HYDROLOGICAL MODELING OF GORANCHATBARI STORM WATER DRAINAGE SYSTEM USING STORM WATER MANAGEMENT MODEL

MD. SHAHADAT HOSSAIN

DEPARTMENT OF WATER RESOURCES ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

MARCH, 2018

HYDROLOGICAL MODELING OF GORANCHATBARI STORM WATER DRAINAGE SYSTEM USING STORM WATER MANAGEMENT MODEL

By

MD. SHAHADAT HOSSAIN

DEPARTMENT OF WATER RESOURCES ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

MARCH, 2018

HYDROLOGICAL MODELING OF GORANCHATBARI STORM WATER DRAINAGE SYSTEM USING STORM WATER MANAGEMENT MODEL

By

MD. SHAHADAT HOSSAIN

Student No. 0412162011

A thesis submitted to the Department of Water Resources Engineering of Bangladesh University of Engineering and Technology, Dhaka, in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering

Department of Water Resources Engineering

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

MARCH, 2018

The thesis titled "**HYDROLOGICAL MODELING OF GORANCHATBARI STORM WATER DRAINAGE SYSTEM USING A STORM WATER MANAGEMENT MODEL**" submitted by Md. Shahadat Hossain, Student No: 0412162011, Session: April, 2012 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering on March 2018.

BOARD OF EXAMINERS

Dr. Md. Mostafa Ali
Professor
Department of WRE, BUET, Dhaka
(Supervisor)

Chairman

Dr. Md. Mostafa Ali
Head
Department of WRE, BUET, Dhaka

Member
(Ex-Officio)

Dr. Md. Sabbir Mostafa Khan
Professor
Department of WRE, BUET, Dhaka

Member

Dr. K. M. Ahtesham Hossain
Assistant Professor
Department of WRE, BUET, Dhaka

Member

Md. Serajuddin
Ex Deputy Managing Director
Dhaka WASA, Dhaka, Bangladesh.

Member
(External)

DECLARATION

I do hereby declare that this Thesis entitled," Hydrological Modeling of Goranchatbari Storm Water Drainage System Using Storm Water Management Model" has been done by me under the supervision of Prof. Dr. Md. Mostafa Ali, Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka. I do hereby declare that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma from any other institution.

24 March 2018

Md. Shahadat Hossain
Student No. 0412162011
Session: April 2012

DEDICATED

TO

MY BELOVED FATHER LATE MD. SHAHAJAHAN HOWLADER,

AND MY BELOVED MOTHER AFROZA BEGUME

ACKNOWLEDGEMENT

It is my pleasure to take the opportunity to thank those who made it possible for me to complete this thesis. First and foremost, I would like to show my deepest gratitude to Almighty Allah.

I want to thank my supervisor, Prof. Dr. Mohammad Mostafa Ali, Professor, Department of Water Resources Engineering (DWRE), Bangladesh University of Engineering and Technology (BUET), Dhaka for providing me continuous support and guideline to perform this research work and to prepare this concerted dissertation. His contribution to complete the thesis can only be acknowledged but never be compensated. His consistent inspiration helped me to work diligently throughout the completion of this research work and also contributed to my ability to approach and solve a problem. Without his continuous guidance this dissertation would not be materialized.

I am deeply grateful to Prof. Dr. Md. Mostafa Ali, Head, DWRE, BUET, for the support and allowing me to do this research and suggestions. I also thank Mr. S.M. Mahbubur Rahman, Director, Water Resources Planning Division, Institute of Water Modelling (IWM), Dhaka, Bangladesh for permission to access the secondary data from his institution.

I also wish to thank my thesis reviewers Prof. Dr. Sabbir Mostafa Khan, Dr. K. M. Ahtesham Hossain and Engr. Md. Serajuddin for their support to finish my tasks properly.

Special thanks to Dr. Zakir, Mr. Sadbir Rahman and Mushfiqur Rahman from Water Resources Planning Division, Institute of Water Modelling (IWM), Dhaka, for their contribution to this study at various stages of work.

At last, I want to thank to my whole family for their encouraging support in completion of this study.

ABSTRACT

Throughout history urban floods have been one of the most severe natural catastrophes, which brought about loss of lives and huge economic losses in addition to the influence on community activities and adverse effects on the environment. We have witnessed enormous flood events almost all over the world, even in the early years of 21st century. The cruel lesson learnt is that we have not coped well with floods in many over populated mega cities like Dhaka.

Stormwater modeling has a major role in preventing issues such as flash floods and urban water-quality problems. However, in-detail modeling of large urban areas is time-consuming as it typically involves model calibration based on highly detailed input data. Stormwater models of a lowered spatial resolution would thus appear valuable if only their ability to provide realistic results could be proved.

An urban inundation model, combining a storm sewer model SWMM and operations of Goranchatbari pumping station, has been developed to simulate inundation in urban areas due to storm water and outlet pumping station. The movement of water in the studied Goranchatbari watershed is characterized by two components, namely, the storm water flow component and the inundation component. SWMM is employed to solve the storm water flow component and to provide the flow hydrographs for surface runoff exceeding the capacity of the storm water. Drainage by pumping stations at outlets of the storm water system has also been taken into consideration.

Rainfall frequency analysis of 30 yr, 50yr and 100yr return periods were conducted for Dhaka BMD and BWDB stations. The effect of rainfall due to climate change was incorporated in this SWMM drainage model to generate future scenarios of study area. The combined study is suitable for analysis of inundation on urban areas due to overflow of storm water and flooding caused by Climate Change. The parameters of the Goranchatbari model were calibrated by pumping water level and velocity verified for discrete storms with some internal khals system. The simulated SWMM model also validated with World Bank study inundation map prepared for actual event 2004. Simulated results applied to establish inundation maps to find out the flooded regions of study area due to waterlogging with different return periods.

Simulated SWMM Model and inundation maps showed that the major drainage takes place at several locations of study area like Kalshi, Mirpur-10, Shewrapara and Kazipara which covering a huge study area from Mirpur-10 to Uttara with Baunia Khal to Digun Khal at retention pond. These area variations modify the features of both urban hydrology and hydraulics, and change the distribution of drainage network. It may lead to dual adverse effects in one specific region like Shewrapara, Kazipara which will risk of flooding on extreme rainfall. Therefore, finding appropriate solutions for these problems has been being a great challenge for the urban city like Dhaka.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

BCL	BCL Associates Ltd
BETs	BETs Consulting Services Ltd.
BGS	British Geological Survey
BM	Bench Mark
BMD	Bangladesh Meteorological Department
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering and Technology
BTM	Bangladesh Transverse Mercator
BWDB	Bangladesh Water Development Board
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DHI	Danish Hydraulic Institute
DoE	Department of Environment
DPHE	Department of Public Health Engineering
DSS	Decision Support System
DWASA	Dhaka Water Supply and Sewerage Authority
FAP	Flood Action Plan
GIS	Geographic Information System
GOB	Government of Bangladesh
GPS	Global Positioning System
GSB	Geological Survey of Bangladesh
IWM	Institute of Water Modelling
JICA	Japan International Co-operation Agency
LA	Land Acquisition
LGD	Local Government Division
LGED	Local Government Engineering Department
MIS	Management Information System
MSL	Mean Sea Level (at Cox's Bazar)
NWMP	National Water Management Plan
NWPo	National Water Policy
PD	Project Director
PWD	Public Works Department
SOB	Survey of Bangladesh
TBM	Temporary Bench Mark
WARPO	Water Resources Planning Organization

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND PRESENT STATE OF THE PROBLEM

The importance of urban stormwater modeling is constantly increasing due to three global trends: urbanization, population growth, and climate change. The first two trends induce a rapid growth of cities, making stormwater management ever more challenging while at the same time a rising number of people is affected by the harmful effects of stormwater on the environment. In many areas, these effects are expected to be amplified in the future due to climate change and associated higher frequencies of extreme weather events. (Hossain, F. et al, 2013)

Stormwater is water generated on the land surface, originating from rainfall or melting snow or ice. The concept of stormwater is strongly related to urban areas where conveyance systems exist. In Finland, conveyance systems have been typically designed based on a 10-minute rain event that has a return period of two years. Urban floods are thus not uncommon, sometimes causing material damage worth up to tens of millions of euros. (Hossain, F. et al, 2013)

Despite flooding, stormwater also is interesting regarding the urban water balance. The expansion of impervious land-cover implies both larger stormwater runoff volumes and peak flows and consequently reduces other components of the hydrologic cycle, e.g. infiltration and evapotranspiration. Moreover, stormwater directly transports harmful substances from urban surfaces into downstream water systems, thus degrading the water quality. (Fred L. Ogden et al, 2004)

Both stormwater quantity and quality issues can be analyzed and tackled with the aid of *stormwater modeling*. There are numerous different stormwater models for such purposes. Modeling can be conducted at different spatial resolutions by aggregating similar features together or presenting them separately. The accuracy of coarse-scale models is not yet clearly known so one cannot fully trust the results. Consequently, high-resolution modeling remains the most exact method, but is often not feasible for large geographical areas. Urban catchments are mostly ungauged, preventing model calibration. And even if the catchments were gauged, the numerous calibration parameters would make calibration hard. In addition, spatial data of sufficient resolution and quality is in many cases unavailable. The parameterization of large-scale stormwater models thus remains challenging, requiring the development of new methodologies. (A. Pathirana et al, 2014)

1.2 IMPORTANCE AND SIGNIFICANCE OF THIS STUDY

Rainfall induced flooding during rainy season is a regular phenomenon in Dhaka City. Almost every year a significant part of the city suffers badly with drainage congestion. There are some highly dense areas with lower ground elevation which submerge under water even with an intense precipitation of few hours. The higher areas also suffer with the drainage problem due to inadequate maintenance of the system and encroachment or illegal filling up of the drainage canals and lakes. Most part of the city suffered from long term urban flooding during historical extreme rainfall events in September 2004, 2007 and July 2009. The situation is likely to be worsening in the future due to climate change, which may lead to more frequent and intense precipitation.

Storm-water drainage modeling has a major role in preventing issues such as flash floods and urban water-quality problems by indicating the vulnerable areas of water logging. A good number of modeling tools are available around the world for hydrological and hydraulic analysis of urban areas like MIKE Urban, SOBEK, Bentley StormCAD, GeoSWMM and EPA SWMM. Among all these tools, EPA SWMM is an open source tools to study the urban drainage problems.

The present scenario of urban morphology of Dhaka city and existing drainage system is complex for hydrological and hydrodynamic modeling. Several studies were carried out including modeling for drainage master plan of Dhaka city like: JICA Studies (1987), FAP 8A (1990), FAP 8B (1991), IWM Study (2006) and DWASA Study (2014). However still knowledge and solutions to the drainage problem for Dhaka city are limited. Therefore, in this study a pilot area of western part of Dhaka city called Goranchatbari will be modeled using EPA SWMM.

1.3 RESEARCH OBJECTIVES

The broad objective of this study is to assess the effects of water logging with the rapid urbanization of Dhaka city. The specific objectives of the study are as follows:

- To set-up a Hydrological and Hydrodynamic Model of the study area using SWMM.
- To prepare flood inundation map of the study area for selected storm event.
- To investigate the effects of climate change and land-use pattern for Goranchatbari study area.
- To compare results with studies done by World Bank named “Urban Flooding of Greater Dhaka Area in a Changing Climate.”

SWMM was applied to a large urban area with Geographic Information Systems (GIS) were utilized to develop a feasible method for defining aggregated values for spatially variable SWMM parameters. In addition, literature values were used where no detailed spatial data on local conditions was available. ESRI ArcGIS 10.1 software was used for all GIS operations. After processing in GIS software, the spatial data was exported into SWMM.

Several SWMM model runs were conducted for different time periods, using the observed long-term hourly precipitation data as model input. The simulation results were compared to results presented in several distinct parts of the study area. In addition, the results were compared to flood depth measurements as well as literature values on the annual urban flooding. Moreover, the relation between the simulated runoff coefficients and the catchment imperviousness was evaluated.

1.4 STUDY AREA

Drainage system of Dhaka city consists of approximately 44 natural channels with 151 km length in addition to about 315 km of storm sewer lines and 10 km of box culverts. Although DWASA is the main government agency responsible for drainage of the core city area, there are other agencies involved in the development and management of drainage infrastructures, namely Dhaka North City Corporation (DNCC), Dhaka South City Corporation (DSCC), Bangladesh Water Development Board (BWDB) and Bangladesh Army (for Cantonment Area) etc.

The western part of the city area is protected from flood by flood embankment while the eastern part remains unprotected and vulnerable to river floods. With the increase of the population, new settlements have developed and continue to develop in low-lying areas by developing lands by land filling without much consideration to drainage requirements or conservation of existing drainage systems. Many of the natural drainage canals or khals are lost due to development of land. Some of the existing canals are encroached by land-grabbers thus reducing the conveyance capacity of the canals. As a result, water logging in some of the areas in Dhaka has become a major problem.

To mitigate water logging problem of Dhaka city in an integrated way the DWASA has prepared Drainage Master Plan (DMP) for the city. In this master plan entire area of the city has been divided into 13 drainage zone for Storm Water Best Management practice. These 13 zones are Zone 1 – Goranchatbari (GCB); Zone 2 – Kallayanpur; Zone 3 – Dholai Khal and Old Dhaka; Zone 4 – DND; Zone 5 – Kamalapur; Zone 6 – Rampura (RMP); Zone 7 – Badda; Zone 8 – Uttar khan; Zone 9 – Gazipur and Tongi; Zone 10 – Savar (SVR); Zone 11 – Keraniganj; Zone 12 – Narayanganj and Zone 13 – Purbachal (PRB). Further the 13 zones have been subdivided into several sub-catchments.

It is fact that, haphazard development of drainage system cannot reduce water logging effectively rather mitigate for sometimes. So, it is worthy to develop drainage system based on individual catchment delineated on DMP. Presently DWASA intended to develop integrated drainage system of drainage Zone 1 – Goranchatbari (GCB) and Zone 2 – Kallayanpur which is about 70.81 and 32.03 sq. km, respectively.

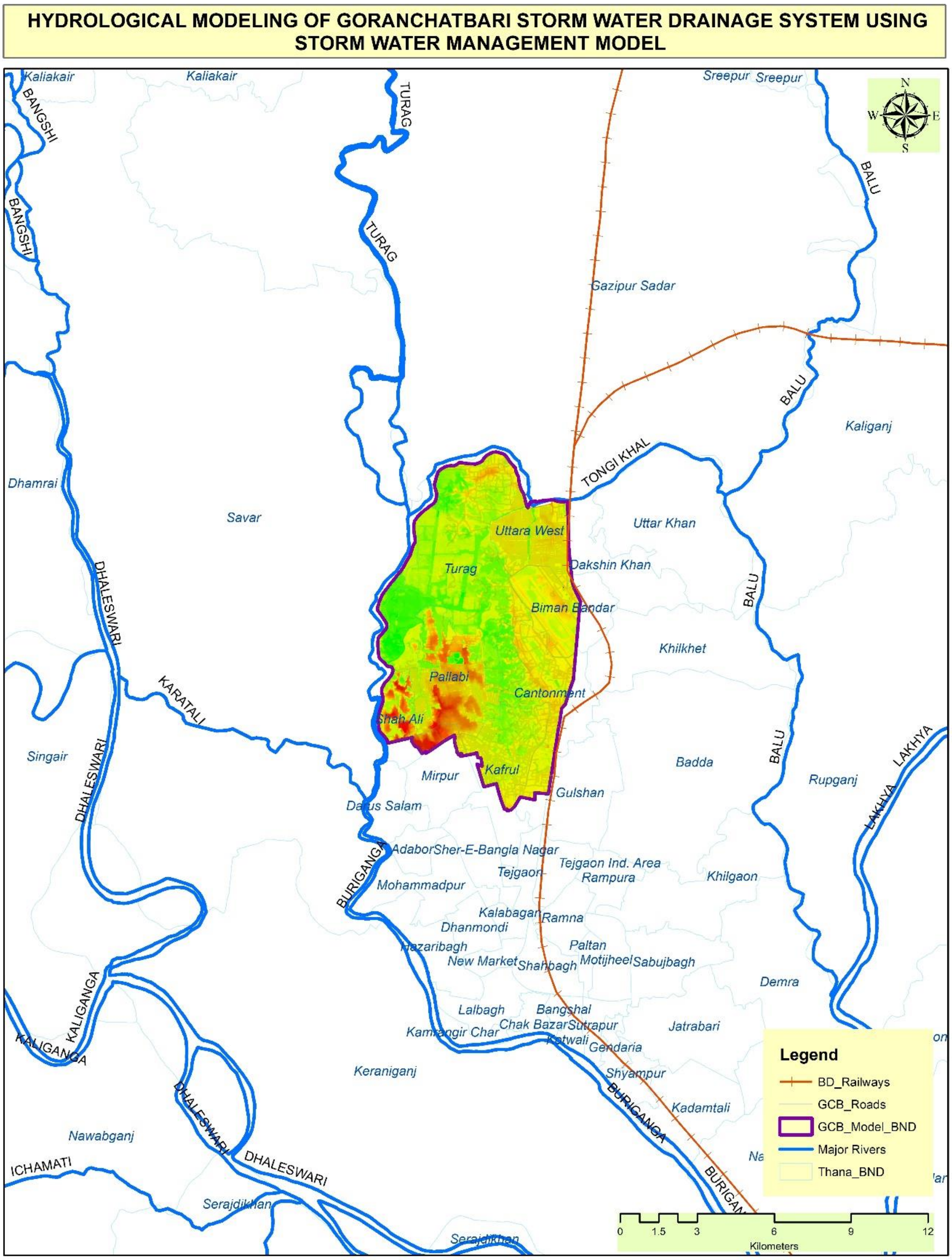


Figure 1-1: Study area with surrounding Rivers

Overall study area (Figure 1-1) includes two drainage zones namely Goranchatbari (Zone 1) and Kallyanpur (Zone 2) as per Dhaka Drainage Master Plan. Total area of the drainage zones is about 102.84 Sq. Km. located in western part of the Dhaka City. Area of drainage zone-1 is about 70.81 Sq. Km. which includes 10 drainage khals along with some pipe networks and a drainage pump station at Goranchatbari.

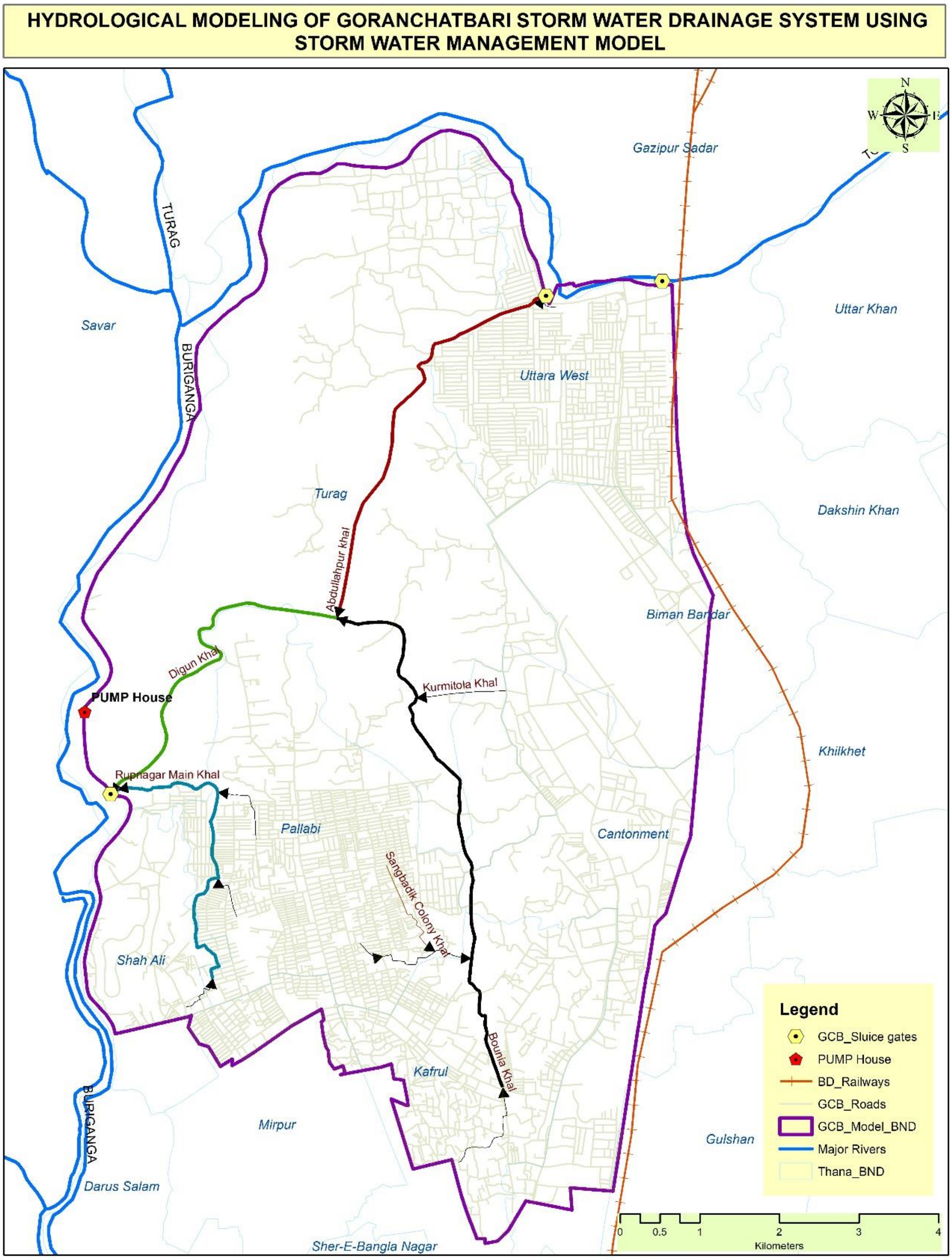


Figure 1-2: Study area with roads and khals.

1.5 THESIS ORGANIZATION

Chapter 1 is the introduction, objectives and overall planning of the study.

Chapter 2 provides details literature review with the background of Dhaka Urban Drainage studies as well as some ideas of Bangladesh flooding and causes. The background section also covers central previous studies related to the research questions.

Chapter 3 presents the Theory and Model Developments of the study by visualizing the research process and showing which methods were applied for each task.

Chapter 4 presents as Methodology for this study. These results are also being discussed in the same chapter, as that way the reader can more easily follow the discussion related to each branch of the results.

Chapter 5 presents as model development for this study. These results are also being discussed in the same chapter, as that way the reader can more easily follow the discussion related to each branch of the results

Chapter 6 presents the results for this study. These results are also being discussed in the same chapter, as that way the reader can more easily follow the discussion related to each branch of the results.

Finally, **Chapter 7** draws the concluding remarks on the study and suggests several interesting areas for further research.

CHAPTER 2: LITERATURE REVIEW

2.1 PREVIOUS STUDIES OF DHAKA DRAINAGE

A number of drainage studies for Dhaka City have been conducted by various international and national organizations to assess the problem associated with storm water management. Though the boundary of study area was not fixed, but main idea was the same. Study area may be divided into three zones: i) Western Dhaka, ii) Eastern Dhaka and iii) DND area. Findings and recommendation of different studies are summarized in this chapter. Overview of the previous studies are shown in Table 2.1

Table 2-1: Overview of the previous studies

Item	**Year**	**Report Prepared by**	**Study Area**	**Objective Related to Drainage**
The study on storm-water drainage system improvement project in Dhaka city	1987	JICA study team in cooperation with DPHE	137.5 km^2 which mainly covers the core Dhaka City	• To prepare a phased program • To conduct a feasibility study on storm-water drainage system improvement project for top priority area. • Preliminary design for the urgent projects
Flood action plan (FAP 8A)	1990	Bangladesh Government, and the Government of Japan		• To review the existing conditions to prepare a detailed study plan and Master Plan study on comprehensive flood control storm-water drainage for DMP area
Flood action plan (FAP 8B)	1990	Bangladesh Government, and the Government of Japan		• Complementary environmental improvement programs • Institutional support for improved efficiencies in urban management and revenue generation
IWM study	2006	IWM	145 km^2	Dhaka Urban Drainage master Plan study and modeling
Urban Flooding of Greater Dhaka	2014	WORLD BANK	Greater Dhaka	Vulnerability, Adaptation and Potential costs

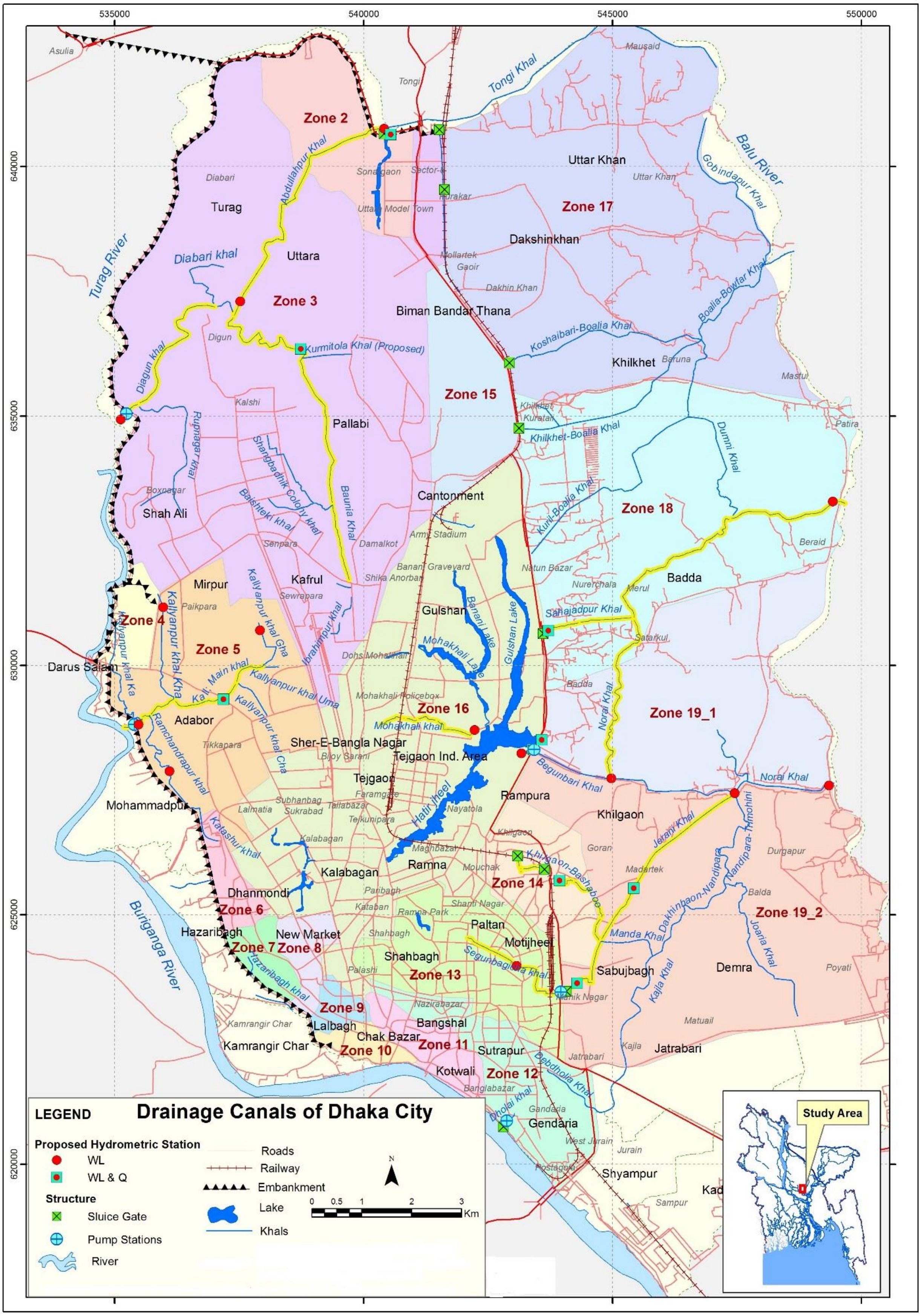


Figure 2-1: Dhaka drainage zones by DWASA [Source: Dhaka WASA]

The earliest large extent study to prepare a Draft Drainage Master Plan for flood protection and internal drainage of Dhaka city was undertaken by the Department of Public Health Engineering (DPHE) in 1968 (IWM, 2006). The study, covering an area of 75 km^2 included construction of an embankment around the city, pump stations, and other internal drainage facilities, had a total cost of Tk. 200 million. Former Water and Power Development Authority (WAPDA) was assigned to construct the embankment and pump stations, and the DPHE was assigned to construct the internal drainage system. However, the plan failed to get approval finally. Afterwards, Bangladesh Water Development Board (BWDB) initiated to prepare a detailed plan covering an area of 144 km^2, having an estimated cost of Tk. 408.6 million. At the same time DPHE also prepared a separate plan for the internal drainage system costing Tk. 130 million and submitted it to the Government in 1976. Considering the amount of money required the Government of Bangladesh wanted to explore an alternate way of financing and advised to prepare a "Crash Programme for Removing Water Logging from Dhaka City".

DPHE prepared a plan with an estimated cost of Tk. 66 million in 1976 which was implemented up to June 1980. In 1978, DPHE reviewed the 1968 Master Plan and prepared a plan of flood control and drainage works covering 144 km^2 of Dhaka City. The estimated cost was Tk. 2,880 million of which Tk. 1,524 million was for flood control and Tk. 1,356 million was for internal drainage. In 1980, following the "Crash Programme" mentioned above, another drainage plan, namely "Interim Scheme for Removing Water Logging within Dhaka Metropolis" was approved at Tk. 190 million, and it was completed in June 1983.

During 1981, a study on "Dhaka Metropolitan Area Integrated Urban Development Project" was completed with the support from ADB and UNDP which covered an area of 256 km^2. However, no detailed flood control and drainage plan was proposed in the study. In addition, the "Revised Crash Programme for Construction of Storm Water Drainage in Water Logged Area of Dhaka Metropolis" was prepared by DPHE in 1985, which was continuing at the time of finalization of report of another comprehensive study, namely "Study on Storm Water Drainage System Improvement Project in Dhaka City" which was carried out by JICA (JICA, 1987). After that study IWM performed a study in 2006 regarding drainage Master plan of Dhaka city. Recently, a study titled 'Updating / Preparation of the Storm Water Drainage Master Plan for Dhaka City under the Dhaka Water Supply and Sanitation Project (DWSSP)' was prepared by JPZ- FCEA-SARM-JV. The following **Table 2.2** gives a list of reports that have been collected and reviewed in this study.

Table 2-2: List of Reviewed Reports

Sl. No.	Reports	Conducted By
1	Drainage System Improvement Project	JICA, 1987
2	Review of JICA Study	JICA ,1990
3	FAP 8A and FAP 8B	JICA , 1991
4	Study on Drainage Master Plan	IWM, 2006
5	Drainage Master Plan Report for Dhaka City	JPZ- FCEA-SARM-JV, 2014
6	Urban Flooding of Greater Dhaka in a Changing Climate	WORLD BANK, 2015

2.1.1 Review of JICA Study

The total drainage area consisting of ten zones has been revised from 137.5 to 134.85 km^2.The proposed measures are constructing two new pump stations with two new sluice gates, improving extensive khal (except for Dholaikhal) and drainage pipe.

Table 2-3: Overview of the JICA studies

Code	Drainage zone	Area (km^2)	Priority	Remarks
A	Buriganga river zone	7.25	Second Priority	▪ drainage pipe ▪ khal improvement ▪ sluice gate
B	Dholaikhal zone	7.24	Highest Priority	▪ drainage pipe ▪ khal improvement ▪ pump station ▪ sluice gate
C	Segunbagicha khal zone	10.92	Highest Priority	▪ drainage pipe ▪ khal improvement
D	Bashabo zone	7.46	Second Priority	▪ drainage pipe ▪ khal improvement
E	North east edge zone	13.93	Second Priority	▪ khal improvement
F	Begunbari khal zone	13.70	Highest Priority	▪ drainage pipe ▪ khal improvement
G	Gulshan Banani zone	17.64	Second Priority	▪ khal improvement ▪ pump station ▪ sluice gate
H	Kallyanpur zone	17.60	Highest Priority	▪ khal improvement ▪ pump station ▪ sluice gate
I	North zone	31.42	Second Priority	▪ khal improvement ▪ pump station ▪ sluice gate
J	Turag river bank zone	7.69	Second Priority	

Khal Improvement Project: There are 3 groups of major drainage khals in the city:

- Digun-Ibrahimpur-kallyanpur khal,
- Gulshan-Banani-Begunbari-Dhanmondi khal,
- Dholai-Gerani-Segunbagicha khal,

Proposed Drainage Plan: A number of drainage structures were proposed in this study. 7 sluice gates were proposed to be installed at the outlets of the proposed khal and drainage pipes in the drainage zones A, B and at the proposed pump stations in zones H and I. The additional trunk drainage pipes (1.5 to 3.7m) were to be installed in the 14 routes for draining a total catchment area of 12.45 km2. Recommended total installation length was 17.00 km of which 14.07 km is for a brick pipe and remaining 2.93 km is for a R.C. box culvert. Khals are to be widened and dredged in 25 stretches. The total length to be improved reaches 36.35 km of which 5.8 km is for box culvert section and the remaining 30.55 km is for open channel. The major work consists dredging 560*103 m3, the construction of bridge culverts at 45 places and the installation of 8.8 km long brick protection. Two pump stations with a total discharge capacity of 24.5m3/s were proposed to be installed. The pump stations cover drainage zones H and I having a total area of 21.54 km^2.

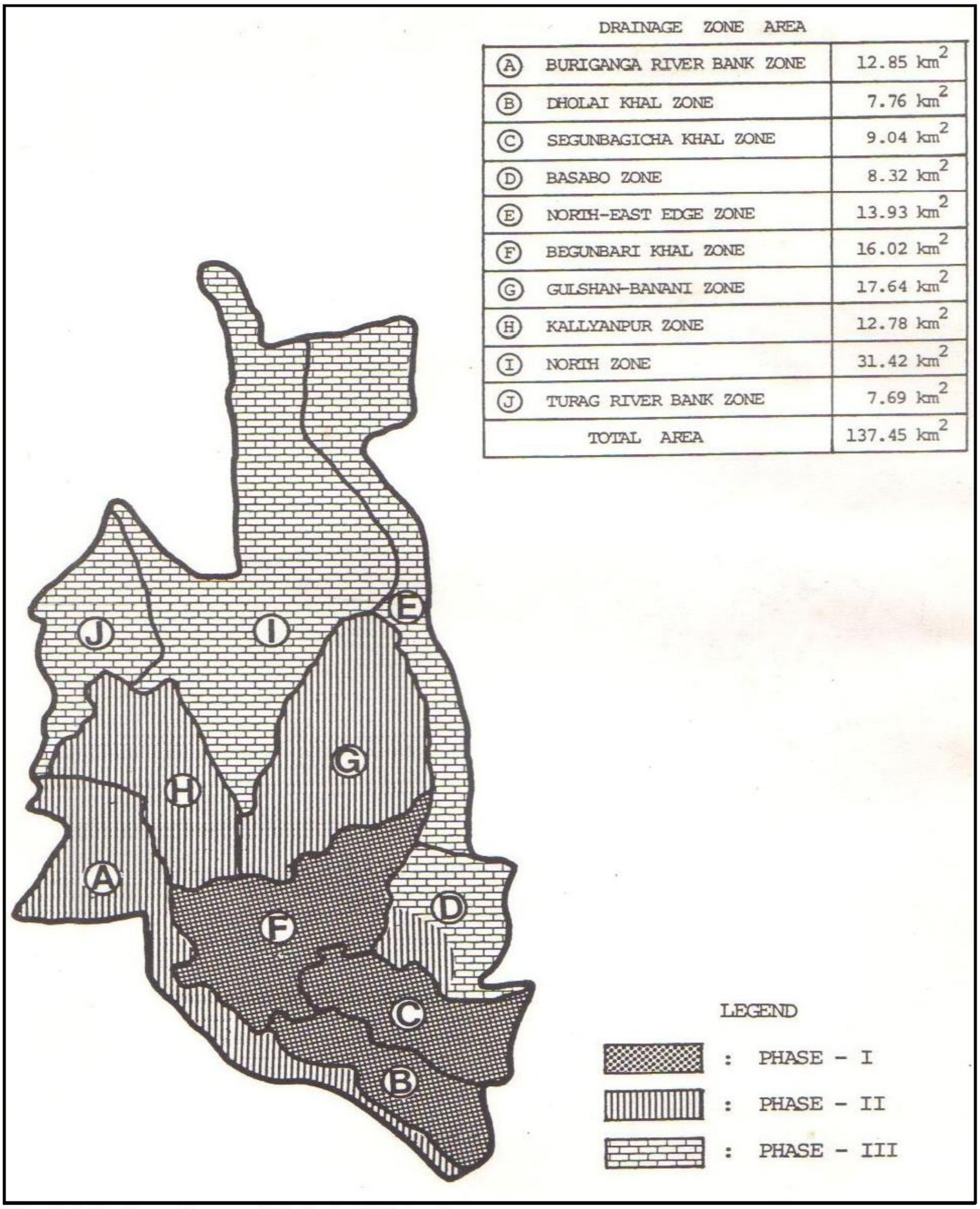


Figure 2-2: Drainage Zones of Dhaka in JICA Study (Source: JICA Report, 1987**)**

2.1.2 FAP-8A Study

Most of the major flood control facilities have been constructed after the 1988 flood. The storm water drainage plan of Greater Dhaka city was prepared by GOB. The Greater Flood Control Committee with the planning minister as its chairman was established to protect the greater Dhaka area from flooding after 1988 flood. For the nearby towns of Savar, Tongi and Narayanganj flood mitigation facility projects were proposed by the institute of Diploma Engineers. No flood mitigation plan for Keraniganj was prepared. A number of flood mitigation structures: embankments, flood walls, sluice gates and stormwater drainage structures: pump stations, drainage pipes, retarding ponds are proposed in this study. Summary of the proposal is shown in **Table 2.3**

Table 2-4: List of proposed facilities according to FAP-8A Study

Area	**Flood mitigation**	**Storm-water drainage**
1. Greater Dhaka		
a) West	embankment (R): 16.7 km flood wall (R): 4.7 km embankment: 6.3 km flood wall:3.0 km sluice gate:11plcs land acquisition:37.0 ha	pump station o: 73.2m^3/sec khal improvement: 42.7 km drainage pipe: 8.1 km retarding pond: 770.0 ha land acquisition: 43.7 ha
b) East	embankment: 26.7 km sub embankment: 11.3 km sluice gate: 5plcs land acquisition: 317.4 ha	pump station no: 179 m^3/s khal improvement: 72.4 km drainage pipe: 8.9 km retarding pond: 1884.0 ha land acquisition: 168.0 ha
2. Narayanganj		
a) DND area	flood wall(R):20.2 km flood wall:10.0 km sluice gate:2 plcs land acquisition:5.8 ha	pump station no:50.2 m^3/s khal improvement:38.0 km retarding pond:681.0 ha land acquisition:90.8 ha
b) West	embankment:6.1 km road cum embankment:4.3 km flood wall:10.5 km sluice gate:7 plcs land acquisition:61.5 ha % evacuation facilities 1 LS	pump station:16.2 m^3/s khal improvement:6.4 km retarding pond:170.0 ha land acquisition:12.2 ha
c) East	embankment :6.6 km road cum embankment:6.5 km flood wall:26.0 km sluice gate:12 places land acquisition:99.2 ha	pump station no:12.5 m^3/s khal improvement:7.4 km retarding pond:130.0ha land acquisition:14.1 ha
3. Tongi	embankment:13.0 km road cum embankment:6.2 km	pump station no:25.2 m^3/s khal improvement:22.0km

	flood wall:2.2 km sluice gate:7 plcs land acquisition:100.9 ha % evacuation facilities:1 LS	retarding pond:265.0 ha land acquisition:42.5 ha
4. Savar	embankment:9.3 km sluice gate:3 plcs land acquisition:62.3 ha %evacuation facilities:1 LS	khal improvement: 30.0 km land acquisition: 66.2 ha
5. Keranigonj	embankment:23.3 km flood wall:3.7 km sluice gate:10 plcs land acquisition:163.7 ha % evacuation facilities:1 LS	pump station:27.7 m^3/s khal improvement:22.5 km retarding pond:292.0 ha land acquisition:50.6 ha

2.1.3 FAP-8B Study

Dhaka Integrated Flood Protection Project FAP 8B was a priority component of the Bangladesh Flood Action Plan (FAP). The underlying rationale for the Project was to provide flood security in Dhaka City to improve the urban efficiencies and environmental conditions, particularly for the urban poor, and to promote stainable long term economic development. A number of projected enlisted in **Table 2.5** indicated the proposed agencies to carry out the development works.

Table 2-5: Scope for Different Government Agencies

Government Agency	Scope of Work
BWDB	▪ Foundation stabilization on 7.8 km of the existing embankment; ▪ Erosion control and slope protection over 11.5 km; ▪ Minor remedial works and slope protection over 24,2 km; ▪ Repair and stabilization of parts of 5.3 km of existing concrete flood wall; ▪ Construction of 1.6 km of new flood wall/embankment; ▪ Construction of 5 additional sluices along the existing embankment; ▪ Raising and flood proofing of the central spine road Construction of the first stage (22.5 cros) of Pump Station No. 3 at. ▪ Establishment of a maintenance program and supply of maintenance equipment to safeguard the flood protection investment.
DWASA	▪ Rehabilitation and upgrading of 21 existing priority khals (including completion of the crash program initiated by the government), for a total length 78.6 km. ▪ Rehabilitation and construction of 50.7 km of pipe drains. ▪ Establishment of a maintenance program and supply of maintenance equipment to safeguard the drainage improvement investment.
DCC	▪ Slum and squatter area improvements covering about 8,725 beneficiary families.

	▪ Solid waste management, including the supply of 30 new trucks and complementary waste handling equipment. ▪ Sanitation improvements, including 30 public toilets and 5 mobile toilets, 5,500 low cost sanitary latrines for low income residents, and 2 septic tank de-slugging trucks. ▪ 1,000 public water standpipes for low income communities; ▪ Rehabilitation and extension of 131 km of minor local drains, and supply of 1 drain cleaning truck.
Others	A Project Implementation Office, headed by the BWDB, staffed by representatives of each participating GOB agency, and strengthened by consulting and training services, was planned to provide the following support: ▪ Planning, detailed design, construction supervision, monitoring and evaluation; ▪ Coordination and management of Project activities; ▪ Equipment and logistical facilities; ▪ Quality assurance and control (including establishment of a materials testing laboratory, to complement and work in cooperation with existing laboratories).

Integrated Environmental Management Plan for Dhaka: Dhaka Integrated Flood Protection Project had been formulated in the context of an Integrated Environmental Management Plan (IEMP) for Dhaka city to provide an integrated framework wherein selected investment components were complementary to the proposed drainage and flood control program, and was expected to mutually reinforce their impacts on an area-wide basis. The existing situation, problems and needs were identified by sector for following:

- Land use management.
- Water quality, sewerage and excreta management.
- Water supply.
- Solid waste management.
- Slum and squatter area improvement.
- Industrial, hazardous and toxic materials and waste management.

Land Use Management: The report identified that there was a lack of effective land use management in Dhaka which had resulted in, on the one hand, uncontrolled and unregulated urban growth with consequent environmental degradation and blocking of natural drainage channels, and, on the other hand, a lack of adequately serviced land to meet the increasing demands for new housing. Actions identified as being necessary to address these problems include the need to:

- Prepare and adopt a national policy for providing clear direction on urban development policies and strategies, and alleviation of urban poverty.
- Preview, approve and adopt physical planning and land use control legislation.
- Prepare up-to-date Master Plan and Structure Plans for long term guidance and strategic planning.
- Develop land use standards, development standards, and control mechanisms.

- Review Government land ownership and needs and recommend appropriate Government policies and strategies for rationalizing the use of vacant and under-utilized lands considering the potentials for disinvesting the lands, converting the lands for public use, for use for low income residential use, or transferring/leasing/selling to squatters/ settlers to provide long term security of tenure.
- Establish a formal development review committee with representatives from RAJUK, DWASA, DCC, DoE and all utility agencies.
- Develop a strategic long term plan for land acquisition for public use and for low income.

2.1.4 Review of IWM Study in 2006

The drainage in study area depends on operation of storm water drainage system including pump and regulator and water levels on peripheral rivers. Western Dhaka was divided into 16 zones, covering a total area of about 145 km^2. Eastern Dhaka was divided into 3 zones, covering a total area of about 116 km^2. It was reported in IWM study that; the drainage system of Dhaka city is inadequate. Expansion and rehabilitation of the existing drainage system is required. Sewer lines should be separated from storm water drainage system. Adequate solid waste disposal system should be made available to the city dwellers. All internal drainage and flood control infrastructure should be handed over to Dhaka WASA for operation and Maintenance. All the existing natural drainage routes should be freed from encroachment immediately. A joint venture program with DCC is required. RAJUK should ensure that development of eastern Dhaka is carried out under a master plan which would integrate land use plan with that of service utilities, like storm water drainage, water supply and sewerage system.

Table 2-6: Drainage Zones in Greater Dhaka of IWM Study

Drainage Zone	Area (sq. km)	Lowest land level (mPWD)	Highest land level (mPWD)
Western Dhaka	145.08		
Zone 1: Uttara	1.45	7.14	10.17
Zone 2: Ranabhola	7.68	2.37	10.49
Zone 3: Goranchatbari	53.87	1.46	15.95
Zone 4: Shirnitec	1.54	2.02	11.39
Zone 5: Kallyanpur	14.36	1.72	14.13
Zone 6: Rayerbazar	1.78	2.82	10.46
Zone 7: Hazaribagh	1.12	1.76	9.65
Zone 8: Nawabganj	1.76	4.70	9.50
Zone 9: Shahidnagar	0.85	2.93	11.29
Zone 10: Killar More	0.96	2.58	12.87
Zone 11: Mitford	1.79	2.48	10.34
Zone 12: Dholai Khal	6.51	1.53	8.08
Zone 13: Maniknagar	7.84	4.67	10.91
Zone 14: Khilgaon	5.13	2.72	7.65
Zone 15: Nikunja	4.51	1.03	8.72

Drainage Zone	Area (sq. km)	Lowest land level (mPWD)	Highest land level (mPWD)
Zone 16: Rampura	33.9	-1.42	14.43
Eastern Dhaka	116.31		
Zone 17: Boalia	38.08	0.87	9.18
Zone 18: Sutibhola	27.32	0.86	8.42
Zone 19: Norai	50.91	0.84	12.01

During the preliminary design of the drainage system the waste water discharge was not considered and one-day rainfall for 5 year return period was considered for design of drainage system. The designed pump capacity was 14.5 cumec only. Though the area was proposed to be used as agricultural land but most of the parts are now used as residential zone. Some specific government plans and policies are required to develop the area.

- Drainage canal should be protected from solid waste, sewerage and public encroachment.
- Legislation should be framed and enforced it to protect the drainage canal from illegal encroachment.
- Separate sewerage system should be developed by detail investigation and study.
- Retarding ponds should be providing for 716 ha.

2.1.5 DAP Studies

Detailed Area Plan project covered the main Dhaka city (350 km^2) and its periphery covering a total area of about 1528 km^2 including Dhaka Metropolitan Development Plan (DMDP) area, Savar, Narayangonj, Tongi, Gazipur, Kadam Rasul areas.

Model Simulation and Calibration: The structure plan includes RAJUK's development control area. The whole structural area is divided into several mouza maps for administrative purposes. The followings are DMDP structure plan functions: Acting on national policies, establishing aims, policies and general proposals to guide Metropolitan Dhaka's long term growth and development and Providing a framework and mechanisms for ensuring coordination of public and private sector agencies and development planning and investment programs and decisions within the metropolitan area in particular, phasing of development.

Pumping Station: There are some strategies which are strictly followed which include embankments and associated works and flood plans. Essential components of drainage system are retention pond and pumps to drain out excess water. Storm water drainage improvement plan may be either pump drainage system or gravity system. Pump water drainage is essential especially for polder areas. For pump drainage area a 2 days' consecutive rainfall with 5 years' frequency is the design criteria for planning pumping capacity in view of technical and financial reasons. It was suggested that, pumped drainage system is very expensive as both investment cost and maintenance cost are very high. To compensate part of expense it is essential to provide retention ponds.

Protection of Lakes and Water Bodies: The report has rightly mentioned that the ponds, lakes, wetlands and dighis serve as immediate detention areas for storm water. Such water bodies are man-made and also natural; may be privately owned or government owned or khas land. Such areas are strongly recommended to be preserved for drainage relief and source of water for emergency use, fisheries, duckeries, irrigation, environment and use for natural purposes. There are plenty of water bodies like pond, ditch, marshy land and khal in the fringe area. With urbanization and industrialization, many ponds and ditches are being filled up by the owners to make profit from increased land value. The report recommended to protect these areas for making sure sustainable natural drainage system can be maintained in the project area.

Capacity of the Drain: The report highlighted that drainage is a vital issue for development. Improper drainage causes stagnation of water, water-logging and even over flooding of roads, houses, commercial and industrial areas, government and private establishments, and sometimes agricultural land. In planning, drainage is given high priority so that any kind of obstruction to drainage due to proposed roads, railways, embankment, filling of ponds, lowlands for housing, reservoirs and wetland etc. do not occur. Maintenance of drains (Tertiary, Secondary and Primary) should be regularly done and public awareness should be created about household wastes, polythene bags etc. not to be thrown into drains. The khals and rivers lose the drainage capacity due to sedimentation, growth of aquatic plant, etc. and should be re-excavated and cleaned at regular intervals.

Land Acquisition and Protective Measures: The report mentioned that the EIA Guidelines given by the DOE should be emphasized on the avoidance of productive (high value) agricultural land during any development project. The urban expansion and land acquisition should be based on the growth rate of urban population. In areas where roads are required to be built on embankments, ROW should include acquisition of extra land, depending on embankment height, and side slope at least 1:1.5. Traditionally owing to administrative complexities, government do not include people in the formulation and planning process of any project and attempts to implement it with own fund through land acquisition. Such policy has some built-in insurmountable problems that strongly resist its implementation. It is also recommended that large scale land development through land acquisition is not possible for financial and social reasons. This can be adequately handled if people are involved in the process. The DND spine road right of way has capacity to accommodate a rail section in it. RAJUK and NHA can go for new land development approaches like, Land Readjustment, Guided Land Development, Infrastructure Based Area Development and area specific action programs.

Integration of Drainage with other infrastructures: With the proper implementation of the DAP, the drainage system of the City would improve. It was highlighted that the essential component of drainage system is detention ponds and pumps to drain out excess storm water. In addition, this system, involves other flood protection infrastructures and canal networks to bring water to the pumping station from detention areas.

Review of Clean Dhaka Master Plan, 2005: In 2005, JICA prepared a solid waste management plan on behalf of Dhaka City Corporation. The Study area covers the jurisdiction of the Dhaka City Cooperation (DCC), which totals about 131 km^2. Sites of the new landfill facility will also be included in the study even if they are located in new urban area outside the jurisdiction of DCC. The Study covered three types of solid wastes generated in the jurisdiction of the Dhaka City Cooperation: namely, Domestic waste, Industrial waste, and Medical waste and master plan was made by focusing on domestic waste.

In Dhaka City, waste collection consists of two parts, namely primary collection and secondary collection. DCC is responsible for secondary waste collection to remove waste from its dustbins/containers, and transport the waste to final disposal sites. Residents are responsible for bringing their waste to DCC's waste collection points where dustbins/containers are located. NGOs/CBOs/private sector provide primary collection services to collect waste door-to-door and transport the waste to dustbins/containers, or sometimes to vacant lands, by rickshaw vans. At present, NGOs/CBOs/private initiative primary collection services are prevalent in wide areas of Dhaka City. JICA conducted study on solid waste generation in dry and wet seasons to obtain the unit waste generation rate of domestic waste and commercial waste. It is estimated that, average waste generation rate from domestic source was 0.34 kg/c/day. From street, the rate of average waste generation is 364.5 kg/km. Road side drains are playing a vital role to collect the storm water and discharge them into nearest water bodies or canals. If the solid waste generated from street is not cleaned properly it will definitely block that storm water drains. It is reported that, DCC cleans the street by deploying approximately 5,000 cleaners. It was estimated that on average, one sweeper sweeps 110 m of road length.

There are six groups of cleaners besides truck/container cleaners. According to DCC, there are 119 storm sewer cleaners and 179 VIP road cleaners. Duties of the storm sewer and road cleaners are to carry the waste to nearest bin or container. But in practical it is found that, solid waste from roads are cleaned and heaped near to a roadside drain, which is supposed to be collected by van or DCC trucks. Many of the cases, these wastes go into the storm drains and results in clogging of storm drains, more specifically inlets. This master plan emphasizes highly on Demarcation and Collaboration Work of Drain Cleaning with WASA as well as sharing of ownership. According to the Clean Dhaka Master Plan, DCC is cleaning all of the channels beside the roads and drainage under the footpath and some roads but not the big pipelines.

Overall Recommendations: In order to protect the land from flooding and eliminate drainage problems and to enhance the security of people in the study area, an optimum flood protection and drainage improvement plan, comprised of either non-structural or structural measures, is essential. Canal network within DND with installation of Pump Stations is a huge project under Water Development Board (WDB). According to JICA proposals, DND is divided into three drainage compartments for efficient discharge of accumulated water from precipitation and accommodate the time lag required for pumping out of the excess water. The proposal includes provision of separate Pump Houses for each compartment, located in three convenient locations for quick discharge into the outfalls.

Drainage Design: The report stated that any physical development activity without considering the drainage plan may create drainage problems. Proper drainage is a vital issue for sustainable and healthy urban development. Improper drainage causes stagnation of water, water-logging and even over flooding of roads, houses, commercial and industrial areas, government and private establishments, and sometimes agricultural land. In planning, drainage should be given high priority such that any kind of obstruction to drainage due to proposed roads, railways, embankment, filling of ponds, lowlands for housing, reservoirs and wetland etc. do not occur. Maintenance of drains (Tertiary, Secondary and Primary) should be regularly done and public awareness should be created about household wastes, polythene bags etc. not to be thrown into drains. The khals and rivers lose the drainage capacity due to sedimentation, growth of aquatic plant, etc. and should be re-excavated and cleaned at regular intervals.

2.1.6 Review of Drainage Master Plan Report for Dhaka City

Bangladesh is a developing country and the capital city Dhaka is the center of all development activities. It is undoubtedly noted that, unplanned rapid growth of development activities results in significant problems for the city dwellers. Being a flat topographic land water logging is one of the major problems for the city resident, especially during the rainy season. The city is already densely populated and the volume of population will further increase in future, following the recent trend. Storm water drainage is essential issue for this city where 40% of the people are slum dwellers and face acute problem during heavy monsoon. In absence of storm water master plan, storm water drainage structures are built up in an unplanned way and there is no specific rules and regulation for operation & maintenance. The present drainage facilities are quite less than adequate and most of the natural drains not functioning properly due to blocked by improperly handled construction material along the road sides, choked by garbage and poor maintenance. Dhaka Water Supply and Sewerage Authority (DWASA) mainly responsible for storm water drainage, has taken a step forward to alleviate the long lasting storm drainage problems of Dhaka city by preparing a master plan. In this regard the consultant group JPZ- FCEA-SARM-JV submitted the Draft Final Report (DFR) to DWASA in April 2014.

The Report submitted as Draft Final Report, covers specific objectives and deliverables such as:

- Description of study area with analyses of existing land use, geology/ soils, meteorology, topography and socio economic condition.
- Baseline data for hydrology and hydraulics of drainage system.
- Inventory of primary, secondary and tertiary drains with their characteristics.
- Digital and paper drainage basin maps and flow diagrams for the watershed and sub-sheds (minimum scale 1:10,000).
- Recommendation for land acquisition and protective measures.
- Ranking methodology for prioritizing drainage improvement projects.
- Specific projects for improvement of DND area.
- Design manual including design standards for designing of drainage infrastructures.
- Cost estimates and feasibility assessment for proposed drainage improvement projects.

- Recommended schedule of implementation of drainage improvement projects.
- Hydrodynamic modelling results.
- Report on incorporating drainage issues from DAP and/or DMDP and other urban area plans and recommendation on concerned law, legislative and institutional arrangement for sustainable development of this sector.
- Solid waste management strategy for drainage control.
- Strategy for water quality management, including removal of waste water inflow.
- Strategy for preserving and improving wetlands/low lands, including land acquisition.
- Funding and cost-sharing strategy for future projects.
- Report on feasibility of combined sewer and sewer overflows to drainage.
- Recommendation for legislative and regulatory reforms necessary to implement the Master Plan.
- Strategic environmental assessment for implementation of the Drainage Master Plan.
- Stakeholder input.

This report contains one main report along with nine annexes. Main report contains nine chapters describing sequentially the introduction, study area, storm drainage issue in Dhaka city, urban planning and drainage development, review of previous study, master planning methodology, storm water best management practices, structural and non-structural proposals regarding the improvement of drainage condition and management, reformation of legal and institutional arrangements, land acquisition & protective measures, strategic environmental assessment, detail cost estimation and cost recovery process.

In the Drainage Master of Dhaka city, 26 nos of drainage khals are described. Descriptions about some of the concerned khals for this study are given below:

Baunia khal: Having a length of 7.6 km starts from Mirpur 14 and falls on Digun khal. It has a bridge near Kalshi. At upstream part of the bridge there exists water body which holds storm water. But this water body is under threat of land filling.

Shangbadik Colony khal: This khal is 2.40 km long which starts from Mirpur 11 and falls on Baishteki khal. This khal is rectangular channel and main problem is sedimentation and solid waste. Another issue is sewerage connection.

Mirpur Housing Khal: Length of this khal is 1.01 km starting from Mirpur 11 and ends on Baishteki khal. People are encroaching from both side of the khal. Solid waste is also reducing the carrying capacity of this khal.

Baishteki khal: Length is 460 meter and carrying the combined discharge of Shangbadik Colony khal and Mirpur Housing khal. It falls on Baunia khal.

