaputra–Meghna
GIS	Geographic Information System
GMSL	Global Mean Sea Level
GPS	Global Positioning System
GOB	Government of Bangladesh
IPCC	Intergovernmental Panel on Climate Change
InSAR	Interferometric Synthetic Aperture Radar
IWM	Institute of Water Modelling
MES	Meghna Estuary Study
MSL	Mean Sea Level
OSL	Optically Stimulated Luminescence
PWD	Public Works Datum

RCPs	Representative Concentration Pathways
R/S	River side
SAT	Surface Air Temperature
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
SMRC	SAARC Meteorogical Research Centre
SWMC	Surface Water Modelling Centre
TAR	Third Assessment Report
TRM	Tidal River Management
U/S	Upstream
USGS	United States Geological Survey
WARPO	Water Resources Planning Organization

ABSTRACT

This research work has been conducted to assess the water logging problem for selected coastal polders namely 17/1 and 17/2 of district Khulna (Dumuria upazila) in the South-West region of Bangladesh. This research work has also evaluated the vulnerability of the existing situation of these polders with changing climate scenario of IPCC 2014 fifth assessment report and the effectiveness of re-excavation of internal khals, dredging of Peripheral Rivers, Tidal River Management (TRM) and introducing pumping system against water logging problem applying as different scenarios. To carry out the study google images, bathymetric data of south-western coastal area, water level and discharge data, precipitation and evaporation data have been used in the available South West Regional Model (SWRM) from Institute of Water Modelling (IWM). Field visit was conducted with a view to obtain a better idea on the existing condition of study area.

The Polder 17/1 and 17/2 has been experiencing severe water-logging problem over the years because of high rate of sedimentation in the peripheral rivers and internal drainage khals. It severely affects the normal social and economic activities of the people of the study area. The drainage system of the study area is composed of Gangril, Haria, Taltola, Bhadra and Salta Rivers along with a vast network of internal drainage khals. These entire river systems have been severely silted up by the incoming silt from the sea with high tide and lost its drainage capacity severely which leads to no drainage condition through the existing structures of the polders. This investigation is made by preparing flood inundation depth maps for 3-day duration maximum water level considering 5-days cumulative rainfall by showing the area of different land classes (F0, F1, F2, F3 and F4) using model results and available Digital Elevation Model (DEM) of the study area. From the local model of Polder 17/1 it has been found that maximum flood free area increased from base condition 17.26% to 69.96% in the final option and Polder 17/2 from base condition 16% to 84% in final option under critical climate change condition.

In this study, TRM is applied as a scientific technique to apply for reducing the water logging problem solution in the selected coastal polders. TRM is not a direct solution for reducing the water logging but a long-term method of solution. It increases the conveyance capacity of the peripheral river. Therefore, the drainage system of the polder achieves high drainage capacity due to increase in the upstream and downstream water level difference at the critical condition. In this research, it is found the tidal prism with TRM is significantly high compared to the required tidal prism, which implies that the river conveyance capacity will be increased and improved drainage conditions will be sustainable. The tidal prism is found in Existing Condition 0.07 (Million-m^3), Proposed condition with Dredging 2.78 (Million-m^3) and Proposed condition with Dredging +TRM 7.76 (Million-m^3) whereas the required tidal prism is 6.06 (Million-m^3). In this research pumping is applied water level up to 1.0 mPWD and lowest at 0.50 mPWD for getting the highest benefit at extreme climate change condition.

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CHAPTER ONE:

INTRODUCTION

1.1 Background of the study

Bangladesh is one of the most vulnerable countries that are facing the early impacts of climate change. The country is most vulnerable to the natural catastrophes (drainage congestion, fresh water scarcity in dry season, inundation of land at monsoon and unsteady morphological processes) which are severe at coastal region. However, natural disaster will be more severe in the near future, due to impact of climate change. The coastal region of Bangladesh has morphologically dynamic river network, sandy beaches and estuarine system. The study area lies in the south-western coastal belt of Bangladesh under Khulna district, is a unique brackish water ecosystem comprising the districts of Satkhira, Khulna, Bagerhat and the southern part of Jessore. Coastal area of Bangladesh is already protected by coastal embankment called polders. It introduced a compartmentalized polder or enclosure system in the south-west tidal areas in 1960 under coastal embankment project (CEP). There are 139 embanked polders in the coastal area (BWDB, 2012), which were constructed in the late sixties to protect the land from tidal and monsoon flooding and saline water intrusion. The main focus was to increase the crop production with fresh water. Height of all these polders varies between 3m to 7m (IWM, 2005 and Rahman et al. 2007). About 11,915 km2 in the coastal area is protected by coastal polders (MES II, 2001). IWM and CEGIS (2007) have studied that about 25 polders in the southwest region would experience severe drainage congestion due to 62 cm SLR.

Continuing process of sedimentation over the years, many of the rivers/channels/canals in the area lost its conveyance causing severe drainage congestion. Inundation problem will more severe due to heavy rainfall event and sea level rise.

In this research work, numerical model has been applied to assess the impact of SLR and precipitation change due to climate change scenario with water logging problem in the selected coastal polder 17/1 & 17/2. Main focus will be on the drainage congestion for the polders.

1.2 Objective of the study

The objectives of the study have been described as follows:

1. To identify the present drainage problem in the selected polders
2. To carry out the rainfall and runoff model and the hydrodynamic model to investigate the drainage problem
3. To investigate alternate solution such as pumping in combination with TRM and dredging for drainage problem

1.3 Possible outcome from this research work

The expected outputs of the research are as follows:

1. Base line information of the existing infrastructure like drainage structures, river network, embankment, drainage canal etc. in the study area;
2. Base line hydraulic condition in the perspective of drainage conditions;
3. Inundation depth-duration maps considering the existing and climate change scenario;
4. Alternate solutions with combination of TRM, pumping and dredging

1.4 Organization of the Thesis

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

Chapter One, provides detailed background information, objectives and scope.

Chapter Two, gives a review of relevant literature on drainage congestion, land subsidence and sea level rise.

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

Chapter Four, contains detailed information of the study area and mathematical model setup including geographical location, water resources, climate, tidal and sediment characteristics, also the climate change scenario.

Chapter Five, contains detailed result analysis and effectiveness of different options have been assessed clearly to lessen the drainage congestion of the selected polder area in changing climate.

Chapter Six, contains conclusion and recommendation have been stipulated. The major findings of the study are shown in this chapter.

CHAPTER TWO:
REVIEW OF PAST STUDIES

2.1 General

The ecological and geological situation of Southwestern part of Bangladesh is unique in many ways. Southwest coastal region of Bangladesh is a unique brackish water ecosystem comprising the districts of Satkhira, Khulna, Bagerhat and the southern part of Jessore. It is the part of inactive delta of large Himalayan Rivers and located just behind the mangrove forest Sunderban and Bay of Bengal. The large portion of the region is coastal wetland formed by the rivers flowing to the sea. Since the Southwest region is located in the coastal zone, it possesses a fragile ecosystem and is exposed to a number of calamities like cyclones, floods, tidal surges, repeated water logging, and land erosion, degradation etc that shaped the lives and livelihood patterns of people (Sarker B.B.S.S., 2010). The climate in Bangladesh is changing and it is becoming more unpredictable every year. The impacts of higher temperatures, more variable precipitation, more extreme weather events, and sea level rise are already felt in Bangladesh and will continue to intensify. Several studies have been carried all over the Bangladesh to see the impact of climate change and to examine the effectiveness of the drainage system of the polders in the changing climate and find climate resilient measures for improved drainage conditions in the near future and the possible adaptations against it. In this chapter, some previous studies have been reviewed which are related to the present study.

2.2 Background Literature

A lot of study related to drainage problem has been completed and those studies proposed different solutions. Researchers investigated the drainage congestion for climate change effect considering the IPCC report.

2.2.1 Drainage related study

In CEIP-1 study (IWM 2013a), the AR4 projection of IPCC fourth assessment for sea level rise and rainfall has been adopted in the mathematical model to simulate the climate change condition in existing and improved drainage congestion for different options. The drainage study shows that some polders are likely to experience water-logging under climate change conditions. To improve the drainage performance under anticipated climate change condition, some options are devised and duly incorporated in the model setup for assessing their effectiveness. These options include the excavation of all the internal drainage khals of polders by 1 m and dredging of the peripheral rivers/khals by 2 m, modification of invert level of drainage structures, extra regulators and increase of vent numbers for some existing drainage structures etc. The analysis of model results revealed that the drainage congestion will improve significantly due to the implementation of these options. Flood inundation indicates that water logging problem is severe in climate change condition. However, dredging of internal canals (1m) and Peripheral River (2m) is proposed, also renovation of existing structure was also suggested.

In Drainage Problems in the Bhabodah Area study (IWM 2011), the present water logging problem has been assessed using the mathematical modelling. This study includes two options; Option-1 includes the construction of embankment on the both bank of Mukteswari River from Dhakuria regulator to Teka Bridge to prevent the water spill from Mukteswari River to the adjacent area. And sequential tidal river management basin is considered for sediment management and to maintain sustained drainage capacity of the Hari, Upper-Bhadra and Gengrail rivers. A link channel is also considered to connect the Teka and the Hari River. Drainage performance of the link channel connecting the Teka and the Hari River in between Bhabodah regulators has been examined by comparing the drainage flow through regulator with that of combined flow through regulator and the link channel. Option-2 includes sequential TRM operation in the Hari, Upper Bhadra and Gengrail River. In addition to TRM a bypass channel from Teka to Upper Sholmari River and Pump House are also considered in this option. Analysis of results shows a decrease of 10 to 15 cm during peak flow at the upstream of Bhabodah regulator if bypass channel is implemented. However, the development of bypass channel requires excavation of almost 27 km long channel and considerable quantity of land acquisition and land owners are against the implementation of this channel. Dredging is not a long term solution, whereas Tidal River Management (TRM) is effective solution which reduces the river sedimentation by trapping the sediment in the tidal beel. Tidal river management shows excellent performance and reduces water logging problem satisfactorily.

In Fahad Khan Khadim et al (2013), IWRM (Integrated Water Resources Management) and TRM (Tidal River Management) Impacts in South West Coastal Zone of Bangladesh has been analyzed using satellite images, RS and GIS technology, Digital Elevation Model (DEM) and field investigations. IWRM concept and TRM practice are both issues generating debates and disputes regarding socio-technical benefits. The study has been developed considering a twofold focus, firstly emphasizing on the positive IWRM impacts in the study area and then establishing some facts on TRM. The impacts would be helpful in clarifying the need of IWRM in regions possessing complicated water management and livelihood groups with conflicting water use. On the other hand, as TRM is an environment friendly, cost effective and economically viable process to raise coastal lands for enhancing agricultural opportunities; the technical conclusions achieved in this study would be extremely helpful in providing TRM planners with information on possible TRM duration, compartment specification and sequence of tidal basin selection. The results of this study, showing the changes achieved in land development, land use, flood resistance and food security clearly reflects the positive consequences of implementing IWRM. IWRM can be extremely helpful in developing countries where water has conflicting demands and uses and ensuring stakeholder participation at all stages of planning and implementation, holistic outcomes of IWRM can be achieved. Fact-Finding of TRM covered in this study would provide planners with a clear perception on sequential selection of tidal basins, as well as predicting the final sedimentation to some extent before implementation of TRM. The results obtained from the consideration of cohesive sedimentation in Beel Bhaina tidal basin can be modeled to predict sedimentation rates and probable duration of TRM operation and such information can satisfy both the stake- holders and implementing authorities involved in the process, resulting in best possible outcome under an arguing social context.

In the study of polder 36/1 (IWM 2013b), the crucial problems in the project area are water-logging, sedimentation in the river bed and scarcity of freshwater due to salinity during dry season. The Bhairab, Chitra-Karamara, Mora Chitra, Old Madhumoti and

Atharobanki river, are the main drainage routes, of the study area. These rivers experienced enormous sedimentation over the decades that results in prolong drainage congestions. Considering the problem of sedimentation of the river, removal of drainage congestion and improvement of socio-economic conditions three options have been devised for sediment and drainage management. The major activities for solution are capital dredging, additional drainage and flushing regulators, tidal river management by allowing natural tidal movement into embanked low-lying beel for sediment management, excavation of khals and tributaries and construction of dyke etc. Restoration of Bhairab River by dredging /excavation would not sustain since there is a tidal meeting point and re-siltation rate is almost 90% within one dry season. Upstream dry season flow will not be able to flush the huge incoming sediment into the river during high tide. Sediment management through TRM by allowing natural tidal movement in an embanked low-lying area is a proven and tested method for sediment management. Utilization of all the potential beels for TRM along the Bhairab river basin would be effective for sediment management and to increase tidal prism, which will result in increasing the drainage capacity of the river. It is seen that Nurnia, Kendua and Baruipara Beel, are effective for tidal basin for Tidal River Management. Model results shows that these beels generate tidal prism in the range of 1.07 to 3.5 Mm3 individually, which is higher compared to the required tidal prism of 0.8 Mm3 for maintaining the design/proper drainage capacity of the river. Monsoon water from the Madhumoti–Baleswar river system enters into the polder easily to submerge the low lying area. Moreover, additional water enters through dredged and excavated in deeper section of channels in the post–project condition. The study results show decrease of about 1.0m water level in Goarakhal which is connected to the Atharobanki river under the final option (Option-2) compared to the present condition. But in the Chitra river & Wapdar khal the decrease of water level is only about 30 cm under the same option. This is because of additional monsoon flow is coming to the adjacent internal khals from the Madhumoti river through Haque Canal and also via khals connected with Old Madhumoti. The reduction of peak water level in the proposed plan implies the improvement of drainage condition. Drainage improvement of polders suggested two different option proposed considering Tidal River Management (TRM) and renovation of existing structure, dredging of silted up internal canals and peripheral rivers. Though TRM is an effective solution in drainage congestion, it requires huge land area requisition which is not always possible. However, option two is comparatively practical, considering the socio-economic context.

In the study of polder 1, 2, 6 & 8 (IWM 2013c), the study has been carried out for devising sustainable drainage and sediment management plan to solve the long standing drainage congestion problem in the Polder 1, 2, 6-8, 6-extension under Kalaroa, Satkhira Sadar, Debhata, Assasuni and Tala upzillas in the Satkhira district. A comprehensive field survey and investigation, focus group discussions at different locations in the study area, mathematical modelling and field level workshop have been carried out in order to identify the causes of the prevailing problems and to devise interventions for solving existing problems. Considering the issue of sedimentation of the river, removal of drainage congestion and improvement of socio-economic conditions two(2) options have been devised for sediment and drainage management and duly tested for their effectiveness. The major interventions considered in the options for removing drainage congestion are dredging/excavation of rivers, additional drainage and flushing regulators, tidal river management by allowing natural tidal movement into embanked low-lying beel for sediment management, excavation of khalsetc. Restoration of Betna, Marirchap and Parulia-Sapmara rivers by dredging/excavation alone would not sustain since re-siltation rate is almost 60-80% during dry season as virtually there is no upstream fresh water flow to flush the huge incoming sediment into the rivers with high tide. Thus, in addition to dredging/excavation, implementation of TRM, using operation of potential tidal basins is required to trap up the incoming sediment inside the basins for sustainable sediment and drainage management. Continuous TRM operation of all the potential beels along the Betna and Marirchap river basin would be effective. TRM can be successfully and continuously operatedin these two river basins using the selected beels for about 45 years or so. However, before implementation of TRM, location of link canal of TRM basin and cross-dam in the river needs to be finalized after detailed field investigation and in consultation with the local stakeholders. Drainage improvement of polders suggested two different option proposed considering Tidal River Management (TRM) and renovation of existing structure, dredging of silted up internal canals and peripheral rivers. Though TRM is an effective solution in drainage congestion, it requires huge land area requisition which is not always possible. However, option two is comparatively practical, considering the socio-economic context.

Idah, P., Musa, J.J., Mutapha H.I. and Arugungu, M.M. 2009, in this study aimed at determining the causes of water logging in the pilot scheme of Zauro Polder project (ZPP) at Nigeria. The Zauro Polder Project (ZPP) was designed to irrigate over 11,000 ha of arable farmland in Kebbi State. The area is equipped with a 2.65km flood protection dyke, 3.5m high, a temporary pumping station with a generator, a main canal which is connected to compensation reservoir four lateral canals and a collector drain. The source of water is man-made diversion channel from the Rima River from which water is pumped into the scheme. Researcher's identified several reasons for water logging, which is stated sequentially. First reason and major reason is topography of the area pilot scheme (ZPP), it is clear that some areas of the scheme are waterlogged. All those areas having elevations less than 100cm are waterlogged, as there is no possibility of surface outflow. However, second reason of water logging is lack of effective management to re-excavate/reconstruct the primary and secondary canals. This situation brings a standstill water on the land thereby causing waterlogging. Another reason of water logging are unplanned irrigation systems by local farmers and improper land grading etc. To improve the conditions in the pilot scheme the following recommendations were suggested, which are re-excavation of the drains and the canals so that smooth inflow and outflow can be obtained. There should be adequate monitoring of the lateral canals in order to forestall illegal activities of the farmers.

2.2.2 Land Subsidence Related Study

Higgins et al. (2014), reconstructed subsidence rates in the eastern portion of the Ganges-Brahmaputra Delta (GBD), Bangladesh, covering more than 10,000km2 at a high spatial resolution of 100m. The map was produced using Interferometric Synthetic Aperture Radar (InSAR) covering the period 2007 to 2011. Eighteen Advanced Land Observing Satellite Phased-Array L-bands SAR scenes were used to generate 30 interferograms calibrated with GPS. Interferograms were stacked to yield average subsidence rates over the study period. Small Baseline Subset-InSAR was then applied to validate the results against an additional GPS record from Dhaka, Bangladesh. Land subsidence of 0 to>10mm/yr is seen in Dhaka, with variability likely related to local variations in shallow subsurface sediment properties. Outside of the city, rates vary from 0 to>18mm/yr, with the lowest rates appearing primarily in Pleistocene Madhupur Clay and the highest rates in Holocene organic-rich muds. Results demonstrate that subsidence in this delta is primarily controlled by local stratigraphy, with rates varying by more than an order of magnitude depending on lithology.

Sarker et al. (2012), stated that the plinth levels of a 15th century mosque at Bagerhat in the north of the tidal floodplain, a 400year-old Hindu temple (standing ancient structure in the Sundarbans is located in Shakher Tek, about one kilometer away from the east bank of the Sibsa River. It is located in Dacope Upazila of Khulna district) in the Sunderbans forest in the south and a 200-year-old temple 25 km north-east of Khepupara (The Doyamayee is located at the side of a tidal creek called Kamlakanto Khal at Galachipa Upazila under Patuakhali district free from the effects of poldering) in the south-east show that long-term subsidence rates in those areas have not exceeded 1–2.5 mm/year. He mentioned that if subsidence had occurred at the 18 mm/year rate given by Syvitski et al., these buildings would now be 2.4–7.6 m below sea-level. Likely annual rate of subsidence varies from 0.4 to 1.9 mm/yr, with hardly 1 mm/yr to be added or deducted

The estimated rates of subsidence for the monuments are presented in the Table 2.1.

Table 2.1: The estimated rates of subsidence for the monuments

Monuments	Present Plinth Level	RSLR	Duration (year)	Subsidence(m)	Estimated Rate of Subsidence(mm/yr)	for 10 mm subsidence	for 20 mm subsidence
Doyamayee Kali Mondir	0.50 m above TPL	0.25	200	0.25	1.25	0.7 m below TPL	2.7 m below TPL

Monuments	Present Plinth Level	RSLR	Duration (year)	Subsidence(m)	Estimated Rate of Subsidence(mm/yr)	for 10 mm subsidence	for 20 mm subsidence
Chunakhola Mosque	0.30 m above TPL	0.90 to 1.25	500	0.65 to 1.25	1.30 to 2.50	3.5 m below TPL	8.5 m below TPL
Bibi Beguni Mosque	0.40 m above HPL	0.90 to 1.25	500	0.65 to 1.25	1.30 to 2.50	3.5 m below TPL	8.5 m below TPL
Shakher Temple	1.20 m above TPL	0.0 to 0.60	400	0.25 to 0.35	0.60 to 0.88	2.5 m below forest floor	6.5 m below forest floor

(Source: Sarker et al., 2012)

Syvitski et al. (2009), using high-resolution satellite altimetric data unsupported by ground truthing, included the Ganges delta – with a stated rate of 8-18 mm/year among 33 'sinking deltas' world-wide, grouping it with deltas experiencing large subsidence rates attributed to human activities such as embankment construction and water or gas abstraction. This assertion is incorrect on several grounds. The Ganges delta also includes the Ganges River Floodplain, not just the Ganges tidal floodplain assumed by the authors; as is described below, there is no field evidence that either of these regions is subsiding at such a very high rate; and subsidence rates are not uniform within the area as implied by the single figure of 18 mm/year given by the authors.

Allison et al., 2003, stated that sediment cores from the Ganges–Brahmaputra delta in Bangladesh were examined for sedimentological character, clay mineralogy, elemental trends (C, N, S), and 14C geochronology to develop a model for the sedimentary sequence resulting from lower delta plain progradation in the late Holocene. Mangrove-vegetated islands and peninsulas represent the final phase of progradation; a Mottled Mud that is deposited by penetration of turbid coastal water into the mangroves during high water events. The lower delta plain west of the modern river mouths was deposited as a Ganges-dominated delta in three phases since 5000 cal years BP, with Brahmaputra influence confined to the Meghna estuary area and to the supratidal section of western delta deposits. Evolution of the lower delta plain in the late Holocene was influenced by regional subsidence patterns in the tectonically active Bengal Basin, which controlled distributaries channel avulsion and migration, and the creation of accommodation space. Calculation of depths to radio-carbon-dated organic materials in the region of the Sundarbans mangrove forest where embankments have not interfered with sedimentation and the region where polder embankment interfere with sedimentation problem show subsidence rates of 1.3–7.1 mm/year (Table 2.2and Figure 2.1). Annual Change in land levels relative to mean sea-level (mm/yr) is calculated by Depth divided by calibrated calendar age = annual change in land levels relative to mean sea-level.

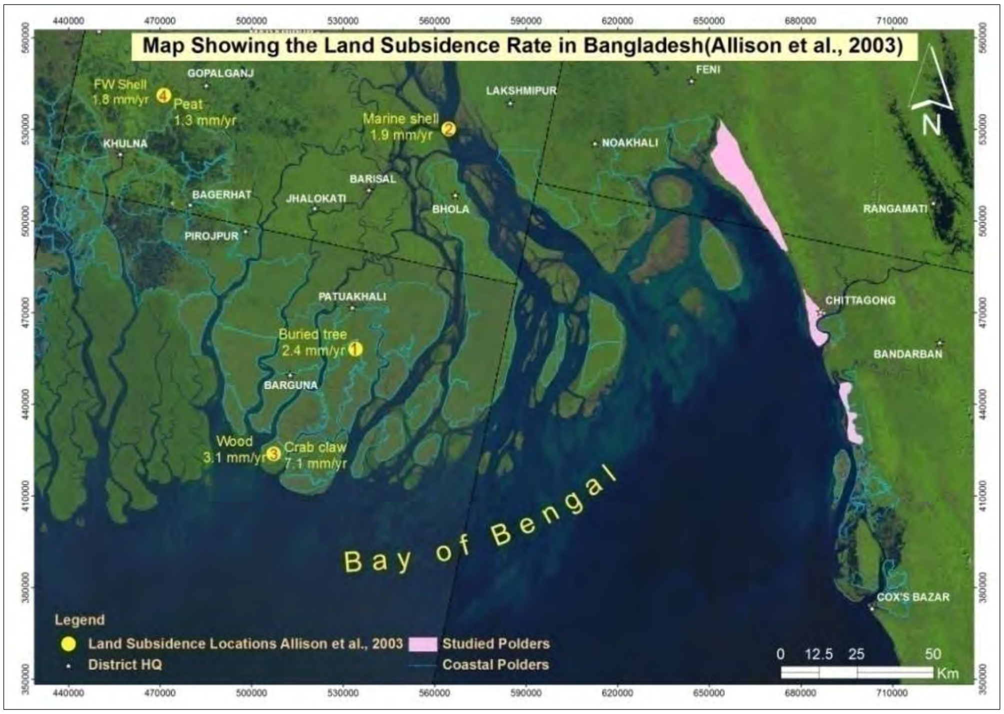


Figure 2.1: Land Subsidence rate on the Ganges Tidal Floodplain (Source: Allison et al., 2003)

Table 2.2: Land subsidence rates on the Ganges Tidal Floodplain

SL No.	Location Name	Location		Depth	Material	Calendar Age	Annual Change in land levels relative to mean sea-level(mm/yr)
		Easting	Northing	(m)			
1	Near Hazir Hat, Amtali Upazila,Barguna	534003	458120	1.5	Buried tree	614±14	2.4
2	Muladi,Barisal	564612	530166	1.4	Marine shell	730±59	1.9
3	Near Arpangasia Hat,Amtali Upazila,Barguna	507229	423775	0.7	Wood	227±48	3.1
	Near Arpangasia Hat,Amtali Upazila,Barguna	507229	423775	2.2	Crab claw	309±8	7.1
4	Near Padmabilla Hat Kalia Upazila,Narail	471305	541124	3.2	Peat	2378±29	1.3
	Near Padmabilla Hat Kalia Upazila,Narail	471305	541124	5.8	FW shell	3192±17	1.8

(Source: Allison et al., 2003)

Stanley and Hait (2000), Litho- and chronostratigraphic radiocarbon-dated cores have been utilized herein to distinguish Holocene deltaic and underlying transgressive units and late Pleistocene alluvial deposits in the western Ganges-Brahmaputra delta. Regional distribution of these facies indicates that neotectonic displacement, including differential land subsidence of delta plain sectors is one of the major controls of late Quaternary depositional patterns in this depocenter. The spatial and temporal configuration of Holocene deltaic sediment thickness, mud and sand layers, peats interstratified in Holocene sequences, and modern mangrove forests that form the Sundarbans are attributed to NE-SW, and to a lesser extent NW-SE, neotectonic trends. Holocene sedimentary and stratigraphic configurations closely parallel geological structures, some of them deep seated, that affected this region during most of the Tertiary and have continued to the present. Extensive mangrove forests developed along the NE-SW zone of thickened Holocene deltaic deposits. Their present configuration is related to natural factors, such as eastward tilting of the delta, rapid sediment accumulation (to 7 mm/yr), marked land subsidence (to 5 mm/yr) and increasing anthropogenic influences, including large-scale land reclamation and decreased river flow influx.

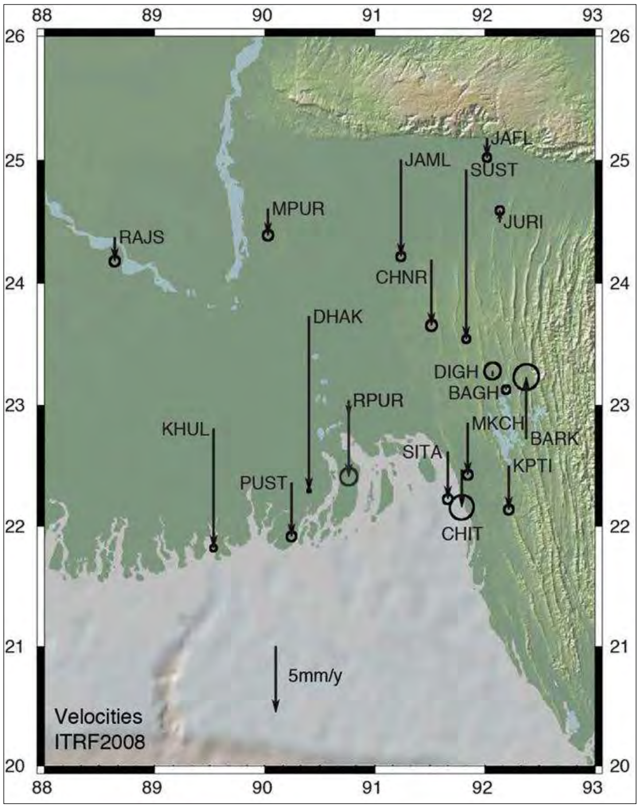


Figure 2.2: Subsidence at different location in Bangladesh (Source: DUEO, 2012)

2.2.3 Sea Level Rise related Study

IPCC (2013), The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has been published based on a new set of scenarios that replace the Special Report on Emissions Scenarios (SRES) standards employed in two previous reports. The process-based projections of GMSL rise for each RCP scenario are based on results from 21 CMIP5 AOGCMs from which projections of surface air temperature (SAT) change and thermal expansion are available where CMIP5 results were not available for a particular AOGCM and scenario, they were estimated (Good et al., 2011; 2013). Changes in glacier and ice-sheet surface mass balance (SMB) are calculated from the global mean SAT projections using parameterizations derived from the results of process-based models of these components (Meehl et al., 2007; Arendt et al., 2012; Marzeion et al., 2012a; Giesen and Oerlemans, 2013; Radic et al.; 2013 and; Bengtsson et al., 2011)); Fettweis et al., 2008; Graversen et al., 2011; Mernild etal., 2010 ; Rae et al., 2012; Seddik et al., 2012; Yoshimori and Abe-Ouchi ,2012). According to the assessment, global mean SAT change is likely to lie within the 5 to 95% range of the projections of CMIP5 models (Meehl et al., 2007b; Gregory and Forster, 2008; Knutti et al., 2008b; Good et al., 2013). Following this assessment, the 5 to 95% range of model results for each of the GMSL rise contributions that is projected on the basis of CMIP5 results is interpreted as the likely range (Kuhlbrodt and Gregory 2012).

Possible ice-sheet dynamical changes by 2100 which as yet provides only a partial basis for making projections related to particular scenarios (Nick et al., 2009, 2012; Vieli and Nick, 2011; Price et al., 2011). They are thus treated as independent of scenario, except that a higher rate of change is used for Greenland ice sheet outflow under RCP8.5 (Rae et al., 2012; Fettweis et al., 2013). Projections of changes in land water storage due to human intervention are also treated as independent of emissions scenario due to lack of sufficient information to give ranges for individual scenarios. The likely range of GMSL rise given for each RCP combines the uncertainty in global climate change, represented by the CMIP5 ensemble (Kuhlbrodt and Gregory, 2012; Knutti and Tomassini, 2008; Kuhlbrodt and Gregory, 2012), with the uncertainties in modelling the contributions to GMSL.

Confidence in projections of global mean sea level rise has increased since the AR4 because of the improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes. Projected change in global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005 has been presented in Table 2.3 and Figure 2.3.

Table 2.3: Projected change in global mean sea level rise

	Scenario	2046-2065		2081-2100	
		Mean	Likely range	Mean	Likely range
Global Mean Sea Level Rise (m)	RCP 2.6	0.24	0.17 to 0.32	0.4	0.26 to 0.55
	RCP 4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP 6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP 8.5	0.3	0.22 to 0.38	0.63	0.45 to 0.82

(Source: AR5, IPCC 2013)

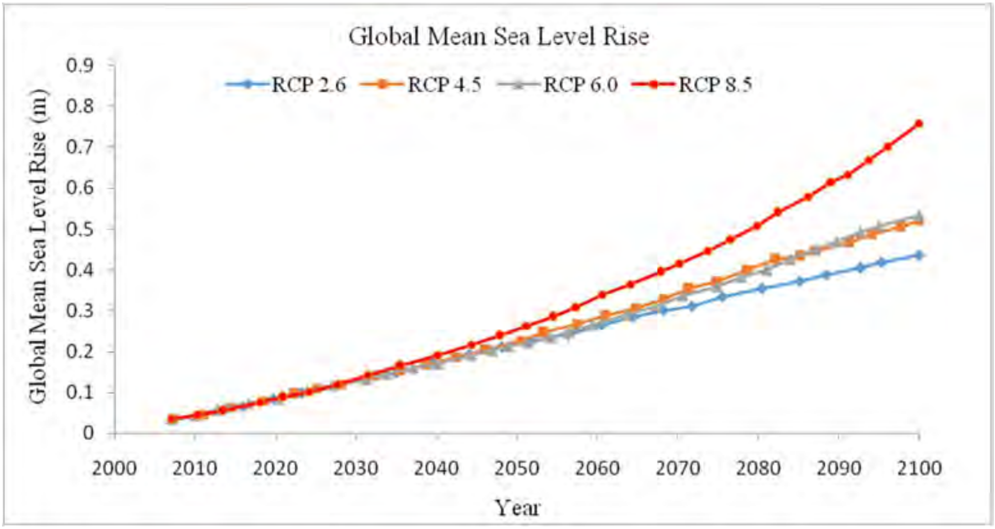


Figure 2.3: Projections of global mean sea level rise (Source: AR5, IPCC 2013)

IPCC (2007), In the six years since the IPCC's Third Assessment Report (TAR), significant progress has been made in understanding past and recent climate change and in projecting future changes. These advances have arisen from large amounts of new data, more sophisticated analyses of data, improvements in the understanding and simulation of physical processes in climate models and more extensive exploration of uncertainty ranges in model results. The dominant factor in the radiative forcing of climate in the industrial era is the increasing concentration of various greenhouse gases in the atmosphere. Several of the major greenhouse gases occur naturally but increases in their atmospheric concentrations over the last 250 years are due largely to human activities. Long-Lived Green House Gases (LLGHGs), for example, CO2, methane

(CH_4) and nitrous oxide (NO_2) are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on climate. The concentration of atmospheric CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The CH_4 abundance in 2005 of about 1774 ppb is more than double of its pre-industrial value. The NO_2 concentration in 2005 was 319 ppb, about 18% higher than its pre-industrial value. If radiative forcing were to be stabilized in 2100 at A1B concentrations, thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300. Over the 1961 to 2003 period, the average rate of global mean sea level rise is estimated from tide gauge data to be 1.8 ± 0.5 mm per yr. projected global average surface warming and sea level rise at the end of the year 2100 based on OGCMs is presented in the Table 2.4.

Table 2.4**:** Projected global average surface warming and sea level rise

Item	Scenarios					
	B1	A1T	B2	A1B	A2	A1Fl
Temperature	1.1-2.9	1.4-3.8	1.4-3.8	1.7-4.4	2-5.4	2.4-6.4
Sea Level Rise	0.18-0.38	0.2-0.45	0.2-0.43	0.21-0.48	0.23-0.51	0.26-0.59

(Source: AR4, IPCC Report, 2007)

IPCC (2001), The Third Assessment of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) was built upon past assessments and incorporates new results from the past five years of research on climate change. The summary report describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties. In order to make projections of future climate, models incorporated past, as well as future emissions of greenhouse gases and aerosols. Projections of global average sea level rise from 1990 to 2100, using a range of AOGCMs (Atmosphere-Ocean General Circulation Model) following the IS92a (Illustrative Scenarios 1992) scenario (including the direct effect of sulphate aerosol emissions), lie in the range 0.11 to 0.77 m. This range reflects the systematic uncertainty of modelling. The main contributions to this sea level rise are:

a. A thermal expansion of 0.11 to 0.43 m, accelerating through the 21st century;

b. A glacier contribution of 0.01 to 0.23 m;

c. A Greenland contribution of -0.02 to 0.09 m and

d. An Antarctic contribution of -0.17 to +0.02 m.

For the full set of SRES scenarios, a sea level rise of 0.09 to 0.88 m is projected for 1990 to 2100, primarily from thermal expansion and loss of mass from glaciers and ice caps.

IWM (2013), the main objective of this study is to analyze sea level change using available tidal water level data at three selected locations namely Hiron Point, Khepupara and Rangadia. The locations were selected based on the availability of historical tidal water level with suitable frequency (1-hr frequency). There are two different methods have been adopted to assess the change in sea level under this study and the methods are (i) trend of maximum/minimum water level and (ii) trend of monthly average water level. It is evident from the first method that the Hiron point shows the highest rate of change in sea level for annual average water level which is about 6.8 mm/yr whereas Khepupara shows the rate of change in annual maximum water level which is about 3.7 mm/yr. On the other hand Rangadia shows trend for (annual maximum water) is4 mm/yr. It is clear from the second method that Hiron Point shows the highest rate of change in sea level for monthly average water level which is about 10.8 mm/yr where as Khepupara and Rangadia show 7.2 mm/yr and 2.9 mm/yr respectively. Rising sea level may increase the cyclone induced inundated area as we have low lying land in our coastal area and salt water may intrude more towards upstream during dry period as there is less amount of fresh water during that period. It is evident from the study findings that 36 more coastal polders may overtop due to 120cm SLR during cyclonic storm surge. It is also evident from the study findings that moderate to high saline river area is likely to increase from 8 percent at the baseline to 17 and 27 percent in the best (47cm RMSLR) and worst (RMSLR 57) case scenarios respectively.

Hasan (2008), has stated that Bangladesh is very much vulnerable to climate change. The high degree of vulnerability of Bangladesh might be attributed to extensive low-lying coastal area, high population density, frequent occurrence of cyclone and high storm-surge. Study estimates that due to 27 cm sea level rise, brackish water area will be increased by 6% and due to 62 cm sea level rise, brackish water area will be increased by 9%.

IWM (2007), has made a detailed assessment of the potential impacts of relative sea-level rise on coastal livelihoods of Bangladesh. The study considered the sea level rise for both low (B1) and high (A2) greenhouse gas emission scenarios according to the 3rd IPCC predictions. The study shows that about 13% more area (551,000 ha) in the coastal region will be inundated in monsoon due to 62 cm sea level rise The study also studied that if 1991 cyclone will come with 27 cm SLR and increased intensity, Chittagong district will be affected more and about 99,000 ha more area (18%) will be exposed to severe inundation (>100cm) compared to 1991 cyclone inundation. Moreover, about 35,000ha area of Cox's Bazar district will be inundated severely (>100cm) compared to 1991 cyclone inundation.

IWM (2005) has made a detailed impact assessment of sea level rise on inundation, drainage congestion, salinity intrusion and change of surge level in the coastal zone of Bangladesh. The potential effects of climate change were studied for different sea level rise i.e.14 cm, 32 cm, and 88 cm for the projected years 2030, 2050 and 2100. Mathematical models of the Bay of Bangle have been used to transfer the sea level rise in the deep sea along the southwest region rivers and the Meghna Estuary. The study shows that about 11% more area (4,107 sq.km) will be inundated due to 88 cm sea level rise in addition to the existing (year 2000) inundation area under the same upstream flow. The 5 ppt saline front moves landward remarkably for sea level rise of 88 cm. About 84% of the Sundarbans area becomes deeply inundated due to 32 cm sea level rise, and for 88 cm sea level rise Sundarbans will be completely lost. Due to 32 cm sea level rise, surge level increase in the range of 5 to 15% in the eastern coast. It also observed that 10% increase in wind speed of 1991 cyclone along with 32 cm sea level rise would produce 7.8-to 9.5 m high storm near Kutubdia- Cox's Bazar coast.

