



Government of the People's Republic of Bangladesh

Ministry of Housing and Public Works

Urban Development Directorate (UDD)

Preparation of Development Plan for Fourteen Upazilas

Package-04

(Saghata Upazila, District: Gaibandha; Sariakandi Upazila and
Sonatala Upazila, District: Bogra)

FINAL SURVEY REPORT

HYDROLOGICAL SURVEY

of

Saghata Upazila, Gaibandha

June, 2017



Modern Engineers Planners & Consultants Ltd.

Letter of Transmittal

Ref No.: MEPC/UDD/2017/64

Date: 04.06.2017

To

The Project Director

“Preparation of Development Plan for Fourteen Upazilas” Project

Urban Development Directorate (UDD)

82 Segun Bagicha, Dhaka-1000.

Subject: Submission of the Draft Hydrological Survey Report of Saghata Upazila, Gaibandha.

Dear Sir,

I have the pleasure to submit herewith the Draft Hydrological Survey Report of Saghata Upazila, Gaibandha District under “**Preparation of Development Plan for Fourteen Upazilas Project**” Package No: 04 (Saghata Upazila, District- Gaibandha; Sonatala Upazila and Sariakandi Upazila, District- Bogra) for your kind information and further action.

Thanking you and assuring you of our best services.

Best Regards

.....
(Engr. A. Sobahan)

Managing Director of MEPC

.....
(Shamim Mahabubul Haque)

Team Leader, Package-4

Executive Summary

This report is the result of hydrological survey data found during the hydrological survey works conducted at Saghata Upazila under Gaibandha district. The task is a part of the project, “Preparation of Development Plan for Fourteen Upazilas”, Package-4. Bathymetric survey of Bangali River and Alai River at Saghata Upazila has been conducted. During rest of the survey works, information regarding any existing water control structure, river crossings etc. were collected. The detailed survey data of the existing drains within the township is also the part of the project. Information about water logging zones or water logging points were also collected along with the existing drainage systems. Cross sections were surveyed at the locations of the existing structures on the rivers, at junctions with and of other channels or rivers for the natural perennial channels. Sizes of the drains were charted at starting locations, junctions and end points. Measurements of the reduced levels of the existing ground at those locations were also included. Dumpy levels were used to measure the reduced levels on the field. The levels were measured with respect to nearby benchmarks or temporary benchmarks of authorized organizations like Bangladesh Water Development Board, Public Works Department, Roads and Highways Department, Local Government Engineering Department, etc. Data of the GPS locations at each BM/TBM location, at the point of start of each cross section, at any structure location and at all the control points of the drains were recorded. Some other data as like as flow directions, channel names, presence of tidal effects etc. were also collected. The information will be incorporated with the DEM on GIS and if needed, adjusted according to the established GCPs. Any sort of numerical watershed analysis and hence extrapolate a prediction for the future can be done from the report. This report also presents the analyzed data of water level gauge stations, the rainfall data analysis and the project site data deduced from them.

Table of Contents

	Page No.
Letter of Transmittal	i
Executive Summary	ii
Table of Contents	iii
List of Tables	iv
List of Figures	iv
List of Maps	v
List of Plates	v
List of Abbreviations/Acronyms	vi
 CHAPTER ONE: INTRODUCTION	 1
1.1 Background of the Study	1
 CHAPTER TWO: METHODOLOGY	 4
2.0 Survey Method	4
2.1 Measuring Reduced Levels	4
2.2 Identification of Location	5
2.3 Data Collection	5
 CHAPTER THREE: PRESENT LAND USED	 7
3.0 Survey Results	7
3.1 Survey of Main Rivers	7
3.2 Dependencies	7
3.3 Survey of the Existing Drainage Systems	10
3.4 Samples of Collected Data	10
 CHAPTER FOUR: HYDROLOGIC DATA ANALYSIS	 13
4.0 Analysis of Hydrological Data	13
4.1 Estimation of Design Discharge and Water Level	13
4.2 Frequency Analysis	14
4.3 Analytical Frequency Analysis	14
4.3.1 Extreme Value Distributions	15
4.3.2 Frequency Analysis using Frequency Factors	16
4.3.3 Goodness of Fit Test	18
4.4 Disaggregation of Daily Rainfall Data	19
4.4.1 Rainfall Cascade Disaggregation Model	19