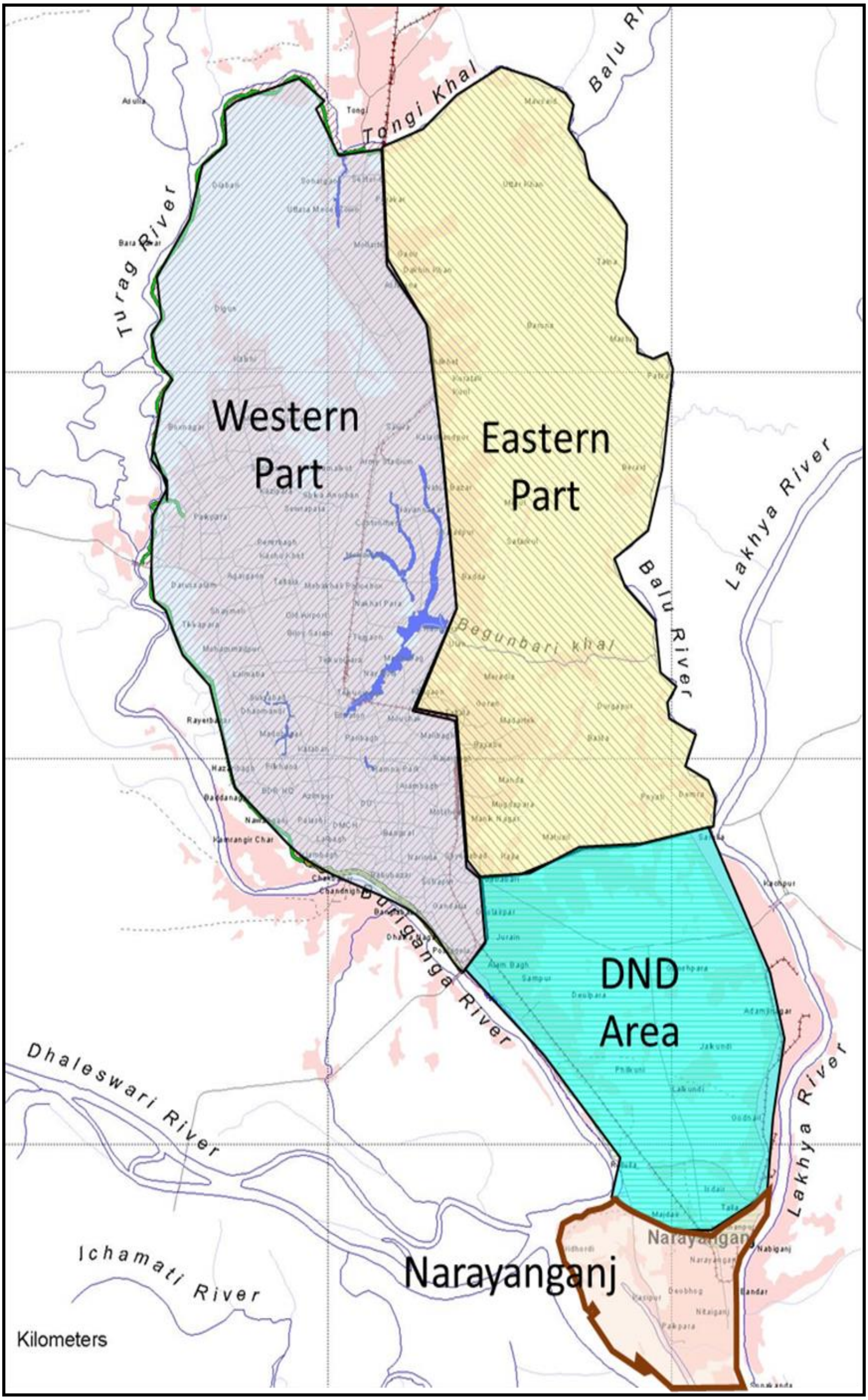


Figure 2-3: Map of Study on Drainage Master Plan for Dhaka City

Hazaribagh Khal: Length of this khal is 0.42 km and it carries storm water from Hazaribag area. The khal is carrying huge tannery waste. Solid waste is also reducing the capacity of the khal.

Sutivola Khal: This khal connects Begunbari khal and Shajadpur khal and total length is about 4.10 km. This khal is still in good condition but development work is progressing on both side of the khal.

Begunbari Khal: One of the most important khals in Dhaka. It drains out the discharge from Rampura pump station and runoff generated from Rampura and Aftabnagar to Meradia Gozaria khal. Bank erosion was observed on left bank of the khal. This khal is also being used as transportation of sand by boat.

Meradia-Gojaria Khal: Total length is about 2.64 km and it drains the discharge of Begunbari khal to Balu River. The capacity of the khal is still good.

Norai Khal: This khal starts from Trimohony and fall on Balu River. It is in good condition.

Khilgaon-Basabo Khal: This khal starts from end of Shajahanpur khal and total length is about 1.96 km. This khals has box culvert and rectangular channel. Sedimentation in box culvert reduces the capacity of box culvert. Solid waste is also a problem of this khal.

Manda Khal: Total length is about 4.09 km and it carries discharge from Basabo khal and Segunbagicha khal.

2.1.7 Review of IWFM studies for Dhaka City Flooding

IWFM undertook a study of the 2004 flood which heavily affected the Greater Dhaka area: "Investigation of Hydrological Aspects of 2004 Flood - with Special Emphasis on Dhaka City" (IWFM 2005). The study focused on identifying the main features of the flooding in terms of extent (area) affected, timing and duration of inundation, etc. Some recommendations in line with the main studies discussed above were also reiterated.

IWFM also undertook a similar study for the 2007 flood: "Hydrological Aspects of 2007 Flood" (IWFM 2008). Again, the focus of the study was an ex-post analysis of the key features of the flood. The study also looked into the performance of the drainage system and provided some recommendations, such as fixing of sluice gates and installation of permanent pumps at Rampura. The recommendations from the Halcrow study have been included in the Eastern Dhaka Future Scenarios modeled in this climate change study.

2.1.8 Other studies

A drainage Master Plan for Narayanganj Pourashava (UGIIP, 2006) was also collected and reviewed. This report identified changes in the drainage system in the township and also provided recommendations.

A modeling study for the Eastern Dhaka area was undertaken in the following project: "Updating/Upgrading the Feasibility Study of Dhaka Integrated Flood Control Embankment cum Eastern Bypass Road Multipurpose Project" (Halcrow 2006). The scenarios modeled included embankments on both sides of Balu River and also just on the right bank. Different pump options were investigated. The study recommended three pump stations with associated retention ponds along the proposed Eastern Embankment. Some potential impacts on RAJUK's Purbachal project were identified in this study.

A report on the Integrated Development of Hatir Jheel Area (RAJUK 2008) was also collected and reviewed. The ongoing changes to the lake area and drainage system have important implications on the drainage system of Central Dhaka. The proposed lake cross-sections and drainage system changes have been included in the Central Dhaka Future Scenarios modeled in this climate change study.

A recent project focusing on the drainage situation of the DND has been collected and reviewed: "Feasibility Study on Drainage Improvement of Dhaka-Narayanganj-Demra (DND) project" (BWDB 2010). The study included modeling of different options in terms of pump sizes and locations. The recommended strategy from the BWDB study has been incorporated in the DND Area Future Scenarios of this climate change study.

Another study reviewed was: "Modelling Study for Ascertaining the Area of Regulating Pond for Kalyanpur Pumping Station, IWM (2011). The recommended pond area of approx. 100ha (1sqkm) agrees with the proposed landuse in DAP for this area. The recommendations from the IWM study has been adopted in the Kallyanpur Area Future Scenarios modelled in this climate change study.

It should be noted that none of the above studies considered scenarios of potential impacts of climate change on the rainfall intensities; flooding extent; etc. This study has incorporated the recommendations for drainage improvements from the above mentioned studies as part of the future scenarios that have been modelled.

2.2 REVIEW OF PAST STUDIES OF GORACHATBARI DRAINAGE

The review of the past studies, and relevant documents is a pre-requisite for assessing existing drainage situation and to determine the extent of work required to address the objective of project. With this view following past study reports have been reviewed:

- Draft Drainage Master Plan for Dhaka City (2014)
- Study on Drainage Master Plan (IWM, 2006)
- FAP 8B- Dhaka Integrated Flood Protection Project (1991)
- Feasibility & ESIA Study of 5 khal of Dhaka City (2015)
- Urban Flooding of Greater Dhaka Area in a Changing Climate: Vulnerability, Adaptation and Potential Costs (2014)
- Assessment of Kallayanpur Regulating Pond Area and Pump Capacity (2013)
- Sewerage Master Plan (2012)
- DAP Study (RAJUK, 2010)

2.2.1 Draft Drainage Master Plan for Dhaka City (2014)

The present feasibility study on drainage zone 1 & 2 (Goranchatbari and Kallayanpur respectively) was initiated by DWASA as a follow-up of the Drainage Master Plan prepared for Dhaka city. Various problems associated with the drainage system preferably khals of all 13 zones within master plan area (1435.89 sq.km) have been identified and several recommendations have been outlined.

Review for Zone 1 (Gorancharbari)

Reduction of conveyance due to sedimentation and dumping of solid wastes have been identified as a common problem for all khals of Zone 1. Encroachments have been identified for Rupnagar khal and its branches. In addition, concern was expressed regarding filling up of low lying areas surrounding Baunia khal, which act as retention areas during wet season. In order to mitigate these problems, several structural and non-structural measures have been recommended in the draft master plan which are summarized in following sections. These recommended measures will be a guideline for the present study as far as identification of future improvements are concerned.

Structural Measures

- 0.47 sq.km storage/retention area at Kalapani for pumping
- Excavation of 7.63 km long khal (up to 40 m width) from Mirpur-14 to Uttara 3rd phase
- Cleaning sediment and debris from all khals and excavation & realignment of Sanbadik Colony Khal, Baisteki Khal and Mirpur Housing Khal
- Remove encroachments and undesirable landuses in available land allocated for Goranchotbari pump station
- Provision of drainage facility to north western part of Uttara and northern area of Uttara 3rd phase
- Construction of 2.0 km long secondary pipe drain from Pallabi to Mirpur-10
- Construction of some secondary drain/ pipe drain at Sheorapara and Kazipara

Non-Structural Measures

- Formulation of a separate drainage management zonal authority
- Protection of all low laying areas and water bodies (gross area greater than 2.0 hectares) from encroachment
- Proper drainage planning for new emerging urban areas such as Uttara 3rd Phase, Mirpur DOHS etc.
- Regular maintenance of the drains/ pipes/ khals before the advent of the monsoon
- Create public awareness to reduce intensity of solid waste dumping in the drainage system and encroachments.

Priority Projects

About 255 priority projects have been identified in Drainage Master Plan. Total 34 priority projects have been identified for Zone 1 and Zone 2 (17 for each zone). All the projects are recommended to implement in 3 phases.

1st phase (2015-2020) priority includes rehabilitation and up-gradation of Katasur Main khal. In 2nd phase (2020-2030) rehabilitation and up-gradation of Rupnagar Main khal, Digun khal along with its branches, Rupnagar Branch “Ka” khal, Sangbadik Colony khal, Abudullahpur Branch “Ka”, “Kha” khal, Baishteki khal, Diabari Main khal, Diabari Branch Ka-Kha-Gha khal, Katasur Branch Ka khal, Kallayanpur Main khal, Kallayanpur Branch Gha and Uma khal have been included. In addition, construction of storm sewer pipe line in Monipur, Ibrahimpur, Cantonment area; construction of RCC/ pre-stress pipe line at Shenpara (mirpur-10), Kazipara, West Shewrapara, Taltola, Kallayanpur paikpara, Shamoli, Shaikhertek, Ring Road, Tajmahal Road, Parliament area, Manikmia avenue, Lalmatia (mirpur road), Zafrabaad, Town hall, Rayer Bazar, Zigatola, Dhanmondi 7/A, 8/A, 9/A, 10/A, 11/A, 12/A, 13/A areas are included in 2nd phase priorities.

3rd phase (2030-2040) priorities includes rehabilitation and up-gradation of Digun Main khal, Ibrahimpur khal, Mirpur Housing khal, Baunia Main khal, Baunia Branch- Ka, Kha, Ga, Gha, Uma khal, Abdullahpur Main khal, Ramchandrapur Main khal, Ramchandrapur Branch Ka khal, Kallayanpur Branch Ka, Kha, Ga and Cha khal. Construction of earthen drain (Unlined Drain) at Noanagar, Uttara Residential Area, Baidertek, Shajalal International Airport Area, MES, Bhashantek area are also included. In addition, construction of retention pond at Potal Beel, Western Housing, Birulia Bridge area and Gabtoli area have been recommended as 3rd phase priorities.

Design Guideline for Drainage Improvement

The Drainage Master Plan has established design criteria for any sort of drainage improvement works in Dhaka city. That design criteria will be used in current study as a guide line for conducting outline design works.

2.2.2 Study on Drainage Master Plan (IWM, 2006)

The Master Plan was prepared for Western Dhaka (145.08 sq.km), Eastern Dhaka (116.31 sq.km) and DND area (56.79 sq.km). For Greater Dhaka (Western and Eastern) area 19 drainage zones have been demarcated based on the catchments of a particular outfall. Among 19 drainage zones, 5 zones are relevant with the project study area. Those 5 zones are Zone 1: Uttara, Zone 2: Ranabhola, Zone 3: Goranchatbari, Zone 4: Shirnirtek and Zone 5: Kallayanpur.

Several drainage improvement measures have been recommended for the 5 zones in the Master Plan which have been summaries in following sections. The recommendations may be used as a guideline for selecting appropriate improvement measures under the present study.

Recommendations for drainage improvement in Zone 1 (Uttara)

- Increasing the conveyance of the existing borrow pit and surface drain of DCC at Sector 6 and connecting the channel with sluice gate of the northern Dhaka flood control.

- Establishment of new drains from Sectors 6 and 8 to the sluice gate on Dhaka flood control embankment.
- Proper maintenance of drain/outlet from sluice gate on flood control embankment to the Turag River.
- Establishment of separate drainage line in Uttara area for facilitating adequate drainage at the northern areas. Prevention of drainage discharge into Uttara Lake by constructing separate drainage line connecting to the branch canal of Abdullahpur khal.
- Establishment of a canal for facilitating as a surface drain ensuring drainage from Sectors 5, 7, 9, 11 areas to Goranchandbari pump station.
- Temporary pumping arrangement is required near Tongi Railway Bridge to drain out storm-water from Sector 6 during high stages in Tongi khal.

Recommendations for drainage improvement in Zone 3 (Goranchatbari)

- Establishment of a canal with sustainable right-of-way and proper conveyance connecting Mirpur to Goranchandbari pump station
- Resuscitation of existing drainage canals in Kallayanpur with proper width and gradients
- Construction of a new pipe drain connecting Pallabi (north part) to Rupnagar-Duaripara storm sewer line. Connection of Mirpur Housing canals of Rupnagar, Duaripara, Shialbari Section-C with Diabari
- Rehabilitation/modification of existing DCC surface drains with adequate conveyance from Pallabi Bus Stand to Muslim bazaar
- Establishment of a new open surface drain with adequate conveyance from BCIC complex to Pallabi 2nd phase to Goranchandbari sluice via western boundary of Rupnagar (Mirpur) residential area
- Establishment of a new pipe drain from Mirpur Section 13 to Ibrahimpur khal
- Establishment of a new pipe drain from Mirpur Section- 10 to Baisteki khal including sufficient numbers of catch pits
- Connecting Shewrapara area to Kallayanpur Branch khal with a pipe or box culvert
- Increasing the conveyance capacity of pipe drain connecting Kazipara to Mirpur section
- Laying a separate pipe drain from Kazipara to Ibrahimpur khal through Senpara-Parabata areas
- Construction of box culverts on Ibrahimpur khal across road crossings and other places to maintain conveyance section for unhindered flow.

2.2.3 FAP 8B- Dhaka Integrated Flood Protection Project (1991)

Dhaka Integrated Flood Protection Project FAP 8B was a priority component of the Bangladesh Flood Action Plan (FAP) funded by the ADB. The project had objectives of identifying Flood Protection, Drainage, Environmental Improvement Program, Implementation Assistance projects which covers 260 sq.km area of Greater Dhaka. As a first phase of a long term flood protection program, the project focused on the highest priority area, the westerly part of Dhaka City covering approximately 136 sq.km. The underlying basis for the Project was to provide flood security in Dhaka City to improve the urban efficiencies and environmental conditions, particularly for the urban poor, and to promote stainable long term economic development. In the final report of FAP 8B, in flood protection part, it was mentioned that there would be construction of gate control structures at each of the 13 drainage channel crossings. Moreover, there was provision of temporary pumping facilities along the easterly boundary for evacuation of internal rainfall during periods of high river stage combined with heavy rainfall. In Drainage part, the proposed drainage works were a necessary complement to the flood protection works, and the primary focus of the drainage improvement programme was on creating an integrated drainage system within the Dhaka urban area to eliminate/ reduce the drainage congestion and regular local flooding which prevails during the monsoon season. Recommended flood protection and drainage improvement measures are as follows:

Infrastructural Recommendations (Flood Protection)

- Works for foundation stabilization on 7.8 km of the existing embankment on the western side of the project area.
- Filling the borrow areas close to embankment and restoration of eroded areas (approx. length 17.67 km); Minor remedial works and slope protection.
- Construction of 1.6 km of new flood wall/embankment, extending from Kellar Morh south-easterly to tie into the existing floodwall of Mitford Hospital.
- Repair and stabilization of parts of 5.3 km of existing concrete flood wall.
- Construction of 5 additional sluices along the existing embankment.
- Construction of the first stage of pump station no. 3 at Goranchatbari (capacity 22 cubic meters per second).
- Raising and flood proofing of the central spine road.

Infrastructural Recommendations (Drainage)

- Dredging and re-profiling of 78 km of major existing drains and repairing of the associated road crossing culverts.
- Rehabilitation and construction of 51 km of piped drainage facilities in the built-up areas of the city.
- Completion of urgent drainage works which commenced under the GoB crash programme designed after the heavy pre-monsoon rains of 1991. Cleaning and unblocking existing covered and open drains in the more densely populated parts of the city, together with a limited programme of construction of small capacity new drains.
- Rigorous operations and maintenance programme for the drainage works over the project implementation phase.

2.2.4 Feasibility & ESIA Study of 5 khal of Dhaka City (2015)

This study was conducted for five khals namely Hazaribagh khal, Baishteki khal, Sangbadik Colony khal, Manda khal and proposed new Kurmitola khal which were needed to secure immediately as there were possibilities that land owners may block the drainage route by constructing different structure. Among the five khals, Baishteki khal, Sangbadik Colony khal and proposed Kurmitola khal are included in this present study.

In the study all field problems associated with the Baisteki and Sangbadik Colony khals were identified by extensive field visits and improvement measures such as khal widening, realignment and construction of walkways were recommended along with outline design and land acquisition plan. Also detailed survey of those two khals and relevant drainage structures were surveyed which can be used as authentic secondary data for the present study.

The study recommended that has to be development of Baishteki khal for a length of 1060 m started from road crossing culvert at Jhutpatti up to the confluence of Baunia khal and development of Shangbadik colony khal for a length of 863 m from road crossing culvert at Kalshi up to the confluence of Baishteki khal. Land acquisition of about 6.385 acres' area at Senpara mouza has been recommended in the study for development of Baishteki and Sangbadik colony khal.

2.2.5 Urban Flooding of Greater Dhaka Area in a Changing Climate (2014)

The study conducted by World Bank covers an area of approx. 1,528 square kilometers (sq.km) corresponds to the Dhaka Metropolitan Development Plan (DMDP) area of RAJUK. Detailed estimate of location specific flood depth and duration have been calculated for the detailed study area of about 345 sq.km. Detailed study area was divided in to 7 subzones of which Kallayanpur and Gorancharbari zones are found relevant with the present feasibility study. Flood simulation with and without climate change factors for 2004 (base), 2025 and 2050 years were carried out for both Goranchatbari and Kallayanpur zones. In addition to the planned improvement measures (e.g. khal widening, constructing large diameter pipe drains and pump stations) by different agencies, some additional improvements and adaptation measures have been recommended in the study.

For Kallayanpur zone, installation of about 2.5 km pipe drains has been recommended of which about 2.0 km pipe drains falls within the current feasibility study area. Increasing capacity of the temporary pump stations at different locations have been recommended. In addition, regular cleaning & maintenance of khals, protecting them from encroachments and preservation of 100 ha retention pond at Kallayanpur pump station have been recommended with high significance.

For Goranchatbari zone, installation of pipe drains of about 5.8 km at different locations has been recommended. In addition, protection of khals and retention areas from encroachments has been highly recommended.

2.2.6 Sewerage Master Plan (2012)

The master plan outlined 13 decentralized sewer catchments within DMDP area and proposed separate Waste Water Treatment Plant (WWTP) and collection networks for each catchment. For Dhaka West (Mirpur) catchment a WWTP location of area about 15 ha to 30 ha (for different treatment technologies) was proposed within the low-lying areas of the storm water retention pond (> 200 ha) at Goranchatbari.

2.2.7 DAP Study (RAJUK, 2010)

Detailed Area Plan (DAP) study covered whole Dhaka Metropolitan Development Plan (DMDP) area (1,528 sq.km) including Greater Dhaka, Savar, Narayanganj, Tongi, Gazipur and Kadam Rasul area. Different proposals and recommendations made in FAP-8B for establishing an efficient drainage system to protect core Dhaka city from drainage flood is accepted by DAP and further development proposals are suggested. Those include general recommendations along with some specific observation for both Kallayanpur and Goranchatbari area. The proposal made in the study for Goranchatbari area were as follows:

- Improvement of secondary and tertiary khals by removing obstruction, unauthorized occupation etc.
- Development of outfall areas of storm sewers and culverts
- Preserving retention ponds at upstream of pump stations equivalent to 12% of whole catchment area.
- Demarcation of retention ponds at upstream of pump to protect retention ponds from encroachment.
- Re-excavation of retention pond areas and water bodies with its approach khals to increase storage capacity.
- Keeping at least 2-4 m of buffer zone with paved area around the small sized wetlands and at least 5-15 m of buffer zone for large sized of wetlands.
- Installation of primary pump stations at different sewer outfalls and to link these pump stations with areas experienced water logging problem.
- Re-excavation of major khals and katcha khals (Arambah Jheel, Katasur and Ramchandrapur khals etc.)
- Cleaning and proper maintenance of pucca drains and creating social awareness to reduce or omit intensity of dumping waste and non-perishable materials into drains.
- Cleaning long box-culverts and its outfall every year.
- Re-excavation of Ibrahimpur khal, Ibrahimpur part-2 (Branch khal), Baunia khal and Digun khal in every 3-4 years to enhance their carrying capabilities leading to Goranchatbari pump station.
- Re-excavation of Abdullahpur khal from Shahjalal Internation Airport to sluice S2 on Tongi Khal

2.3 STUDY AREA

Overall study area includes Goranchatbari (Zone 1) as per DWASA Drainage Master Plan. Total area of the drainage zones is about 70.81 sq.km. which includes 12 drainage khals along with some pipe networks and a drainage pump station at Goranchatbari. Drainage.

2.3.1 Topography of Study Area

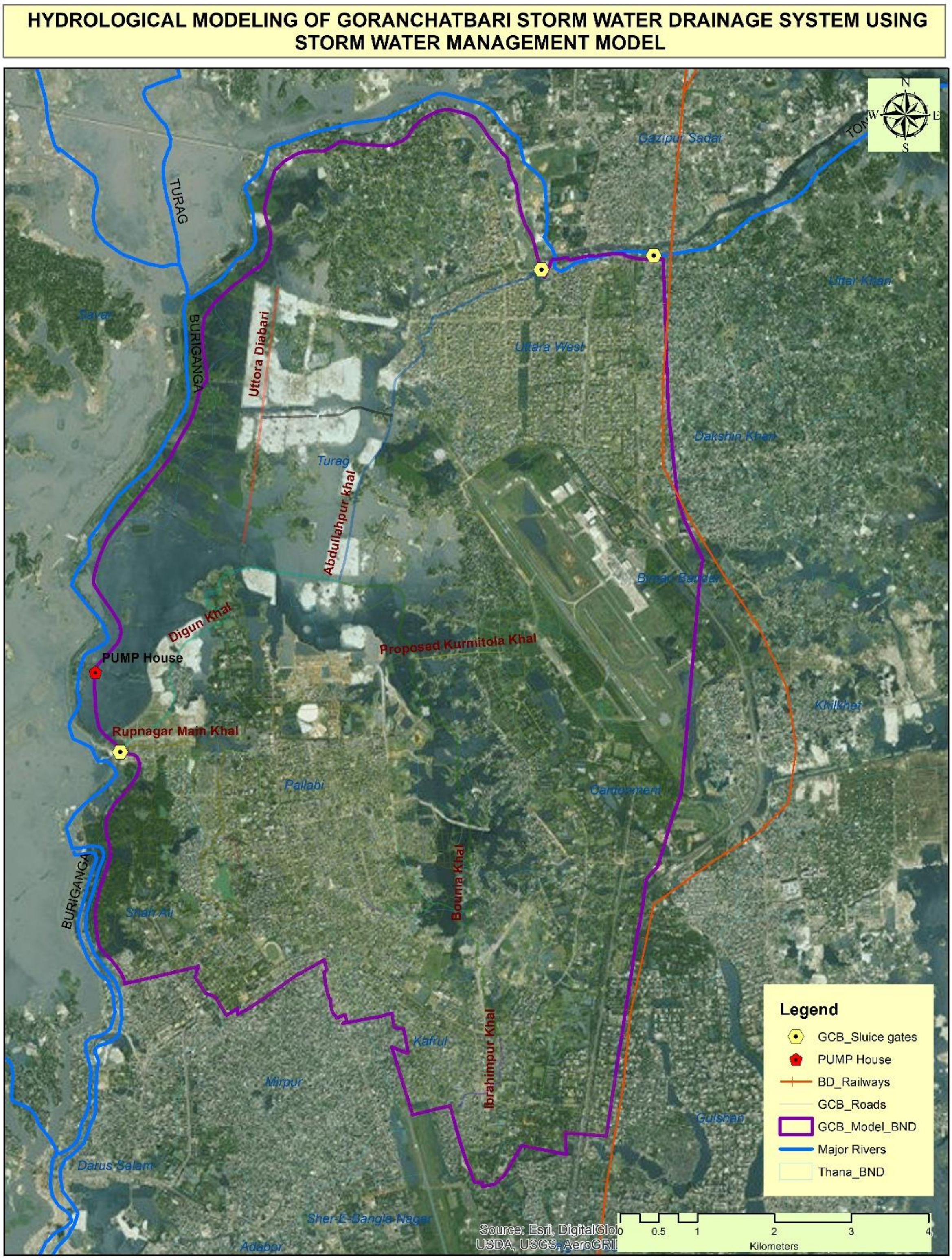


Figure 2-4: Study area with different locations around Goranchatbari

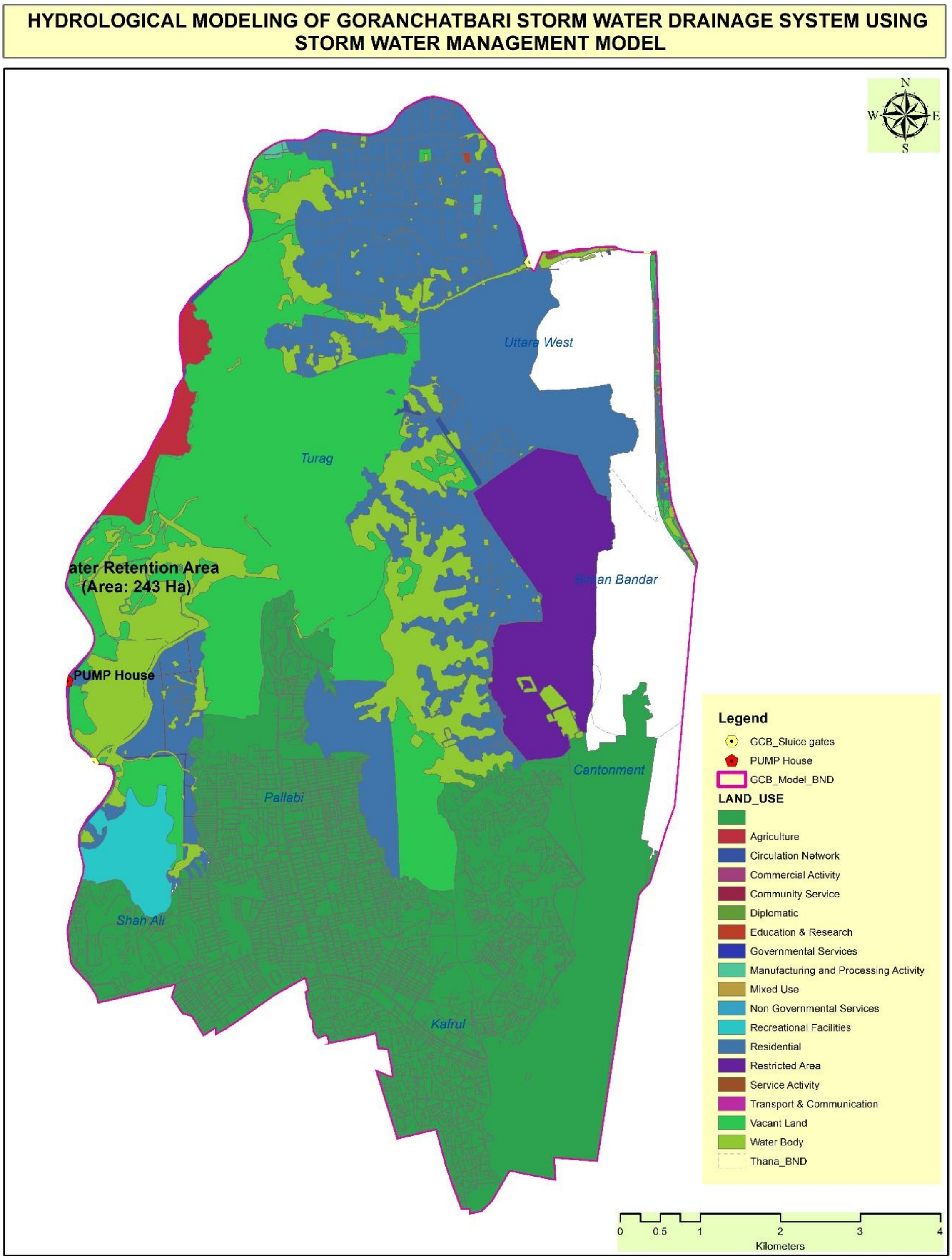


Figure 2-5: Goranchatbari existing landuse

Overall study area shows wide range of topographic variations on Figure 2.5. Ground elevation varies from -8.8 mPWD to 17.0 mPWD. About 48% area stands below 6.0 mPWD and about 13% area is above 8.0 mPWD. Zone-1 (Goranchatbari) comprises flat land & high land in the urban trajectory. It also comprises lots of low lying areas including a huge retention pond. Most of the area is within the range of 5.0 mPWD to 9.0 mPWD. It also consists some high lands and some low laying areas in form of a retention pond.

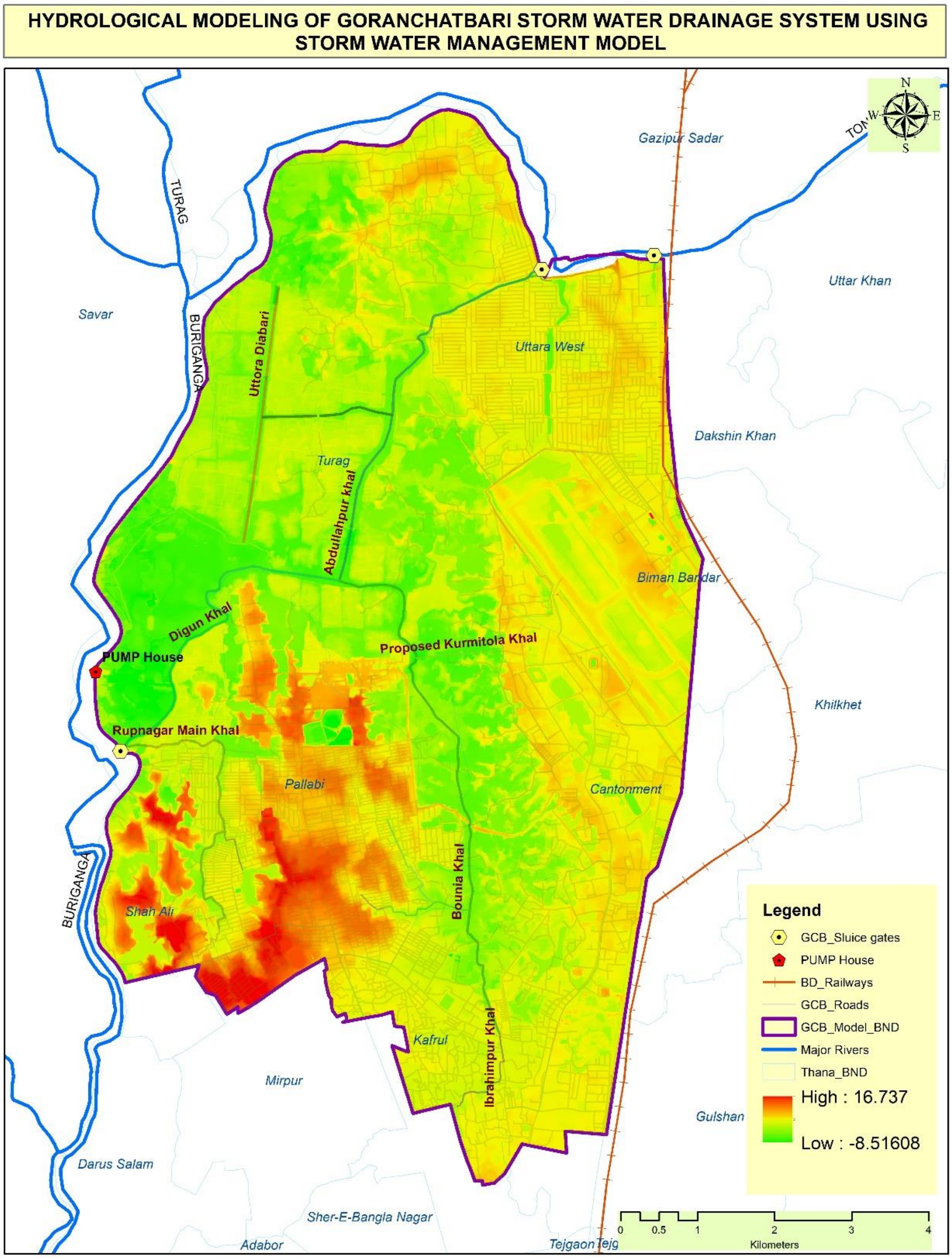


Figure 2-6: Digital Elevation Model (DEM) of Study Area

Population density provided in the census of 2001 and 2011 was linearly interpolated to estimate density for base scenario. Thana-wise future densities (up to the year 2050) were projected using the census data of 2011 (IWM 2012). Changes of population density over various time periods for GCB Model area are shown in **Figure 2-7**.

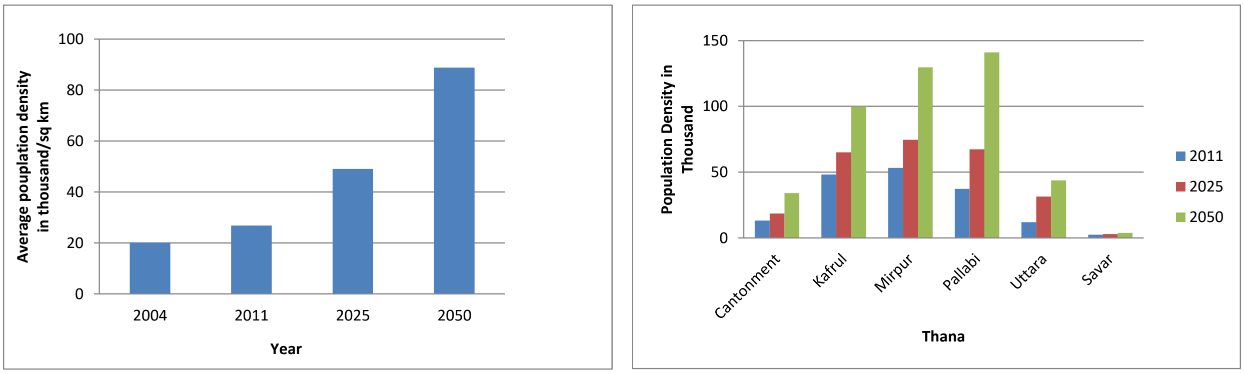


Figure 2-7: Changes of Population Density of Granchatbari study area

The population density of the Goranchatbari area has been steadily increasing from about 20,000 people/sqkm in 2001 to about 27,000 people/sqkm in 2011 according to the National Population survey. The density of Goranchatbari area is projected to increase to approx. 49,000 and 92,000 people/sqkm by the year 2025 and 2050, respectively in the Water Supply Master Plan (DWASA). The socio-economic situation varies widely within the study area. The study area comprises mainly residential, commercial and industrial features.

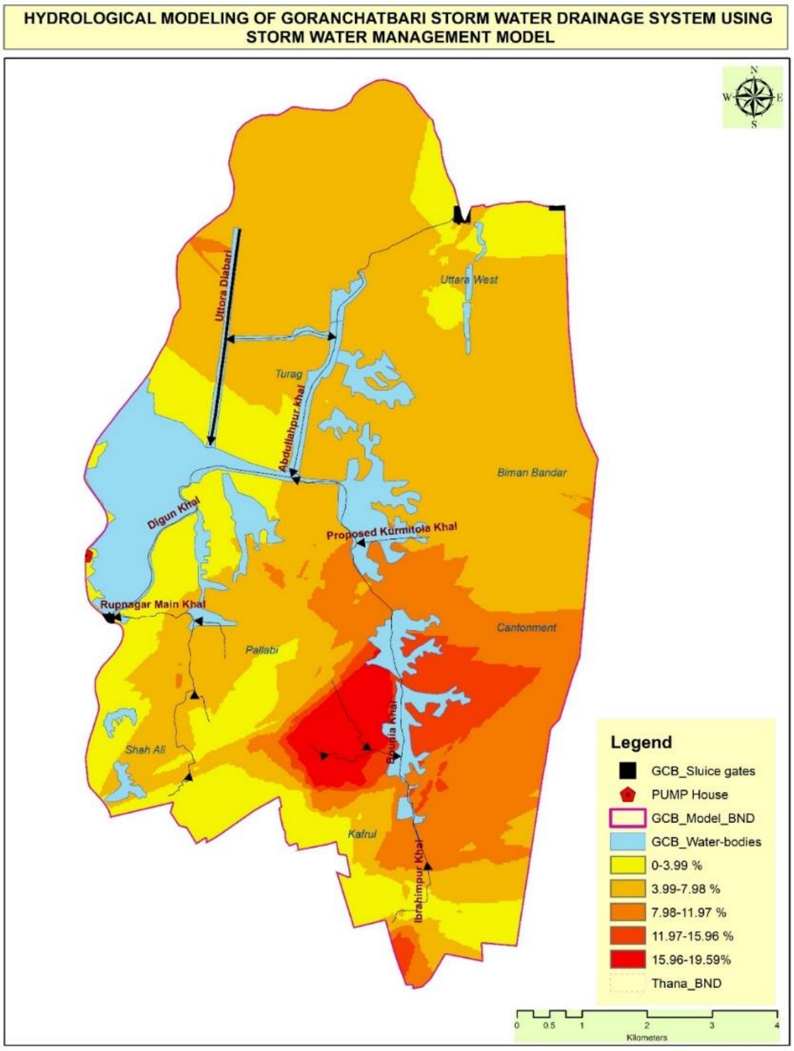


Figure 2-8: Change of land use in future after 2030 with imperviousness

In the northeastern part of the study area, some storm water also drained to Tongi Khal through sluice gates. For all the model simulations, these gates were kept closed due to high river levels, representing the worst possible situation for urban flooding. The drainage system for base scenario included about 112.6 km drainage networks, khals and storm sewers. The model area was divided into 69 sub-catchments for base scenario. Catchments were delineated according to the distribution of drainage networks and land terrain.

For runoff computation, “XP-SWMM Urban Model” was used based on the "Time-Area" method. The runoff amount is controlled by the initial loss, size of the catchment area, percentage impervious area of the catchments and loss due to evapotranspiration and depression storage. Based on the estimated 2011 population densities and DAP land use pattern, the overall impervious fraction was 51%. Change of DEM is showing on the Figure 2-8 where the area is developing according to the population growth,

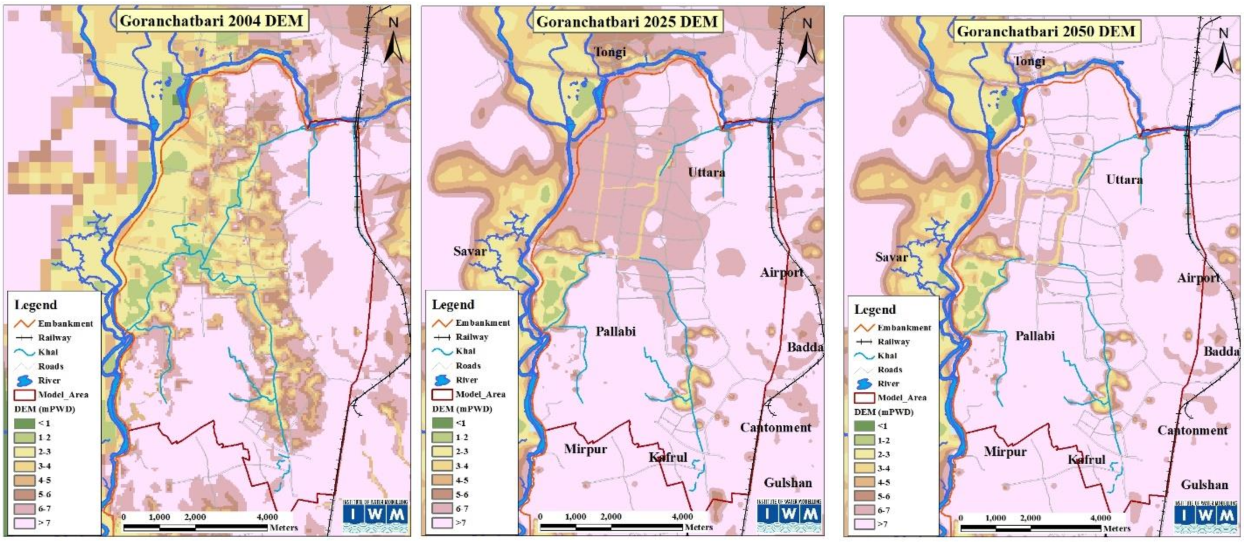


Figure 2-9: Goranchatbari DEM 2004, 2025 and 2050 according to DAP (*Source IWM*)

2.3.2 Existing Drainage System

The existing drainage network includes 12 drainage khals shown on Figure 2-6 which act as primary drainage system associated with secondary pipe drains (450 mm to 2300 mm) and box-culverts. Total length of the primary and secondary drainage networks is about 83 km. The combined system ultimately drains towards Turag River. During dry season the whole system discharges to Turag River and Tongi Khal by three sluice gates at different locations along Dhaka western embankment.

There is a large retention area at Goranchatbari along with a permanent pump station (present capacity 44 cumec) which evacuates runoff during wet season.

List of the khals for drainage Zone-1 is listed below.

Table 2-7: Existing Drainage Khals in Study area

Drainage Zone	Existing Drainage Khals
Goranchatbari	1. Rupnagar Main Khal 2. Rupnagar Branch-1 (Zoo) khal 3. Rupnagar Branch-2 (Arambagh) khal 4. Rupnagar Branch-3 (Duaripara) khal 5. Digun khal 6. Ibrahimpur khal 7. Mirpur Housing khal/ Paris khal 8. Baishteki khal 9. Sangbadik Colony khal 10. Abdullahpur khal 11. Baunia khal 12. Uttara Diabari khal

2.3.3 Existing Drainage Khals

Ibrahimpur Khal

The khal having a total length of about 1260 m (including 360 m box-culvert) starts from North Kafrul area near Civil Aviation boundary and falls to Baunia khal at Mirpur 14 bus stand. It carries runoff from part of Civil Aviation area, North Kafrul, South Kafrul and Ibrahimpur area.

Rupnagar Branch-1 (Zoo) Khal

The khal starts from Zoo road at BCIC staff colony and flows towards Mirpur section-3 and meets to Rupnagar main khal. It carries runoff from Zoo area and part of Mirpur 1. Total length of the khal is about 578 m. The khal is subjected to encroachment in downstream portion.

Rupnagar Branch-2 (Arambagh) Khal

The khal starts from a low lying area at Mirpur section-6 (“Ta” block) and falls to Rupnagar main khal near Jheelpar road. It carries runoff from Arambagh residential area, areas surrounding to Milk Vita road and part of Mirpur section- 6 & 7. Total length of the khal is about 637 m among which about 150 m is twin pipe (diameter 1000 mm each) drain.

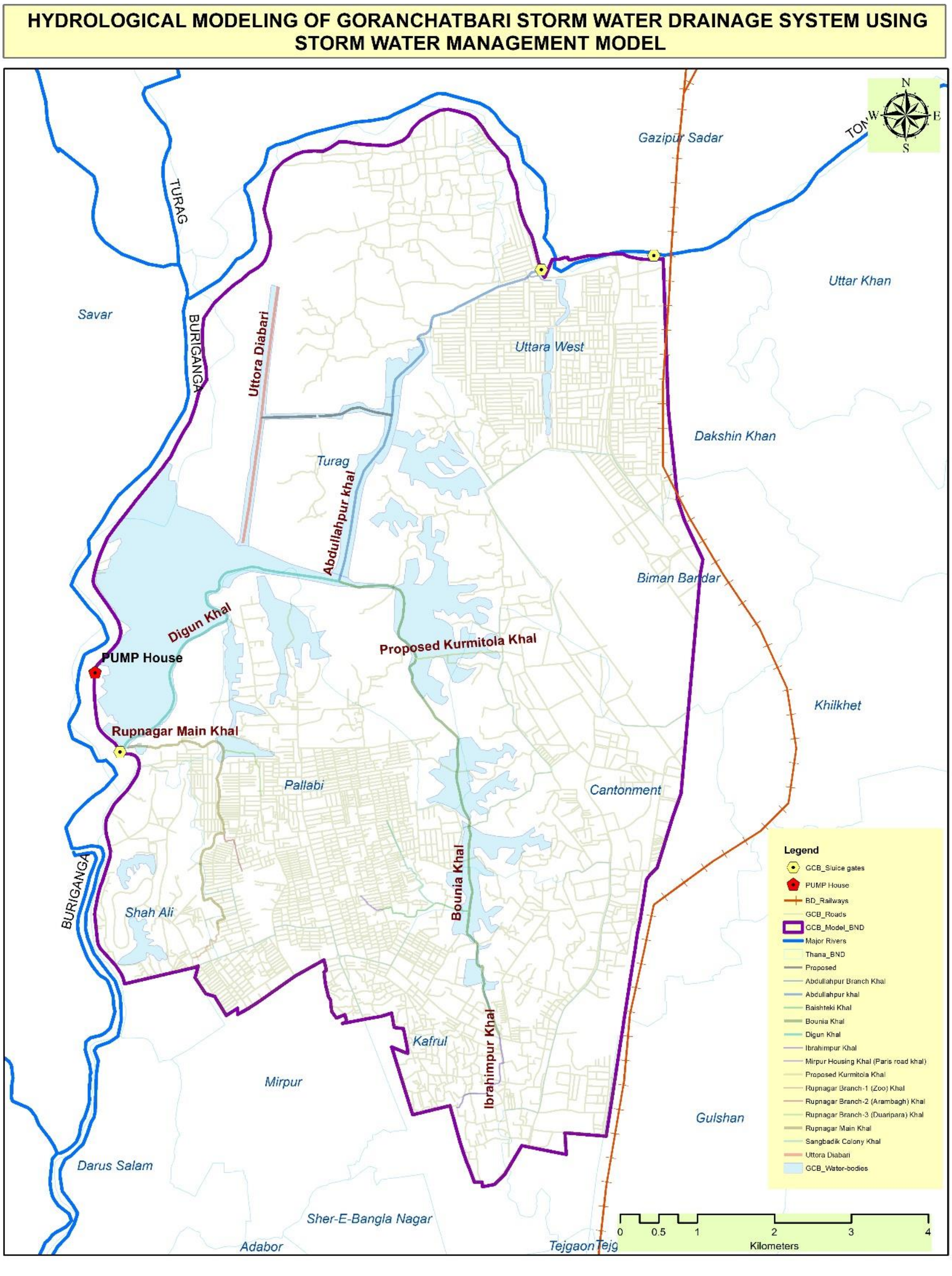


Figure 2-10: Existing Drainage System of Goranchatbari Drainage Zone

Rupnagar Branch-3 (Duaripara) Khal

The khal having a total length of about 843 m starts from eastern side of Duraipara DWASA staff quarter (near Vola Basti) and falls to a low area near Pallabi Jheel Jame Mosque. Flow from this low lying area ultimately drains to Rupnagar main khal through eastern housing area.

It carries runoff from Pallabi, Eastern Pallabi, Extended Pallabi, Part of Mirpur section 12 and Duaripara area.

Rupnagar Main Khal

The khal starts from Mirpur section-3 where Rupnagar Branch-1 (Zoo) khal ends, flows in northern direction and falls to Digun khal near Goranchatbari pump station. It carries runoff from Rupnagar Branch-1 (Zoo), Branch-2 (Arambagh) and Brnch-3 (Duaripara) khal along with flow from Eastern housing area. Total length of the khal is about 3930 m.

Sangbadik Colony Khal

The khal starts from Kalshi road near Sangbadik Residential Area high school, flows in southern direction and falls to Baisteki khal at Palashnagar. It carries runoff from Mirpur 11, Mirpur 12 and Sangbadik Colony area. Total length of the khal is about 1260 m. Major identified problems are encroachment, in fact at downstream a part of the khal becomes a narrow drain. Problem of solid waste deposition also exists. Frequent water logging of the surrounding area occurs in wet season even during less intense rainfall.

Figure 2-11: Sangbadik Colony Khal and Baunia Khal

Baishteki Khal

The khal starts from Mirpur Section-10 at Jhut Potti culvert and falls to Baunia khal near Dewanpara. On the way at Palashnagar, there is confluence of Sangbadik Colony khal and Baisteki khal. At the upstream of Baisteki khal there is a drainage khal of approximately 350 m length which starts from Paris road. This khal was developed by housing authority and locally known as Housing khal. Baishteki khal carries runoff from part of Mirpur 10, 11 and 13 areas along with flow from Sangbadik Colony khal. Total length of the khal is about 1235 m. Both Baisteki and Mirpur Housing/ Paris khal faces encroachment and solid waste deposition.

Baunia Khal

The khal having a total length of about 6609 m starts from Mirpur 14 bus stand where Ibrahimpur khal ends. It falls to Digun khal near Uttara Phase-III carrying runoff from Ibrahimpur khal, Baishteki khal, Sangbadik Colony khal, Kachukhet, Mirpur 13 and 14, Vasantek, Dewanpara, part of cantonment, Airport, BAF area and Sagufta housing area. There are several large water bodies surrounding this khal which provide extra storage during wet season and plays vital role to mitigate drainage congestion during an intense rainfall event. The water bodies are already subjected to land development activities which is a concern for future.

Abdullahpur Khal

The khal having a total length of about 5000 m starts from Abdullahpur sluice gate near Ashulia embankment. During dry season flow from this khal drains to Tongi khal through Abdullahpur sluice gate but in wet season the khal drains to Digun khal near Uttara Phase-III. It carries runoff from Utarra sector- 1, 3, 5, 7, 9, 10, 11, 12, 13, 14, part of Diabari and Amarpara area.

Figure 2-12: Existing Digun khal and Rupnagar Khal

Digun Khal

The khal originates from the confluence of Baunia, Abdullahpur and Digun khal near Uttara phase– III and flows to Turag River. During dry season flow regulates through an 8 vent sluice gate located on western embankment but in wet season flow from the khal discharges to the river through Goranchahbari pump station. It carries runoff from Rupnagar Main khal, Baunia khal, Abdullahpur khal, part of Mirpur cantonment and Alokdigram area. Total length of the khal is about 4390 m. The khal flows along eastern side of Goranchatbari retention pond and becomes a part of the storage reservoir during wet season.

Uttara Diabari Khal

The khal having a total length of about 3345 m starts from low lying area at Noa Nagar and discharges to Digun khal. The khal has already been developed by RAJUK as a part of Uttara phase-3 project. It carries runoff from Noa Nagar, Dhour, Rajabari area and Utarra sector-16 and 18. During dry period runoff from Noa nagar, Dhour and Rajabari area drains to Turag River through a 2 vent sluice gate on Dhaka western embankment while in wet season flow goes to Goranchatbari retention pond through diabari khal.

2.3.4 Existing Pipe Network and Box-culverts

In addition to the primary drainage khals (described in article 3.3.1) there are about 31 km of pipe drains (diameter varies from 450 mm to 2300 mm) and 2.3 km of box culverts in zone 1. These infrastructures are present mainly in Mirpur section 13 & 14, Ibrahimpur and Uttara Model town areas shown on the Figure 2-6.

2.3.5 Existing Drainage Control Structures

(a)

(b)

(c)

Figure 2-13: Sluice Gates at Outlet of (a) Digun khal, (b) Noa Nagar area and (c) Abdullahpur Khal

There is a permanent drainage pump station in Zone 1 at Goranchatbari Retention pond. It plays crucial role to control drainage congestion during wet season, regulating runoff from this zone to Turag River. Present capacity of the pump station is about 44 cumec and expected to increase up to 66 cumec by 2018. On average, pumping starts at inside water level of 3.50 mPWD.

Flow regulating mechanism in zone 1 during dry season is more dependent on gravity drainage infrastructures. There are three (3) sluice gates (width varying from 2 to 8 vent) located on western embankment which regulate flow towards Turag River and Tongi khal during dry season. Flow from overall planned drainage network discharges through sluice gates located at the outfall of Digun khal and Abdullahpur khal while flow from some areas lacking proper drainage planning discharges through sluice gate located on Noa Nagar area.

2.3.6 Goranchatbari Retention Pond

Figure 2-14: Goranchatbari Retention Pond (Satellite Image, 2016)

The retention pond was preserved during the 90s according to the recommendation of FAP 8B. Total area of the retention pond at present is about 260 ha (**Figure 2-14**) which is consistent with DAP proposed land use. But it has been informed by BWDB that for constructing metro rail (MRT) in Dhaka city they have allocated about 40 ha to MRT. Also according to the proposal of DWASA Sewerage Master Plan, part of the retention pond area will be required for constructing sewage treatment plant for Dhaka-West (Mirpur) catchment. Total area of land required will be about 15 ha to 30 ha depending on the treatment technology adopted. It means in future about 190 ha area will be available as retention pond which must be preserved and well maintained for efficient functioning of the overall drainage system of Zone-1.