PDO-ICZM (2004) has focused on the likely climate change scenarios of Bangladesh. The report states that efforts have been made to quantify climate changes in Bangladesh. The analysis of 22 years water level data (1977 – 1998) showed that the SLR to 7.8 mm/year, 6.0 mm/year and 4.0 mm/year at Cox's Bazar, Char Chenga and Hiron Point respectively (SMRC 2000a, 2000b). Projected precipitation fluctuations are -1.2% to -3.0% in winter season and +4.7% to +11.8% in monsoon season for the forecasted year of 2030 to 2100.

2.3 Summary

Several studies have been carried out on the coastal area of Bangladesh to understand the impact of climate change induced SLR and storm surge. It has been observed that, previous studies to assess the impact of both the SLR and precipitation according to AR4 scenarios for the coastal polders individually. In the present study considering climate change effect for precipitation, temperature and sea level rise incorporating IPCC fifth assessment (AR5) scenario has been applied in the mathematical model to find out the drainage congestion severity. Current study, considers, extreme climate change scenario (RCP8.5) for calculating precipitation change and sea level rise.

CHAPTER THREE:
THEORY AND METHODOLOGY

3.1 General

Drainage model study is a trusted means of investigating the effectiveness of potential drainage improvement plans and its possible impacts on the physical processes. It can also assist to establish the existing drainage patterns of a drainage basin and helps to identify the future problem that might persist due to the implementation of the potential drainage improvement interventions. As such, under this research, drainage modelling has been carried out for 2 selected coastal polders 17/1 & 17/2, to investigate the present drainage condition along with the adequacy and performance of the existing structures and drainage systems and providing design parameters for the potential drainage improvement interventions. The existing calibrated and validated Southwest Regional Model available at IWM has been used as the basis of drainage model for this study.

The theories that are used in the model have been discussed in this chapter. A numerical 1-dimensional model named MIKE11 developed by DHI Water and Environment has been used for simulation in this study. MIKE 11 has several modules for different purpose and each module has different sets of equations. In this study, MIKE 21 has been used to find out the boundary conditions. The governing equations for these modules have been described in the next section.

3.2 Governing Equations of Hydrodynamics & Model

(i) Basic Hydrodynamic Equations

The basic governing equations for incompressible fluid flow are time independent and two dimensional. Equations in Cartesian coordinates (x,y) are as follows:

Continuity Equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (3.1)$$

Momentum Equation:

$$p\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial P}{\partial x}\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (3.2)$$

$$p\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial P}{\partial y}\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \qquad (3.3)$$

Where, V= (u,v) is the velocity field. The first term on the RHS in Equations (3.2) & (3.3) refers to pressure forces, ∇. P. The rest of the RHS describe viscous forces, μ∇^2 v. The LHS is the momentum change that any element experiences as it moves between regions of different velocity in the flow field. This has the dimensions of a force, and is referred to as the inertia force, ρv .∇v.

(ii) MIKE 11 Hydrodynamic Equations

The equations which are solved for the flow simulations are called Saint Venant equation. These are derived from the Navier Stokes equation. Saint Venant equations are:

$$\frac{\delta q}{\delta x}+\frac{\delta A_{fl}}{\delta t}=q_{in} \qquad (3.4)$$

$$\frac{\delta q}{\delta t}+\frac{\delta\left(\alpha\frac{q^2}{A_{fl}}\right)}{\delta x}+gA_{fl}\frac{\delta h}{\delta x}+gA_{fl}I_f=\frac{f}{\rho_w} \qquad (3.5)$$

Where,

q	Discharge
Afl	Flow area
qin	lateral inflow
h	water level
α	momentum distribution coefficent
If	Flow resistance

f Momentum forcing

ρw Density of Water

Equation (3.4) is called the mass equation or continuity equation and expresses conservation of mass. Equation (3.5) is called the momentum equation and expresses conservation of momentum.

3.3 Mathematical Modelling

A mathematical model can be consisting of simple to complex mathematical equations with linear and/or non-linear terms and ordinary or partial differential equation terms. Mathematical Modelling is a simplified representation of a complex system in which the behaviour of the system is represented by a set of equations, together with logical statements, expressing relations between variables and parameters (Clarke).

Since studying the real-world processes could be extremely time consuming, expensive and even dangerous, models are constructed to study pertinent system responses. Therefore, a model can be viewed as a decision-making tool which provides approximate but reasonable description of the behavior of a complex system. Because of the approximations involved, a model could never be considered as a one-to-one representation of the reality. As noted by, a model will never describe every aspect of the real world and will contain aspects that have no corresponding counterpart in the real world. In general, a model is constructed in such a way that it is as simple as possible and as complex as needed to produce results of required resolution and accuracy.

Mathematical models could be classified in many different ways based on the specific technique used, nature of input and output, discretization of the decision space and so on. These classifications are obviously overlapping and not mutually exclusive. Because of this, all the possible groups cannot be represented in a simple tree format. Different types of mathematical models which are mainly used in water resources are shown in Figure 3.1.

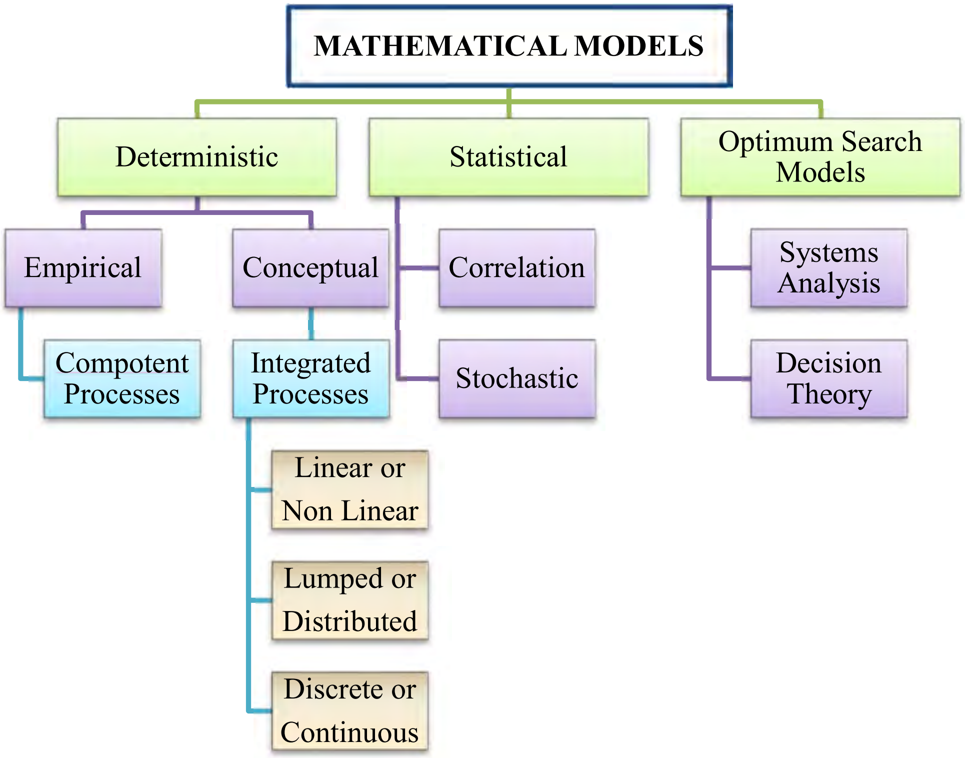
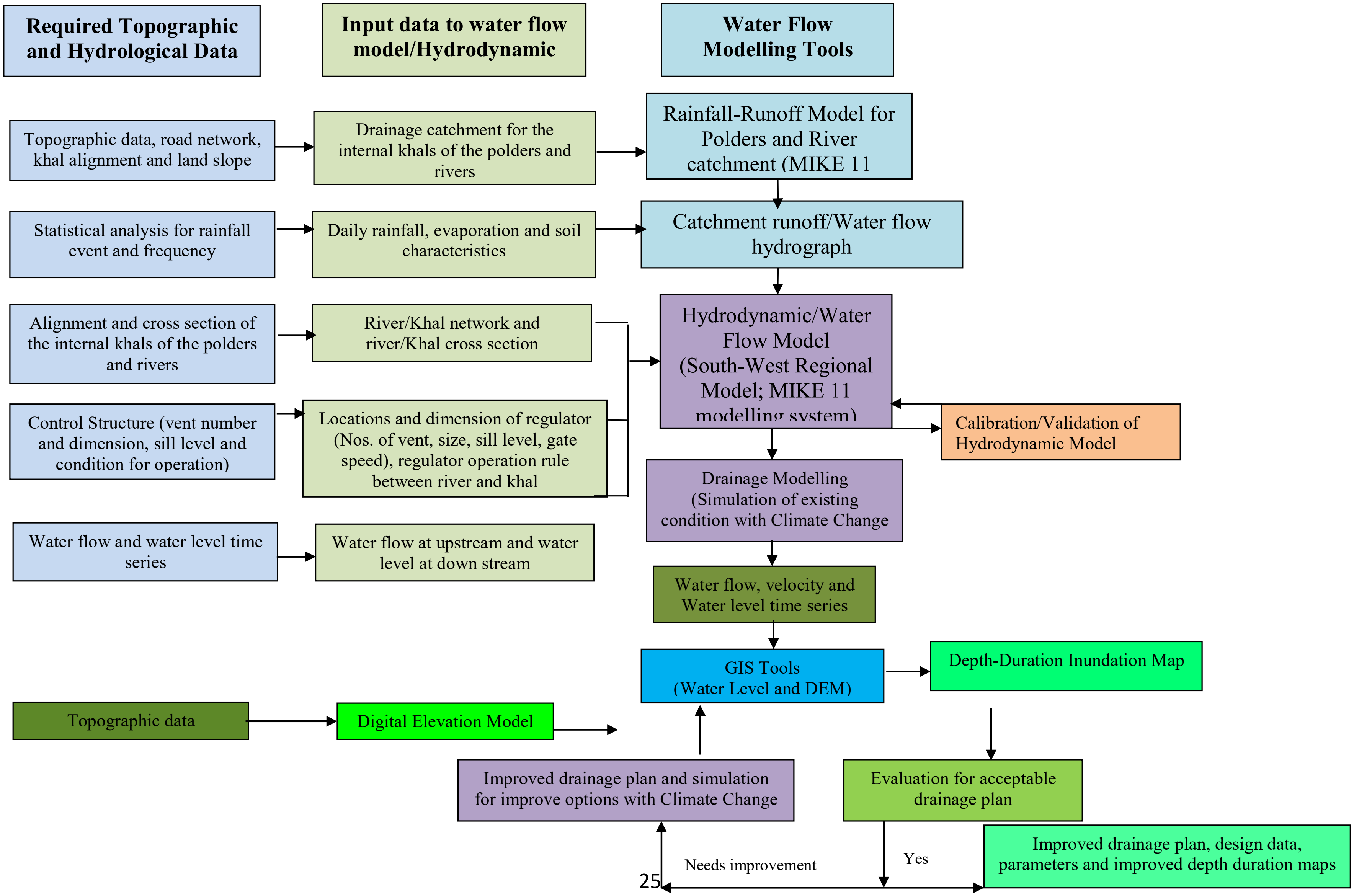


Figure 3.1: Classification of Mathematical Modelling

Many modelling software are available in the market for the water flow and salinity modelling. The list of the software packages are MIKE, ISIS, SOBEK, HEC-RAS, RiverWare, WEAP, MODSIM, RIBASIM, WaterWareetc. All those models are capable of dealing with hydrodynamic and water quality modelling. Different types of Mathematical model used in water resources are described is below:

Now a day's technology such as mathematical modelling and respective tools are incredibly available and improved for water resources engineering and DHI is exceptional than any other organization in the world for their tools for mathematical modelling. MIKE by DHI software is the result of years of experience and dedicated development. It transforms science into practice and gives the competitive edge. MIKE by DHI truly models the world of water - from mountain streams to the ocean and from drinking water to sewage. In this study MIKE was used for One-Dimensional.

Flow Chart on Drainage Modelling



3.4 Establishment of Climate change projection

Future projection is made on hydrological parameter; precipitation, evaporation and sea level rise based on IPCC 5th Assessment Report.

3.4.1 Projection of Precipitation for 2050

Drainage modeling for this study has been carried out to cope with polder drainage for expected climate change conditions up to 2050. The boundary conditions and input changed precipitation has been used based on IPCC 5th Assessment Report (AR5) published in September 2014. In this study extreme climate change scenario RCP 8.5 has been used for assessing the climate change condition on the existing drainage system and for finding the effective drainage improvement options.

Assessment Report 5 of IPCC (IPCC, AR5, 2014) has provided the projections on temperature, precipitation and sea level rise for the latest 4 climate change scenarios in global and regional scale. Table 3.1 presents the projection on precipitation for South Asia. The precipitation responses are first averaged for each model over the 1986–2005 periods from the historical simulations and in the projected periods of the RCP8.5 experiments.

Table 3.1: Precipitation change projections

Scenario	Region	Month	Year	Min	25%	50%	75%	100%
RCP 8.5	South Asia	DJF	2035	-13	-2	1	6	20
			2065	-16	-4	4	10	23
			2100	-17	-1	12	21	42
		JJA	2035	-3	1	3	5	16
			2065	-1	7	10	13	27
			2100	-9	13	17	23	57
		Annual	2035	-2	1	3	5	11
			2065	0	6	8	11	17
			2100	-7	11	18	21	45

(Source: IPCC, AR5, 2014)

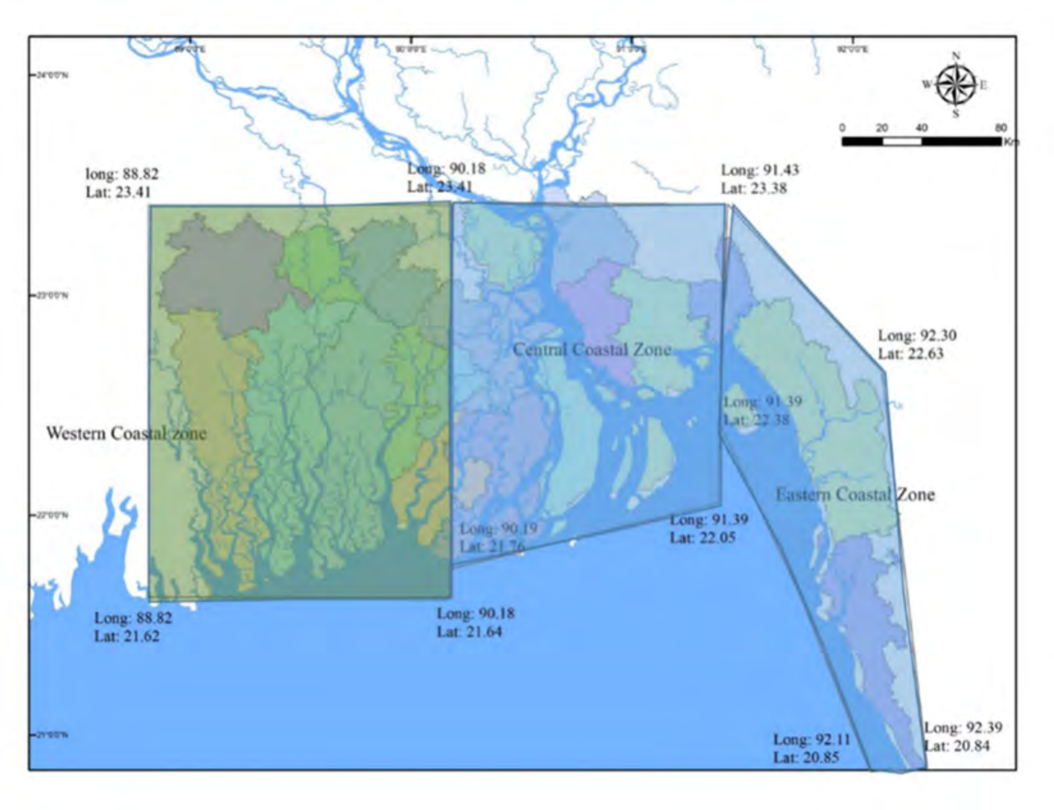


Figure 3.2: Coastal zones for downscaling results of GCMS (Source: IWM, 2015)

This projection is in regional scale and is not wise to use for coastal area of Bangladesh. The present study used the projections based on statistical downscaling for the coastal area through literature review. Delta Plan 2100 (GOB, 2014) suggests that the climate change scenarios will be based on the analyses on a low (RCP4.5) and high emission scenarios (RCP8.5). For the current study projections on precipitation were established based on the World Bank report (20-13). Temperature and Rainfall projections are based on downscaling of 15 GCM models at three coastal zones (Figure 3.2). The lists of GCMs are given in the Table 3.2.

Table 3.3 presents the precipitation projections at 2050's (Multi model mean of 15 GCM's) for three costal zones. These projections are used in simulating the drainage condition of the polder for assessing the effectiveness of existing and proposed drainage systems. Polder 17/1 and 17/2 are situated in the western coastal zone of

Bangladesh. So, the changes of precipitation for 2050 have been used for simulating the rainfall runoff model.

Table 3.2: List of GCMs Model

SL No.	GCMs Model	SL No.	GCMs Model	SL No.	GCMs Model
1	ipsl-cm5a-lr.	6	mpi-esm-lr.	11	canesm2.
2	Ipsl-cm5a-mr.	7	mpi-esm-mr.	12	ccsm4.
3	miroc-esm.	8	mri-cgcm3.	13	cesm1-bgc.
4	miroc-esm-chem.	9	bcc-csm1-1.	14	cnrm-cm5.
5	miroc5.	10	bnu-esm.	15	gfdl-esm2g.

(Source: IWM, 2013)

Table 3.3: Precipitation projection for 2050

West coastal zone Rainfall	
Month	% change
May	3.06
June	1.05
July	15.75
August	16.08
September	22.47
October	14.46

(Source: IWM, 2015)

3.4.2 Projection on Sea Level Rise

One of the most important impacts of climate change for low lying countries such as Bangladesh is sea lever rise. Sea level rise is caused by global warming which affects two main processes. First of all, higher ocean water temperature causes thermal expansion and secondly, atmospheric warming results in the melting of land ice.

Thermal expansion of sea water is the change in volume of water in response to a change in temperature. In the present study, global sea level rise was reviewed for different climate change scenario. Projected change in global mean sea level rise (m) for the mid- and late 21st century relative to the reference period of 1986–2005 (IPCC, AR5 2014) is presented in the following Table 3.4. Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 to RCP8.5 is presented in the Figure 3.3. From the figure, the global mean sea level rise is found about to 0.32m (Source: IPCC, AR5, 2013)

Table 3.4: Projected change in global mean sea level rise

Scenario	2046-2065	
	Mean	Likely range
RCP 2.6	0.24	0.17 to 0.32
RCP 4.5	0.26	0.19 to 0.33
RCP 6.0	0.25	0.18 to 0.32
RCP 8.5	0.3	0.22 to 0.38

(Source: IPCC, AR5, 2013)

Brown et al. (2014) studied regional future sea level rise for Bangladesh. Regional sea level scenarios for the Bay of Bengal were developed based on the global scenarios by Hinkel et al. 2014. The results showed that sea level rise in Bangladesh are slightly higher than the global average mean. However, the differences between the global and regional scenarios are small in most cases less than 5% with a maximum of 10% higher (Brown et al. 2013). This means that by 2050 sea level rise could be up to 4 cm higher than global mean and by the end of the century up to 10 cm.

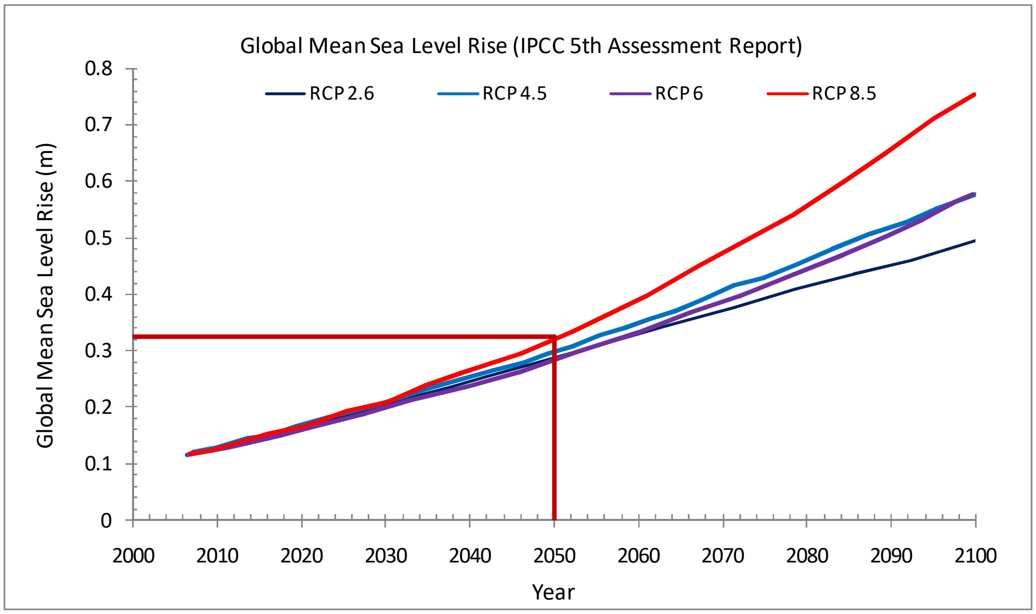


Figure 3.3: Projections of global mean sea level rise (Source: IPCC, AR5, 2013)

A projection on relative sea level change has been made in the IPCC 5th Assessment report for nine representative coastal locations where long tide-gauge measurements are available. Among them one tide gauge is available at Haldia (Lat 22.0°N, Long 88.1°E) in Bay of Bengal. The projection for Bay of Bengal is presented in the figure (Source: Figure 13.23, IPCC Climate Change, 2013 report, page 1198). In the figure, vertical bars at the right sides of each panel represent the ensemble mean and ensemble spread (5 to 95%) of the likely (medium confidence) sea level change at each respective location at the year 2100 inferred from RCPs 2.6 (dark blue), 4.5 (light blue), 6.0 (yellow) and 8.5 (red).

Under the current study relative sea level rise has been established based on review of the recent literature, IPCC AR5 and the study report on relative sea level rise along the coast carried out by BUET, CEGIS and IWM under Department of Environment (DOE). The Relative mean sea level rise is established based on Global Mean Sea Level Rise and local effects. This computation was made for southwest costal area. IPCC projected the Global Mean Sea Level rise (GMSL) with respect to year 2005.

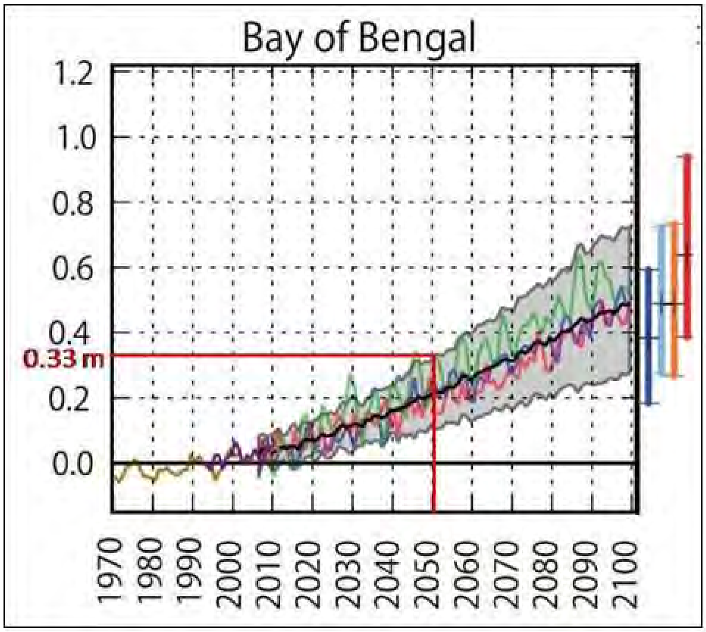


Figure 3.4: Observed and projected relative sea level change at Bay of Bengal (Source: IPCC, AR5, 2013)

3.5 Incorporation of Climate Change result

3.5.1 Recommended Land Subsidence

Many of the researches are based on remotely sensed data such as satellite images or GPS, Holocene sedimentary and stratigraphic configurations closely parallel geological structures or submerged salt-producing kiln sites in the coastal Sundarbans or data of the shorter time-scale (one to two years' sedimentation rate). The observations from the shorter period may be biased by short-term perturbation and may not be representative of the prevailing decade or century scale processes. It is very difficult to measure the land subsidence directly and there are several ways to do so indirectly. Every type of measurement has its limitations. In this thesis, 4mm/yr land subsidence has been considered to calculate the Relative Sea Level Rise (RSLR). Three archaeological monuments have been selected in the tidal plains for assessing the rate of land subsidence, which can provide a very good indication about the range of subsidence for quite a longer period than reflecting short-term perturbations.

3.5.2 Relative Sea Level Rise (RSLR)

In the present thesis, four different RCP's scenarios have been discussed: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. However, the projected increase in sea level rise, which is termed as eustatic sea level rise, is averaged over the whole world. The increase in local/regional scale is not readily available for Bangladesh because of lack of data. For a realistic projection, local effects such as subsidence should be considered.

According to IPCC AR5 report, projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6, RCP 4.5, RCP 6.0 and RCP8.5. The increasing global mean sea level value have been calculated for the other period compared to the period 0f 2012 in this thesis. The increased value of global mean sea level has been extracted for the period of 2050 and 2100 from the projection which has been predicted in AR5 report. It is seen that in 2050, the global sea level is likely to be increased 0.168m (RCP2.6), 0.174m (RCP4.5), 0.163m (RCP6.0), and 0.203m (RCP8.5). At 2100, the likely ranges are 0.44 m (RCP2.6), 0.53m (RCP4.5), 0.55m (RCP6.0), and 0.74m (RCP8.5). The changing global mean sea level rise has been presented in Table 3.5.

Table 3.5**:** The changing value of Global Mean Sea Level based on 2012

	Scenario	2012	2050	2100	Increased in 2050(m)	Increased in 2100(m)
Global Mean Sea Level Rise (m)	RCP 2.6	0.051	0.219	0.435	+0.168	+0.384
	RCP 4.5	0.051	0.225	0.521	+0.174	+0.470
	RCP 6.0	0.054	0.217	0.534	+0.163	+0.481
	RCP 8.5	0.051	0.254	0.729	+0.203	+0.678

(Source: IPCC, AR5, 2014)

RCP4.5 and RCP6.0 are very similar at the mid period and end of the century but RCP4.5 has a greater rate of rise earlier in the century than RCP6.0. To avoid this scenario in RCP 4.5 and RCP 6.0, RCP 8.5 has been considered to estimate the global mean sea level rise under this thesis. The increased global sea level rise for the RCP 8.5 scenario has been plotted in the Figure 3.5.

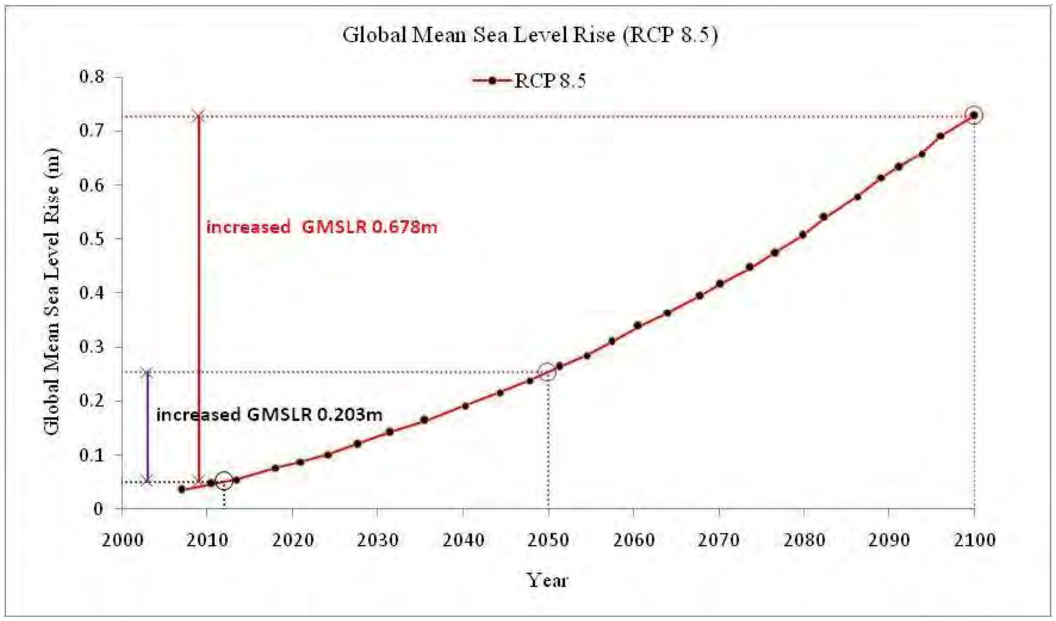


Figure 3.5: Increased Global Sea Level Rise for the RCP 8.5 scenario (Source: IPCC, AR5, 2014)

Local sea level change, which is of more direct concern to coastal communities, is a combination of the rise in sea level and the change in land elevation. Some areas of the country, such as areas within coastal portion, are experiencing an additional dynamic factor is land subsidence. Due to counteract by sedimentation from the rivers at high tide and the construction of embankments cut off this natural sediment accretion within polders. In contrast, areas of the Bangladesh coast are experiencing land subsidence at varying rates, accelerating the rate of seal level rise.

Many of the researches are based on remotely sensed data such as satellite images or GPS, Holocene sedimentary and stratigraphic configurations closely parallel geological structures or submerged salt-producing kiln sites in the coastal Sundarbans or data of the shorter time-scale (one to two years sedimentation rate). The observations from the shorter period may be biased by short-term perturbation and may not be representative of the prevailing decade or century scale processes. It is very difficult to measure the land subsidence directly and there are several ways to do so indirectly. Every type of measurement has its limitations. In this thesis, 3mm/yr land subsidence has been considered to calculate the Relative Sea Level Rise (RSLR).

Relative Sea Level Rise (RSLR) can be expressed in the format which has been presented in the equation 3.6.

$$\text{Relative Sea Level Rise (RSLR)} = \text{Global Sea Level Rise (GSLR)} + \text{Land Subsidence} \quad (3.6)$$

Analysing long term tide gauge data at Hiron Point (1977-2013), Khepupara (1988-2012) and Rangadia (1993-2012), the yearly maximum water level is increased by 7.8, 8.1, 5.8 mm/yr and yearly average water level is increased by 6.8, 3.7, 4 mm/yr respectively (IWM, 2013; Analyzing the trend of Water level time series at the coastal area of Bangladesh). The sea level rise was found to be 6 mm/year at Char Changa (Meghna Estuary) and 7.8 at Cox's Bazar during the period of 1977-1998 (Bangladesh Delta Plan 2100 Baseline Study Climate Change –Zero Draft, 2014). The study of CEGIS (2011) has shown that the sea level rise is 5.5 mm/year at Hiron Point, 7.5 mm/year at Mohesh Khali, 5.1 mm/year at Cox's Bazar and 7 mm/ year at Sandwip. It indicates the positive sign of sea level rise. According to some other scientists' the local effects can be as low as 1-2mm/yr. Due to these uncertainties three different levels of subsidence has been presented in this thesis: 2, 3 and 4 mm/yr.

According to the IPCC AR5, global mean sea level rise for RCP 8.5 and 3mm/yr land subsidence rate gives the 32cm and 94 cm relative sea level rise for 2050 and 2100 respectively. The relative sea level rise combined with the effects of global sea level rise and the different land subsidence rates 2mm/yr, 3mm/yr and 4mm/yr with different RCP scenarios have presented in the Table 3.6, Table 3.7 and Table 3.8.

Relative Sea Level Rise for the Coastal Area of Bangladesh including global sea level rise and local effect considering 2mm/yr land subsidence rate respectively.

Table 3.6: Relative Sea Level Rise for the Coastal Area of Bangladesh including global sea level rise and local effect considering 2mm/yr land subsidence rate

Year	GSLR (cm)				Subsidence (2mm/yr)				Total RSLR (cm)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5					RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2012	0.05	0.05	0.05	0.05								
2030	7.69	7.76	7.37	8.30	3.6	3.6	3.6	3.6	11	11	11	12
2050	16.79	17.39	16.35	20.31	7.6	7.6	7.6	7.6	24	25	24	28
2100	38.44	46.99	48.09	67.80	17.6	17.6	17.6	17.6	56	65	66	85

Table 3.7: Relative Sea Level Rise for the Coastal Area of Bangladesh including global sea level rise and local effect considering 3mm/yr land subsidence rate

Year	GSLR (cm)				Subsidence (3mm/yr)				Total RSLR (cm)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5					RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2012	0.05	0.05	0.05	0.05								
2030	7.69	7.76	7.37	8.30	5.4	5.4	5.4	5.4	13	13	13	14
2050	16.79	17.39	16.35	20.31	11.4	11.4	11.4	11.4	28	29	28	32
2100	38.44	46.99	48.09	67.80	26.4	26.4	26.4	26.4	65	73	74	94

Table 3.8: Relative Sea Level Rise for the Coastal Area of Bangladesh including global sea level rise and local effect considering 4mm/yr land subsidence rate

Year	GSLR (cm)				Subsidence (4mm/yr)				Total SLR (cm)			
	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5					RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
2030	7.5	7.4	7.1	8.0	7.2	7.2	7.2	7.2	15	15	14	15
2050	16.3	17.3	16.3	26.9	15.2	15.2	15.2	15.2	32	33	32	42
2100	37.0	45.7	47.5	66.2	35.2	35.2	35.2	35.2	72	81	83	101

3.6 Data Collection

3.6.1 Data on Drainage System of polders

The Data has been collected from different sources which are listed below:

Table 3.9: Data type and collected data agency

Data Type	**Source**
Discharge (Q), Water Level (WL)	BWDB, BIWTA
Meteorological data (Temperature, Rainfall)	BMD
Topographic Information	IWM Survey
Structure Information	IWM Survey
Satellite Images	USGS
River Bathymetry	BWDB

3.6.2 Discharge and Water Level

Discharge (Q) U/S boundary condition which has been derived from Q vs. WL relationship. Three open boundaries are applied at the upstream locations which are Gorai Railway Bridge, Baruria and Bhairab Bazar. Hourly time series water level data and quarterly discharge is collected from BWDB. Hourly time series tidal water level data at the downstream location of the model network is collected from BIWTA.

3.6.3 Rainfall

The daily time series rainfall data of the nearest rainfall stations to the study area is collected from BWDB. All the data is available in IWM. Rainfall data forms the basic input to the Rainfall Runoff Model (NAM) which yields the run-off generated from the catchments.

3.6.4 Topographic Information

Topographic (land level) data is so basic and very important for the assessment of inundation patterns during monsoon in the study area. Accurate topographic data is also needed for assessment of benefited areas with project conditions in terms of land classification coverage. The topography data of these polders is surveyed by IWM under the CEIP-1 project.

3.6.5 Structure Information

Structure information (no. of vents, vent size, sill level etc.) is used to develop the polder drainage model.

3.6.6 River Bathymetry

In this study, IWM developed south-west regional model is used which is updated every year by the recent bathymetry data. The cross sections of the peripheral river of the polder 17/1 and 17/2 are updated which is surveyed by IWM under CEIP-1 project.

3.7 Summary

In this chapter the theory that determines the rainfall-runoff and hydrodynamic condition has been described. The governing equations of hydrodynamics module has been discussed in a gist way. Projection and Incorporation of climate change, data collection and recommendations has been described here in short. Sea level rise for the Bay of Bengal has been developed considering global mean sea level rise and land subsidence rate has been estimated from different literature review. The methodology which has been adopted for the study outlined here step by step.

CHAPTER FOUR:
STUDY AREA AND MODEL SETUP

4.1 General

The study area is located in the Southwest Coastal region of Bangladesh. The entire southwest coastal part of Bangladesh has been experiencing river sedimentation and drainage congestions over the last few decades. The tidal creeks have lost the sufficient capacity for flushing the incoming sediment with high tide from the sea due to the significant reduction of fresh water flow from the Ganges and polderization effects. This leads to large scale river bed sedimentation in the peripheral rivers of polders and reduced the drainage capacity. Consequently, polder areas were suffering from water logging and drainage congestion. Rainfall Runoff Model is applied to estimate the runoff generated from rainfall occurring in the catchment. Drainage modelling has been carried out in order to investigate the adequacy and performance of the existing structures and drainage systems of the selected polders and providing potential drainage improvement interventions for developing the climate resilient polder system. The existing calibrated and validated Southwest Regional Model which is available at IWM has been used as the basis of development of drainage model for this study.

4.2 Study Area Polder 17/1

4.2.1 Background

The Polder was conceived in the year of 1960 under Coastal Embankment Project (CEP). Construction of the Polder was started in1969 and completed in 1971. The original concept of construction of this Polder was only to protect the agricultural lands from salinity intrusion caused due to tidal inundation from the sea and river. Parts of the polder are threatened by drainage congestion which could worsen with changes occurring with on-going climate change.

4.2.2 Location

The Polder is located in Upazila Dumuria under Khulna District. The Polder covers the Union Parishads (U/P), namely Magurkhal, Shouna and Atlia. The polder is bounded by Salta and Taltola to the west and North, Gangrail and Bhadra River to the East and South. In Figure 4.1, the study area has been shown and some present photographs during study in Figure 4.2.

4.2.3 Description of the Polder

The entire embankment is classified as Interior Dyke having side slopes C/S: 1:2 and R/S: 1:3. The summary of the existing infrastructures are given below:

Total length of Embankment: 38.50 km

Design Crest Level: 4.27 mPWD

Total number of Drainage Sluice: 11 nos

Drainage khals: 43.00 km

Gross protected area: 5020 ha.

Cultivable area: 4000 ha.

4.2.4 Present Condition of the Polder

The present condition of the polder is vulnerable. Many of the hydraulic structures are fully or partially damaged and are non-functioning due to which internal drainage congestion is prevalent. The other structures, though functional, are in an extremely bad condition. The gates are corroded by saline water and concrete surface of the structures are in a very deplorable condition. There are some places where there are existing khals but no drainage structures are present. The internal drainage channels have become silted up due to lack of maintenance for a long time.