	Page No.
CHAPTER FIVE: DESIGNING STORM SEWER	21
5.0 Capacity Estimate and Designing Drain Sections (Prismatic)	21
5.1 Manning's Formula	21
CHAPTER SIX: CONCLUSION	25
6.0 Conclusion	25
REFERENCES/BIBLIOGRAPHY	26
ANNEXURE	30
Annexure-I (a)	31
Annexure-I (b)	37
Annexure-II: Instructions to Surveyors	44
Annexure-III: Comments and Corrections of TMC Meeting dated on 07.06.2017	48

List of Tables

	Page No.
Table 3.1 : Sample of Collected water level data of BWDB station SW 46, SW 46.9R and SW 97	11
Table 3.2 : Sample of Collected water level and discharge data of BWDB station SW 155 and rainfall data of BWDB station CL 156	12
Table 5.1 : Manning's N For Channels (Chow 1951)	21

List of Figures

	Page No.
Figure 1.1 : An integrated 1D-2D flood model on a flood plain showing flood conditions at different water level and flow time using Mike Flood (DHI)	2
Figure 1.2 : An integrated 1D-2D flood model showing flood conditions in a city area using HEC-RAS	2
Figure 1.3 : Model developed using EPA SWMM simulating undeveloped (left) and developed (right) conditions to calculate and compare the difference of discharge	2
Figure 2.1 : A Dumpy level establishes a horizontal plane to measure the relative elevation differences throughout a project area. A hand GPS is used to get the location of the base	4

Page No.

- Figure 3.1 : Cross-Section of Banglai River at Chainage of N=2770886.00m and E=755022.1m as surveyed. 10
- Figure 3.2 : Cross-Section of Banglai River at Chainage of N=2778621.55m and E=753067.78m as surveyed. 11
- Figure 3.3 : Cross-Section of Banglai River at Chainage of N=27936514.93m and E=757080.93m as surveyed. 12
- Figure 3.4 : Locations of BWDB Water Level, Discharge and Rainfall gauge stations in and around Saghata, Gaibandha, of which the data has been collected (SW 46, SW 46.9R, SW 97, SW 155, CL 156) 13

List of Maps

Page No.

- Map 3.1 : Map Showing The Main Drainage Channels As Identified At Saghata Upazila Under Gaibandha District 8
- Map 3.2 : Map Showing The Main Drainage Channels As Identified At Saghata Upazila Under Gaibandha District 9

List of Plates

Page No.

- Plate 2.1 : Mahimaganj Railway Bridge over Katakhal (Bangali) River 5
- Plate 2.2 : The confluence point of Alai River and Katakhal (Bangali) River near Ramnagar Bazar 5
- Plate 2.3 : Hydrologist is collecting data and talking to local people. 6

List of Abbreviations/Acronyms

GIS	Geographical Information System
BADC	Bangladesh Agricultural Development Corporation
BM	Benchmark
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
DEM	Digital Elevation Model
EGL	Existing Ground Level
EPA SWMM	The United States Environmental Protection Agency (EPA) Storm Water Management Model (SWMM)
EV I	The first asymptotic distribution of extreme values
GCP	Ground Control Point
GPS	Global Positioning System
HEC-HMS	The Hydrologic Modeling System is designed to simulate the precipitation runoff processes of dendritic drainage basins. HEC-HMS is a product of the Hydrologic Engineering Center within the U.S. Army Corps of Engineers.
HEC-RAS	A computer program that models the hydraulics of water flow through natural rivers and other channels developed by the US Department of Defense, Army Corps of Engineers.
HFL	Highest Flood Level
IDF	Intensity Duration Frequency
L/B	Left bank
LFL	Lowest Flood Level
LGED	Local Government Engineering Department
mPWD	RL found against a PWD benchmark in meters
PWD	Public Works Department
R/B	Right Bank
RHD	Roads and Highway Department
RL	Reduced Level
TBM	Temporary Benchmark
UDD	Urban Development Directorate
MEPC	Modern Engineers Planners and Consultant