2.4 GORANCHATBARI FIELD VISIT

Field observation of existing khals cross sections

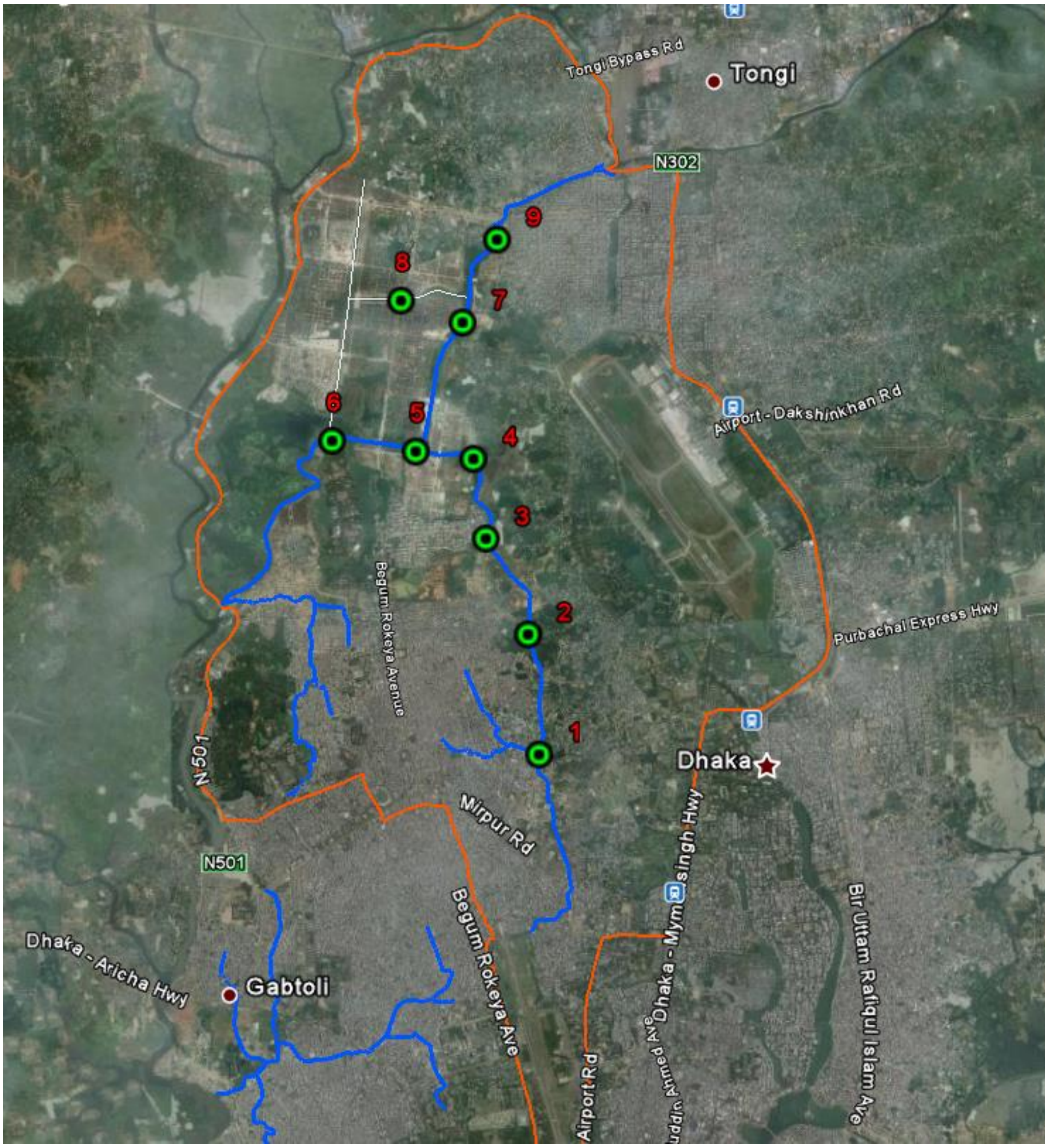


Figure 2-15: Goranchatbari Field visit locations

Table 2-8: Existing Drainage Khals in Study area

Location	Khal Name	Latitude	Longitude
1	Baunia khal	23°48'42.96"N	90°23'1.68"E
2	Baunia khal	23°49'33.27"N	90°22'56.63"E
3	Baunia khal	23°50'13.39"N	90°22'37.32"E
4	Baunia khal	23°50'46.73"N	90°22'31.61"E
5	Digun khal	23°50'49.86"N	90°22'5.23"E
6	Digun khal	23°50'54.34"N	90°21'26.96"E
7	Abdullahpur khal	23°51'43.88"N	90°22'26.66"E
8	Side channel of Abdullahpur khal	23°51'53.05"N	90°21'58.46"E
9	Abdullahpur khal	23°52'18.62"N	90°22'42.45"E

Upstream of Bridge Downstream of Bridge

Figure 2-16: Upstream of Location of Matikata road near kalshi road

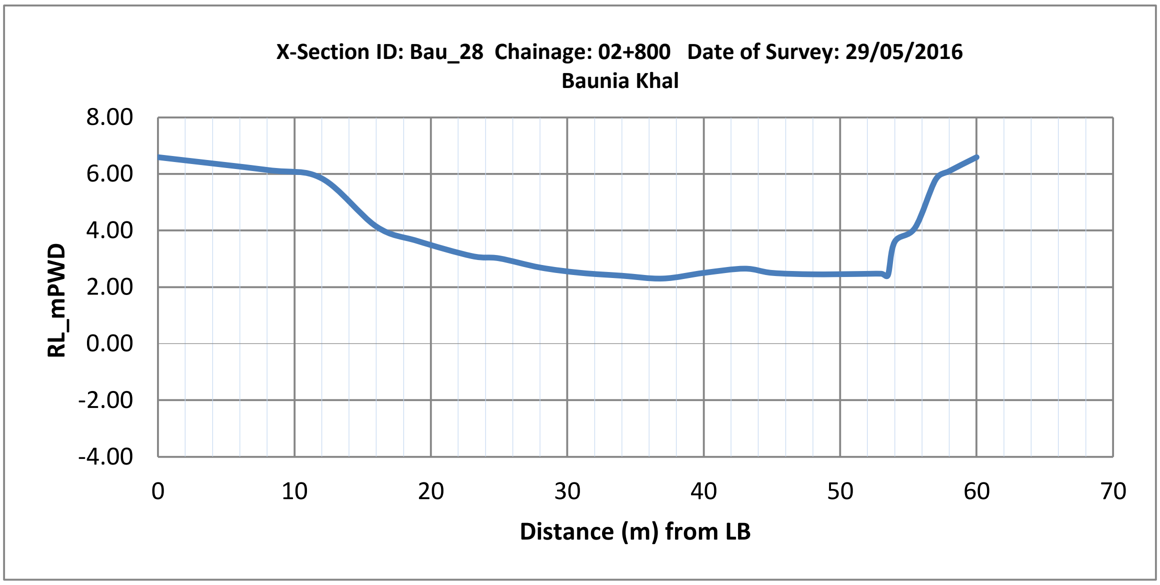


Figure 2-17: Matikata road near kalshi road (Bridge and canal cross section)

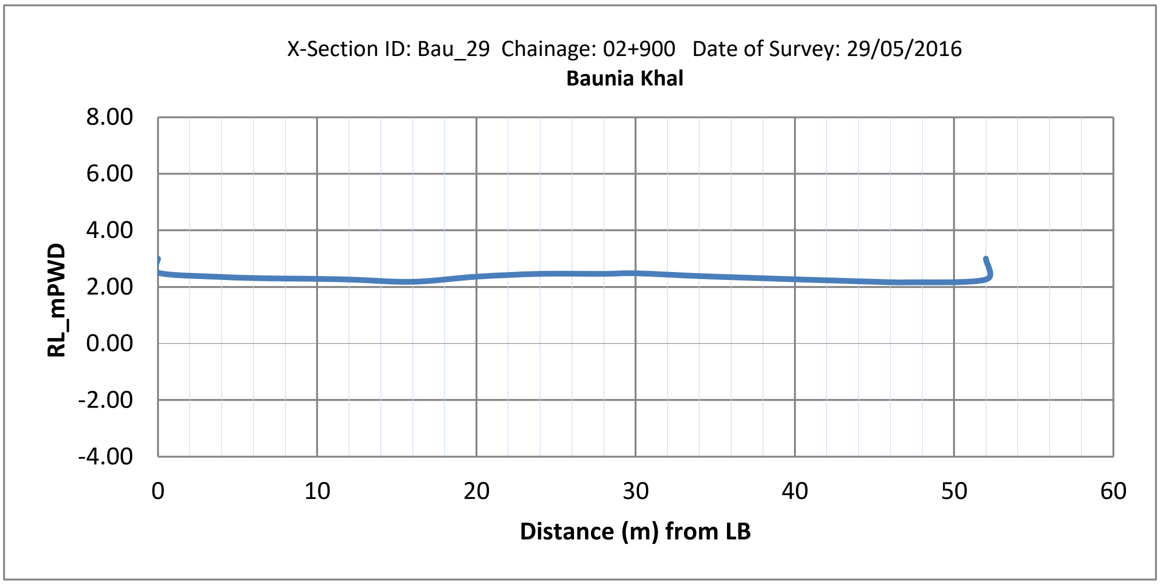
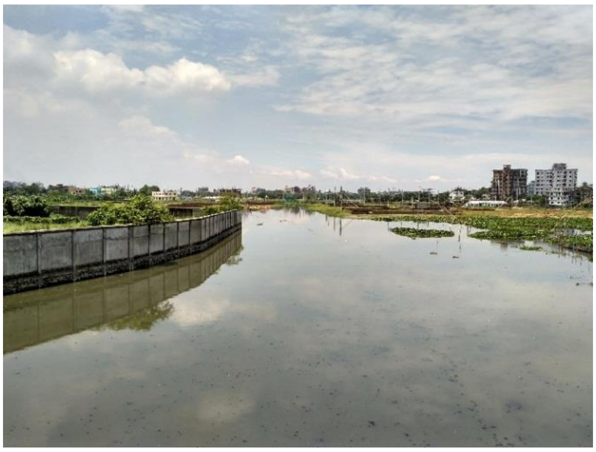


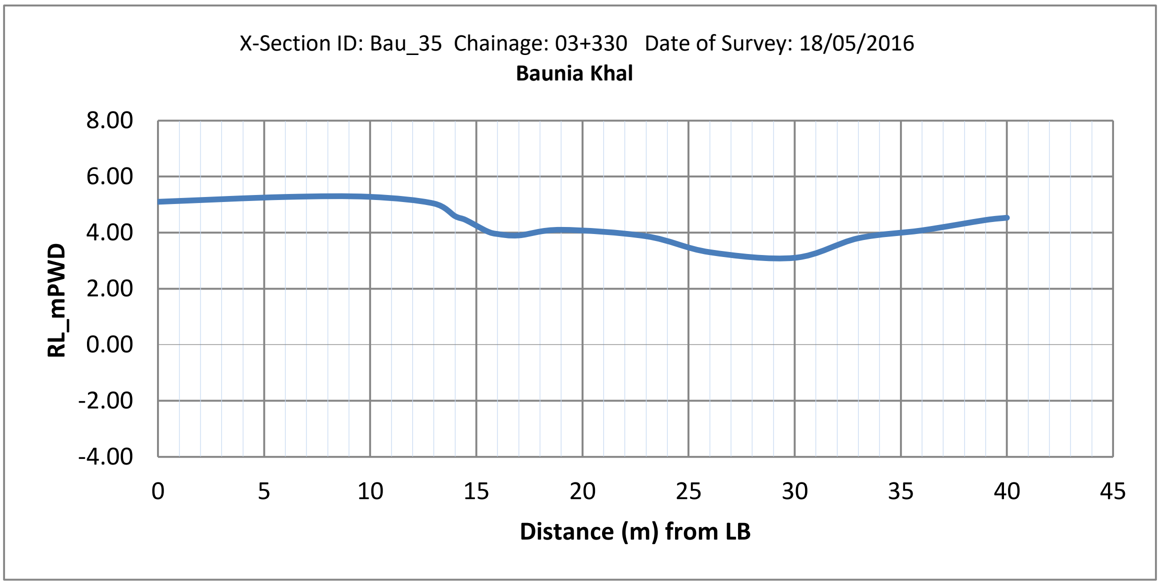
Figure 2-18: Matikata road near kalshi road (Canal existing cross section)

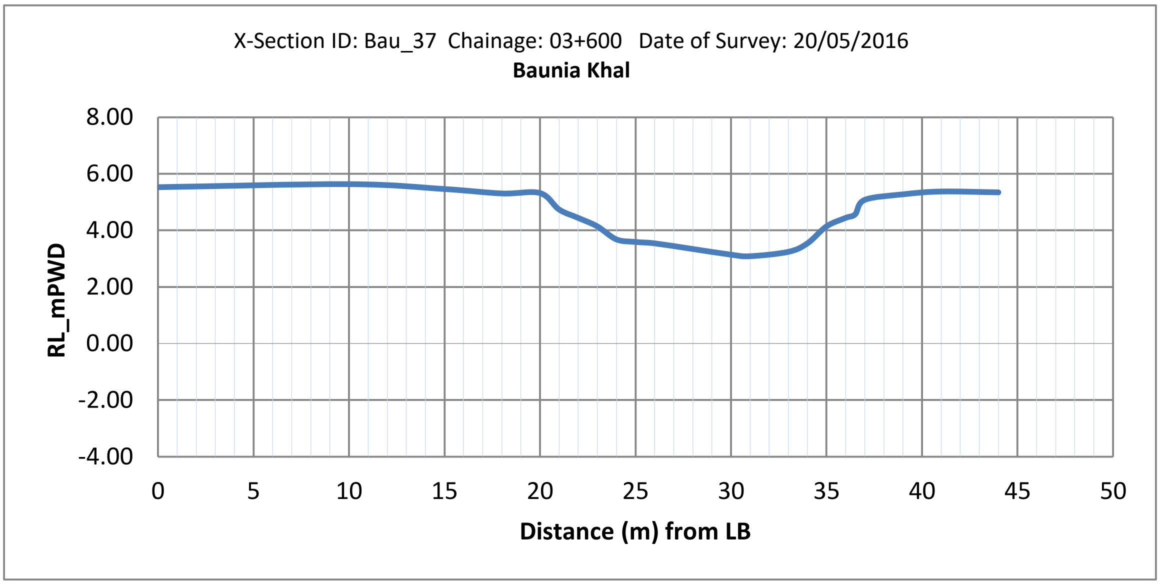
Figure 2-19: Location of Beguntila, Pallabi



Upstream of Bridge

Downstream of Bridge





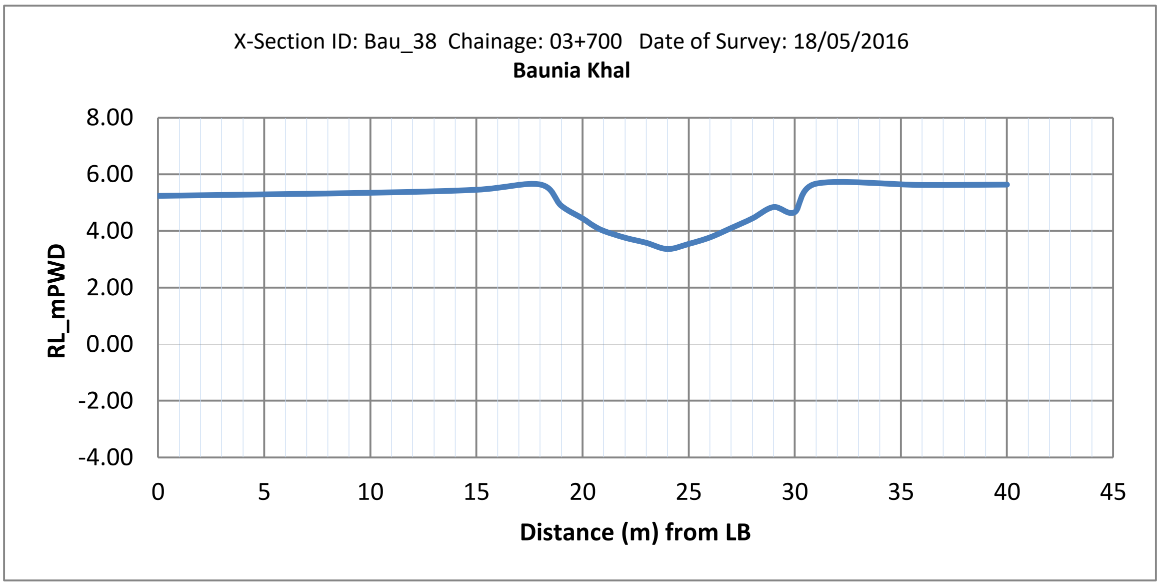


Figure 2-20: Beguntila, Pallabi canal cross sections

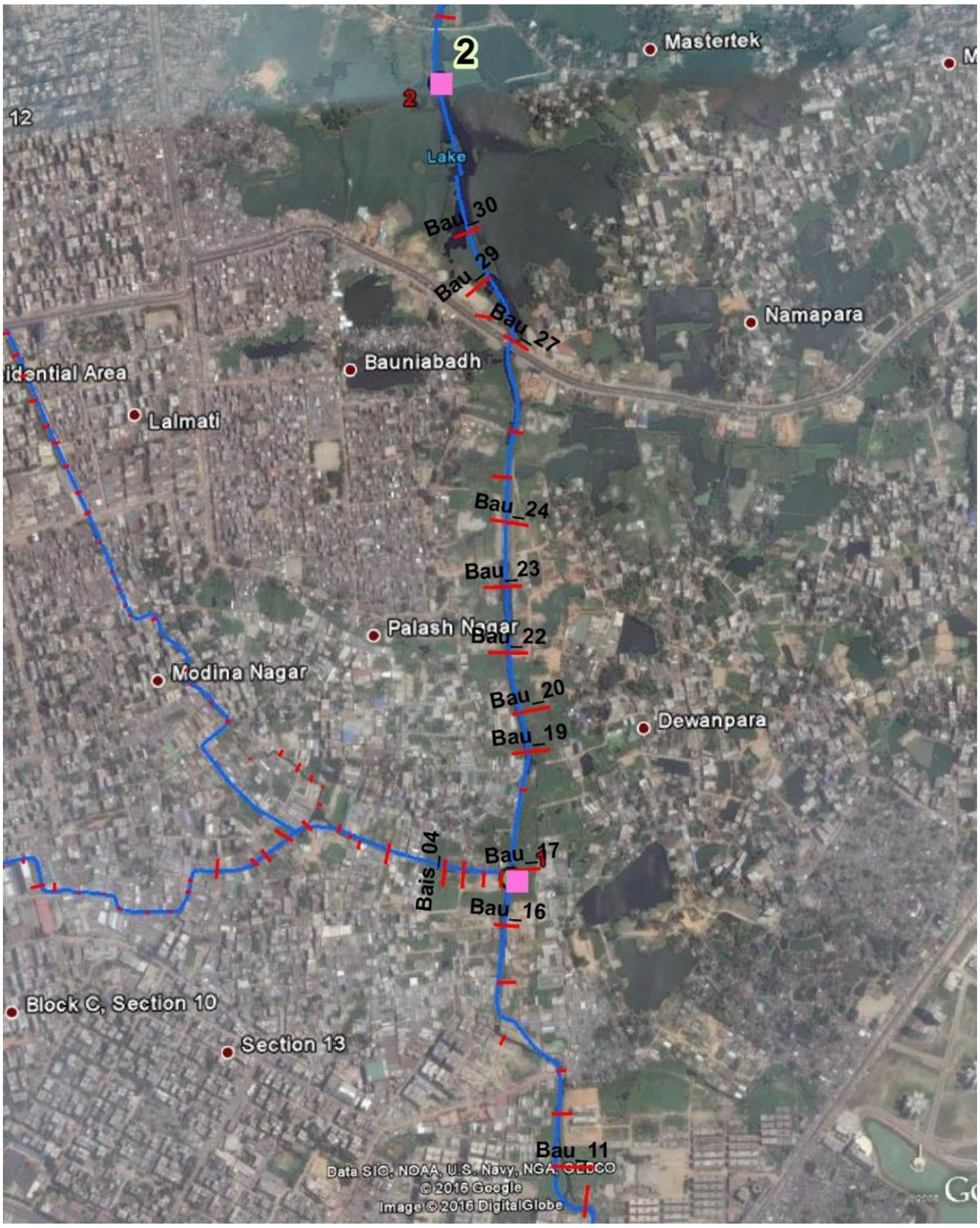


Figure 2-21: Confluence of Baishteki and Baunia near Polash Nagar

Figure 2-22: Near Mirpur DOHS

Figure 2-23: Cross section around Uttara section-17


Figure 2-24: Canal of Uttara section-17

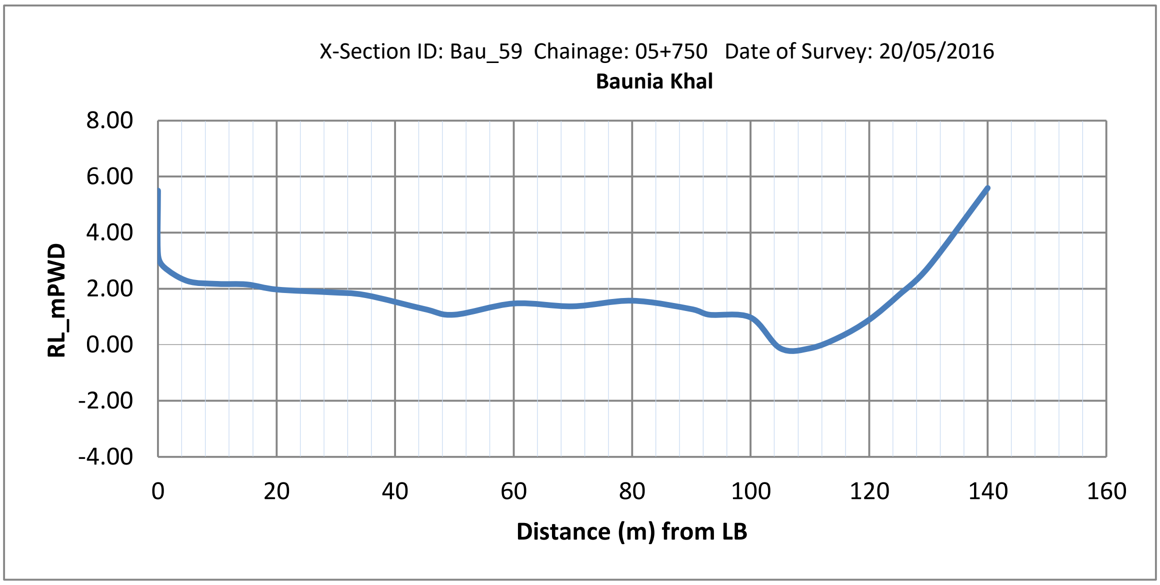


Figure 2-25: Cross sections of Baunia Canal around uttara.

Figure 2-26: Near confluence of Abdullahpur & Baunia khal

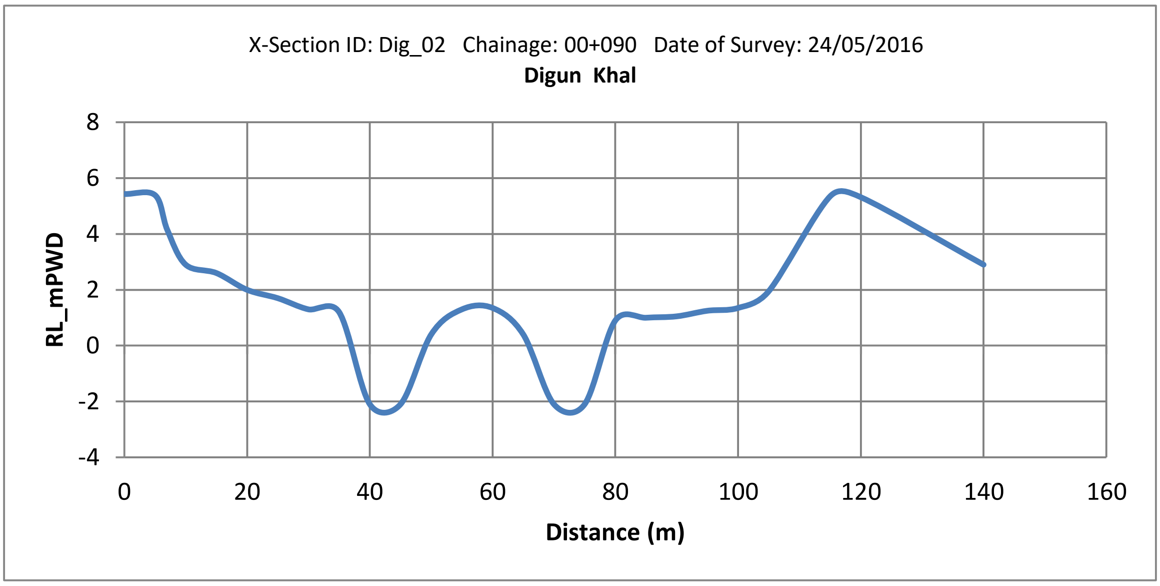


Figure 2-27: Cross section of Digun Khal

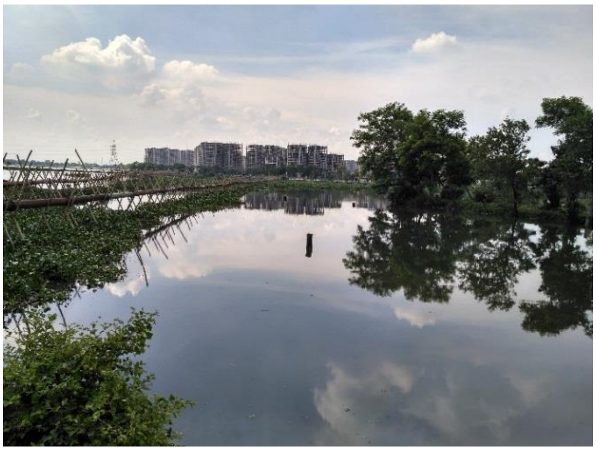


Figure 2-28: Digun Khal near retention pond

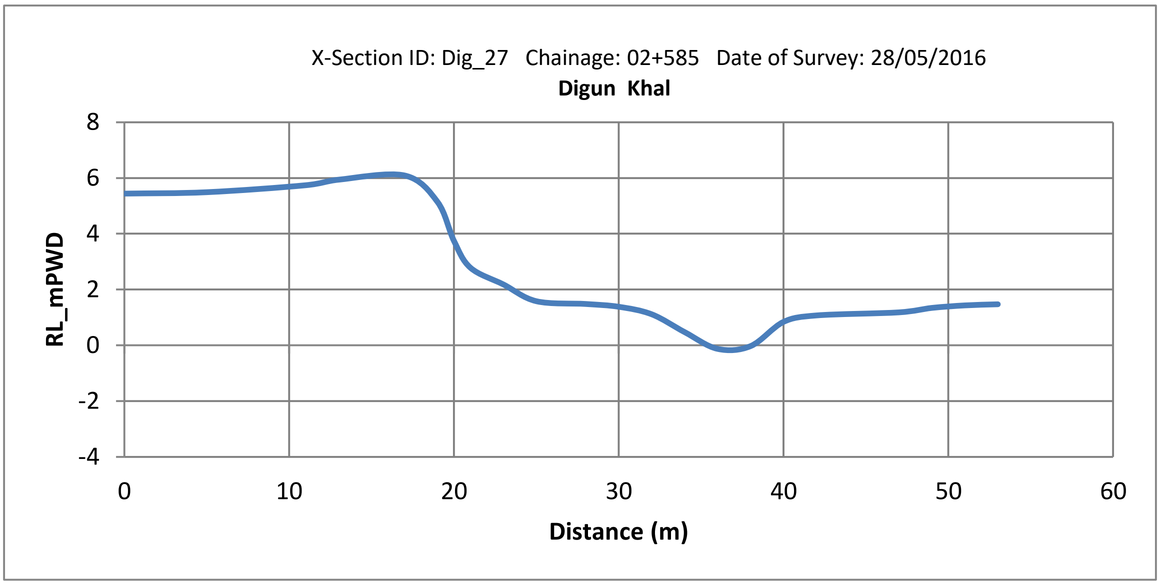
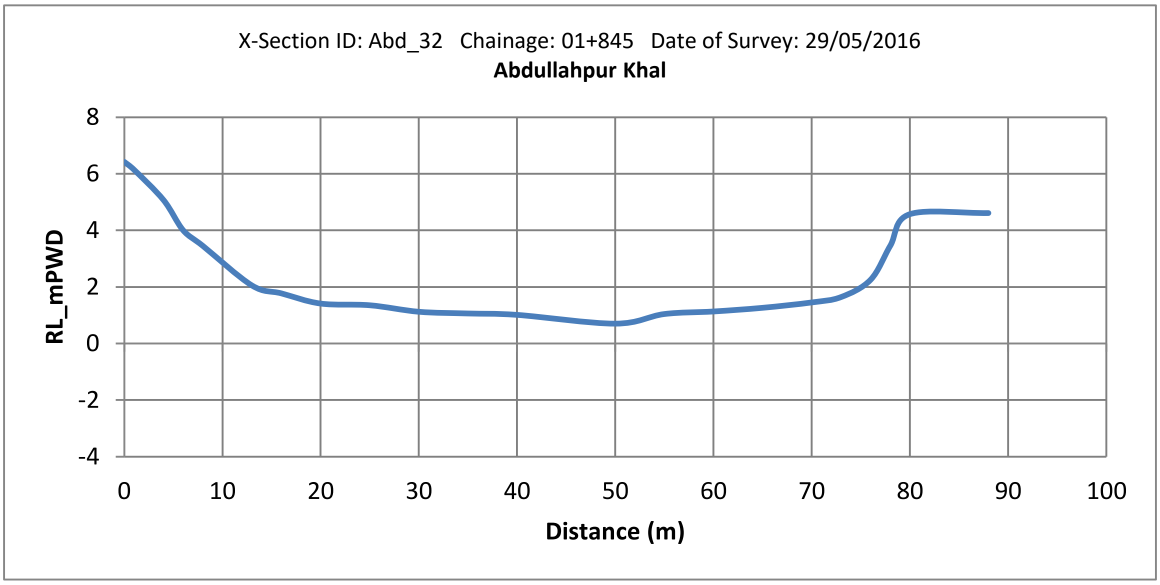


Figure 2-29: Cross sections of Digun Khal near retention pond

Figure 2-30: Uttara 3rd phase



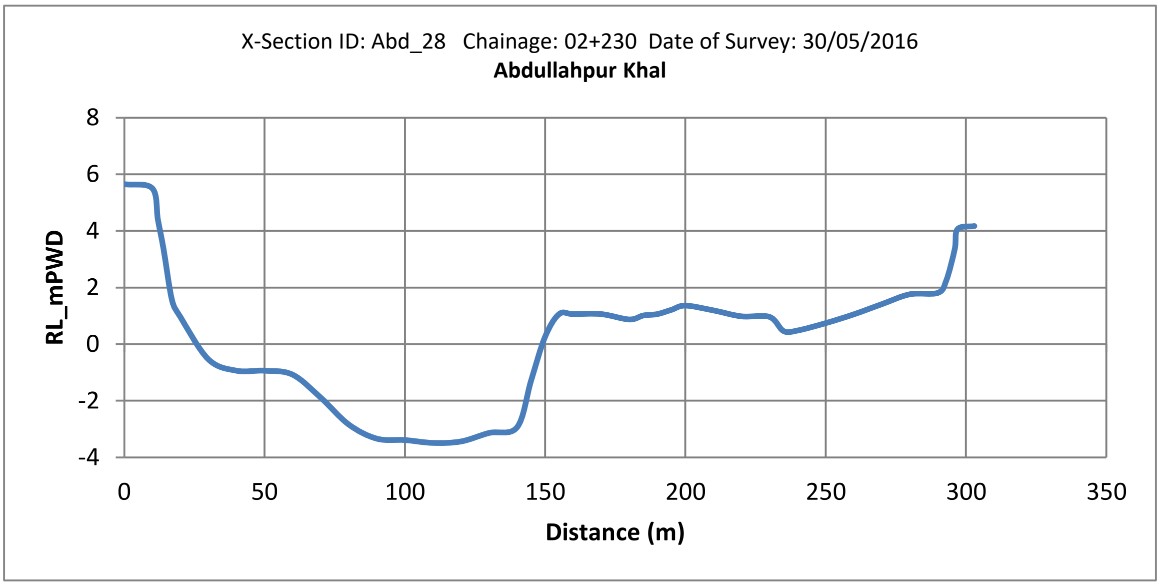


Figure 2-31: Cross sections of Abdullahpur Khal

Figure 2-32: Khalpar near sonargaon janapath road

Figure 2-33: Cross sections of Khalpar near sonargaon janapath road

Figure 2-34: Abdullahpur Khal

Figure 2-35: Uttara 3rd phase near Uttara Model Town

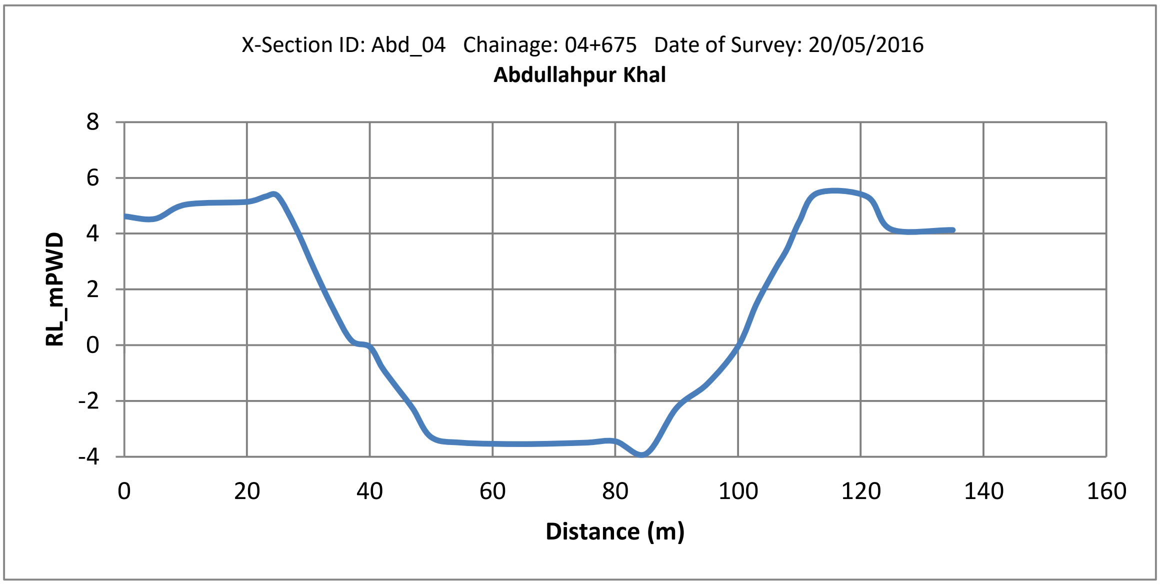


Figure 2-36: Cross sections of Abdullahpur Khal near Uttara Model Town

<u>Field observation of Water Level Measurement</u>

Figure 2-37: Observed the connection with retention ponds with khals (Jan-2016)

2.5 IDENTIFIED FIELD PROBLEMS

The field visit inspection study area on 25th to 30th November, 2017 identified different field problems that are adversely impacting the existing drainage systems in those areas. Specific problems which were identified during the filed visit are as follows:

- **Encroachment:** This is a major issue in most of the locations. Rupnagar khal has been encroached at most downstream section (from where Rupnagar khal starts) by constructing low income community residences. Rupnagar branch-2 (Arambagh) khal has been encroached massively at an intermediate section and there is no existence of a defined channel. Most of the khal segments were found encroached by permanent residences, high rise buildings, motor garage etc.
- **Conversion of khals into pipe drain:** In many places the existing khals have been converted to pipe drains but with inadequate size. A portion of Rupnagar main khal (about 1.2 km) has been filled up by land developers and flow is now passing through a twin pipe each of diameter 1800 mm. Also similar phenomenon was observed for Rupnagar branch-2 khal, at an intermediate section flow is passing through a pipe of diameter 1800 mm.

Figure 2-38: Conversion of khals into pipe drain at the mouth of Ibrahimpur Khal

- **Improper maintenance:** Massive deposition of solid waste and floating debris was found in Rupnagar main khal, Housing khal i.e upstream of Baishteki khal and Sangbadik colony khal. In some segments high growth of aquatic plants was observed.
- **Inadequate cross-section:** Cross-section of Rupnagar branch-1 (Zoo) khal is likely to be inadequate inside BCIC staff colony area. The colony area faces water logging problem almost every year during wet season. In addition, conveyance capacity of some khals at different places has been reduced to a great extent by constructing narrow road culverts.
- **Filling of surrounding low laying areas:** This is a major concern specifically for Baunia khal which is one of the drainage arteries in zone-1 (Goranchatbari). Almost all low laying lands surrounding to this khal are presently subjected to development by different agencies. There is no defined boundary of the khal in those developing areas which may result encroachment of the khal in near future if immediate action is not taken.

Encroachment of Rupnagar branch-2 (Arambagh) khal

Encroachment of Rupnagar main khal at starting

Rupnagar branch-2 (Arambagh) khal flowing through storm sewer pipe

Deposition of solid waste in Rupnagar main khal

Deposition of solid waste in Housing khal (u/s of Baishteki khal)

Deposition of solid waste in Sangbadik Colony khal

Massive growth of aquatic plants in Rupnagar main khal

Massive growth of aquatic plants in Rupnagar branch-2 (Arambagh) khal

Figure 2-39: Field level observation of study area near Rupnagar

CHAPTER 3: THEORY AND MODEL DESCRIPTION

3.1 BASIC HYDROLOGICAL AND HYDRAULIC CONCEPTS

3.1.1 The catchment and the regional water balance

The basic regional unit in most hydrological considerations and modeling is a catchment (alias drainage basin). A catchment is defined as the area contributing to the stream flows at a certain cross section. Catchments are delineated based on the topography of the area (A. Pathirana et al, 2011). The line from which water might drain to either one of two different catchments is called a divide. Moreover, the stream cross section through which all the runoff exits the catchment is called a pour point. This point can be located in any part of the stream network, depending on the size of the area of interest for the study at hand. (Henri Tikkanen, 2013)

Traditionally, catchments have been delineated using topographic maps that show contours for the study area. In the last decades, however, digital elevation models (DEMs) have become the main data source used. They can be analyzed with computer software to obtain information on the catchment delineation, slope, and other parameters. (Shouhong Zhang et al, 2014)

The catchment is often considered as a system, consisting of a control volume subject to the regional water-balance equation:

$$P+G_{in}-(Q+ET+G_{out})=\Delta, \quad (1)$$

Where,

P = precipitation [mm d^{-1}],
G_{in} = ground-water inflow [mm d^{-1}],
Q = stream outflow [mm d^{-1}],
ET = evapotranspiration [mm d^{-1}],
G_{out} = ground-water outflow [mm d^{-1}],
ΔS = change of (liquid and solid) water storages [mm d^{-1}].

When averaged over a long time period, the change of storage can be approximated as zero due to the conservation of volume of water. In addition, ground-water inflow is usually negligible as ground water commonly tends to follow flow paths somewhat similar to the surface flow, that is, towards the pour point. (SWMM, 2010)

3.1.2 Changes in the regional water balance due to urbanization

On urban areas, several mechanisms (e.g. soil sealing) cause the regional water balance to differ from natural conditions. Most of the water-balance changes related to urbanization are induced by the rising share of impervious surfaces. The effects are further enhanced as even non-sealed surfaces in urban areas often have a practically impervious nature because of compaction. The components of the water balance and the changes in these components due to urbanization shall now be described in more detail. (Henri Tikkanen, 2013)

3.1.3 Precipitation

The origin of precipitation: Like in natural conditions, precipitation is the most important water input mechanism also in the water balance of urban areas. This study mainly focuses on that part of the hydrologic cycle where water is in close contact with land. The process that brings water into this part of the cycle is precipitation. According to Dingman (1994), there are four-steps needed in order for precipitation to occur: (i) The air has to cool down to a temperature close to the dew-point, (ii) condensation nuclei need to be present to form cloud droplets or ice crystals, (iii) these droplets or crystals should grow into raindrops, snowflakes or hailstones, (iv) additional water vapor has to be available for the process to be sustained.

Spatial and temporal variability of precipitation: There are several factors affecting precipitation conditions on different regions around the globe. These include latitude, altitude, distance to areas of evaporation, dominating wind directions, position in relation to mountain ranges, and the temperature gradient between sea and continent.

Precipitation varies also with time. It occurs in events with random intervals, intensities, and durations. In addition, there are also seasonal differences, and the intensity of precipitation rarely remains constant even during a single event. Thus, the time-pattern of precipitation typically is highly complex. It is typical for the Finnish climate that the rainiest months of the year are July and August. This is due to the heavy convective rainfall which is customary during warm and sunny summer days.

Precipitation measurement: Accurate precipitation measurements are crucial for successfully studying and modeling the processes that take place in a catchment. However, these input data always are subject to some degree of uncertainty. This uncertainty is induced by both the methods used for observing precipitation, and the methods used for generalizing the measurements to cover the whole area of the studied system, e.g. the catchment. (Dingman, 1994)

The traditional way of measuring precipitation at a single point is simple. It is done by placing a vessel on an open field and measuring the amount of water caught. The results can be observed at certain intervals, say, once a day, or continuously with an automated metering system. The data gained is typically disturbed by errors from several sources. These include obstructions nearby, losses due to splash, evaporation or wetting, instrument errors, observer errors, errors due to varying observation intervals, and so on. Several different types of precipitation gages have been developed to minimize the impact of different error sources. In addition, the observed values are usually corrected to take into account any known systematic errors. (KUUSISTO, E., 1986a)

The effect of urbanization on precipitation: On urban areas, precipitation is typically increased compared to natural conditions. This is due to the urban heat island effect and the effect of aerosols such as SO_2 or NO_x in the urban air.

3.1.4 Evapotranspiration

Evapotranspiration includes all the processes occurring in the proximity of land or water surfaces that result in evaporation of liquid water into atmospheric water vapor. (Dingman, 1994) In the southern parts of Finland, the evapotranspiration sums up to ca. 60 % of the annual precipitation. (VAKKILAINEN, P., 1986) Evapotranspiration can be divided into two main components, caused by different physical phenomena. The first one, evaporation, refers to all the evaporation of water from the surface of ground, water, or a snowpack. This takes place when the water molecules on a surface acquire a sufficient amount of energy to escape the surface and enter the gas phase. The energy captured in the process is called latent heat. To be more accurate, both evaporation and condensation usually take place simultaneously. It is the net effect of these two that defines whether evaporation takes place or not. The rate of evaporation is dictated by the difference in partial pressure of water vapor between the air and the surface. (Dingman, 1994)

One important point of view is the difference between the terms potential evapotranspiration and actual evapotranspiration. The first one refers to the possible evaporation rate if the amount of water in the soil was not limited, and if no advection or heat-storage effects took part. In other words, it assumes evapotranspiration to be energy-limited. In some regions, or during dry seasons, however, the process is limited by the soil water content. Thus, the amount of actual evapotranspiration differs from the potential value. The areal actual evapotranspiration can be measured or calculated in a number of ways. These may incorporate water-balance approaches, lysimetric or evaporation pan measurements, as well as empiric or semi-empiric formulas, etc. One of the commonly used methods simple empirical method worth mentioning here is the Hargreaves' equation: (HARGREAVES, G. et al, 2003)

$$ETo = 0.0023(T_C+17.8)_{0.50,} \quad (2)$$

Where,

ET_o = evapotranspiration rate [mm/d],
R_a = total incoming extraterrestrial radiation [mm/d],
T_C = temperature [°C],
T_R = daily temperature range [°C].

Evapotranspiration on urban areas

There is a documented relation between the degree of soil imperviousness and evapotranspiration. As the imperviousness increases, the rate of evapotranspiration linearly decreases. This is mainly due to reduction in vegetation. Thus, the impact of evapotranspiration is somewhat reduced when comparing the urban regional water balance with the rural areas. When considering stormwater modeling of short rainfall events on urban areas, the impact of evapotranspiration may remain almost negligible. (HAASE, D., 2009)

3.1.5 Infiltration

Infiltration is defined as *'the movement of water from the soil surface into the soil'*. It is measured as the infiltration rate – the rate at which water is infiltrating into the soil. The maximum possible infiltration rate of a soil is called the infiltration capacity (or infiltrability). Moreover, the rate at which water arrives to the surface, e.g. through precipitation, is named the water-input rate. (DINGMAN, S.L., 1994)

The infiltration process can be limited in one of three different ways. (i) The process can be supply-controlled, meaning the water-input rate is less than or equal to the infiltration capacity, and all the incoming water is immediately infiltrated. (ii) The process may be limited by the infiltration capacity when the capacity is exceeded by the water-input rate. (iii) The rising of the ground-water table to the ground surface level or above may completely stop the infiltration process, setting the infiltration rate to zero. Infiltration takes place due to vertical differences in the hydraulic head. (DINGMAN, S.L., 1994)

$$H=h_g+h, \tag{3}$$

Where, H = hydraulic head [cm],

h_g = elevation head [cm],

h_t = pressure head [cm].

In case the hydraulic head is not constant, its difference over a certain distance is called the hydraulic gradient. The presence of the hydraulic gradient causes water in the soil to flow towards regions of lower hydraulic head. Particularly, if the vertical hydraulic gradient is zero, no vertical flow occurs. In that situation, the water content of the soil column is said to be at the field capacity. If additional water is now brought onto the surface of that soil column, the pressure head, and subsequently, the hydraulic head at the surface increases. This generates a flow downwards from the surface, and so infiltration occurs. (Vakkilainen et al., 1986; DINGMAN, S.L., 1994)

Infiltration rate at a point rarely remains constant during a single rainfall event. Typically, infiltration rates are high at the beginning of an event. Then they tend to promptly decline, asymptotically approaching a constant value. There are several factors influencing the infiltration rate and its temporal changes (DINGMAN, S.L., 1994):

− The rate at which new water arrives to the surface, or, in case of ponding, the depth of ponds;
− The saturated hydraulic conductivity of the soil profile;
− The initial moisture state of the soil pores;
− Soil surface inclination and roughness;
− The chemical characteristics of the soil surface;
− The physical and chemical properties of water.

Infiltration over an area is hard to determine. This is because infiltration capacity shows great variations even within a range of few meters. In addition, not all the variations can be explained by soil properties, but they are also related to plant and animal activity as well as small-scale topographic features. (DINGMAN, S.L., 1994). To examine the rate at which infiltration occurs, one must first be familiar with the concepts of hydraulic conductivity as well as the Darcy's Law. The hydraulic conductivity, *Kh* (cm s-1), describes the relation of the water flow rate through a porous medium with the gradient of potential energy. The main factor affecting the hydraulic conductivity is the size of the cross-sectional area through which water is able to flow. This, in turn, is dictated by the soil-grain size and the degree of saturation. (DINGMAN, S.L., 1994)

Infiltration reduction caused by impervious surfaces

In urban areas, impervious surfaces eliminate infiltration and thus increase surface runoff. Reduced infiltration also affects groundwater recharge and results in lowered groundwater levels. The effect may be enhanced through groundwater seepage into drainage networks. Lowered groundwater levels may for example pose problems for groundwater use and reduce the base flows of urban streams. (FLETCHER, T. 2012)

3.1.6 Surface and subsurface event flow

Surface runoff is a process that takes place on saturated sloping surfaces. As mentioned above in Chapter 2.1.4, input of water to a saturated surface causes ponding. If the depth of ponding (d) grows higher than the roughness of the ground (d_p), and the ability of surface tension to hold water motionless becomes exceeded, overland flow occurs. (DINGMAN, S.L., 1994)

Two main mechanisms can cause the saturation of a surface. First, it can be saturated from above (HORTON, R.E., 1933). The resulting phenomenon is called Hortonian overland flow. It is considerable especially during intense rainfalls preceded by dry catchment conditions, or areas where the conductivity of the soil surface is low, the latter including e.g. urban impermeable areas as well as areas with soil frost. Second, saturation from below may result in saturation overland flow. In that case, the ground-water table rises up to the level of the ground surface, constraining all additional water input to become overland flow. (DUNNE, T., 1978)

Overland flow is not the only process leading to stream response after rainfall events. In some soils, subsurface event flow can be of importance, too. Typically, this flow takes place in soil layers just below the surface and not connected to the regional ground-water aquifer. Depending on the circumstances, the subsurface event flow may form – and flow through – either a saturated or an unsaturated zone in the soil. Especially hill slopes containing macrospores can produce rapid subsurface responses, as the macropores enable the water to bypass the soil matrix of lower hydraulic conductivity. One classic situation is called the sloping slab, which occurs on hill slopes with a thin layer of permeable soil on top of a less permeable layer, say, clay. In such a case, subsurface flow is likely to happen through the upper layer. (DINGMAN, S.L., 1994)

3.1.7 Open Channel flow and pipe flow

As noted above, the overland flow channelizes rather easily. These channels may appear in all kinds of depressions, including gutters, ditches, etc. On urban and sub-urban areas, some or all of the flow is usually collected into underground stormwater or combined sewer network. To understand these conduit systems, one should be familiar with the basics of open-channel flow as well as closed-conduit flow. There is a wide variety of flow routing methods for modeling these flows. Some of these are briefly discussed below.

Open-channel flow

Despite of its name, open-channel not only takes place in ditches and streams, but also sewers not flowing full. This includes most stormwater conduits, as they are typically designed to operate well below their full depth, mainly to avoid flooding. The nature of open-channel flow is in most real cases highly complex. Therefore, before modeling it, some assumptions are usually made (DURRANS, S.R., 2003). These include one-dimensional flow, hydrostatic pressure distribution, constant water density, and channel length much greater than the flow depth. The Saint-Venant equations, based on mass continuity and the conservation of momentum, are partial differential equations accurately describing flow in these conditions. These equations can be written in several forms, but cannot be solved analytically, only numerically. The numerical solution of the complete Saint-Venant equations is called the dynamic wave routing. It may be done with the finite difference or the finite element method, for example.

Various approximations of the Saint-Venant equations have been developed, e.g. kinematic, diffusion, and gravity waves. For instance, when flow changes are slow and the depth-discharge relationship is not considerably looped the two last terms in the parentheses in Equation 10 can be ignored. This yields the kinematic wave approximation:

$$\partial_Q/\partial_t + c\partial/Q\partial_x = 0 \ , \qquad (11)$$

Where,
c = kinematic wave celerity, d_Q/d_A [m/s]. (DURRANS, S.R., 2003)

In some applications, even the steady-flow routing can be sufficient. It directly translates and sums the inflow hydrographs to acquire an outflow hydrograph. The relation between discharge and flow depth can then be solved using e.g. the Manning equation (DURRANS, S.R., 2003):

$$V = C_f / n \ R^{2/3} S_0{}^{1/2} \ , \qquad (12)$$

Where,
V = flow velocity [m/s],
C_f = unit conversion factor [m$^{1/3}$/s]
n = friction factor [-],
R = hydraulic radius [m],
S_0 = channel slope [m/m].

The friction factor n in Equation 12 is often referred to as the 'Manning's roughness coefficient n'. It is largely defined by the surface material of the streambed or the pipe, and plenty of n values for different materials appear in the literature. In stormwater modeling, it is also important to understand overland flow. Overland flow refers to thin sheet-flow that occurs before the runoff gets channelized due to surface irregularities. The length of true overland flow is rarely more than 100 m. The open-channel flow routing principles can typically be applied to overland flow as well. Overland flow modeling may however need huge simplifications as the irregularities of the land surface are typically substantial compared to the thickness of the overland flow layer. The Manning equation may be used for turbulent overland flow, yet keeping in mind that the roughness coefficient n may vary considerably depending on the Reynolds number. (WOOLHISER, D.A., 1981)

Closed-conduit flow

As opposed to open-channel flow, closed-conduit flow occurs in pipes that are full with water, i.e. there is no free water surface in the cross-section of the pipe. The pipe flow is typically modeled based on conservation of energy. According to the energy equation the sum of pressure, elevation, and velocity heads must equal between two cross-sections of a pipe, excluding energy losses and inputs on the way. Thus, evaluating the losses is a central part of the modeling. These losses can be classified into either frictional or local losses, of which the first mentioned are, in most cases, of higher significance. (DURRANS, S.R., 2003). The energy loss due to friction can be solved e.g. from the Darcy-Weisbach equation:

$$h_L = f * L/D * V^2/2 \text{ ,} \quad (13)$$

Where

h_L = head loss due to friction [m],
f = friction factor [-],
L = pipe length [m],
D = pipe diameter [m],
V = cross-sectional averaged flow velocity [m/s],
g = acceleration of gravity [9.81 m/s2].

Several other methods of computing the frictional loss exist, too, including the Manning equation (Eq. 12), the Chézy equation, and the Hazen-Williams equation. (DURRANS, S.R., 2003)

3.2 URBAN DRAINAGE BASIC CONCEPTS

3.2.1 Urban Flooding

Urban flooding is the term used to describe inundation that occurs after heavy rainfall events, which causes runoff exceeding the capacity of the local drainage system. As a result, water remains stagnant in the built-up area for extended periods. Sometimes, this type of flooding is also known as rain flooding or water logging. However, these terms can also apply to a rural setting.

Figure 3-1: Urban flooding at Kazipara, Mirpur

Urban flooding is the inundation of land or property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers. Dhaka, the capital of Bangladesh and one of the world's rapidly growing megacities, is an urban hotspot for climate risks. Preparing for the unfolding impacts of climate-related changes – socio demographic, environmental, economic, and political - is a daunting task. It requires that Dhaka's policymakers, like those in other megacities of South Asia's low-lying deltas, understand how climate change is anticipated to affect natural hazards that lead to flooding in the cities. (WB, Urban Flooding of Greater Dhaka in a Changing Climate, 2015)

3.2.2 Return period

The return period of a hydrological event (e.g. rainfall or river flow) is an estimate of the time interval between two events of the same size or intensity. It is a statistical measure of the average recurrence interval over a long period of time and is the inverse of the probability that the event will be exceeded in any one year. Hence, a 10 year, 20 years and a 30-year rainfall amount has a 10%, 5% and 3.3% chance of occurring in any given year, respectively. However, this does not mean that if an event of a 10 year return period occurs, then the next will occur in about 10 years' time - instead, it means that, in any given year, there is a 10% chance that it will happen, regardless of when the last similar event was. Or, put differently, it is 10 times more likely to occur than a flood with a return period of 100 years (or a probability of 1%). The amount of rainfall (expressed as a depth, such as mm) increases as the return period increases. In other words, a 100-year rainfall event will be larger compared to a 20 year or 30-year event.

The choice of return period for design purposes depends on various factors, including the size of the drainage area, the risk of failure, the importance of structures at risk, and the desired degree of conservatism (risk-aversion) by decision makers and stakeholders. Shorter return periods tend to be based on observed data (where available) and longer periods are estimated from a statistical distribution.

The return period for urban flooding event is similar to the return period of the rainfall event causing that inundation for areas protected from river flooding. However, for urban areas that are susceptible to river flooding, the return period of urban flooding depends not only on the return period of the rainfall event but also on the return period of the river stage (water level). In other words, the return period of urban flooding in unprotected areas is a joint probability function related to the frequency of rainfall events and high river stages. There are also other factors that affect the return period of urban flooding events, such as land cover changes, condition of the drainage channels, etc. However, it is difficult to assign probability distributions to these factors and in hydrologic analyses (modeling) these factors are normally kept constant for a given scenario.

3.2.3 Climate Change and Adaptation

In climate change studies, the term “adaptation” refers to any activity undertaken to reduce or completely remove potential harms of climate change. This can be “planned adaptation” via a deliberate policy decision or it can be “reactive adaptation”, i.e. occurring after the change has occurred. Adaptation benefits are avoided damage costs or the accrued benefits following the implementation of an adaptation measure. (Sonia Binte Murshed et al, 2011)

“Adaptation deficit” refers to the gap between current practice/performance and the desired or targeted practice/performance. For example, in the context of an urban drainage system that is designed to prevent flooding streets from 100mm rainfall in 6 hours but can only achieve that when 70mm falls in 6 hours. In this simple example, the adaptation deficit (30mm in 6 hours) needs to be addressed before climate change adaptation is considered. Or else the costs (and potentially the benefits) of climate change adaptation measures will be overestimated.

3.2.4 Detention and Retention Ponds

Low laying areas and water bodies are important components of any drainage system. Detention ponds “detain” or delay the flood peak by storing some storm-water runoff for a certain period (i.e. temporarily). This helps prevent the rest of the drainage system (pipes, pumps, etc.) from being overwhelmed by particularly large rainfall events. Water is removed from the detention pond by a pipe/culvert at the bottom of the pond (lowest point). The detention pond area remains dry when there is no rainfall over extended periods and can be used for other purposes, e.g. sports field, agriculture, etc.

On the other hand, retention ponds “retain” storm-water and always contain water, i.e. a permanent water body. During rainfall events, the water level increases up to a certain height, after which the level is controlled by a pump or outlet structure.

3.3 RAINFALL-RUNOFF MODELING

Modeling can be defined as simulating the natural world with a model representing a part of that world. Mathematical models are *'explicit sets of equations and numerical and logical steps'*, converting numerical inputs to numerical outputs (DINGMAN, S.L., 1994). According to the theory conceptual modeling consists of the following steps:

- Conceptualization of the problem;
- Selection (or development) of a suitable model;
- Parameter sensitivity analysis.
- Model structure identification and parameter estimation (or calibration);
- Model verification;
- Model acceptance testing (or validation);
- Parameter sensitivity analysis.

Rainfall-runoff modeling predicts the hydrological response (runoff) to a certain input (precipitation), usually as a function of time. The mechanisms of prediction differ. So-called 'black-box models' (or the systems view) seek for an abstract function relating the input and output functions, whereas physically-based models try to thoroughly describe the underlying processes. In practice, most rainfall-runoff models fall between these two extremes. When applying the systems approach, the systems modeled can be classified into two categories: (i) linear and (ii) non-linear. A system is linear if for input *au1+bu2* applies (DINGMAN, S.L., 1994).

$$(t) = (au_1+bu_2) = af\ (u_1) + bf\ (u_2) = az_1+bz_2, \qquad (14)$$

Where

(t) = model output;
(t) = state of the model;
(t) = model input;
$(x(t), u(t),t)$ = arbitrary function;
$a,$ = any two scalar quantities.

Spatial boundaries of the system are typically defined according to catchment borders. Conceptually, the modeled system can either include all the hydrological processes in a catchment system, or be restricted to a surface runoff system. The difference is that the surface-runoff system uses only the fraction of precipitation that actually causes runoff as input, known as the effective precipitation. Another difference is that the catchment system, due to its complexity, is evidently non-linear. In contrast, the surface-runoff system can at times be reasonably approximated as being linear. (DISKIN, M.H., 1981).

The rational method assumes a simple linear correlation between the effective rainfall intensity and the peak discharge induced. Thus, this method is typically used for calculating the peak flows induced by a rainfall with a certain intensity or return period, and is widely used in design purposes in urban areas. The runoff coefficient used as a parameter is catchment-specific, varying with land use and other catchment properties. The values for the coefficient are highest for impermeable surfaces such as pavements and rooftops. Due to its simplicity, the rational method has some major limitations. It works well only in small catchments with areas less than 80 hectares. Also, the method cannot account for any larger storage such as detention ponds in the catchment area. As stated above, physically-based models describe physical processes occurring in the catchment area, including precipitation, evapotranspiration, infiltration, snowmelt, overland flow, channel flow, and ground-water flow. (DINGMAN, S.L., 1994)

3.4 STORM WATER MANAGEMENT MODEL (SWMM)

There are numerous different rainfall-runoff simulation software packages for all kinds of modeling purposes (ZOPPOU, C., 2001). The EPA Storm Water Management Model (SWMM) is one of the most commonly used. Among all similar software, this study focuses on SWMM for a few reasons. (i) SWMM is widely used in analysis and design of storm-water drainage systems, especially on urban areas. (ii) There have been previous studies carried out on the same geographical area using the same software. (iii) The U.S. Environmental Protection Agency (EPA) provides the SWMM model and a related graphical user interface free of charge.

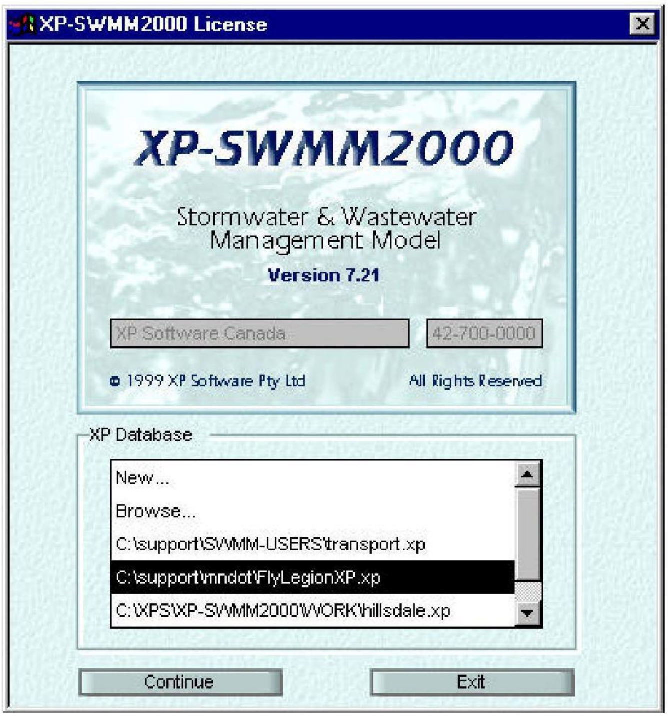


Figure 3-2: XP-SWMM 2000

SWMM was first developed in 1971, and has since then been upgraded several times. The current version (number 5) was completely re-written by the U.S. EPA and a consulting firm of CDM, Inc. (ROSSMAN, L.A., 2010). SWMM can be used for a range of applications. It is suitable for modeling either single precipitation events or continuous modeling of multiple events. The simulation period consists of multiple time steps, and SWMM can track both runoff quantity and quality for each time step. The model is conceptually divided into four major environmental compartments:

(i) the atmosphere compartment, accounting for precipitation and pollutants from air;
(ii) the land surface compartment, modeling areas receiving precipitation and generating runoff;
(iii) The transport compartment, routing flow from runoff source areas through a network of pipes, channels, etc.;
(iv) The ground-water compartment, receiving infiltration from the land surface and providing input to the transport compartment.

Of these, (ii) and (iii) are discussed in more detail below. The objects and processes in these four compartments account for all the major components affecting the regional water balance (see Chapter 2.1.1). (ROSSMAN, L.A., 2010).

3.4.1 The land surface compartment

The processes occurring on the land surface are an essential part of SWMM. For modeling, the land surface is commonly divided into small, sufficiently homogeneous subcatchments, each draining to a single discharge point. All of the subcatchments have their own sets of hydrological parameters such as imperviousness and depression storage. Based on these, several hydrological phenomena are simulated during every time step. (ROSSMAN, L.A., 2010). Water input to the subcatchments is deducted from the atmosphere compartment. Each subcatchment is assigned a Rain Gage element, containing data on rainfall intensity or volume at certain time intervals. If there is standing water on subcatchment surfaces, evaporation occurs. Evaporation rates (e.g. daily or monthly) can be defined by the user, or they can be computed from a data series of daily air temperatures. In case they are computed, the Hargreaves' method is used. In addition to daily air temperatures, the site's latitude must be known. (ROSSMAN, L.A., 2010)

SWMM offers a selection of three different built-in infiltration models. These are (i) the Horton's equation (HORTON, R.E., 1933), (ii) the Green-and-Ampt method (Green and Ampt, 1911), and (iii) the Curve Number method. Infiltration only takes place on the pervious fraction of the sub-catchment, defined by the imperviousness parameter. To model the ground-water conditions more precisely, one can include optional Aquifer objects in the model. Aquifers simulate the vertical movements of ground water and may exchange water with the drainage system, e.g. through leaking pipes. In cold conditions, precipitation may be stored in an assigned Snow Pack object. These objects have parameters for modeling snow accumulation and snowmelt within the sub-catchment. In addition, snow removal can be accounted for using a special set of parameters. (ROSSMAN, L.A., 2010)

Both precipitation and snowmelt can import water on the sub-catchment surfaces. SWMM conceptualizes the creation of surface runoff based on the same principles as presented. (ROSSMAN, L.A., 2010).

SWMM calculates the outflow from a sub-catchment as follows (PARK ET AL., 2008):

$$Q = W/n * (d - d_p)^{5/3} / S_0^{1/2}, \qquad (15)$$

Where

Q = subcatchment outflow [m3/s],
W = subcatchment width [m],
n = Manning’s roughness coefficient [-],
d = water depth [m],
d_p = depth of depression (retention) [m],
S = slope [%].

Surface runoff generated at the source areas is defined to flow either into another subcatchment or into a drainage system entry point.

3.4.2 The transport compartment

The other major part of SWMM is the transport compartment. It describes the hydraulic routing of runoff and possible external inflows through a network of pipes and channels, also known as conduits. These conduits are the links of the drainage network, joined together at junction nodes, which can represent manholes, pipe connection fittings, etc. Typical conduit parameters include invert elevations at both ends, the conduit length, the Manning's roughness coefficient n, and cross-sectional geometry. Similarly, junction nodes have parameters such as invert elevation and depth from the ground surface. There are also other possible types of nodes, e.g. flow dividers, storage units, pumps, and flow regulators. SWMM offers three different options of flow routing: (i) steady flow routing, (ii) kinematic wave routing, and (iii) dynamic wave routing. These methods were briefly presented in Chapter 2.1.7. The choice of the routing method affects the accuracy of the results, as well as the time taken by running a simulation. (Rossman, 2010)

Flows exceeding the capacity of the drainage system may cause ponding. This means temporarily storing the excess volume at a certain junction, and allowing this pond to dry when system capacity is again available. Ponding can also be disabled by the user, causing all excess volume to overflow the system and be lost. (Rossman, 2010)

3.4.3 Calibration against data

SWMM parameters should typically be calibrated and validated against measurements to reach reliable results. However, some of the model parameters are quite straightforward to deduct from e.g. accurate spatial data and can be reasonably defined even without calibration. Those include subcatchment areas and slopes, for instance. On the other hand, parameters such as the flow width, the depression storage, the roughness coefficients, and the infiltration parameters involve larger uncertainties and are commonly used as calibration parameters. Nevertheless, also the first mentioned ‘straightforward’ parameters involve uncertainties and are often calibrated for a better fit. (Liong et al., 1991).