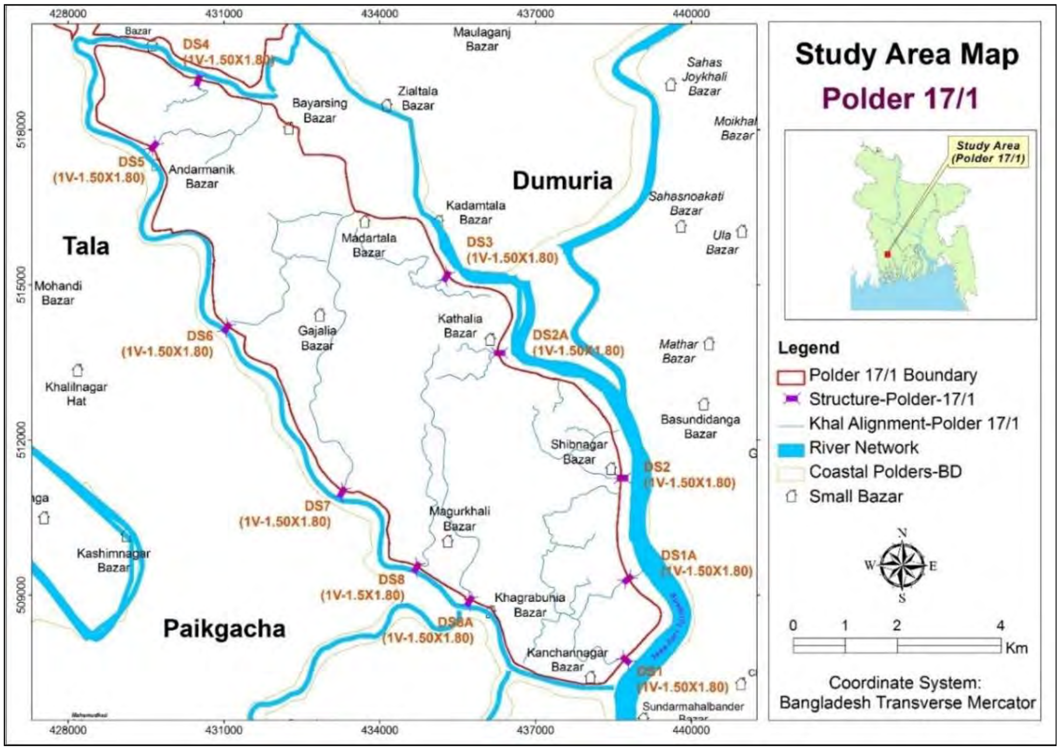


Figure 4.1: Study area of Polder 17/1

Figure 4.2: Present condition of DS-5 in polder 17/1(C/S at figure-a and R/S at figure-b)

4.3 Study Area Polder 17/2

4.3.1 Background

The polder was conceived in the early 1960s. Construction of the Polder was started in 1970 and completed on 1978 under Coastal Embankment Project (CEP). Cyclone is the main threat to cause damage of life and properties of the polder area. In

Figure 4.3, the study area has been shown and some present photographs during study in Figure 4.4.

4.3.2 Location

The polder is located in Upazila Dumuria under Khulna District. The polder Covers the Union Parishad (U/P) namely Atlia under Dumuria Upazila in the district of Khulna. The polder is surrounded by river Hari to the East, Upper Salta River to the South West, Taltola River to the West and Gangrail River to the North.

4.3.3 Description

The entire length of embankment of the Polder is Interior dyke having Side Slope C/S 1:2 and R/S 1:3. The details of the existing embankment and other hydraulic structures are furnished below:

Total length of embankment:	11.00 km
Design Crest Level:	4.27 PWD
Total number of Regulator:	6 Nos.
Gross protected area:	3400 hac.
Drainage Khals:	21 km
Net benefitted area:	2700 hac.

4.3.3 Present Condition of the Polder

The present condition of the Polder is extremely vulnerable. Most of the length of the embankment is remained under sectioned. The conditions of the existing structures are also very dilapidated. The concrete surface of the structure has deteriorated. The barrel portion of some of the structure has been blocked due to siltation and diversion channels have been silted up. The outfall river (Taltola River) at the outer periphery of the embankment and in between polder-17/1 and polder-17/2 from small Andharmanik gate to Teligati River (at a length of about 9 km) has been fully silted up causing drainage congestion to the adjacent area. The bed level of the aforesaid portion of the river is almost similar to the ground level and people are cultivating crops there. The internal drainage channels have become silted up due to lack of maintenance for a long time.

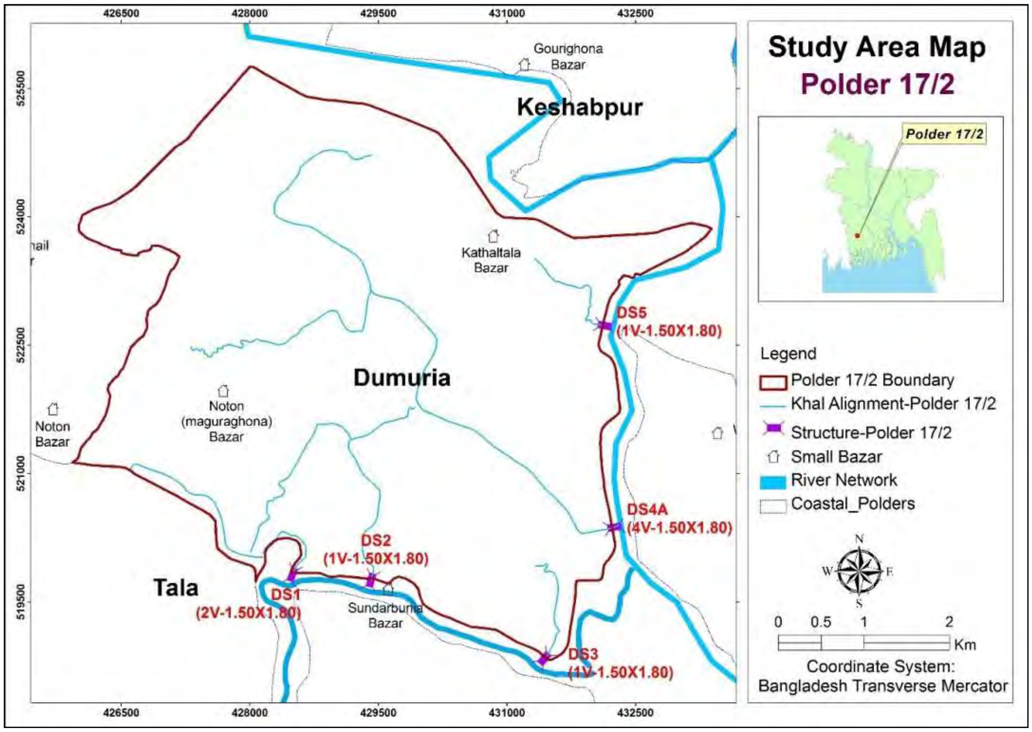


Figure 4.3: Study area of Polder 17/2

Figure 4.4: Present condition of DS-4A in polder 17/2 (C/S at figure-a and R/S at figure-b)

4.4 Hydrological Analysis and Selection of Design Flood Event

The drainage flow of the study area is exclusively generated from the catchment due to rainfall. As such, hydrological analysis on historical rainfall data in the study and surrounding areas has been carried out to identify the design flood event for the drainage study. In order to determine this flood event rainfall data are analyzed using the software HYMOS, a hydrological data management and processing tool developed by Delft Hydraulics.

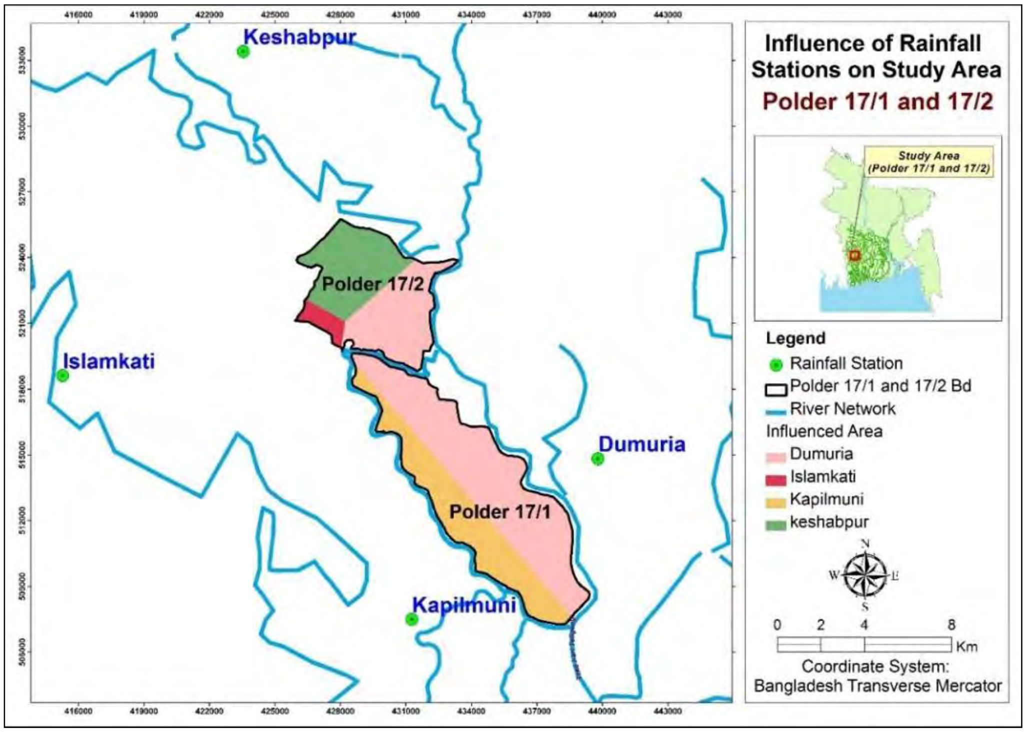


Figure 4.5: The Influence of different rainfall Stations on study area (Polder 17/1 and 17/2)

The study area (Polder 17/1 and polder 17/2) is situated in the south-west catchment number 23 (SW-23). This catchment is influenced by the rainfall station Dumuria, Kapilmuni, Paikgacha, Nalianala. The influence of these rainfall stations has been made by generating the Theisen Polygon method (Figure 4.5).

According to the Theisen polygon analysis considering the four rainfall stations, Dumuria covers 57% of the study area where Kapilmuni, Keshobpur and Islamkati covers about 23%, 17% and 3% respectively. The Figure and Table shows the area weightage influence of the stations in the study area. Considering the influence and availability of data a Five days (05) cumulative historical rainfall data (REF: i) Design Workshop Small Scale Water Control Structures, Volume-1, BWDB and CIDA, Northwest Hydraulic Consultant, 1993, ii) Standard Design Manual, Volume – I:

Standard Design Criteria, BWDB) of Dumuria, Kapilmuni, Keshobpur and Islamkati stations has been used for the analysis.

Table 4.1: Influence area & influence factor

Station	Influence Area	Influence Factor
Kapilmuni	18.34	23%
Dumuria	45.47	57%
Keshobpur	13.48	17%
Islamkati	2.00	3%
Total Area	79.29	100%

About 29 years (from 1985 to 2013) rainfall data has been considered for the statistical analysis. The 5-day cumulative yearly maximum rainfall of Dumuria, Kapilmuni, and Keshobpur station is shown in Figure 4.6, Figure 4.7 and Figure 4.8 respectively. For the statistical analysis, Gumbel, Log Normal and Log Pearson Type III distribution method have been used. Figure 4.6, Figure 4.7 and Figure 4.8 shows the 5-day cumulative annual maximum rainfall of Dumuria, Kapilmuni and Keshobpur. Table 4.2, Table 4.3 and Table 4.4 shows the statistical analysis for all rainfall stations for different return period.

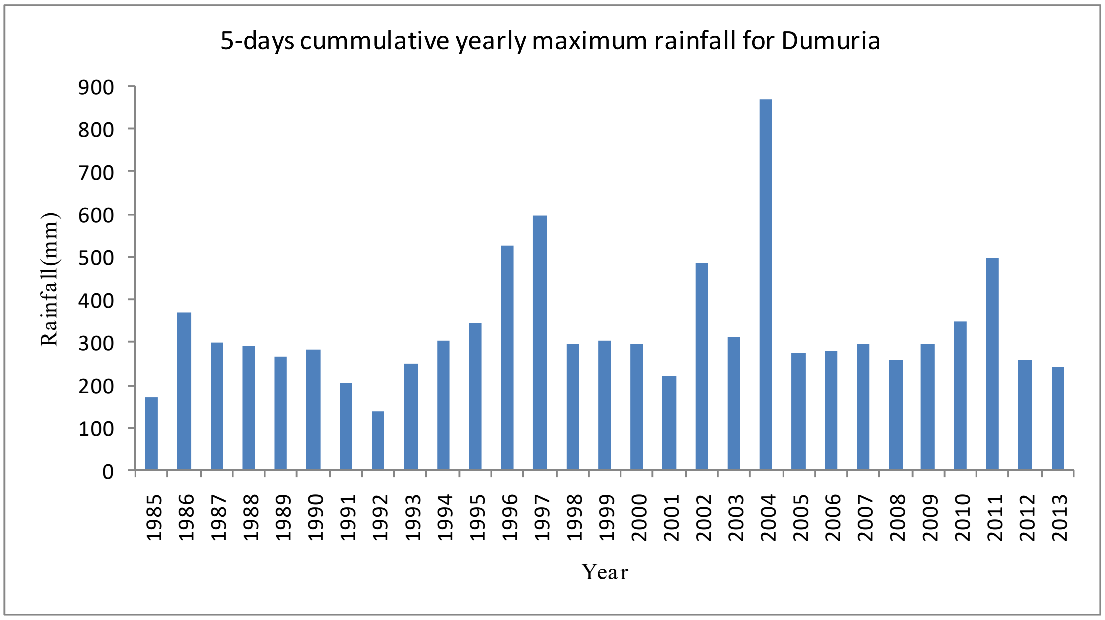


Figure 4.6: Annual maximum 5-day cumulative maximum rainfall at Dumuria station

Table 4.2: Statistical distribution of 5-day cumulative rainfall for Dumuria

	Return Period [years]	Log Normal/MOM	Gumbel/MOM	Log Pearson Type 3/MOM/LOG
Estimated quantile	2.33	329	332	312
	10	496	523	507
	20	568	606	614
	25	590	632	651
	50	661	712	777
	100	731	792	921
Goodness-of-fit statistics	CHISQ	5.31	9.45	11.52
	KS	0.21	0.21	0.15

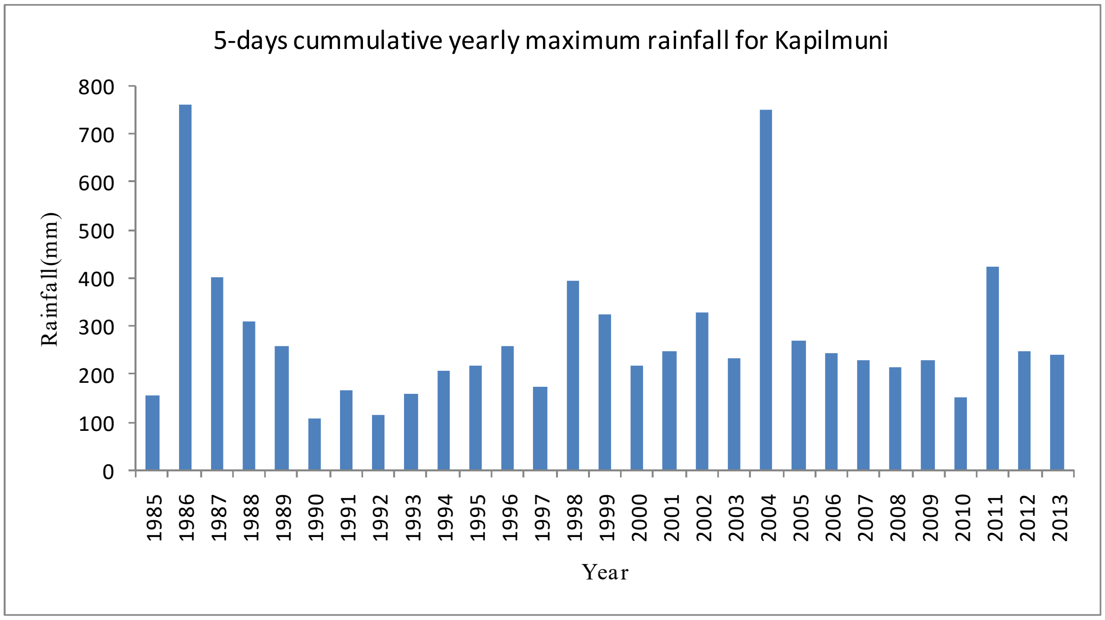


Figure 4.7**:** Annual maximum 5-day cumulative maximum rainfall at Kapilmuni station

Table 4.3: Statistical distribution of 5-day cumulative rainfall for Kapilmuni

	Return Period [years]	Log Normal/MOM	Gumbel/MOM	Log Pearson Type 3/MOM/LOG
Estimated quantile	2.33	269	277	252
	10	440	475	451
	20	517	561	569
	25	542	588	611
	50	620	672	757
	100	700	755	930
Goodness-of-fit statistics	CHISQ	4.62	9.10	7.38
	KS	0.15	0.17	0.15

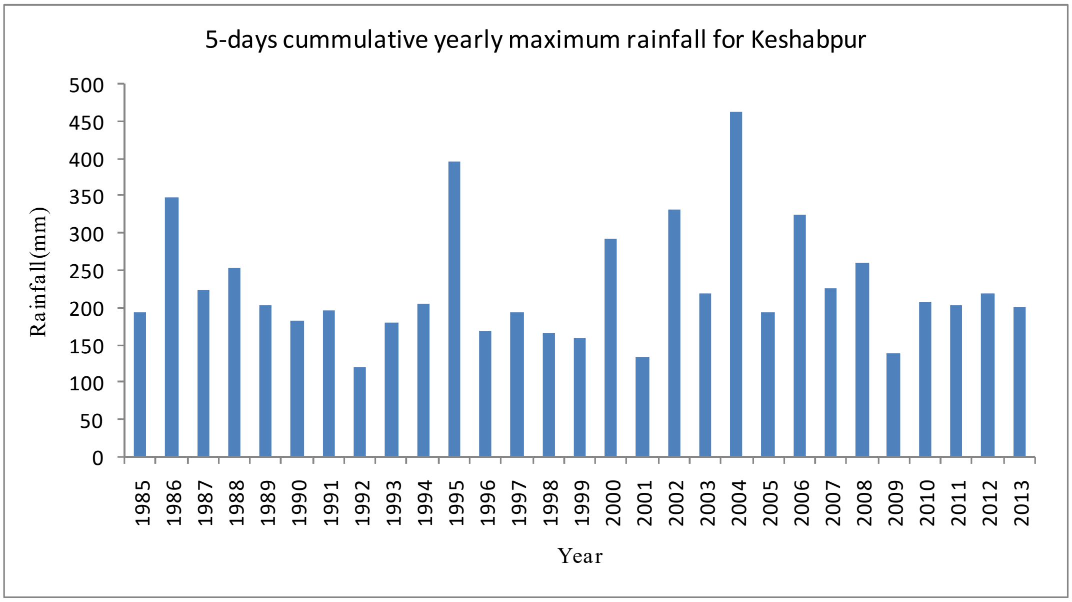


Figure 4.8: Annual maximum 5-day cumulative maximum rainfall at Keshobpur station

Table 4.4**:** Statistical distribution of 5-day cumulative rainfall for Keshabpur

	Return Period [years]	Log Normal/MOM	Gumbel/MOM	Log Pearson Type 3/MOM/LOG
Estimated quantile	2.33	226	225	218
	10	324	330	329
	20	365	375	385
	25	378	390	403
	50	417	434	464
	100	456	478	530
Goodness-of-fit statistics	CHISQ	4.62	7.72	6.69
	KS	0.15	0.15	0.11

Most of the study area is influenced by the Dumuria rainfall station which is about 57%. So, the rainfall of Dumuria is considered for the final analysis. Figure 4.9, Figure

4.10 and Figure 4.11 shows the different return period value for different statistical method.

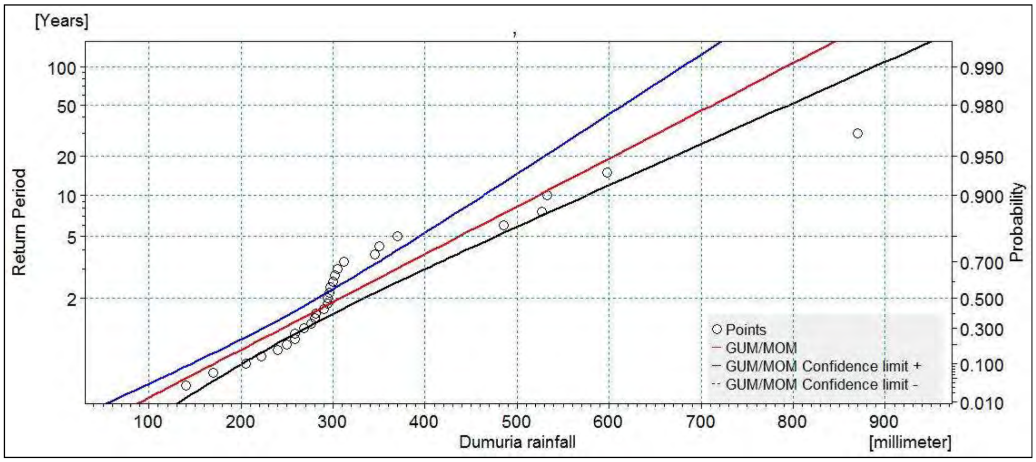


Figure 4.9: Frequency analysis for Dumuria rainfall station by Gumbel Distribution

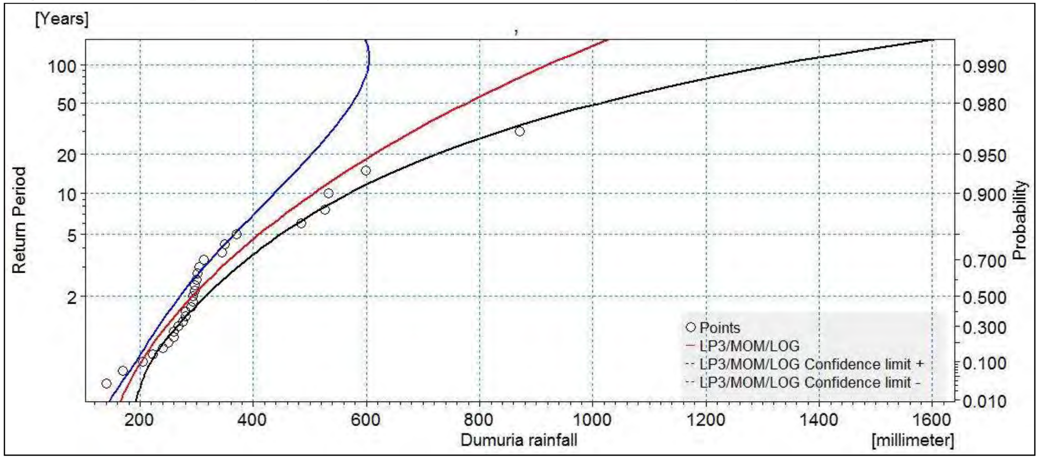


Figure 4.10: Frequency analysis for Dumuria rainfall station by Log Normal Distribution

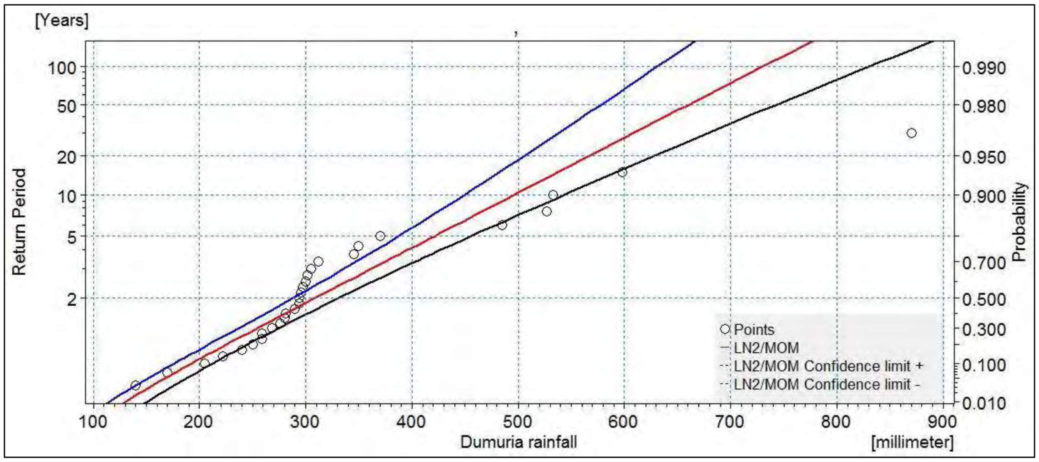


Figure 4.11: Frequency analysis for Dumuria rainfall station by Log Pearson Type III

Ten (10) years return (REF: i) Design Workshop Small Scale Water Control Structures, Volume-1, BWDB and CIDA, Northwest Hydraulic Consultant, 1993, ii) Standard Design Manual, Volume – I: Standard Design Criteria, BWDB) period has been selected to observe the drainage condition of the selected polder area. Different statistical method has been tested for selecting the suitable statistical method. It is seen that Chi-Square values is smaller in Log Normal distribution than the other methods for all rainfall station data analysis. Lower standard deviation is also found for the Log Normal distribution method. So, Log Normal distribution has been selected for the further statistical analysis.

Table 4.5: Statistical Analysis result and selected simulation year

Polder ID	Rainfall Station	Method of Analysis	Rainfall in mm	Coincident Year
			1 in 10 Yr	1 in 10 Yr
Polder 17/1 and Polder 17/2	Dumuria	Log Normal	496	2011 (498)
		Gumbel Method	523	
		Log Pearson Type-III	507	
	Kapilmuni	Log Normal	440	2011(425)
		Gumbel Method	475	
		Log Pearson Type-III	451	
	Keshabpur	Log Normal	324	2006 (324)
		Gumbel Method	330	
		Log Pearson Type-III	329	

Frequency analysis shows 10 year return period rainfall is about 496 mm of Dumuria station in Log-Normal distribution. It is also found that year 2011 has the value of 498 mm for Dumuria station. Based on frequency analysis result of 5 rainfall stations in this area the hydrological year 2011 has been selected as design flood event and the Rainfall-Runoff model and polder drainage model has been simulated for the year

2011 for assessing the drainage performance of the study area and effectiveness of the potential improvement options.

4.4 Mathematical Model Setup

4.4.1 Hydrological (Rainfall-Runoff) Model

Rainfall Runoff Model is applied to estimate the runoff generated from rainfall occurring in the catchment. The model takes into consideration the basin characteristics including specific yield, initial soil moisture contents and initial ground water level and irrigation/abstraction from the surface or ground water sources. The catchments of the rainfall runoff model are delineated according to the topographic barriers/water shed boundaries, roads and river networks. The existing calibrated Southwest rainfall runoff model (NAM) contains 44 catchments. About 27 no. catchments exist in the south-west region and 17 no. catchments exist in the south-central region. Polder 17/1 and Polder 17/2 is situated in the south-west catchment number 23 and defined in the model network as SW-23. All of the drainage channels are also included into the rainfall-runoff model under the catchment SW-23.

According to the findings of the hydrological analysis rainfall-runoff model has been carried out for the year 2011(1in 10 year) for extreme flood event study. Finally, this model result has been used in the Hydrodynamic model as an input file for generating the runoff according to catchment-wise.

4.4.2 South West Regional Model

In the present study south west regional model available at IWM is used for drainage study of the selected polders (polder 17/1 and polder 17/2). 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 Institute of Water Modelling (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. Drainage model for the selected polders is prepared from the hydrodynamic model of south-west regional model by adding the polder drainage khal network, water control structure (Sluice gate) and delineated catchment for each of the drainage khals. The schematic diagram of the south-west regional model is presented in the Figure 4.12.

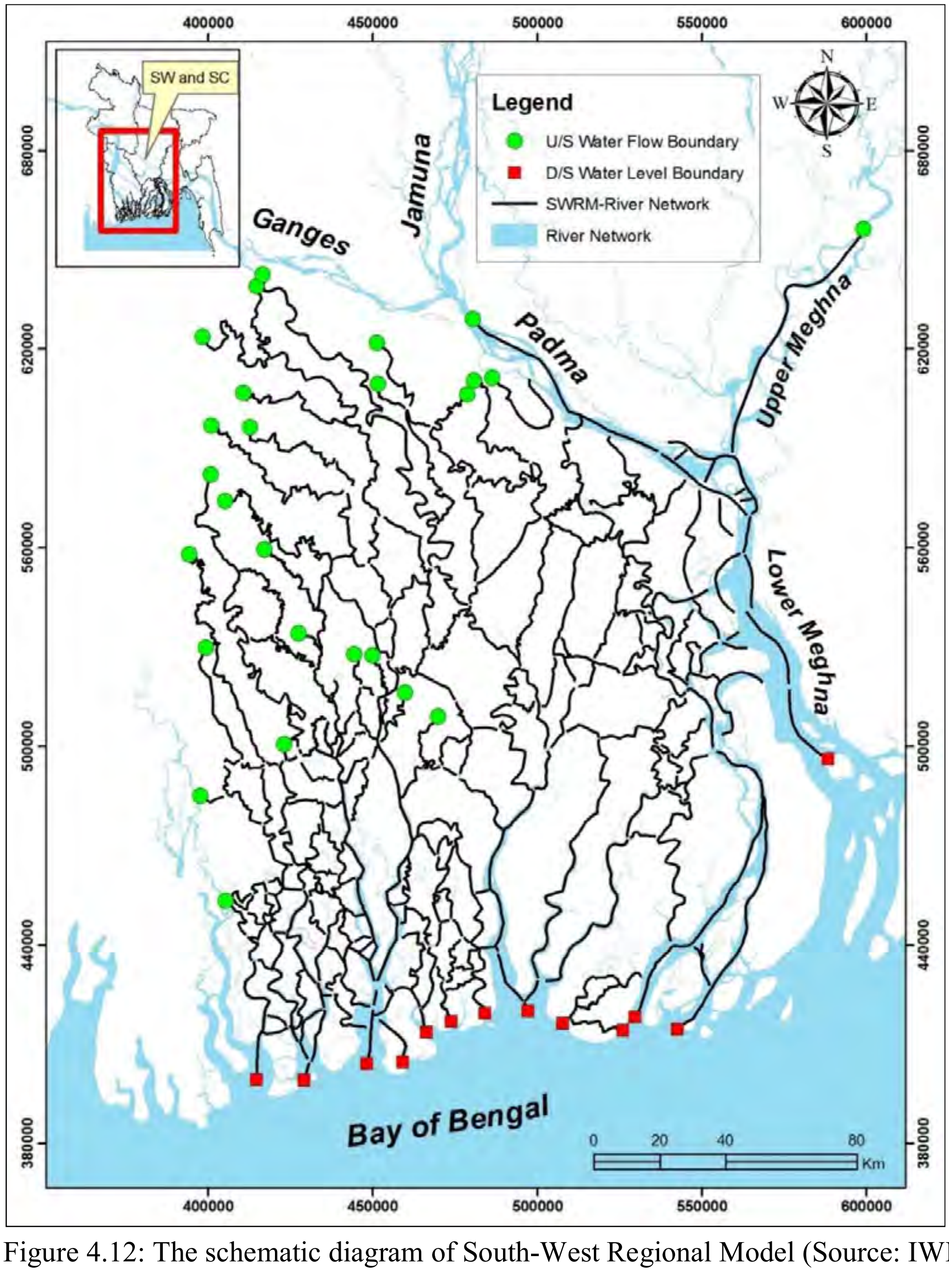


Figure 4.12: The schematic diagram of South-West Regional Model (Source: IWM)

Calibration and validation of South-West Regional Hydrological Model

Calibration and validation of hydrological model for South-west regional model is not carried out in this thesis work. This calibrated and validated hydrological model is used for simulating the hydrological model for the study area. The study area is located in the south-west catchment SW-23 which is calibrated and validated in different period in IWM. Calibration and verification of Hydrological model for south west and south-central region is done in Surface Water Simulation Modelling Programme Phase II which is published in 1993. Figure 4.13 and Figure 4.14 shows the results of calibration and validation of NAM models.

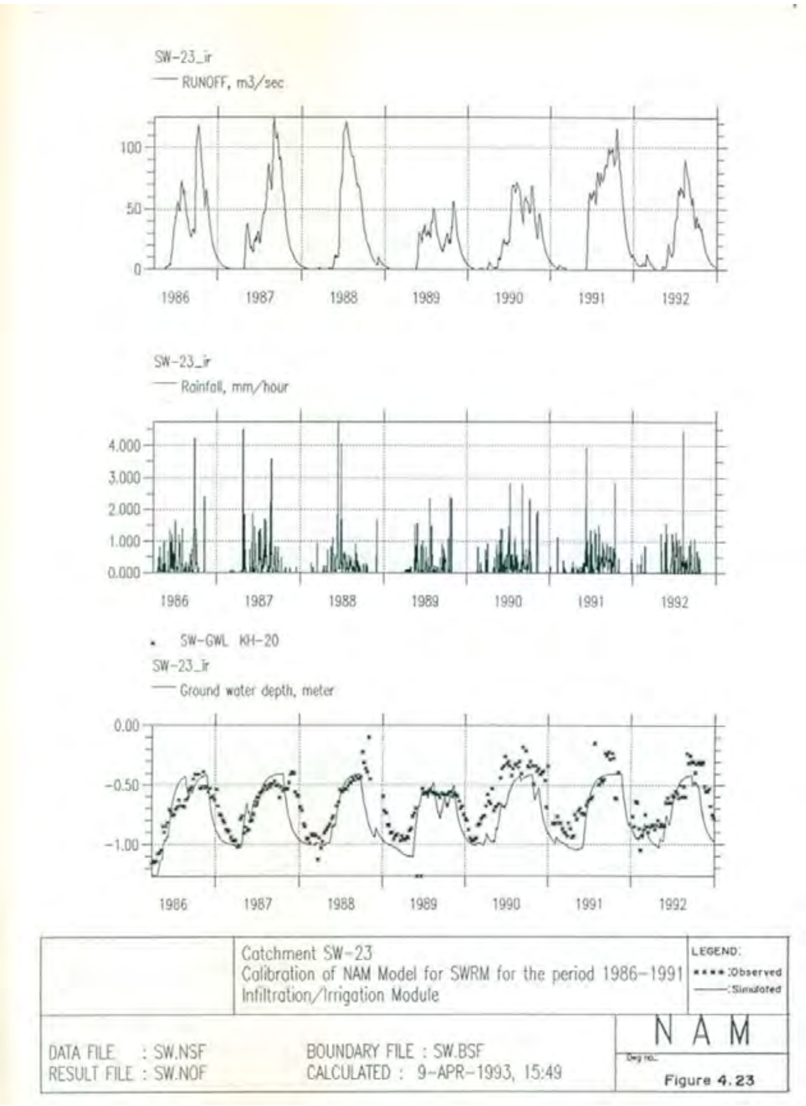


Figure 4.13**:** Calibration plot of South-West catchment SW-23 against Ground Water Depth (Source: IWM 1993)

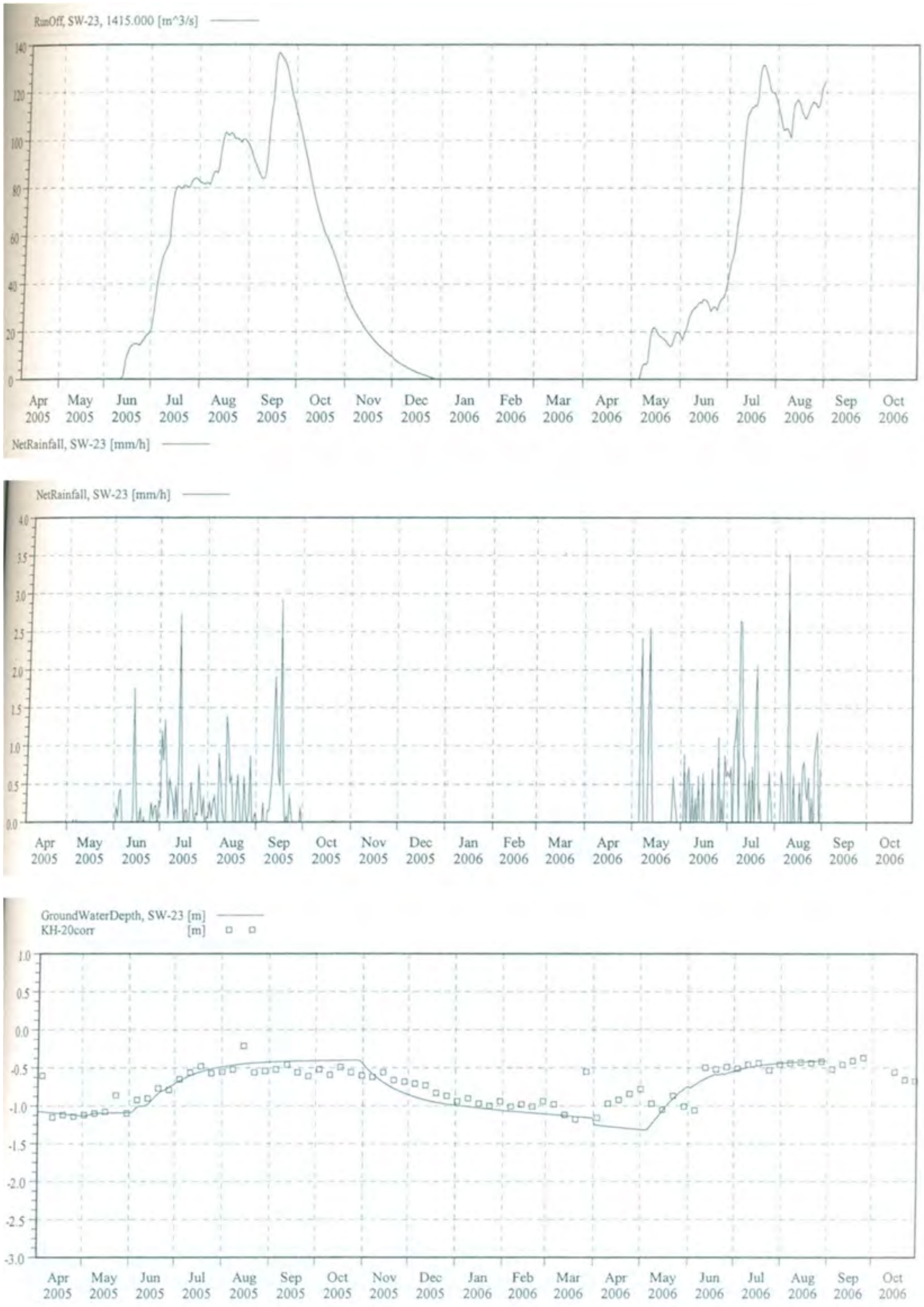


Figure 4.14: Validation of rainfall runoff model for South-West catchment SW-23 against Ground Water depth (Source: IWM 2006)

4.4.3 Development of Boundary Conditions

There are two types of boundaries is applied in this study for developing the hydrodynamic model. Time series discharge data is used at the upstream open boundary and water level time series is used at the downstream boundary.