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Urban Development Directorate, Ministry of Housing and Public Works, Government of Bangladesh initiates the project, “Preparation of Development Plan for Fourteen Upazilas”. The goal of the project is upgrading the living standard of the local people. The Bangali River, which is locally called Katakhalī River, is the main drainage channel in the area. Numerous unnamed small channels and water courses carry water from the adjacent low areas and discharges into this river. Alai River flows in from Gaibandha and falls into the Katakhalī (Bangali) River near Ramnagar Bazar. Although The Jamuna River is close by, there is no connection between the Jamuna River and Katakhalī (Bangali) River. The banks of Jamuna are protected by flood protection embankments and protective works. If the flood embankment works do not breach, the area only faces moderate flooding during monsoon. Normally, the highest level of monsoon flood sustains for a month or two and then subsides. Because of the flood plain mechanism the slope of the land here is towards Katakhalī (Bangali) and Alai River, making them the major drainage channels. The drainage system is insufficient in the urban areas. To solve this problem understand flooding conditions, identify the water logging areas and establish the drainage requirements is necessary. This can be performed by a Flood Modeling Software. The efficiency of the existing and proposed drainage system can be analyzed using the same model.

One aspect of this Hydrological Survey is the bathymetric survey of the Katakhalī River and Alai River to provide bathymetric information. Since the Jamuna River is severed by the flood embankments and protective works from the watersheds of Katakhalī and Alai River, bathymetric survey of that river is not necessary. During bathymetric survey, information regarding any hydraulic structure is collected. The data found in the field will be incorporated in DEM through “Burning” process”. Using this the surface water flow to assess flood through flood modeling software will be analyzed. It is required to assess the flood conditions during different time period and season against different water levels and discharge (Sample results shown in Figure 1.1 and Figure 1.2). This type of analysis will be helpful for preparation of effective and long lasting development plans for this Upazila. Hence, accuracy of the analysis is of prime importance. If the actual cross-section of the river or channel is not obtained, the analysis will be faulty and will overstate the flood.

Discharge and rainfall data of the vicinity have been collected from secondary source and analyzed. Water level data of BWDB gauge stations SW 46 at Kamarjani, SW 46.9R at Fulchhari, SW 97 at Gaibandha and SW 155 at Mahimganj Railway Crossing have been

collected. The rainfall data of the station CL 156 at Gaibandha has been collected. The water level, discharge and rainfall data for different return period will be obtained analyzing the data.