3.4.4 The effect of spatial resolution on rainfall-runoff modeling

This study mainly concentrates on the parameterization of a SWMM rainfall-runoff application. The first step in such a parameterization is the catchment delineation and subdivision. Chen and Tucker (2003) compared different approaches for catchment delineation, e.g. to burn a stream network into a digital elevation model (DEM) and to use the *Watershed* tool in ArcGIS (ESRI, 2012). They concluded that GIS is a powerful tool for catchment delineation if there are comprehensive and accurate spatial data sources available and the details of the sewer system are correctly accounted for. They also add that manual fine-tuning is often necessary after the automated delineation process.

Based on the spatial resolution, GIS-based catchment modeling can be divided into distributed (or high-resolution) and aggregated (or low-resolution) approaches. A distributed model accounts for all minor spatial variations within the study area while an aggregated model excludes and generalizes details of the input data. Highly distributed models are typically used e.g. for modeling event peak-flows, whereas the more aggregated approaches are mainly suitable for studying large-scale processes like climate change as their limitations are less relevant in long-time-scale modeling. The difference between these two is the level at which features within the catchments are aggregated, i.e. the size of the sub-catchments modeled. Aggregation results in loss of complexity but, simultaneously, makes data collection easier. Even the most distributed models usually incorporate some aggregated parameters due to the lack of fully-detailed data on spatial variations of parameters. The key question remains; which level of aggregation is still acceptable in order to maintain a certain degree of accuracy in modeling. (Jacobson, 2011)

Park et al. (2008) performed SWMM simulations with varying levels of sub-catchment aggregation. They concluded that the simulated surface runoff was not affected by the spatial resolution of the model. On the other hand, accumulated pollution loads were reduced with an increasing level of aggregation. The peak flows appeared at slightly different time instants but otherwise the hydrograph was not affected by the model aggregation. Similarly, Ghosh and Hellweger (2011) did SWMM runs for 50 storm events. Their results indicated that the annual runoff is not dependent on the spatial resolution of the model. The effect of spatial resolution on simulated peak flows was altered. While for small storms the peak flows increased with an increasing level of aggregation a decrease was found for large storms.

On the contrary, Smith et al. (2005) found that the aggregation level of the catchment affected the difference between measured and simulated runoff volumes. They recommended minimizing those differences through calibration of model parameters such as the flow width. For natural catchments, Jang et al. (2007) found out that non-calibrated SWMM models were most accurate if the whole catchment was modeled as one single runoff unit. Those models provided good simulation results without calibration for three undeveloped Korean watersheds with areas ranging from 8.5 km^2 to 55.9 km^2.

There have also been several studies regarding the aggregation level of other rainfall-runoff models similar to SWMM. Thompson and Cleveland (2009) concluded that fully-distributed modeling with HEC-HMS is not feasible in cases where no calibration data is available. The possibilities of scaling the input data of the distributed KINEROS model to match different aggregation levels were studied by Thieken et al. (1999). The outcome was that the flow length could be used as a scaling factor for adapting the same model to catchment delineations of different scales. Zhang et al. (2013) summarized several previous studies and concluded that the flood volume is insensitive to the degree of catchment subdivision. They also noted that only a few studies have concentrated on the effect of catchment subdivision on water balance components like evapotranspiration and infiltration. Their results with a HEC-HMS model showed that (i) overland flow length increases with increasing sub-catchment area, (ii) infiltration parameters are independent of the model aggregation level, (iii) the quality of results decreases if the number of sub-catchments is too large or too small, and (iv) unlike in previous studies, the aggregation level affects the components of the water balance. Zhang et al. (2013) also conclude that catchment subdivision is useful if detailed data on parameter variations between the sub-catchments is available.

Besides the surface runoff processes, also the conveyance system is subject to generalization. The sewer network may be ‘skeletonized’ by disregarding minor pipes. The combined sewer modeling protocol of Department of Water Management for the City of Chicago defines, for example, that no conduits with a diameter smaller than 1070 mm are modeled, unless they have substantial hydraulic importance in the sewer system (Cantone and Schmidt, 2013).

3.4.5 Estimating and calibrating SWMM parameters

A SWMM application includes numerous different parameters, of which several vary from sub-catchment to sub-catchment. These parameters can be classified to measured parameters (e.g. sub-catchment area; pipe lengths, pipe shapes, bed slopes, and diameters; manhole type; soil types; land-use types; and rainfall depth) and inferred parameters (e.g. flow width; infiltration parameters; Manning’s *n* for pervious and impervious areas; depression storage for pervious and impervious areas; imperviousness; and Manning’s *n* for conduits) (Choi and Ball, 2002). The measured parameters are typically easier to obtain, while the inferred parameters usually need to be calibrated. Nevertheless, also the first mentioned may sometimes involve large uncertainties arising from e.g. inaccuracies in sub-catchment delineation. However, if no runoff measurements required for calibration exist, literature values can be found for several of these parameters. Many parameter values are suggested e.g. in the SWMM User’s Manual (Rossman, 2010). In contrast, other parameters such as flow width, hydrological slope, and imperviousness have to be obtained from spatial data.

Detailed spatial data on land cover types etc. is important for calibrating SWMM applications for urban catchments (Jacobson, 2011). Because such data is not always available, there have been attempts to reduce the complexity of the calibration process by concentrating only on the parameters the model is most sensitive to. The problem is, however, that SWMM is sensitive to different parameters in different catchments (e.g. Beling et al., 2011). This highlights the importance of always performing a sensitivity analysis before model calibration. In addition, the method of sensitivity analysis affects the obtained model sensitivity to different parameters (Jacobson, 2011).

Whether calibration could be left undone in some cases is an interesting question. According to Jang et al. (2007), even a non-calibrated SWMM model performs better than an ordinary hydrograph when modeling urbanizing (or urbanized) areas. Amaguchi et al. (2012) developed a vector-based distributed model similar to SWMM which was able to achieve a good reproduction of observed stream flows. However, they recognized the demand of detailed spatial data, and recommended calibration of some parameters (e.g. imperviousness) if only possible. Overall, it seems there have been experiments with calibrated SWMM models of a low spatial resolution, as well as with non-calibrated high-resolution SWMM models. No studies were yet found where a low-resolution model was applied without calibration to a large urban area for continuous simulation. Thus, the application of this approach is definitely both interesting and challenging.

CHAPTER 4: METHODOLOGY

4.1 MODELLING APPROACH

This research is a short-term investigation based on limited primary & secondary data collection and analyses, field visits, analyses of data collected from secondary sources, review of studies already conducted on **Chapter 2**, develop a model using an open source tools named SWMM for study area and run for different scenarios to understand the problems of study area according to the inundation maps. The sequence and relationship between these overall activities are shown in **Figure 4-1** with the overall activities of modeling tasks.

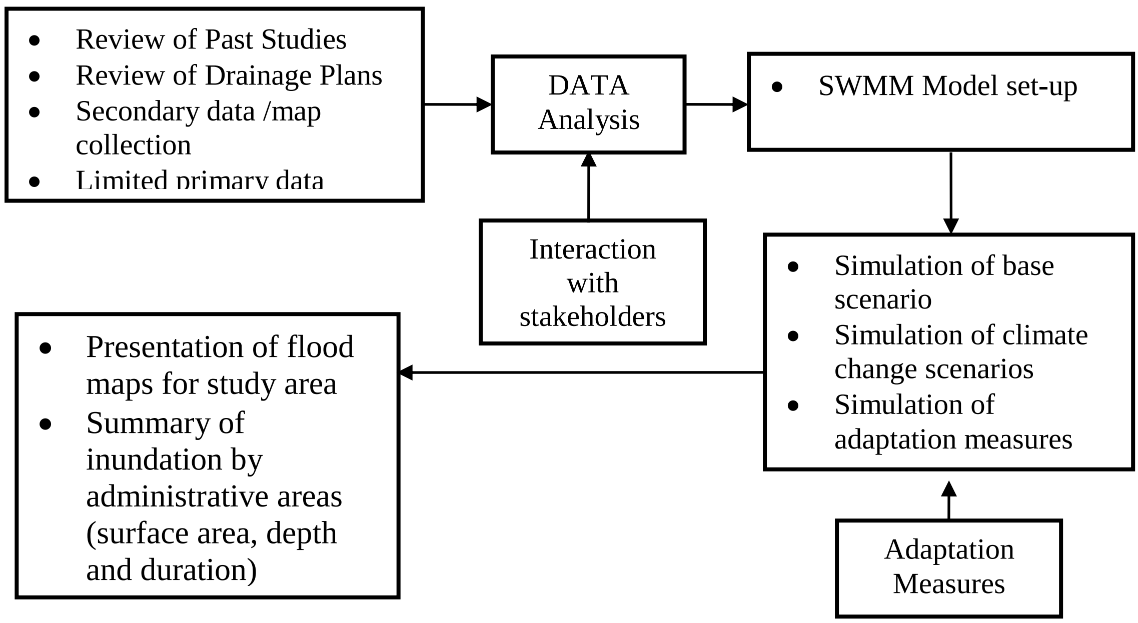


Figure 4-1: Overall Study Approach and Methodology

The overall study approach was followed by the data sources from primary and secondary sources. With the all the data and studies helped to set the goals of this study. A schematic diagram for drainage network modelling is shown on **Figure 4-2**. Details of modelling steps of drainage network modeling are discussed in following.

Step-1: Hydrological (Rainfall Run-off) Model

The runoff generated due to rainfall in the individual catchment area of major drainage route sub-catchment were determined through SWMM modelling tool. The concept of Runoff Model was based on "Time Area" method. According to this method the runoff amount is controlled by the initial loss, imperviousness, size of the sub-catchments and by a continuous hydrological loss. The shape of the runoff hydrograph is controlled by the concentration time and by the time-area (T-A) curve. These two parameters represent a conceptual description of the catchment reaction speed and the catchment shape.

Step-2: Hydraulic Model

1-D network module of SWMM modelling tool was used to develop the hydraulic model for the individual drainage zones. The runoff generated through Runoff Model was used as input to the SWMM hydraulic model. **Figure 4-2** is showing the details step of Hydrological Model & Hydraulic Model development and simulation.

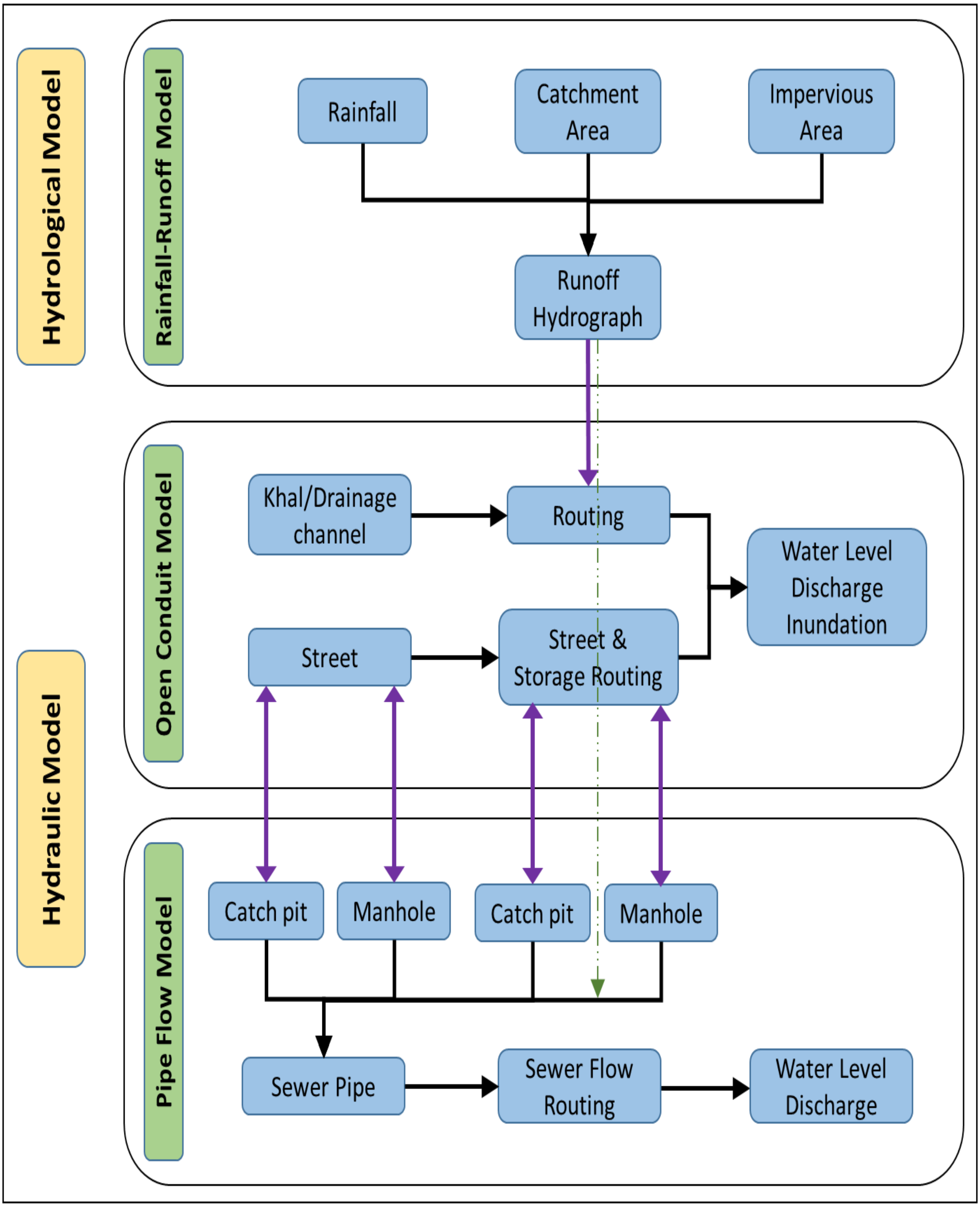


Figure 4-2: Schematic Diagram for Drainage Network Modelling

Estimation of Impervious Area

The 2004 and proposed land-cover information was based on Detailed Area Plan (DAP) data. Based on the various types of land cover identified in each catchment, the percentages of pervious and impervious area were estimated for the detailed study area, using typical values in the field (i.e., the actual percent values corresponding to a particular land cover) (WB, Urban Flooding of Greater Dhaka in a Changing Climate, 2015)

The modeling framework proposed for this study is illustrated in **Figure 4-3**. At first, hydrological model simulation was carried out. For this purpose, catchment delineation and methodology of computing catchment parameters were followed the defined catchment delineation DWASA Drainage Master Plan according to IWM (Institute of Water Modelling et al 2006). The simulated surface runoff from the hydrological model were then used in hydrodynamic modelling along with other input data (e.g. updated drainage network information from filed survey and discussion with DWASA officials, updated DEM, boundary conditions etc.). Time series water depth and discharge data were generated from the hydrodynamic model. Verification of the design cross-section of khals and determination of other improvement measures were done based on the model output.

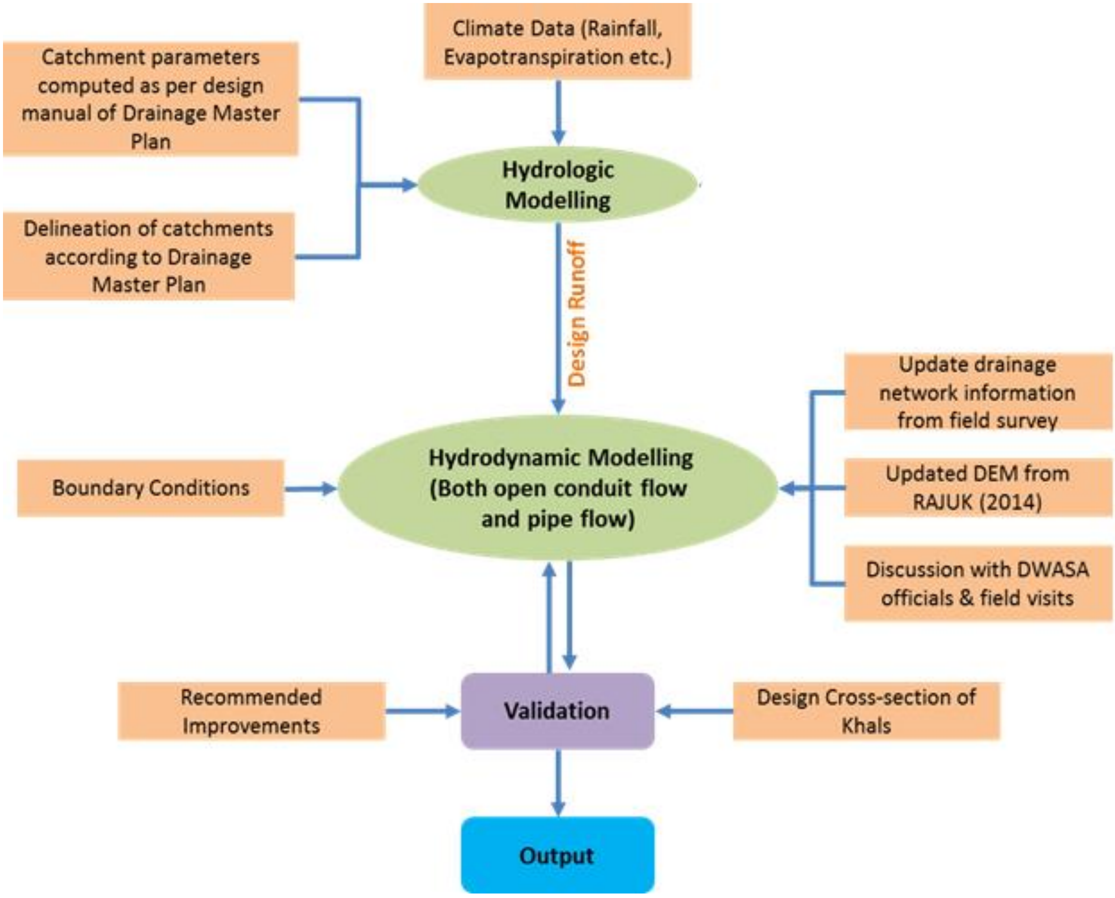


Figure 4-3: Modelling Framework to simulate the SWMM Model of GCB study area

When modeling development methodology was finalizing, different data were collected from filed level and secondary sources to develop the SWMM Model. Basically the model development works were followed by the SWMM manual to calibrate and validate the model properly to make it stable.

4.2 DATA COLLECTION

Adequate data is a prerequisite for conducting a comprehensive research works. In general, data on the following aspects are necessary to conduct research regarding urban drainage. Technical data related to various aspects like:

- Existing drainage situation analysis,
- Assessment of flow during monsoon along the drainage route/path and characterization of its pattern,
- Hydraulic behavior of drainage route,
- Adequacy of drainage structures,
- Outline design drainage infrastructures etc.

4.2.1 Secondary Reports and Data Collection

Available secondary data (e.g. drainage route, rainfall, pump station data, water level in peripheral rivers etc.) and relevant past study reports have been collected and reviewed to assess existing drainage situation in the study. **Table 4-1** shows the summary of secondary data collected under the study.

Table 4-1: Summary of Secondary Data Collected

Data	Source
Topography (DEM)-2014	RAJUK, 2014
Meteorological (Rainfall, evaporation etc.) [1953-2015]	BMD
Drainage route [2010]	DWASA
Drainage pump station [2017]	DWASA, BWDB
Retention Pond Topography	IWM
Land coverage [2014	RAJUK (DAP)
River Water Level [1987-2012]	BWDB
Population Density [1991,2001,2011]	BBS
Drainage Canal Sections [2016]	IWM

4.2.2 Data Processing for Mapping

Geographical information system (GIS) is a system of collecting, storing, manipulating, analyzing and presenting geographically referenced information in different forms as in map. In this study Arc/View GIS software was used for producing maps at different stages.

Projection System for Mapping

Bangladesh Transverse Mercator (BTM), Bangladesh Universal Transverse Mercator (BUTM) and SPOT Image Projection System of the Mercator family are widely used in Bangladesh. These projection systems are quite similar and these have been developed from the original UTM projection to suit the geographical position of Bangladesh.

Bangladesh Transverse Mercator (BTM) Projection System were adopted for mapping work in this study based on the fact that most existing cartographic data in Bangladesh including recent

IRS image maps are based on this system. The characteristics or parameters of this projection are:

Bangladesh Transverse Mercator (BTM)

Coordinate system	:	BTM	
Spheroid (Ellipsoid)	:	Everest 1830	
		Semi-major axis	a=6377276.34518m
		Semi-minor axis	b=6356075.41511m
		Inverse flattening	1/f = 300.8017

4.3 COMPILATION AND ANALYSIS OF DATA

4.3.1 Network Data

Records and maps from earlier design and construction phase of the existing drainage network provided data on material, diameter and invert level of pipes; cross-sections of open canals; location, material, dimension and invert level of manholes; height, width, material, size and shapes of weirs, orifices and gates. All these secondary drainage network data were updated or verified by the primary data obtained by extensive survey works.

4.3.2 Boundary Data

Boundary data e.g. hydro-meteorological data including rainfall, evapotranspiration and downstream water level data were collected from secondary sources and used. Drainage catchments were defined considering topography of the area, land use pattern, exiting drainage connectivity and recommendation of Drainage Master Plan of DWASA.

4.3.2 UHM- Unit Hydrograph Model Development

With this research study the UHM module simulates runoff from a single rainfall event as a base condition which simulates flow of water through drainage channels/pipes by taking surface runoff as an input from the hydrologic model. It can also simulate the operation of infrastructures at the end of the drainage system, such as sluice gates, pumps, etc.

For this study, the following steps were conducted using SWMM and GIS tools:

1. Simulation of hydrologic model for base year (September 2004)
2. Adjustment of catchment rainfall series for climate change and simulate hydrologic models based upon it.
3. Simulation of future (2025 and 2050 monsoon season) hydraulic models for climate change scenario CC with pump active.
4. Simulation of future (2025 and 2050 monsoon season) hydraulic models for climate change scenario with some adaptation measures.
5. Calculation of flood depth and durations using GIS for each scenario.

Output from this Model is time series data of flood depth within the model boundary. Indicative flood maps were also prepared for this study area for various scenarios.

CHAPTER 5: MODEL DEVELOPMENT

5.1 INPUT DATA

Different types of input data were needed to run the SWMM Model according to find out the flooded area for the Goranchatbari study site for different scenarios. Basically urban flooding is influenced by the amount of precipitation over the city area, as well as the prevailing water level in the surrounding rivers that act as outfall channels. So rainfall, evapotranspiration, imperviousness, topographic etc. were the major secondary data.

5.1.1 Rainfall Data

Heavy rainfall is one of the main factors that cause urban flooding. Therefore, changes in rainfall intensities need to be studied in order to model urban flooding and its impacts. Secondary rainfall data from the Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD) were analyzed.

Intensity Duration Frequency: The most common form of design rainfall data required for use in peak discharge estimation is the intensity duration-frequency (IDF) curves shown in **Figure 5-1**. The IDF can be developed from the historical rainfall data, which is done for all the rainfall stations available in the study area (**Figure 5-7**). The design rainfall values for Dhaka for different return periods and durations are presented in the **Table 1-3**.

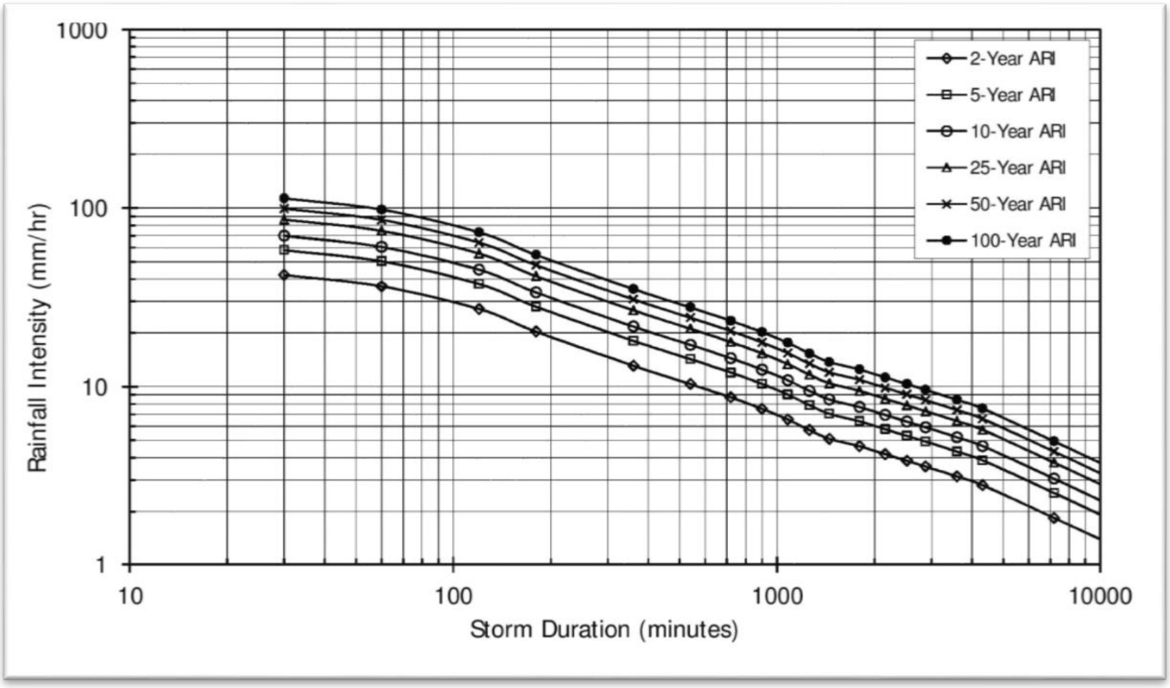


Figure 5-1: Intensity Duration Frequency (IDF) Curve for Dhaka City

The study analyzed daily rainfall data from several BWDB stations around Dhaka. The Banani Station covered the longest period (1957–2011). The time-series record showed that two recent extreme events have broken previous records: September 13, 2004 (341 mm per day) and July 28, 2009 (448 mm per day). The previous record was set on May 12, 1965 (222 mm per day). These findings highlight a trend of increasing variability in daily rainfall (**Figure 5-2**).

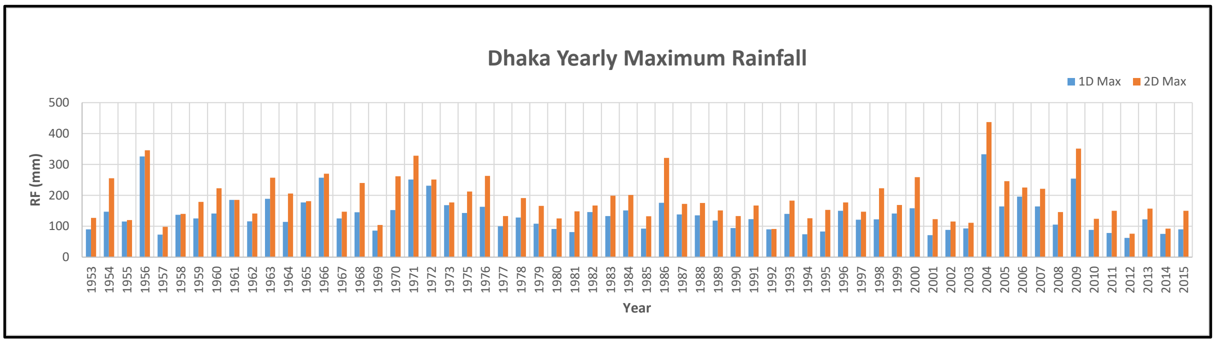


Figure 5-2: Dhaka yearly maximum rainfall (mm)

The study analyzed daily rainfall data from several BWDB stations around Dhaka. The Banani Station covered the longest period (1957–2011). The time-series record showed that two recent extreme events have broken previous records September 13, 2004 (341 mm per day) and July 28, 2009 (448 mm per day). The previous record was set on May 12, 1965 (222 mm per day). These findings highlight a trend of increasing variability in daily rainfall (**Figure 5-2**). Frequency analyses were conducted on the Dhaka (Banani) station data and compared to JICA (2000) findings. According to the JICA analyses, the September 2004 event of 341 mm per day would be classified as more than a 1,000-year, return-period event. However, the IWFM (2005) classified the event as a 100-year return-period event. The inclusion of more recent data—including the extreme event of July 2009—further reduced the return period to 50 years. These findings clearly show that return periods are decreasing; that is, larger events are occurring more frequently (**Figure 5-3**).

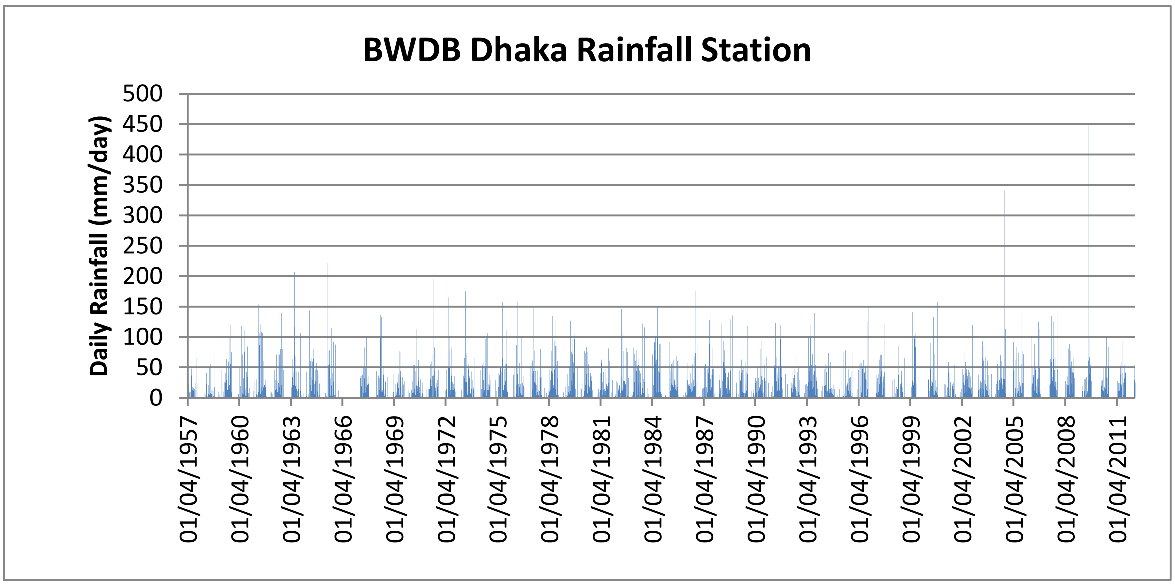


Figure 5-3: Daily Rainfall Time Series at BWDB Dhaka Station

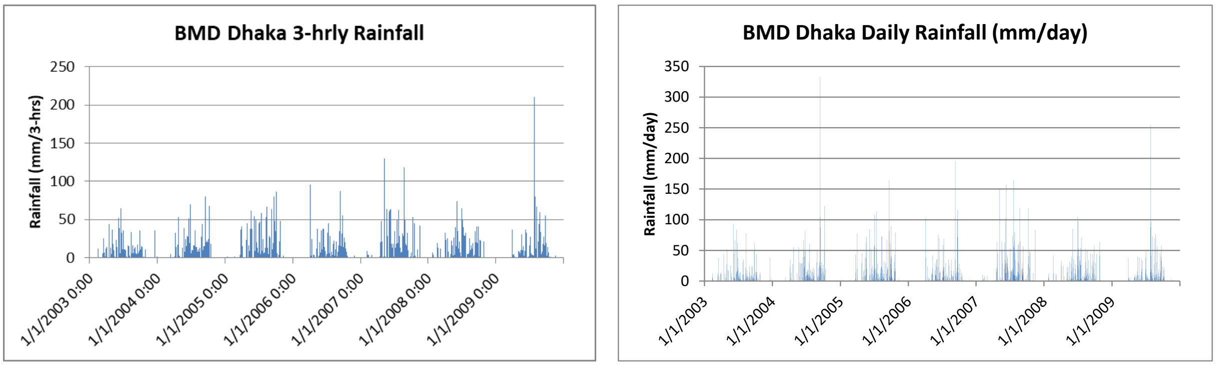


Figure 5-4: Dhaka Daily Rainfall & 3-hrly Rainfall at BMD Dhaka Station

Distribution of daily rainfall of BMD Dhaka station & Dhaka 3-hrly rainfall is showing on **Figure 5-4** from the year 2003 to 2009. On the year 2004 there is a showing a major spike where the maximum rainfall is almost 345 mm. The study also analyzed BMD Dhaka station data, including more detailed, sub- daily rainfall data, which are required for urban flood modeling. An interesting observation is that, compared to the BWDB data, the 2004 event is recorded as larger than the 2009 event (figure B.7a). The reason is that the two agencies collate daily rainfall data at different times of the day. BMD's three-hourly rainfall data reveals that the 2009 event was much more intense compared to other rainfall events since 2003 (**Figure 5-4**).

Table 5-1: Rainfall amount at different return period

Return period	**Dhaka station**				
	1-day	**2-day**	**3-day**	**5-day**	**7-day**
2	135	183	212	255	281
3	162	212	244	293	322
5	192	245	279	336	367
10	229	285	324	390	424
20	265	325	367	441	479
50	312	375	422	508	550
100	347	413	464	558	604

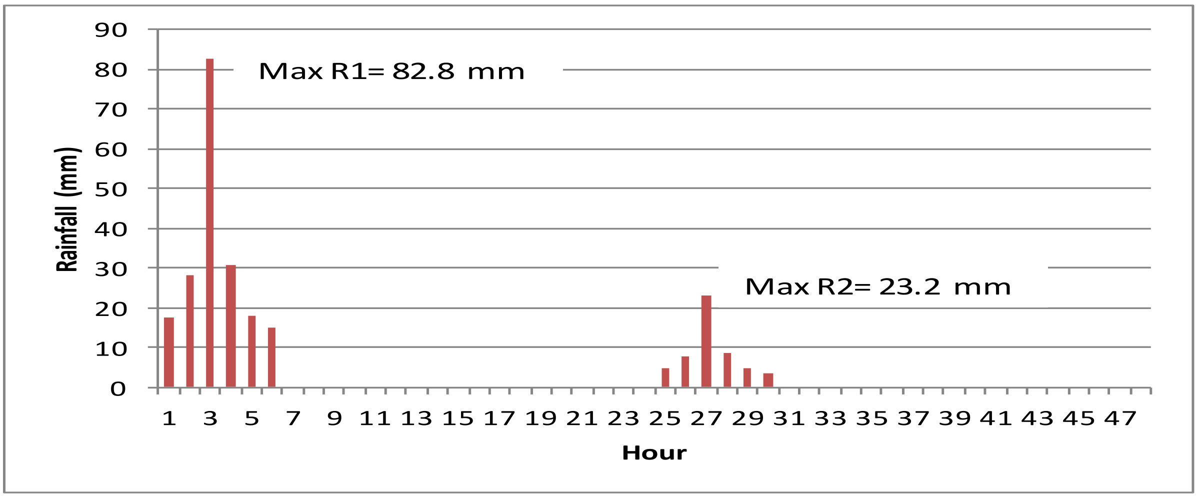


Figure 5-5: Hourly distribution of 2day 10year rainfall (Design Rainfall)

For urban drainage modelling and design, the 2 day 10 year rainfall data of 245mm need to be distributed hourly. For this purpose, the first and second day's rainfall pattern of the 2-day 10-yr design storm has been followed. The pattern (shown in **Figure 5-4**) consists of peak intensity 3 hours after the beginning of storm. In this formulation 192 mm (78%) rainfall occur in the 1st day and remaining 53 mm (22%) occur during 2nd day.

Table 5-2: Intensity Duration Frequency for Dhaka City

Duration	Rainfall in mm for the Return Period of					
	2 Yr	**5 Yr**	**10 Yr**	**20 yr**	**50 Yr**	**100 Yr**
30 Min	21.0	31.0	38.5	48.4	56	63.5
1 hr	34.5	50.9	63.2	79.6	91.9	104.3
2 hr	45.4	66.8	83.1	104.6	120.8	137.0
3 hr	53.2	78.4	97.5	122.7	141.7	160.8
6 hr	69.9	103.0	128.1	161.2	186.2	211.3
9 hr	82.1	120.9	150.3	189.1	218.5	247.9
12 hr	91.9	135.4	168.3	211.8	244.7	277.6
15 hr	100.4	147.9	183.8	231.3	267.2	303.1
18 hr	107.8	158.9	197.5	248.5	287.1	325.7
21 hr	114.6	168.8	209.8	264.1	305.1	346.1
24 hr	120.8	177.9	221.2	278.3	321.6	364.8
30 hr	131.9	194.3	241.5	303.9	351.1	398.3
36 hr	141.7	208.8	259.5	326.5	377.3	428.0
42 hr	150.6	221.8	275.7	347.0	400.9	454.8
48 hr	158.7	233.8	290.6	365.7	422.6	479.4
60 hr	173.3	255.3	317.3	399.4	461.4	523.4
72 hr	186.2	274.3	341.0	429.1	495.8	562.4
120 hr	227.7	335.3	417.0	524.8	606.3	687.8

This study reviewed previous research that investigated trends and changes in rainfall frequencies in and around Dhaka city. The Climate Change Cell (CCC) (2009) analyzed rainfall trends at 8 BMD and 11 BWDB stations around Bangladesh, including Dhaka, for 1960–2001. The findings showed that mean monsoon rainfall in Dhaka decreased marginally for the 1960–80 and 1981–2001 periods. However, for the latter period, the standard deviation doubled. The decade trend for monsoon rainfall (June–October) was decreasing, at −27 mm per decade; however, it was increasing for the other seasons: 13 mm per decade in winter (November–February), 28 mm per decade in summer (March–May), and 16 mm per decade in the critical period (March 11–May 10). The decade trend for September alone was also positive, at 11 mm per decade. Trends in 10-day rainfalls were analyzed, and findings similar to the monthly analyses were reported. The research also found that the trend in annual maximum rainfall for Dhaka was –10 mm per decade. The study did not examine changes in return period for rainfall events.

Murshed, Islam, and Khan (2011) also investigated the impact of climate change on rainfall intensity in Bangladesh. For the 1953–2009 period, it was found that the annual maximum rainfall at BMD's Dhaka station was decreasing at a rate of 0.0154 mm per year. However, over a more recent period (1979–2009), the trend was increasing at 2.7 mm a year. The main factors identified for the increase were the two quite large events that occurred during the most recent 10-year period. Omitting these two events results in a declining trend of 1.06 mm per year. The study also compared observed mean daily rainfall data with similar output from PRECIS, a regional climate model.

The observed data showed an increasing trend of 0.0103 mm per year for the 1953–2009 period, and the model showed a trend of 0.014 mm per year. The model was then used to predict the trend in monsoon rainfall up to the year 2100 for the high-emissions scenario (CC) of the Intergovernmental Panel on Climate Change (IPCC). The simulated results showed an increasing trend of 0.121 mm per year for monsoon rainfall. But the study did not investigate possible changes in return period for different-size rainfall events. Ahammed and Hewa (2012) analyzed rainfall data from BMD's Dhaka station for the 1953–2009 period. Various frequency analyses of daily rainfall data were conducted. For rainfall events with return periods of 3, 20, 45, and 100 years, the respective daily rainfall amounts were 200 mm, 325 mm, 375 mm, and 425 mm. The study also developed intensity-duration-frequency diagrams based on BMD rainfall data.

Hossain et al. (2013) studied Dhaka's rainfall trends in the context of the city's expansion over the past few decades. The analysis covered 20 years of rainfall data (1985–2005) from 254 BMD and BWDB stations. The findings showed that urban areas tended to receive less rainfall, in terms of frequency and intensity, than did rural areas. They further showed that areas downwind of urban centers tended to receive more rainfall than upwind areas.

5.1.2 Evapotranspiration Data

To determine evapotranspiration, only evaporation has been taken into account, because transpiration data for Dhaka is not available. The average monthly evaporation in Dhaka for the month of September is 118 mm (JICA, 1987). Total 1-day rainfall for 1 in 10-year event is 181mm in 6 hours. The percentage of evapotranspiration, thus computed as 0.5 % of total rainfall.

5.1.3 Boundary Conditions

Flood controlling structures i.e. sluice gates were considered to be closed as the modelling exercises were conducted considering wet season scenario. Thus the river water levels were not used as external boundaries. Inside water level maintained at Goranchatbari pump station (3.5 mPWD) were used as initial d/s boundary condition.

5.1.4 Land Cover and Percent Permeable

Design guidelines of DWASA Drainage Master Plan (2014) provides a table (**Table 5-3**) for computing runoff coefficients of drainage catchments which is an indicator of catchment imperviousness. From the table, runoff coefficient for the catchments can be determined based on the land use pattern. Accordingly, imperviousness of the catchments for Goranchatbari was determined analyzing DAP proposed land use data and the runoff co-efficient table provided in Drainage Master Plan (2014).

Table 5-3: Runoff Coefficients for various land use (Source: Drainage Master Plan of DWASA)

Land Type	**Density of Population (in thousand per sq. kilometer)**									
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**Up to 300**
	Low Density			**Moderate Density**			**High Density**			
	Impervious Area by Land Type (in percent)									
Agriculture	0	1	1	1	1	1	1	1	1	1
Circulation Network	60	65	70	75	80	85	90	95	100	100
Commercial Activity	19	27	35	44	50	56	63	68	73	78
Community Service	21	30	39	48	55	62	69	74	80	86
Diplomatic	9	14	18	22	25	28	31	34	36	38
Education & Research	11	16	21	26	30	34	38	41	44	47
Governmental Services	9	14	18	22	25	28	31	34	36	38
Manufacturing and Processing Activity	15	22	28	35	40	45	50	54	58	62
Mixed Use	21	30	39	48	55	62	69	74	80	86
Recreational Facilities	4	5	7	9	10	11	13	14	15	16
Residential	18	26	34	42	48	54	60	65	70	75
Restricted Area	2	3	4	4	5	6	6	7	7	8
Service Activity	9	14	18	22	25	28	31	34	36	38
Transport & Communication	60	65	70	75	80	85	90	95	100	100
Vacant Land	4	5	7	9	10	11	13	14	15	16
Water Body	0	1	1	1	1	1	1	1	1	1
Historical	9	14	18	22	25	28	31	34	36	38

Western Dhaka is very potential for urban development. At present a significant part of the land is low and used for agricultural purpose. Most of the residential areas are built up on raised lands mostly on the eastern part of this study area. Now-a-days many land development companies and the land owners are developing this area up to the average flood level. In this way the land use pattern is changing very rapidly.

The land use pattern of 2004 and 2015 (DAP) have been reviewed. Most of the study area (about 90.75%) was mainly dedicated to four categories of land use in 2004; Cultivated or open space (36.4%), residential (31.32%), and swamp, marsh or water body (23.03%). Remaining areas were functioning as transportation network, commercial activity, restricted area, public facilities and mix use zone. A small portion of the area was designated as industrial and urban green/park area.

Table 5.4: Existing and planned land use categories (Source: Drainage Master Plan of DWASA)

Existing Land Use Category	2015 Area (%)	Planned Land Use Category	Proposed Area (%)
Commercial	1.38%	Administrative Zone	0.41%
Cultivated Land/Open Space/Forest	36.40%	Agricultural Zone	0.09%
Industrial Area	0.46%	Commercial Zone (Business)	0.37%
Mixed Use area	0.69%	Commercial Zone (Office)	0.01%
Park/Playground/Urban green area	0.40%	Flood Flow Zone	3.32%
Public Facilities	1.79%	General Industrial Zone	1.62%
Residential Area	31.32%	Heavy Industrial Zone	0.00%
Restricted Area/Brick Field	0.86%	Institutional Zone	1.33%
Road/Railways	3.65%	Mixed Use Zone (Residential-Commercial)	8.07%
Swamp/Marsh/Char/Island/Water bodies	23.03%	Non-Conforming Use	0.00%
		Open Space	2.43%
		Overlay Zone	3.32%
		Proposed Road Network	7.99%
		Rural Settlement Zone	0.54%
		Transportation & Communication	2.48%
		Urban Residential Zone	44.07%
		Water Retention Area	20.60%
		Waterbody	3.34%
Total	**100%**	**Total**	**100%**

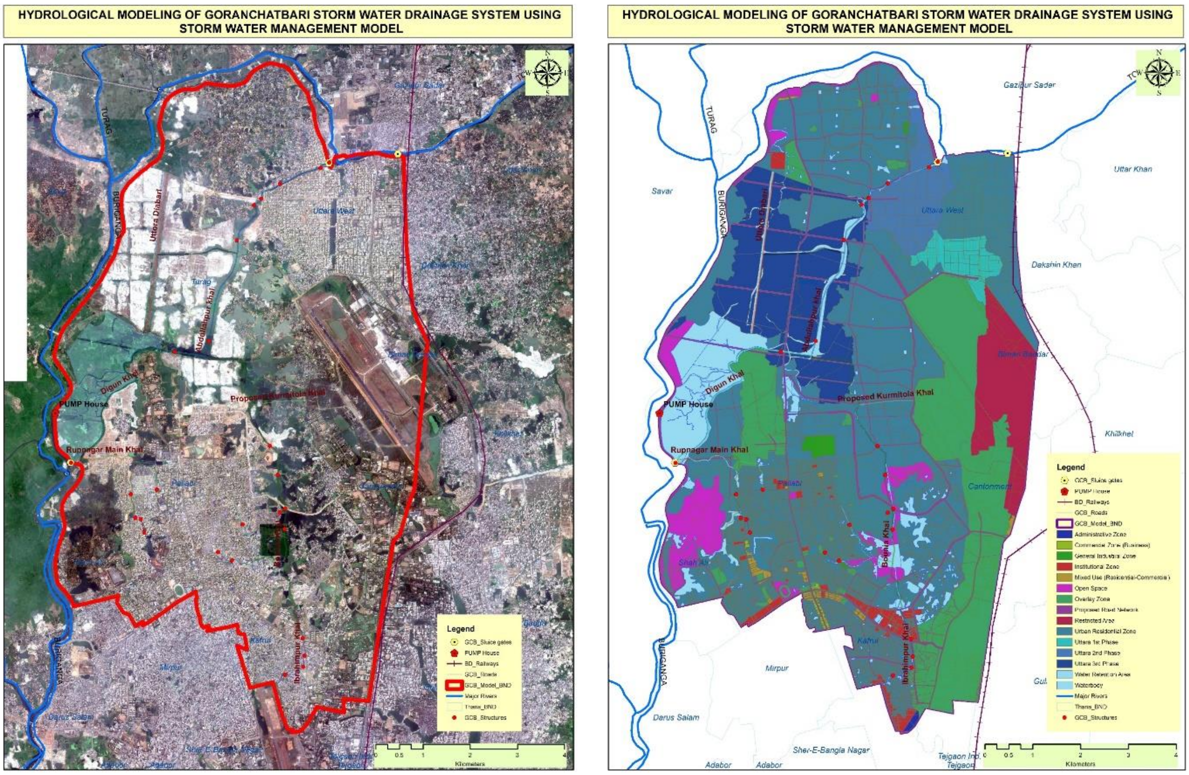


Figure 5:6: Existing land use pattern of study area (Sattelite Image, 2016) & proposed land use pattern of study area (RDP, 2035)

The majority of the area is planned to become residential, water retention area, mixed use (residential-commercial) and transportation network in the developed phase. Open spaces and agricultural areas are expected to decrease and changed into residential area and mixed use zones. The impervious area is expected to increase from 12% in 2004 to 70% in 2050.

5.1.5 Topographic data analysis

The DEM has been prepared for 2016 based on the topographic data collection by secondary source, SoB map and land fill information. From the DEM the area-elevation curve has been developed as shown in Error! Reference source not found.. The area elevation curve shows that bout 70% land area of Eastern Dhaka is below the average flood level (12.0mPWD). The land developing companies and land owners are developing the low lying areas by earth filling above 10 mPWD. If the trend continues further 45% areas will be elevated in future (excluding the water retention and water body areas).

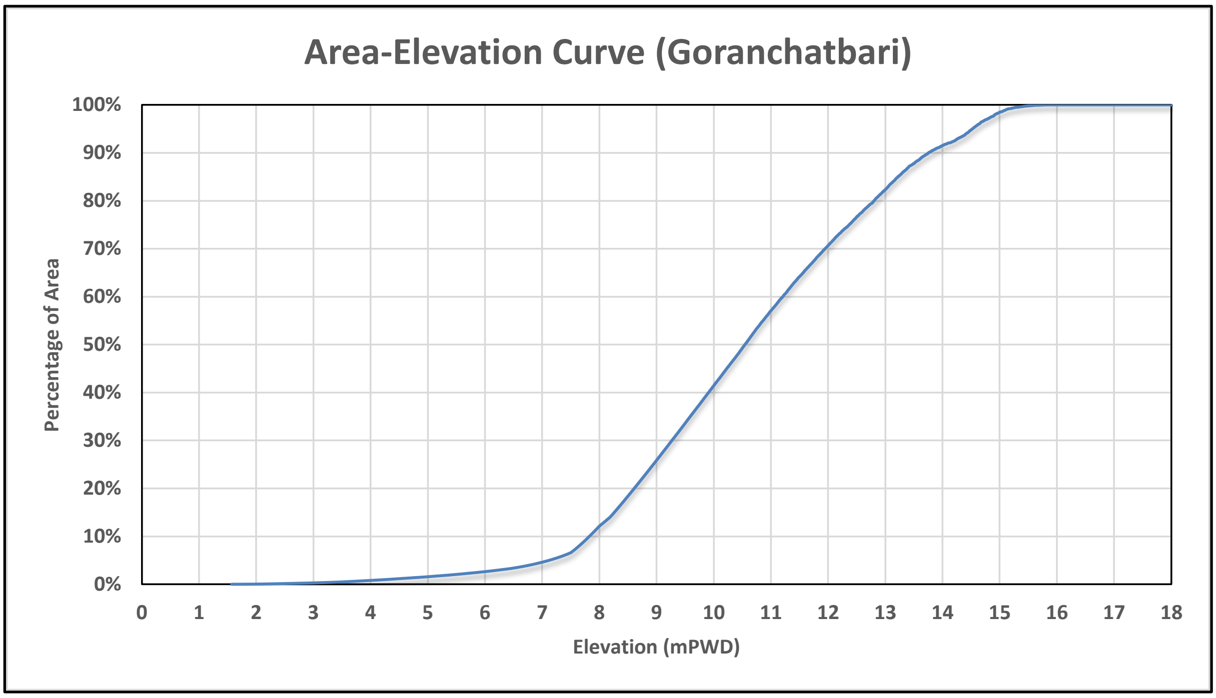


Figure 5-7: Area-Elevations Curve of Study area in 2016

5.1.6 Key Assumptions

- Domestic wastewater has not been considered in modelling exercises.
- The initial loss and reduction factor assumed remain same in future.
- Water losses due to transpiration is considered negligible
- The catchment areas will not change in future.
- Sediment depth was considered as 20% of pipe diameter, 30% of section height for box-culverts.
- During wet season sluice gates will remain close thus external river water level will have no influence on drainage congestion within the study area.

5.2 MODEL SETUP (NETWORKS AND CATCHMENTS)

This section presents an outline of the approach and methodology which have been followed in the study activities. Works conducted under this study involved identification and addressing specific problems, survey and investigation, development of drainage plan, detailed mathematical model study, preparation of feasibility level outline design, drawings. Methodology of the study was based on the proper understanding of the study objectives.

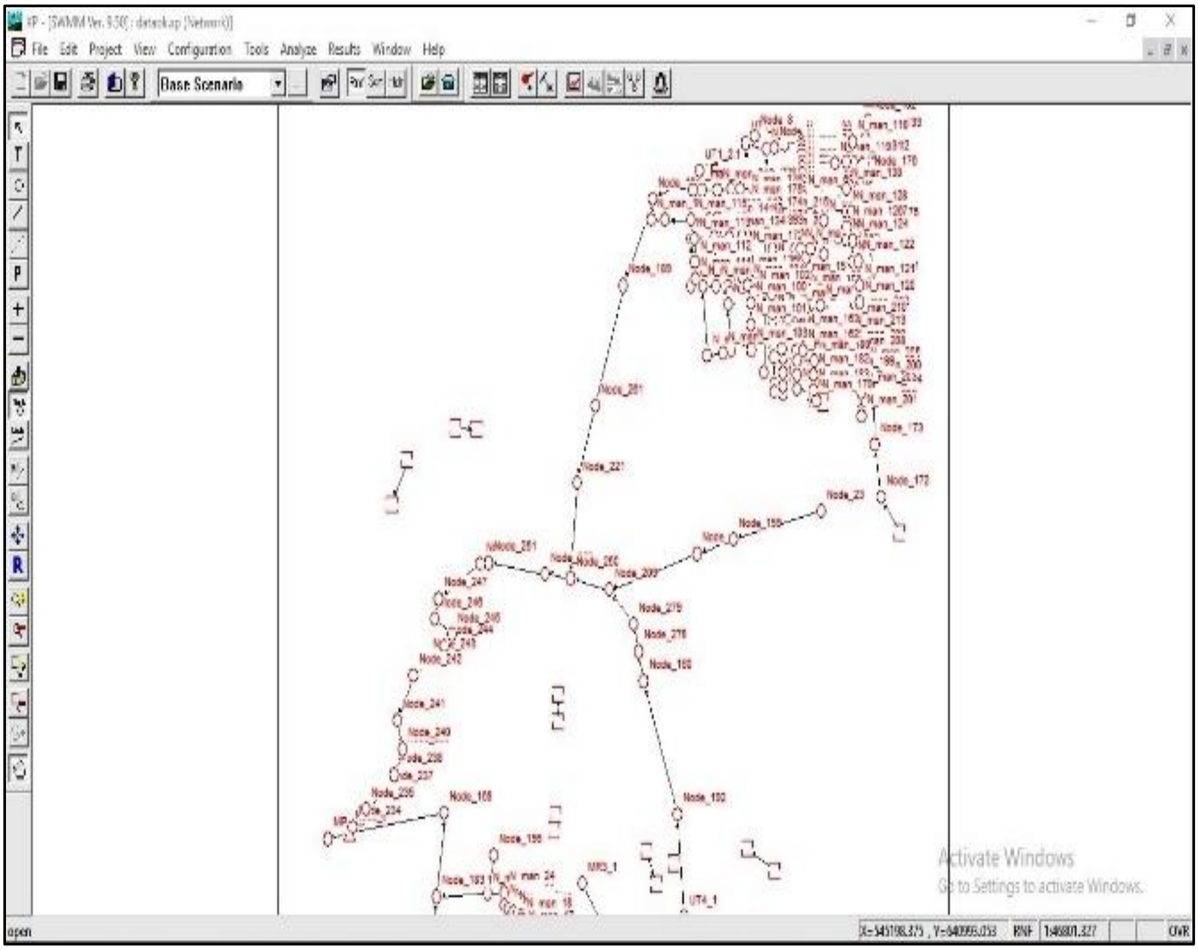


Figure 5-8: Model development (Node ID & Links ID)

The available drainage models were developed mainly based on secondary drainage network data from MIS of DWASA and some as-built drawing up to 2012. Network survey at some predefined locations were made to verify those secondary data. Primary data were collected through field survey where there was lack of sufficient data. Specifically, cross-section data of all khals collected from field survey were compiled in the models. In addition, recent as-built information's from DWASA were collected and incorporated in the models. Finally several discussions were made with DWASA drainage division regarding the updated model network and according to their observations set-up of model networks are finalized.

Delineation of catchments according to DWASA Drainage Master Plan (2014) were analyzed based on practical experience, extensive field investigation, existing drainage pattern and topography. To conduct more realistic modelling exercise, rearrangement of some catchments were done and in some cases catchments were divided in to more sub-catchments. According to the secondary data from DWASA there are 12 khals and secondary drainage pattern A Hydrological Model was prepared on SWMM to develop a calibrated Hydraulic and Hydrological Model of Goranchatbari.

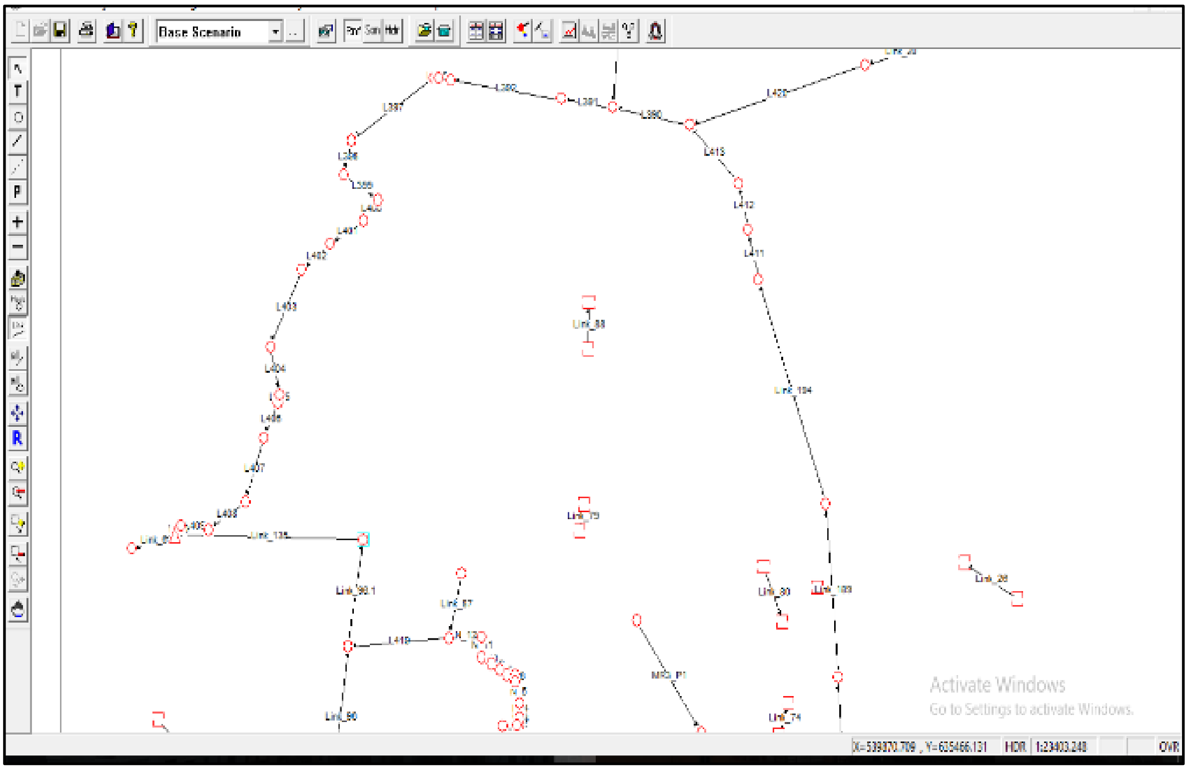


Figure 5-9: Model development (Links ID)

For SWMM model development 2004 was treated as base year and various 10yrs, 30 yrs and 50 yrs return period analysis were done to develop the final model. Then observed pump station data, khals velocity and water level were used to calibrate and validate the model. Four scenarios were used to find out the appropriate inundation map for the study area. **Figure 5-10** is showing the layout of the model with networks and nodes. As well as **Figure 5-11 & Figure 5-12 is** showing catchments and existing structures of the stud area.