Downstream Boundary Conditions

In the south-west regional model, there are about 13 no. of downstream open boundary is available. The measured water level time series data is used for developing the hydrodynamic model at base condition. The relative mean sea level is calculated for the development of hydrodynamic condition at downstream to assess the climate change effects.

In this study, Syvitski et al., (2009) formula is used for calculating the relative sea level rise. According to the Syvitski et al., (2009), relative mean sea is determined considering the contributions of global mean sea level, subsidence, sedimentation and tectonic movement.

$\Delta RSL = A - \Delta E - CN - CA \pm M$

Where,

A = delta Aggradation Rate.

ΔE = global sea level rise/ (eustatic sea-level)

CN , CA = Natural compaction (CN) and Accelerated compaction (CA) of deltaic deposit

M= Vertical land surface movement (plate tectonic)

If only the vertical land elevation change is considered, the equation can be simplified as, $\Delta RSL = \Delta E + C - A$

Estimation of the relative mean sea level using Syvitski's law 2009 was established for 2050 with respect to base year 2012 (Scenario: RCP 8.5)

Global sea level rise at Bay of Bengal in 2050 is 33 cm. (Figure: 3.4)

Land subsidence rate = 4 mm/year (Higgins et el. 2014)

Sedimentation rate = 2 mm/year (Syvitski et al, 2009)

Relative mean sea level rise = 33 cm+ (2050-2012) year * (4-2) mm/year

= 40.6 cm ≈ 41 cm

The calculated relative mean sea level rise (41 cm) is used at the downstream boundary of the south-west regional model (Figure 4.12) for the development of the future climate condition.

Upstream Boundary Conditions

Time series discharge boundary is applied at the upstream open boundaries (1. Bhairab Bazar in Upper Meghna, 2. Baruria in Padma and 3. Gorai railway Bridge in Gorai River) of the South-West Regional Model for the development of base condition (2012). In this study the future condition is developed by increasing the upstream flow condition. Increase of flow of Ganges with 16 -28%, Brahmaputra with 8.5% to 18.5% and Upper Meghna with 8% to 11% during May to November (CEIP-1) based on GBM basin model results under climate change scenario is added at the upstream flow boundaries of south-west regional model for generating the climate change condition 2050.

Sea level rise and increase of precipitation under climate change scenario RCP (8.5) is applied in the polder drainage model for assessing the effectiveness of the existing drainage system for the year 2050. After simulation of the south-west regional model, water level and water flow time series data is extracted from the model result. The extracted time series data is used for developing the polder drainage model of polder 17/1 and polder 17/2.

4.4.4 Drainage Model

Drainage model is a very effective tool for investigating the performance of potential drainage improvement plans and its possible impacts on the physical processes. It can also assist to establish the existing drainage patterns of a drainage basin and also helps to identify the future problem that can persist due to the implementation of the potential drainage improvement interventions. Drainage modelling for the polder 17/1 and polder 17/2 has been carried out in order to investigate the adequacy and performance of the existing structures and drainage systems and potential drainage improvement interventions. A dedicated drainage model for polder 17/1 and 17/2 has been simulated by taking the peripheral river network, drainage canal system, catchment area for each of the drainage channels and drainage sluices of Polder no. 17/1 and 17/2. At upstream of the model, water flow boundary and at downstream, water level has been applied as boundary file for simulating the drainage model. The schematic diagram of the dedicated drainage model for polder 17/1 and polder 17/2 is given in Figure 4.15.

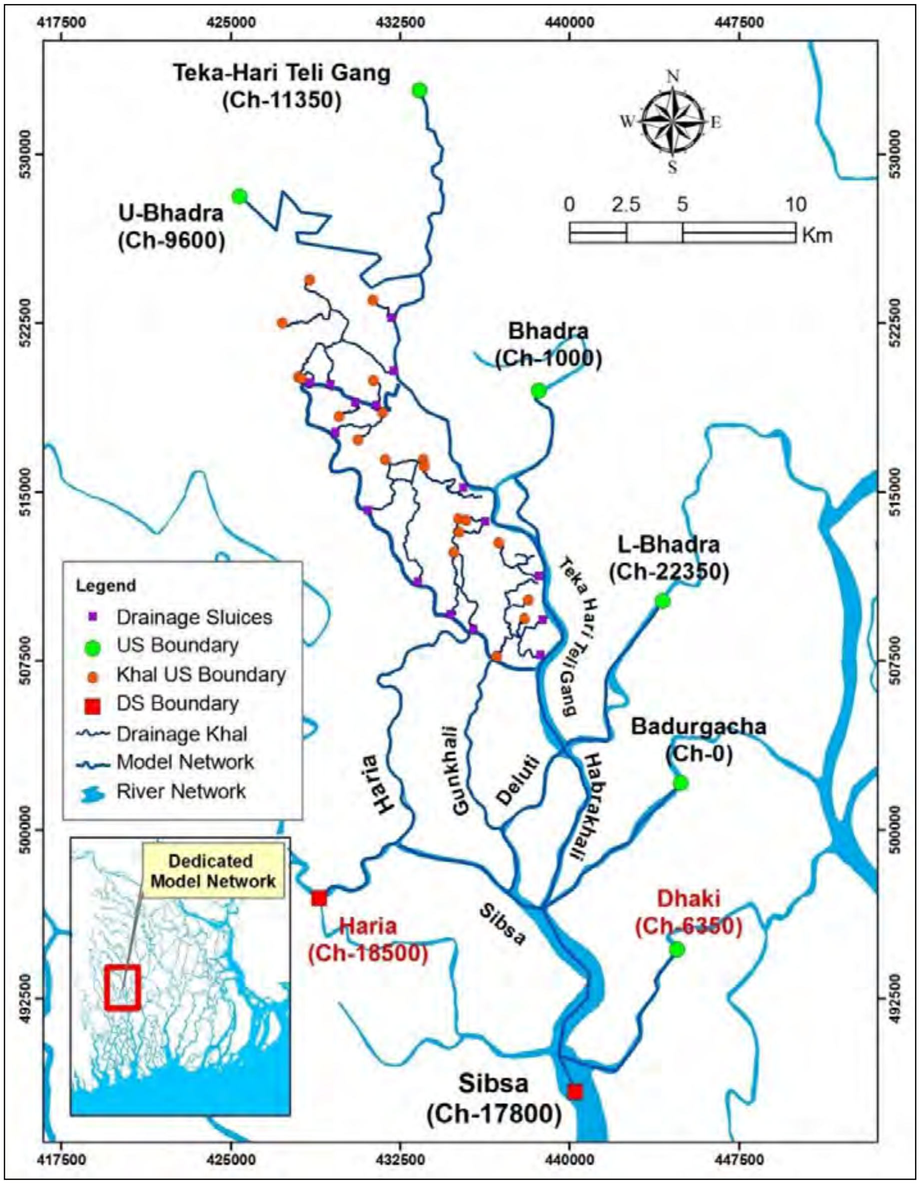


Figure 4.15: The schematic diagram of Drainage model for Polder 17/1 and 17/2

4.4.5 Boundary Conditions of Drainage Model

Boundary condition basically represents the hydrodynamic influence of the river networks outside the model domain. Hence, for reliable presentation of nature within the model setup, accurate boundary condition is a fundamental requirement for development of model. The drainage model of Polder 17/1 and 17/2 contains total 8 boundaries, of which 6 are upstream and 2 are downstream boundaries. 2012 has been selected as Base year and 2011 has been selected as hydrological design year. At first South-West, regional model has been simulated for generating the boundary for 2012. After calibration and validation, the base model set-up has been simulated for the design year 2011. Then the boundary condition of the developed drainage model has been extracted from the hydrological design event model 2011. The schematic diagram for the upstream water flow at Badurgacha (chainage Km 0.00) and downstream water level at Haria (chainage km 18+500) is shown in Figure 4.16 and Figure 4.17 respectively.

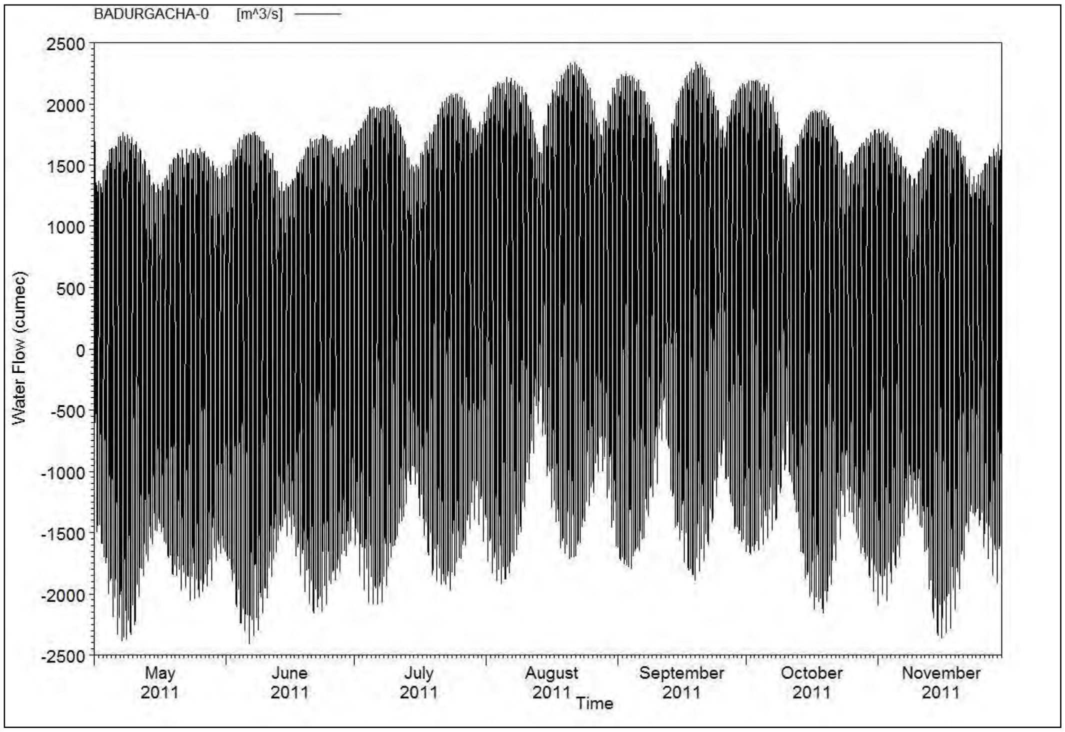


Figure 4.16: Water flow at Badurgacha as upstream boundary

Climate change projection has been applied into the downstream water level time series data, upstream rated time series data. About 41 cm sea level has been added into the downstream water level data and increase of flow of Ganges with 16 -28%, Brahmaputra with 8.5 % to 18.5% and Upper Meghna with 8% to 11% during May to November also been added into upstream discharge time series data.

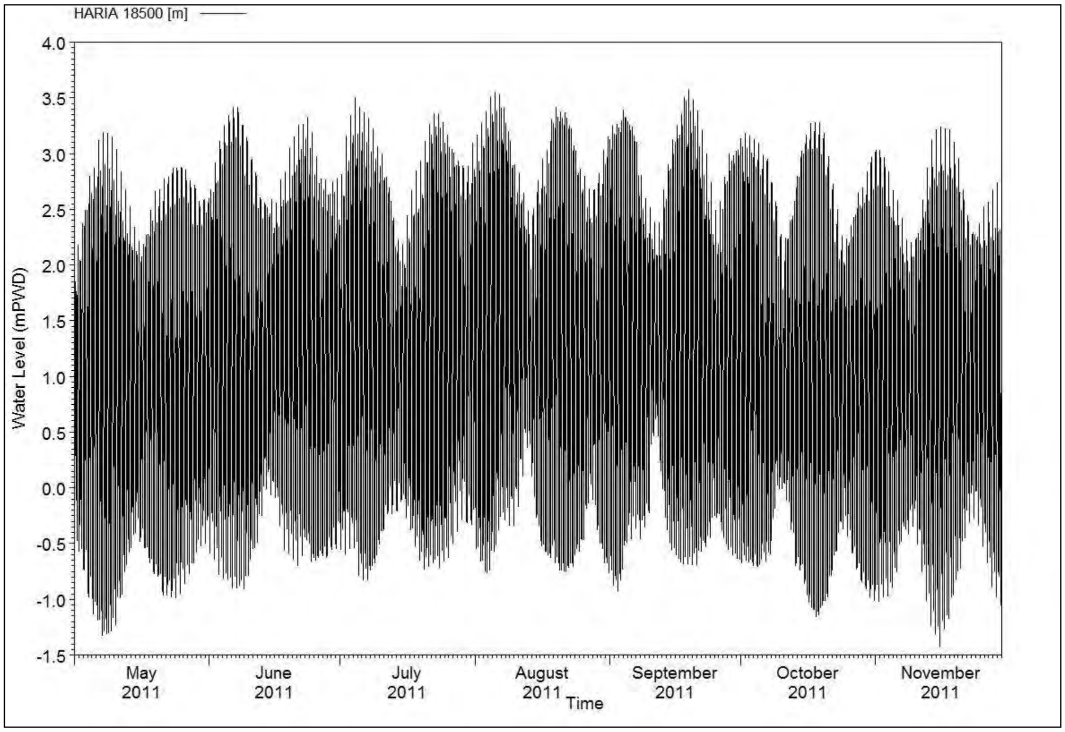


Figure 4.17: Water level at Haria as downstream boundary

After simulation of south-west regional model time series water level (Figure 4.19) and discharge (Figure 4.18) data has been extracted from south-west regional model result for generating the boundary data for the dedicated polder model.

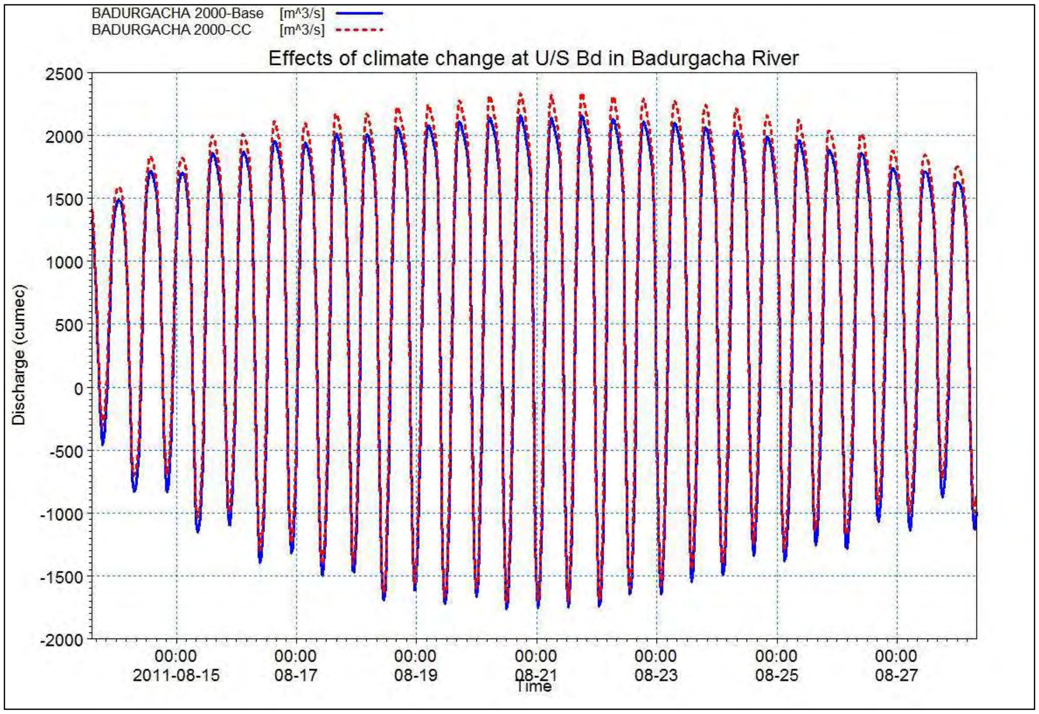


Figure 4.18: Climate change effects at the upstream discharge data in Badurgacha River

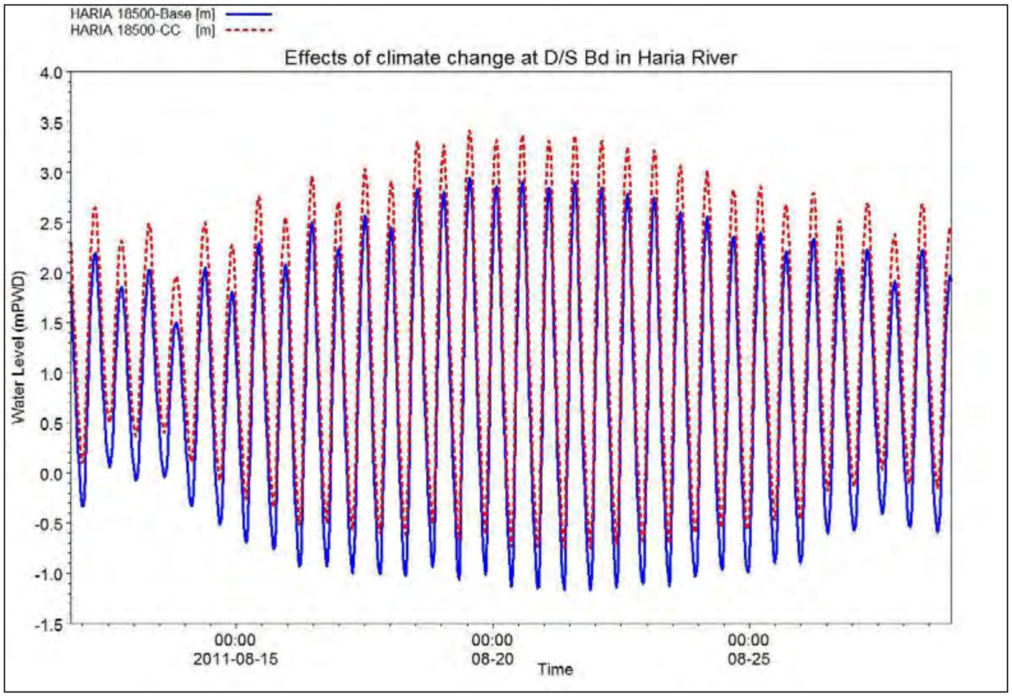


Figure 4.19: Climate change effects at the downstream water level data in Haria River

4.4.6 Delineation of Drainage Catchments and Distributions

The main purpose of the catchments delineation is to sub-divide the whole polder area for the existing drainage networks and hydraulic structures incorporated in the drainage model set-up. In the process of catchment delineation (Figure 4.20) single or multiple channels are grouped together to form a single hydrological unit which drained through a single structure. Delineation of catchments area has been done on the basis of:

- Land level data of the polder;
- Alignment of existing khals, hydraulic structures, and other topographical features including road networks;
- Satellite Images.

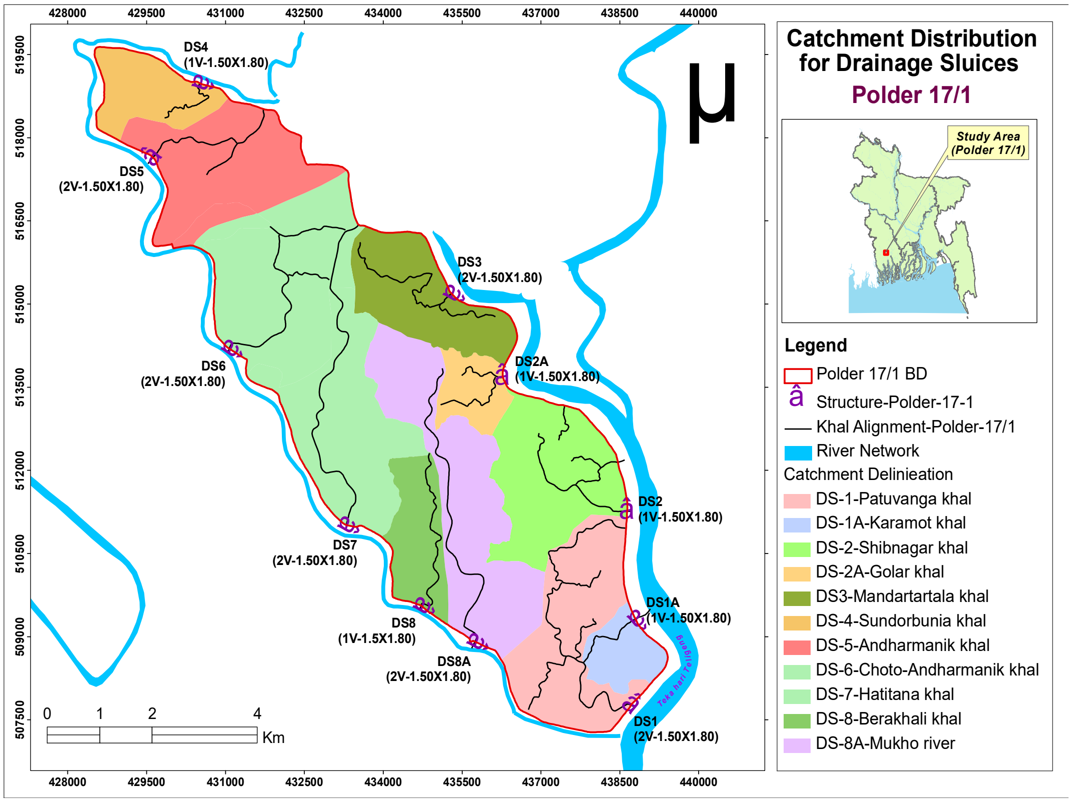
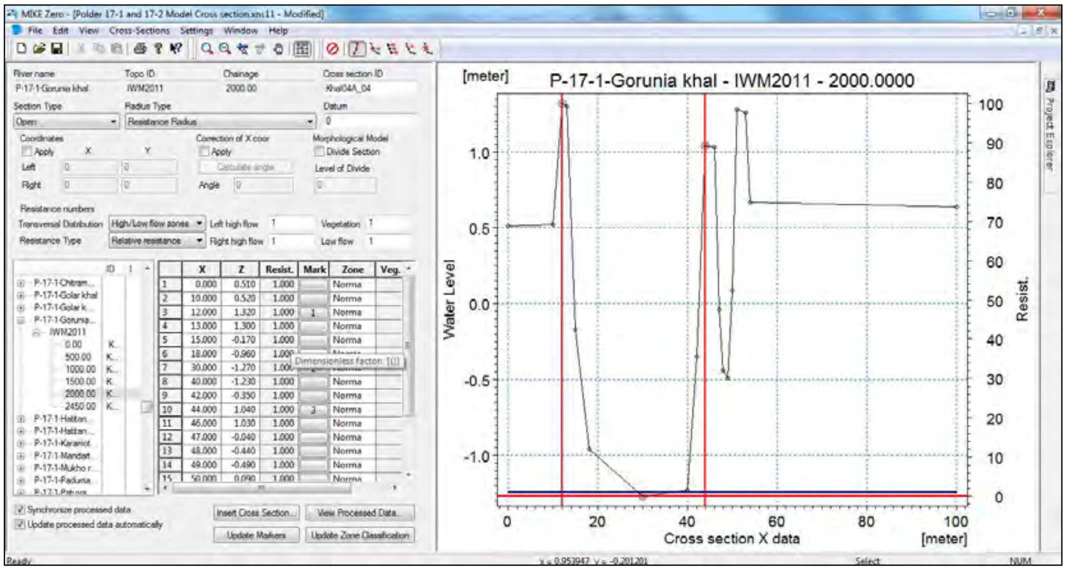


Figure 4.20: Catchment delineation for drainage sluices of Polder 17/1

4.4.7 Incorporation of Drainage Channels and Regulators of Polders

The drainage channels/khals network under this study has been provided as input into the existing calibrated dedicated model set-up for incorporating the polder drainage system into the peripheral river system. The polder drainage network drains under gravity when the outside river level falls below the internal (polder) water level. The drainage channel cross section, dimensions of all the drainage and flushing regulators has been collected from Institute of water modelling (IWM). Basically there are two types of hydraulic structures inside the polder 17/1 and 17/2 termed as drainage and flushing; during critical period flushing regulator also drains. All drainage regulator existing proposed and flushing regulators with long and deep canal are provided as input to the model set-up of polders. The structures are represented in the model set-up in terms of their full dimensions (width, height, invert level and no. of vents). An operation rule for each structure is also programmed into the model set-up which ensures the smooth drainage of the polder and restricts the entry of river water inside the polder considering hydraulic conditions of peripheral rivers and khals in the polder.



River name: P-17-1-Gorunia khal
Topo ID: IWM2011
Chainage: 2000.00
Cross section ID: Khal04A_04
Section Type: Open
Radius Type: Resistance Radius
Datum: 0

Coordinates: ☐ Apply
Left: X 0, Y 0
Right: X 0, Y 0

Correction of X coor: ☐ Apply
Angle: 0

Morphological Model: ☐ Divide Section
Level of Divide: 0

Resistance numbers
Transversal Distribution: High/Low flow zones
Resistance Type: Relative resistance
Left high flow: 1
Right high flow: 1
Vegetation: 1
Low flow: 1

	X	Z	Resist.	Mark	Zone	Veg.
1	0.000	0.510	1.000		Norma	
2	10.000	0.520	1.000		Norma	
3	12.000	1.320	1.000	1	Norma	
4	13.000	1.300	1.000		Norma	
5	15.000	-0.170	1.000		Norma	
6	18.000	-0.960	1.000		Norma	
7	30.000	-1.270	1.000	2	[illegible]	
8	40.000	-1.230	1.000		Norma	
9	42.000	-0.350	1.000		Norma	
10	44.000	1.040	1.000	3	Norma	
11	46.000	1.030	1.000		Norma	
12	47.000	-0.040	1.000		Norma	
13	48.000	-0.440	1.000		Norma	
14	49.000	-0.490	1.000		Norma	
15	50.000	0.090	1.000		Norma	

☑ Synchronize processed data
☑ Update processed data automatically

Ready x = 0.953947 y = -0.201201 Select NUM

Figure 4.21: Typical cross section as an input file in the model network

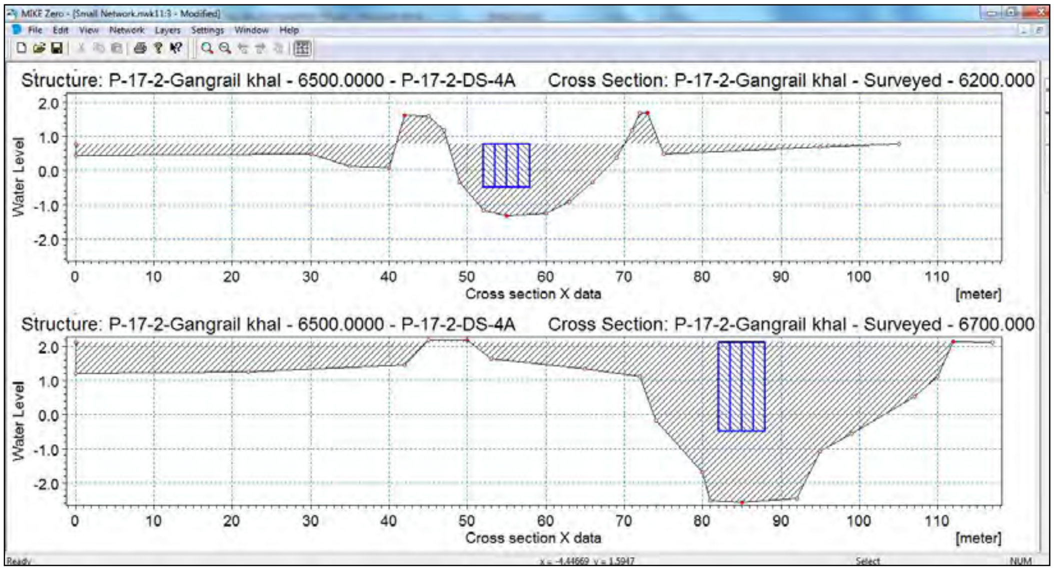


Figure 4.22: Typical drainage sluice DS-4A (Polder 17/2) added on Gangrail Khal

4.5 Summary

In this chapter the design year and calibration year detected for the selected coastal polders. The statistical method is applied to determine the design year. The climate change effect has also been incorporated and the extreme condition for RCP 8.5 has been adopted for determining the drainage congestion problems. The catchment delineation has also been a major component to identify the water logging problem in the area. The model has also been calibrated and validated for the proper use of results.

CHAPTER FIVE:
RESULTS AND DISCUSSIONS

5.1 General

The calibration and validation of the model work is presented in this chapter. After calibration and validation of the model work, the polder model is used for developing the inundation depth for existing condition. Different improved options have been generated by applying different interventions in the existing system. Dredging of all drainage khals and Peripheral River, modification of drainage sluice invert levels, adding the supplementary pumping system and Tidal River Management - these interventions has been added into the existing drainage system. In this chapter result of all modelling simulations has been described in briefly.

5.2 Calibration of the Dedicated Water-Flow Model

Calibration is an iterative procedure to make an adjustment between observed values and simulated values of a variable with a desired level of accuracy through adjusting certain parameters of model. Channel roughness (Manning's M is the inverse of Manning's n) is the controlling calibration parameter of water-flow model. The calibration of the Polder Drainage Model is done by comparing the simulated water level and discharge with observed values of Upper-Bhadra and Haria River. Calibration location of the water level and discharge is shown in the Figure 5.3. The calibration plot for water level is shown in Figure 5.2 and Figure 5.3 and the calibration plot for discharge is presented in Figure 5.4 and Figure 5.5. From the above listed figures, it is revealed that the simulated result matched well with the observed values for both water level and discharge.

The dedicated water-flow model is also validated with the measured water level and discharge. Validation of the drainage model is done for the year 2009, only changing the upstream and downstream boundary and remaining the same modelling parameter. The water level and discharge validation in Teka Hari Teli Gang is presented in Figure 5.6 and Figure 5.7 respectively.