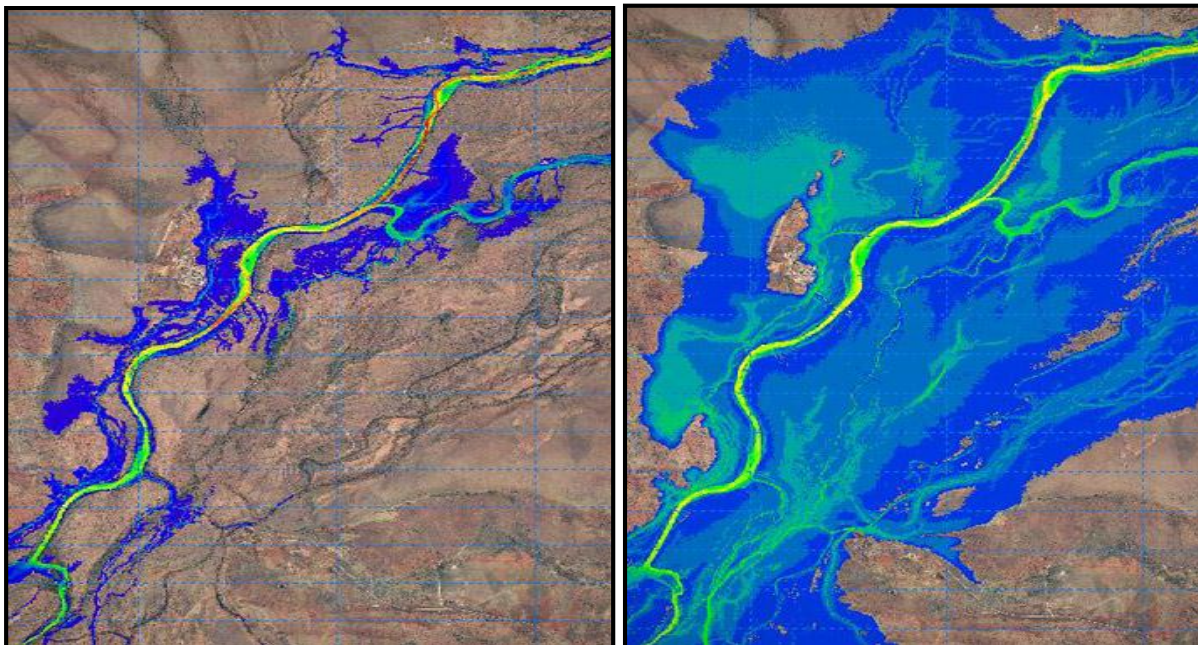


Figure 1.1: An integrated 1D-2D flood model on a flood plain showing flood conditions at different water level and flow time using Mike Flood (DHI)

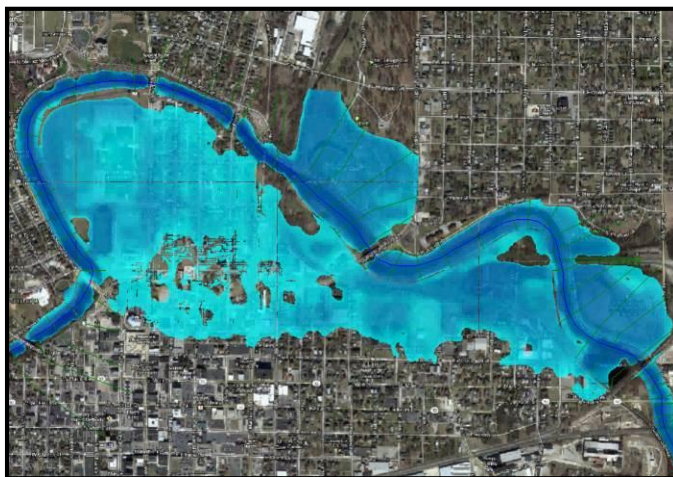


Figure 1.2: An integrated 1D-2D flood model showing flood conditions in a city area using HEC-RAS

Understanding the water logging problems within the town area and proposing a comprehensive drainage system is another aspect of the survey. Assessment of capacity and utility of any existing drainage system and planning drains is required. Information of the existing drains in Saghata have been collected which includes depth, width and EGL at the junction points of the drains. 3-hourly rainfall data, collected from Goddard Earth Sciences Data and Information Service Center, will be used to prepare the hourly rainfall data or the intensity duration

frequency (IDF) curve for designing storm sewer system. This will be used to assess the capacity of the existing drainage system and in designing the proposed drainage system (Figure 1.3).