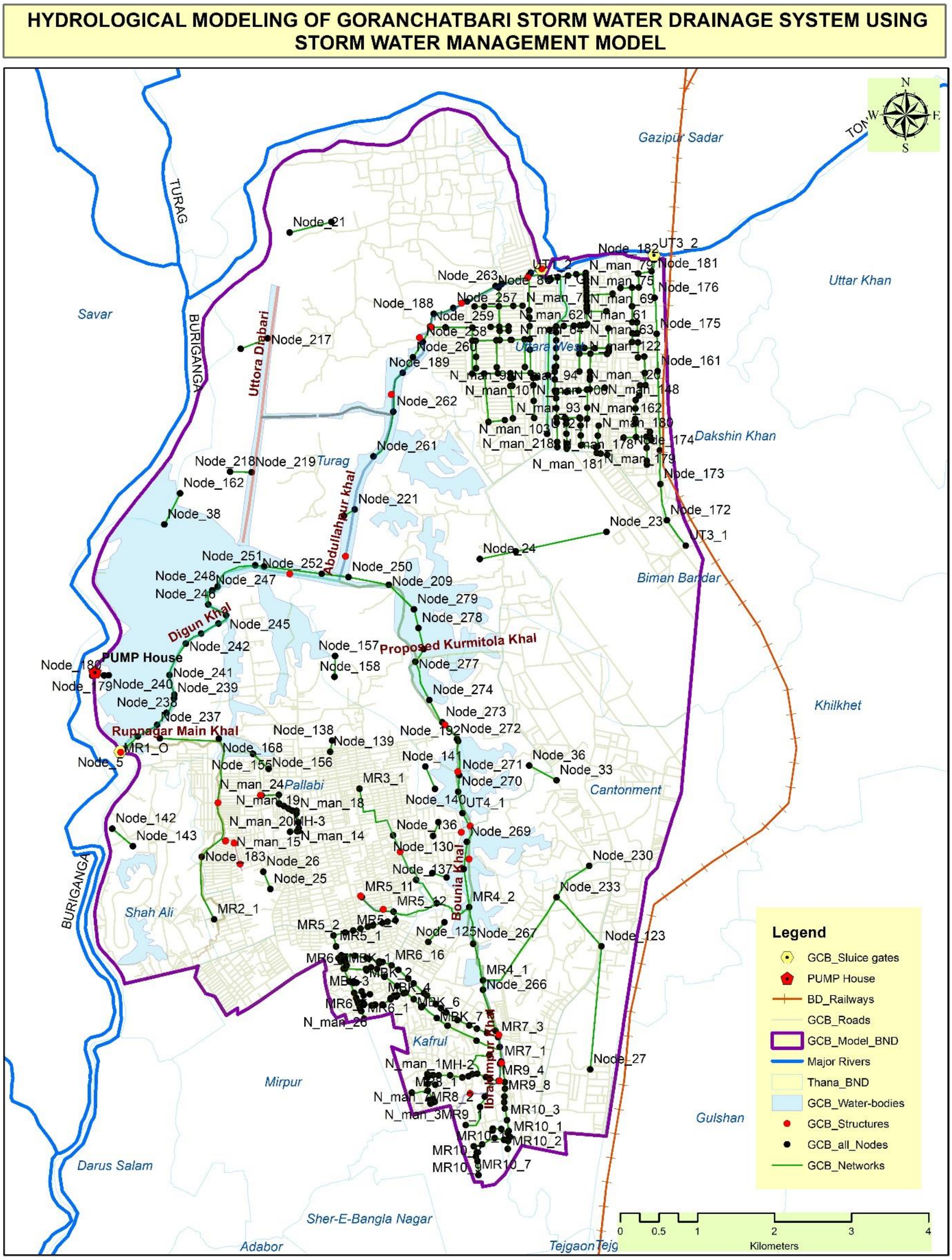


Figure 5-10: Model Networks with nodes of study area Goranchatbari

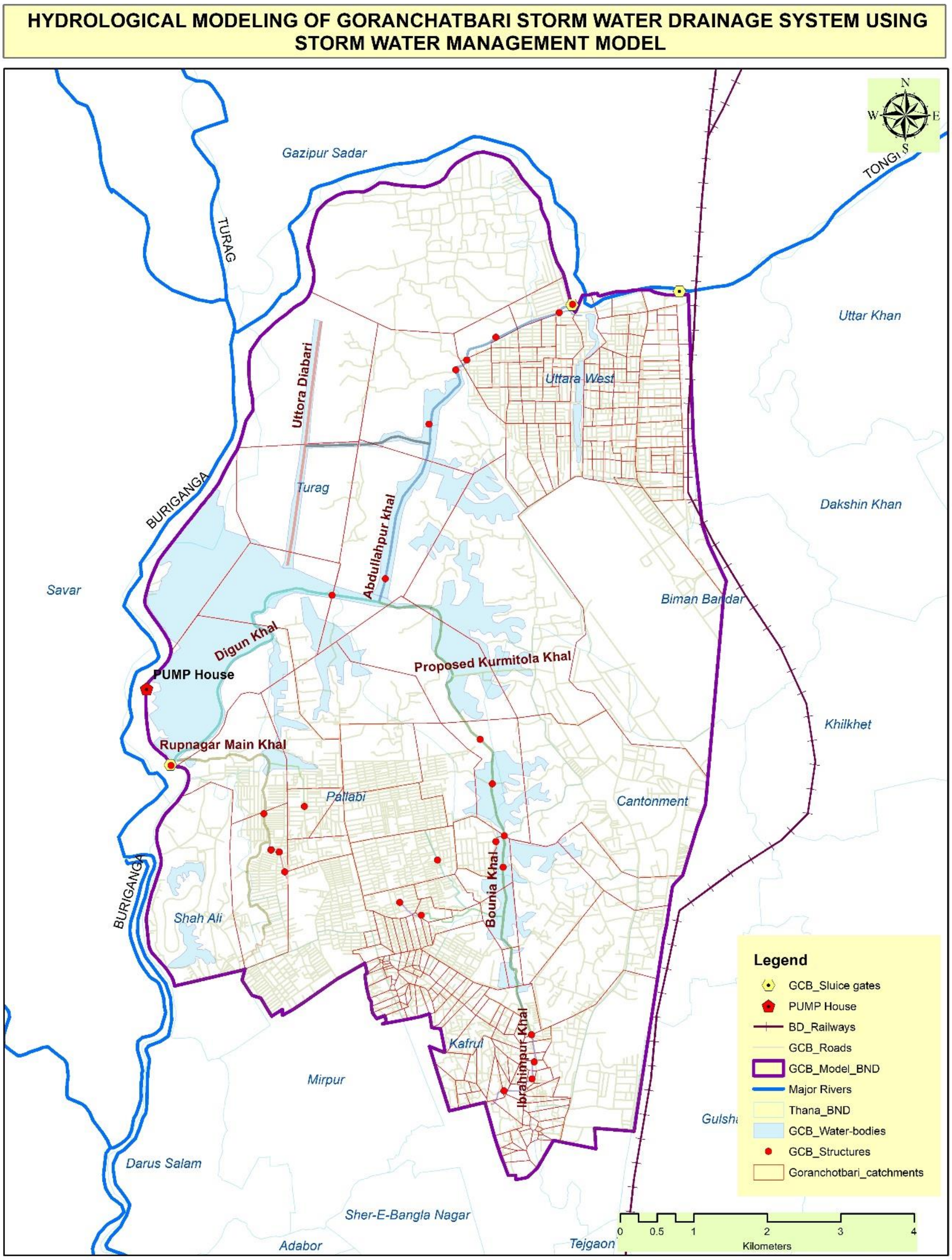


Figure 5-11: Catchments of study area Goranchatbari

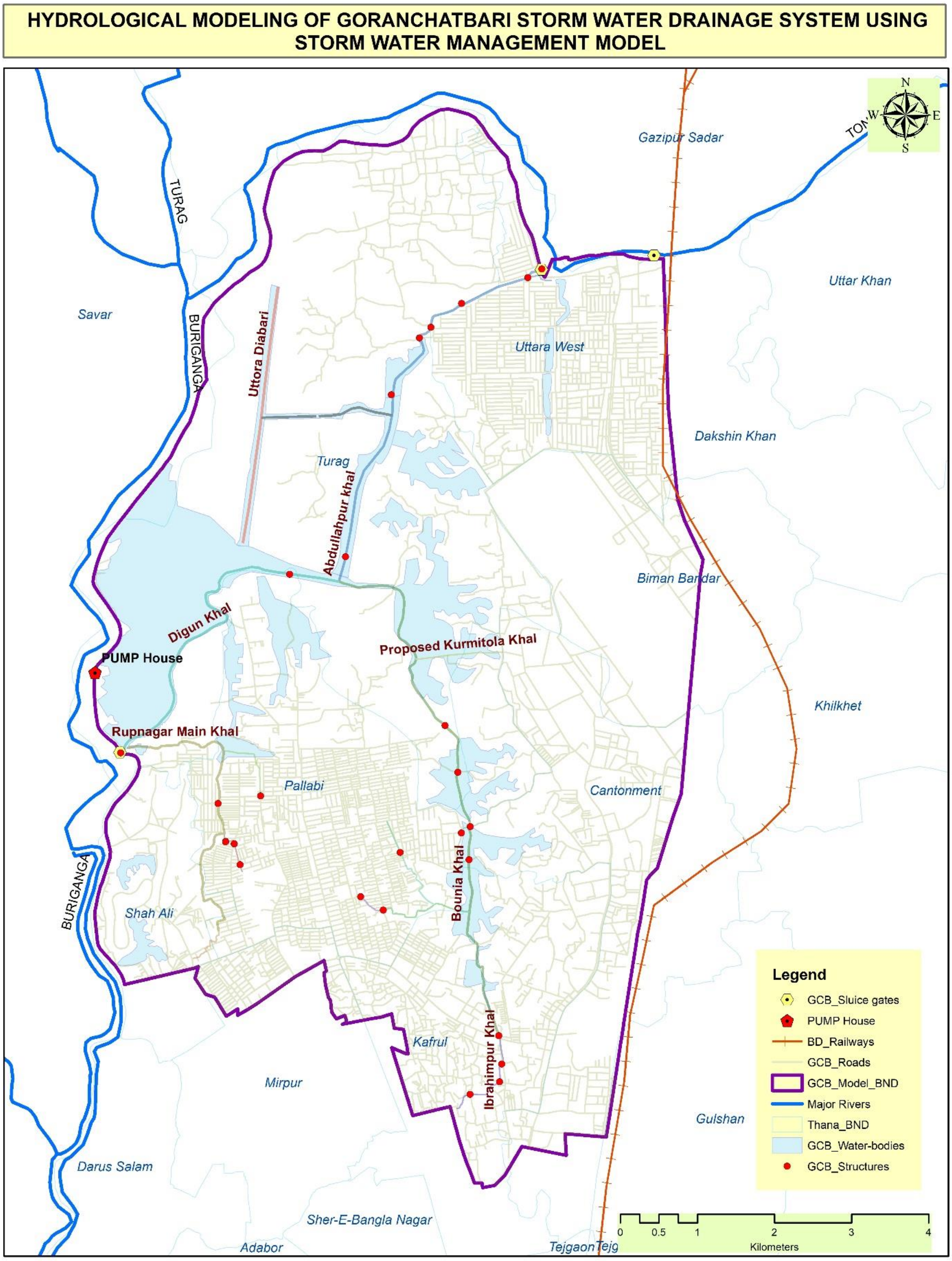


Figure 5-12: Existing structures of study area Goranchatbari

5.3 DRAINAGE CRITERION FOR PUMPING

In search of locating best scenario from 1 to 4, additional scenarios with different design criterion can be used as **Table 5.5**.

Table 5.5: Drainage criterion for various scenario analyses

Max. allowable WL	(a) 3.5 mPWD
Khal widening	Near the pump stations (Abdullahpur khal, Digun Khal)
Retention pond	(a) 6.15 km^2 (as RDP 2035)
Pump start level	3.5 mPWD
Pump stop level	3 mPWD
Pump operational period	Max. 48 hours

Pump Selection:

Maximum allowable water level:

Two very important criterion are the maximum water level that would be allowed in the retention ponds during monsoon and the pumping periods. As land filling in the catchment area of study area is happening at a very faster rate the low lying areas are moving to higher ground level. It is observed that in the study area all land developments at current time are happening at elevation > 5mPWD which also supports ultimate selection of scenario 4 (not to allow flooding above 3.5 mPWD).

From the area elevation curve of the pumping areas it is observed that about 24% to 70% areas are below 5mPWD which would be elevated in future (except the water retention and drainage khal areas) for urban development.

Pump start & stop level:

It is considered that all pumps would be operational when the water level in the retention pond area rises to 3.5 mPWD and would stop when it goes down to 3.3 mPWD. So in the retention areas there would be 1 to 1.5m storage level if maximum allowable level is considered 4 mPWD or 4.5 mPWD respectively.

Pump operation period:

The pump capacity and retention area would be considered in such a way that maximum 2day is required to pump out the runoff generated from 2day 5year rainfall.

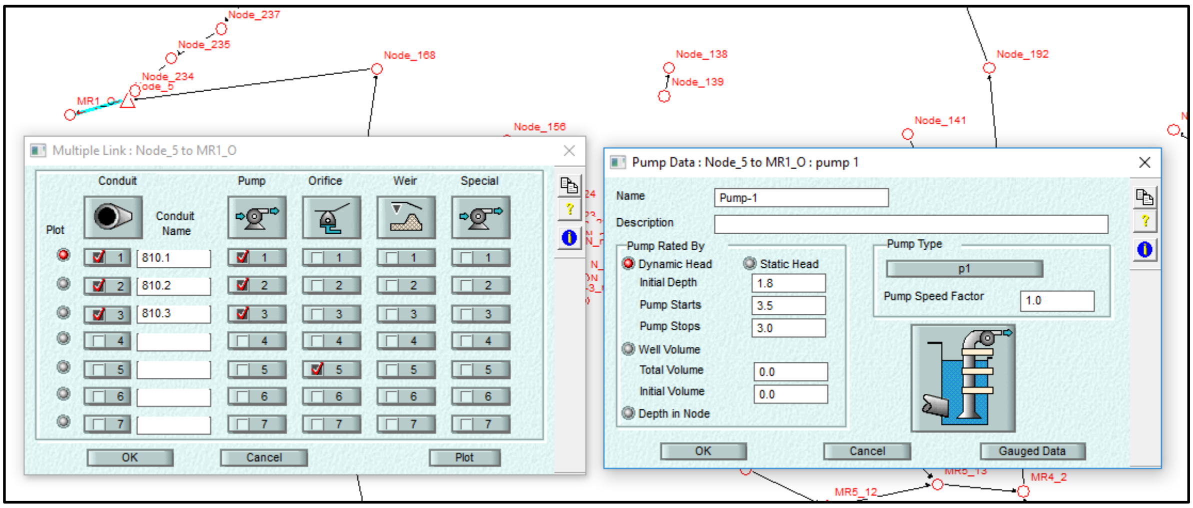


Figure 5-13: Pump set-up in the Model

Retention Pond:

Retention pond is required to store storm water for a certain period and facilitate pumping options. In RDP land use planning about 6.15 km^2 is kept for retention pond to facilitate the pumping stations. To reduce the land requirement and thereby land acquisition cost, other options are simulated with reduced retention pond of about 4.51 km^2, 3.63 km^2 and 2.96 km^2 (including 0.174 km^2 khal widening) and accordingly the pump capacity is estimated through modelling.

Figure 5-14: Retention pond near Goranchatbari Pump Station (River Side)

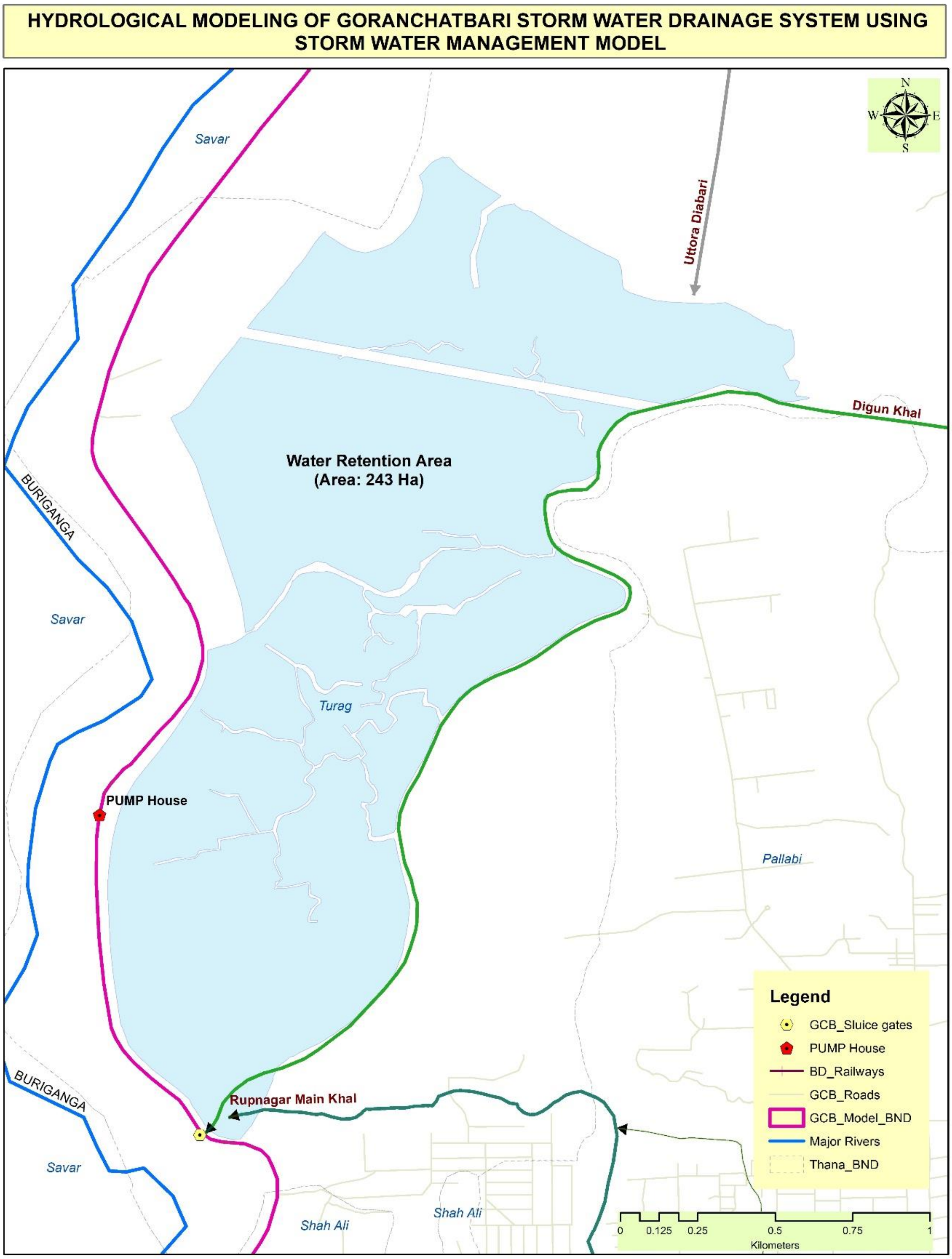


Figure 5-15: Retention pond of Goranchatbari Pump Station

The total area of Goranchatbari pump station is 243 Ha which have a huge water retention options.

5.4 MODEL CALIBRATION & VALIDATION

The model was calibrated based on a comparison of simulated and observed data at 3 locations is showing on **Figure 5-13** where measured water level and velocity data were available. The calibrated model was validated against known events without changing model parameters with the inundation map of World Bank study (WB, CLIMATE AND DISASTER RESILIENCE OF GREATER DHAKA AREA, 2014). From the comparison plots, it was evident that the model-generated water levels matched reasonably well with the observed data (**Figure 5-16**). Therefore, the model was considered suitable for application runs to study climate change scenarios.

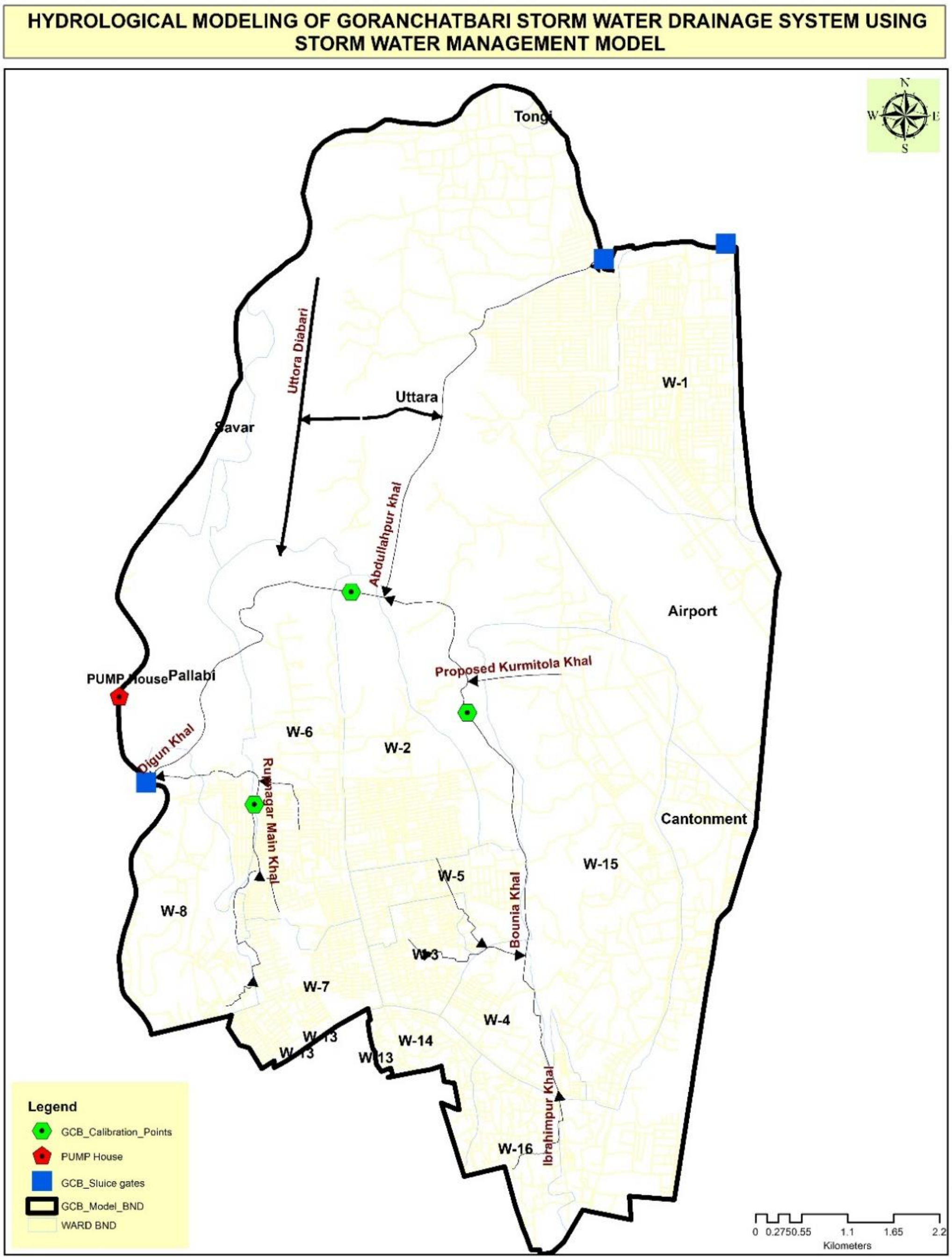


Figure 5-16: Simulated Water Level at retention pond of Goranchatbari

5.4.1 Calibration with Pump data

In order to drain out storm water after completion of the Western Dhaka embankment drainage regulator at 5 outfalls have been considered for gravity drainage towards retention pond. Once water level inside the study area reaches 3.5 mPWD pump will start running. Model run results under all scenarios show that with active pump which is not possible to drain out the storm water within design period even after installation of maximum number of pumps.

Figure 5-17: Goranchatbari Pump Station (River Side) & pump start level.

At present condition Goranchatbari has two pumps and another pump construction work is going on. According to the drainage master plan in the year 2004 there was only one pump house to pump out the whole water from Goranchatbari retention pond. As a limited data from pump house we have only pump start level and stop level. The minimum pump start level is 3.5 mPWD and pump stop level is 3.0 mPWD according to the pump house data. The pump is operated by BWDB.

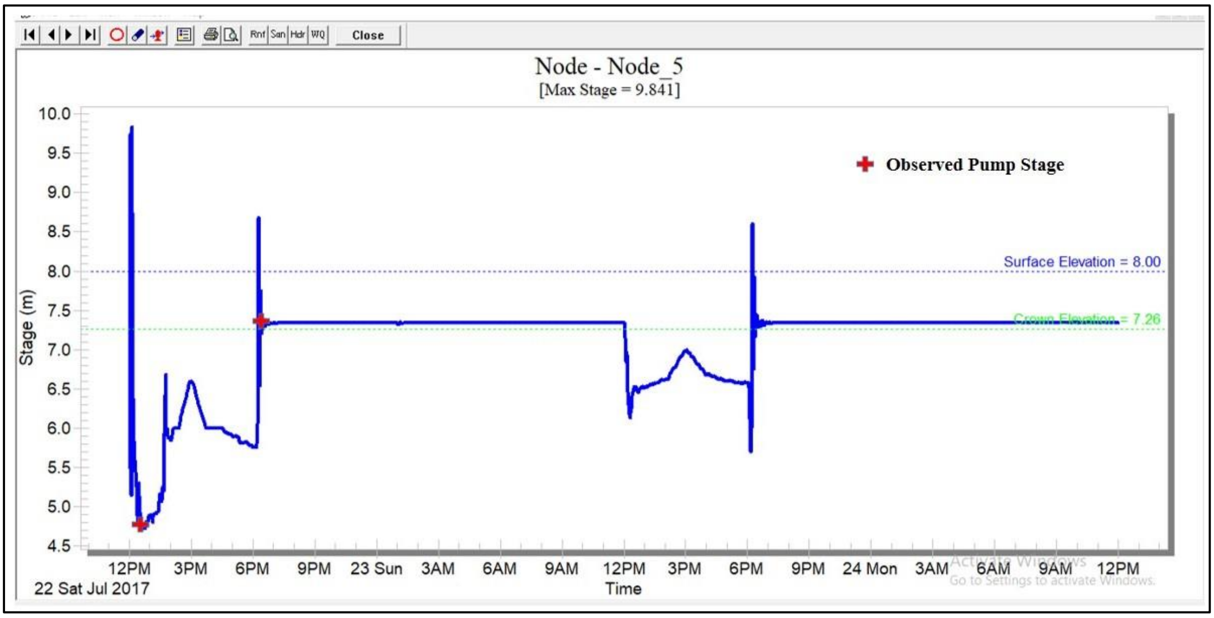


Figure 5-18: Goranchatbari pumping station water level to start the pump & shutdown

5.4.2 Calibration with observed velocity

Some observed velocity from the calibration point location shows on **Figure 5-12** according to the IWM (2016) study of Feasibility and SEIA Study for Expansion of Drainage Networks and Development of Canals in Dhaka City, were collected. Digun Khal velocity shows that the observed velocity is higher than the simulated velocity. R^2 of this observed velocity vs simulated velocity is 0.985 and MSE is 0.008 which is showing on the **Figure 5-15** and **Figure 5-16.**

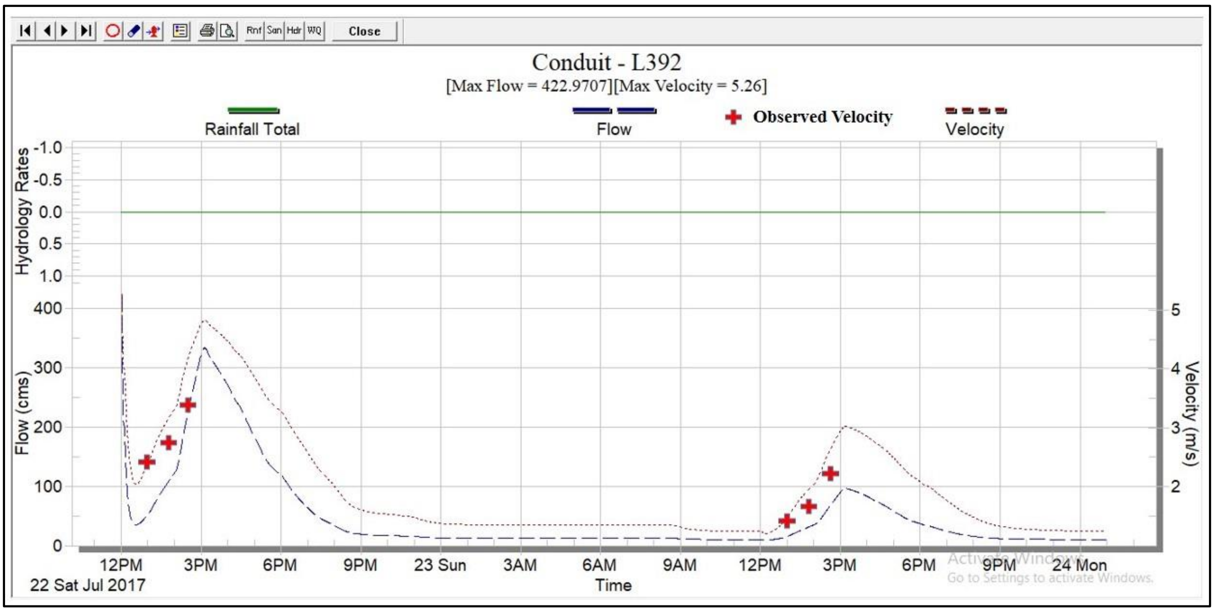


Figure 5-19: Observed & Simulated Velocity from site of Digun Khal

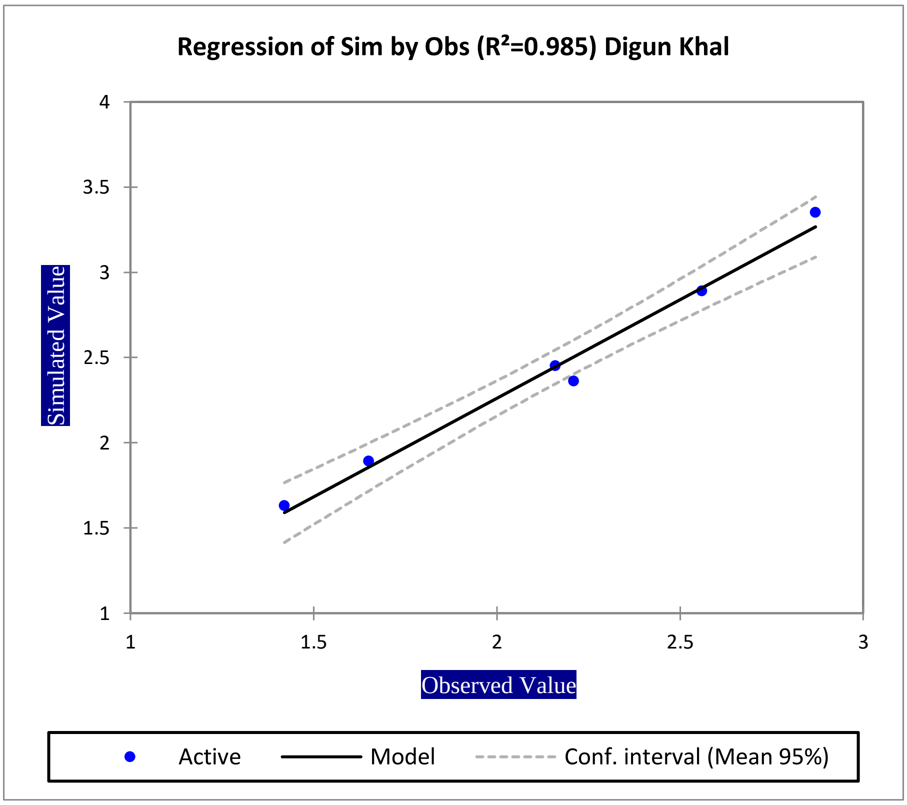


Figure 5-20: Digun Khal Calibation Valid Linear Regression Goodness of Fit

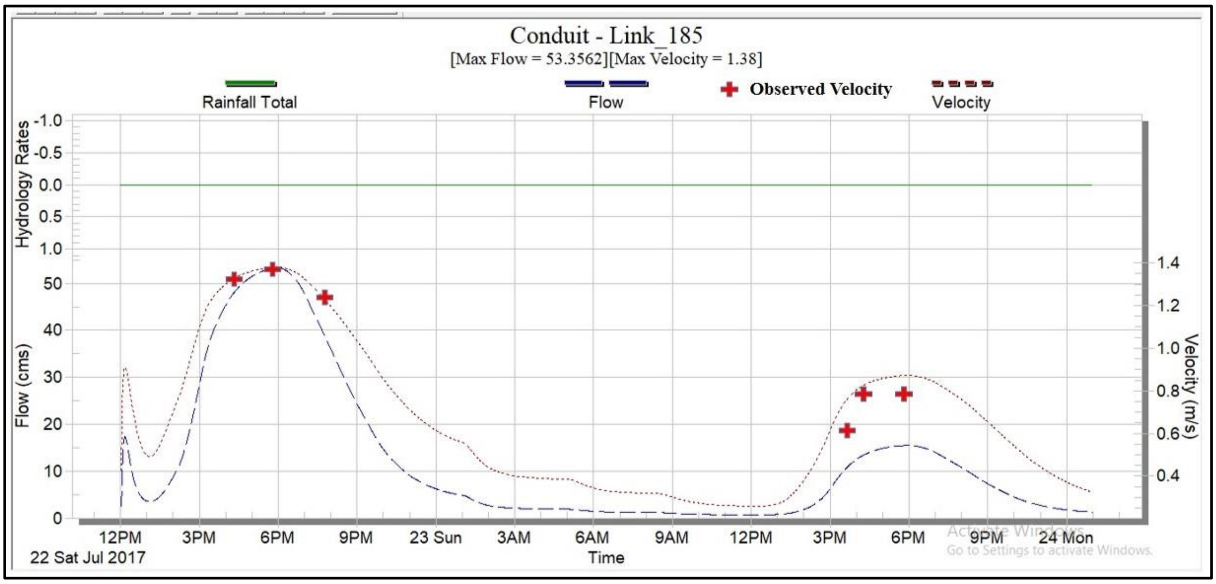


Figure 5-21: Observed & Simulated Velocity from site of Bounia Khal

For Baunia Khal velocity shows that the observed velocity is higher than the simulated velocity on **Figure 5-17**. R^2 of this observed velocity vs simulated velocity is 0.807 and MSE is 0.029 which is showing on the **Figure 5-18.**

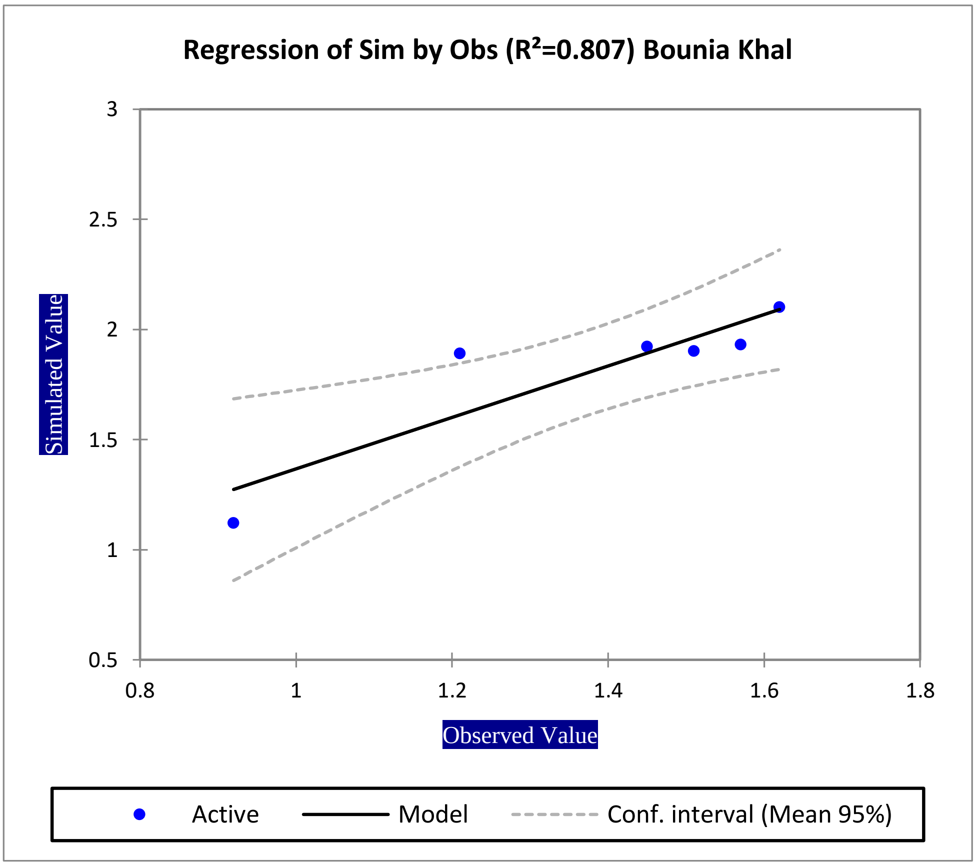


Figure 5-22: Bounia Khal Calibation Valid Linear Regression Goodness of Fit

5.4.3 Model Validation with World Bank studied inundation maps

According to the study by World Bank (Zaman, Asif M. 2014) a simulation of inundation depths was run for the historic 100-year, return-period rainfall event in 2004 shown on **Figure 5-21** where the inundated areas were shown. The most western part of this study area were flooded by extreme rainfall event.

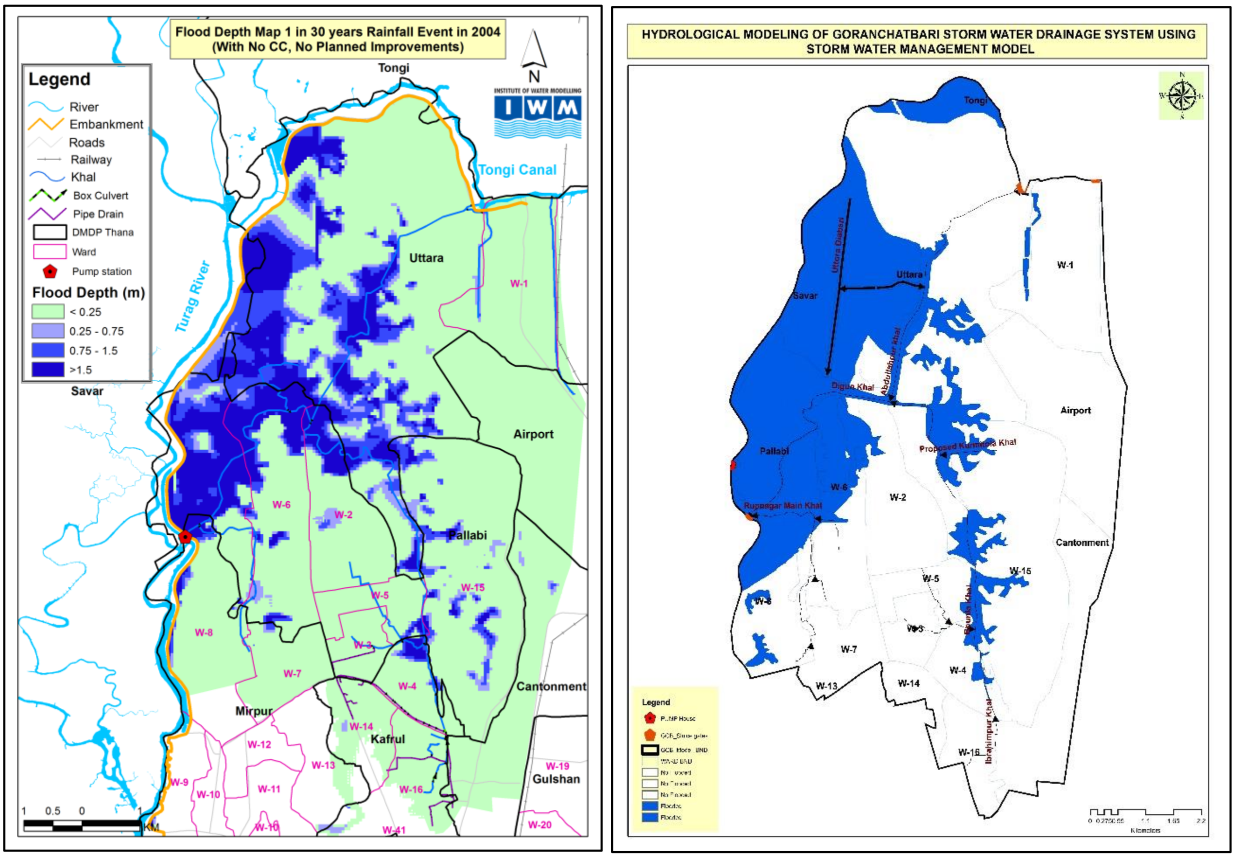


Figure 5-23: Comparison with WB simulated Flood & SWMM simulated Flood

By using the similar event like 2004 the model was run with 48 hours' rainfall and collect the water level of nodes. By using the water level, a flood inundation map was produced by using the same event as World Bank done. By comparing the both map it was assured that the western part of Dhaka was flooded due to heavy rainfall.

CHAPTER 6: RESULTS AND ANALYSIS

6.1 MODEL SCENARIOS (CASES)

When the model is ready with proper calibration and validation then four scenarios were chosen like base scenario with pump active, climate change scenario with pump active, land use change scenario with pump active and scenario with adaptation measures. Drainage criterion for various scenario analysis listed with the **Table 6.1** where model setup and outcomes are shown.

Table 6-1: Drainage criterion for various scenario analyses

No.	Name	Model Setup	Outcomes
1.	Calibration Scenario-BASE-1 (BASE)	# Current Drainage Networks # Pump Active # 2016 Land Use # 3 Hourly Rainfall	# Indicates the current efficiency of storm water management facility while pump is fully active # Calibration and Validation
2.	Climate Change Scenario-CC (BASE+CC)	# Current Drainage Networks # Pump Active # 2016 Land Use # 100 Years Design Rainfall	# Identifies future max overflow locations if existing drainage remains unchanged # Indicates requirements of new drainage facilities due to climate change.
3.	Impact Scenario-LU (BASE+LU)	# Current Drainage Networks # Pump Active # 2035 Land Use # 100 Years Design Rainfall	# Identifies future max overflow locations if current drainage remains unchanged but land use changed # Indicates requirements of new drainage facilities for land use pattern change.
4	Impact Scenario-Adaptation (BASE+ADP+LU)	# Current Drainage Networks # Pump Active # 2035 Land Use # 100 Years Design Rainfall # New drains add	# Identifies future max overflow locations if some adaptation drainage networks incorporated but land use changed # Indicates requirements for waterlogging zones with proposed adaptation.

The SWMM Model platform was selected for the Goranchatbari system model, and the area modeled spans about 63.79 km^2 in Northwestern Dhaka. The drainage system model area shares borders with the adjoining areas of Eastern Dhaka to the east, Central Dhaka to the southeast, and Kallyanpur to the south. The Western Embankment from the Tongi Rail Station to Kellarmor on the city’s west side protects the area from flooding of the Turag River shown at **Figure 4-1**. Different parameters and key features is showing on the **Table 6-2** where the summery of study area also attached.

Table 6-2: Goranchatbari System Model - Different Parameters and Key Features

Parameter / Feature	2010	2030	2050
Population density (people/sqkm, weighted average)	20,066	49,023	88,776
Average Land level (mPWD	6.19	7.48	7.68
No. of catchments	69	69	69
Imperviousness (weighted average)	42%	54%	62%
Time of concentration (min, weighted average)	85	68	68
Total Length of Pipes/Culverts/Khals (km)	44.6	66.4	66.4
Wastewater (% of total domestic load)	100%	0%	0%
Sedimentation for pipes (%)	0%	0%	0%
Ponding area (sqkm)	2.43	2.43	2.43
Permanent pumps	2	3	3
Total pump capacity (m^3/s)	44	66	66
Working efficiency of pumps	85%	90%	90%

Compared to the base (2004) scenario, important changes in the drainage system include:

- Increase in catchment impervious areas (overall from 42% to 54% then to 62%)
- Increase in pump capacity at Goranchatbari Pump Station (to 66 m^3/s)
- New drainage pipes giving total length of approx. 133 km
- Some changes to khal cross-sections with restoration works by DWASA.

The study area consists of newly formed storm sewer network. Hence it was assumed that sedimentation in those pipes is not prominent and all pipes were considered free from sediment in all scenarios. As there are no external inflows to the Goranchatbari system no upstream boundaries were used. For downstream boundary, it was assumed that flood controlling structures such as sluice gates remain closed for all model scenarios. Thus, the river water level will have no influence on the flooding and was not used as an external boundary. Water level of Goranchatbari pump station (3.5 mPWD) was used as initial condition for all scenarios.

The future scenarios (30 years, 50 years and 100 years) incorporated population growth and subsequent increases in impervious area and land levels. Planned drainage improvements included all major improvements to drainage system from 2004 to 2015 and proposed or planned changes in the future by the relevant drainage authority (such as DWASA or BWDB). Planned improvements also assume that RAJUK's DAP, DWASA's Sewerage Master Plan and NCC Concept Vision Plan will be implemented. Additional drainage improvements were designed so that the acceptable flooding criteria will be met for the extreme rainfall event. The set criteria are that 90% of the administrative area must have less than 0.25m flooding and no area can be inundated for more than 12 hours.

6.2 RESULT COMPARED AND FINDINGS

Simulations of inundation depths and flood duration were run for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 30 years, 50 years & 100 years with Climate Change, adaptation and land use changes. The average duration of the actual 100-year flood in 2004 was 16 hours. For of the 30-year flood in 2004 was 18 hours, alternative scenarios were simulated using flood criteria of 0.25 m (i.e., 90 percent of the administrative areas with a maximum inundation depth less than 0.25 m and duration less than 11 hours). Details results are showing on Annex 6 with several tables and summery of this results are on **Table 6-3**.

Table 6-3: Summary of Inundation Extent and Duration for all Scenarios for 30 years return period with original event on 2004.

Scenario	Area in model (km^2)	Max Flooded Area (sq km)				Average duration above 0.25m depth (Hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	
(BASE, Original Event)	63.80	45.73	3.90	5.54	8.63	15.98
(BASE) 30 yrs	63.80	49.53	3.90	5.54	4.82	17.90
(BASE+CC) 30 yrs	63.80	51.53	3.90	5.54	2.82	16.54
(BASE+CC+ADP) 30 yrs	63.79	55.73	3.10	2.54	2.42	11.81
(BASE+ADP+LU) 30 yrs	63.80	54.91	3.70	2.57	2.62	10.48

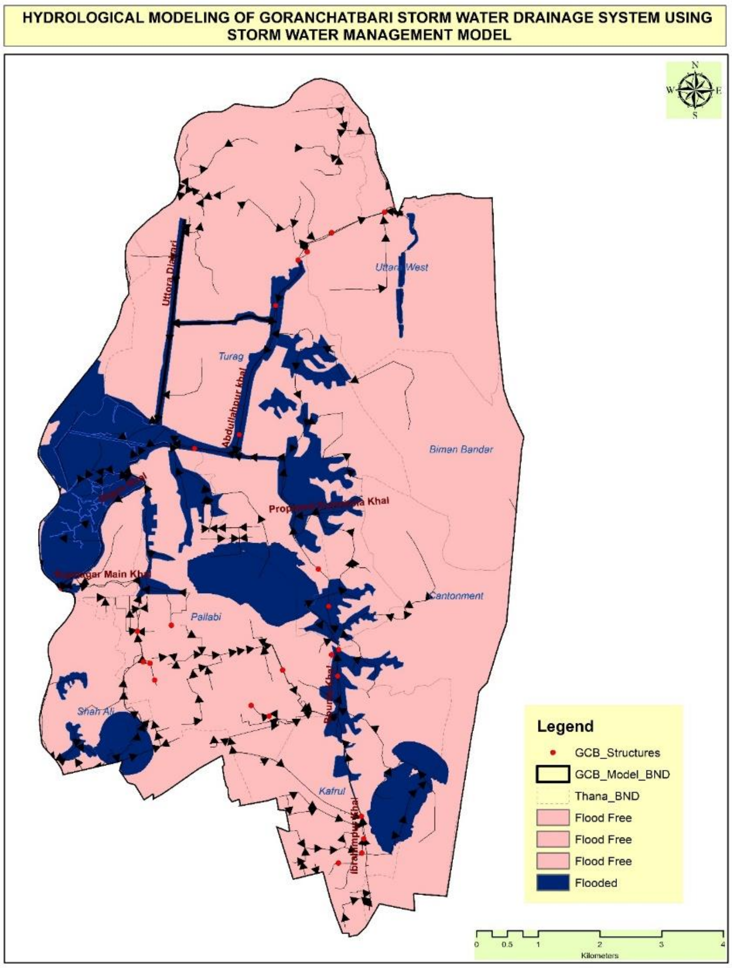


Figure 6-1: Flooded area of Groanchatbari for the historic 30-year return-period

Table 6-4: Summary of Inundation Extent and Duration for 50 years return period

Scenario	Area in model (sq km)	Max Flooded Area (sq km)				Average duration above 0.25m depth (Hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	
(BASE,Orginal Event)	63.80	45.73	3.90	5.54	8.63	15.98
(BASE) 50 yrs	63.80	44.73	3.90	6.54	8.63	19.34
(BASE+CC) 50 yrs	63.80	40.73	5.90	8.54	8.63	17.18
(BASE+CC+ADP) 50 yrs	63.80	53.80	3.37	4.01	2.62	8.14
(BASE+ADP+LU) 50 yrs	63.81	56.71	2.40	2.07	2.62	9.89

For of the 50-year return period flood in 2004 about 70% area was flood free and average duration above 0.25 depth was 19.34 hours. Otherwise with the effect of climate change with the base run it was found that about 64% area will be flood free. But with the adaptation measurements it was found that about 84% area will be flood free which shows that 20% flood free area will be increased with adaptation measures.

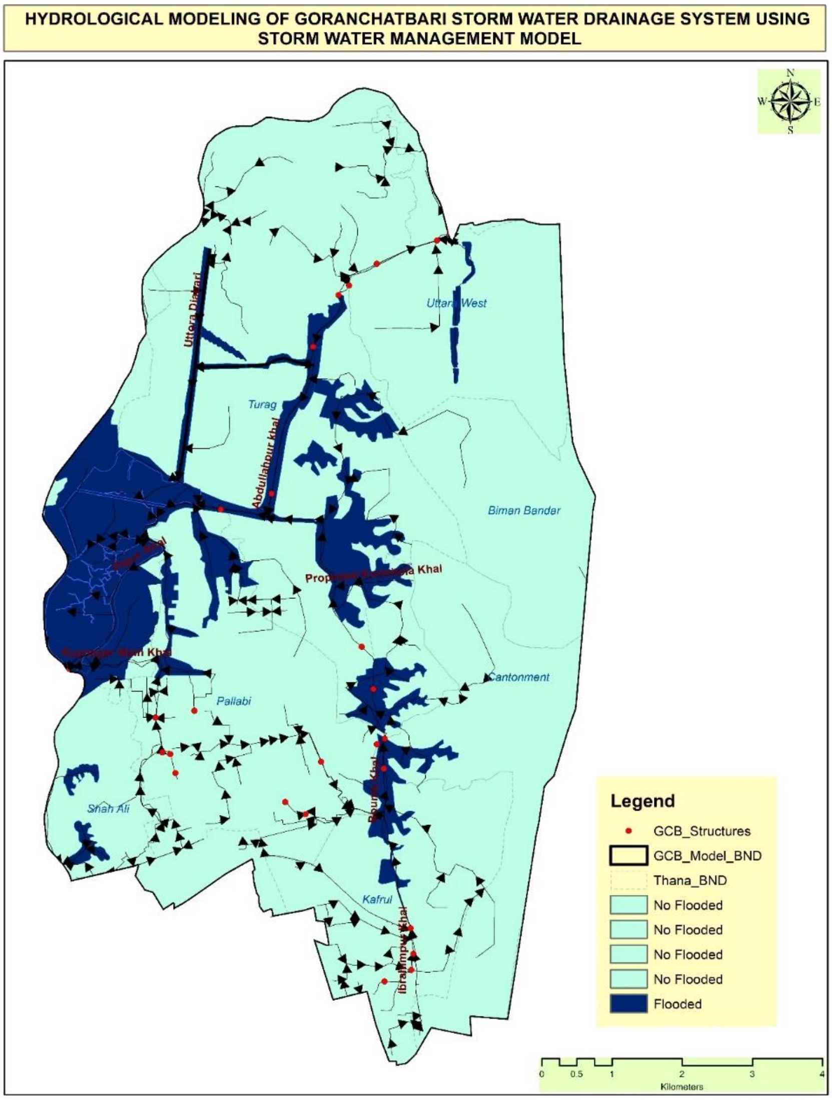


Figure 6-2: Flooded area of Groanchatbari for the historic 50-year return-period rainfall event in 2004 rainfall with climate change and land use changes.

Table 6-5: Summary of Inundation Extent and Duration for 100 years return period

Scenario	Area in model (km^2)	Max Flooded Area (km^2)				Average duration above 0.25m depth (Hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	
(BASE,Orginal Event)	63.80	45.73	3.90	5.54	8.63	15.98
(BASE) 100 yrs	63.80	39.73	6.90	7.54	9.63	22.88
(BASE+CC) 100 yrs	63.80	42.73	5.90	6.54	8.63	22.95
(BASE+CC+ADP) 100 yrs	63.80	56.80	2.90	2.50	1.60	7.08
(BASE+ADP+LU) 100 yrs	63.81	58.01	2.40	1.77	1.62	8.68

For of the 100-year return period flood in 2004 about 62% area was flood free and average duration above 0.25 depth was 22.88 hours with no climate change and infrastructures development (**Figure 6-3**). Otherwise with the effect of climate change with the base run it was found that about 67% area will be flood free. But with the adaptation measurements it was found that about 89% area will be flood free which shows that 22% flood free area will be increased with adaptation measures as well as will reduce the flooding time (**Table 6-5**).

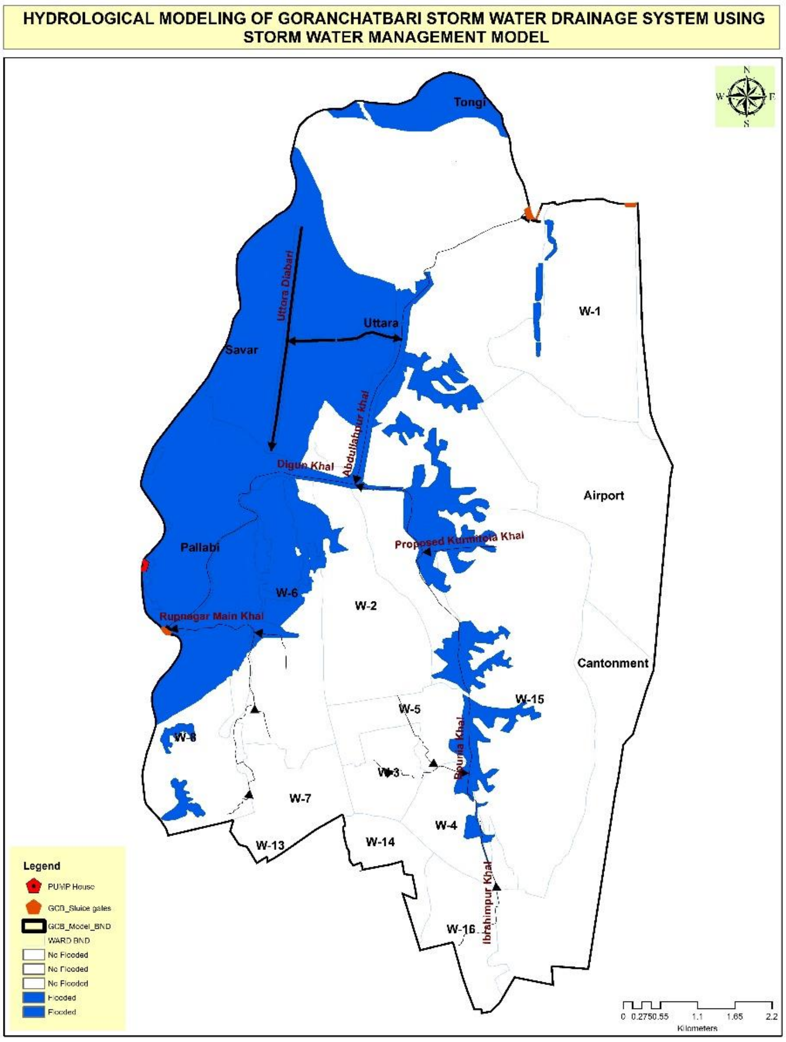


Figure 6-3: Flooded area of Groanchatbari for the historic 100-year return-period rainfall event in 2004 rainfall with climate change and land use changes.

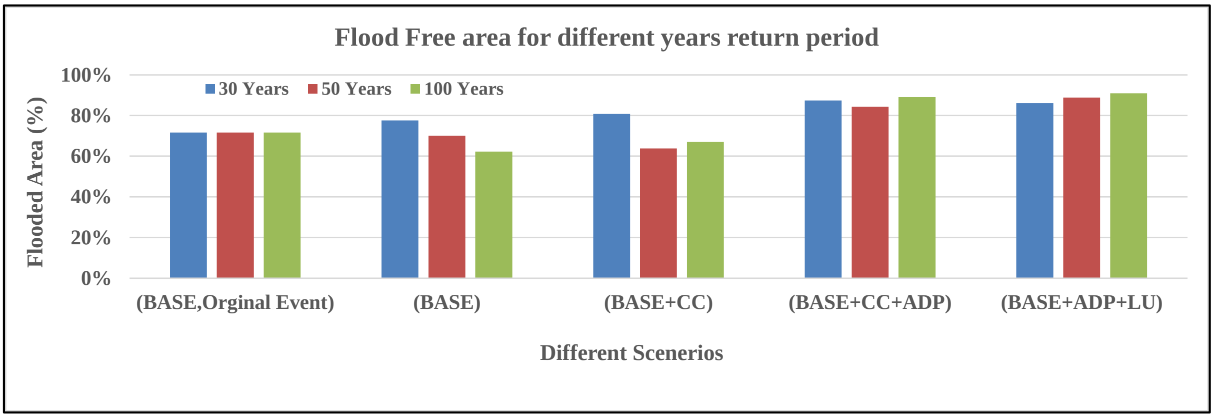


Figure 6-4: Flooded area of Groanchatbari for different return-period rainfall event in 2004 rainfall with climate change and land use changes.

Comparison of the 30, 50 & 100-year rainfall event with the actual 2004 storm showed on **Figure 6-4** where the change of flood free areas was marked. With the improvement in the flooding situation, with significantly less flooding depth and average duration of flooding were observed in **Table 6-3**, **Table 6-4** & **Table 6-5** where the various scenarios were classified. The improved performance is made possible by the laying of new drainage pipes, doubling the capacity of the Goranchatbari Pump Station, and proper solid waste management which clogged the flow path of drainage to the pump's retention pond. The raising of land levels with the ongoing process of urbanization in the area also contributes to the reduced extent of flooding.