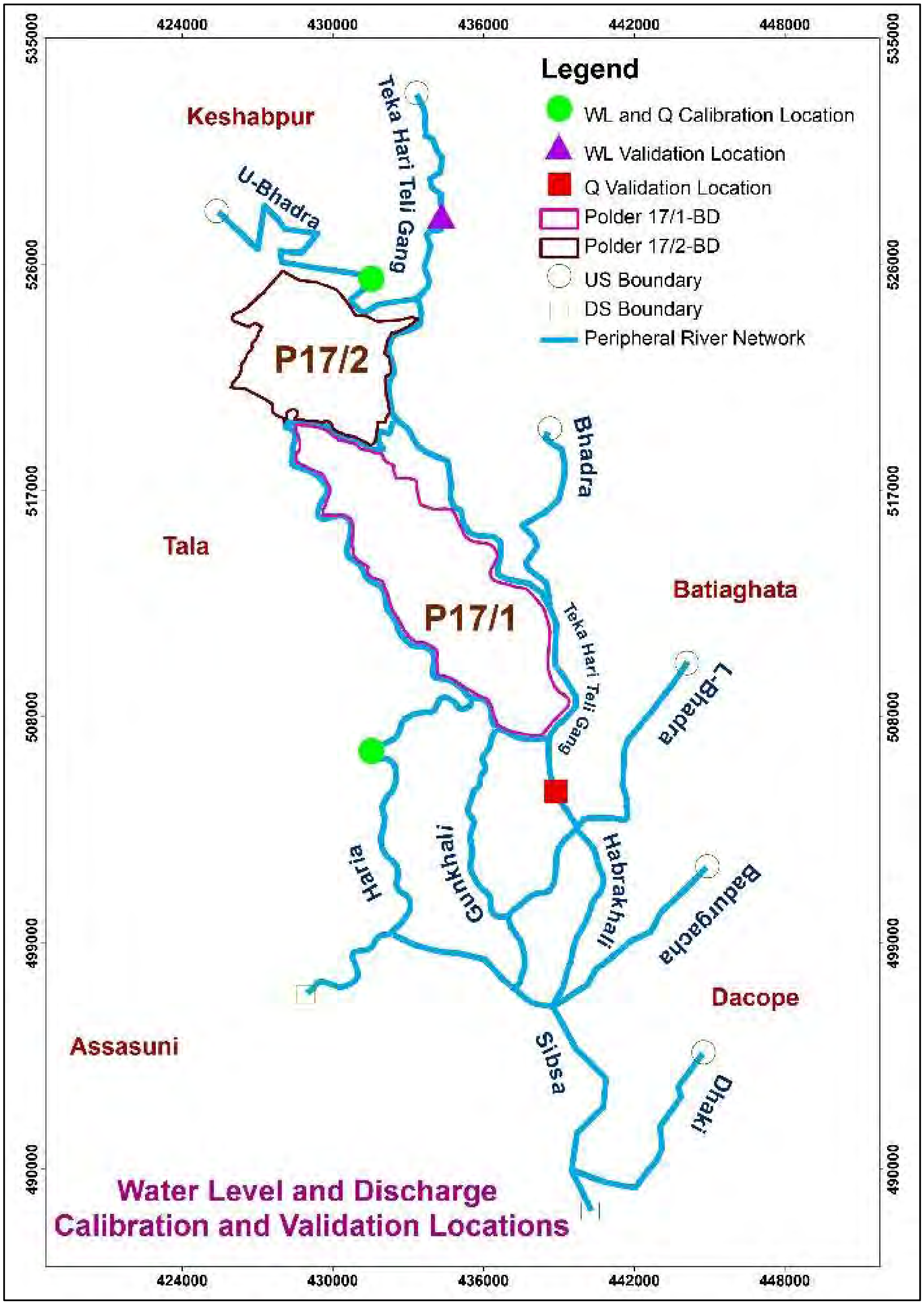


Figure 5.1: Water Level and Discharge calibration locations

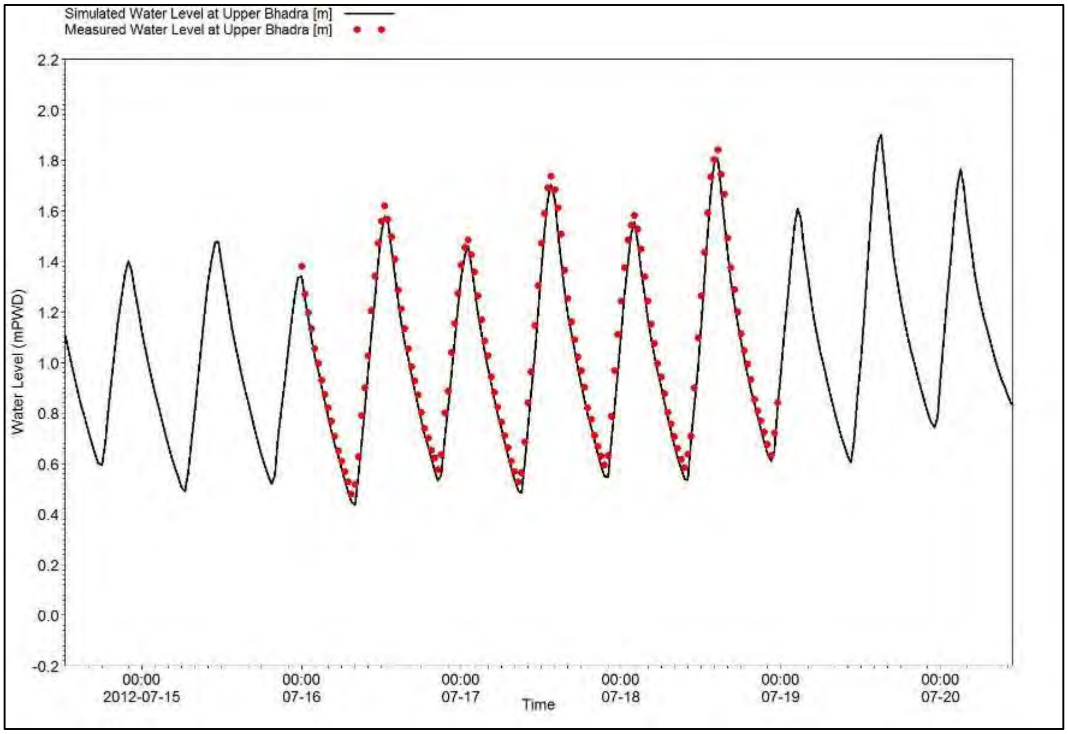


Figure 5.2: Water level calibration at Upper-Bhadra River

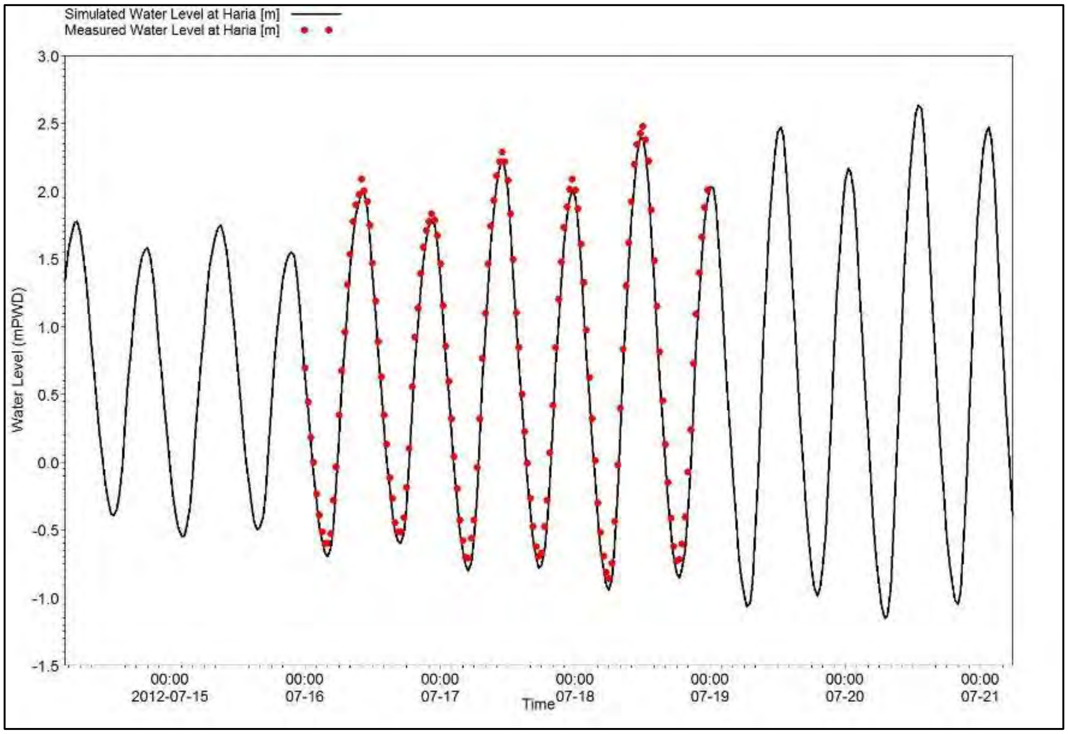


Figure 5.3: Water level calibration at Haria River

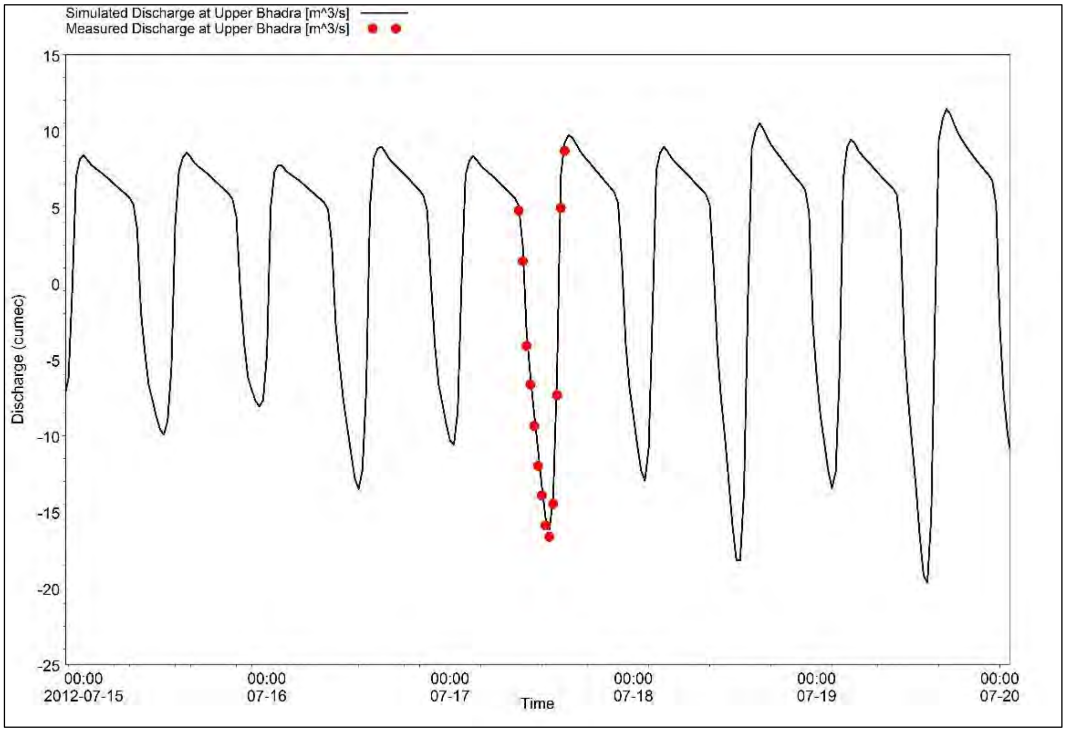


Figure 5.4: Discharge calibration at Upper-Bhadra River

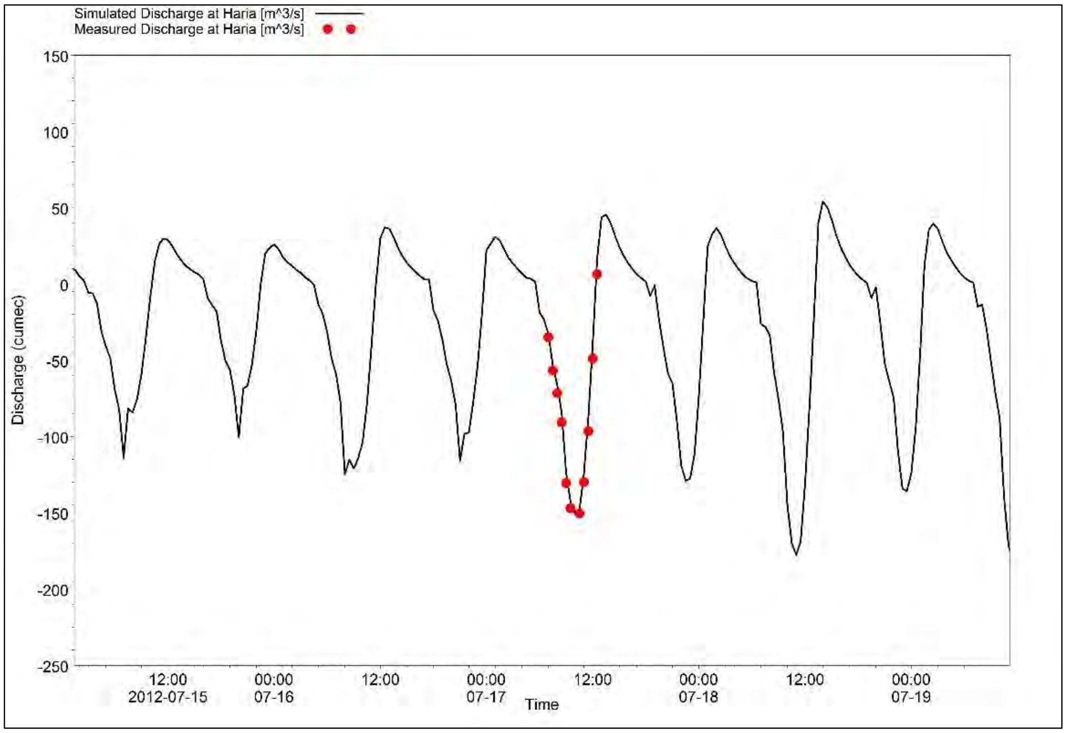


Figure 5.5: Discharge calibration at Haria River

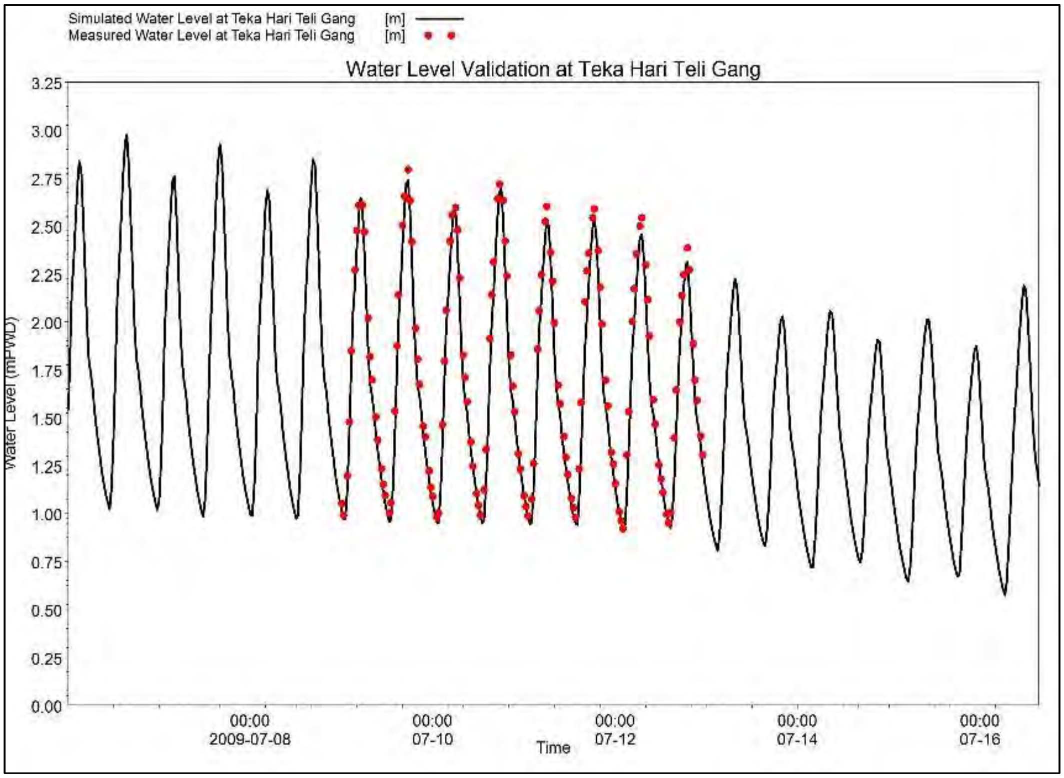


Figure 5.6: Water Level validation in Teka Hari Teli Gang River

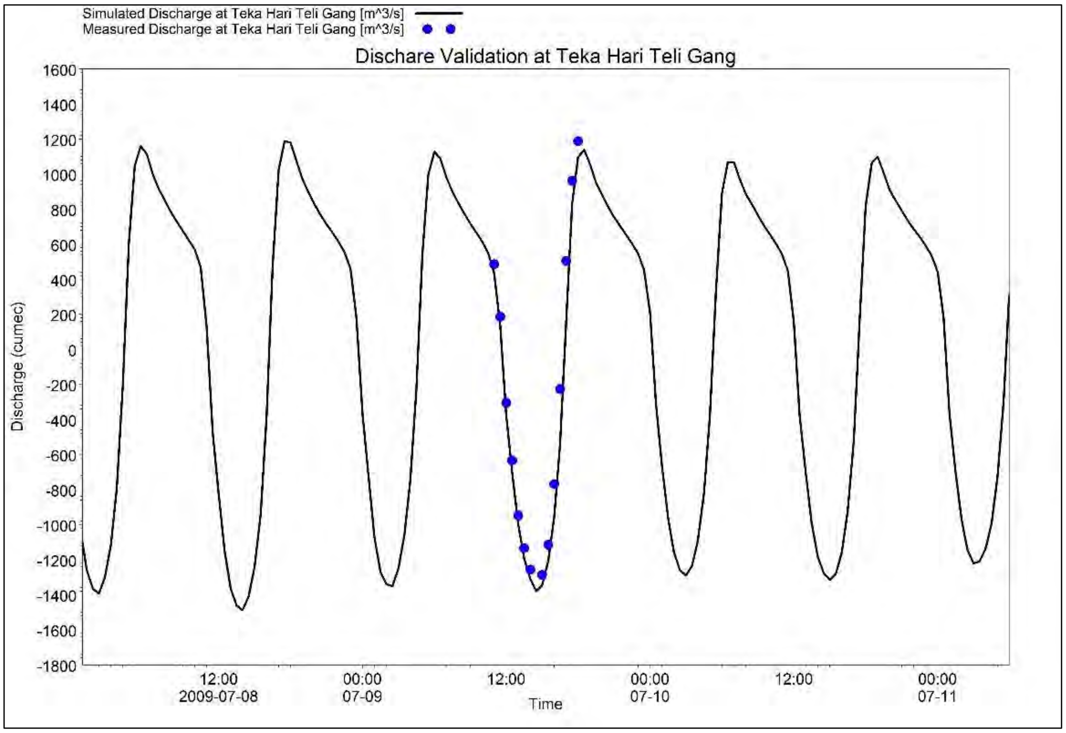


Figure 5.7: Water flow validation in Teka Hari Teli Gang River

5.3 Discussion on Model Result

Inundation depth for the existing condition of polder drainage system is developed for assessing water logging location considering the future climate condition. Then projected scenarios have been developed for removing the present condition and build climate resilient polder system.

5.3.1 Inundation depth at different Condition of the selected Polders

The drainage performance/effectiveness of each option is evaluated in terms of decrease of flood, inundation area and depth of the polder area (land classification) compared to the existing condition. It is essential to examine the proposed drainage improvement plan to find out whether the study area can be drained within three days through the drainage system to save the agricultural crops and to avoid the prolong water-logging. This investigation is made by preparing flood inundation depth maps for 3-day duration maximum water level showing the area of different land classes (F0, F1, F2, F3 and F4) using model results and available Digital Elevation Model (DEM) of the study area. In this study land classification F0 is defined for water depth 0.0m to 0.30m, F1 is defined for 0.30m to 0.90m, F2 is defined for 0.90m to 1.80m, F3 is defined for 1.80m to 3.60m and F4 land is classified for water depth>3.60m. Flood Free (FF), F0 land and F1 land is considered as Flood Free area for agricultural purposes and agricultural production.

5.3.2 Assessment of Effectiveness of Present Drainage System

In the existing condition of polder 17/1, about 61.57% area remains flood free (i.e., inundation up to 0.3 m depth of water). About 10.08% area remains under deeply inundation depth (depth>0.90m). The analysis of inundation of polder 17/2 shows that about 91.39% area remains flood free (i.e., inundation up to 0.3 m depth of water) in the existing condition and 8.61% area is in between water depth 0.30m to 9.0m. The percentage of inundation area at the existing drainage system for the polder 17/1 and polder 17/2 has been illustrated in the Table 5-1 and Table 5-2. The Inundation depth map of polder 17/1 and polder 17/2 for 3-days duration and land class at existing condition is shown in Figure 5.8 and Figure 5.9.

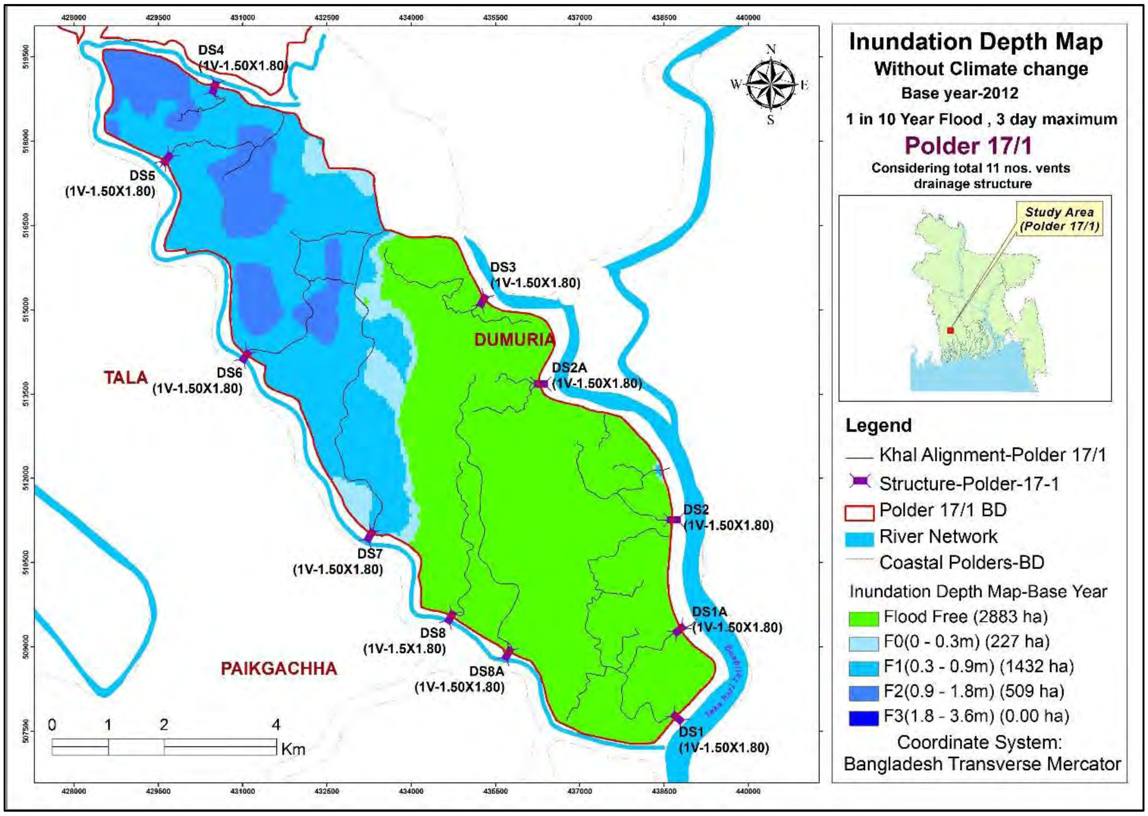


Figure 5.8: Inundation depth map of polder 17/1 for 3-days duration and land class at existing condition

Table 5-1**:** Inundation depth of Polder 17/1 at existing drainage condition

Existing Condition ((Inundation depth considering existing drainage system)	% inundated area							
		F0	F1	F2	F3	F4	Total (%)	Total (%)
	Flood Free	(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	2883	227	1432	509	0	0	3109	4541
Percentage (%)	57.08%	4.49%	28.35%	10.08%	0.00%	0.00%	61.57%	89.92%

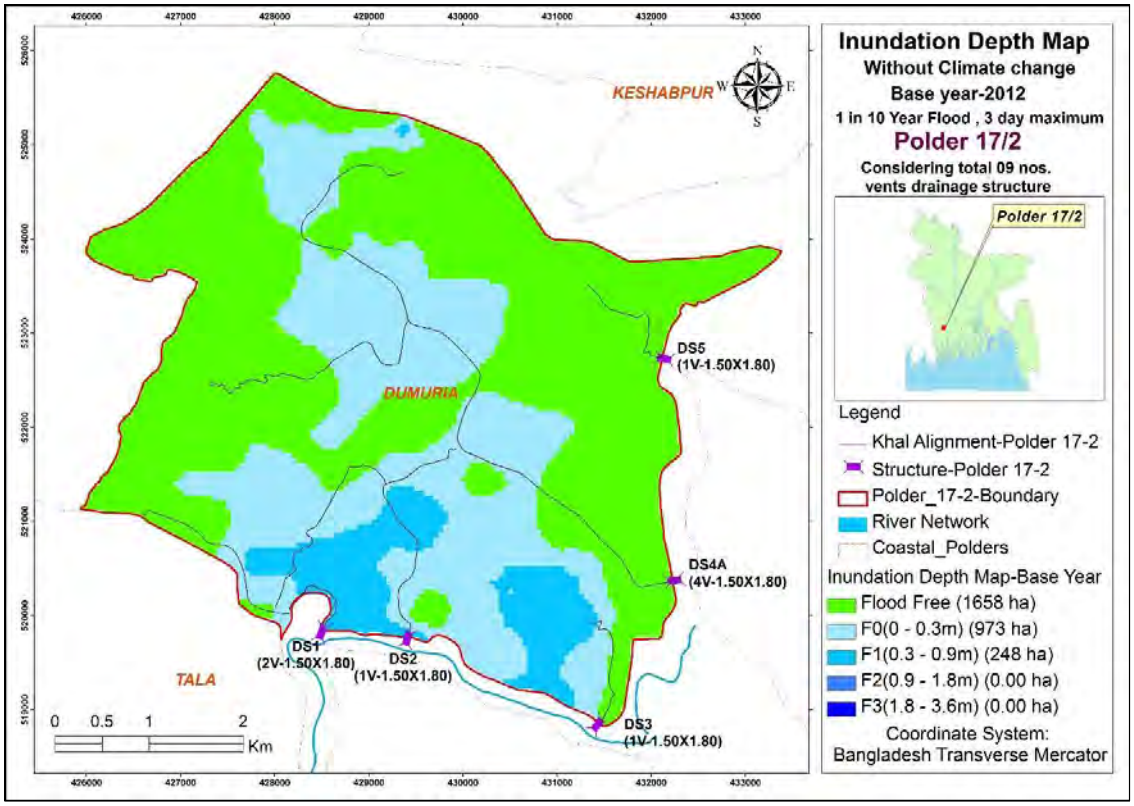


Figure 5.9**:** Inundation depth map of polder 17/2 for 3-days duration and land class at existing condition

Table 5-2: Inundation depth of Polder 17/2 at existing drainage condition

Existing Condition ((Inundation depth considering existing drainage system)	% inundated area							
	Flood Free	F0	F1	F2	F3	F4	Total (%)	Total (%)
		(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	1658	973	248	0	0	0	2631	2879
Percentage (%)	57.58%	33.81%	8.61%	0.00%	0.00%	0.00%	91.39%	100.00%

Comparison with Satellite image

Inundation at base condition (monsoon, 2012) pattern also analyzed with satellite image. The satellite image shows the similar inundation pattern as I have found in the mathematical model. The inundation depth map from satellite image is shown in the Figure 5.10.

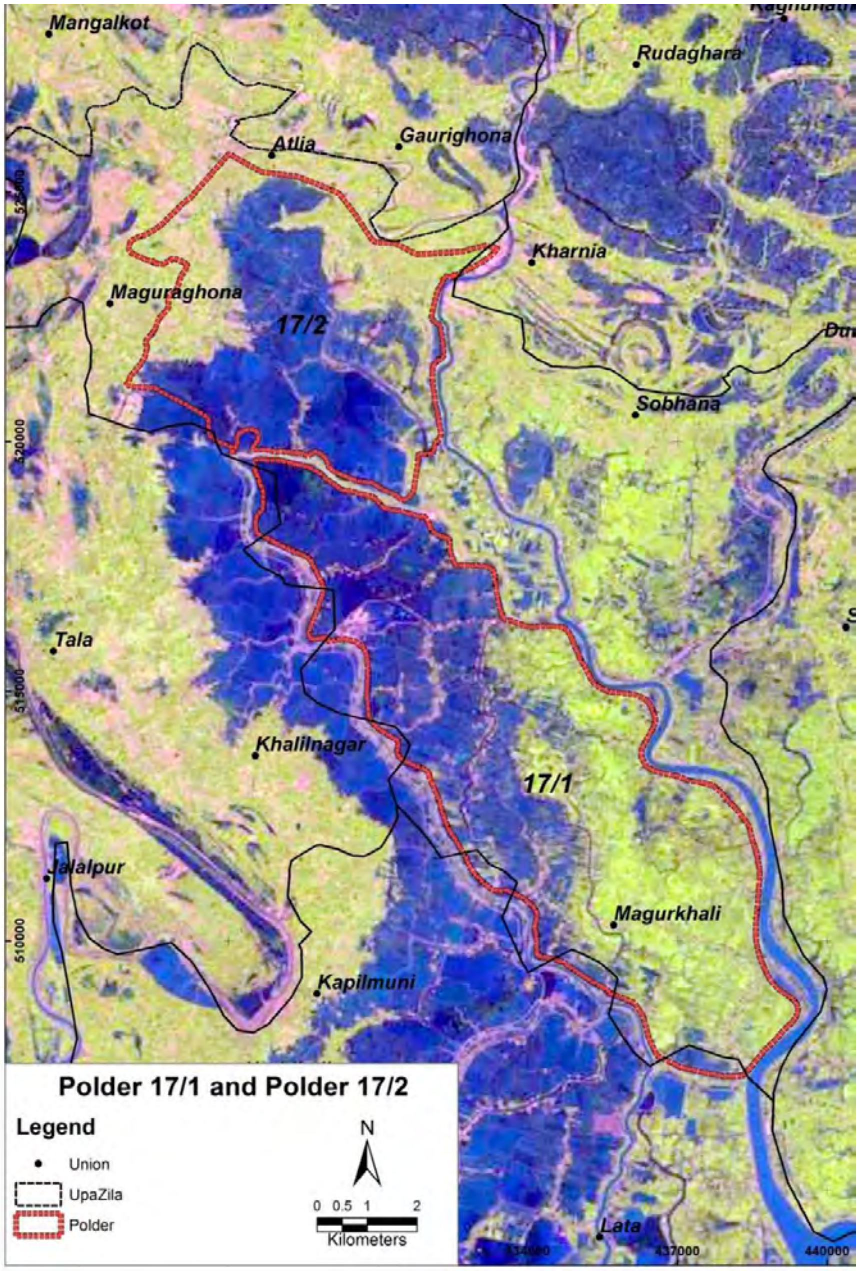


Figure 5.10: Inundation depth map for Polder 17/1 and Polder 17/2 from Satellite image

5.3.3 Assessment of Effectiveness of Present Drainage System during Design Flood Event

Design flood event has been established based on 5-days cumulative rainfall of 10-years return period for the adjacent rainfall station of the study area. By analysis the historical rainfall, year 2011 has been selected for the design return period. Inundation depth has been analysis for the design period on the existing drainage system. Climate change (change in precipitation, increase in sea level rise and increase in upward flow) has been applied on the existing system during the design flood event for assessing the inundation condition.

Polder 17/1

In the design flood event at existing condition, it is seen that about 43.54% area remains flood free (i.e., inundation up to 0.3 m depth of water) which is about 61.57% in the existing condition. About 42.14% area remains under deeply inundation depth (depth>0.90m) which is more than (10.08%) in the existing condition. In the climate change condition of polder 17/1 under the design flood event, the analysis shows that about 17.26% area remains flood free which is about 43.54% in the design flood event considering existing condition. The deeply inundated area increases from 42.14% to 45.65% (depth>0.90m).

The percentage of inundation area for the polder 17/1 at the existing drainage system during the design flood event considering without and with climate change condition is presented in the Table 5-3 and Table 5-4. The Inundation depth map of polder 17/1 for 3-days duration and land class at existing drainage system considering without and with climate change condition for the design flood year is shown in Figure 5.11 and Figure 5.12.

Table 5-3: Inundation depth map of Polder 17/1 for design flood event at existing drainage condition

Existing Condition (Inundation depth considering flood event on existing drainage system)	% inundated area							
	Flood Free	F0	F1	F2	F3	F4	Total (%)	Total (%)
		(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	821	1378	723	1392	736	0	2199	2922
Percentage (%)	16.26%	27.28%	14.32%	27.57%	14.58%	0.00%	43.54%	57.86%

Table 5-4: Inundation depth map of Polder 17/1 for extreme flood event under extreme climate change at existing drainage condition

Existing Condition (Inundation depth considering flood event under climate change condition on existing drainage system)	% inundated area							
	Flood Free	F0	F1	F2	F3	F4	Total (%)	Total (%)
		(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	71	801	1873	1171	1134	0	872	2745
Percentage (%)	1.40%	15.86%	37.09%	23.19%	22.46%	0.00%	17.26%	54.35%

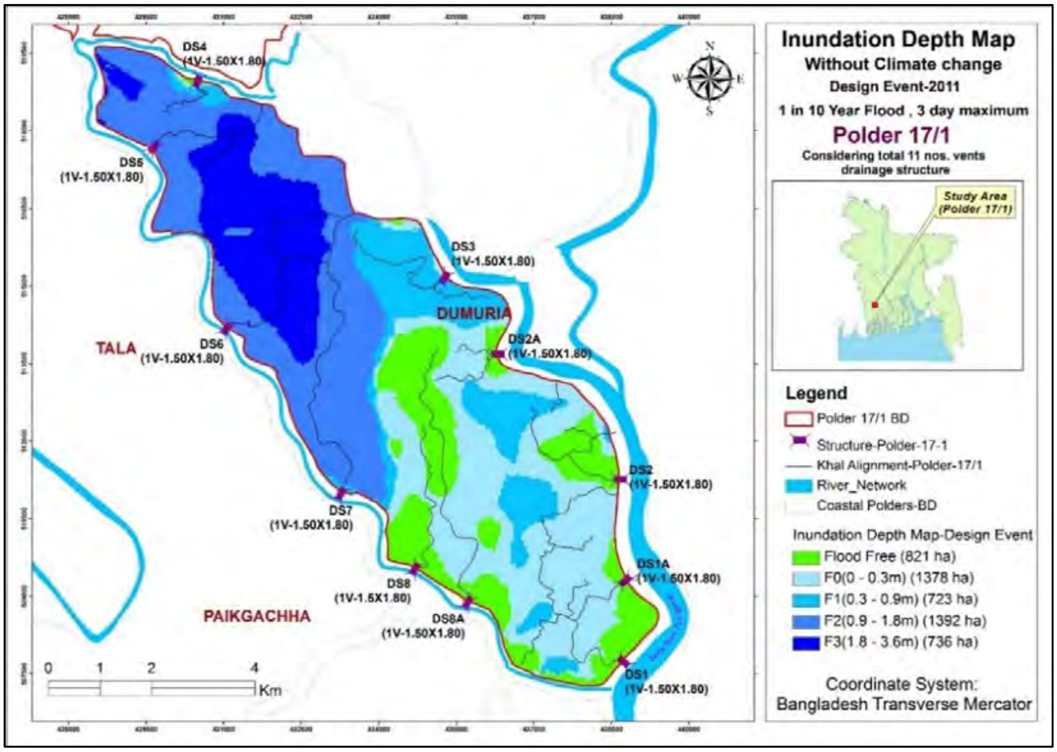


Figure 5.11: Inundation depth map of polder 17/1 for 3-days duration and land class during design year considering without climate change condition

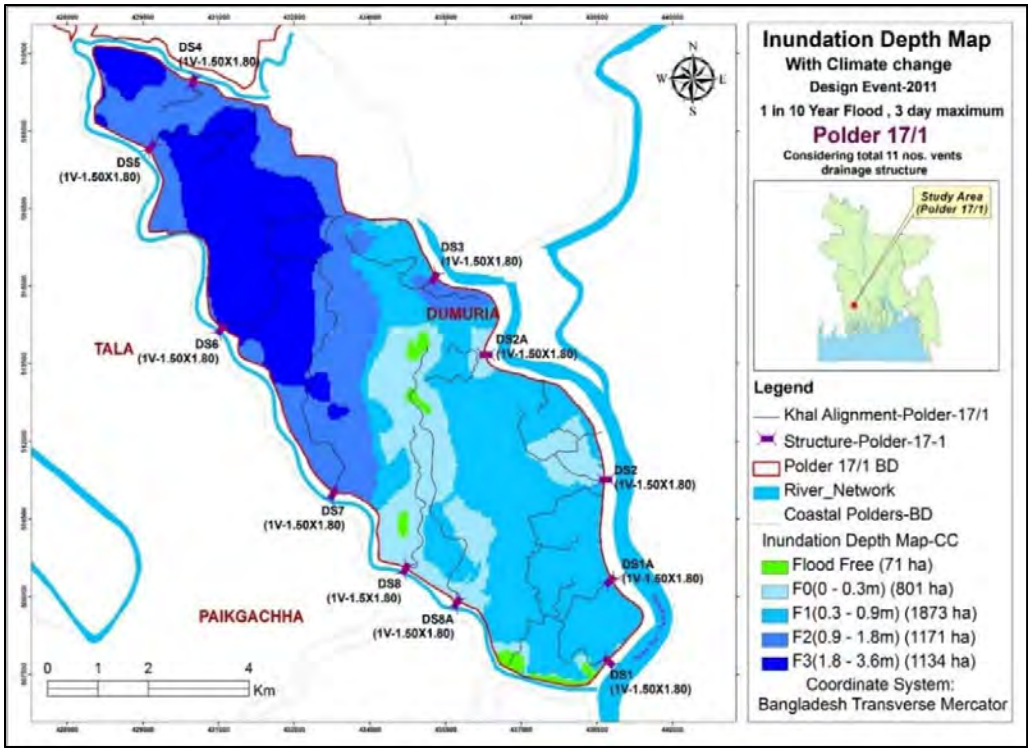


Figure 5.12: Inundation depth map of polder 17/1 for 3-days duration and land class during design year considering with climate change condition

Polder 17/2

In case of polder 17/2 under the design flood event, it is seen that about 19.33% area remains flood free (water depth up to 0.30m) at without climate change condition whereas it is about 16.17% at climate change condition. About 37.70% land area is under water depth 0.30m to 0.90m at existing condition whereas it is about 21.43% under climate change condition. It means under the climate change condition F1 (0.30m to 0.90m) land decreases and F2 land (0.90 to 1.80m) increases. The deeply inundated (depth>0.90m) area increases from 42.97% (without climate change condition) to 62.40% (with climate change condition) considering the existing scenario of the polder 17/2.

The percentage of inundation area for the polder 17/2 at the existing drainage system during the design flood event considering without and with climate change condition is presented in the Table 5-5 and Table 5-6. The Inundation depth map of polder 17/2 for 3-days duration and land class at existing drainage system considering without and with climate change condition for the design flood year is shown in Figure 5.13 and Figure 5.14.

Table 5-5: Inundation depth of Polder 17/2 for design flood event at existing drainage condition

Existing Condition (Inundation depth considering flood event on existing drainage system)	% inundated area							
		F0	F1	F2	F3	F4	Total (%)	Total (%)
	Flood Free	(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	431	126	1085	1237	0	0	557	1642
Percentage (%)	14.96%	4.37%	37.70%	42.97%	0.00%	0.00%	19.33%	57.03%

Table 5-6**:** Inundation depth of Polder 17/2 for design flood event under extreme climate change condition at existing drainage condition

Existing Condition (Inundation depth considering flood event under extreme climate change condition on existing drainage system)	% inundated area							
		F0	F1	F2	F3	F4	Total (%)	Total (%)
	Flood Free	(inundation up to 0.30m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6m)	(FF and F0)	(FF, F0 & F1)
Area (ha)	350	116	617	1796	0	0	466	1082
Percentage (%)	12.16%	4.01%	21.43%	62.40%	0.00%	0.00%	16.17%	37.60%

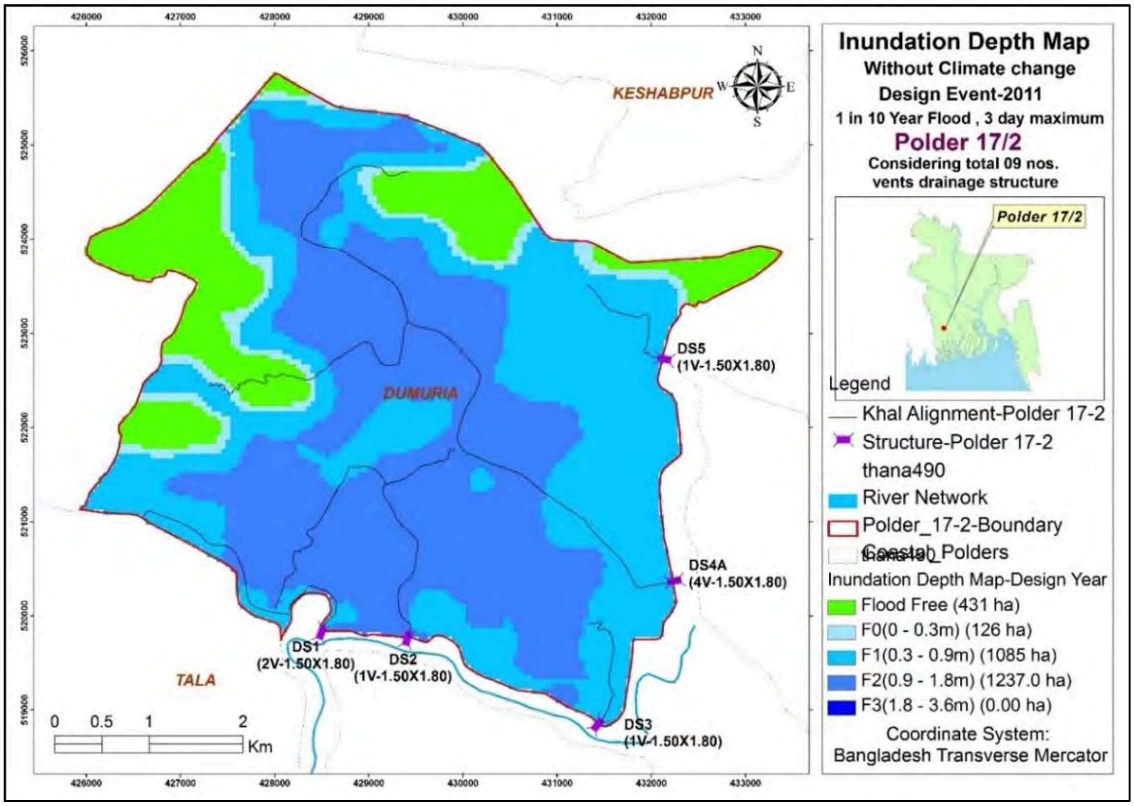


Figure 5.13: Inundation depth map of polder 17/2 for 3-days duration and land class during design year without climate change

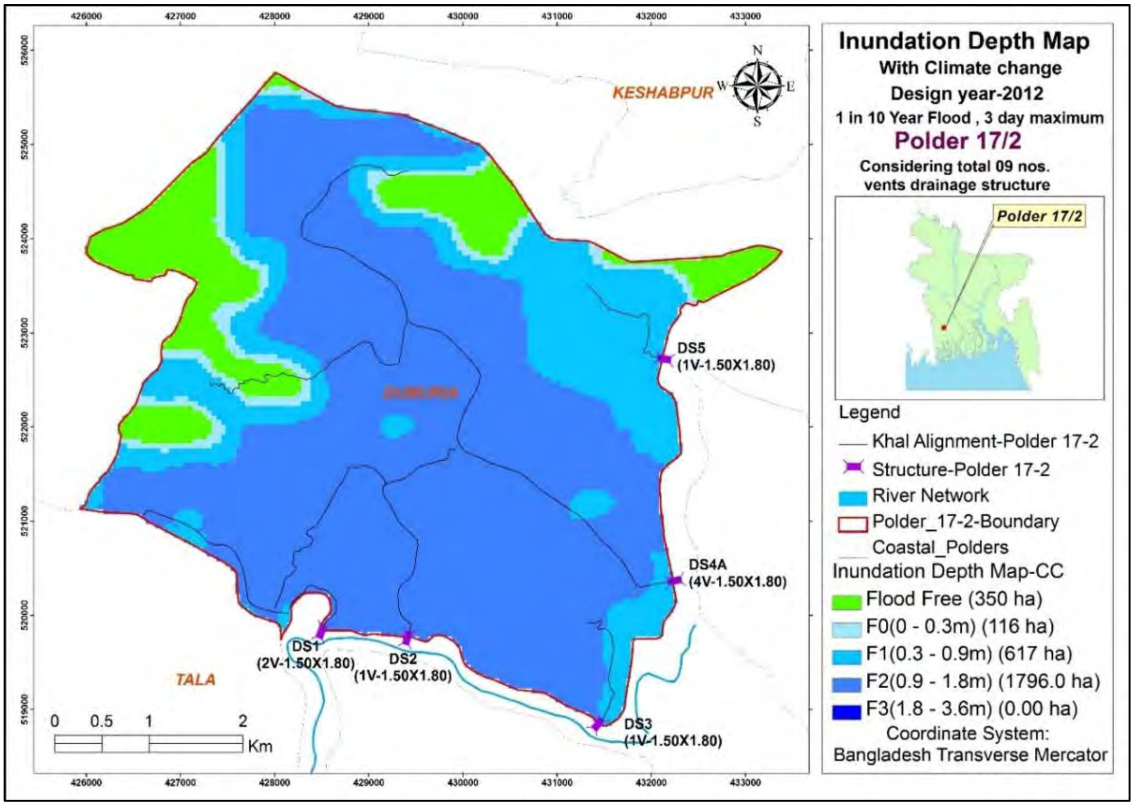


Figure 5.14: Inundation depth map of polder 17/2 for 3-days duration and land class during design year considering with climate change condition

5.4 Assessment of effectiveness of drainage system and Potential Drainage

The polder system facing severe siltation problem which reduces the conveyance of the peripheral rivers and khals, also the internal khals. Then the water level increases due to decrease of river depth. So to make a flood free embankment the crest level needs to increase, it is severe in climate change conditions. However, to lessen the drainage problem in the polders some options has been selected and their effectiveness has been described in this portion.