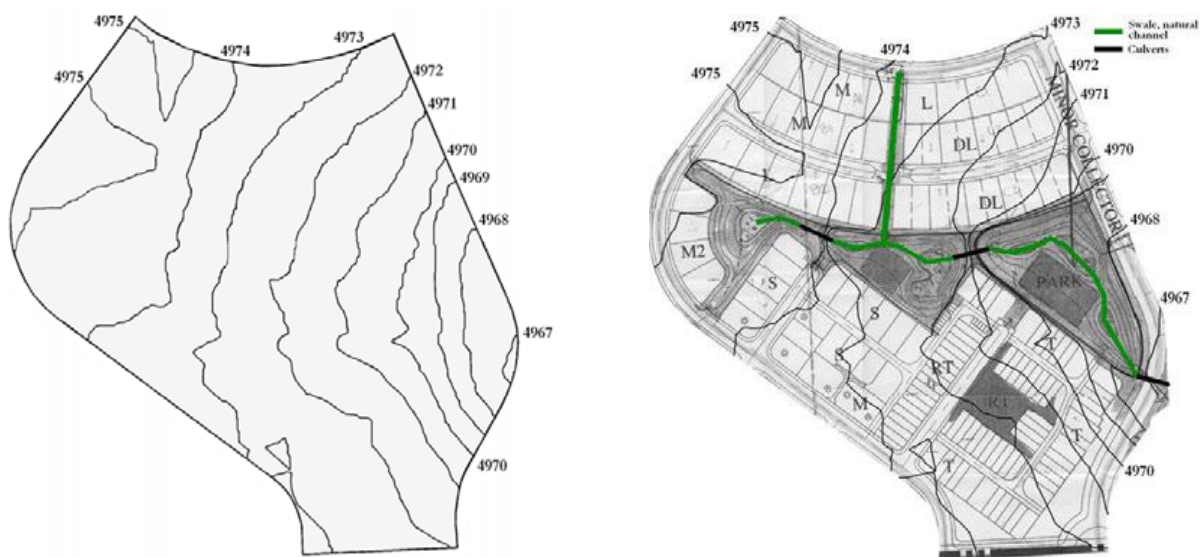


Figure 1.3: Model developed using EPA SWMM simulating undeveloped (left) and developed (right) conditions to calculate and compare the difference of discharge

With the above in view, the overall objectives of the survey are as listed below:

- Bathymetric survey of Bangali River.
- Identification of hydraulic structures and collecting information regarding capacity and sill levels of the structures.
- Identification of flood hazard locations.
- Identification of flow directions.
- Collection of observed flood levels in the field.
- Collecting information of any existing drainage system.
- Identification of water logging zones.
- Collecting information regarding encroachments of natural water bodies and drains.
- Collection of water level, discharge and rainfall data from secondary sources.

The analyses of the collected water level data done using EV I distribution are added in Annexure- I (b). The Rest of the analysis using the Normal distribution, Log normal distribution and Log Pearson III distribution along with the goodness of fit analysis will be added in the final planning report of the project, “Preparation of Development Plan for Fourteen Upazilas”.

CHAPTER TWO: METHODOLOGY

2.0 Survey Method

2.1 Measuring Reduced Levels

To measure the reduced levels, dumpy levels and 5m staffs were used. In case of rivers, the levels were measured with respect to the nearest known benchmarks of Bangladesh Water Development Board or temporary benchmarks of any authorized government organizations viz., Roads and Highways Department or Local Government Engineering Department etc. After establishing a horizontal line of collimation/line of sight with respect to a BM/TBM, staff readings are taken within the range of visibility of the dumpy level. For any reading beyond the visibility range, the dumpy level needs a change of station. A temporary benchmark is established and further measurements are made with respect to that. In case of a change of level of more than the height of the staff (5m generally), the levelling machine needs to be shifted and setup again. Subtracting the level of line of sight from the staff readings provides the reduced levels at the point concerned. In Figure 2.1, a schematic diagram of survey method using Dumpy Levels is shown. In Plate 2.1 and Plate 2.2, a dumpy level, a 5m staff and a view of the cross-hair is shown.