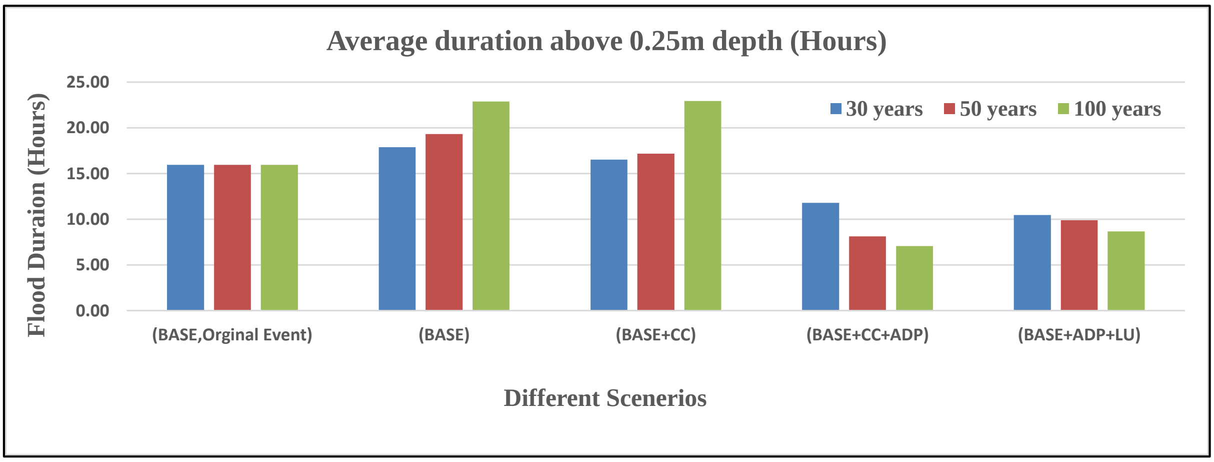


Figure 6-5: Flood duration of Groanchatbari flooded area for different year return-period rainfall event in 2004 rainfall with climate change and land use changes.

The reason for the improved performance of the drainage system for the 30-yr, 50-yr & 100-yr events is the laying of new pipes and doubling of the capacity at Goranchatbari Pump Station. The increased pump capacity has more than compensated for the higher imperviousness in 2030 compared to 2004 (**Figure 6-4**). The average duration of flooding in the model area has also decreased significantly due to the increased pump capacity and better drainage to the pump's retention pond. The increase in land levels for 30-years, 50-years & 100-years also contributed to the reduction in flooding extent.

The 2004 flooding for Base condition is shows with the comparison in flood depths and durations for the three simulations are shown in Table 6-5. From the results table it is clear that there is no significant worsening of the flooding situation due to climate change in 2050 for the 30-yr event. It is expected that the 30-yr and 50-yr events would show even less difference due to rainfall pattern.

As expected, the flood free area decreases for the 100-yr event compared to the 50-yr event but only marginally shows on **Figure 6-6**. However, deep flooded area increase by about 25%. The duration of flooding for the 100-yr event is considerably lower than the 30-yr event because a criterion of 0.25m was used for the former and a criterion of 0.1m was used for the latter event.

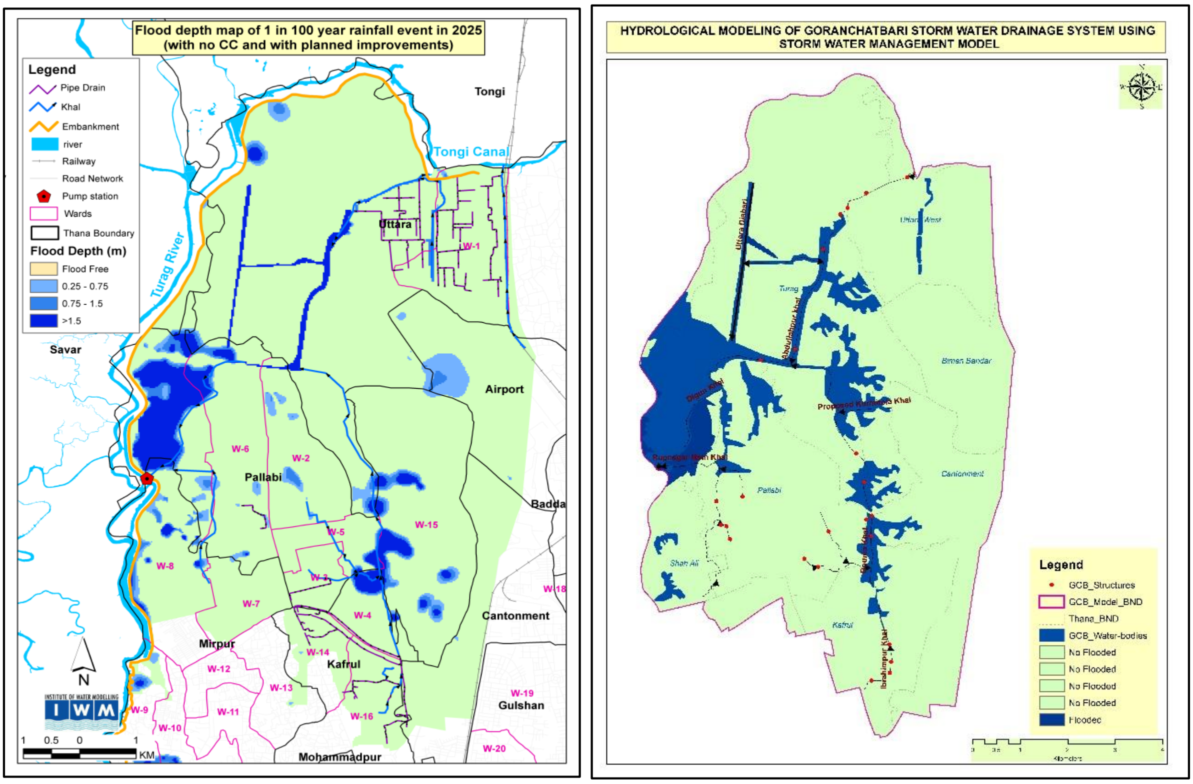


Figure 6-6: Flood map of 50 year return period event in Climate Change for Base year

Comparing the 100-yr results of 2050 with the 2025 results shows marginal increase in flooding area and durations in 2050. Although there is slight increase in land levels in 2050 compared to 2025, the increase in imperviousness has more of a detrimental effect on the flooding pattern for this system.

Simulations of inundation depths and flood duration were run for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 30-year, 50-year & 100-year return period rainfall event with climate change, land use and adaptation measures. The average duration of the actual 100-year flood in 2004 was 15.98 hours. Summary of inundation extent with average duration of flood is showing at Table 6-3 for 30-years return period for various scenarios.

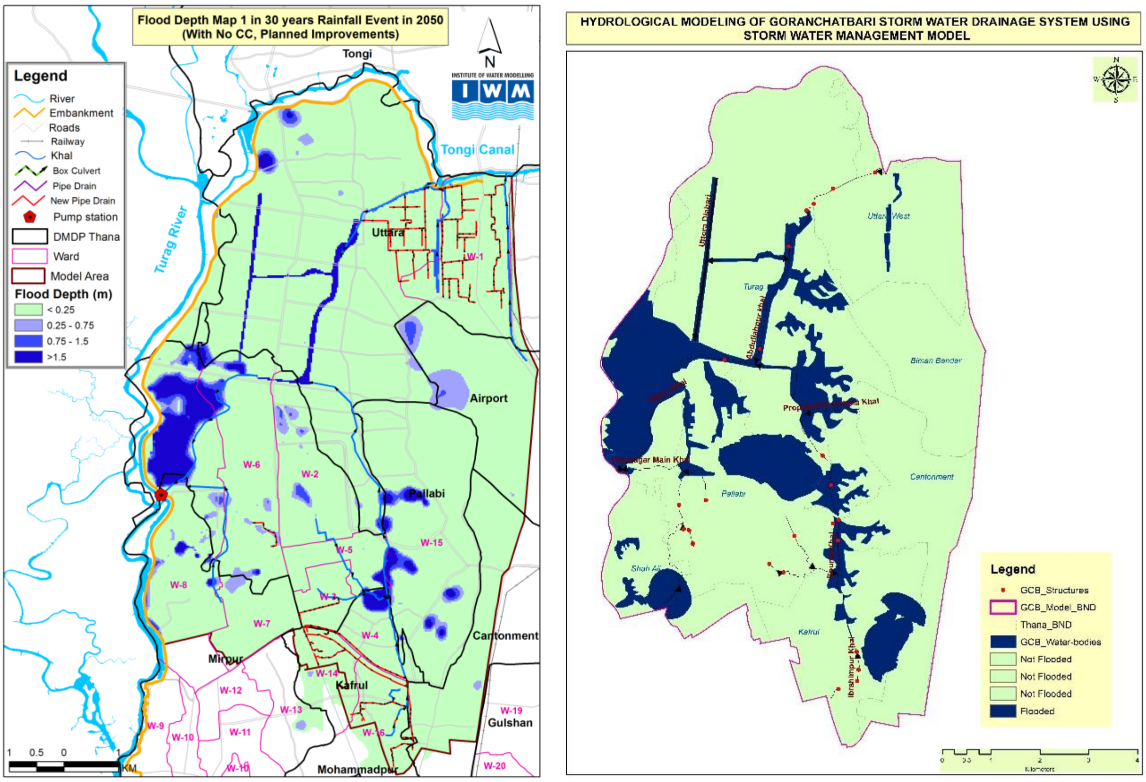


Figure 6-7: Flood map of 30 year return period event with World Bank study

As the checking of World Bank study maps with the SWMM Modeled inundation map will provide the idea of the validation of this model.

The actual 100-yr event (that occurred in 2004) with the World Bank Studies (Susmita Dasgupta, 2015) is expected to become more frequent as a result of climate change and this event was modeled on the other scenarios. The flood map for the 30 years return period scenario is shown in **Figure 6-7**. The inundation areas and duration of flooding are summarized in Table 6-4 earlier. Compared to the 50 years return period results, there is a marked improvement in the flooding situation due to adaptation infrastructures.

In 2017, drainage system of Goranchatbari area was dominated by natural drainage through open canals (khals), which brought storm water to Goranchatbari Pumping Station from where the water was pumped to Turag River through the Western Embankment. In 2017, total pumping capacity at Goranchatbari was 44 cumecs, with two pumps, each of capacity 22 cumecs. Based on observation of pump logbook at pump house, all pumps were run simultaneously at different extreme events. For future scenarios another 22 cumecs new pump have been included as currently construction is underway to increase the total pumping capacity at Goranchatbari Pump Station. An efficiency level of 85% was considered for the pumps both in base (2004) and future scenarios.

CHAPTER 7: CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

Dhaka receives about 2,000 mm of rainfall annually, of which almost 80% falls during the monsoon. Floods are one of the main natural hazards affecting the city and are associated with river water overflow and rain water stagnation. The city has become more vulnerable to intense urban flooding due to heavy and unpredictable rainfall in recent years. The drainage capacity of the city has also decreased alarmingly due to development of unauthorized settlements. Illegal occupation of drainage canals and wetlands by land grabbers has further contributed to the problem.

This study presents a systematic approach in the preparation of flood inundation depth with average duration of Goranchatbari with the application of open source tools named SWMM for modeling and ArcGIS for mapping. The change of water logging with different scenarios also shown in this study by flood depth analysis and inundation mapping. The aim of this study is to develop an urban storm water management model for Goranchandbari watershed of western part of Dhaka city.

Several scenarios model simulations were conducted for different time periods for different scenarios, using the observed long-term hourly precipitation data as model input. Due to the lack of data the developed model was calibrated and validated by using observed pump house water level data and canals velocity data.

Three pumping stations would drain out a total of 66 cumec flood flow to maintain internal water level not to exceed 4.0 mPWD at times of design storm evacuating the excess flooding within 2 days. For smooth operation and economy of placement of total number of pumps, pump operation will start at 3.5m PWD and stop at 3mPWD in the monsoon. The calibrated model's water level and velocity results are comprised with observation at node-5 with observed pump data and links L392, L189 & L 96.1. Therefore, the linear regression (observed vs simulated) showed good correlations ($R > 0.89$) among different scenarios and standard mean errors rate was <5.3%.

Major drainage takes place at several locations like Kalshi, Mirpur-10 and Kazipara covering a huge project area from Mirpur-10 to Uttara with Baunia Khal to Digun Khal at other end. Moreover, in future scenario the qualitative comparison somewhere found no significant major differences with previously conducted in WB study for Uttara and Mirpur areas.

The drainage design covers excess runoff arising from 2 days one in 30 year return period to drain not over 2 days including climate change impact of 2050. Rapid urbanization may raise paved/impervious area, short duration of intense rainfall, time of concentration and pump operation failure are the key phenomenon of urban water logging and flooding.

The obtained results of this study can be applied for the urban flood reduction strategies and it can guide the future requirements of management aspects to improve the drainage facility. As well as open water-bodies encroachment will cause the problem.

7.2 RECOMMENDATIONS

A short study about the climate change impact on flood inundation for Western part of Dhaka city is done in this study. Based on the simulated results and the experience gained during the study to develop an urban drainage model with SWMM for Goranchatbari study area some recommendations are made.

Current SWMM uses 1D model with flood plain. However, it does not have 1D/2D coupled model. For future studies, a 1D/2D (such as XP-SWMM, HEC- GeoRAS) coupled model can be used to see the differences between this two models.

For instance, discharge rate (time series) need to be measured using depth and velocity in some calibration points (nodes/conduits). For more accurate results like velocity, flood level & flow, we need more observed data to develop a stable hydrologic model in future studies. Real-time discharge time series can be obtained using PCM Flow Tott or other Doppler sensor (ADPC) which is currently not available at BUET and cost-effective for this study.

Different canals cross sections can be studied with proper design and can be incorporated with SWMM drainage model development. Lack of real time Infiltration and Evapotranspiration measurements for study area also a limitation which can be collected from detail data collection. Future socioeconomic changes of study area can be added as a scenario for social changes of people.

Short duration rainfall patterns (e.g. 5 minutes' interval) gauge stations (tripping bucket) observed can be used for more accurate inundation map. Moreover, it can lead the poor estimation in discharge beyond the time of concentration which is an important calibration parameter. So for future study we can use spatially distributed rainfall to know the real time scenario from the model.

Additional inflows coming from households to outlets were added to the model by the empirical formula. However, in reality, the households discharge measuring is quite difficult task and cost-effective. So waste water was ignored for this model development which can be used for future research works.

In future the flood damage and adaptation costs can be calculated based on the estimates of extent, depth, and duration of flooding, as simulated from the model. Also the study can be examined the flood damage that would result if the 100-year, return-period rainfall was to hit with greater frequency (i.e., once every 50, 33, or 20 years) with urbanization prediction based on DAP by RAJUK.

Precise urban drainage networks hydraulic design with applied hydrological features are somewhat challenging to develop a realistic model. Hydraulics of pipelines, various type of conduits, open or closed nodes, stream networks, regulators, retention-pond and pump stations structural data are required to optimize the storm water management model.

REFERENCES

ADB (2013) Bangladesh: Strengthening the Resilience of the Urban Water Supply, Drainage, and Sanitation to Climate Change in Coastal Towns, Final Report, TA 7890-BAN

A.K. Gain and M.M. Hoque (2012) Flood risk assessment and its application in the eastern part of Dhaka City, Bangladesh.

A. Pathirana, S. Tsegaye, B. Gersonius, and K. Vairavamoorthy (2011) A simple 2-D inundation model for incorporating flood damage in urban drainage planning, Hydrol. Earth Syst. Sci., 15, 2747–2761

Ahammed, F., and G. A. Hewa. 2012. Development of Hydrological Tools Using Extreme Rainfall Events for Dhaka, Bangladesh, Water International 37 (1): 43–52.

AMAGUCHI, H., KAWAMURA, A., OLSSON, J. and TAKASAKI, T., 2012. Development and testing of a distributed urban storm runoff event model with a vector-based catchment delineation. Journal of Hydrology, 420, pp. 205-215.

BBS (Bangladesh Bureau of Statistics). 2012. Bangladesh Population and Housing Census 2011. National Series, Vol. 4. Dhaka: Bangladesh Bureau of Statistics.

BELING, F., GARCIA, J., PAIVA, E., BASTOS, G. and PAIVA, J., 2011. Analysis of the SWMM Model Parameters for Runoff Evaluation in Periurban Basins from Southern Brazil, 12nd international conference on urban drainage 2011, pp. 11-16.

BWDB (Bangladesh Water Development Board). 2010. Feasibility Study on Drainage Improvement of Dhaka-Narayanganj-Demra (DND) Project. Dhaka: Bangladesh Water Development Board.

CCC (Climate Change Cell). 2009. Characterizing Long-Term Changes of Bangladesh Climate in Context of Agriculture and Irrigation. Dhaka: Climate Change Cell, Department of Environment, Ministry of Environment and Forestry and Component 4B, Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management.

CHOI, K. and BALL, J.E., 2002. Parameter estimation for urban runoff modelling. Urban Water, 4(1), pp. 31-41.

CHEN, M. and TUCKER, C., 2003. Comparing Different Approaches of Catchment Delineation.

Claudia Teutschbein and Jan Seibert (2012) Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods, Journal of Hydrology 456–457 (2012) 12–29

David J. Rosa Graduate Student, John C. Clausen Prof. and Michael E. Dietz Director (2015) Calibration and Verification of SWMM for Low Impact Development, JAWRA Journal of the American Water Resources Association.

DINGMAN, S.L., 1994. Physical hydrology. Prentice Hall Upper Saddle River, NJ.

DISKIN, M.H., 1981. Nonlinear Hydrologic Models, V.P. SINGH, ed. In: Rainfall-Runoff Relationship, May 18-21 1981, Water Resources Publications, pp. 127--146.

DUNNE, T., 1978. Field studies of hillslope flow processes. Hillslope hydrology, 227, pp. 293.

DURRANS, S.R., 2003. Stormwater Conveyance Modeling and Design. Waterbury, CT: Haestad Methods, Inc.

DWASA (Dhaka Water Supply and Sewerage Authority). 2014. "Preparation/Updating of Stormwater Drainage Master Plan for Dhaka City." Prepared by Jurutera Perunding Zaaba Sdn. Bhd. (Malaysia), Farhat Consulting Engineers and Architects Limited, and SARM Associates Limited for the World Bank–funded Dhaka Water Supply and Sanitation Project, Dhaka.

F. A. Beling, J. I. B. Garcia, E. M. C. D. Paiva, G. A. P. Bastos and J. B. D. Paiva (2011) Analysis of the SWMM Model Parameters for Runoff Evaluation in Periurban Basins from Southern Brazil. 12nd International Conference on Urban Drainage, Porto Alegre/Brazil, 11-16 September 2011

FLETCHER, T., ANDRIEU, H. and HAMEL, P., 2012. Understanding, management and modelling of urban hydrology and its consequences for receiving waters; a state of the art. Advances in Water Resources, .

Fred L. Ogden, Nawa Raj Pradhan, Charles W. Downer and Jon A. Zahner (2011) Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment, Water Resource. Res., 47, W12503, doi: 10.1029/2011WR010550.

HARGREAVES, G. and ALLEN, R., 2003. History and Evaluation of Hargreaves Evapotranspiration Equation. Journal of Irrigation and Drainage Engineering, 129(1), pp. 53-63.

Haque, M. A. 2010. "Experience of Bangladesh on Flood Disaster Mitigation." Presentation at UN ESCAP meeting. http://www.unescap.org/idd/events/2010_Pakistan_Floods_II/Bangladesh.pdf

HAASE, D., 2009. Effects of urbanisation on the water balance – A long-term trajectory. Environmental Impact Assessment Review, 29(4), pp. 211-219.

Henri Tikkanen (2013) Hydrological modeling of a large urban catchment using a storm-water management model (SWMM)

HORTON, R.E., 1933. The role of infiltration in the hydrologic cycle. Transactions, American Geophysical Union, 14, pp. 446-460.

Hossain, F., A. M. Degu, A. T. Woldemichael, W. Yigzaw, C. Mitra, J. M. Shepherd, and A. H. M. Siddique-E-Akbor. 2013. "Water Resources Vulnerability in the Context of Rapid Urbanization of Dhaka City (a South Asian Megacity)." In Climate Vulnerability: Understanding and Addressing Threats to Essential Resources, edited by R. Pielke, Vol. 5. Amsterdam: Elsevier.

IPCC (2014) Climate change 2014: impact, adaptation and vulnerability. In: Aldunce P., Ometto J.P., Raholijao N., Yasuhara K., Working Group II Contribution to the IPCC 5th Assessment Report. Final draft accepted WGII report accepted 30 March 2014.

IWFM (2005) Investigation of Hydrological Aspects of Flood – 2004 with Special Emphasis on Dhaka City, Final Report, April 2005

IWM and CCC (2008) Impact Assessment of Climate Change and Sea Level Rise on Monsoon Flooding, Institute of Water Modeling and Climate Change Cell, Department of Environment, Ministry of Environment and Forests, Government of Bangladesh.

IWM (Institute of Water Modelling), et al (2001); Impact of Land use Change upon Stormwater Drainage and Wetlands in the Eastern Part of Dhaka City.A joint study by IWM, Institute of Water and Flood Management.

IWM (Institute of Water Modelling), et al (2006); Study on Drainage Master Plan for Dhaka City and DND Area.

IWM (Institute of Water Modelling, 2016) Feasibility and SEIA Study for Expansion of Drainage Networks and Development of Canals in Dhaka City.

JACOBSON, C.R., 2011. Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. Journal of environmental management, 92(6), pp. 1438-1448.

James Nakamura and Nick Villagra (2009) Hydrologic Modeling of the Little Crum Creek Watershed with SWMM

JANG, S., CHO, M., YOON, J., YOON, Y., KIM, S., KIM, G., KIM, L. and AKSOY, H., 2007. Using SWMM as a tool for hydrologic impact assessment. Desalination, 212(1), pp. 344-356.

JICA (Japan International Cooperation Agency). 1987. Study on Storm Water Drainage System Improvement Project in Dhaka City. Tokyo: JICA.

KUUSISTO, E., 1986a. Sadanta. In: S. MUSTONEN, ed, Sovellettu hydrologia. Mänttä: Vesiyhdistys ry, pp. 29-47.

LIONG, S., CHAN, W. and LUM, L., 1991. Knowledge-based system for SWMM runoff component calibration. Journal of Water Resources Planning and Management, 117(5), pp. 507-524.

Lucia De Stefano, James Duncan, Shlomi Dinar, Kerstin Stahl, Kenneth Strzepek and Aaron T. Wolf (2010) Mapping the Resilience of International River Basins to Future Climate Change-Induced Water Variability, The World bank

Marc F. P. Bierkens (2015) Global Hydrology: State, trends, and directions, AGU Review Article

M. Masood, P. J.-F. Yeh, N. Hanasaki, and K. Takeuchi (2015) Model study of the impacts of future climate change on the hydrology of Ganges–Brahmaputra–Meghna basin

Moynihan, Kyle P., and Jose G. Vasconcelos. (2014) SWMM Modeling of a Rural Watershed in the Lower Coastal Plains of the United States.

M. R. Kabir and Islam Md. Faisal (2006) Impact of Climate Variability on Flood Management in Dhaka City, UAP Journal of Civil and Environmental Engineering, Vol. 2, No. 1, 2006

Muhammad Masood and Kuniyoshi Takeuchi (2015) Climate Change Impact on the Manageability of Floods and Droughts of the Ganges-Brahmaputra-Meghna Basins Using Flood Duration Curves and Drought Duration Curves, Journal of Disaster Research 07/2015; 10(5):991-1000.

Murshed, S. B., A. K. M. S. Islam, and M. S. A. Khan. 2011. "Impact of Climate Change on Rainfall Intensity in Bangladesh." Paper presented at 3rd International Conference on Water and Flood Management organized by Institute of Water and Flood Management,Bangladesh University of Engineering and Technology, Dhaka.

N. Hoegh Nielsen, A. T. Joergensen and A. Larsen (2011) Use of spectral analysis in urban drainage modelling, 12th International Conference on Urban Drainage, Porto Alegre/Brazil, 11-16 September 2011

PARK, S.Y., LEE, K.W., PARK, I.H. and HA, S.R., 2008. Effect of the aggregation level of surface runoff fields and sewer network for a SWMM simulation. Desalination, 226(1–3), pp. 328-337.

RAJUK (2010) Preparation of Detailed Area Plan for Dhaka Metropolitan Development Planning (DMDP) Area by Ministry of Housing and Public Works, Government of the People's Republic of Bangladesh.

ROSSMAN, L.A., 2010. Storm Water Management Model User's Manual - Version 5.0. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100ERK4.txt edn. Cincinnati, OH: U.S. Environmental Protection Agency.

Sarder Mohammad Yahya , Shahriar Shams, A K M Sadrul Islam, K. Mahmud (2010) Climate Change Impacts on Flood Vulnerability for Dhaka City, Proc. of International Conference on Environmental Aspects of Bangladesh (ICEAB10), Japan, Sept. 2010

Shouhong Zhang and Yiping Guo, M.ASCE (2014) SWMM Simulation of the Storm Water Volume Control Performance of Permeable Pavement Systems, DOI: 10.1061/ (ASCE) HE.1943-5584.0001092. © 2014 American Society of Civil Engineers. Journal of Hydrologic Engineering.

Sonia Binte Murshed, AKM Saiful Islam and M.Shah Alam Khan (2011) Impact Of Climate Change On Rainfall Intensity In Bangladesh, 3rd International Conference on Water & Flood Management (ICWFM2011), Bangladesh

SMITH, D., LI, J. and BANTING, D., 2005. A PCSWMM/GIS-based water balance model for the Reesor Creek watershed. Atmospheric Research, 77(1), pp. 388-406.

Sujit Kumar Bala, Akm Saiful Islam, Jahir Uddin Chowdhury, Md. Rezaur Rahman, M. Anisul Haque, M. Shah Alam Khan and Mashfiqus Salehin (2009) Performance of flood control works around Dhaka city during major floods in Bangladesh, 2nd International Conference on Water & Flood Management (ICWFM-2009), Dhaka, Bangladesh.

SWMC (1997); Stormwater Drainage Modelling for Dhaka City - A Pilot Study; Surface Water Simulation Modelling Programme, Phase-III; River Research Institute; Ministry of Water Resources, Government of Bangladesh.

SWMM (2010) Storm Water Management Model User's Manual Version 5.0, National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Oh 45268

THIEKEN, A.H., LUECKE, A., DIEKKRUEGER, B. and RICHTER, O., 1999. Scaling input data by GIS for hydrological modelling. Hydrological Processes, 13(4), pp. 611-630.

T. Arriero Shinma and L.F. Ribeiro Reis (2013) Incorporating Multi-event and Multi-site Data in the Calibration of SWMM, Procedia Engineering 70 (2014) 75 – 84

VAKKILAINEN, P., 1986. Haihdunta. In: S. MUSTONEN, ed, Sovellettu hydrologia. Mänttä: Vesiyhdistys ry, pp. 64-81.

WOOLHISER, D.A., 1981. Physically Based Models of Watershed Runoff, V.P. SINGH, ed. In: Rainfall-Runoff Relationship, May 18-21 1981, Water Resources Publications, pp. 189--202.

Zaman, Asif M. (2014). Urban Flooding of Greater Dhaka Area in a Changing Climate: Vulnerability, Adaptation and Potential Costs. Background report prepared for this study, Bangladesh Climate Change Resilience Fund and Institute of Water Modelling, Dhaka.

ZHANG, H., WANG, Y., WANG, Y., LI, D. and WANG, X., 2013. The effect of watershed scale on HEC-HMS calibrated parameters: a case study in the Clear Creek watershed in Iowa, USA. Hydrology and Earth System Sciences Discussions, 10, pp. 965-998.

ZOPPOU, C., 2001. Review of urban storm water models. Environmental Modelling & Software, 16(3), pp. 195-231.

ANNEXES

A1. MODEL INPUT DATA (NODES)

Name	Node X	Node Y	Area [Subcatch 1]	Sub-Catchment Flag [Subcatch 1]	Slope [Subcatch 1]	Impervious Percentage [Subcatch 1]	Initial Depth	Invert Elevation
MR2_1	536346.5	633050.9	0	0	0	0	1	3.24
Node_25	537014.7	633421.1	0	0	0	0	1	4
Node_26	536929.8	633628.1	177.2	1	1.52	70.8	1	3.65
Node_142	535128	634128.8	0	0	0	0	1	3.5
Node_143	535364.9	633924	222.4	1	3.19	48.3	1	3.2
Node_183	536194.2	633788.7	0	0	0	0	1	3.14
Node_156	536990.5	634841.8	74.8	1	2.97	51.2	1	2.98
MH-3	537244.9	634097	23.8	1	1.92	65.9	1	4.93
N_man_14	537330.5	634104.4	2	0	0.1	2	1	5.17
N_man_15	537348.4	634105	2	1	0.1	2	1	4.7
N_man_16	537347.8	634141.6	2	1	0.1	2	1	4.4
N_man_17	537346.7	634208.2	0	0	0	0	1	4.33
N_man_18	537322.5	634313.8	0	0	0	0	1	3.95
N_man_19	537321.8	634346.1	0	0	0	0	1	3.55
N_man_20	537270.2	634348.7	0	0	0	0	1	3.53
N_man_21	537226.5	634372.4	13.7	1	0.98	64.9	1	3.46
N_man_22	537172.8	634401.6	0	0	0	0	1	4.02
N_man_23	537115.6	634432.7	0	0	0	0	1	3.94
N_man_24	537113.8	634530.7	0	0	0	0	1	3.8
N_man_25	536915.1	634525.7	29.6	1	1.67	63.8	1	3.5
Node_183.1	536293.1	634485.7	2	0	0.2	2	1	3.04
Node_168	536386.8	635004.9	122.2	1	1.41	53.3	1	2.94
MR5_11	538099.4	633328.7	20.6	1	1.55	61.1	1	3.63
MR5_1	537795.4	632744.9	6.2	1	0.94	67.8	1	9.02
MR5_2	537765.3	632875.2	3.2	1	0.62	75.1	1	8.57
MR5_3	537905.5	632909.9	5.3	1	0.87	63	1	8.34
MR5_4	537999.5	632932.8	4.3	1	0.73	63	1	8.18
MR5_5	538085.1	632956.9	3.9	1	0.96	63.8	1	8.06
MR5_6	538173.1	632979.1	3.2	1	1.56	63.9	1	8.03
MR5_7	538233	632994.3	3.8	1	2.25	65.7	1	7.97
MR5_8	538345.3	633023.1	3.8	1	1.56	67.3	1	7.88
MR5_9	538406	633038.9	2.4	1	2.4	63.8	1	7.85
MR5_10	538499.6	633056.8	12.9	1	1.51	69.4	1	6.88
MR5_12	538476.9	633158.5	8	1	1.81	65.5	1	3.59
MR3_1	538068.1	634612.2	68.3	1	1.09	63.7	1	3.72
Node_136	538463.8	634063.8	80.5	1	1.19	61.5	1	3.63

Node_137	538744	633534.2	21.8	1	1.55	63.9	1	3.57
MR5_13	538988.3	633258.6	12.9	1	1.51	69.4	1	3.53
Node_27	540816.1	631301.3	194.9	1	0.62	4.8	1	4.5
Node_123	540945.9	632755.5	154.8	1	0.91	34.7	1	4
Node_230	540799.4	633704.7	57.6	1	1.01	28.2	1	6.9
Node_233	540416	633331.6	120.9	1	1.36	70.6	1	3.5
MR6_32	538213.2	632500.9	0.9	1	0.49	75.4	1	6.84
MR6_25	538284.6	632480.6	0.8	1	0.35	73.8	1	6.81
MR6_26	538307	632548	0.4	1	0.53	70	1	6.77
MR6_27	537921.4	632523	0.4	1	0.75	75.8	1	7.8
MR6_28	537908.4	632561	0.4	1	0.75	76.2	1	7.57
MR6_29	537901.8	632595.9	0.3	1	0.32	77.4	1	7.41
MR6_30	537895.8	632624.7	0.5	1	0.13	70.1	1	7.39
MR6_31	537823.3	632607.4	1.8	1	0.19	79.9	1	7.25
MR6_33	538038.8	632317.5	1.8	1	0.34	72	1	7.86
MR6_34	538007.6	632315.9	0.4	1	0.48	78.4	1	7.85
MR6_35	538006.6	632331.5	0.3	1	0.34	75.5	1	7.69
MR6_36	538199.3	632181.6	1.1	1	0.18	71.6	1	8.07
MR6_37	538124.1	632168.7	0.9	1	0.24	71.9	1	8.03
MR6_38	538101.5	632215.9	1.2	1	0.24	71.7	1	7.86
MR6_5	538011.5	632197.2	3.4	1	0.36	75.2	1	7.66
MR6_6	537955.7	632333	4.8	1	0.34	69.9	1	7.51
MR6_7	537886.2	632483.7	3.6	1	0.7	75.1	1	7.34
MR6_8	537850.8	632572.9	1	1	0.32	79	1	7.25
MR6_9	537852.6	632617.2	0.1	1	0.13	84.9	1	7.2
MR6_10	537859	632640.1	0.2	1	0.13	73.6	1	6.86
MR6_11	538017.9	632636.7	2.1	1	0.99	60.1	1	6.72
MR6_12	538155.4	632610.1	1.9	1	1.27	59	1	6.59
MR6_13	538184.6	632601.6	1.6	1	1.27	65.3	1	6.41
MR6_14	538309.4	632570.4	1.7	1	0.99	66.5	1	6.32
MR6_15	538350.4	632562.1	1.9	1	0.76	63.7	1	6.28
MR6_16	538454.2	632524.6	2.6	1	0.66	69.1	1	6.12
MR6_17	538536.6	632470.4	3.1	1	0.39	77.3	1	6.1
MR6_18	538653.1	632367.6	3.1	1	0.34	72.7	1	5.83
MR6_19	538718.1	632311.5	3.5	1	0.42	67.1	1	5.76
MR6_20	538841.8	632197.5	2.9	1	0.49	71.5	1	5.67
MR6_21	538876.5	632169.5	3.2	1	0.47	50.6	1	5.62
MR6_22	538981	632067.7	3.5	1	0.86	54.4	1	5.49
MR6_23	539042.9	632018.8	2.1	1	2	82.9	1	5.43
MR6_24	539103.3	631970.9	5	1	0.91	60.5	1	5.34
MR7_5	539240.1	631881.6	2.2	1	0.91	60.8	1	4.86
MR7_6	539378.5	631818.6	3.7	1	0.32	60.9	1	4.81
MR7_7	539470.6	631779	3.1	1	0.66	55.4	1	4.74
MR7_8	539589.4	631729.4	2.3	1	0.5	65	1	4.67
MR10_18	539660.1	630575.4	0.8	1	0.32	68.4	1	5.91

MR10_19	539663.7	630599	1.6	1	0.32	50	1	5.88
MR10_20	539763.2	630594.3	1.2	1	0.21	25	1	5.63
MR10_21	539838.2	630547.1	0.4	1	0.32	7	1	5.54
MR10_7	539494.9	630051	6.6	1	0.52	34.3	1	6.77
MR10_8	539480.9	630216.6	3.8	1	0.56	19.7	1	6.68
MR10_9	539462.5	630268.5	1.4	1	1.02	37.1	1	6.66
MR10_10	539472.6	630318.1	1.2	1	0.27	65.9	1	6.63
MR10_11	539436.8	630390.5	3	1	0.68	36.9	1	6.59
MR10_12	539536.3	630413.8	3	1	0.26	66.7	1	6.54
MR10_13	539683.2	630485.7	2.1	1	0.17	62.9	1	6.46
MR10_14	539796.1	630467.5	1	1	0.11	33.1	1	6.4
MR10_15	539847.4	630480.3	0.2	1	0.31	7	1	6.33
MR10_16	539841.3	630361.7	6.6	1	0.29	6.7	1	6.43
MR10_17	539845	630454.5	0.8	1	0.24	3	1	6.39
MR10_1	539868.4	630500.9	3.6	1	0.48	4	1	5.98
MR10_2	539852.8	630572.3	3	1	0.83	4	1	5.22
MR10_3	539831.1	630699.9	6	1	0.29	3.9	1	4.9
MR10_4	539805.4	630836.5	5.7	1	0.42	16.5	1	4.76
MR10_5	539796.8	630912	3.1	1	0.45	14.3	1	4.68
MR10_6	539798.8	630979.7	5.4	1	0.48	5.6	1	4.62
MR9_8	539805.9	631070.7	0.9	1	0.29	8.8	1	4.03
MR9_9	539804.1	631148.8	3.5	1	0.19	3	1	3.99
MR8_10	539620.7	631469.9	5.3	1	0.31	71.7	1	4.99
N_man_4	538979	631115.9	1.2	1	0.16	71.8	1	8.24
MR8_1	538699.6	631021.7	7.8	1	0.25	70.4	1	5.76
N_man_3	538921.9	630891.6	2.2	1	0.18	22.1	1	8.66
N_man_12	538913	630937.3	2	0	0.2	2	1	8.52
N_man_6	538972.4	630913.6	3.3	1	0.32	40.4	1	8.4
N_man_7	538960.1	630910.1	2	0	0.2	2	1	8.25
N_man_8	538946.5	630945.2	2	0	0.2	2	1	8.21
MR8_2	538888.9	631044.8	2.8	1	0.28	70.4	1	5.57
N_man_9	538887.7	631124	2	0	0.2	2	1	7.95
N_man_10	538886.6	631201.5	11.9	1	0.37	73.1	1	7.88
N_man_1	538883.4	631241.3	2	0	0.2	2	1	7.8
N_man_11	538951.9	631229	2	0	0.2	2	1	7.74
MH-2	539018	631227.7	4.3	1	0.43	74.6	1	5.32
MR8_5	539154.2	631227.9	12.5	1	0.33	70	1	5.1
MR8_6	539298.6	631201.7	6.7	1	0.37	70.4	1	4.96
MR8_7	539372.6	631216.7	2.6	1	0.27	72.4	1	4.88
MR8_8	539417.8	631242.2	3.5	1	0.2	72.3	1	4.83
MR8_9	539475.7	631247.3	2.5	1	0.29	72.7	1	4.77
MR9_5	539580.3	631207.7	2.1	1	0.43	73.7	1	4.66
MR9_6	539625.3	631185.3	1.7	1	0.83	72.8	1	4.61
MR9_1	539344.2	630644.2	10.5	1	0.9	48.4	1	4.31
MR9_2	539511.1	630854	6.9	1	0.61	72.6	1	4.13

MR9_3	539565.6	630978.7	3.7	1	1.03	74.5	1	4.06
MR9_4	539732.1	631163.5	1.8	1	0.67	59.8	1	3.92
MR9_7	539746.4	631365.1	3.3	1	0.35	31.9	1	3.82
MR7_1	539761.2	631395.1	2.4	1	0.56	30.8	1	3.8
N_man_27	538035	632138.9	2.8	1	0.25	78.3	1	8.81
N_man_29	538049.5	632102.8	2	0	0.2	2	1	8.55
MR6_1	538131.1	631894.3	0	0	0	0	1	7.98
N_man_26	538098	631981.4	3.1	1	0.41	75.4	1	7.9
N_man_28	538081.2	632023.3	2	0	0.2	2	1	7.7
N_man_30	538063.5	632067.8	3.2	1	0.24	74.4	1	7.68
N_man_31	538091.6	632081.7	2	0	0.1	2	1	8.05
N_man_32	538115	632089.3	2	0	0.1	2	1	7.91
N_man_33	538131.5	632065.9	0.5	1	0.34	74.2	1	7.99
N_man_34	538219.5	632049.7	0	0	0	0	1	7.86
N_man_35	538263.5	632058.5	4.1	1	0.26	73.7	1	7.97
N_man_36	538349.2	632061.1	3.9	1	0.26	71.6	1	7.85
N_man_37	538443.7	632122.8	2.7	1	0.33	71.4	1	7.78
N_man_38	538447.3	632136.6	1	0	0.1	1	1	7.88
N_man_39	538486.5	632166.9	2	0	0.1	2	1	7.77
N_man_40	538509.2	632154.3	1	1	0.19	67.6	1	7.72
N_man_41	538524.3	632170.7	2	0	0.2	2	1	7.85
N_man_42	538599.9	632193.6	2.1	1	0.19	71.8	1	7.63
MBK_1	537904.1	632483.5	1.9	1	0.67	74.3	1	8.46
MBK_2	538150.7	632480.9	2.5	1	0.49	73.7	1	8.37
MBK-3	538158.1	632463.3	2	0	0.2	2	1	8.37
MBK_4	538374.8	632391.7	3.3	1	0.41	72.9	1	7.67
MBK_5	538523.2	632281.9	1.3	1	0.24	73.3	1	7.37
Node_201	538626.6	632201	1.1	1	0.31	75.3	1	7.2
MBK_6	538722	632124	5.6	1	0.28	71.2	1	7.03
Node_198	538810.9	632029.2	3.2	1	0.34	72.1	1	6.9
Node_199	538823.5	632043.9	2	0	0.2	2	1	6.88
MBK_7	538992.6	631903.3	11.3	1	0.24	72.4	1	6.66
Node_210	539123.1	631813.6	13.9	1	0.31	72	1	6.47
MBK_8	539466.1	631637.5	4.2	1	0.44	71.9	1	6.22
MR7_2	539741.4	631564.5	4.9	1	0.28	25.5	1	3.71
MR7_3	539722.7	631679.3	3.7	1	0.54	21	1	3.66
Node_264	539622.1	631967.6	21.4	1	1.57	62	1	3.5
MR4_1	539556.1	632351.3	9.4	1	1.11	72.1	1	3.3
MR4_2	539386.4	633226.8	25.6	1	0.83	83.3	1	3.29
UT4_1	539304.6	634333.8	68	1	1.85	29.8	1	3.16
Node_192	539227.9	635177.5	92.4	1	1.41	64	1	3.28
Node_160	538815	636269.7	169.9	1	1.67	54.2	1	3.22
Node_278	538752.4	636511.5	2	0	0.2	2	1	3.22
Node_279	538693.7	636739.4	2	0	0.2	2	1	3.22
Node_23	540982.3	637668	539.9	1	0.94	3.8	1	7.6

Node_159	539906.5	637436.1	391.3	1	1.54	48.9	1	7.5
Node_24	539469.4	637312.5	1	1	0.1	1	1	3.4
Node_209	538393.7	637022.8	120	1	0.23	80	1	3.21
N_man_93	539878.3	638983.2	13.4	1	0.35	26.5	1	8.37
N_man_94	539846.4	639367.1	0	0	0	0	1	7.75
N_man_95	539869.9	639368.9	6.8	1	0.3	26	1	7.73
N_man_96	539864.2	639457.4	0	0	0	0	1	7.64
N_man_97	539847.3	639457.4	0	0	0	0	1	7.62
N_man_98	539847.3	639514.7	0	0	0	0	1	7.4
N_man_103	540127.3	638988.9	9.5	1	0.47	27.2	1	8.18
N_man_101	540124.3	639192.3	2.8	1	0.19	26	1	7.9
N_man_100	540119.2	639376.2	0	0	0	0	1	7.71
N_man_99	540116.8	639463	0	0	0	0	1	7.6
N_man_102	540158.2	639466.8	5	1	0.24	26	1	7.39
N_man_104	540085.7	639520.1	0	0	0	0	1	6.87
N_man_172	540079.3	639794.4	4.6	1	0.15	26	1	6.73
N_man_136	540017.9	639590.8	3.8	1	0.24	26	1	8.28
N_man_134	539860.1	639910.4	4	1	0.28	26	1	8.04
N_man_139	540013.3	639917.2	0	0	0	0	1	7.49
N_man_173	540076.5	639918.1	3.9	1	0.21	26	1	6.6
N_man_174	540072.8	640073.8	2.7	1	0.28	26	1	6.37
N_man_175	540070.5	640175.6	0	0	0	0	1	6.32
N_man_176	540068.5	640260.8	0	0	0	0	1	6.17
UT2_1	540284.3	638802.6	19.1	1	2.73	26.5	1	4.5
Node_195	540291.3	639495.5	19.1	1	2.73	26.5	1	4.5
Node_196	540306.4	640030.8	22.2	1	2.77	41.5	1	3.9
UT2_2	540320.4	640625.1	0	0	0	0	1	4
Node_8	540169.2	640743.4	1	1	0.1	1	1	2.7
UT1_2	540058.7	640688.6	0	0	0	0	1	2.75
N_man_236	539988.7	640314.7	0	0	0	0	1	7.19
N_man_237	539878.6	640311.6	6.7	1	0.73	27.6	1	7.03
N_man_234	539418.8	640303.1	4.9	1	1.88	31	1	7.23
N_man_235	539531.4	640304.6	0	0	0	0	1	7.03
N_man_145	539611	640062.3	0	0	0	0	1	7.25
N_man_138	539685.9	639586.2	4.7	1	0.43	26	1	7.81
N_man_137	539680.4	639906.1	5	1	0.11	26	1	7.4
N_man_111	539441	639575.4	0	0	0	0	1	7.59
N_man_112	539438.6	639710.2	2.7	1	0.31	26	1	7.24
N_man_113	539435.2	639904.5	4.6	1	0.23	26	1	7.06
N_man_135	539848.9	639909.8	0	0	0	0	1	7.54
N_man_140	539719	639908	0	0	0	0	1	7.04
N_man_141	539718.1	640015.6	2.1	1	0.14	26	1	6.93
N_man_142	539824.8	640018.3	0	0	0	0	1	6.81
N_man_143	539823.8	640067.7	3.6	1	0.08	26	1	6.75
N_man_144	539713.5	640066.5	4	1	0.14	26	1	6.47

N_man_216	539714.5	640304.3	8.3	1	1	27.3	1	6.7
UT1_2.1	539500.4	640458.5	30.5	1	1.14	35	1	2.74
N_man_108	539699.6	639514.2	4.3	1	0.39	26	1	7.05
N_man_105	539781.4	638964.1	13.5	1	0.44	26.8	1	8.2
N_man_106	539588.4	638941.6	30.2	1	1	29	1	7.61
N_man_109	539536	639513.2	5.4	1	0.24	26	1	7.04
N_man_116	539393.8	639510.2	10.8	1	0.22	26	1	6.8
N_man_114	539395.6	639903.6	6.2	1	0.16	26	1	6.6
N_man_115	539393.8	640059	6.5	1	0.27	26	1	6.19
Node_211	539074.9	640059.6	12.8	1	0.63	25.4	1	5.7
N_man_117	538909.4	640059.3	0	0	0	0	1	3.9
Node_188	538928.9	640229.8	27	1	1.41	55.9	1	2.73
Node_189	538569.6	639517.6	225.6	1	1.43	29.1	1	2.16
Node_221	537993.8	637899.2	241.3	1	1.36	23.1	1	2.5
Node_250	537920.8	637107.1	241.3	1	1.36	23.1	1	2.5
Node_252	537604.4	637149.8	241.3	1	1.36	23.1	1	3.75
Node_251	536924.5	637240.1	2	1	1.34	5	1	3.2
Node_249	536850.5	637249	2	1	0.01	2	1	3.2
Node_248	536821.4	637251.6	143.9	1	1.32	55.5	1	3.2
Node_247	536315.7	636947.7	2	1	0.01	2	1	3.48
Node_246	536268.8	636779.9	136.1	1	1.21	28.2	1	3.29
Node_245	536481.4	636658.1	2	1	1	2	1	3.29
Node_244	536388.8	636557.7	0	0	0	0	1	3.25
Node_243	536183.8	636442.6	2	1	0.2	2	3	3.45
Node_242	536008.5	636316.5	201.4	1	1.52	79.5	3	3.45
Node_241	535816.5	635944.7	2	0	0.2	2	1	3.3
Node_240	535873.8	635712.3	2	0	0.2	2	1	3.35
Node_239	535862.9	635672.3	2	0	0.2	2	1	3.33
Node_238	535775.7	635500.9	0	0	0	0	1	3.33
Node_237	535664.6	635188.4	0	0	0	0	1	3.3
Node_235	535435.4	635053.4	0	0	0	0	3	3.3
Node_234	535267.9	635072.3	0	0	0	0	3	3.2
Node_5	535229.7	635028.6	200	1	0.12	100	3	2.69
MR1_O	534964.5	634961.6	0	0	0	0	3.5	2.5

A2. MODEL INPUT DATA (LINKS)

Link Name	Initial Flow	Diameter (Height) meter	Length (meter)	Roughness	Upstream Crown Elevation (m)	Downstream Crown Elevation (m)	Upstream Node Name	Downstream Node Name
Link_109	0	2	807	0.01	5.24	5.14	MR2_1	Node_183
Link_21	0	2.5	221	0.01	6.5	6.3	Node_25	Node_26
L416	0	2.5	200	0.014	6.2	6	Node_26	Node_183
Link_81	0	2.5	319	0.01	6	5.8	Node_142	Node_143
L417	0	3	250	0.014	6.5	6.32	Node_143	Node_183
Link_96	0	4	770	0.01	7.14	7.04	Node_183	Node_183.1
Link_87	0	2	254	0.01	6	5.7	Node_156	N_man_25
N_1	0	0.9	86	0.01	6.53	6.2	MH-3	N_man_14
N_2	0	1.2	18	0.01	6.5	6.36	N_man_14	N_man_15
N_3	0	1.2	36	0.01	6	5.7	N_man_15	N_man_16
N_4	0	1.2	66	0.01	5.7	5.65	N_man_16	N_man_17
N_5	0	1.37	108	0.01	5.82	5.77	N_man_17	N_man_18
N_6	0	1.37	33	0.01	5.42	5.34	N_man_18	N_man_19
N_7	0	1.52	52	0.01	5.42	5.25	N_man_19	N_man_20
N_8	0	1.52	50	0.01	5.12	4.98	N_man_20	N_man_21
N_9	0	1.68	61	0.01	6.14	6.1	N_man_21	N_man_22
N_10	0	1.68	65	0.01	5.88	5.82	N_man_22	N_man_23
N_11	0	1.83	101	0.01	6.07	6.02	N_man_23	N_man_24
N_12	0	2	202	0.01	6.19	6	N_man_24	N_man_25
L419	0	3	200	0.014	6.7	6.31	N_man_25	Node_183.1
Link_96.1	0	4	790	0.01	7.04	6.94	Node_183.1	Node_168
Link_135	0	2	715	0.01	5.94	5.93	Node_168	Node_5
MR5_P11	0	2.5	446	0.01	6.13	6.09	MR5_11	MR5_12
MR5_P1	0	1.05	135	0.01	10.07	9.62	MR5_1	MR5_2
MR5_P2	0	1.52	144	0.01	10.09	9.86	MR5_2	MR5_3
MR5_P3	0	1.52	97	0.01	9.86	9.7	MR5_3	MR5_4
MR5_P4	0	1.52	89	0.01	9.7	9.58	MR5_4	MR5_5
MR5_P5	0	1.52	91	0.01	9.58	9.55	MR5_5	MR5_6
MR5_P6	0	1.52	62	0.01	9.55	9.49	MR5_6	MR5_7
MR5_P7	0	1.52	116	0.01	9.49	9.4	MR5_7	MR5_8
MR5_P8	0	1.52	63	0.01	9.4	9.38	MR5_8	MR5_9
MR5_P9	0	1.52	95	0.01	9.42	9.39	MR5_9	MR5_10
MR5_P10	0	2.3	165	0.01	9.18	5.89	MR5_10	MR5_12
MR5_P12	0	2	560	0.01	5.59	5.53	MR5_12	MR5_13
MR3_P1	0	3	879	0.01	6.72	6.63	MR3_1	Node_136
Link_78	0	3	637	0.01	6.63	6.57	Node_136	Node_137
Link_77	0	2	390	0.01	5.57	5.53	Node_137	MR5_13
MR4_P2	0	2	497	0.01	5.53	5.48	MR5_13	MR4_2
Link_70	0	3	1460	0.01	7.7	7.6	Node_27	Node_123
Link_22	0	3	786	0.01	8	7.5	Node_123	Node_233

New1-1	0	3	551	0.01	9.9	9.8	Node_230	Node_233
New1-2	0	4	1391	0.01	7.8	7.57	Node_233	MR4_1
MR6_S1	0	0.9	74	0.01	7.74	7.71	MR6_32	MR6_25
MR6_S2	0	0.9	70	0.01	7.71	7.67	MR6_25	MR6_26
MR6_S3	0	0.9	46	0.01	7.67	7.18	MR6_26	MR6_15
MR6_S4	0	0.75	40	0.01	8.55	8.32	MR6_27	MR6_28
MR6_S5	0	0.75	36	0.01	8.32	8.16	MR6_28	MR6_29
MR6_S6	0	0.75	29	0.01	8.16	8.14	MR6_29	MR6_30
MR6_S7	0	0.75	123	0.01	8.14	7.47	MR6_30	MR6_11
MR6_S8	0	0.9	32	0.01	8.15	8.1	MR6_31	MR6_9
MR6_S9	0	0.45	31	0.01	8.31	8.3	MR6_33	MR6_34
MR6_S10	0	0.45	16	0.01	8.3	8.14	MR6_34	MR6_35
MR6_S11	0	0.6	51	0.01	8.29	8.11	MR6_35	MR6_6
MR6_S12	0	0.45	76	0.01	8.52	8.48	MR6_36	MR6_37
MR6_S13	0	0.45	52	0.01	8.48	8.31	MR6_37	MR6_38
MR6_S14	0	0.6	95	0.01	8.46	8.26	MR6_38	MR6_5
MR6_P5	0	0.75	147	0.01	8.41	8.26	MR6_5	MR6_6
MR6_P6	0	0.75	166	0.01	8.26	8.09	MR6_6	MR6_7
MR6_P7	0	0.75	96	0.01	8.09	8	MR6_7	MR6_8
MR6_P8	0	0.75	45	0.01	8	7.95	MR6_8	MR6_9
MR6_P9	0	0.9	24	0.01	8.1	7.76	MR6_9	MR6_10
MR6_P10	0	0.9	160	0.01	7.76	7.62	MR6_10	MR6_11
MR6_P11	0	0.9	140	0.01	7.62	7.49	MR6_11	MR6_12
MR6_P12	0	0.9	31	0.01	7.49	7.31	MR6_12	MR6_13
MR6_P13	0	1.37	129	0.01	7.78	7.69	MR6_13	MR6_14
MR6_P14	0	1.37	42	0.01	7.69	7.65	MR6_14	MR6_15
MR6_P15	0	1.37	111	0.01	7.65	7.49	MR6_15	MR6_16
MR6_P16	0	1.37	99	0.01	7.49	7.47	MR6_16	MR6_17
MR6_P17	0	1.37	156	0.01	7.47	7.2	MR6_17	MR6_18
MR6_P18	0	1.52	86	0.01	7.35	7.28	MR6_18	MR6_19
MR6_P19	0	1.52	168	0.01	7.28	7.19	MR6_19	MR6_20
MR6_P20	0	1.52	45	0.01	7.19	7.14	MR6_20	MR6_21
MR6_P21	0	1.52	146	0.01	7.14	7.01	MR6_21	MR6_22
MR6_P22	0	1.52	79	0.01	7.01	6.95	MR6_22	MR6_23
MR6_P23	0	1.52	77	0.01	6.95	6.86	MR6_23	MR6_24
MR6_P24	0	1.52	164	0.01	6.86	6.38	MR6_24	MR7_5
MR7_P5	0	1.85	152	0.01	6.71	6.66	MR7_5	MR7_6
MR7_P6	0	1.85	100	0.01	6.66	6.59	MR7_6	MR7_7
MR7_P7	0	1.85	129	0.01	6.59	6.52	MR7_7	MR7_8
MR7_P8	0	1.85	143	0.01	6.52	5.51	MR7_8	MR7_3
MR10_S12	0	0.6	24	0.01	6.51	6.48	MR10_18	MR10_19
MR10_S13	0	0.6	100	0.01	6.48	6.23	MR10_19	MR10_20
MR10_S14	0	0.75	89	0.01	6.38	6.29	MR10_20	MR10_21
MR10_S15	0	0.75	29	0.01	6.29	5.97	MR10_21	MR10_2
MR10_S1	0	0.75	166	0.01	7.52	7.43	MR10_7	MR10_8

MR10_S2	0	0.75	55	0.01	7.43	7.41	MR10_8	MR10_9
MR10_S3	0	0.75	51	0.01	7.41	7.38	MR10_9	MR10_10
MR10_S4	0	0.75	81	0.01	7.38	7.34	MR10_10	MR10_11
MR10_S5	0	0.75	102	0.01	7.34	7.29	MR10_11	MR10_12
MR10_S6	0	0.75	164	0.01	7.29	7.21	MR10_12	MR10_13
MR10_S7	0	0.75	115	0.01	7.21	7.15	MR10_13	MR10_14
MR10_S8	0	0.75	53	0.01	7.15	7.08	MR10_14	MR10_15
MR10_S9	0	0.75	29	0.01	7.08	6.73	MR10_15	MR10_1
MR10_S10	0	0.75	93	0.01	7.18	7.14	MR10_16	MR10_17
MR10_S11	0	0.75	52	0.01	7.14	6.73	MR10_17	MR10_1
MR10_P1	0	1.05	73	0.01	7.03	6.27	MR10_1	MR10_2
MR10_P2	0	1.05	130	0.01	6.27	5.95	MR10_2	MR10_3
MR10_P3	0	1.2	139	0.01	6.1	5.96	MR10_3	MR10_4
MR10_P4	0	1.2	76	0.01	5.96	5.88	MR10_4	MR10_5
MR10_P5	0	1.2	68	0.01	5.88	5.82	MR10_5	MR10_6
MR10_P6	0	1.2	91	0.01	5.82	5.23	MR10_6	MR9_8
MR9_P8	0	1.7	78	0.01	5.73	5.69	MR9_8	MR9_9
MR9_P9	0	1.7	250	0.01	5.69	5.5	MR9_9	MR7_1
MR8_P9	0	2.5	440	0.01	7.49	7.27	MR8_10	MR8_9
N_214	0	0.9	91	0.01	9.14	8.85	N_man_4	N_man_9
MR8_P1	0	1.2	193	0.01	6.96	6.77	MR8_1	MR8_2
N_213	0	0.6	47	0.01	9.26	9.12	N_man_3	N_man_12
N_221	0	0.6	34	0.01	9.12	8.81	N_man_12	N_man_8
N_215	0	0.75	13	0.01	9.15	9	N_man_6	N_man_7
N_216	0	0.75	38	0.01	9	8.96	N_man_7	N_man_8
N_217	0	0.75	115	0.01	8.96	6.32	N_man_8	MR8_2
N_212	0	0.9	79	0.01	8.856	8.852	MR8_2	N_man_9
N_218	0	0.9	78	0.01	8.85	8.78	N_man_9	N_man_10
N_219	0	1.05	40	0.01	8.93	8.85	N_man_10	N_man_1
N_211	0	1.05	70	0.01	8.85	8.79	N_man_1	N_man_11
N_220	0	1.05	66	0.01	8.79	6.37	N_man_11	MH-2
MR8_P4	0	1.2	136	0.01	6.52	6.3	MH-2	MR8_5
MR8_P5	0	1.2	147	0.01	6.3	6.16	MR8_5	MR8_6
MR8_P6	0	1.2	75	0.01	6.16	6.08	MR8_6	MR8_7
MR8_P7	0	1.2	52	0.01	6.08	6.03	MR8_7	MR8_8
MR8_P8	0	1.2	58	0.01	6.03	5.97	MR8_8	MR8_9
MR8_P10	0	1.2	112	0.01	5.97	5.86	MR8_9	MR9_5
MR9_P4	0	1.2	50	0.01	5.86	5.81	MR9_5	MR9_6
MR9_P5	0	1.2	109	0.01	5.81	5.12	MR9_6	MR9_4
MR9_P1	0	2.5	352	0.01	6.81	6.63	MR9_1	MR9_2
MR9_P2	0	1	140	0.01	5.13	5.06	MR9_2	MR9_3
MR9_P3	0	2	281	0.01	6.06	5.92	MR9_3	MR9_4
MR9_P6	0	2	203	0.01	5.92	5.82	MR9_4	MR9_7
MR9_P7	0	1	33	0.01	4.82	4.8	MR9_7	MR7_1
MR7_P1	0	1	171	0.01	4.8	4.71	MR7_1	MR7_2