5.4.1 Improvement Options

The present condition of the selected polders is vulnerable. Many of the hydraulic structures are fully or partially damaged and are non-functioning due to which internal drainage congestion is prevalent. The other structures, though functional, are in an extremely bad condition. The gates are corroded by saline water and concrete surface of the structures are in a very deplorable condition. There are some places where there are existing khals but no drainage structures are present. The internal drainage channels have become silted up due to lack of maintenance for a long time and the bed level of the peripheral rivers has raised due to lack of fresh water from upland and upward movement of sediment from the sea during the flood tide. Considering the drainage problems, climate change issue, water-logging risk reduction an improvement option has been devised in this study. Two options have been tested for the establishment of the final intervention. Potential options have been illustrated in the Table 5-7 and Table 5-8.

Table 5-7: Potential Drainage Improvement Option of Polder 17/1 under Climate Change Scenario (RCP 8.5)

Existing	**Improved Option: Option-1**	**Improved Option: Option-2**	**Final Improved Option: Option-3**
DS-1 (1V-1.5X1.8)	DS-1 (1V-1.50X1.80) (only sill level modified)	DS-1 (2V-1.50X1.80) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-1 (2V-1.50X1.80) (additional 1 no. vent is required for discharging the extra water during peak period)
DS-1A (1V-1.5X1.8)	DS-1A (1V-1.5X1.8) (only sill level modified)	DS-1A (1V-1.5X1.8) (only sill level modified)	DS-1A (1V-1.5X1.8) (only sill level modified)
DS-2 (1V-1.5X1.8)	DS-2 (1V-1.5X1.8) (only sill level modified)	DS-2 (1V-1.5X1.8) (only sill level modified)	DS-2 (1V-1.5X1.8) (only sill level modified)
DS-2A (1V-1.5X1.8)	DS-2A (1V-1.5X1.8) (only sill level modified)	DS-2A (1V-1.5X1.8) (only sill level modified)	DS-2A (1V-1.5X1.8) (only sill level modified)

Existing	**Improved Option: Option-1**	**Improved Option: Option-2**	**Final Improved Option: Option-3**
DS-3 (1V-1.5X1.8)	DS-3 (1V-1.5X1.8) (only sill level modified)	DS-3 (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-3 (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)
DS-4 (1V-1.5X1.8)	DS-4 (1V-1.5X1.8) (only sill level modified)	DS-4 (1V-1.5X1.8) (only sill level modified)	DS-4 (1V-1.5X1.8) (1 no. Pump is required for discharging the extra water during peak period)
DS-5 (1V-1.5X1.8)	DS-5 (1V-1.5X1.8) (only sill level modified)	DS-5 (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-5 (2V-1.5X1.8) (additional 1 no. vent and pump is required for discharging the extra water during peak period)
DS-6 (1V-1.5X1.8)	DS-6 (1V-1.5X1.8) (only sill level modified)	DS-6 (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-6 (2V-1.5X1.8) (additional 1 no. vent and pump is required for discharging the extra water during peak period)
DS-7 (1V-1.5X1.8)	DS-7 (1V-1.5X1.8) (only sill level modified)	DS-7 (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-7 (2V-1.5X1.8) (additional 1 no. vent and pump is required for discharging the extra water during peak period)

Existing	Improved Option: Option-1	Improved Option: Option-2	Final Improved Option: Option-3
DS-8 (1V-1.5X1.8)	DS-8 (1V-1.5X1.8) (only sill level modified)	DS-8 (1V-1.5X1.8) (only sill level modified)	DS-8 (1V-1.5X1.8) (only sill level modified)
DS-8A (1V-1.5X1.8)	DS-8A (1V-1.5X1.8) (only sill level modified)	DS-8A (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-8A (2V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)
Internal Drainage Khal Cross Section	Excavation is made considering the invert level and slope of the khal.	Excavation is made considering the invert level and slope of the khal.	Excavation is made considering the invert level and slope of the khal.
Peripheral River Cross Section	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.

Table 5-8: Potential Drainage Improvement Option of Polder 17/2 under Climate Change Scenario (RCP 8.5)

Existing	Improved Option: Option-1	Improved Option: Option-2	Final Improved Option: Option-3
DS-1 (2V-1.50X1.80)	DS-1 (2V-1.50X1.80) (only sill level modified)	DS-1 (2V-1.50X1.80) (only sill level modified)	DS-1 (2V-1.50X1.80) and Pump (additional 1 no. pump is required for discharging the extra water during peak period)
DS-2 (1V-1.5X1.8)	DS-2 (1V-1.5X1.8)	DS-2 (2V-1.5X1.8)	DS-2 (2V-1.5X1.8) and Pump

Existing	**Improved Option: Option-1**	**Improved Option: Option-2**	**Final Improved Option: Option-3**
	(only sill level modified)	(additional 1 no. vent is required for discharging the extra water during peak period)	(additional 1 no. vent and pump is required for discharging the extra water during peak period)
DS-3 (1V-1.5X1.8)	DS-3 (1V-1.5X1.8) (only sill level modified)	DS-3 (1V-1.5X1.8) (only sill level modified)	DS-3 (1V-1.5X1.8) and Pump (additional 1 no. pump is required for discharging the extra water during peak period)
DS-4A (4V-1.5X1.8)	DS-4A (4V-1.5X1.8) (only sill level modified)	DS-4A (5V-1.5X1.8) (additional 1 no. vent is required for discharging the extra water during peak period)	DS-4A (5V-1.5X1.8) and Pump (additional 1 no. vent and pump is required for discharging the extra water during peak period)
DS-5 (1V-1.5X1.8)	DS-5 (1V-1.5X1.8) (only sill level modified)	DS-5 (1V-1.5X1.8) (only sill level modified)	DS-5 (2V-1.5X1.8) (only sill level modified)
Internal Drainage Khal Cross Section	Excavation is made considering the invert level and slope of the khal	Excavation is made considering the invert level and slope of the khal	Excavation is made considering the invert level and slope of the khal
Peripheral River Cross Section	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.	Excavation/Dredging is made considering the longitudinal slope of the river and sedimentation.

5.4.2 Sill Level Fixation

The invert level/Sill level of the Sluices have been ascertained in the proposed improvement options based on the following criteria;

(i) Average minimum water level of the monsoon period,
(ii) Average ground level of the drainage basin;
(iii) Re-excavated long profile of the drainage channel; and
(iv) Existing sill level.

The area elevation curve for polder 17/1 (Figure 5.15) and polder 17/2 (Figure 5.16) is also followed for the fixation of the invert level of the drainage and flushing sluices.

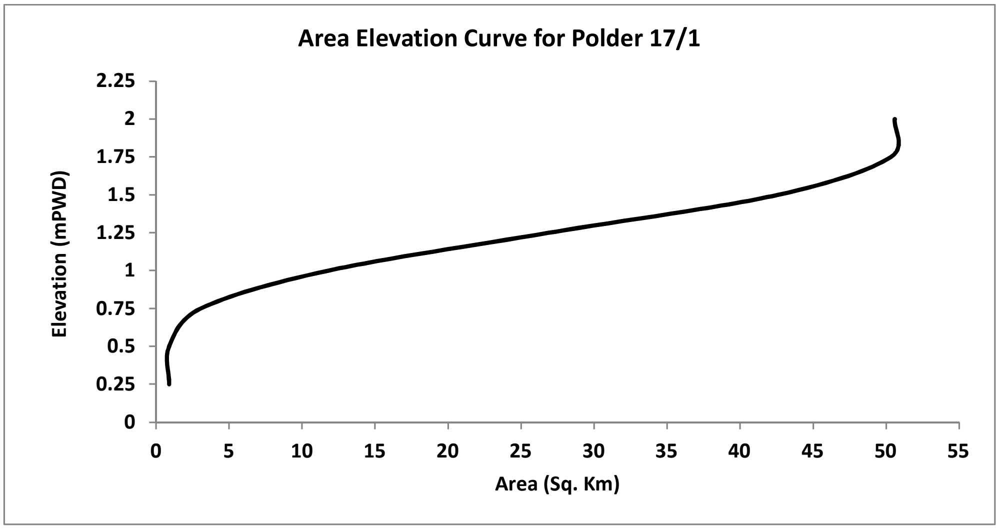


Figure 5.15: Area Elevation curve for polder 17/1

From the area elevation curve, it is seen that most of the area lies into the elevation from 0.50 mPWD to 1.75 mPWD. The lowest water level of the peripheral River also been considered for the fixation of the invert level of the drainage sluices. Considering the above conditions, the invert level of the polder 17/1 has been fixed as -0.50 mPWD.

Most of the area of the polder 17/2 lies into the basin level from 0.60 mPWD to 1.20 mPWD. The lowest tide level of the peripheral and average ground level has also been considered for fixation of the invert level of the water controlling structures. All of the assumptions have been considered for fitting the invert level as 0.0 mPWD.

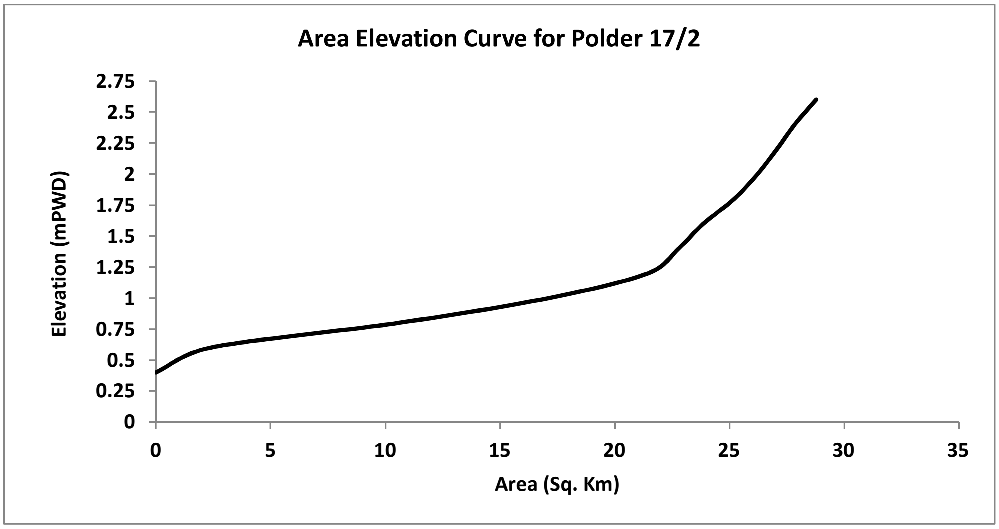


Figure 5.16**:** Area Elevation curve for polder 17/2

Table 5-9: Proposed sill level of the drainage sluices of Polder 17/1

Khal Name	Structure ID	Existing Invert Level (mPWD)	Proposed Sill Level(m PWD)	Name of Outfall River	Lowest Tide Level(mPWD)	Average Elevation around the Structure(mPWD)
Patuvanga khal	DS-1	-1.51	-0.50	Bhadra River	-0.69	0.81
Karamot khal	DS-1A	-1.43	-0.50	Bhadra River	-0.53	0.92
Shibnagar khal	DS-2	-1.80	-0.50	Bhadra River	-0.49	0.58
Golar khal	DS-2A	-2.17	-0.50	Bhadra River	-0.43	0.83
Mandartartala khal	DS3	-1.83	-0.50	Gangrail River	-0.43	0.52
Sundorbunia khal	DS-4	-2.69	-0.50	Taltala River	-0.14	0.95
Andharmanik khal	DS-5	-2.15	-0.50	Salta River	0.12	0.90
Choto-Andharmanik khal	DS-6	-2.12	-0.50	Salta River	0.16	0.98
Hatitana khal	DS-7	-1.71	-0.50	Salta River	0.17	0.68
Berakhali khal	DS-8	-2.08	-0.50	Salta River	-1.38	0.93
Mukho river	DS-8A	-1.78	-0.50	Haria River	-1.71	0.79

Table 5-10**:** Proposed sill level of the drainage sluices of Polder 17/2

Khal Name	Structure ID	Existing Invert Level (mPWD)	Proposed Sill leve (mPWD)	Name of Outfall River	Lowest Tide Level (mPWD)	Lowest Elevation of Basin (mPWD)
Golabda Khal	DS-1	-2.334	-0.5	Taltola River	0.056	0.90
Changamari khal	DS-2	-1.57	-0.5	Taltola River	0.009	1.15
Nikramari Khal	DS-3	-2.68	-0.5	Taltola River	-0.138	1.32
Gangrail Khal	DS-4A	-2.164	-0.5	Gangrail River	-0.358	1.36
Talighati Khal	DS-5	-2.555	-0.5	Gangrail River	-0.356	0.67

5.4.3 Dredging/ Re-excavation of Peripheral Rivers/Khals

The overall peripheral river network of the study area has been silted up due to reduction of fresh water flow from upstream and upward movement of tidal water during flood tide, raise the bed level of the surrounding rivers. The critical silted up stretches of Bhadra, Upper Bhadra, Teka Hari Teli Gang, Haria, Gunkhali and peripheral khal of the selected polders need to be excavated to increase the drainage capacity. Drainage improvement measures by re-excavation of internal drainage khals, increase number of vents of the existing drainage structures will not be effective unless the outfall Rivers are made smoothly functional by dredging or excavation.

5.4.4 Re-excavation of Internal Drainage khals

About 33 numbers of internal drainage channels have been excavated by 1m in order to accelerate smooth drainage of the polder area. The channels are excavated by adjusting the invert level of the drainage sluices. Most of the khals have been silted up due to lack of re-excavation works under periodic maintenance. So, all the major and minor internal khals have been proposed for re-excavation to increase drainage and storage facility. The list of khals proposed for re-excavation in Polder-17/1 and polder 17/2 have been furnished in the Table 5-11. The water level condition at the upstream of Andharmanik khal in polder 17/1 and at Changamari khal in polder 17/2 during the dredging condition is shown in Figure 5.17 and Figure 5.18 respectively.

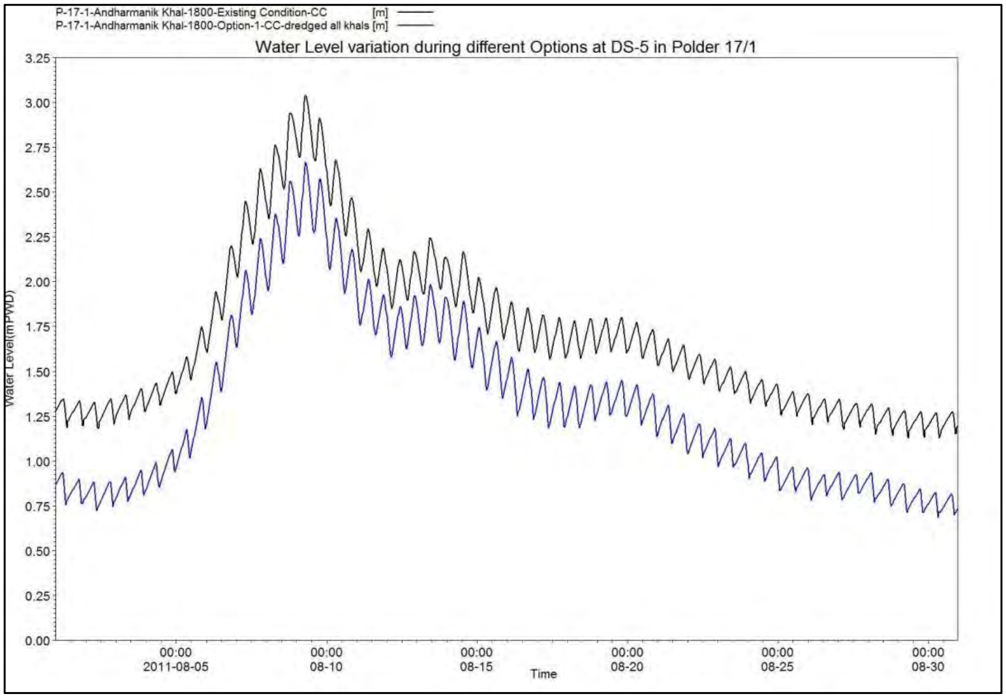


Figure 5.17: Water level condition at Andharmanik Khal in Polder 17/1 during Option-1

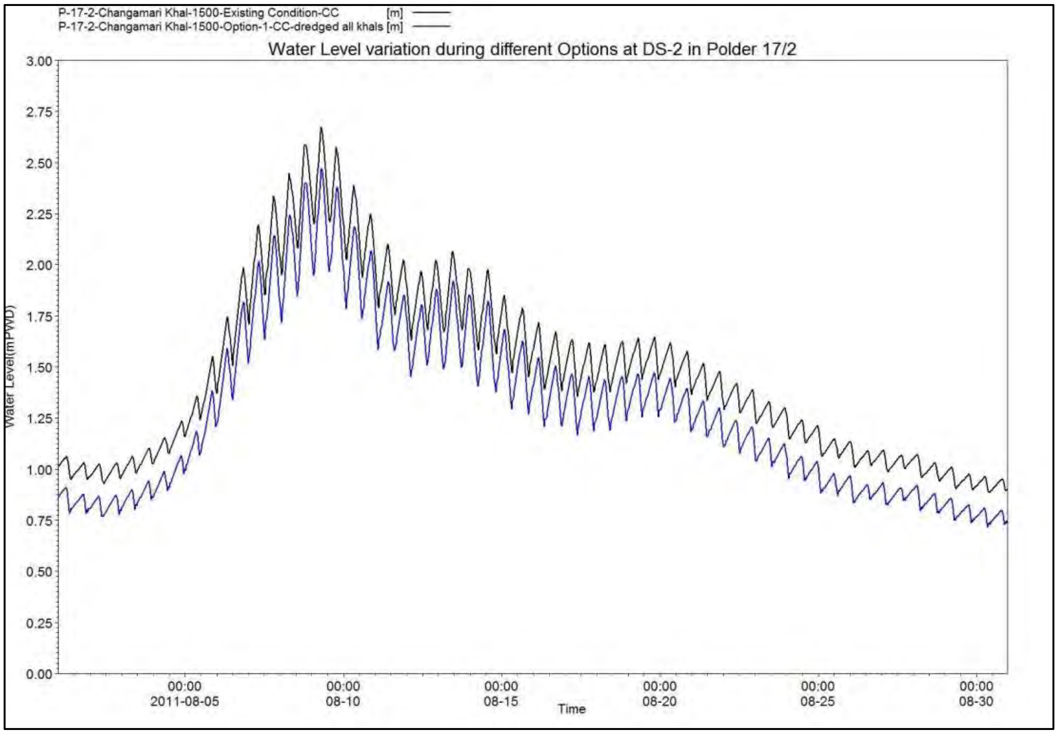


Figure 5.18: Water level condition at Changamari Khal in Polder 17/2 during Option-1

Table 5-11: List of khals proposed for re-excavation khals of Polder 17/1 and 17/2

Serial no.	Drainage khals	Khal Length , m	Upstream connection name	Upstream connection chainage	Downstream connection name	Downstream connection chainage
1	P-17/1 Andharmanik khal	1997			P-17/1-Peripheral khal	9002
2	P-17/1 Belar khal	902			P-17/1-Patuvanga khal	0
3	P-17/1 Berakhali khal	3599	P-17/1-Mukho river	1733	P-17/1-Peripheral khal	20682
4	P-17/1-Boaria Khal1	872			P-17/1 Andharmanik khal	0
5	P-17/1-Boaria Khal2	830			P-17/1 Andharmanik khal	0
6	P-17/1- Boroshinger khal	666			P-17/1-Shibnagar khal branch	349
7	P-17/1- Chitramari khal	886	P-17/1-Hatitana Khal-2	1220	P-17/1-Soto-Andarmanik khal	1170
8	P-17/1-Golar khal	1126			Teka-Hari-Teli-Geng	35364
9	P-17/1-Golar khal branch	1580			P-17/1-Golar khal	855
10	P-17/1-Gorunia khal	2480			P-17/1-Patuvanga khal	0
11	P-17/1-Hatitana khal-1	5346	P-17/1-Hatitana Khal-2	1351	P-17/1-Peripheral khal	18242
12	P-17/1-Hatitana khal-2	1351				
13	P-17/1-Karamot khal	1754	P-17/1-Patuvanga khal	2252	Teka-Hari-Teli-Geng	40759
14	P-17/1-Mandartartala khal	3657			Teka-Hari-Teli-Geng	32764

15	P-17/1-Mukho river	6158			P-17/1-Peripheral khal	21914
16	P-17/1-Padumanir khal	1287			P-17/1-Mandartartala khal	3290
17	P-17/1-Patuvanga khal	4481			Teka-Hari-Teli-Geng	43193
18	P-17/1-Peripheral khal	23500	Teka-Hari-Teli-Geng	26740	P-17/1-Peripheral khal south	0
19	P-17/1-Peripheral khal south	2000			Teka-Hari-Teli-Geng	43619
20	P-17/1-Shibnagar khal	2887			Teka-Hari-Teli-Geng	39020
21	P-17/1-Shibnagar khal branch	1060			P-17/1-Shibnagar khal	1637
22	P-17/1-Shimanar khal	1566			P-17/1-Patuvanga khal	1920
23	P-17/1-Shrikhalir khal	1122			P-17/1-Patuvanga khal	2105
24	P-17/1-Soto-Andarmanik khal	3566			P-17/1-Peripheral khal	14030
25	P-17/1-Soto-Andarmanik khal branch	1292	P-17/1-Hatitana Khal-2	235	P-17/1-Soto-Andarmanik khal	241
26	P-17/1-Sundorbounia khal	1577			P-17/1-Peripheral khal	3232
27	P-17/2-Arua khal	3231			P-17/2-Gangrail khal	3850
28	P-17/2-Changamari khal	1974	P-17/2-Arua khal	2358	P-17/1-Peripheral khal	4548
29	P-17/2-Gangrail khal	6748			Teka-Hari-Teli-Geng	26450
30	P-17/2-Golabda khal	1200			P-17/1-Peripheral khal	5542
31	P-17/2-Nikramari khal	1529			P-17/1-Peripheral khal	2342
32	P-17/2-Shitla khal	3091			P-17/2-Gangrail khal	1966
33	P-17/2-Taligati khal	1511			Teka-Hari-Teli-Geng	24000

5.4.5 Construction of New or Additional Water Control Structures

Many of the hydraulic structures are fully or partially damaged and are non-functioning due to deplorable condition of the existing sluices. The other structures, though functional, are in an extremely bad condition. From the inundation depth analysis, it is seen that the selected drainage sluices (DS-3, DS-4, DS-5, DS-6, DS-7, and DS-8A) of polder 17/1 and the selected water control structures of polder 17/2 (DS-2 and DS-4A) are not able to drain the additional amount of water at the extreme climate change condition. So, in the potential improvement option, one additional vent is required for facing the future climate condition. One drainage sluice with an additional vent may be constructed on the diversion channel of the existing drainage sluice. In the improved option-2, dredging of internal drainage channels and additional vent as per requirement have been applied to assess the water level condition. The water level condition at the combined effects on the upstream of Andharmanik khal in polder 17/1 and at Changamari khal in polder 17/2 is shown in Figure 5.19 and Figure 5.20 respectively.

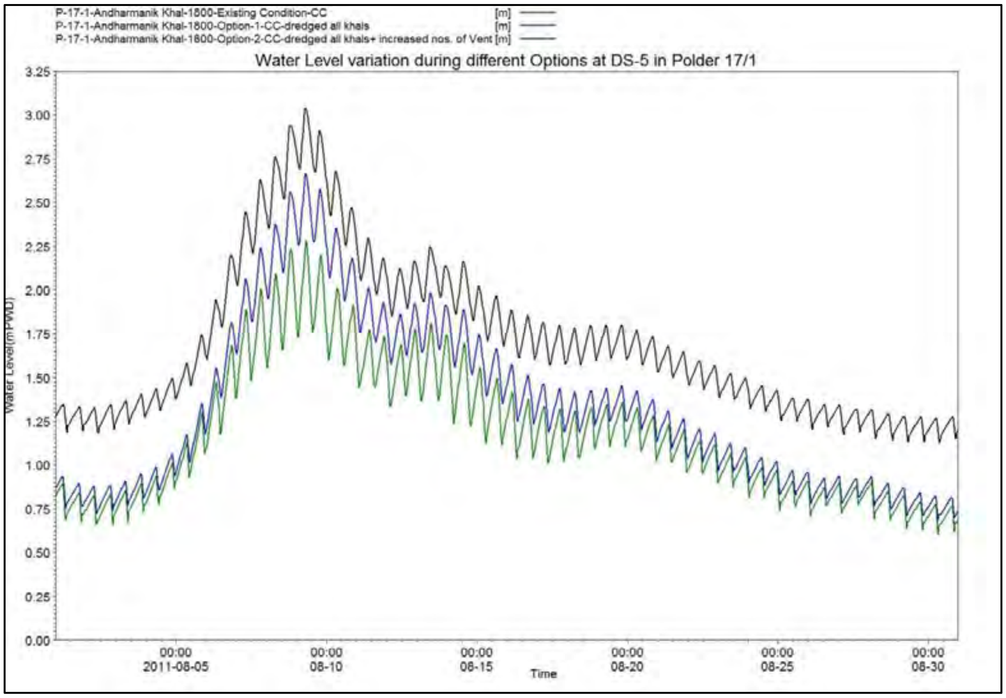


Figure 5.19: Water level condition at Andharmanik Khal in Polder 17/1 during Option-2

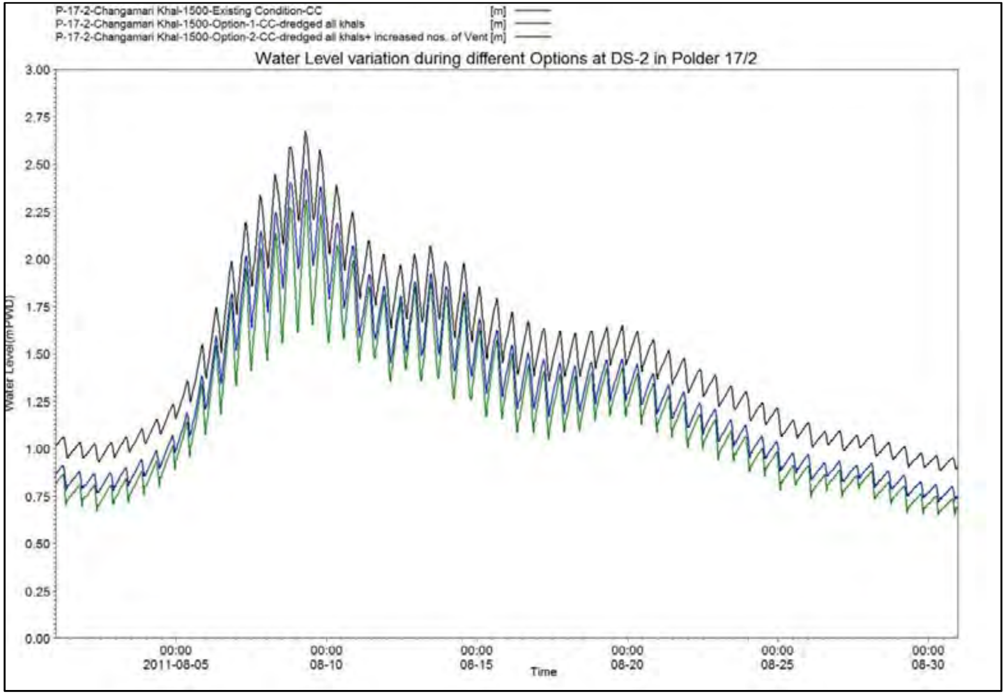


Figure 5.20: Water level condition at Changamari Khal in Polder 17/2 during Option-2

5.4.6 Supplementary Pump System

The long-term effectiveness of the drainage system would depend on projected climate change effects including sea level rise and precipitation changes as well as the expected rate of ground level subsidence. There is a possibility that the polder lands will become permanently waterlogged at some time in the future. Gravity driven drainage will remain viable only if one can raise the land level within the polder to keep up with sea level rise or the bed level of the peripheral River raise due to high sedimentation. The use of supplementary pumps to assist drainage, even as an interim solution is an alternative that must also be investigated. This is very easy to study using the available polder drainage models.

In this study, four numbers of supplementary pump at DS-4, DS-5, DS-6 and DS-7 in polder 17/1 and four nos. at DS-1, DS-2, DS-3 and DS-4A in polder 17/2 is used to reduce the inundation depth. The pumps used were identical units each with capacity (5 m3/s) which would switch on when the upstream (inside polder) water level exceeds 1.0 mPWD and switch off when the level falls to 0.5 mPWD. In the final improved option (Option: 3) supplementary pump is used where gravitational drainage is not perform well. The water level condition after applying the pump with adding the number of vent under the dredging condition at the Andharmanik khal in polder 17/1 and the Changamari khal in polder 17/2 has been presented in the Figure 5.21 and Figure 5.22.

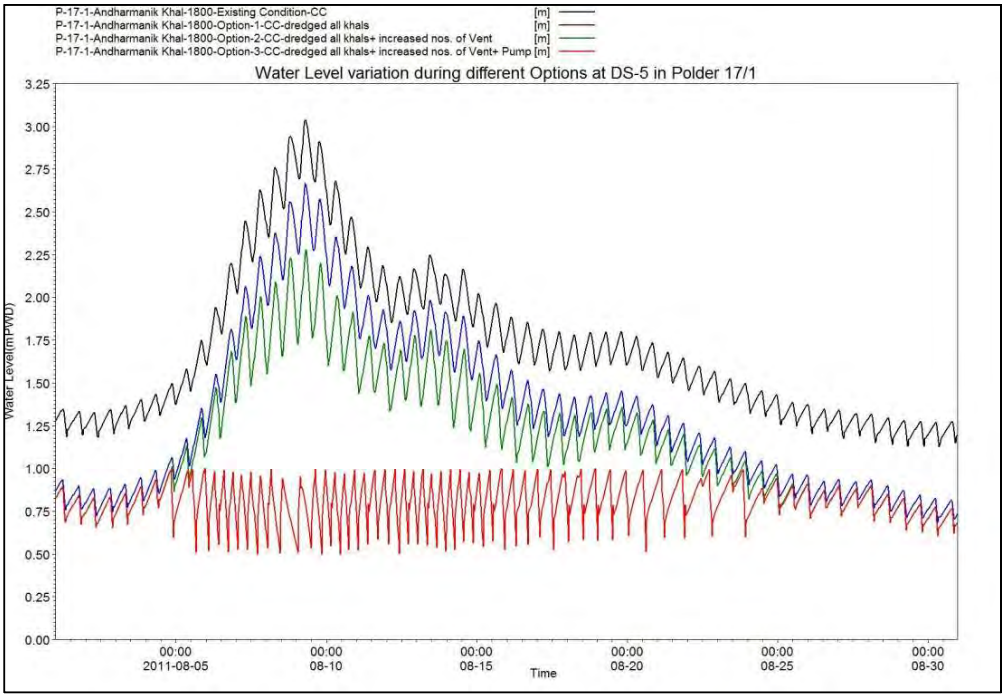


Figure 5.21: Water level condition at Andharmanik khal in polder-17/1 during Option-3

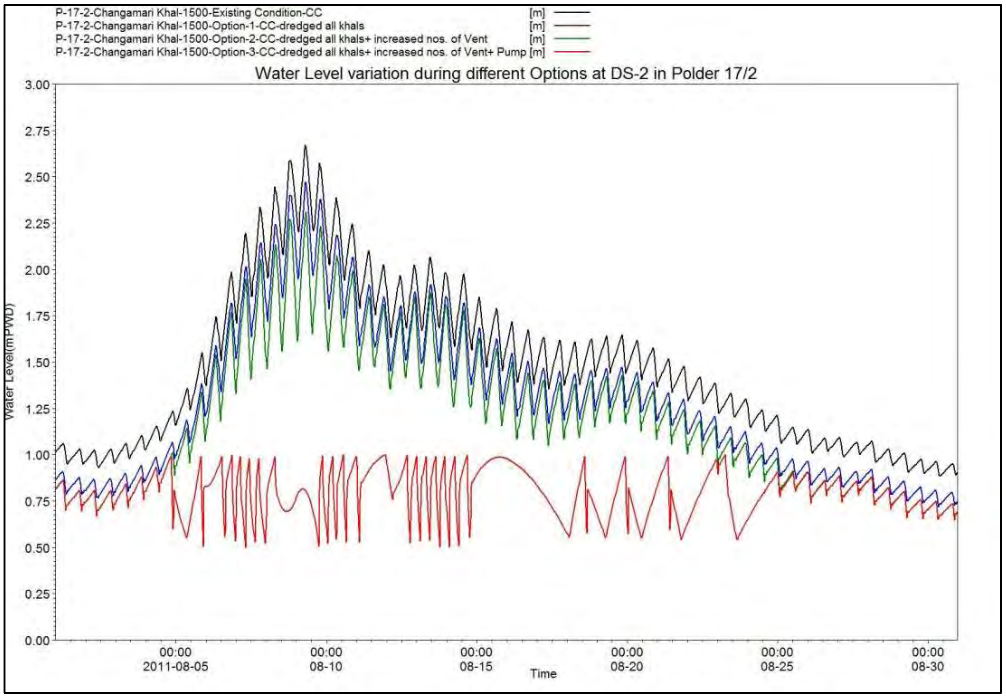


Figure 5.22: Water level condition at Changamari khal in polder-17/2 during Option-3

5.4.7 Effectiveness of Drainage Improvement Options

The drainage performance/effectiveness of all option are evaluated in terms of decrease of flood, inundation area and depth of the polder area (land classification) compared to the existing condition. It is essential to determine the proposed drainage improvement plan to find out whether the study area can be drained within three days through the drainage system to save the agricultural crops and to avoid the prolong water-logging. This investigation is made by preparing flood inundation depth maps for 3-day duration maximum water level showing the area of different land classes (F0, F1, F2, F3 and F4) using model results and available Digital Elevation Model (DEM) of the study area. Analysis has been made for three improved options. Final proposed options (option-3) is devised for both older based on the inundation result of option-1 and option-2.

5.4.8 Improvement Option for Polder 17/1: Option-1 and Option-2

Modification of invert level of drainage sluices and dredging of drainage channels and peripheral rivers are included into the intervention of option-1. Inundation depth has generated for 3days maximum water level. Based on the inundation depth map, remodelling/ increase number of vents is added as an additional input intervention parameter into the improved option-1 for developing the improvement option-2. The percentage of inundation based on different class for the projected improved option-1 and option-2 of polder 17/1 is shown in Table 5-12. The potential improved option-1 and option-2 for polder 17/1 is presented in the Figure 5.23 and Figure 5.24 respectively.

In the improved option, about 22.50% (option-1) and 28.38% (option-2) area remains flood free (i.e., inundation up to 0.3 m depth of water) which is about 17.26% in the existing condition. These percentage of land is suitable for people movement, agricultural production. About 43.27% (option-1) and 52.49% (option-2) area lies in between the water depth 0.30m to 0.90m which is about 37.09% in the pre-present condition. It indicates that about 34.23% and 19.14% land exists in the deeply inundation depth (water depth >0.90m) in the improved option-1 and improved option-2 respectively. The overall agricultural production land including fish culture (Gher) increases from 54.35% (existing condition) to 65.77% and 80.85% in option-1 and Option-2 respectively (Table 5-12).

Table 5-12: % of inundation depth for polder 17/1 in option-1 and option-2

Existing Condition and Potential Improved Options under climate change condition	% Inundated Area of Polder 17/1							
		F_0	F_1	F_2	F_3	F_4	Total (%)	Total (%)
	Flood Free	(inundation up to 0.3m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6 m)	(FF and F0)	(FF, F0 & F1)
Existing Condition	1.40%	15.86%	37.09%	23.19%	22.46%	0.00%	17.26%	54.35%
Option -1	1.61%	20.89%	43.27%	31.44%	2.79%	0.00%	22.50%	65.77%
Option -2	5.53%	22.85%	52.49%	17.67%	1.47%	0.00%	28.37%	80.86%

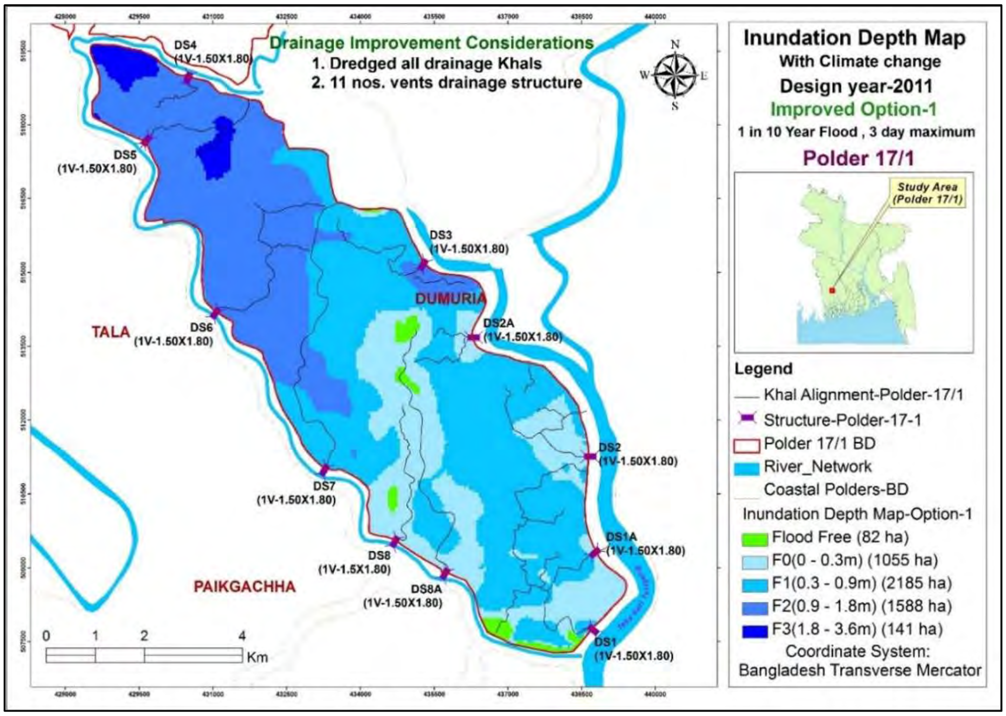


Figure 5.23: Inundation depth map for polder 17/1 under improved option-1

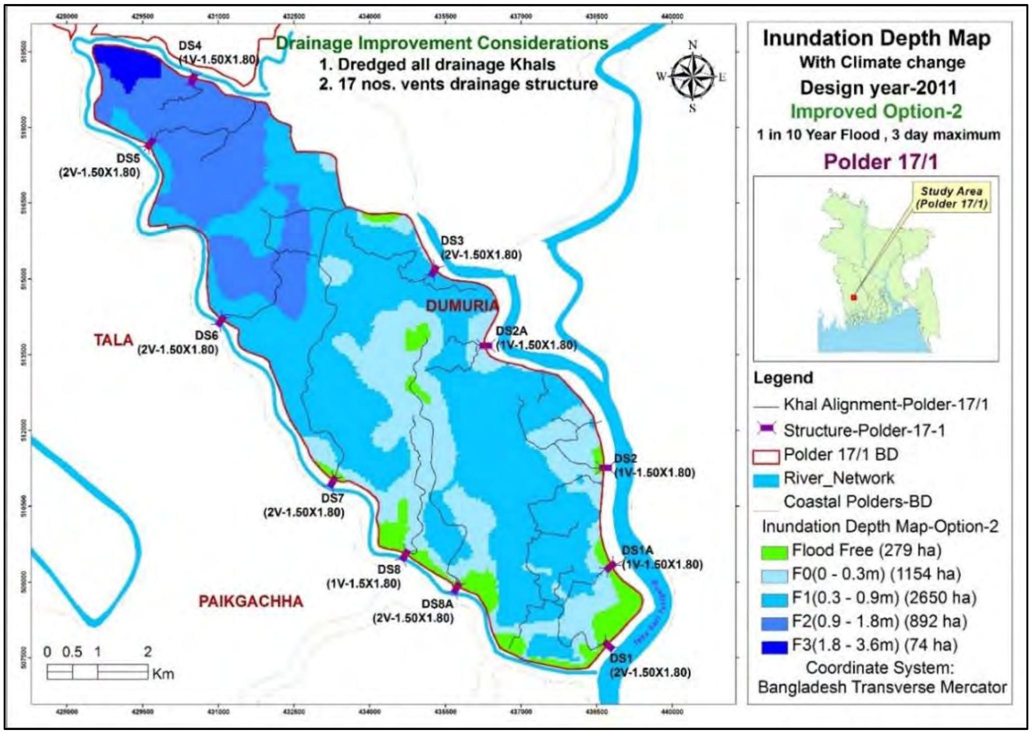


Figure 5.24**:** Inundation depth map for polder 17/1 under improved option-2

5.4.9 Proposed Improvement Option for Polder 17/1: Option-3

Four types of intervention have taken for developing the proposed final improvement option-3. Dredging of all drainage channels, Peripheral River, modification of invert level/added additional vent and supplementary pumping system has applied in an integrated way. Figure 5.25 shows the proposed intervention for polder 17/1.