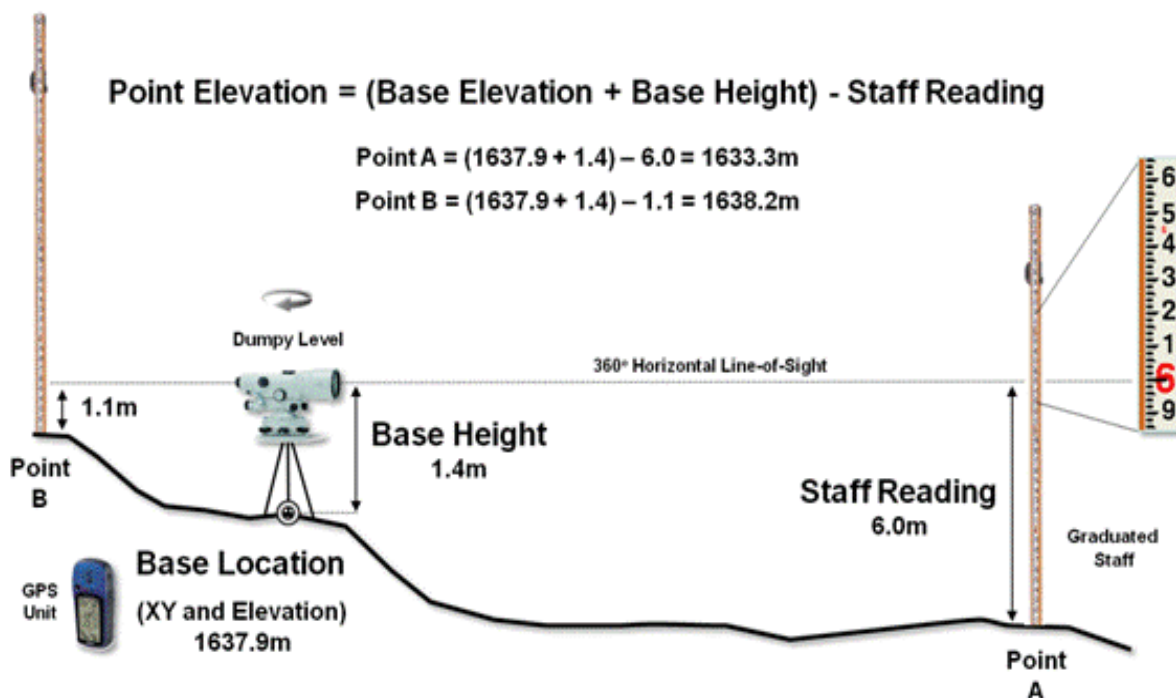


Figure 2.1: A Dumpy level establishes a horizontal plane to measure the relative elevation differences throughout a project area. A hand GPS is used to get the location of the base

2.2 Identification of Location

A hand GPS was used to identify the location of the cross-sections, structures, drain control points etc.

2.3 Data Collection

Information of the water control structures of that area were collected from responsible government organizations regarding water resources development. The three government organizations that are active in the area are Bangladesh Water Development Board (BWDB), Local Government Engineering Department (LGED) and Bangladesh Agricultural Development Corporation (BADC). Key information of the structures about invert level, number and size of vents etc. were collected.

Plate 2.1 Shows Mahimaganj Railway Bridge over Katakali (Bangali) River on which BWDB station SW 155 is established. Plate 2.2 shows the confluence point of Alai River and Katakali (Bangali) River near Ramnagar Bazar.

	
Source: Field Survey, 2015	Source: Field Survey, 2015
Plate 2.1: Mahimaganj Railway Bridge over Katakali (Bangali) River	Plate 2.2: the confluence point of Alai River and Katakali (Bangali) River near Ramnagar Bazar

To identify locations that are prone to flood hazards or water logging problems, questionnaire was prepared and information was collected accordingly. The questionnaire is attached to Annexure-II. During the engineering survey, information like highest and normal flood levels, highest tide levels and lowest tide levels were collected from the local farmers, fishermen or boatmen.

As for the secondary data, water level data of the gauge stations SW 46, SW 46.9R, SW 97 and SW 155 of Bangladesh water development are collected. Daily Rainfall data of BWDB gauge CL 156 has also been collected.



Source: Field Survey, 2016

Plate 2.3: Hydrologist is Collecting Data and Talking to Local People

CHAPTER THREE: FINDINGS OF SURVEY WORKS

3.0 Survey Results

3.1 Survey of Main Rivers

The bathymetric survey of the Katakhal (Bangali) River and Alai River has been completed, in addition to that, Bangali River being a very big river makes survey works during rainy season complicated. The locations of cross-sections to be taken are shown in Map 3.2. Cross-sections have been prepared using the reduced levels obtained in the field against Bangladesh Water Development Board benchmarks. Later, when the photogrammetric images will be processed, the cross-sections will be converted to MSL datum. During the physical feature survey, information about hydraulic structures on the rivers and along the banks of the rivers has already been collected.