N_14	0	0.9	39	0.01	9.71	9.45	N_man_27	N_man_29
N_16	0	0.9	37	0.01	9.45	8.58	N_man_29	N_man_30
MR6_P1	0	0.75	93	0.01	8.73	8.65	MR6_1	N_man_26
N_13	0	1.05	45	0.01	9.25	8.95	N_man_26	N_man_28
N_15	0	1.05	48	0.01	9.25	8.73	N_man_28	N_man_30
N_17	0	1.2	31	0.01	9.27	9.26	N_man_30	N_man_31
N_18	0	1.2	25	0.01	9.25	9.11	N_man_31	N_man_32
N_19	0	1.2	29	0.01	9.2	9.195	N_man_32	N_man_33
N_20	0	1.2	89	0.01	9.19	9.06	N_man_33	N_man_34
N_21	0	1.2	45	0.01	9.18	9.175	N_man_34	N_man_35
N_22	0	1.2	86	0.01	9.17	9.05	N_man_35	N_man_36
N_23	0	1.2	113	0.01	9.05	8.98	N_man_36	N_man_37
N_24	0	1.2	14	0.01	9.09	9.085	N_man_37	N_man_38
N_25	0	1.2	49	0.01	9.08	8.97	N_man_38	N_man_39
N_26	0	1.2	26	0.01	8.97	8.92	N_man_39	N_man_40
N_27	0	1.2	22	0.01	9.07	9.06	N_man_40	N_man_41
N_28	0	1.2	79	0.01	9.05	8.83	N_man_41	N_man_42
N_29	0	1.2	25	0.01	8.83	8.4	N_man_42	Node_201
Mun_7	0	1.2	248	0.01	9.66	9.57	MBK_1	MBK_2
Mun_6	0	1.2	19	0.01	9.57	9.57	MBK_2	MBK-3
Mun_5	0	1.2	227	0.01	9.57	8.87	MBK-3	MBK_4
Mun_4	0	1.37	185	0.01	9.04	8.74	MBK_4	MBK_5
Link_128	0	1.52	130	0.01	8.89	8.72	MBK_5	Node_201
Mun_3	0	1.52	123	0.01	8.72	8.55	Node_201	MBK_6
Mun_2	0	1.68	132	0.01	8.71	8.58	MBK_6	Node_198
Link_125	0	1.68	21	0.01	8.58	8.56	Node_198	Node_199
Link_124	0	1.68	221	0.01	8.56	8.34	Node_199	MBK_7
Mun_1	0	1.83	159	0.01	8.49	8.3	MBK_7	Node_210
Link_138	0	1.83	388	0.01	8.3	8.05	Node_210	MBK_8
Mun_0	0	2	306	0.01	8.22	5.71	MBK_8	MR7_2
MR7_P2	0	1	117	0.01	4.71	4.66	MR7_2	MR7_3
L421	0	1.85	250	0.014	5.69	5.47	MR7_3	Node_264
L422	0	4	630	0.014	7.5	7.4	Node_264	MR4_1
Link_185	0	4	1000	0.01	7.52	7.48	MR4_1	MR4_2
MR4_P3	0	2	1000	0.01	5.4	5.36	MR4_2	UT4_1
Link_189	0	2	406	0.01	5.62	5.5	UT4_1	Node_192
Link_194	0	2	1200	0.01	5.43	5.32	Node_192	Node_160
L411	0	5	270	0.033	8.42	8.4	Node_160	Node_278
L412	0	4	230	0.033	7.29	7.28	Node_278	Node_279
L413	0	4	425	0.033	7.26	7.23	Node_279	Node_209
Link_89	0	2	1100	0.01	9.7	9.6	Node_23	Node_159
Link_20	0	2	436	0.01	9.6	9.45	Node_159	Node_24
L420	0	2	200	0.014	5.5	5.3	Node_24	Node_209
L390	0	4	486.5	0.003	7.83	7.22	Node_209	Node_250
N_163	0	0.9	385	0.01	9.27	8.65	N_man_93	N_man_94

N_164	0	1.2	24	0.01	8.95	8.93	N_man_94	N_man_95
N_165	0	1.2	89	0.01	8.93	8.84	N_man_95	N_man_96
N_166	0	1.2	17	0.01	8.84	8.82	N_man_96	N_man_97
N_167	0	1.2	58	0.01	8.82	8.6	N_man_97	N_man_98
N_168	0	1.2	238	0.01	8.6	8.07	N_man_98	N_man_104
N_153	0	0.9	148	0.01	8.46	8.3	N_man_98	N_man_108
N_170	0	1.05	204	0.01	9.23	8.95	N_man_103	N_man_101
N_172	0	1.05	184	0.01	8.95	8.76	N_man_101	N_man_100
N_171	0	1.05	87	0.01	8.76	8.65	N_man_100	N_man_99
N_169	0	1.05	42	0.01	8.65	8.44	N_man_99	N_man_102
N_173	0	1.2	122	0.01	8.59	8.07	N_man_102	N_man_104
N_96	0	1.52	274	0.01	8.39	8.25	N_man_104	N_man_172
N_97	0	1.52	124	0.01	8.25	8.12	N_man_172	N_man_173
N_126	0	0.9	326	0.01	9.18	8.39	N_man_136	N_man_139
N_124	0	0.9	153	0.01	8.94	8.39	N_man_134	N_man_139
N_129	0	1.2	63	0.01	8.69	7.8	N_man_139	N_man_173
N_98	0	1.52	156	0.01	8.12	7.89	N_man_173	N_man_174
N_99	0	1.7	102	0.01	8.07	8.02	N_man_174	N_man_175
N_100	0	1.7	85	0.01	8.02	7.87	N_man_175	N_man_176
N_101	0	1.85	413	0.01	8.02	5.42	N_man_176	UT1_2
UT2_P1	0	2	693	0.01	6.6	6.5	UT2_1	Node_195
Link_121	0	2	536	0.01	6.5	6.3	Node_195	Node_196
Link_122	0	2	821	0.01	6.3	6	Node_196	UT2_2
UT2_P2	0	2	276	0.01	6	5.57	UT2_2	UT1_2
Link_169	0	3.5	94	0.01	7.27	7.2	Node_8	UT1_2
UT1_P1	0	2	625	0.01	4.8	4.79	UT1_2	UT1_2.1
N_74	0	0.9	110	0.01	8.09	7.93	N_man_236	N_man_237
N_75	0	0.9	171	0.01	7.93	7.7	N_man_237	N_man_216
N_72	0	0.9	114	0.01	8.13	7.93	N_man_234	N_man_235
N_73	0	0.9	175	0.01	7.93	7.7	N_man_235	N_man_216
N_135	0	1.05	103	0.01	8.3	7.52	N_man_145	N_man_144
N_128	0	0.9	320	0.01	8.71	8.3	N_man_138	N_man_137
N_156	0	0.9	245	0.01	8.3	7.96	N_man_137	N_man_113
N_127	0	0.9	39	0.01	8.3	7.94	N_man_137	N_man_140
N_157	0	0.9	135	0.01	8.49	8.14	N_man_111	N_man_112
N_158	0	1.05	190	0.01	8.29	8.11	N_man_112	N_man_113
N_159	0	1.05	40	0.01	8.11	7.65	N_man_113	N_man_114
N_125	0	0.9	130	0.01	8.44	7.94	N_man_135	N_man_140
N_130	0	1.2	108	0.01	8.24	8.13	N_man_140	N_man_141
N_131	0	1.2	107	0.01	8.13	8.01	N_man_141	N_man_142
N_132	0	1.2	49	0.01	8.01	7.95	N_man_142	N_man_143
N_133	0	1.2	110	0.01	7.95	7.67	N_man_143	N_man_144
N_134	0	1.37	242	0.01	8.17	8.12	N_man_144	N_man_216
N_222	0	1.37	221	0.01	8.27	6.07	N_man_216	UT1_2.1
UT1_P1.1	0	2	625	0.01	4.79	4.78	UT1_2.1	Node_188

N_154	0	1.05	164	0.01	8.61	8.09	N_man_108	N_man_109
N_151	0	0.9	194	0.01	9.1	8.51	N_man_105	N_man_106
N_152	0	1.2	574	0.01	8.81	8.24	N_man_106	N_man_109
N_155	0	1.37	142	0.01	8.41	8.17	N_man_109	N_man_116
N_162	0	1.52	389	0.01	8.32	8.12	N_man_116	N_man_114
N_160	0	1.52	155	0.01	8.12	7.71	N_man_114	N_man_115
N_161	0	1.85	319	0.01	8.04	7.98	N_man_115	Node_211
Link_139	0	1.85	166	0.01	7.55	6.55	Node_211	N_man_117
L423	0	1.85	50	0.014	5.95	5.85	N_man_117	Node_188
Link_174	0	3	201	0.01	6.15	5.7	Node_188	Node_189
L414	0	3	600	0.014	5.69	5.68	Node_189	Node_221
L415	0	3	860	0.014	5.67	5.66	Node_221	Node_250
L391	0	4	355	0.003	7.79	7.76	Node_250	Node_252
L392	0	4	1200	0.003	7.75	7.65	Node_252	Node_251
L393	0	4	125	0.003	7.237	7.227	Node_251	Node_249
L396	0	4	575.2	0.003	7.716	7.231	Node_249	Node_248
L397	0	4	101.2	0.003	7.716	7.484	Node_248	Node_247
L398	0	4	217.4	0.003	7.515	7.484	Node_247	Node_246
L399	0	4	265	0.003	7.515	7.493	Node_246	Node_245
L400	0	4	210	0.003	7.485	7.473	Node_245	Node_244
L401	0	4	255	0.003	7.47	7.468	Node_244	Node_243
L402	0	4	233	0.003	7.474	7.468	Node_243	Node_242
L403	0	4	428	0.003	7.474	7.376	Node_242	Node_241
L404	0	4	260	0.003	7.375	7.37	Node_241	Node_240
L405	0	4	70	0.003	7.365	7.36	Node_240	Node_239
L406	0	4	220	0.003	7.345	7.34	Node_239	Node_238
L407	0	4	197	0.003	7.34	7.335	Node_238	Node_237
L408	0	4	285	0.003	7.335	7.33	Node_237	Node_235
L409	0	4	245	0.003	7.32	7.31	Node_235	Node_234
L410	0	4	20	0.003	7.28	7.26	Node_234	Node_5
Link_6	0	0.75	0	0	0.75	0.75	Node_5	MR1_O
Link_6	0	0.75	0	0	0.75	0.75	Node_5	MR1_O

A3. MODEL RESULTS DATA (Nodes)

Node Name	Max Water Depth (m)				Max Flow (m^3/s)			
	Scen-01	Scen-02	Scen-03	Scen-04	Scen-01	Scen-02	Scen-03	Scen-04
MBK_1	1.00	1.00	1.00	2.91	0.174	0.174	0.226	0.226
MBK_2	1.00	1.00	1.00	2.02	0.391	0.391	0.51	0.51
MBK_4	1.06	1.06	1.06	2.39	0.682	0.682	0.889	0.889
MBK_5	1.24	1.24	1.24	2.63	0.796	0.796	1.038	1.038
MBK_6	1.24	1.24	1.24	2.98	2.769	2.769	3.295	3.295
MBK_7	1.11	1.11	1.11	2.92	4.014	4.014	4.919	4.919
MBK_8	1.00	1.00	1.00	3.52	4.488	4.488	4.601	4.601
MBK-3	1.00	1.00	1.00	2.01	0.391	0.391	0.51	0.51
MH-2	1.91	1.91	1.91	4.70	1.776	1.776	1.966	1.966
MH-3	1.08	3.59	1.08	3.59	3.124	3.124	4.794	4.794
MR1_O	3.50	6.00	3.50	6.00	9.845	9.845	9.845	14.768
MR10_1	1.00	1.00	1.00	3.70	1.91	1.91	2.226	2.226
MR10_10	1.00	1.00	1.00	3.63	0.632	0.632	0.737	0.737
MR10_11	1.00	1.00	1.00	3.47	1.028	1.028	1.234	1.234
MR10_12	1.00	1.00	1.00	3.69	1.016	1.016	1.238	1.238
MR10_13	1.00	1.00	1.00	3.91	0.825	0.825	0.97	0.97
MR10_14	1.00	1.00	1.00	3.82	0.574	0.574	0.643	0.643
MR10_15	1.00	1.00	1.00	3.55	0.606	0.606	0.62	0.62
MR10_16	1.00	1.00	1.00	3.58	1.489	1.489	1.942	1.942
MR10_17	1.00	1.00	1.00	3.52	0.492	0.492	0.547	0.547
MR10_18	1.00	1.00	1.00	4.28	0.182	0.182	0.237	0.237
MR10_19	1.00	1.00	1.00	4.29	0.545	0.545	0.711	0.711
MR10_2	1.76	1.76	1.76	4.62	3.037	3.037	3.546	3.546
MR10_20	1.46	1.46	1.46	4.53	0.701	0.701	0.783	0.783
MR10_21	1.51	1.51	1.51	4.30	0.583	0.583	0.61	0.61
MR10_3	1.31	1.31	1.31	5.17	2.688	2.688	2.927	2.927
MR10_4	1.09	1.09	1.09	5.39	2.592	2.592	3.082	3.082
MR10_5	1.03	1.05	1.03	5.38	2.501	2.501	2.721	2.721
MR10_6	1.04	1.06	1.04	5.35	2.794	2.794	3.147	3.147
MR10_7	1.00	1.00	1.00	3.70	1.494	1.494	1.949	1.949
MR10_8	1.00	1.00	1.00	3.65	1.207	1.207	1.468	1.468
MR10_9	1.02	1.02	1.02	3.65	0.628	0.628	0.725	0.725
MR3_1	1.03	1.77	1.03	6.49	6.153	6.153	9.805	9.805
MR4_1	1.30	2.05	1.30	4.85	83.7	83.7	83.701	83.701
MR5_1	1.00	1.00	1.00	2.58	0.543	0.543	0.865	0.865
MR5_10	1.00	1.00	1.00	2.48	3.097	3.097	3.857	3.857
MR5_11	1.25	1.75	1.25	6.17	1.892	1.892	3.012	3.012
MR5_12	1.26	1.79	1.26	5.39	4.968	4.968	6.858	6.858
MR5_13	1.06	1.82	1.06	4.07	20.413	20.413	31.563	31.563
MR5_2	1.00	1.00	1.00	3.30	0.807	0.807	1.186	1.186

MR5_3	1.00	1.00	1.00	3.83	1.244	1.244	1.898	1.898
MR5_4	1.06	1.06	1.06	4.06	1.613	1.613	2.49	2.49
MR5_5	1.11	1.11	1.11	4.18	1.956	1.956	3.039	3.039
MR5_6	1.02	1.02	1.02	4.12	2.148	2.148	2.32	2.32
MR5_7	1.00	1.00	1.00	3.98	2.495	2.495	2.873	2.873
MR5_8	1.00	1.00	1.00	3.22	2.844	2.844	3.41	3.41
MR5_9	1.00	1.00	1.00	2.32	2.049	2.049	2.182	2.182
MR6_1	1.27	1.27	1.27	2.10	0	0	0	0
MR6_10	1.16	1.16	1.16	4.67	0.9	0.9	1.015	1.015
MR6_11	1.17	1.17	1.17	4.42	1.057	1.057	1.215	1.215
MR6_12	1.02	1.02	1.02	3.95	0.927	0.927	1.027	1.027
MR6_13	1.15	1.15	1.15	3.77	1.069	1.069	1.253	1.253
MR6_14	1.13	1.13	1.13	3.50	1.22	1.22	1.494	1.494
MR6_15	1.09	1.09	1.09	3.54	1.572	1.572	1.999	1.999
MR6_16	1.13	1.13	1.13	3.63	1.805	1.805	2.37	2.37
MR6_17	1.05	1.05	1.05	3.64	1.376	1.376	1.461	1.461
MR6_18	1.14	1.14	1.14	3.95	1.655	1.655	1.825	1.825
MR6_19	1.12	1.12	1.12	4.04	1.972	1.972	2.296	2.296
MR6_20	1.01	1.01	1.01	4.14	2.234	2.234	2.633	2.633
MR6_21	1.01	1.01	1.01	4.18	2.521	2.521	3.068	3.068
MR6_22	1.00	1.00	1.00	4.19	2.839	2.839	3.566	3.566
MR6_23	1.00	1.00	1.00	4.14	3.034	3.034	3.152	3.152
MR6_24	1.00	1.00	1.00	4.28	3.494	3.494	3.877	3.877
MR6_25	1.00	1.00	1.00	3.22	0.149	0.149	0.195	0.195
MR6_26	1.00	1.00	1.00	3.03	0.185	0.185	0.247	0.247
MR6_27	1.00	1.00	1.00	3.58	0.035	0.035	0.045	0.045
MR6_28	1.00	1.00	1.00	3.78	0.069	0.069	0.09	0.09
MR6_29	1.00	1.00	1.00	4.01	0.094	0.094	0.123	0.123
MR6_30	1.00	1.00	1.00	4.06	0.135	0.135	0.175	0.175
MR6_31	1.00	1.00	1.00	4.30	0.367	0.367	0.477	0.477
MR6_32	1.00	1.00	1.00	3.39	0.079	0.079	0.103	0.103
MR6_33	1.01	1.01	1.01	2.91	0.16	0.16	0.209	0.209
MR6_34	1.00	1.00	1.00	2.95	0.16	0.16	0.188	0.188
MR6_35	1.00	1.00	1.00	3.11	0.196	0.196	0.235	0.235
MR6_36	1.00	1.00	1.00	2.28	0.102	0.102	0.132	0.132
MR6_37	1.00	1.00	1.00	2.33	0.217	0.217	0.258	0.258
MR6_38	1.00	1.00	1.00	2.60	0.325	0.325	0.381	0.381
MR6_5	1.00	1.00	1.00	2.78	1.048	1.048	1.346	1.346
MR6_6	1.01	1.01	1.01	3.35	1.78	1.78	2.151	2.151
MR6_7	1.00	1.00	1.00	4.03	1.312	1.312	1.558	1.558
MR6_8	1.00	1.00	1.00	4.25	0.648	0.648	0.702	0.702
MR6_9	1.00	1.00	1.00	4.33	0.889	0.889	1.001	1.001
MR7_1	1.82	1.82	1.82	5.85	4.191	4.191	4.594	4.594
MR7_2	2.14	2.14	2.14	6.01	5.665	5.665	6.005	6.005
MR7_3	1.62	1.69	1.62	6.02	4.812	4.812	5.387	5.387

MR7_5	1.16	1.16	1.16	4.88	3.696	3.696	4.2	4.2
MR7_6	1.00	1.00	1.00	4.96	3.327	3.327	3.524	3.524
MR7_7	1.00	1.00	1.00	5.08	3.609	3.609	3.975	3.975
MR7_8	1.00	1.00	1.00	5.13	3.816	3.816	4.197	4.197
MR8_1	3.81	3.81	3.81	3.87	1.774	1.774	2.309	2.309
MR8_10	1.00	1.00	1.00	4.64	0.469	0.469	0.611	0.611
MR8_2	3.25	3.25	3.25	4.09	3.347	3.347	3.539	3.539
MR8_5	2.37	2.37	2.37	4.81	3.196	3.196	4.213	4.213
MR8_6	1.74	1.74	1.74	4.77	2.887	2.887	3.238	3.238
MR8_7	1.50	1.50	1.50	4.76	2.4	2.4	2.578	2.578
MR8_8	1.21	1.21	1.21	4.76	2.091	2.091	2.202	2.202
MR8_9	1.18	1.18	1.18	4.78	2.441	2.441	2.659	2.659
MR9_1	1.29	1.29	1.29	5.27	2.382	2.382	3.106	3.106
MR9_2	1.46	1.47	1.46	5.37	3.951	3.951	5.149	5.149
MR9_3	1.60	1.61	1.60	5.48	1.592	1.592	1.845	1.845
MR9_4	1.70	1.70	1.70	5.65	3.935	3.935	4.388	4.388
MR9_5	1.00	1.00	1.00	4.85	2.001	2.001	2.084	2.084
MR9_6	1.00	1.00	1.00	4.93	1.96	1.96	2.031	2.031
MR9_7	1.80	1.81	1.80	5.75	4.146	4.146	4.788	4.788
MR9_8	1.60	1.60	1.60	5.84	2.991	2.991	3.403	3.403
MR9_9	1.65	1.65	1.65	5.84	3.227	3.227	3.453	3.453
N_man_1	1.00	1.00	1.00	2.20	1.708	1.708	1.708	1.708
N_man_10	1.00	1.00	1.00	2.04	2.395	2.395	3.064	3.064
N_man_100	1.00	1.00	1.00	1.79	1.207	1.207	1.207	1.207
N_man_101	1.00	1.00	1.00	1.60	1.31	1.31	1.892	1.892
N_man_102	1.00	1.00	1.00	2.04	1.708	1.708	2.011	2.011
N_man_103	1.00	1.00	1.00	1.32	1.023	1.023	1.636	1.636
N_man_104	1.49	1.49	1.49	2.63	2.979	2.979	3.312	3.312
N_man_105	1.00	1.00	1.00	1.43	1.457	1.457	2.325	2.325
N_man_106	1.01	1.01	1.01	1.93	4.768	4.768	6.742	6.742
N_man_108	1.21	1.21	1.21	2.45	0.842	0.842	1.11	1.11
N_man_109	1.05	1.05	1.05	2.46	3.114	3.114	3.715	3.715
N_man_11	1.00	1.00	1.00	2.27	1.145	1.145	1.145	1.145
N_man_112	1.00	1.00	1.00	2.26	0.273	0.273	0.44	0.44
N_man_113	1.00	1.00	1.00	2.44	1.083	1.083	1.755	1.755
N_man_114	1.08	1.08	1.08	2.90	4.47	4.47	5.709	5.709
N_man_115	1.17	1.17	1.17	3.27	5.748	5.748	7.139	7.139
N_man_116	1.18	1.18	1.18	2.70	4.304	4.304	5.094	5.094
N_man_117	1.25	2.72	1.25	3.48	4.266	4.266	5.279	5.279
N_man_12	1.00	1.00	1.00	1.05	0.47	0.47	0.47	0.47
N_man_134	1.00	1.00	1.00	1.48	0.386	0.386	0.616	0.616
N_man_136	1.00	1.00	1.00	1.22	0.373	0.373	0.598	0.598
N_man_137	1.00	1.00	1.00	2.10	0.916	0.916	1.465	1.465
N_man_138	1.00	1.00	1.00	1.69	0.457	0.457	0.731	0.731
N_man_139	1.00	1.00	1.00	2.03	0.758	0.758	1.214	1.214

N_man_14	1.00	3.23	1.00	1.32	1.56	1.56	1.56	1.56
N_man_140	1.11	1.11	1.11	2.46	0.659	0.659	1.054	1.054
N_man_141	1.10	1.10	1.10	2.58	0.852	0.852	1.363	1.363
N_man_142	1.28	1.28	1.28	2.72	0.852	0.852	1.363	1.363
N_man_143	1.31	1.31	1.31	2.79	1.182	1.182	1.89	1.89
N_man_144	1.41	1.41	1.41	3.05	1.576	1.576	2.523	2.523
N_man_145	1.00	1.00	1.00	2.25	0	0	0	0
N_man_15	1.00	3.61	1.00	1.00	1.56	1.56	1.56	1.56
N_man_16	1.04	3.64	1.04	1.04	1.56	1.56	1.56	1.56
N_man_17	1.00	3.28	1.00	1.00	1.56	1.56	1.56	1.56
N_man_172	1.38	1.38	1.38	2.77	2.739	2.739	3.009	3.009
N_man_173	1.27	1.27	1.27	2.91	3.876	3.876	4.828	4.828
N_man_174	1.17	1.17	1.17	2.91	4.138	4.138	4.384	4.384
N_man_175	1.00	1.00	1.00	2.56	3.086	3.086	3.086	3.086
N_man_176	1.00	1.00	1.00	2.08	3.086	3.086	3.086	3.086
N_man_18	1.19	3.30	1.19	1.00	1.56	1.56	1.56	1.56
N_man_19	1.62	3.63	1.62	1.35	1.56	1.56	1.56	1.56
N_man_20	1.62	3.64	1.62	1.40	1.56	1.56	1.56	1.56
N_man_21	1.69	3.57	1.69	1.41	2.298	2.298	2.351	2.351
N_man_216	1.00	1.00	1.00	2.61	4.093	4.093	5.014	5.014
N_man_22	1.01	2.82	1.01	2.82	2.185	2.185	2.861	2.861
N_man_23	1.09	2.76	1.09	2.77	2.183	2.183	2.86	2.86
N_man_234	1.00	1.00	1.00	2.27	1.109	1.109	1.446	1.446
N_man_235	1.00	1.00	1.00	2.47	1.074	1.074	1.074	1.074
N_man_237	1.00	1.00	1.00	2.48	0.797	0.797	1.242	1.242
N_man_24	1.23	2.74	1.23	2.85	2.178	2.178	2.859	2.859
N_man_25	1.53	2.88	1.53	3.20	14.774	14.774	18.073	18.073
N_man_26	1.05	1.05	1.05	2.21	0.705	0.705	0.918	0.918
N_man_27	1.00	1.00	1.00	1.49	0.637	0.637	0.829	0.829
N_man_28	1.30	1.30	1.30	2.44	0.705	0.705	0.918	0.918
N_man_29	1.00	1.00	1.00	1.69	0.637	0.637	0.829	0.829
N_man_3	1.00	1.00	1.00	1.00	0.497	0.497	0.649	0.649
N_man_30	1.39	1.39	1.39	2.51	2.071	2.071	2.695	2.695
N_man_31	1.00	1.00	1.00	2.14	0.944	0.944	0.944	0.944
N_man_32	1.11	1.11	1.11	2.29	0.944	0.944	0.944	0.944
N_man_33	1.00	1.00	1.00	2.20	0.885	0.885	0.919	0.919
N_man_34	1.07	1.07	1.07	2.29	0.885	0.885	0.919	0.919
N_man_35	1.00	1.00	1.00	2.22	1.107	1.107	1.276	1.276
N_man_36	1.03	1.03	1.03	2.35	1.477	1.477	1.759	1.759
N_man_37	1.08	1.08	1.08	2.39	1.591	1.591	1.669	1.669
N_man_38	1.00	1.00	1.00	2.28	1.09	1.09	1.09	1.09
N_man_39	1.07	1.07	1.07	2.33	1.09	1.09	1.09	1.09
N_man_4	1.00	1.00	1.00	1.58	0.273	0.273	0.355	0.355
N_man_40	1.00	1.00	1.00	2.37	1.177	1.177	1.228	1.228
N_man_41	1.00	1.00	1.00	2.23	1.177	1.177	1.219	1.219

N_man_42	1.00	1.00	1.00	2.36	1.362	1.362	1.461	1.461
N_man_6	1.00	1.00	1.00	1.17	0.748	0.748	0.975	0.975
N_man_7	1.00	1.00	1.00	1.32	0.748	0.748	0.975	0.975
N_man_8	1.00	1.00	1.00	1.37	0.987	0.987	0.987	0.987
N_man_9	1.00	1.00	1.00	1.84	0.453	0.453	0.535	0.535
N_man_93	1.00	1.00	1.00	1.21	1.413	1.413	2.269	2.269
N_man_94	1.00	1.00	1.00	1.75	1.013	1.013	1.013	1.013
N_man_95	1.00	1.00	1.00	1.77	1.685	1.685	2.092	2.092
N_man_96	1.00	1.00	1.00	1.86	1.685	1.685	1.724	1.724
N_man_97	1.00	1.00	1.00	1.88	1.685	1.685	1.724	1.724
N_man_98	1.00	1.00	1.00	2.10	1.685	1.685	1.724	1.724
N_man_99	1.00	1.00	1.00	1.89	1.207	1.207	1.207	1.207
Node_123	1.19	1.37	1.19	5.96	29.234	29.234	40.633	40.633
Node_136	1.00	1.76	1.00	4.01	13.382	13.382	21.427	21.427
Node_137	1.03	1.79	1.03	3.33	15.464	15.464	24.725	24.725
Node_143	1.79	3.22	1.79	3.30	48.451	48.451	65.789	65.789
Node_156	2.38	3.45	2.38	6.56	17.75	17.75	25.2	25.2
Node_159	1.00	1.00	1.00	2.15	54.445	54.445	82.373	82.373
Node_160	1.47	2.89	1.47	5.20	57.777	57.777	71.011	71.011
Node_168	2.17	3.46	2.17	4.01	90.703	90.703	100.048	100.048
Node_188	2.07	3.45	2.07	3.30	28.742	28.742	35.243	35.243
Node_195	1.00	1.64	1.00	2.00	4.083	4.083	6.523	6.523
Node_196	1.18	2.27	1.18	2.40	7.643	7.643	12.121	12.121
Node_198	1.21	1.21	1.21	3.12	3.037	3.037	3.645	3.645
Node_199	1.21	1.21	1.21	3.14	3.037	3.037	3.644	3.644
Node_201	1.22	1.22	1.22	2.78	2.255	2.255	2.626	2.626
Node_209	1.50	4.62	1.50	1.00	14.362	14.362	15.753	15.753
Node_210	1.14	1.14	1.14	3.16	5.198	5.198	6.463	6.463
Node_211	1.00	1.00	1.00	2.89	4.266	4.266	5.28	5.28
Node_23	1.00	1.00	1.00	2.40	68.478	68.478	89.51	89.51
Node_230	1.00	1.00	1.00	1.80	6.338	6.338	10.076	10.076
Node_233	1.20	1.85	1.20	5.19	46.866	46.866	65.607	65.607
Node_24	1.43	4.61	1.43	1.07	4.365	4.365	4.365	4.365
Node_248	2.47	4.38	2.47	4.37	110.83	110.83	186.997	186.997
Node_26	1.32	2.75	1.32	2.75	20.977	20.977	27.331	27.331
Node_264	1.13	1.86	1.13	6.11	5.71	5.71	6.899	6.899
Node_27	1.00	1.00	1.00	5.62	15.653	15.653	20.513	20.513
Node_278	1.46	2.98	1.46	5.17	47.047	47.047	47.108	47.108
Node_279	1.47	3.03	1.47	4.58	60.632	60.632	60.632	60.632
UT1_2	2.10	4.37	2.10	1.08	8.315	8.315	8.466	8.466
UT1_2.1	2.11	3.96	2.11	1.01	18.762	18.762	22.12	22.12
UT2_1	1.00	1.83	1.00	2.10	2.042	2.042	3.265	3.265
UT2_2	1.21	3.00	1.21	1.00	6.056	6.056	6.032	6.032
UT4_1	1.44	2.19	1.44	5.40	54.161	54.161	57.654	57.654

A4. MODEL RESULTS DATA (Links)

Link Name	Max Velocity (ft/s, m/s)				Maximum Water Elevation (DS)(m)			
	Scen-01	Scen-02	Scen-03	Scen-04	Scen-01	Scen-02	Scen-03	Scen-04
L390	3.96	3.96	3.96	0	4.729	4.57	1.509	4.347
L391	1.81	1.81	1.81	1.74	4.748	4.114	4	4.043
L392	1.01	1.01	1.01	3.73	5.254	4.124	1.604	3.721
L393	0.69	0.69	0.69	6.67	5.235	4.487	2.017	0.979
L396	0.91	0.91	0.91	0.02	5.672	4.374	2.441	4.36
L397	0.65	0.65	0.65	-3.3	5.63	4.031	2.146	4.031
L398	0.86	0.86	0.86	-3.25	5.408	4.031	2.115	4.031
L399	1.39	1.39	1.39	6.45	5.656	4.173	2.163	4
L400	1.79	1.79	1.79	6.55	5.451	4.257	2.171	1.921
L401	0.97	0.97	0.97	0	6.21	4.26	2.742	2.742
L402	1.13	1.13	1.13	0	6.381	4.097	2.913	2.913
L403	3.03	3.03	3.03	0	5.884	4.359	2.907	4.359
L404	1.71	1.71	1.71	-4.85	6.372	4.36	3.002	4.36
L405	1.47	1.47	1.47	1.42	6.405	4.236	3.045	4.365
L406	1.41	1.41	1.41	1.42	5.898	4.015	3.06	4.03
L407	1.61	1.61	1.61	1.29	5.826	4.01	2.558	4.01
L408	2.02	2.02	2.02	2.33	6.166	4.19	2.836	4.19
L409	2.7	2.7	2.7	-1.82	5.866	6.44	2.846	6.44
L410	1.94	1.94	1.94	2.91	5.783	7.961	2.586	7.833
L411	0.36	0.36	0.36	20.05	4.684	2.795	1.284	5
L412	0.22	0.22	0.22	1.42	4.696	2.967	1.416	5.11
L413	0.49	0.49	0.49	1.98	4.709	4.6	1.479	4.54
L414	0.74	0.74	0.74	4.97	4.763	5.82	2.089	5.32
L415	0.45	0.45	0.45	-0.74	4.729	5.83	2.093	5.331
L416	1.1	1.1	1.1	0.95	4.937	2.923	1.437	4.035
L417	0.28	0.28	0.28	-1.72	4.937	3.103	1.617	4.215
L419	1.21	1.21	1.21	1.33	5.002	3.01	1.692	3.74
L420	1.39	1.39	1.39	1.83	4.709	4.538	1.409	0.974
L421	2.05	2.05	2.05	0.64	4.655	1.741	1.442	5.99
L422	0.4	0.4	0.4	3.88	4.6	1.954	1.2	6.11
L423	2.43	2.43	2.43	0.54	4.927	2.674	1.057	3.285
Link_109	0.42	0.42	0.42	7.14	4.937	6.485	1.797	7.11
Link_121	1.14	1.14	1.14	0.35	5.084	1.876	0.997	2
Link_122	1.42	1.42	1.42	1.34	5.205	3	1.205	2
Link_124	2.18	2.18	2.18	2.56	7.769	1.209	1.209	3.15
Link_125	2.05	2.05	2.05	2.49	8.089	1.212	1.212	3.15
Link_128	1.48	1.48	1.48	2.11	8.454	1.254	1.254	2.78
Link_135	1.17	1.17	1.17	1.48	5.783	7.291	1.853	7.163
Link_138	2.2	2.2	2.2	3.28	7.19	1.14	1.14	3.52
Link_139	3.87	3.87	3.87	2.18	5.366	2.074	0.972	2.886
Link_169	0.74	0.74	0.74	5.21	4.856	3.53	1.156	0.131

Link_174	2.06	2.06	2.06	0	4.779	3.1	2.079	3.1
Link_185	0.57	0.57	0.57	2.07	4.552	1.861	1.08	4.63
Link_189	0.64	0.64	0.64	2.61	4.613	1.864	1.113	5.61
Link_194	0.9	0.9	0.9	2.86	4.693	2.787	1.373	5.68
Link_20	1.48	1.48	1.48	3.52	7.942	0.897	0.897	2.05
Link_21	1.76	1.76	1.76	4.25	4.974	3	1.174	3
Link_22	1.12	1.12	1.12	1.77	4.702	0.85	0.202	4.96
Link_70	0.77	0.77	0.77	2.09	5.185	0.8	0.8	5.42
Link_77	0.36	0.36	0.36	0.84	4.587	1.819	1.057	4.07
Link_78	0.35	0.35	0.35	-2.72	4.604	1.792	1.034	5.352
Link_81	0.62	0.62	0.62	0.96	4.993	3.171	1.693	3.2
Link_87	1.31	1.31	1.31	0.63	5.034	2.693	1.403	5.54
Link_89	0.66	0.66	0.66	6.25	8.497	0.9	0.9	2.3
Link_96	1.09	1.09	1.09	1.1	5.002	3.283	1.962	4.395
Link_96.1	0.89	0.89	0.89	-1.88	5.109	3.469	2.169	4.01
MR10_P1	2.73	2.73	2.73	-1.88	6.977	1.757	1.757	4.62
MR10_P2	2.05	2.05	2.05	3.07	6.358	1.788	1.788	5.17
MR10_P3	1.89	1.89	1.89	2.36	5.906	1.458	1.458	5.4
MR10_P4	2.12	2.12	2.12	2.3	5.71	1.146	1.146	5.4
MR10_P5	2.27	2.27	2.27	2.72	5.67	1.078	1.05	5.38
MR10_P6	2.36	2.36	2.36	3.19	5.651	1.627	1.621	5.84
MR10_S1	0.35	0.35	0.35	3.74	7.67	0.99	0.99	3.7
MR10_S10	0.95	0.95	0.95	0.95	7.209	0.958	0.958	3.58
MR10_S11	2.05	2.05	2.05	1.22	6.968	0.988	0.988	3.7
MR10_S12	0.4	0.4	0.4	2.3	6.841	0.965	0.965	4.3
MR10_S13	1.12	1.12	1.12	0.81	7.107	1.477	1.477	4.64
MR10_S14	1.33	1.33	1.33	1.11	7.051	1.511	1.511	4.64
MR10_S15	1.79	1.79	1.79	1.95	7.008	1.788	1.788	4.62
MR10_S2	0.58	0.58	0.58	1.77	7.707	1.047	1.047	3.65
MR10_S3	0.66	0.66	0.66	1.38	7.618	1.047	1.047	3.65
MR10_S4	0.76	0.76	0.76	1.87	7.583	0.993	0.993	3.63
MR10_S5	0.87	0.87	0.87	2.11	7.541	1.001	1.001	3.69
MR10_S6	1.07	1.07	1.07	2.48	7.458	1.001	1.001	3.91
MR10_S7	1.36	1.36	1.36	2.65	7.368	0.998	0.998	3.91
MR10_S8	2.04	2.04	2.04	2.96	7.132	0.969	0.969	3.84
MR10_S9	3.22	3.22	3.22	3.19	6.968	0.988	0.988	3.7
MR3_P1	0.42	0.42	0.42	3.24	4.63	1.774	1.026	6.49
MR4_P2	1.05	1.05	1.05	0.76	4.552	1.861	1.072	4.07
MR4_P3	0.68	0.68	0.68	-2.05	4.596	1.992	1.236	5.2
MR5_P1	1.26	1.26	1.26	3.5	9.571	1.001	1.001	3.3
MR5_P10	1.5	1.5	1.5	1.56	4.848	1.79	1.258	5.39
MR5_P11	0.76	0.76	0.76	2.54	4.848	1.79	1.258	6.17
MR5_P12	0.89	0.89	0.89	0.51	4.587	1.819	1.258	5.39
MR5_P2	1.17	1.17	1.17	1.21	9.341	1.001	1.001	3.831
MR5_P3	1.25	1.25	1.25	1.37	9.252	1.072	1.072	4.056

MR5_P4	1.41	1.41	1.41	1.46	9.168	1.108	1.108	4.176
MR5_P5	1.53	1.53	1.53	1.41	9.049	1.108	1.108	4.176
MR5_P6	1.72	1.72	1.72	2.01	8.972	1.019	1.019	4.115
MR5_P7	1.74	1.74	1.74	2.94	8.884	1.004	1.004	3.983
MR5_P8	1.68	1.68	1.68	4.49	8.813	1.004	1.004	3.22
MR5_P9	2.4	2.4	2.4	6.37	8.705	0.913	0.913	2.27
MR6_P1	0.39	0.39	0.39	5.19	9.182	1.488	1.488	2.21
MR6_P10	1.27	1.27	1.27	0.21	7.926	1.273	1.273	4.67
MR6_P11	1.74	1.74	1.74	3.1	7.634	1.206	1.206	4.42
MR6_P12	2.18	2.18	2.18	3.36	7.577	1.167	1.167	3.98
MR6_P13	1.34	1.34	1.34	4	7.45	1.167	1.167	3.91
MR6_P14	1.57	1.57	1.57	2.58	7.411	1.131	1.131	3.54
MR6_P15	1.59	1.59	1.59	1.85	7.252	1.132	1.132	3.63
MR6_P16	1.55	1.55	1.55	1.67	7.152	1.132	1.132	3.64
MR6_P17	1.87	1.87	1.87	1.55	6.969	1.139	1.139	3.95
MR6_P18	1.6	1.6	1.6	1.87	6.882	1.139	1.139	4.04
MR6_P19	1.72	1.72	1.72	1.6	6.678	1.122	1.122	4.14
MR6_P20	1.86	1.86	1.86	1.72	6.63	1.01	1.01	4.18
MR6_P21	1.93	1.93	1.93	1.86	6.492	1.01	1.01	4.19
MR6_P22	2.07	2.07	2.07	1.93	6.425	1.002	1.002	4.19
MR6_P23	2.29	2.29	2.29	2.07	6.321	0.995	0.995	4.28
MR6_P24	2.49	2.49	2.49	2.29	6.03	1.17	1.17	4.88
MR6_P5	0.8	0.8	0.8	2.49	8.619	1.109	1.109	3.35
MR6_P6	1.12	1.12	1.12	0.79	8.374	1.092	1.092	4.03
MR6_P7	1.38	1.38	1.38	1.09	8.256	1.034	1.034	4.25
MR6_P8	1.77	1.77	1.77	1.48	8.085	1.019	1.019	4.33
MR6_P9	1.95	1.95	1.95	2.44	8.133	1.273	1.273	4.67
MR6_S1	0.66	0.66	0.66	2.43	7.806	0.996	0.996	3.39
MR6_S10	0.86	0.86	0.86	0.66	8.77	1.08	1.08	3.11
MR6_S11	0.82	0.82	0.82	0.68	8.619	1.109	1.109	3.35
MR6_S12	0.48	0.48	0.48	0.82	8.932	0.966	0.966	2.33
MR6_S13	1.06	1.06	1.06	0.48	8.82	0.96	0.96	2.6
MR6_S14	0.9	0.9	0.9	1.04	8.739	1.079	1.079	2.78
MR6_S2	1.12	1.12	1.12	0.84	7.612	0.996	0.996	3.22
MR6_S3	1.78	1.78	1.78	1.12	7.411	1.131	1.131	3.54
MR6_S4	0.7	0.7	0.7	1.78	8.493	0.923	0.923	3.78
MR6_S5	1.11	1.11	1.11	0.7	8.249	0.923	0.923	4.01
MR6_S6	1.15	1.15	1.15	1.11	8.191	0.842	0.842	4.06
MR6_S7	1.46	1.46	1.46	1.15	7.926	1.206	1.206	4.42
MR6_S8	0.18	0.18	0.18	1.46	8.085	0.951	0.951	4.33
MR6_S9	0.43	0.43	0.43	0.73	8.843	1.007	1.007	2.95
MR7_P1	1.78	1.78	1.78	0.33	5.847	2.137	2.137	6.01
MR7_P2	2.8	2.8	2.8	2.73	5.282	2.137	2.137	6.02
MR7_P5	1.67	1.67	1.67	4.26	5.816	1.17	1.17	4.96
MR7_P6	1.94	1.94	1.94	1.66	5.741	1.006	1.006	5.16

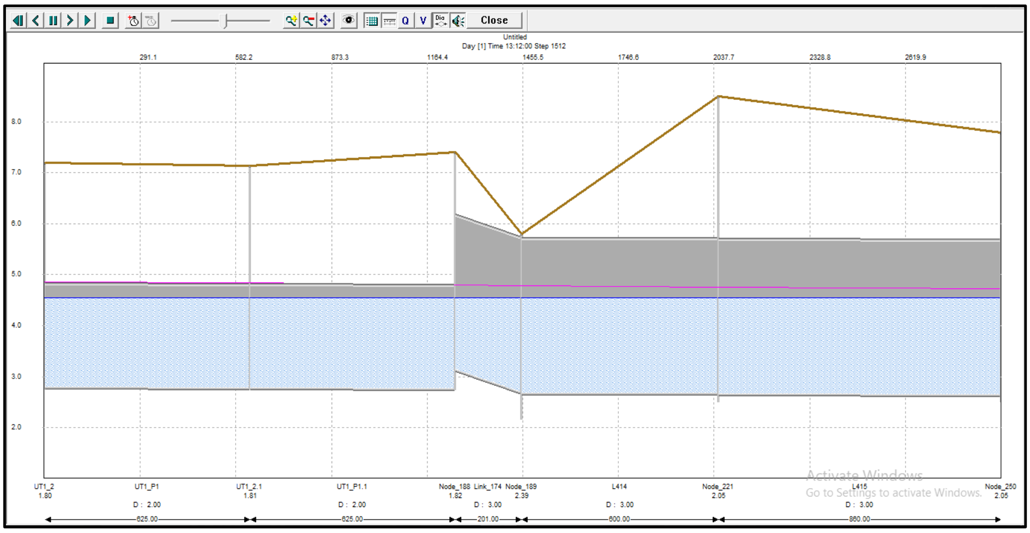
MR7_P7	2.17	2.17	2.17	1.94	5.617	1.001	1.001	5.16
MR7_P8	2.58	2.58	2.58	2.17	5.282	1.697	1.622	6.02
MR8_P1	0.09	0.09	0.09	2.58	9.66	4.09	4.09	4.09
MR8_P10	2.33	2.33	2.33	0.43	5.66	1.175	1.175	4.85
MR8_P4	1.67	1.67	1.67	2.33	7.474	2.515	2.515	4.81
MR8_P5	2.16	2.16	2.16	2.54	7.205	2.383	2.383	4.81
MR8_P6	1.98	1.98	1.98	2.87	6.765	2.246	2.246	4.77
MR8_P7	1.68	1.68	1.68	3.24	6.753	1.923	1.923	4.76
MR8_P8	2.05	2.05	2.05	3.7	5.945	1.923	1.923	4.78
MR8_P9	0.36	0.36	0.36	4.22	5.945	1.175	1.175	4.78
MR9_P1	0.28	0.28	0.28	0.31	5.589	1.468	1.459	5.37
MR9_P2	1.48	1.48	1.48	0.28	5.664	1.607	1.604	5.48
MR9_P3	0.24	0.24	0.24	1.48	5.619	1.704	1.699	5.651
MR9_P4	2.61	2.61	2.61	0.24	5.608	1.001	1	4.93
MR9_P5	2.76	2.76	2.76	2.61	5.619	1.704	1.699	5.651
MR9_P6	0.23	0.23	0.23	2.76	5.631	1.833	1.811	5.753
MR9_P7	1.63	1.63	1.63	0.23	5.636	1.835	1.836	5.85
MR9_P8	0.98	0.98	0.98	-1.05	5.669	1.687	1.679	5.84
MR9_P9	0.88	0.88	0.88	2.21	5.636	1.835	1.836	5.85
Mun_0	3.43	3.43	3.43	2.56	5.847	2.137	2.137	6.01
Mun_1	2.14	2.14	2.14	3.43	7.61	1.14	1.14	3.16
Mun_2	2.01	2.01	2.01	2.14	8.112	1.247	1.247	3.12
Mun_3	2.14	2.14	2.14	2.1	8.277	1.254	1.254	2.98
Mun_4	1.65	1.65	1.65	2.35	8.608	1.238	1.238	2.63
Mun_5	2.11	2.11	2.11	1.65	8.739	1.069	1.069	2.39
Mun_6	1.66	1.66	1.66	2.11	9.345	1.003	1.003	2.29
Mun_7	0.94	0.94	0.94	1.66	9.373	1.003	1.003	2.91
N_1	2	2	2	0.94	5.923	3.099	0.623	2.89
N_10	1.36	1.36	1.36	5.68	5.032	2.64	0.892	2.64
N_100	3.41	3.41	3.41	-2.61	7.153	0.987	0.987	2.563
N_101	4.24	4.24	4.24	4.91	4.856	3.63	1.286	2.079
N_11	1.64	1.64	1.64	5.43	5.03	2.47	0.84	2.47
N_12	1.51	1.51	1.51	-1.79	5.034	2.46	1.034	2.7
N_124	1.54	1.54	1.54	-1.75	8.381	0.891	0.891	2.03
N_125	0.9	0.9	0.9	1.54	8.239	1.199	1.199	2.46
N_126	1.79	1.79	1.79	0.91	8.381	0.95	0.95	2.03
N_127	1.6	1.6	1.6	1.79	8.239	1.199	1.199	2.46
N_128	1.28	1.28	1.28	2.48	8.322	0.968	0.968	2.1
N_129	3.29	3.29	3.29	1.28	7.877	1.277	1.277	2.91
N_13	1.23	1.23	1.23	3.29	9.085	1.185	1.185	2.24
N_130	0.99	0.99	0.99	0.53	8.042	1.199	1.199	2.58
N_131	1.21	1.21	1.21	1.37	8.099	1.289	1.289	2.72
N_132	1.18	1.18	1.18	1.64	8.06	1.31	1.31	2.79
N_133	1.26	1.26	1.26	2	7.891	1.421	1.421	3.05
N_134	1.62	1.62	1.62	2.81	7.677	1.091	1.091	2.72

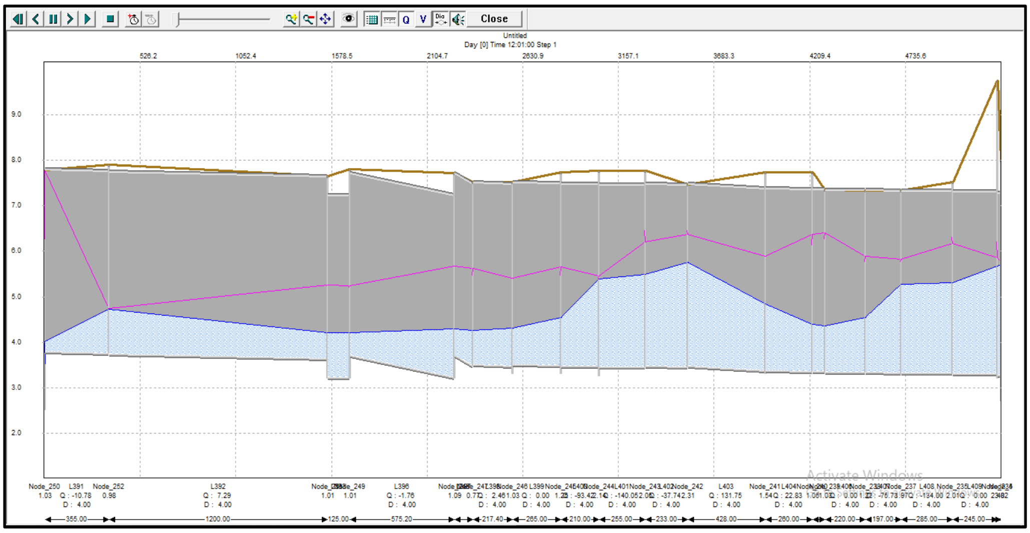
N_135	1.51	1.51	1.51	3.07	7.891	1.421	1.421	3.05
N_14	1.74	1.74	1.74	1.51	9.27	0.789	0.789	1.69
N_15	1.33	1.33	1.33	1.74	9.068	1.388	1.388	2.51
N_151	1.29	1.29	1.29	0.87	8.621	1.011	1.011	1.93
N_152	1.26	1.26	1.26	1.29	8.093	1.053	1.053	2.46
N_153	1.17	1.17	1.17	1.26	8.262	0.862	0.862	2.1
N_154	1.44	1.44	1.44	1.17	8.093	1.053	1.053	2.46
N_155	1.7	1.7	1.7	1.44	7.978	1.178	1.178	2.7
N_156	1.31	1.31	1.31	1.7	7.978	0.922	0.922	2.44
N_157	0.95	0.95	0.95	1.31	8.248	1.008	1.008	2.26
N_158	1.47	1.47	1.47	0.95	7.978	1.008	1.008	2.44
N_159	2.64	2.64	2.64	1.47	7.675	1.075	1.075	2.9
N_16	2	2	2	2.64	9.068	1.388	1.388	2.51
N_160	2.48	2.48	2.48	2	7.36	1.17	1.17	3.267
N_161	1.78	1.78	1.78	3.39	6.978	1.17	1.17	3.266
N_162	1.64	1.64	1.64	3.63	7.675	1.178	1.178	2.9
N_163	1.35	1.35	1.35	2.19	8.752	1.002	1.002	1.75
N_164	1.33	1.33	1.33	1.36	8.729	1.002	1.002	1.77
N_165	1.57	1.57	1.57	1.33	8.638	0.999	0.999	1.86
N_166	1.78	1.78	1.78	1.57	8.589	0.998	0.998	1.88
N_167	1.87	1.87	1.87	1.78	8.397	0.997	0.997	2.1
N_168	1.26	1.26	1.26	2.08	8.365	1.495	1.495	2.63
N_169	2.15	2.15	2.15	2.02	8.388	0.998	0.998	2.04
N_17	1.02	1.02	1.02	2.16	9.062	1.002	1.002	2.13
N_170	0.96	0.96	0.96	0.93	8.905	1.005	1.005	1.6
N_171	1.89	1.89	1.89	0.96	8.536	0.996	0.996	1.89
N_172	1.43	1.43	1.43	1.89	8.706	1.005	1.005	1.79
N_173	1.84	1.84	1.84	1.43	8.365	1.495	1.495	2.63
N_18	0.95	0.95	0.95	1.83	9.04	1.13	1.13	2.32
N_19	0.92	0.92	0.92	1.15	9.033	1.04	1.04	2.23
N_2	2.63	2.63	2.63	1.5	5.731	3.165	0.623	1.187
N_20	0.96	0.96	0.96	4.7	8.962	1.102	1.102	2.29
N_21	1.11	1.11	1.11	1.83	8.954	0.982	0.982	2.215
N_211	2.19	2.19	2.19	2.05	8.541	1.023	1.023	2.27
N_212	0.66	0.66	0.66	3.24	8.916	1.704	1.704	1.838
N_213	1.32	1.32	1.32	2.47	9.541	1.021	1.021	1.05
N_214	0.81	0.81	0.81	1.32	8.916	0.966	0.966	1.84
N_215	0.25	0.25	0.25	0.81	9.311	1.061	1.061	1.32
N_216	1.13	1.13	1.13	1.18	8.945	1.031	1.031	1.37
N_217	3.74	3.74	3.74	1.13	9.66	4.09	4.09	4.09
N_218	1.69	1.69	1.69	3.74	8.864	0.984	0.984	2.04
N_219	1.92	1.92	1.92	2.84	8.823	1.023	1.023	2.2
N_22	1.24	1.24	1.24	2.57	8.902	1.052	1.052	2.35
N_220	4.12	4.12	4.12	2.36	7.835	2.515	2.515	4.73
N_221	2.54	2.54	2.54	5.94	8.945	1.021	1.021	1.37

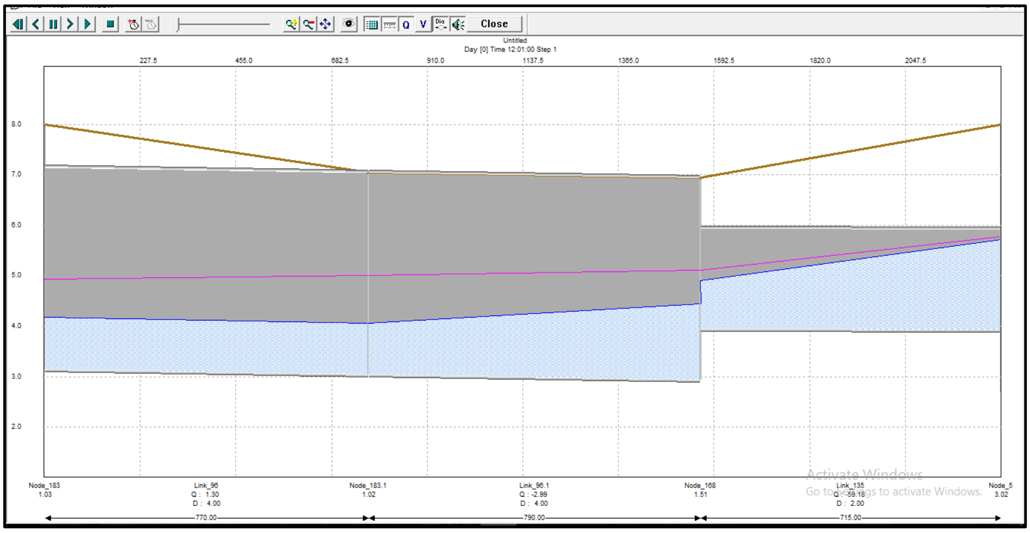
N_222	4.44	4.44	4.44	2.54	5.303	2.43	0.777	2.412
N_23	1.32	1.32	1.32	5.94	8.888	1.108	1.108	2.39
N_24	1.66	1.66	1.66	2.67	8.872	0.998	0.998	2.28
N_25	1.7	1.7	1.7	2.88	8.843	1.073	1.073	2.33
N_26	1.69	1.69	1.69	3.14	8.855	1.135	1.135	2.37
N_27	1.88	1.88	1.88	3.37	8.782	0.987	0.987	2.22
N_28	2.18	2.18	2.18	3.74	8.447	0.932	0.932	2.36
N_29	2.27	2.27	2.27	4.05	8.454	1.254	1.254	2.78
N_3	1.59	1.59	1.59	4.61	5.553	3.7	1.053	1.053
N_4	1.36	1.36	1.36	1.59	5.32	3.7	1.052	1.052
N_5	1.45	1.45	1.45	1.36	5.15	3.29	0.87	0.87
N_6	1.28	1.28	1.28	1.45	5.181	3.487	1.211	0.929
N_7	0.68	0.68	0.68	1.28	5.197	3.556	1.467	1.202
N_72	0.88	0.88	0.88	0.39	8.013	0.983	0.983	2.47
N_73	1.44	1.44	1.44	1.09	7.677	0.983	0.983	2.512
N_74	0.78	0.78	0.78	2.18	8.008	0.978	0.978	2.48
N_75	1.42	1.42	1.42	0.78	7.677	0.978	0.978	2.512
N_8	0.53	0.53	0.53	1.86	5.175	3.6	1.715	1.451
N_9	1.64	1.64	1.64	0	5.035	2.6	0.715	2.42
N_96	1.66	1.66	1.66	-3.46	8.16	1.495	1.495	2.77
N_97	2.05	2.05	2.05	2.12	7.877	1.43	1.43	2.91
N_98	2.52	2.52	2.52	2.54	7.568	1.277	1.277	2.912
N_99	2.55	2.55	2.55	3.41	7.307	1.198	1.198	2.912
New1-1	2.87	2.87	2.87	3.72	7.667	0.995	0.995	1.891
New1-2	0.78	0.78	0.78	2.87	4.6	1.784	1.03	4.891

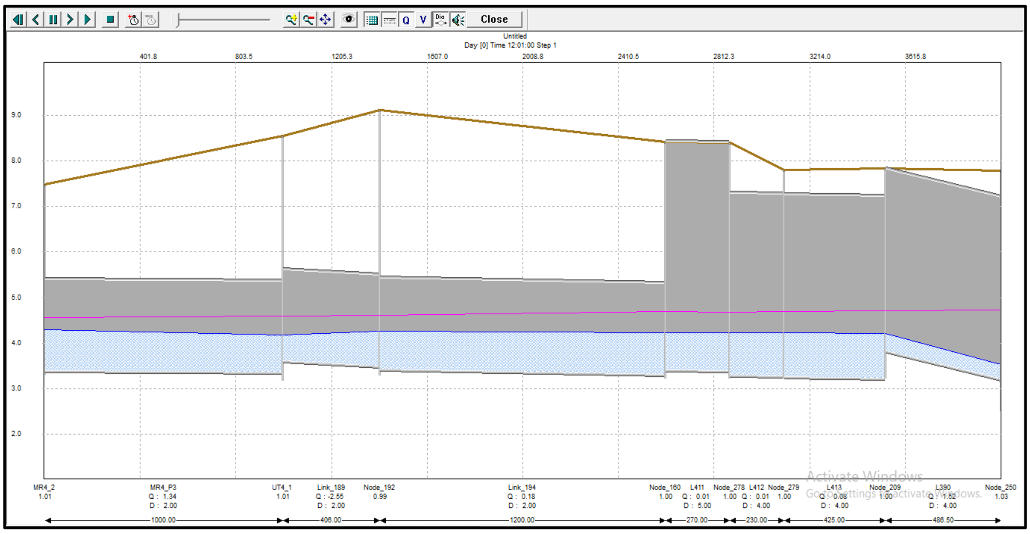
A5. MODEL RESULTS FOR DIFFERENT SCENARIOS