Figure 5.26 shows the water level difference at upstream and downstream of drainage sluice DS-5. The Figure 5.26 indicates when the head difference occurs then the additional amount of water is discharge by the drainage sluice DS-5. Water is only discharge during the ebb tide period. Water is not discharging full time of the ebb period. Figure 5.27 shows the discharge hydrograph at existing condition and proposed improved condition in drainage sluice DS-5.

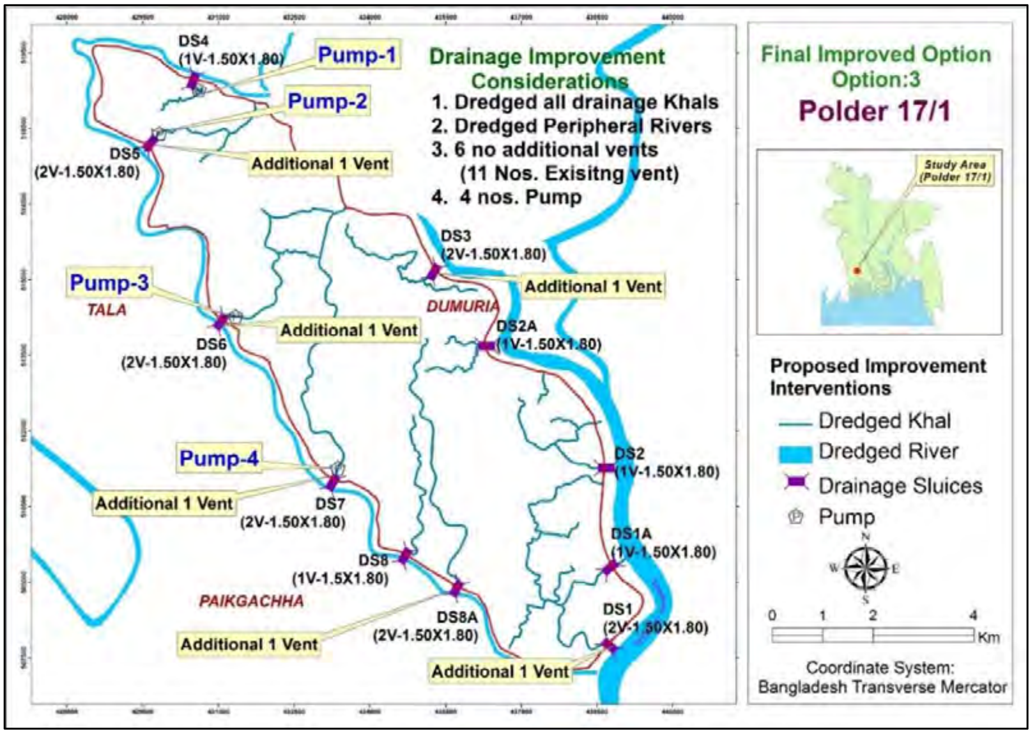


Figure 5.25: Proposed improvement interventions map for polder 17/1

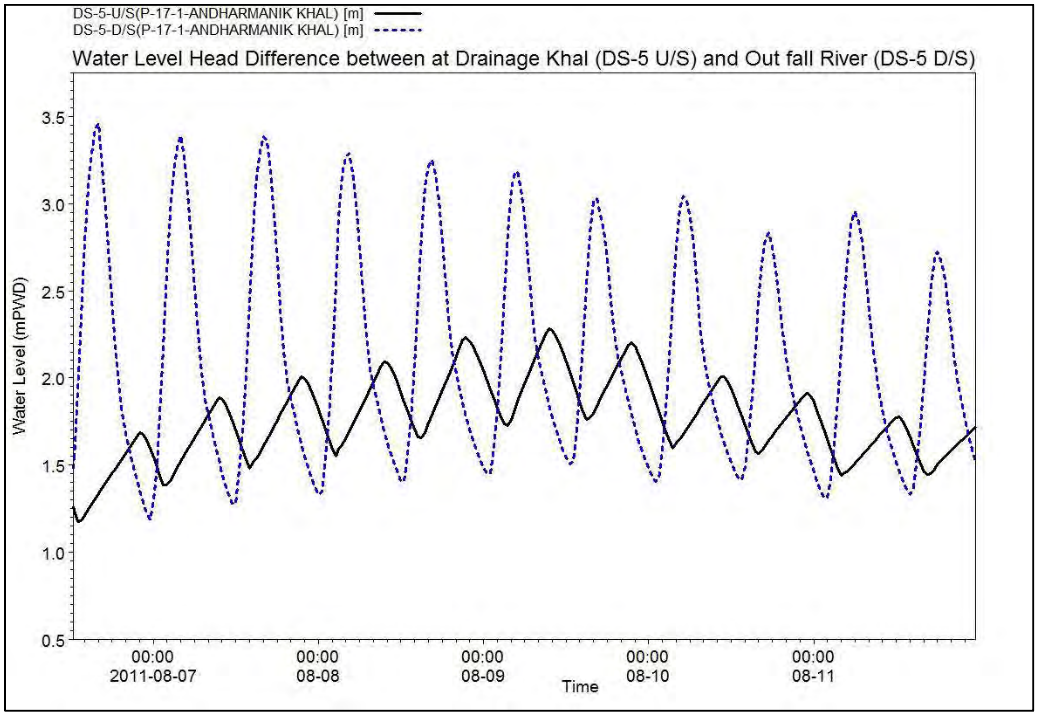


Figure 5.26: U/S and D/S water level head difference at DS-5 in polder 17/1

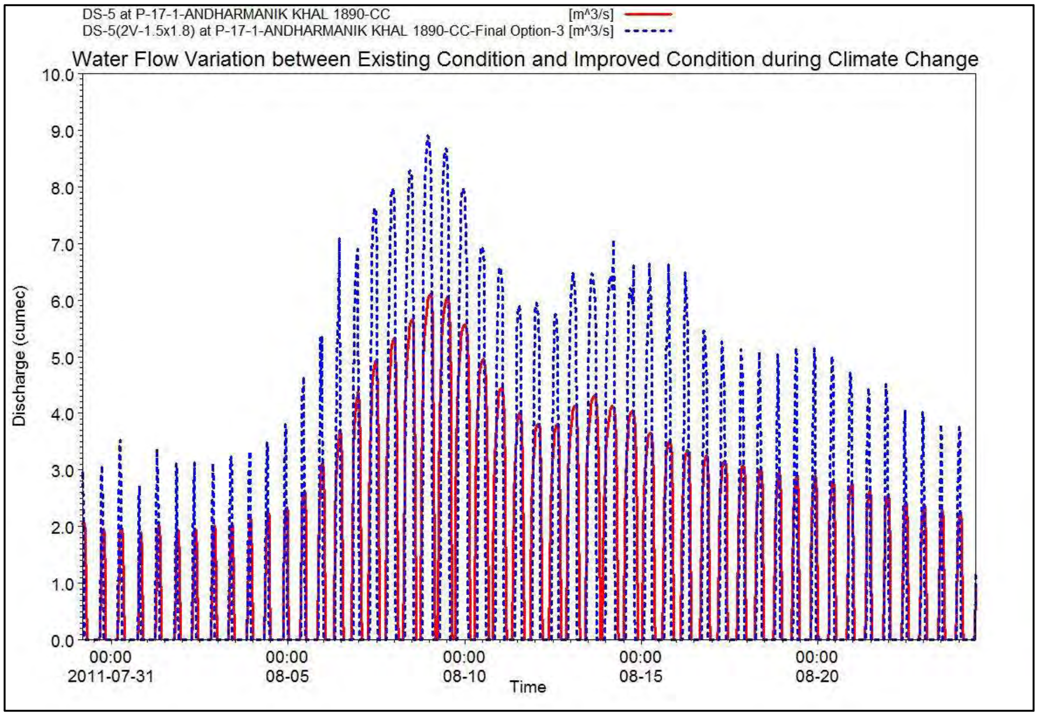


Figure 5.27: Discharge additional amount of water at DS-5 in polder 17/1 during proposed improved option

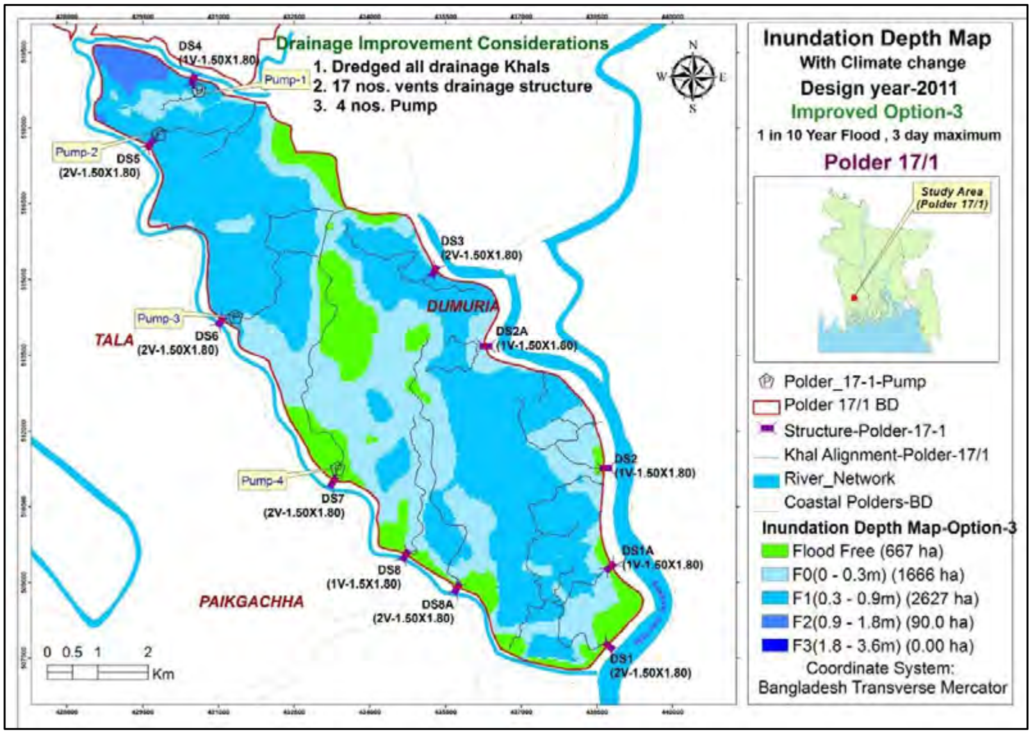


Figure 5.28: Inundation depth map for polder 17/1 under proposed improved option-3

Table 5-13: % of inundation under the proposed final improved option of polder 17/1

Existing Condition and Potential Improved Options under climate change condition	% Inundated Area of Polder 17/1							
	Flood Free	F_0	F_1	F_2	F_3	F_4	Total	Total
		(inundation up to 0.3m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6 m)	(FF and F0)	(FF, F0 & F1)
Existing Condition	1.40%	15.86	37.09%	23.19%	22.46%	0.00%	17.26%	54.35%
Option -1	1.61%	20.89	43.27%	31.44%	2.79%	0.00%	22.50%	65.77%
Option -2	5.53%	22.85	52.49%	17.67%	1.47%	0.00%	28.37%	80.86%
Option-3	13.21%	32.98	52.03%	1.77%	0.00%	0.00%	46.20%	98.23%

Table 5-13 shows the percentage of inundation for existing condition and proposed improvement options. It is seen that about 46.20% area remains flood free (i.e., flood free and F0 land class) which is about 22.50% in the projected option-1 and 28.37% during the proposed improved option-2. The percentage of Inundation area (inundation depth 0.30m to 0.90m) remain increases from 37.09% (existing condition) to 43.27% (option-1), 52.49% (option-2) and 52.03% (option-3) In the improved option it is seen that about 98.23% land becomes productive for people movement and agricultural production and fish culture. About 46.20% land area is suitable for people movement and agricultural production.

Total inundation area (inundation depth >0.90m) decreases from 46.56% in the pre-study condition to 34.23% and 19.14% in the proposed drainage improvement option-1 and option-2 respectively. The total deeply inundation area decreases to about 1.77% in the final improved option (option-3) (Figure 5.29).

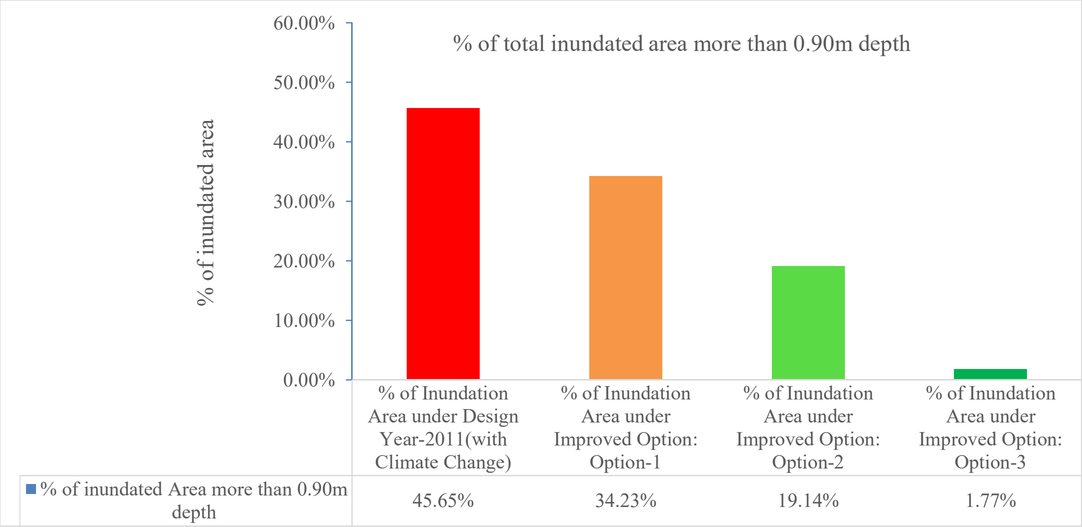


Figure 5.29: % of inundation area more than 0.90m depth in polder 17/1 for all options

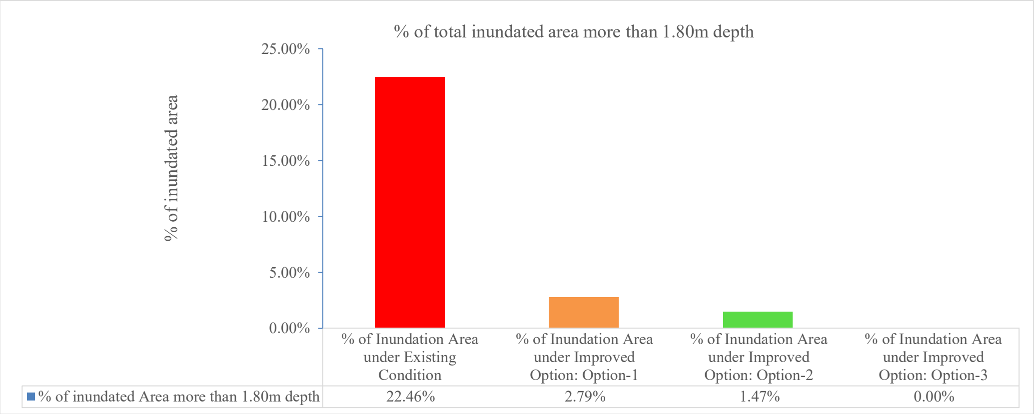


Figure 5.30: % of inundation area more than 1.80m depth in polder 17/1 for all options

It is seen (Figure 5.30) that about 22.46% areas is likely to be flooded by more than 1.80 m depth under existing condition which seems to be reduced to only 2.79% and 1.49% under the proposed drainage improvement option 1 and 2 respectively. There is no deeply inundation (inundation depth > 1.80m) in the final improved option (option-3).

5.4.10 Improvement Option for Polder 17/2: Option-1 and Option-2

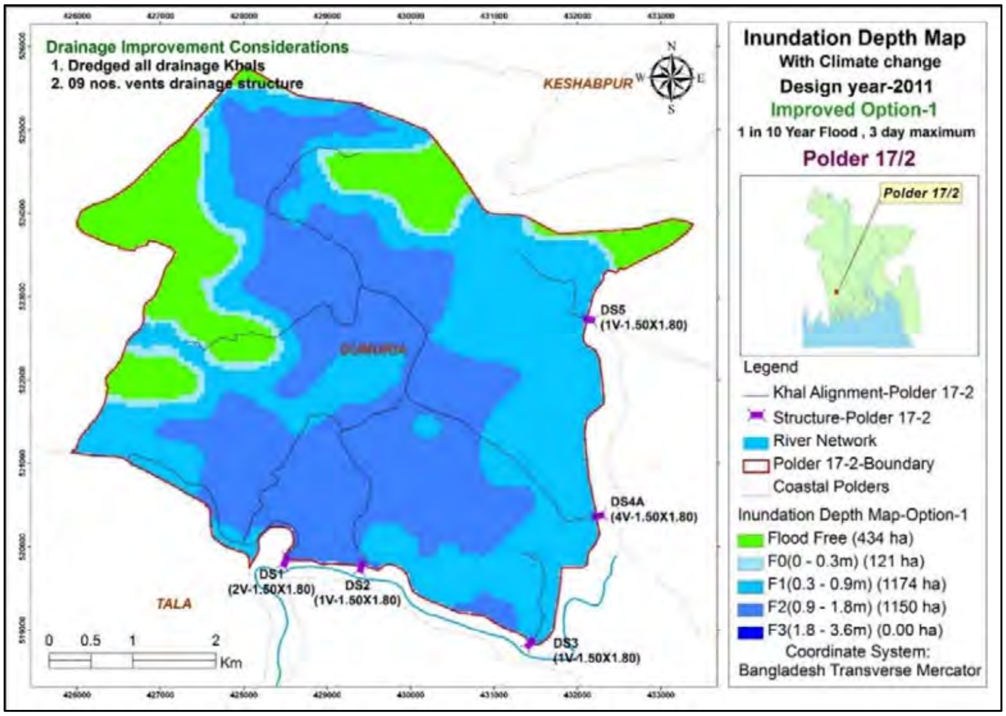


Figure 5.31: Inundation depth map for polder 17/2 under improved option-1

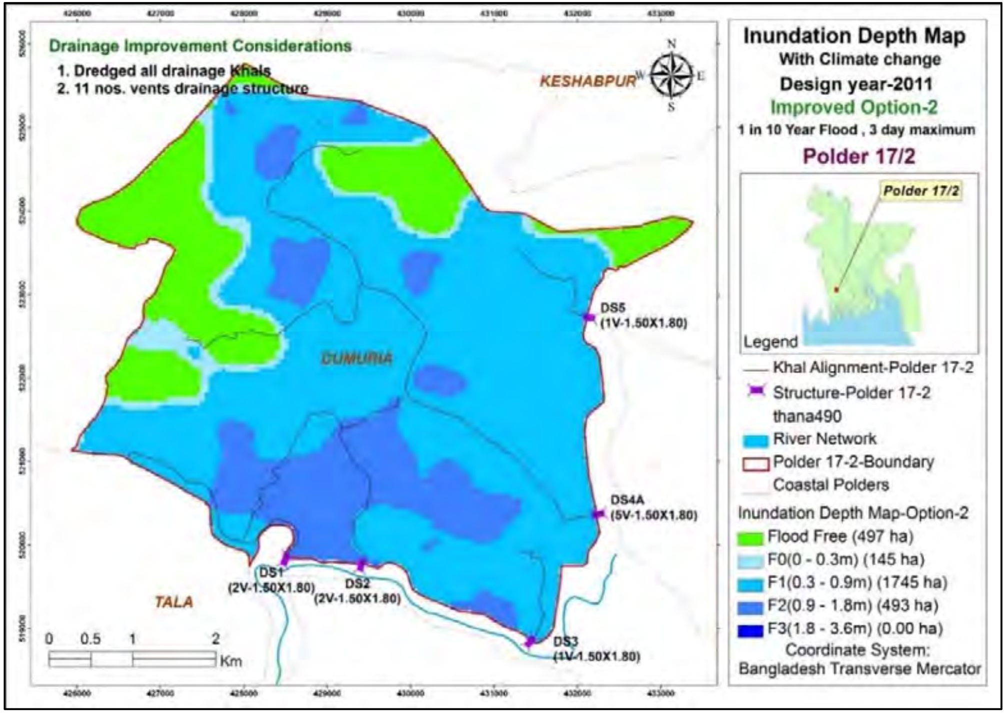


Figure 5.32: Inundation depth map for polder 17/2 under improved option-2

Table 5-14: % of inundation depth for polder 17/2 in option-1 and option-2

Existing Condition and Potential Improved Options under climate change condition	% Inundated Area of Polder 17/2							
		F_0	F_1	F_2	F_3	F_4	Total	Total
	Flood Free	(inundation up to 0.3m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6 m)	(FF and F0)	(FF, F0 & F1)
Existing Condition	12.16%	4.01%	21.43%	62.40%	0.00%	0.00%	16.17%	37.60%
Option -1	15.07%	4.19%	40.78%	39.96%	0.00%	0.00%	19.26%	60.04%
Option -2	17.25%	5.02%	60.60%	17.13%	0.00%	0.00%	22.27%	82.87%

Comprehensive analysis of model results has been made to assess the improvement of inundation area. From the Table 5.14 it is seen that the flood free area considering the people movement and agricultural production (inundation depth up to 0.30m) increases from 16.17% (existing condition) to 19.26% (option-1) and 22.27% (option-2). These percentage presents free movement of local people and suitable for agricultural production. The area under flood free and F1 (0.3m to 0.9m) for 3-hours under the option-1(40.78%) and option-2(60.60%) where at the existing condition which is 21.43%. The higher value of F1 land indicates reduction of F2 and F3 land. Deeply inundation area, i.e., F2 land (0.9m to 1.8m) reduces from 62.40% (existing condition) to 39.96% in option-1 and 17.13% in option-2. There is no inundation in the land class F3 (1.8m to 3.6m) and F4 (> 3.6m). Table 5-14 shows the inundated area at different inundation depth of 6 hours duration for existing and drainage improvement options (Option-1 and Option-2).

5.4.11 Proposed Improvement Option for Polder 17/2: Option-3

Option-3 is considered as a final proposed condition. Dredging of all drainage channels, peripheral River, remodelling of drainage sluices including addition of new vent and modification of invert level, addition of supplementary pumping system as per requirement is considered for developing the proposed improved option: option-3. The considerations are included in the Figure 5.33.

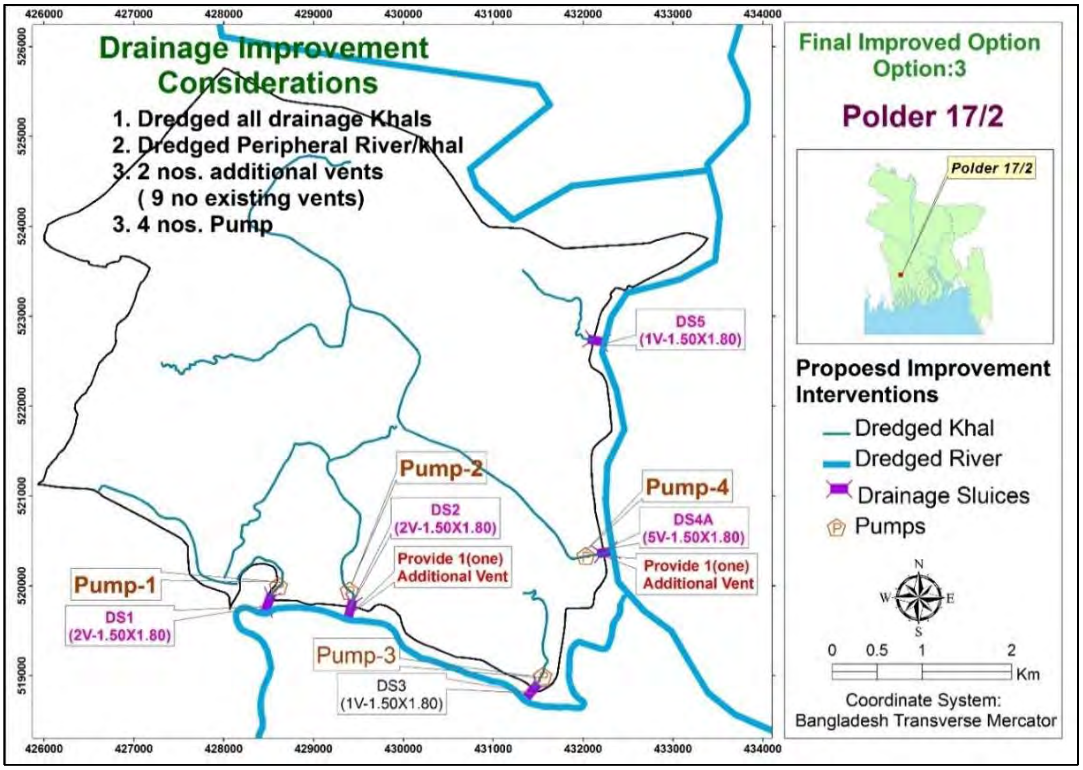


Figure 5.33: Proposed improvement interventions map for polder 17/2

The amount of water discharge through the drainage sluices depends on the upstream and downstream water level of the khal and river. The water is discharge when the water level of the khal is higher than the water level of the river. A typical water level hydrograph at drainage sluice DS-2 in polder 17/2 is presented in the Figure 5.34. However, the water is only discharge when ebb tide occurs. The changes of discharge at DS-2 during the proposed improved option (option-3) and existing condition is shown in Figure 5.35.

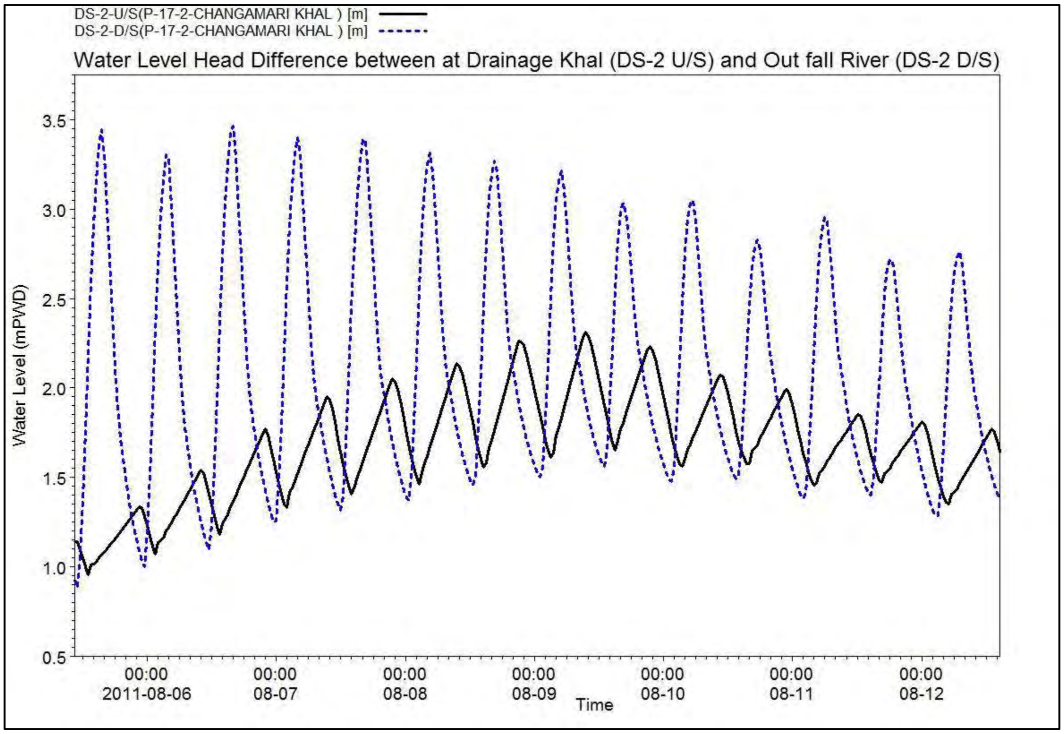


Figure 5.34: U/S and D/S water level head difference at DS-2 in polder 17/2

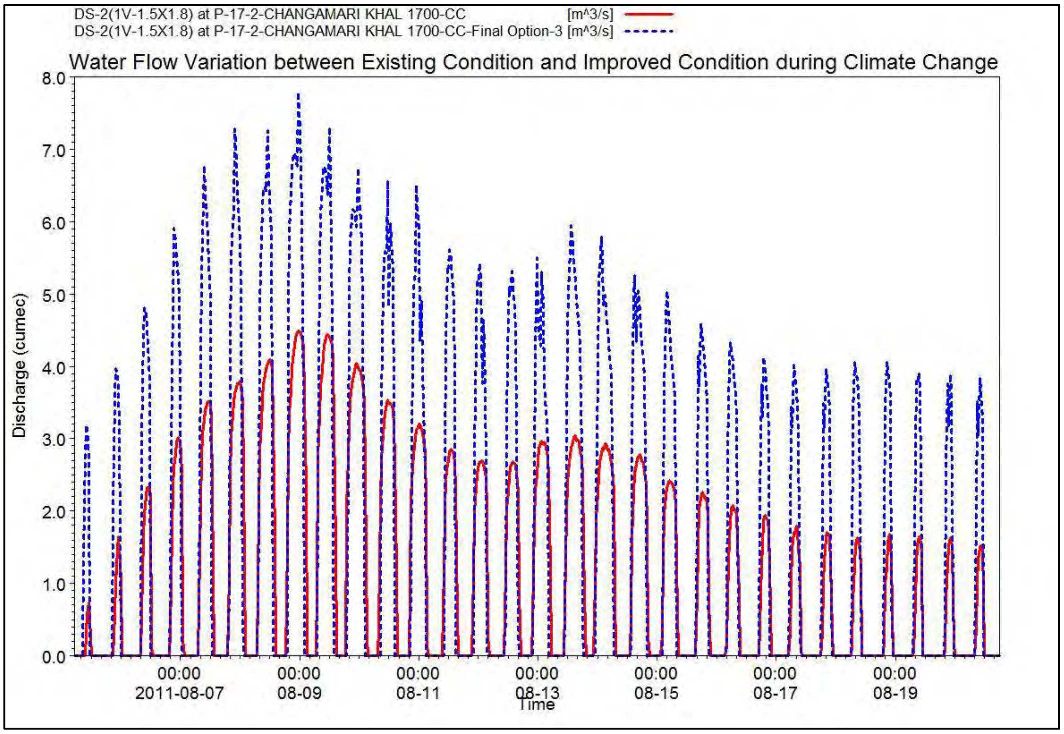


Figure 5.35: Discharge additional amount of water at DS-2 in polder 17/2 during proposed improved option

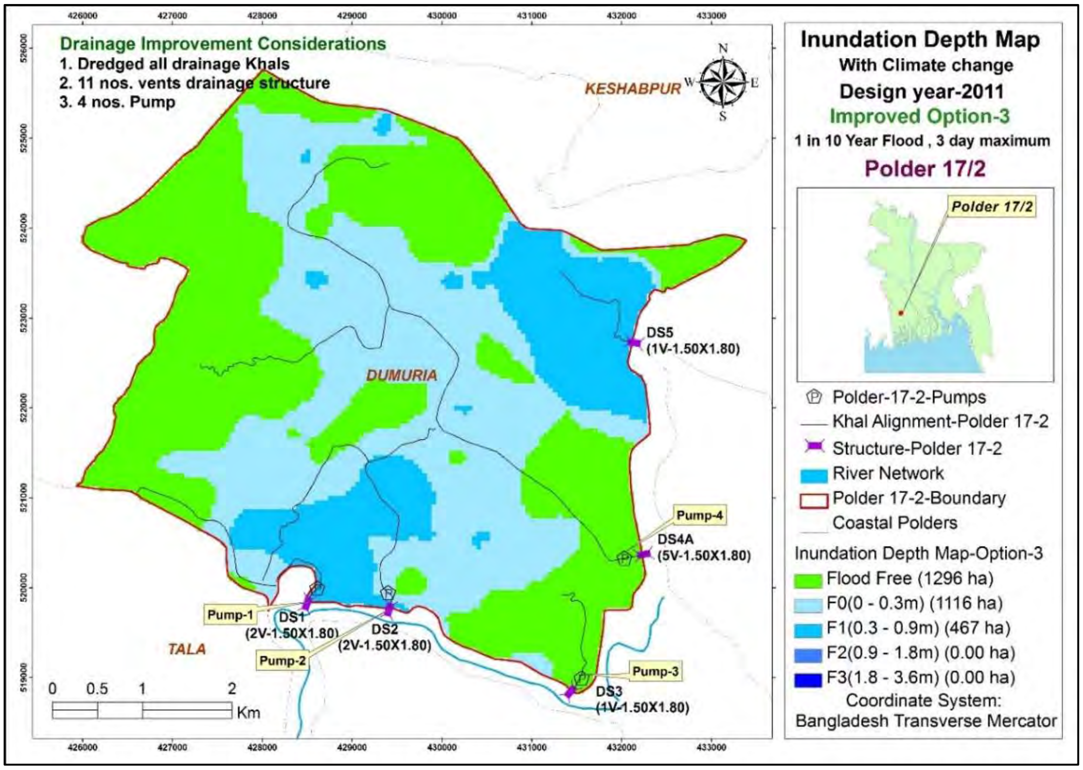


Figure 5.36: Inundation depth map for polder 17/2 under proposed improved option-3

From the Table 5-15 it is seen that the flood free area (inundation depth up to 0.30m) increases from 16.17 % (existing condition) to 83.78% in the final improved option (option-3). A significant improvement has been made by using supplementary pumping system. The inundation area including F1 land class in the improved option-3 is found about 100% whereas it is 37.60% in existing condition, 60.04% in option-1, 22.27% in option-2. There is no deep inundation in the final improved option. Table 5-15 shows the inundated area at different inundation depth of 6 hours duration for existing and final drainage improvement option (option-3) with the improved option-1 and Option-2.

Table 5-15: % of inundation under the proposed final improved option of polder 17/2

Existing Condition and Potential Improved Options under climate change condition	% Inundated Area of Polder 17/2							
	Flood Free	F_0	F_1	F_2	F_3	F_4	Total	Total
		(inundation up to 0.3m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6 m)	(FF and F0)	(FF, F0 & F1)
Existing Condition	12.16%	4.01%	21.43%	62.40%	0.00%	0.00%	16.17%	37.60%
Option -1	15.07%	4.19%	40.78%	39.96%	0.00%	0.00%	19.26%	60.04%
Option -2	17.25%	5.02%	60.60%	17.13%	0.00%	0.00%	22.27%	82.87%
Option-3	45.01%	38.78%	16.22%	0.00%	0.00%	0.00%	83.78%	100.00%

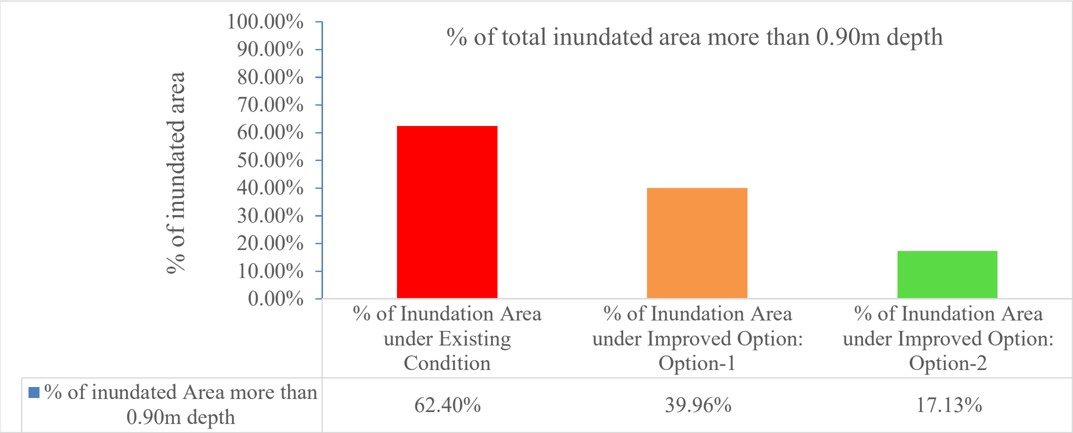


Figure 5.37**:** % of inundation area more than 0.30m depth in polder 17/2 for all options

A significant improvement is found during the improvement condition. It is seen from the Figure 5.37 that about only 17.13% area is under deeply inundation (inundation depth > 0.90m) during the improved option-2 whereas it is about 39.96% in option-1. It is also seen that about 62.40% areas of the polder are deeply inundated (inundation depth > 0.90m) whereas it decreases in the different improved options and it is about to zero inundation depth under the final improved option.