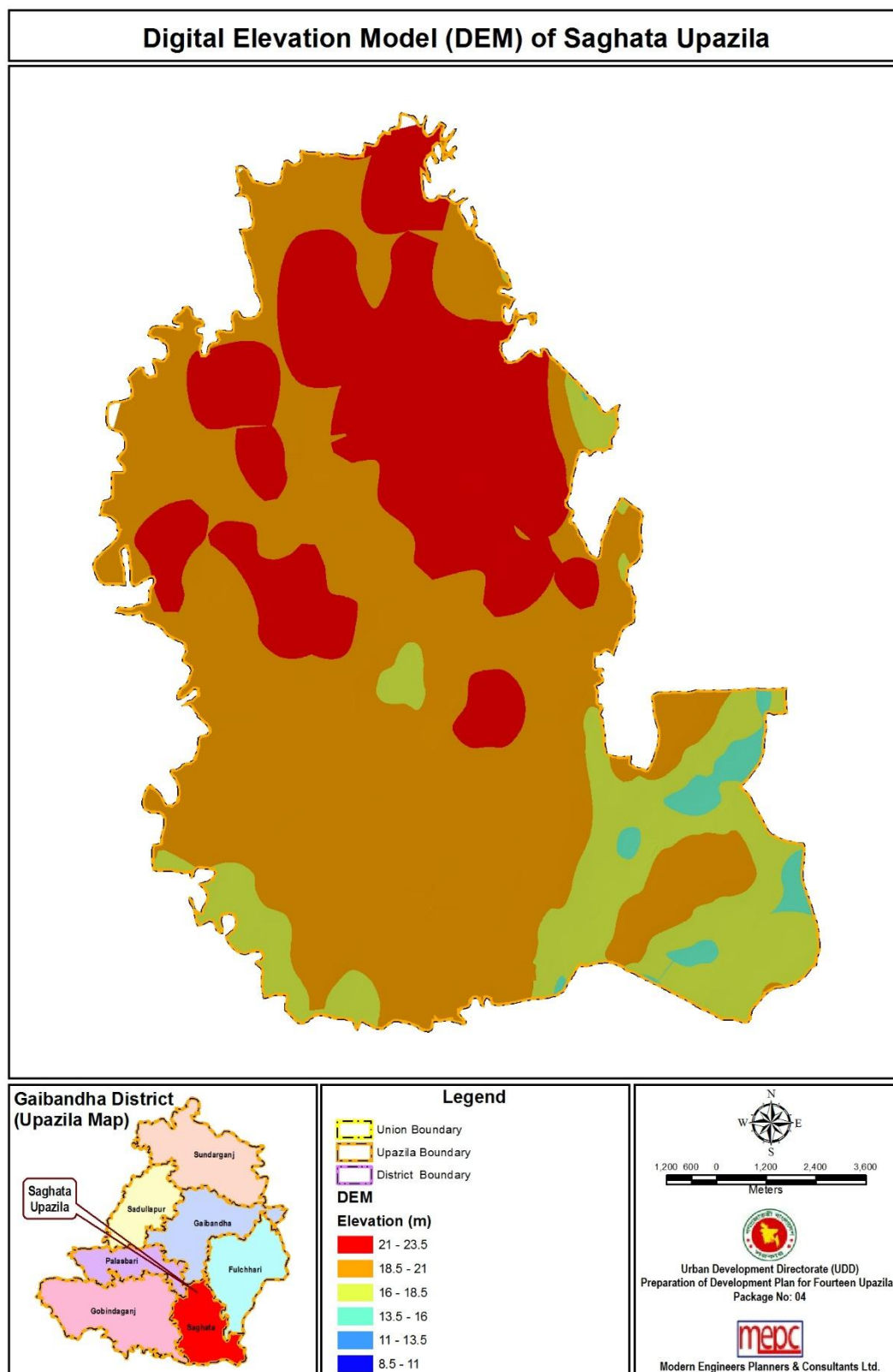
3.2 Dependencies

The hydrological works are dependent upon the land use survey, topographic survey and physical feature survey for the respective outcomes of those survey works done under this project. During Physical feature survey, information regarding hydraulic structures has been collected. The local offices of Government Agencies like BWDB, BADC and LGED have been contacted to get data about any irrigation projects or drainage projects that is either currently being operated or being planned by them. The responses of the local populace have been inquired to understand their attitude towards those projects.