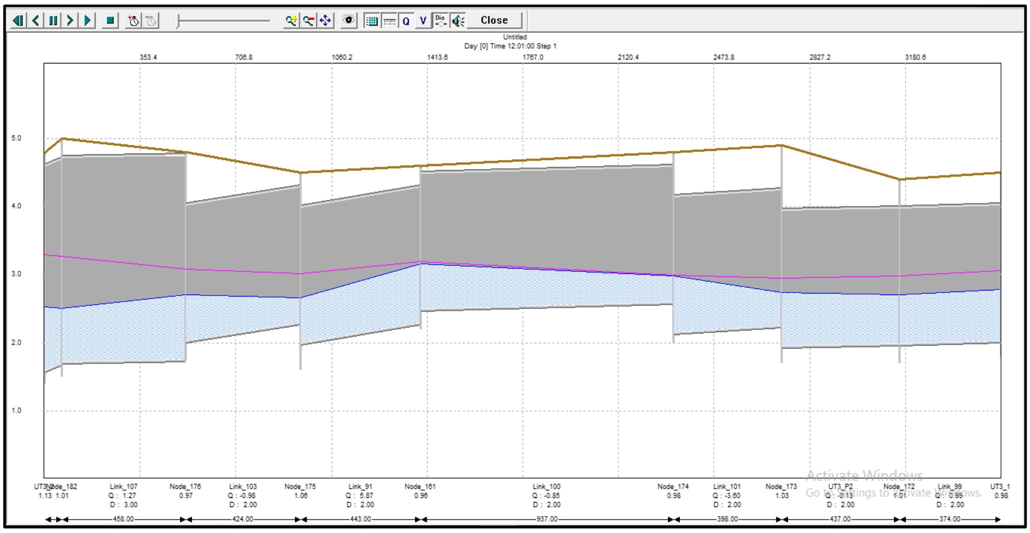
SCENARIO-BASE (PUMP INACTIVE)

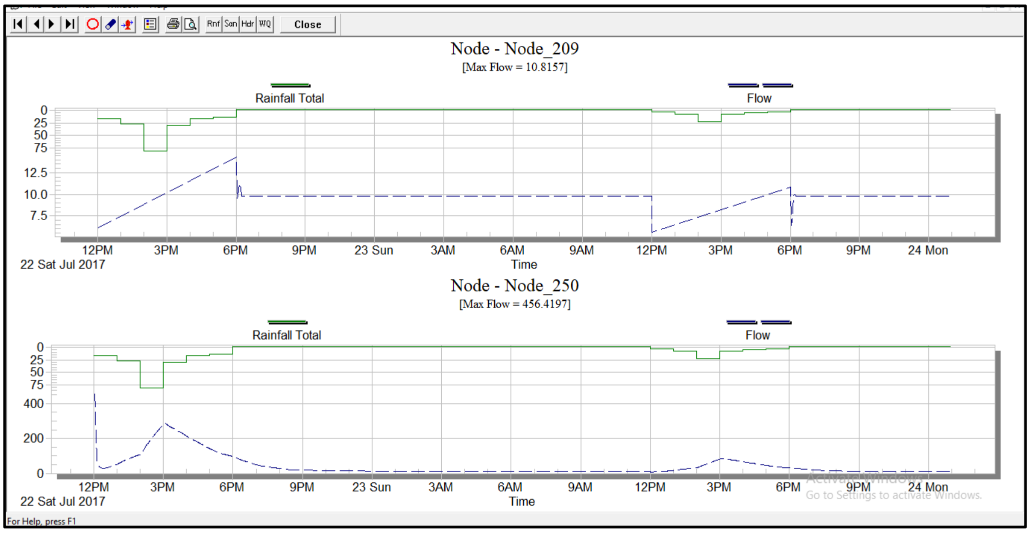


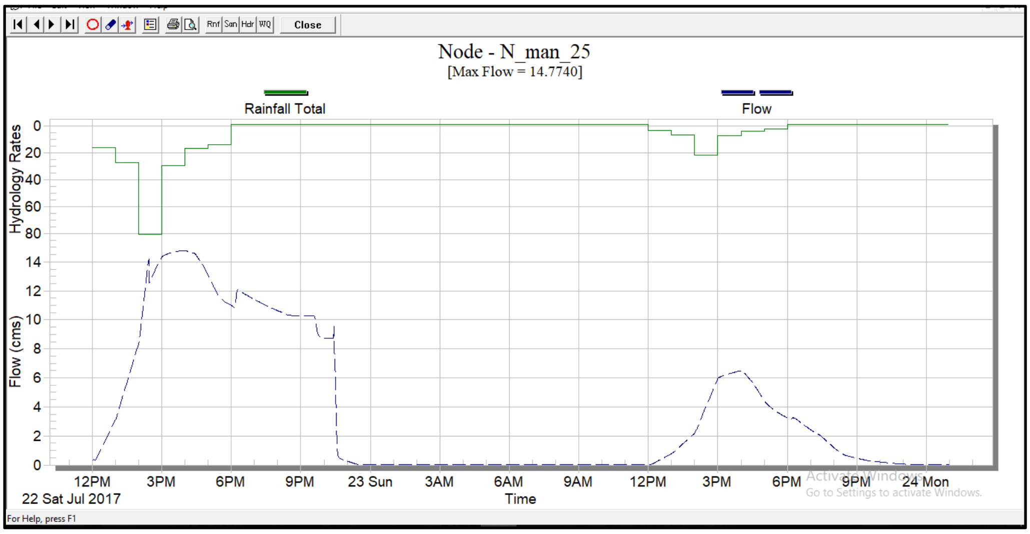


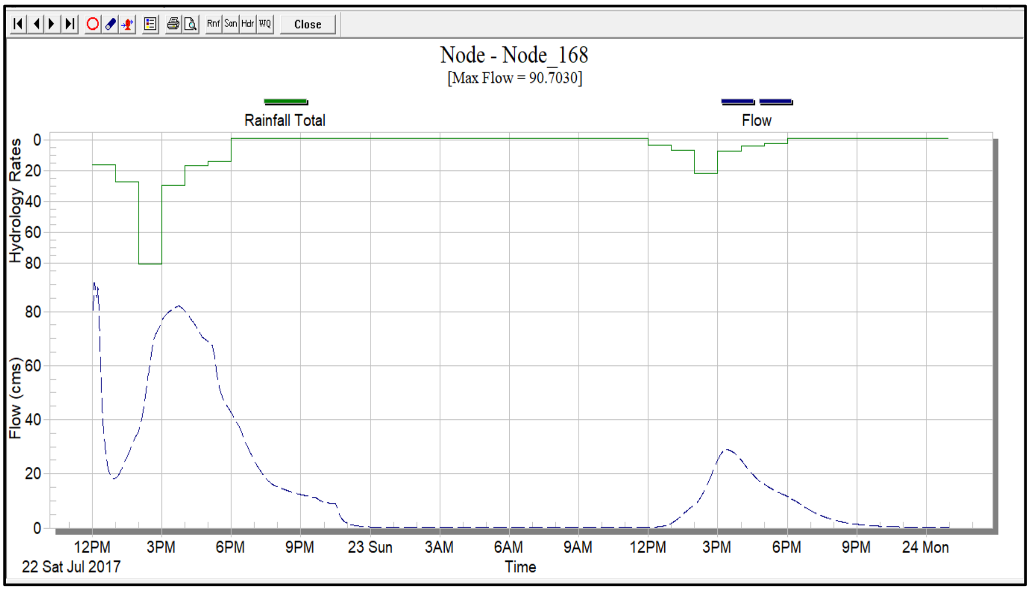




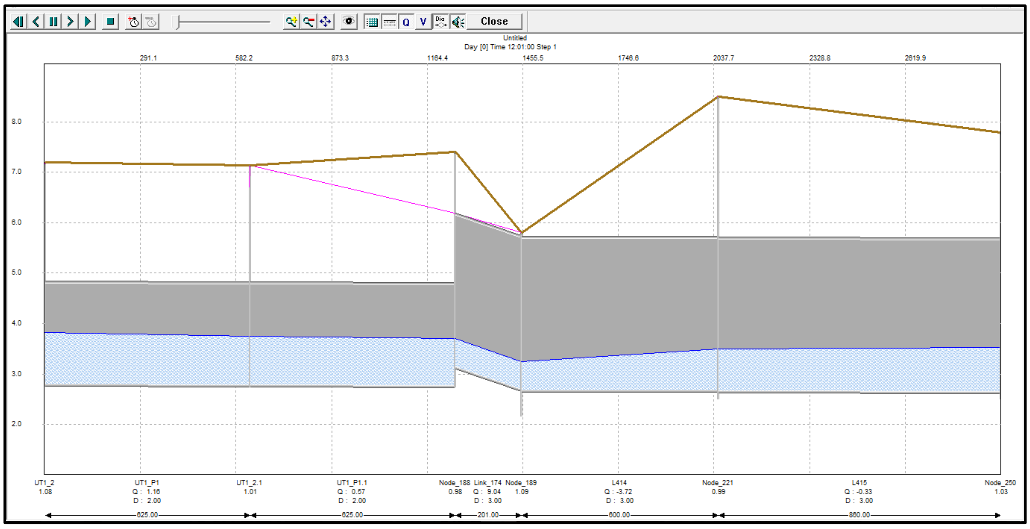


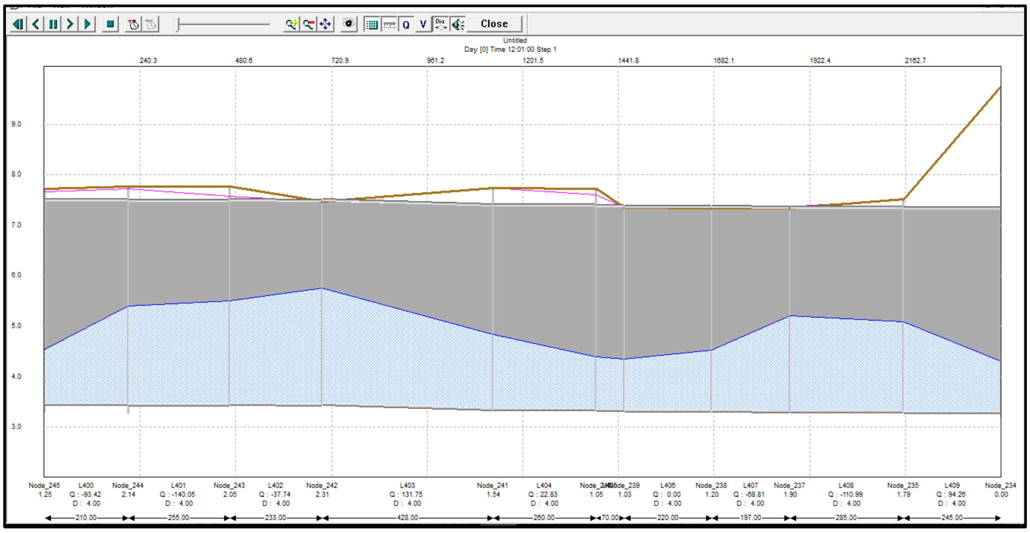

Close
Node - Node_209
[Max Flow = 10.8157]
Rainfall Total
Flow
12PM 3PM 6PM 9PM 23 Sun 3AM 6AM 9AM 12PM 3PM 6PM 9PM 24 Mon
22 Sat Jul 2017
Time
Node - Node_250
[Max Flow = 456.4197]
Rainfall Total
Flow
12PM 3PM 6PM 9PM 23 Sun 3AM 6AM 9AM 12PM 3PM 6PM 9PM 24 Mon
22 Sat Jul 2017
Time
For Help, press F1

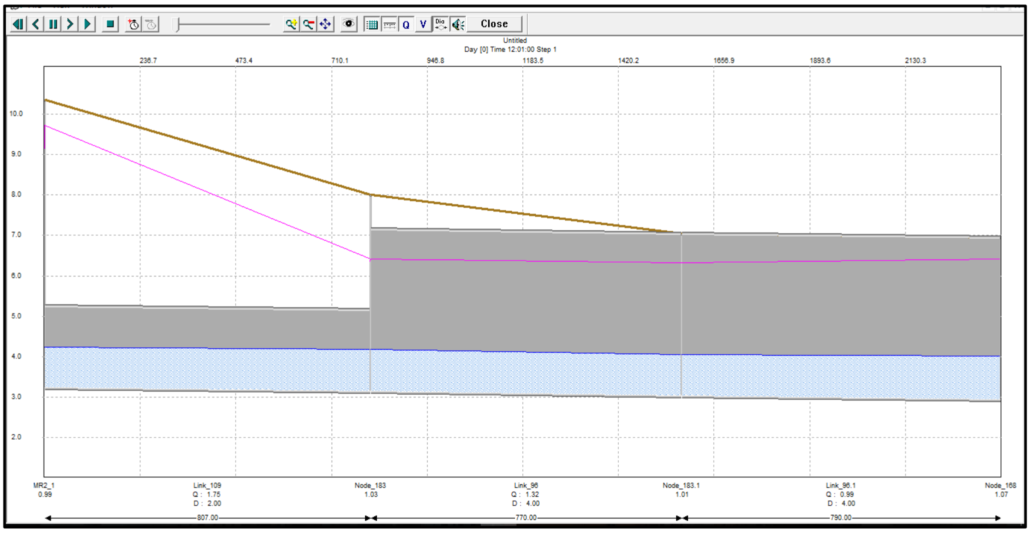

Close
Node - N_man_25
[Max Flow = 14.7740]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time
For Help, press F1

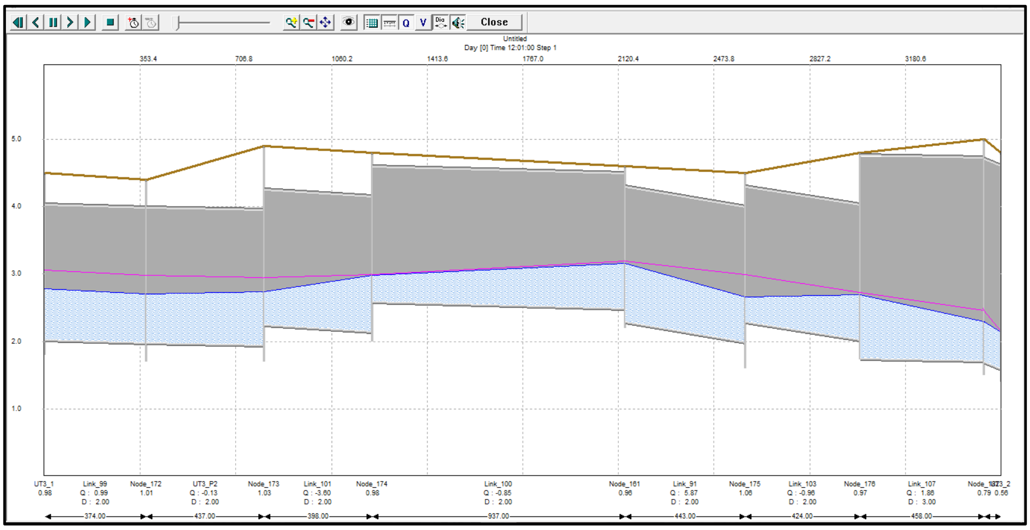

Close
Node - Node_168
[Max Flow = 90.7030]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

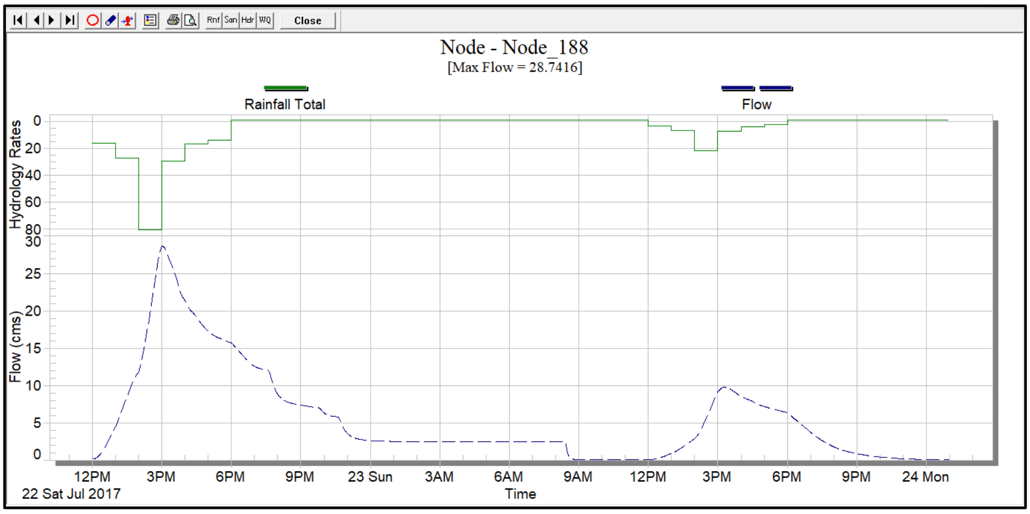
SCENARIO-BASE (2 PUMP ACTIVE)

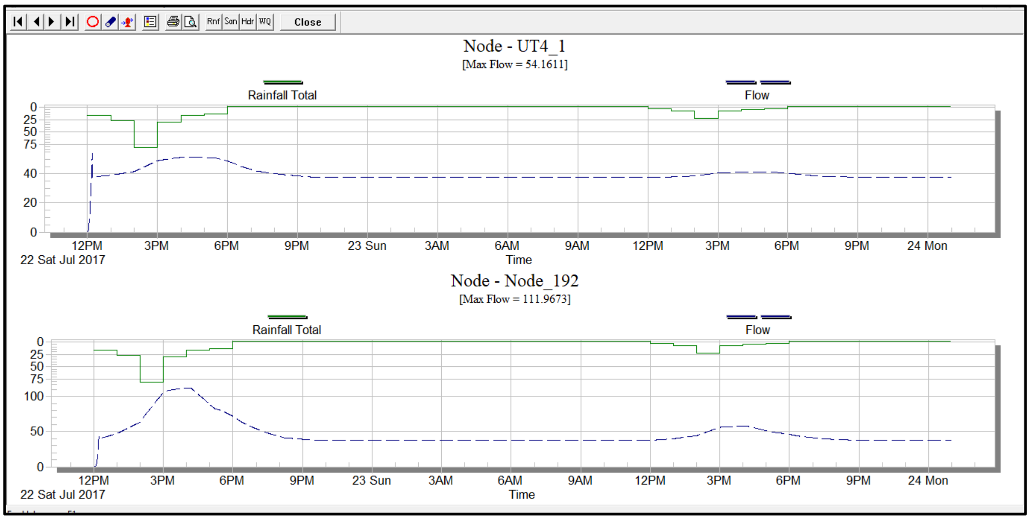




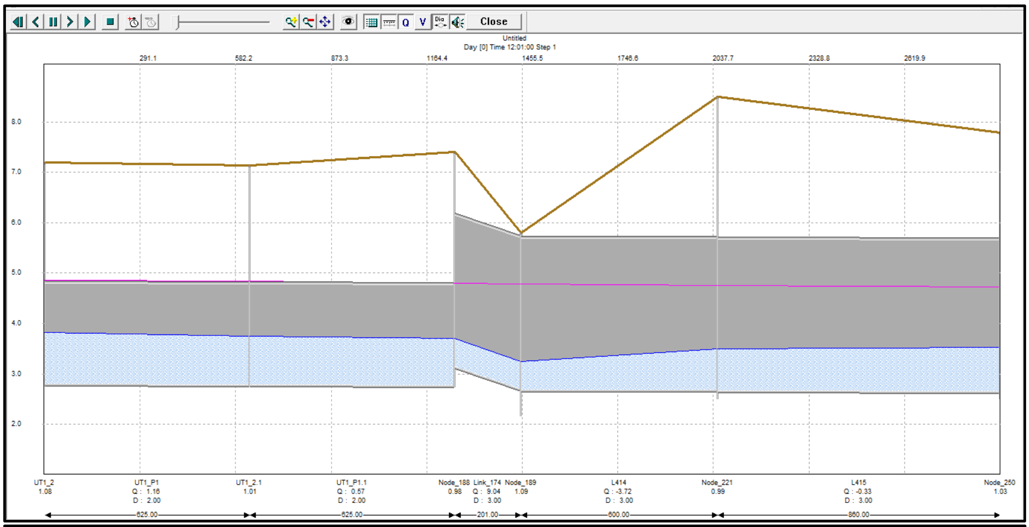


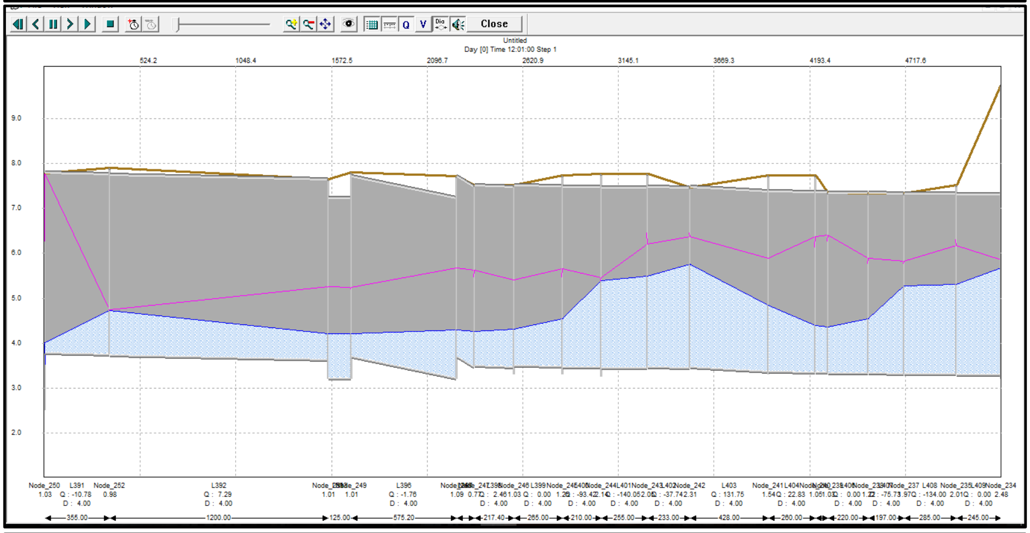


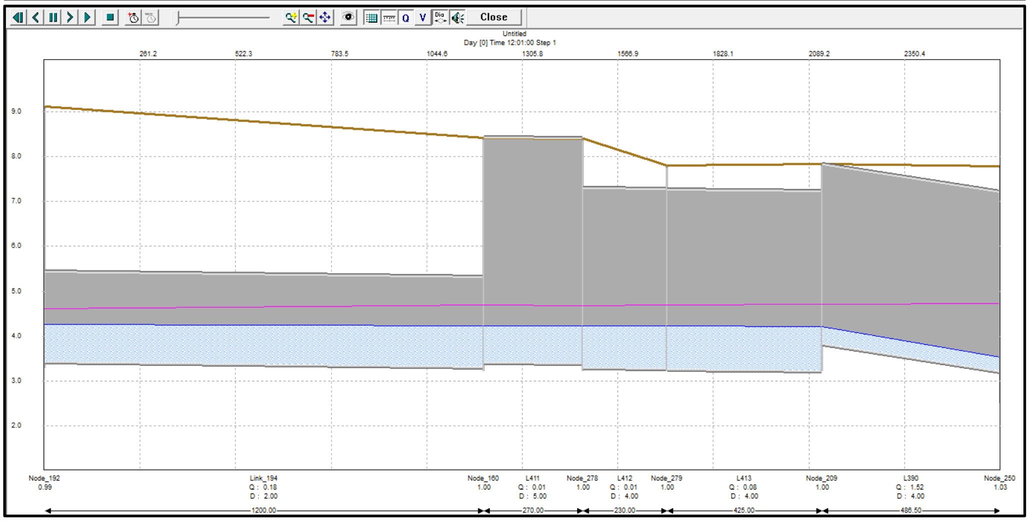

Close
Node - Node_188
[Max Flow = 28.7416]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
0
20
40
60
80
30
25
20
15
10
5
0
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

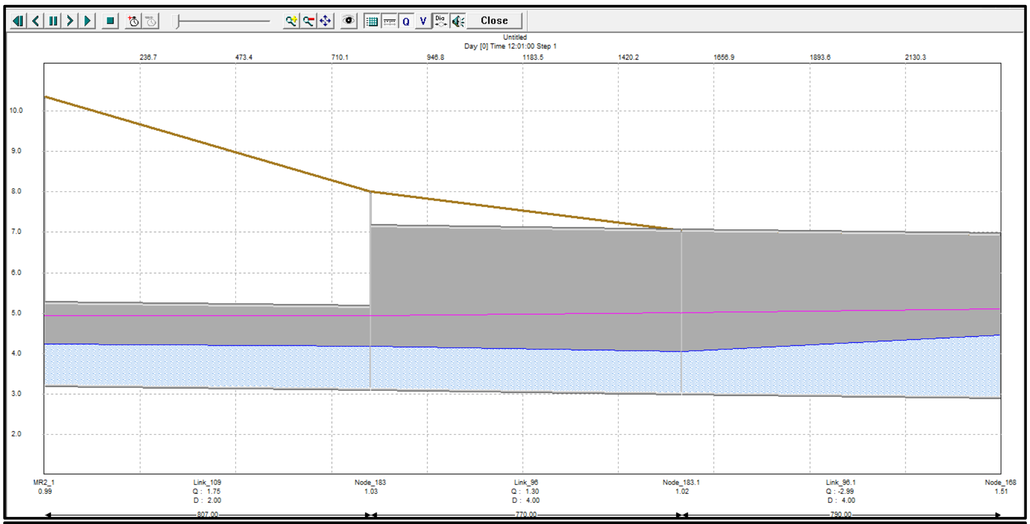

Close
Node - UT4_1
[Max Flow = 54.1611]
Rainfall Total
Flow
0
25
50
75
40
20
0
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time
Node - Node_192
[Max Flow = 111.9673]
Rainfall Total
Flow
0
25
50
75
100
50
0
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

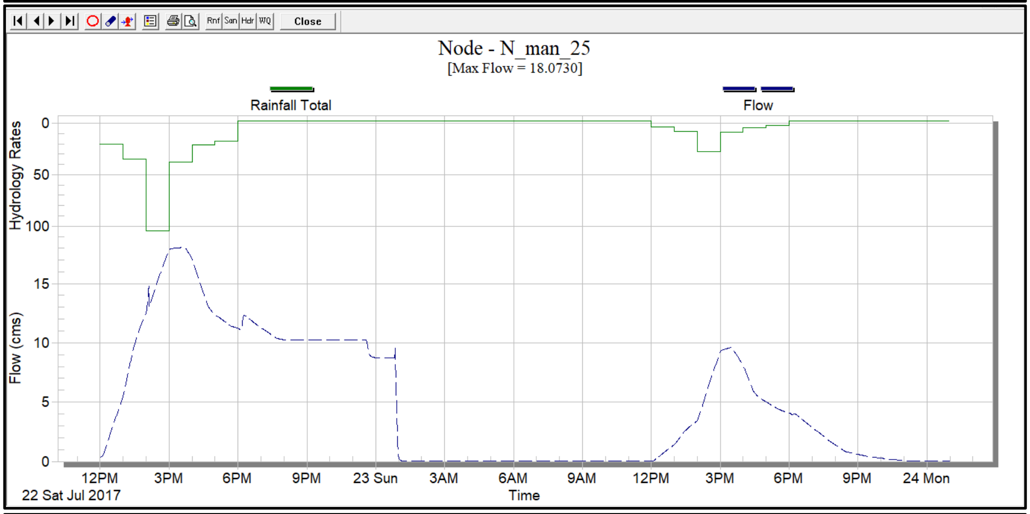
SCENARIO-CLIMATE CHANGE

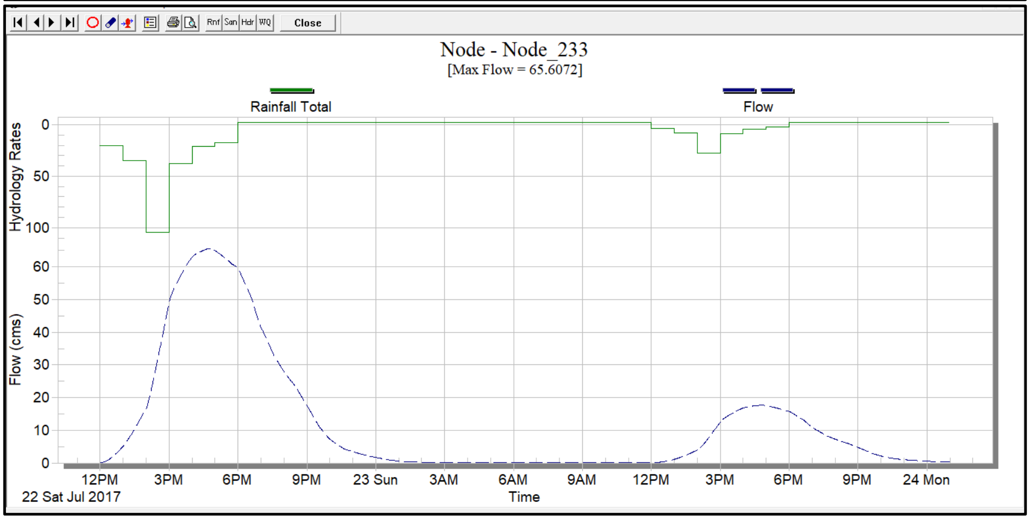


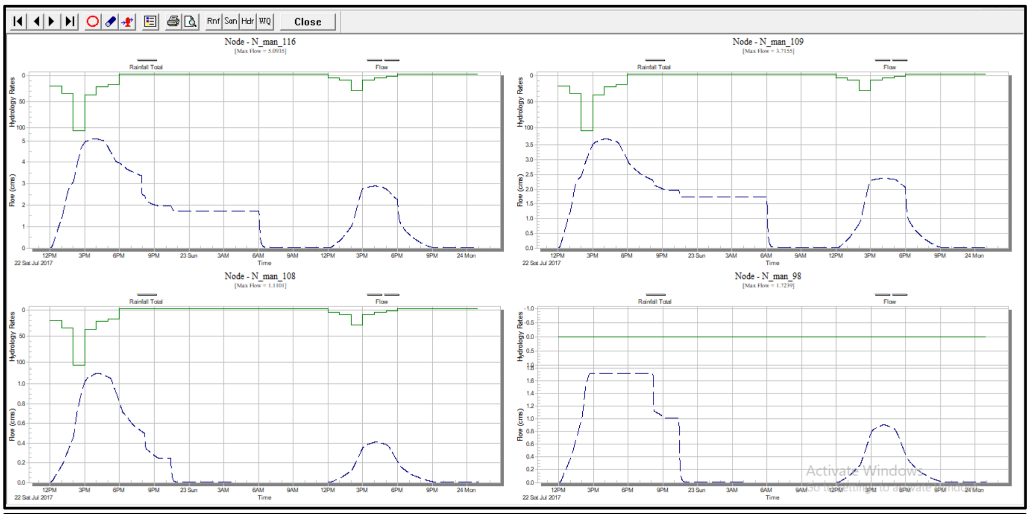


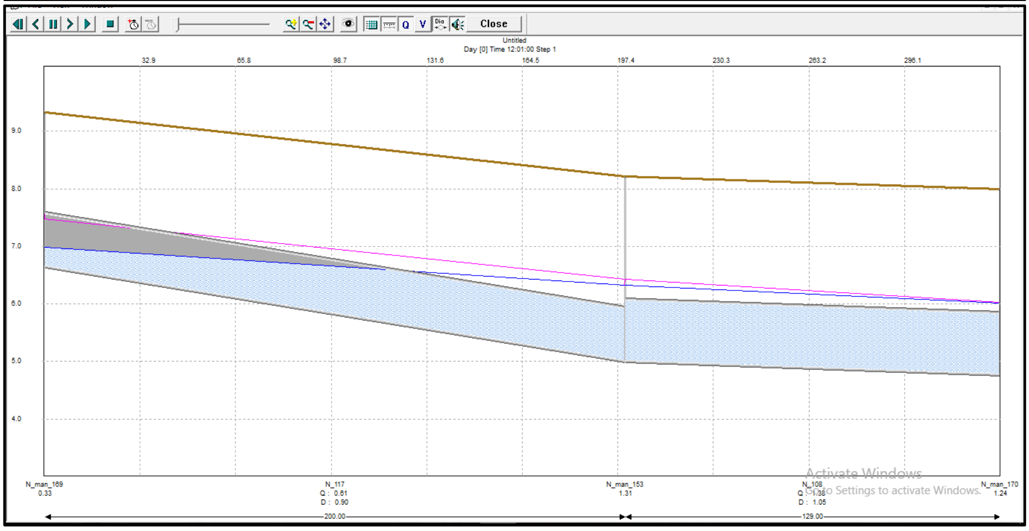


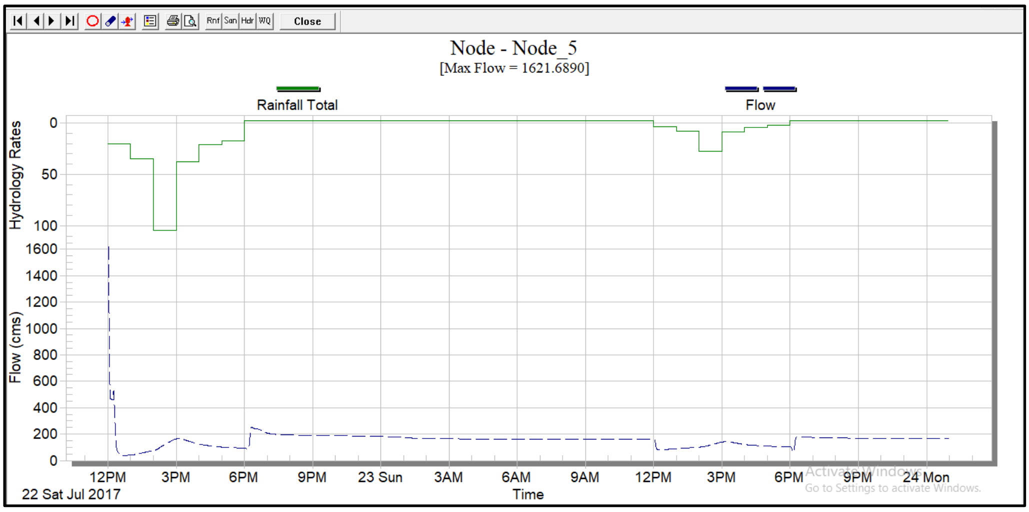

Close


Close
Node - N_man_25
[Max Flow = 18.0730]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

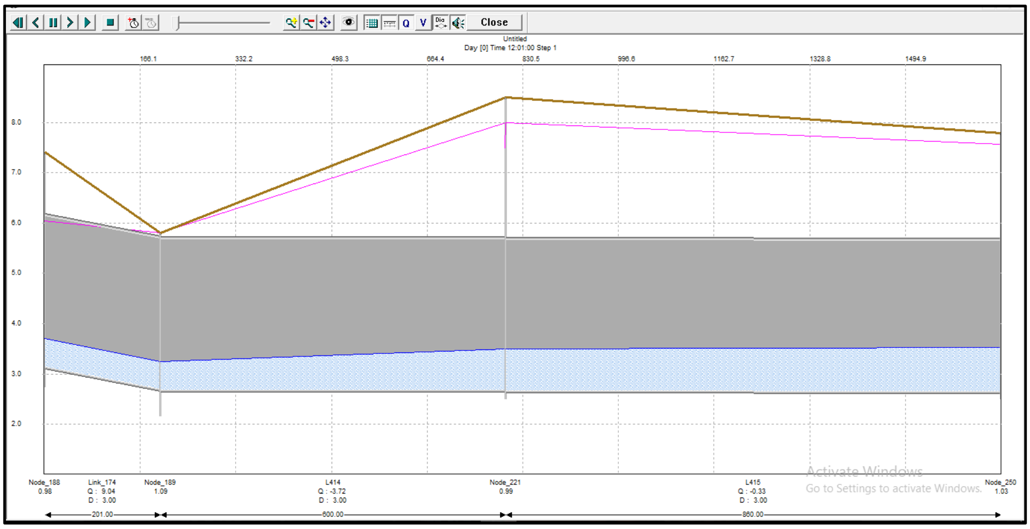

Close
Node - Node_233
[Max Flow = 65.6072]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

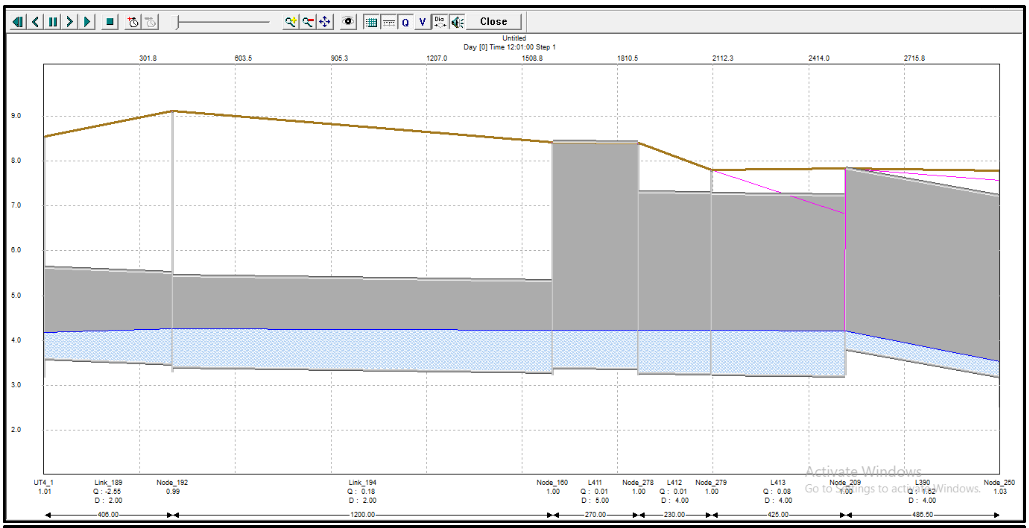

Close
Node - N_man_116
Node - N_man_109
Node - N_man_108
Node - N_man_98
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
Time
22 Sat Jul 2017

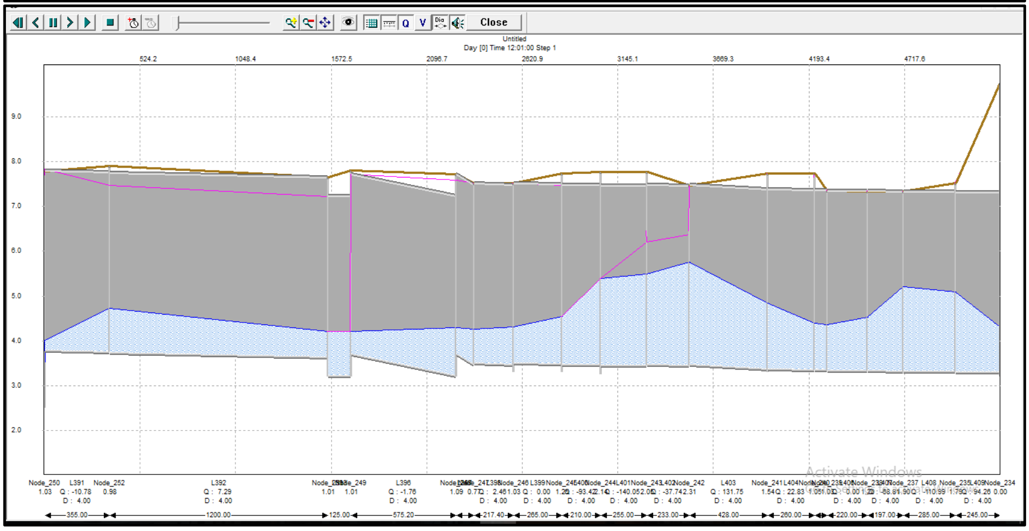

Close
Untitled
Day [0] Time 12:01:00 Step 1
N_man_169
N_117
N_man_153
N_108
N_man_170

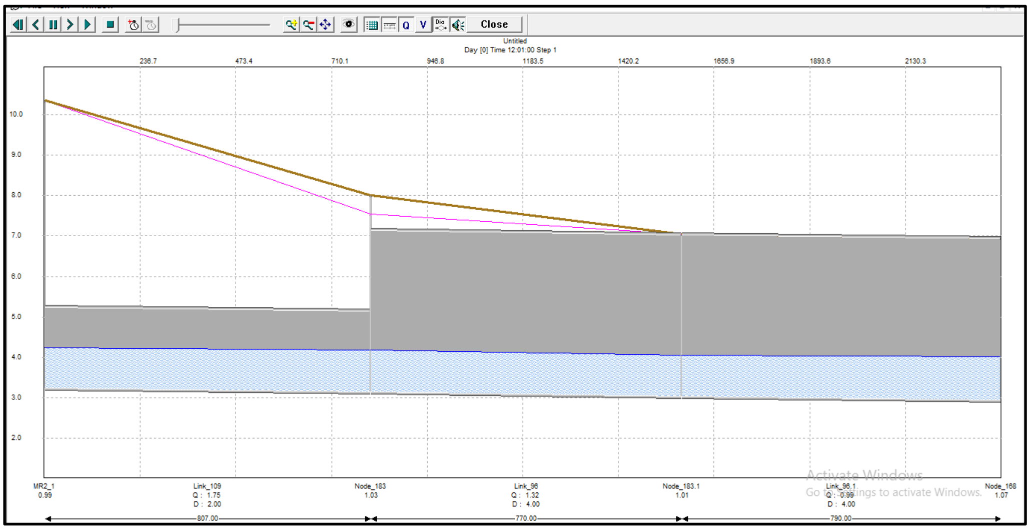

Close
Node - Node_5
[Max Flow = 1621.6890]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
0
50
100
1600
1400
1200
1000
800
600
400
200
0
12PM
3PM
6PM
9PM
23 Sun
3AM
6AM
9AM
12PM
3PM
6PM
9PM
24 Mon
22 Sat Jul 2017
Time

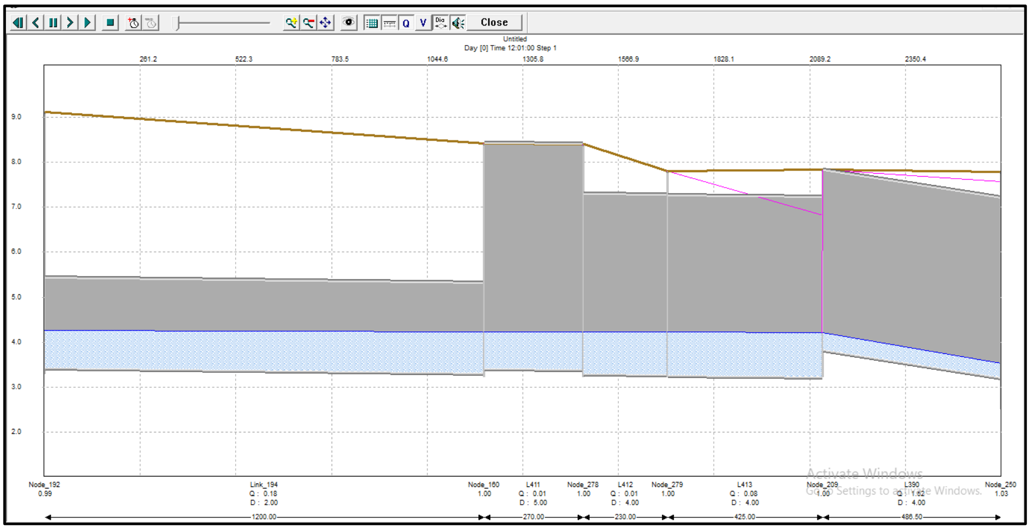
SCENARIO-LAND USE CHANGE (3 PUMP ACTIVE)

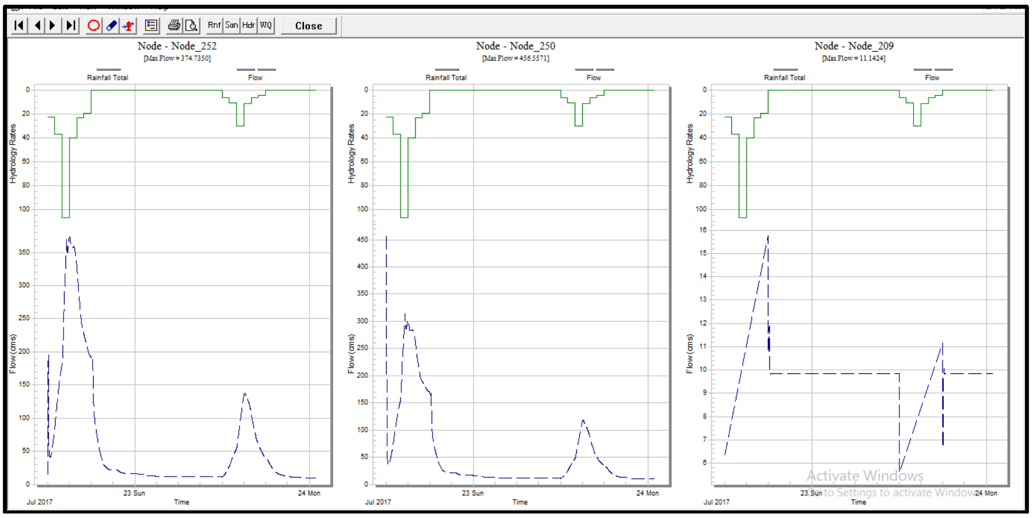


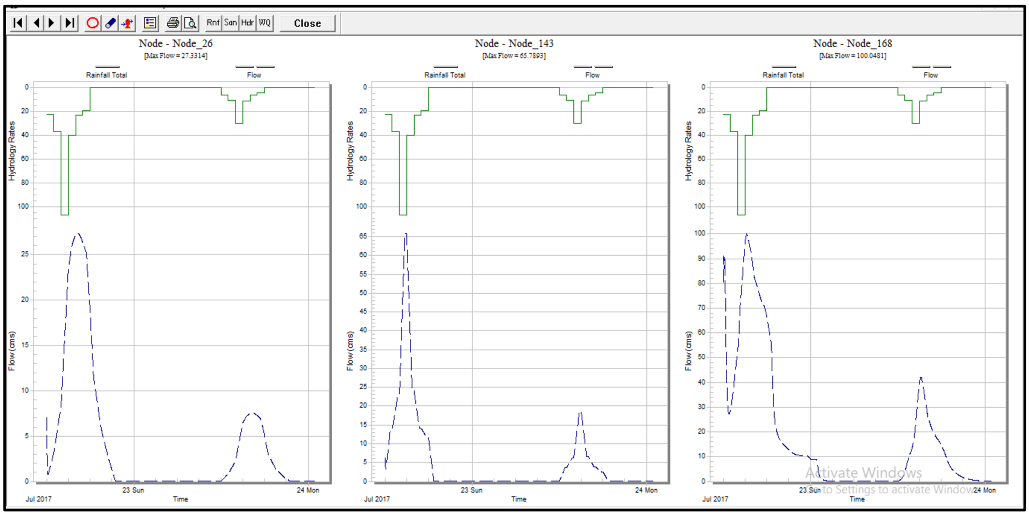


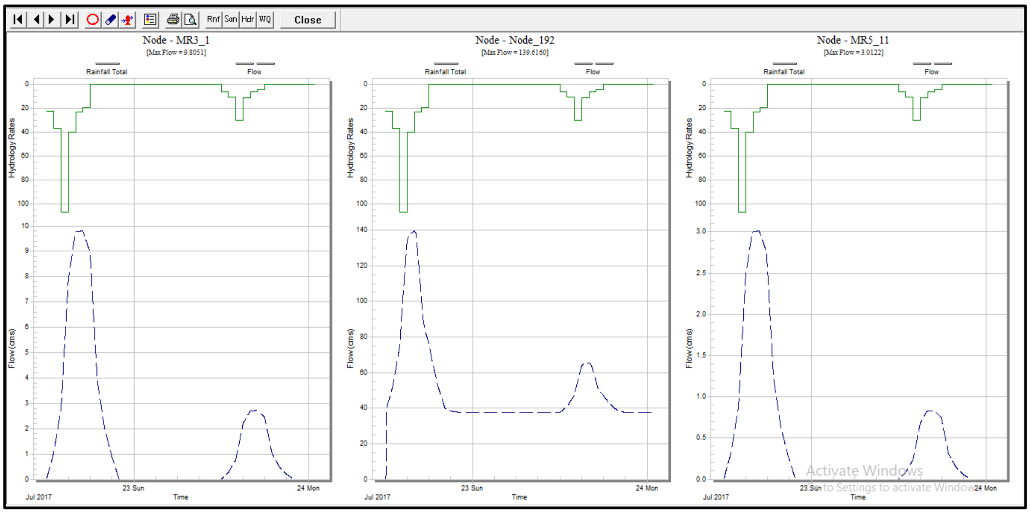









Close
Node - Node_26
[Max Flow = 27.3314]
Node - Node_143
[Max Flow = 65.7893]
Node - Node_168
[Max Flow = 100.0481]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
23 Sun
24 Mon
Jul 2017
Time


Close
Node - MR3_1
[Max Flow = 9.8051]
Node - Node_192
[Max Flow = 139.6160]
Node - MR5_11
[Max Flow = 3.0122]
Rainfall Total
Flow
Hydrology Rates
Flow (cms)
23 Sun
24 Mon
Jul 2017
Time

A6. FLOODING RESULTS FOR DIFFERENT SCENARIOS

FLOODING RESULTS OF ACTUAL EVENT (2004)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km^2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	1.74	0.30	0.00	0.00	12.30
Cantonment	3.78	3.75	0.01	0.02	0.00	0.44
Pallabi	3.56	3.53	0.01	0.02	2.30	0.60
Savar	0.75	0.75	0.20	0.00	0.00	23.40
Uttara	20.36	11.26	0.50	1.60	3.40	45.60
W-1	3.89	1.82	0.06	1.20	0.32	12.45
W-2	3.10	3.07	0.43	0.01	0.56	12.60
W-3	1.03	1.03	0.30	0.00	0.23	23.40
W-4	1.37	1.27	0.09	0.23	1.20	4.07
W-5	1.36	1.32	0.04	0.00	1.20	12.67
W-6	4.61	2.30	0.10	0.40	0.30	14.50
W-7	1.74	1.69	0.40	0.01	0.04	11.89
W-8	3.00	1.87	0.05	0.07	0.02	34.50
W-13	0.31	0.45	0.43	0.45	0.00	54.70
W-14	0.91	0.86	0.34	0.45	0.00	2.78
W-15	8.06	7.86	0.13	0.07	0.43	1.76
W-16	1.23	0.15	0.02	0.00	1.23	3.94
Total	**63.80**	**44.73**	**3.40**	**4.52**	**11.22**	**15.98**

FLOODING RESULTS OF BASE-30yrs

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	12.30
Cantonment	3.78	3.75	0.01	0.02	0.00	12.87
Pallabi	3.59	3.53	0.01	0.02	0.03	15.87
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	14.26	0.50	1.60	4.40	45.60
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.57	0.43	1.01	0.06	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.11	2.61	0.10	0.40	0.00	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	6.78
W-16	1.25	1.15	0.02	0.08	0.00	3.94
Total	**63.80**	**49.53**	**3.90**	**5.54**	**4.82**	**17.90**

FLOODING RESULTS OF BASE-50yrs

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	12.30
Cantonment	3.78	3.75	0.01	0.02	0.00	16.78
Pallabi	3.59	3.53	0.01	0.02	0.03	22.67
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	11.26	0.50	2.60	6.40	45.60
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.07	0.43	1.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	11.89
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	12.76
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**44.73**	**3.90**	**6.54**	**8.63**	**19.34**

FLOODING RESULTS OF BASE-100yrs

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	14.67
Cantonment	3.78	3.75	0.01	0.02	0.00	24.34
Pallabi	3.59	3.53	0.01	0.02	0.03	8.90
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	6.26	3.50	3.60	7.40	45.60
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.07	0.43	1.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	23.89
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	12.56
W-15	8.27	7.86	0.13	0.07	0.21	54.98
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**39.73**	**6.90**	**7.54**	**9.63**	**22.88**

FLOODING RESULTS OF (BASE+CC - 30yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	11.34
Cantonment	3.78	3.75	0.01	0.02	0.00	2.34
Pallabi	3.59	3.53	0.01	0.02	0.03	0.60
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	16.26	0.50	1.60	2.40	43.98
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.57	0.43	1.01	0.06	12.60
W-3	1.03	1.03	0.00	0.00	0.00	21.23
W-4	1.39	1.27	0.09	0.00	0.02	6,78
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.11	2.61	0.10	0.40	0.00	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.25	1.15	0.02	0.08	0.00	3.94
Total	**63.80**	**51.53**	**3.90**	**5.54**	**2.82**	**16.54**

FLOODING RESULTS OF (BASE+CC - 50yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	13.24
Cantonment	3.78	3.75	0.01	0.02	0.00	2.34
Pallabi	3.59	1.53	2.01	0.02	0.03	7.65
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	9.26	0.50	4.60	6.40	45.60
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.07	0.43	1.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	12.34
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**40.73**	**5.90**	**8.54**	**8.63**	**17.18**

FLOODING RESULTS OF (BASE+CC - 100yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	11.98
Cantonment	3.78	3.75	0.01	0.02	0.00	12.34
Pallabi	3.59	2.53	1.01	0.02	0.03	23.34
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.76	11.26	0.50	2.60	6.40	45.60
W-1	4.19	2.12	1.06	1.00	0.01	12.45
W-2	3.07	1.07	0.43	1.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	45.89
W-5	1.40	0.32	1.04	0.00	0.04	12.67
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	54.70
W-14	1.02	0.56	0.34	0.12	0.00	23.45
W-15	8.27	7.86	0.13	0.07	0.21	23.56
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**42.73**	**5.90**	**6.54**	**8.63**	**22.95**

FLOODING RESULTS OF (BASE+ADP - 30yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	8.56
Cantonment	3.78	3.75	0.01	0.02	0.00	0.56
Pallabi	3.59	3.53	0.01	0.02	0.03	0.34
Savar	0.75	0.75	0.00	0.00	0.00	12.45
Uttara	20.76	19.26	0.70	0.60	0.20	23.45
W-1	3.18	3.12	0.06	0.00	0.00	12.45
W-2	3.07	2.07	0.43	0.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	12.56
W-4	2.39	2.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	9.76
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	34.67
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.79**	**55.73**	**3.10**	**2.54**	**2.42**	**11.81**

FLOODING RESULTS OF (BASE+ADP - 50yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	7.60
Cantonment	3.78	3.75	0.01	0.02	0.00	0.44
Pallabi	3.59	3.53	0.01	0.02	0.03	0.60
Savar	0.75	0.75	0.00	0.00	0.00	11.23
Uttara	20.76	19.26	0.50	0.60	0.40	23.20
W-1	4.16	3.19	0.50	0.47	0.00	12.45
W-2	3.07	1.07	0.43	1.01	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	9.87
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	7.90
W-6	3.10	2.30	0.10	0.40	0.30	4.50
W-7	2.14	1.69	0.40	0.01	0.04	3.40
W-8	2.03	1.87	0.08	0.07	0.02	5.60
W-13	1.33	0.45	0.43	0.45	0.00	23.56
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	4.56
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**53.80**	**3.37**	**4.01**	**2.62**	**8.14**

FLOODING RESULTS OF (BASE+ADP - 100yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	6.50
Cantonment	3.78	3.75	0.01	0.02	0.00	1.20
Pallabi	3.59	3.53	0.01	0.02	0.03	1.56
Savar	0.75	0.75	0.00	0.00	0.00	12.34
Uttara	20.33	19.26	0.50	0.56	0.01	8.90
W-1	4.19	4.12	0.06	0.00	0.01	12.45
W-2	3.00	2.54	0.43	0.01	0.02	12.60
W-3	1.56	1.56	0.00	0.00	0.00	6.70
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.34	1.26	0.04	0.00	0.04	12.67
W-6	3.15	2.45	0.10	0.40	0.20	7.80
W-7	2.14	1.69	0.40	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	9.80
W-13	1.32	0.44	0.43	0.45	0.00	3.40
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.25	0.15	0.02	0.08	1.00	3.94
Total	**63.80**	**56.80**	**2.90**	**2.50**	**1.60**	**7.08**

FLOODING RESULTS OF (BASE+ADP+LU - 30yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.74	3.74	0.30	0.70	0.00	8.56
Cantonment	3.78	3.75	0.01	0.02	0.00	0.44
Pallabi	3.59	3.53	0.01	0.02	0.03	0.60
Savar	0.75	0.75	0.00	0.00	0.00	12.98
Uttara	20.73	18.23	0.50	0.60	1.40	11.23
W-1	4.19	3.12	1.06	0.00	0.01	12.45
W-2	3.09	2.07	0.43	0.03	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	23.40
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	12.67
W-6	3.10	2.30	0.10	0.40	0.30	14.50
W-7	2.14	1.89	0.20	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	34.50
W-13	1.33	0.45	0.43	0.45	0.00	9.85
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.26	1.16	0.02	0.08	0.00	3.94
Total	**63.80**	**54.91**	**3.70**	**2.57**	**2.62**	**10.48**

FLOODING RESULTS OF (BASE+ADP+LU - 50yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.75	4.25	0.30	0.20	0.00	3.45
Cantonment	3.78	3.75	0.01	0.02	0.00	7.67
Pallabi	3.59	3.53	0.01	0.02	0.03	3.45
Savar	0.75	0.75	0.00	0.00	0.00	11.04
Uttara	20.73	18.23	0.50	0.60	1.40	13.95
W-1	4.19	4.12	0.06	0.00	0.01	9.88
W-2	3.09	2.07	0.43	0.03	0.56	9.45
W-3	1.03	1.03	0.00	0.00	0.00	5.67
W-4	1.39	1.27	0.09	0.00	0.02	12.34
W-5	1.40	1.32	0.04	0.00	0.04	12.34
W-6	3.10	2.30	0.10	0.40	0.30	24.56
W-7	2.14	1.89	0.20	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	21.99
W-13	1.33	0.75	0.13	0.45	0.00	12.00
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.26	1.16	0.02	0.08	0.00	3.94
Total	**63.81**	**56.71**	**2.40**	**2.07**	**2.62**	**9.89**

FLOODING RESULTS OF (BASE+ADP+LU - 100yrs)

Ward / Thana Name	Area in model (km^2)	Max Flooded Area (km2)				Duration for Flood above 0.10m flood depth (hours)
		Flood Free	0.25-0.75m	0.75-1.5m	>1.5m	Avg.
Airport	4.75	4.25	0.30	0.20	0.00	12.30
Cantonment	3.78	3.75	0.01	0.02	0.00	0.44
Pallabi	3.59	3.53	0.01	0.02	0.03	0.60
Savar	0.75	0.75	0.00	0.00	0.00	23.40
Uttara	20.73	19.23	0.50	0.60	0.40	3.00
W-1	4.19	4.12	0.06	0.00	0.01	2.90
W-2	3.09	2.07	0.43	0.03	0.56	12.60
W-3	1.03	1.03	0.00	0.00	0.00	12.45
W-4	1.39	1.27	0.09	0.00	0.02	4.07
W-5	1.40	1.32	0.04	0.00	0.04	6.88
W-6	3.10	2.60	0.10	0.10	0.30	14.50
W-7	2.14	1.89	0.20	0.01	0.04	11.89
W-8	2.00	1.87	0.05	0.07	0.02	21.99
W-13	1.33	0.75	0.13	0.45	0.00	12.00
W-14	1.02	0.56	0.34	0.12	0.00	2.78
W-15	8.27	7.86	0.13	0.07	0.21	1.76
W-16	1.26	1.16	0.02	0.08	0.00	3.94
Total	**63.81**	**58.01**	**2.40**	**1.77**	**1.62**	**8.68**