5.5 Tidal River Management

The peripheral river of Polder-17/1 and Polder 17/2 have been experienced huge siltation over the years and consequently the drainage capacity of these rivers is reduced causing prolong drainage congestions. The drainage improvement plans of these polders include river dredging and simulation results show that significant improvement of drainage conditions of the polder 17/1 with dredging of rivers and increase of drainage capacity of the drainage regulators. The crucial issue is sustainability of the improved drainage condition since the re-siltation rate is enormous and the drainage capacity of these rivers are very likely to be lost within few years. The peripheral embankment of polder 17/1 and Polder 17/2 prevents the spreading of the tide and sediment deposition over the tidal flood plain and this phenomenon causes decrease of the tidal prism and siltation in the river. In the peripheral river sediment management is the key to water management of these polders.

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

$$Ac = CPn \qquad (5.1)$$

where, Ac is the minimum inlet cross-sectional area in the equilibrium condition, C is an empirically determined co-efficient, P is the tidal prism (typically during the spring tide/mean tide) and n is an exponent usually slightly less than unity. This type of analysis was carried out for the tidal rivers of southwest region in Bangladesh. Data of Kobadak River, Hari River, Pussur River and other rivers of this region has been used with a view to establishing a consistent relationship. In doing this, an excellent relationship was found between cross-sectional area & tidal prism expressed by the following equation:

$Ac = 43.42P0.9985$ (5.2)

where, P = mean tidal prism (ebb + flood) in Mm^3

Ac = cross-sectional area below mid tide level in m^2

Figure 5.38 shows the relationship of x-sectional area and tidal prism (O'Brien Equilibrium relationship).

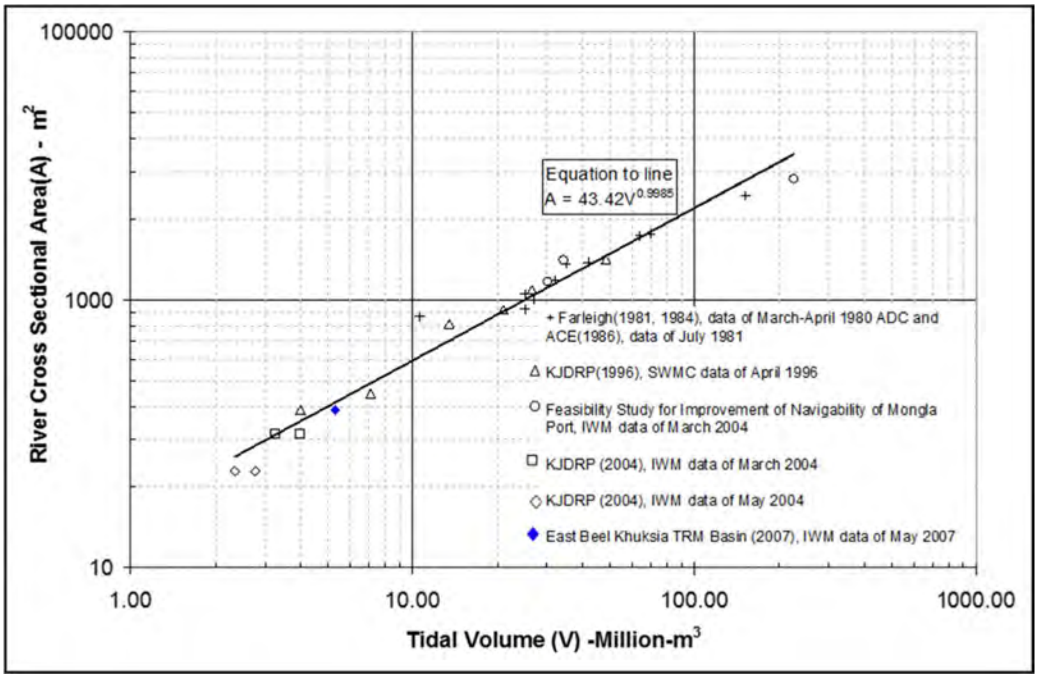


Figure 5.38: Relationship between Tidal Prism and Cross-sectional Area

Tidal prism is an indicator for stability of a tidal river. This relationship is applied to assess the required tidal prism for sustaining the design river section of the peripheral rivers.

5.5.1 Development of TRM Model

A physically based TRM model has been developed for the assessment of effectiveness of the selected beel as a tidal basin to maintain the required drainage capacity of the peripheral river of Polder 17/1 and Polder 17/2 using Mike11 one-dimensional river modelling system. In the model set up the downstream boundary is defined as tidal boundary providing half an hourly tidal water level time series for the dry season. The upstream boundary is defined as flow boundary or closed boundary depending on the upstream flow conditions. In the model set up the beel is connected to the main drainage route (rivers) with a link channel. The beel is schematized as a wide tidal basin based on its bottom topography and is allowed for natural tidal movement.

In this thesis, one TRM beel at Boyrasinga in the Polder 17/1 is selected for assessing the effects of TRM. TRM beel is selected considering the land level of polder area which area is low lying compared to other area of polder and hydrodynamic condition of the peripheral river of Polder 17/1 and Polder 17/2. The location of the selected beels of Polder 16 and Polder 17/1 are shown in the Figure 5.39.

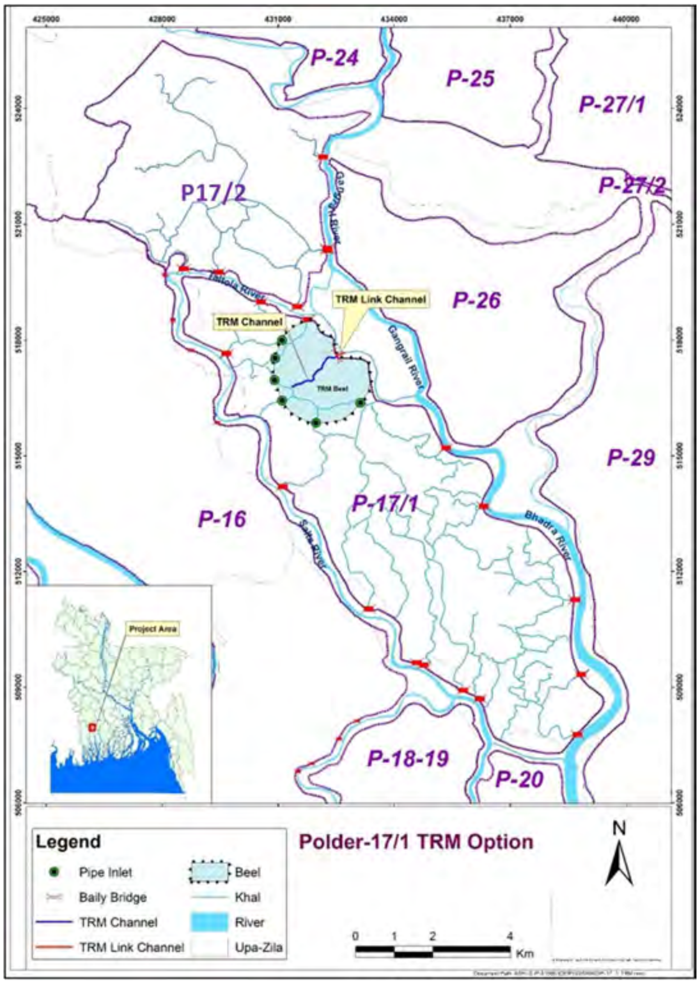


Figure 5.39: Tidal River Management (TRM) beel location in the Polder 17/1

5.5.2 Effectiveness of Beels for Tidal River Management

In the mathematical modelling system beel is utilized as a tidal basin for creating enabling environment for sediment deposition during high tide. It is important to assess the effectiveness of a beel for TRM before implementation since beels may not be effective to generate required volume of tidal prism for sustaining the drainage capacity of the river and sedimentation inside the basin. The performance of TRM basin varies depending on the location, area and bottom topography of the beel, length and location of the connecting channel and also the river bathymetry. Tidal range is calculated in the TRM beel flood land and TRM link channel to assess the tidal fluctuation in the beel area. Tidal prism is calculated in the peripheral rivers to determine the effectiveness of the TRM beel.

It is found that the tidal range in the TRM beel of Polder 17/1 is found 1.55m and the tidal range in the TRM beel of Polder 17/1 is shown in the Figure 5.40.

Tidal range and tidal prism calculation locations for the Polder 17/1 are shown in the Figure 5.41.

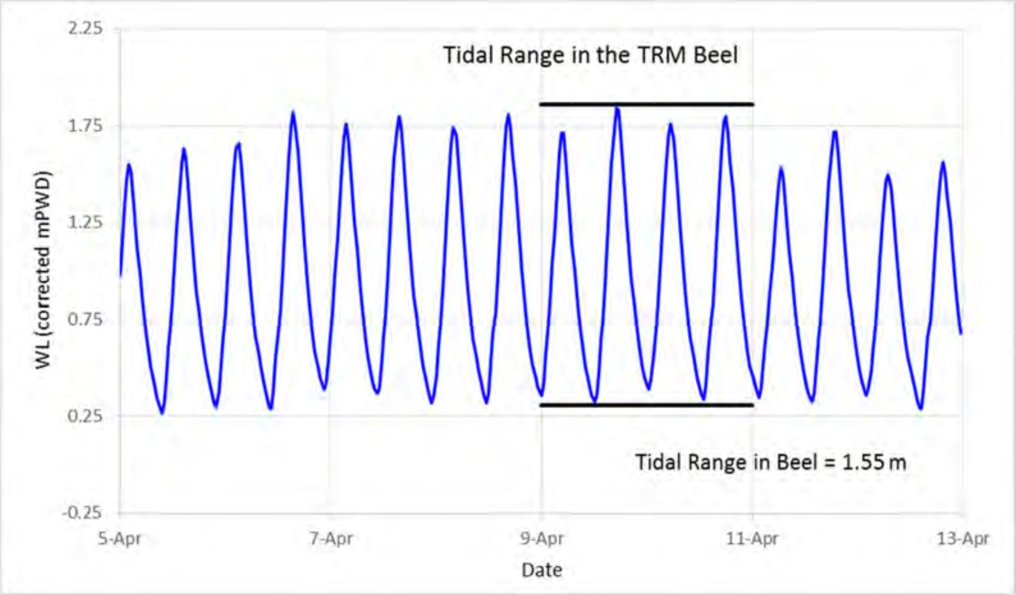


Figure 5.40: Tidal range in the TRM beel of Polder 17/1

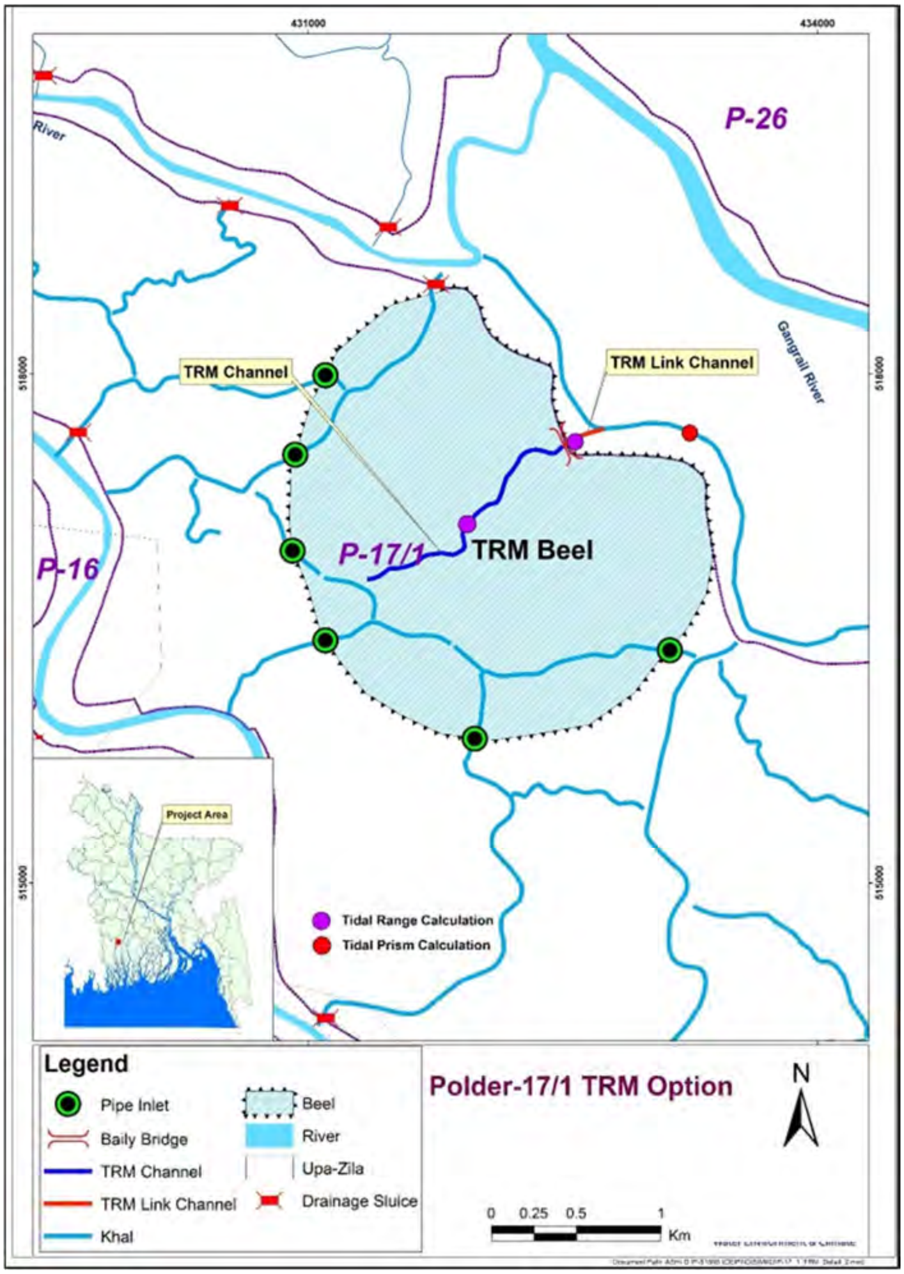


Figure 5.41: Locations of tidal range and prism calculation in the Polder 17/1

Tidal prism is also calculated to assess the TRM effectiveness at different conditions. Prism is calculated at base condition (without engineering interventions), excavation/dredging of peripheral rivers and internal drainage khals without any change in the polder system and combination of TRM network with dredging/excavation. The outcome for the beel of Polder 17/1 is presented in the Table 5-16.

Table 5-16: Effectiveness of TRM Basin in the Polder 16 and Polder 17/1

Tidal Prism	Condition			
	Existing Condition (Million-m3)	Proposed condition with Dredging (Million-m3)	Proposed condition with Dredging +TRM (Million-m3)	Required Tidal Volume in the River (Million-m^3)
Peripheral Khal of Polder 17/1 and Polder 17/2	0.07	2.78	7.76	6.06

Simulation result shows that the tidal prism with TRM is significantly high compared to the required tidal prism, which implies that the river conveyance capacity will be increased and improved drainage conditions will be sustainable as long as the TRM is active.

5.5.3 Combined Effects of Pumping and TRM

The long term effectiveness of the drainage system would depend on projected climate change effects including, sea level rise and precipitation changes as well as the expected rate of ground level subsidence. There is a possibility that the polder lands will become permanently waterlogged at some time in the future. Gravity driven drainage will remain viable only if one can raise the land level within the polder to keep up with sea level rise. The use of supplementary pumps inside the polder to assist drainage, even as an interim solution is an alternative that must also be investigated. At that we have to think about the peripheral river system to maintain the sediment regularly. Tidal river management may be an innovative scientific approach for maintaining the sediment management properly. The combined effects of TRM with and without pumps is observed at DS-5 on the Andharmanik khan and at DS-7 on the Hatitana khal in the Polder 17/1. The pumping effects are presented in the Figure 5.42 and Figure 5.43 respectively.

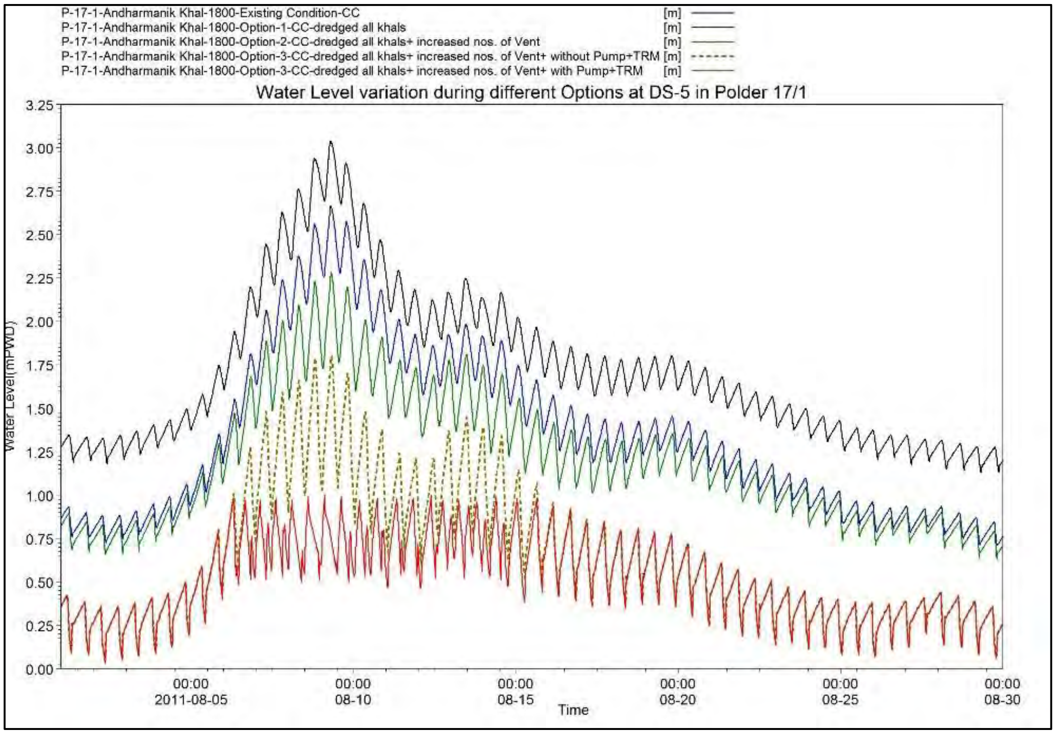


Figure 5.42: Water level variation in the Andharmanik khal at D/S-5 in the Polder 17/1

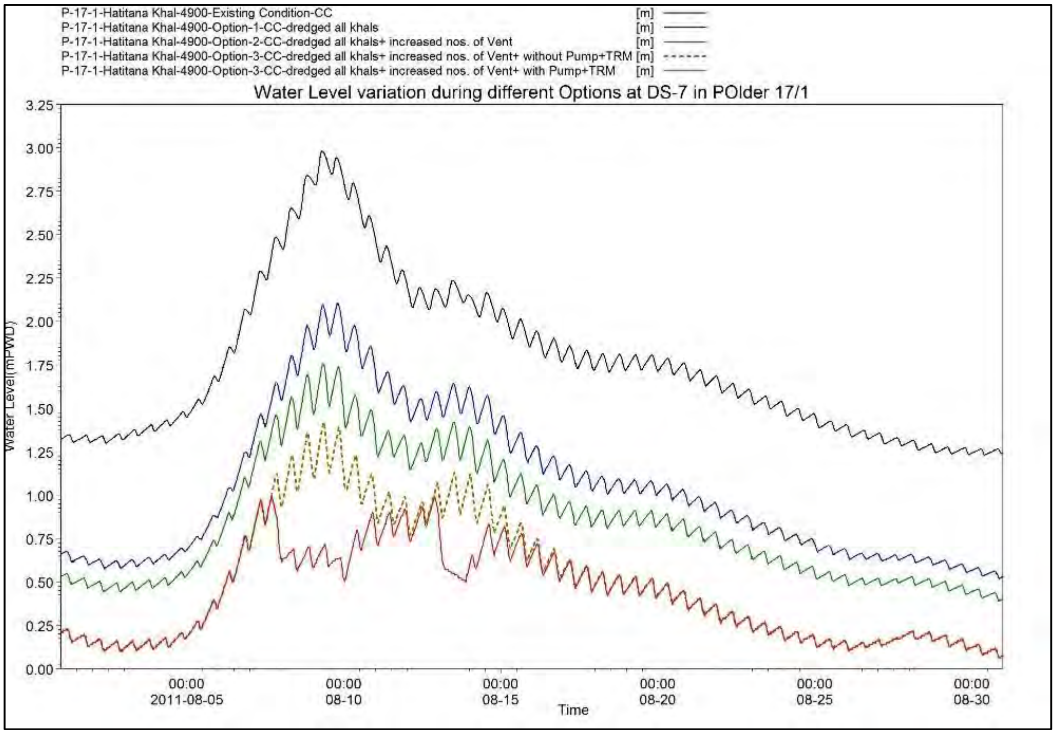


Figure 5.43: Water level variation in the Hatitana khal at D/S-7 in the Polder 17/1

The cross section of the peripheral river of Polder 17/1 and Polder 17/2 is designed from the O'Brien Equilibrium relationship. As a result the conveyance capacity of the peripheral river is increased and it becomes capable of carrying high volume of water and fluctuation of water. It indicates, more water discharge from the inside from the polder by the drainage sluices. Inundation depth map is prepared to assess the TRM effect in combined with supplementary pumping system and without pumping system. Simulations are carried out for different options and options are presented below.

1. Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + without PUMP)
2. Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + with PUMP)

The inundation depth of Polder 17/1 for improved option-3 considering TRM without pumping system and TRM with pumping system is presented in the Figure 5.44 and Figure 5.44 respectively.

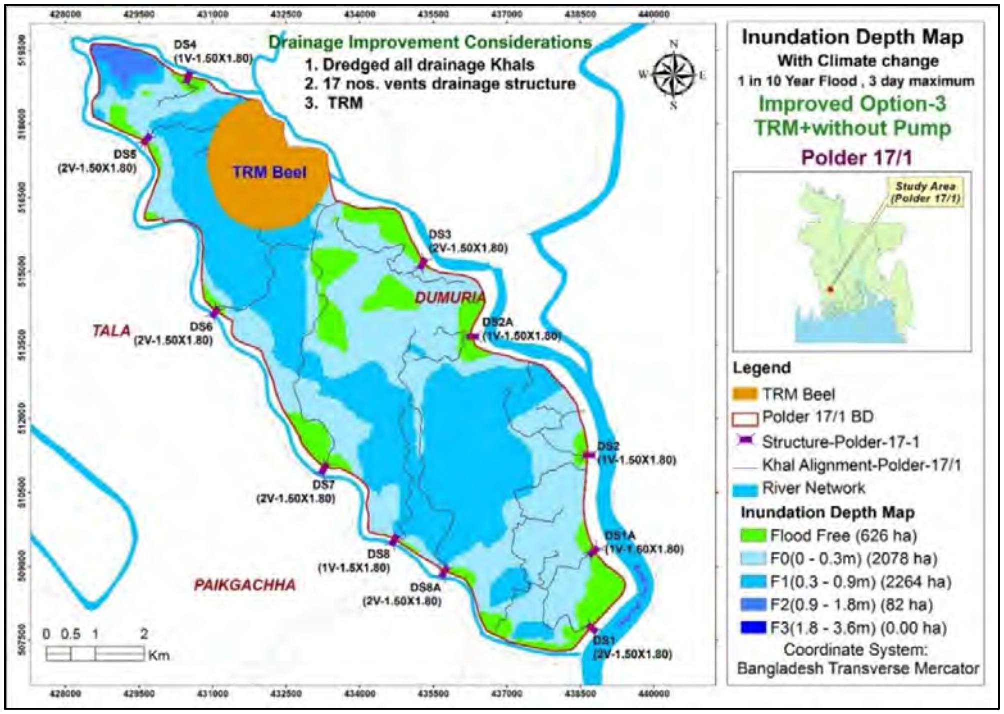


Figure 5.44: Inundation are for polder 17/1 at effective dredged channel considering

no pump

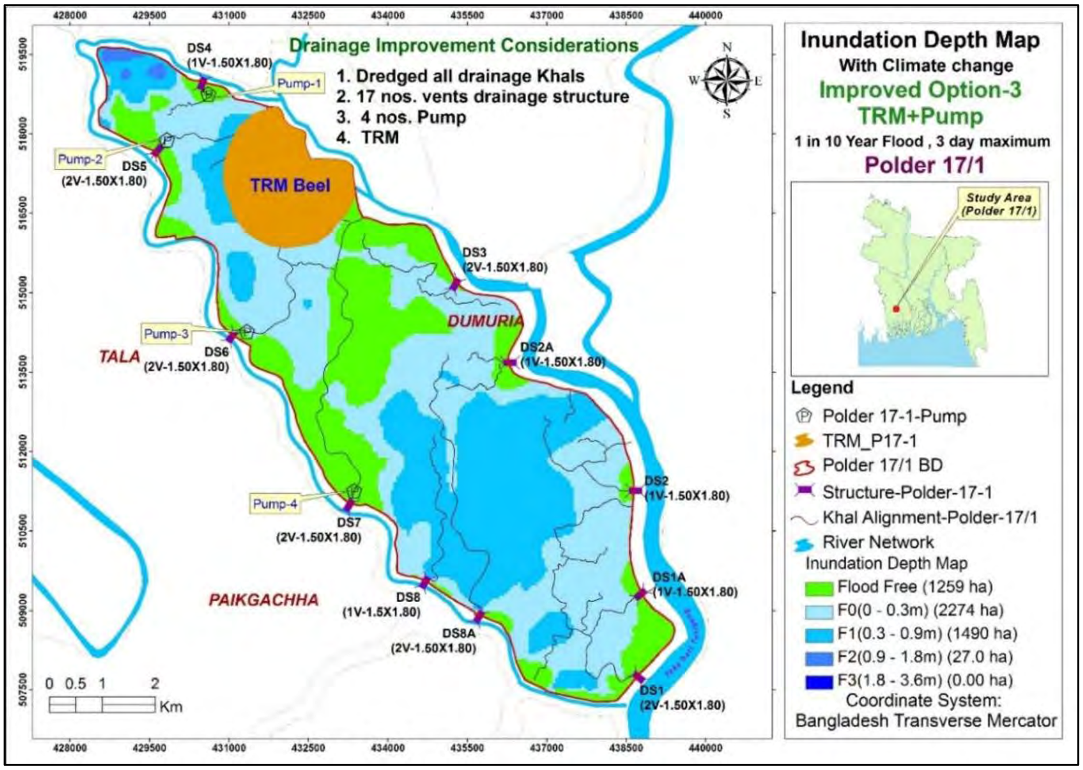


Figure 5.45: Inundation are for polder 17/1 at effective dredged channel considering pump

It is observed that, during the period of TRM, operation of supplementary pumps, about 24.92% becomes flood free whereas without operation of pump it is about 12.40% which is 2 times less compared to operation of pump. During the operation of pumping system, it is about 45.03% land area under 0.30m water depth and only 0.53% land area becomes under deeply inundation depth (water depth up to 0.90m). It is seen that few percentage areas are under deep inundation depth (inundation depth 1.80m to 3.60m) in the improved option-1 and option-2. The inundation depth for different improved options for Polder 17/1 is presented in the Table 5-17.

Table 5-17: Percentage of inundation area for Polder 17/1 under different improved Options

Condition under climate change	Inundation Depth					
	Flood Free	F0	F1	F2	F3	F4
	<0.0m	(inundation up to 0.3m)	(inundation 0.3m to 0.9m)	(inundation 0.9m to 1.8m)	(inundation 1.8m to 3.6m)	(inundation >3.6 m)
Existing Condition	1.40%	15.86%	37.09%	23.19%	22.46%	0.00%
Option -1	1.61%	20.89%	43.27%	31.44%	2.79%	0.00%
Option -2	5.53%	22.85%	52.49%	17.67%	1.47%	0.00%
Option-3	13.21%	32.98%	52.03%	1.77%	0.00%	0.00%
% of Inundation Area for Polder 17/1 (Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + without PUMP)	12.40%	41.15%	44.84%	1.61%	0.00%	0.00%
% of Inundation Area for Polder 17/1 (Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + with PUMP)	24.92%	45.03%	29.51%	0.53%	0.00%	0.00%

In this study the flood free (FF) and F0 land is considered as effective land for people movement from one place to another and agricultural production, and combination of FF+F0+F1 is considered as an effective both for agriculture, fish culture and people livelihood in an extreme flood event. It is seen that, about 69.96% areas becomes effective during the period of TRM and Pumping operation. About 53.54% land areas are effective during operation of TRM without pumping system. It is almost similar for the combination of agriculture, people movement and fish culture during the period of operation of TRM with pumping and without pumping. The percentage of land area for different purposes for the different options is presented in the Table 5-18.

Table 5-18: Percentage of effective land area for Polder 17/1

Condition under climate change	Inundation Depth Area	
	Total (%) (FF+ F0)	Total (%) (FF+F0+F1)
Existing Condition	17.26%	54.35%
Option -1	22.50%	65.77%
Option -2	28.37%	80.86%
Option-3	46.20%	98.23%
Inundation Depth Map for Polder 17/1 (Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + without PUMP)	53.54%	98.39%
Inundation Depth Map for Polder 17/1 (Revised Invert Level + Excavation of khals + Dredging of Peripheral River + TRM + with PUMP)	69.96%	99.47%

5.6 Comparison with IWM study CEIP

The main purpose of Coastal Embankment Improvement Project (CEIP) was to develop design parameters for the drainage sluices. Improvement options are designed based on three considerations such as i. dredging of peripheral rivers as per design ii. excavation of drainage khals as per design iii. remodelling of drainage sluices. In this thesis work similar improved options have been done which were considered in the CEIP project. But consideration of number of vents and sill levels are different than CEIP improved options. In addition in this research, the peripheral rivers and all internal drainage khals are excavated by 1m randomly. Both cases inundation depth maps are developed for water levels which are stagnant consecutive 3-days. Therefore, percentage of inundation depth is different at final improved option for both condition.

In the CEIP project Design Flood Event is selected based on 26 years (1985-2010) rainfall data whereas in this research rainfall analysis is done for 29 years (1986-2013). 2011 is the selected Design Flood Year in the Research and 2006 is in the CEIP project. Therefore, inundation depth map for design flood event under climate change and different options are different. Moreover, options are not similar. No. of vents are different in different options for both Polders. In the CEIP project analysis the flood free land (FF+F0) without climate change was found 21.58% and 13.84% in the Polder 17/1 and Polder 17/2 respectively. The flood free land reduces when climate change is applied in the drainage model and it was 11.03% and 8.11% respectively. In this research the flood free land (FF+F0) is calculated 43.54% and it is reduced after adding the climate change effects and which is only 17.26% in the Polder 17/1. In the Polder the flood free land is determined about 19.33% at without climate change and 16.17% with climate change condition.

Three improve options are made both in the CEIP project and in this Research. The differences are in the sill level fixation, selection of vent size and excavation of peripheral rivers and internal drainage khals. In the final option of CEIP project the flood free land was found 83.37% in the Polder 17/1 and 86.95% in the Polder 17/2. In this research the flood free land is obtained only 46.20% in the Polder 17/1 and 83.78% in the Polder 17/2. The less amount of flood free land in the polder 17/1 is that the excavation of the drainage khals and peripheral Rivers were not excavated as per design. Therefore, proper conveyance capacity is not considered in this research but detailed plans are carried out in the CEIP project.

Comparison of CEIP final options and Research final improved options are presented in the Table 5-19 and Table 5-20 for understanding the difference easily.

Table 5-19: Comparison of Improved option of Polder 17/1 in CEIP and Research

Improved Consideration of Polder 17/1					
Drainage Sluice	Existing No. of Vent	Improved Option(CEIP)		Improved Option(Research)	
		No. of Vents	Sill Level (mPWD)	No. of Vents	Sill Level(mPWD)
DS-1	1V	1V	-1.3	2V	-0.5

DS-1A	1V	1V	-1.3	1V	-0.5
DS-2	1V	2V	-1.2	1V	-0.5
DS-2A	1V	2V	-1.2	1V	-0.5
DS-3	1V	2V	-1.2	2V	-0.5
DS-4	1V	1V	-1	1V	-0.5
DS-5	1V	1V	-1	2V	-0.5
DS-6	1V	1V	-1	2V	-0.5
DS-7	1V	2V	-1	2V	-0.5
DS-8	1V	2V	-1	1V	-0.5
DS-8A	1V	2V	-1	2V	-0.5
DS-9(Proposed)	-----	1V	-1	---------	---------

Table 5-20: Comparison of Improved option of Polder 17/2 in CEIP and Research

Improved Consideration of Polder 17/2					
Drainage Sluice	Existing No. of Vent	CEIP-Improved Option		In This Research (Improved Option)	
		No. of Vents	Sill Level(mPWD)	No. of Vents	Sill Level(mPWD)
DS-1	2V	2V	-1	2V	-0.5
DS-2	1V	1V	-1	1V	-0.5
DS-3	1V	1V	-1	2V	-0.5
DS-4A	4V	6V	-1	1V	-0.5
DS-5	1V	1V	-1	2V	-0.5

In this research, two additional options are added which are not considered in the CEIP project. One is introduction of centrifugal pumps and Tidal River Management. The bed level of the peripheral rivers becomes high due to sedimentation management problem in the study area. Gravitational flow throughout the sluice gates from the remote place to Peripheral River is not possible due to high deposition rate. Therefore, pumping system is added in the polder drainage model for pumping the additional amount of water during the extreme condition. Pumping idea has been devised in this research for removing the additional water level where gravitation flow is not possible. The pumping mechanism and reduction in water level has been described in the chapter Five (section 5.4.6). Excavation of rivers, khals and introduction pumping systems are not a suitable solution for polder management. Therefore, an innovative scientific approach Tidal River Management (TRM) has been devised in this research for sediment management in the peripheral river. TRM modelling procedures and findings all are added in the chapter five (section 5.5)

Finally, it can be concluded that all of the interventions can be selected for polder management in the South-West Region.

5.7 Summary

In this chapter, inundation depth map has been developed for base year and design year both for without climate change and with climate change. Base on the inundation depth map of the design year, three potential options has been developed to develop the climate resilient polder system. Dredging of Peripheral River, excavation of the drainage channel system, remodelling of the existing drainage sluices including modification of the invert level, using the supplementary pumping system methods and Tidal River Management (TRM) are included in the potential improvement system. Tidal volume required is quite satisfactory after the TRM implementation.

CHAPTER SIX:
CONCLUSIONS AND RECOMMENDATIONS

6.1 General

In this research, the main task is to assess the drainage problem in the Polder 17/1 and Polder 17/2 and find out the sustainable solutions. Connection with this, drainage condition at the base condition and climate change scenario have been analyzed. The climate change scenario makes the situation worst. Some options have been devised in the model and see the effectiveness to lessen the drainage problems of the polders 17/1 and 17/2. In near future gravity drainage is dreaming and the alternative one will drainage through the pumps, which has been devised in this study.

6.2 Conclusions of the study

Four types of interventions have taken for developing the proposed final improvement option. Dredging of all drainage channels and Peripheral River, modification of invert level/added additional vent and supplementary pumping system has applied in an integrated way. The results have been discussed as follows:

1. Improved option showing the following results in inundation area percentage in polder 17/1, about 46.20% (option-3) area remains flood free (i.e., flood free and F0 land class) which is about 22.50% in the projected option-1 and 28.37% during the proposed improved option-2. The percentage of Inundation area (inundation depth 0.30m to 0.90m) increases from 37.09% (existing condition) to 43.27% (option-1), 52.49% (option-2) and 52.03% (option-3) In the improved option it is seen that about 98.23% land becomes productive for people movement, agricultural production and fish culture. About 46.20% land area is suitable for people movement and agricultural production.

2. For polder 17/2, it is seen that the flood free area (inundation depth up to 0.30m) increases from 16.17 % (existing condition) to 83.78% in the final improved option (option-3). A significant improvement has been made by using

supplementary pumping system. The inundation area including F1 land class in the improved option-3 is found about 100% whereas it is 37.60% in existing condition, 60.04% in option-1, 22.27% in option-2. There is no deep inundation in the final improved option.

3. In this research, Tidal River Management model also carried out to maintain the river sustainable and it is found the tidal prism with TRM is significantly high compared to the required tidal prism, which implies that the river conveyance capacity will be increased and improved drainage conditions will be sustainable. The tidal prism is found in Existing Condition 0.07 (Million-m^3), Proposed condition with Dredging 2.78(Million-m^3) and Proposed condition with Dredging +TRM 7.76(Million-m^3) whereas the required tidal prism is 6.06 (Million-m^3). In this research pumping is applied water level up to 1.0 mPWD and lowest at 0.50 mPWD for getting the highest benefit at extreme climate change condition.

6.3 Recommendations for further study

Analysis based on real data has been carried out in this research work and the results have already been discussed. Some recommendations can be summarized as part of the ongoing researches for climate change. Some recommendations have been summarized below:

1. Bathymetry, cross section and other data of 2011 has been used in this research work. Inclusion of more recent data will improve the reliability of the model results of the present research work.
2. The study has been carried out considering the RCP 8.5 extreme condition. But there are more cases like RCP 6.5, RCP 4 and RCP 2.0. So, this study can be updated considering the other cases and compare with the drainage congestion for RCP 8.5 scenario.

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APPENDIX A: SITE VISIT PHOTOGRAPHS OF POLDERS AND STRUCTURES

Appendix A: Photographs & Discussions with local people

Polder 17/2, Existing 4-vent regulator

Polder 17/2, Closed regulator near 4-vent Existing regulator

Polder 17/1, 1-Vent 1.50X1.80 regulator closed

Polder 17/1 1-Vent 1.50X1.80 regulator

Polder 17/2 4-Vent 1.5X1.80 active regulator, Discussion with local people

Polder 17/1, 1-Vent 1.50X1.80 regulator closed by local people, Discussion with people

Polder 17/1, 1-Vent 1.50X1.80 regulator water is draining out

Polder 17/1, 1-Vent 1.50X1.80 regulator broken

Polder 17/1, Discussion with local people over the embankment about failure of embankment