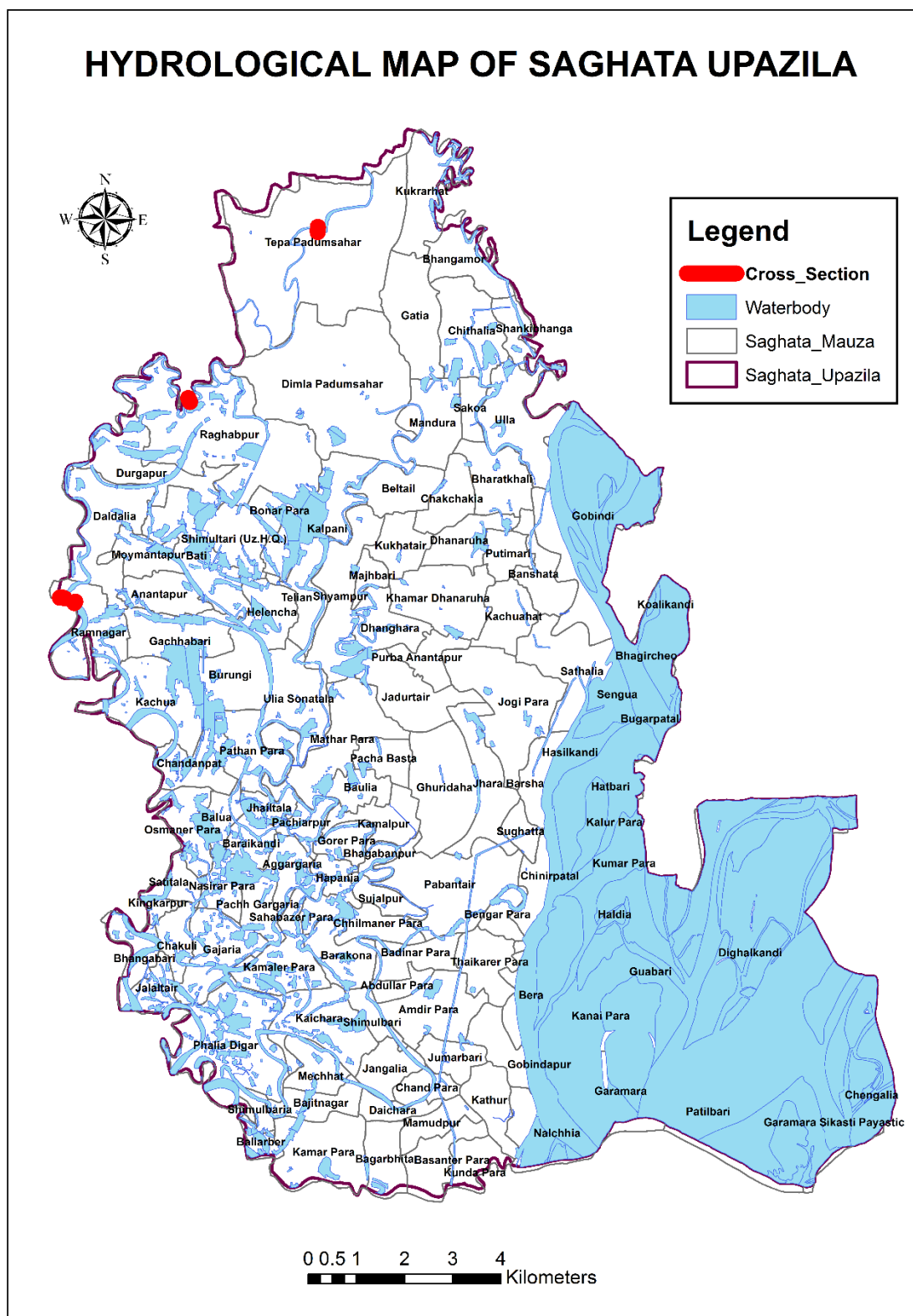
The land use survey will be required to prepare the rainfall runoff model for Saghata. Depending upon the use of land, the runoff over a certain segment of land will vary. On a surface exhibiting vegetation, the rainwater shall be impeded from reaching any natural or man-made drainage system. A portion of the precipitation will be intercepted by the canopy before the rain water can reach the ground, also the infiltration rate will be high. All these factors prevent the accumulation of rain water and thus reduce runoff. On the other hand, on a buildup area, much of the vegetation is gone and the land is more or less covered with impervious construction. Interception and infiltration hence reduces, resulting in an increase in net runoff.

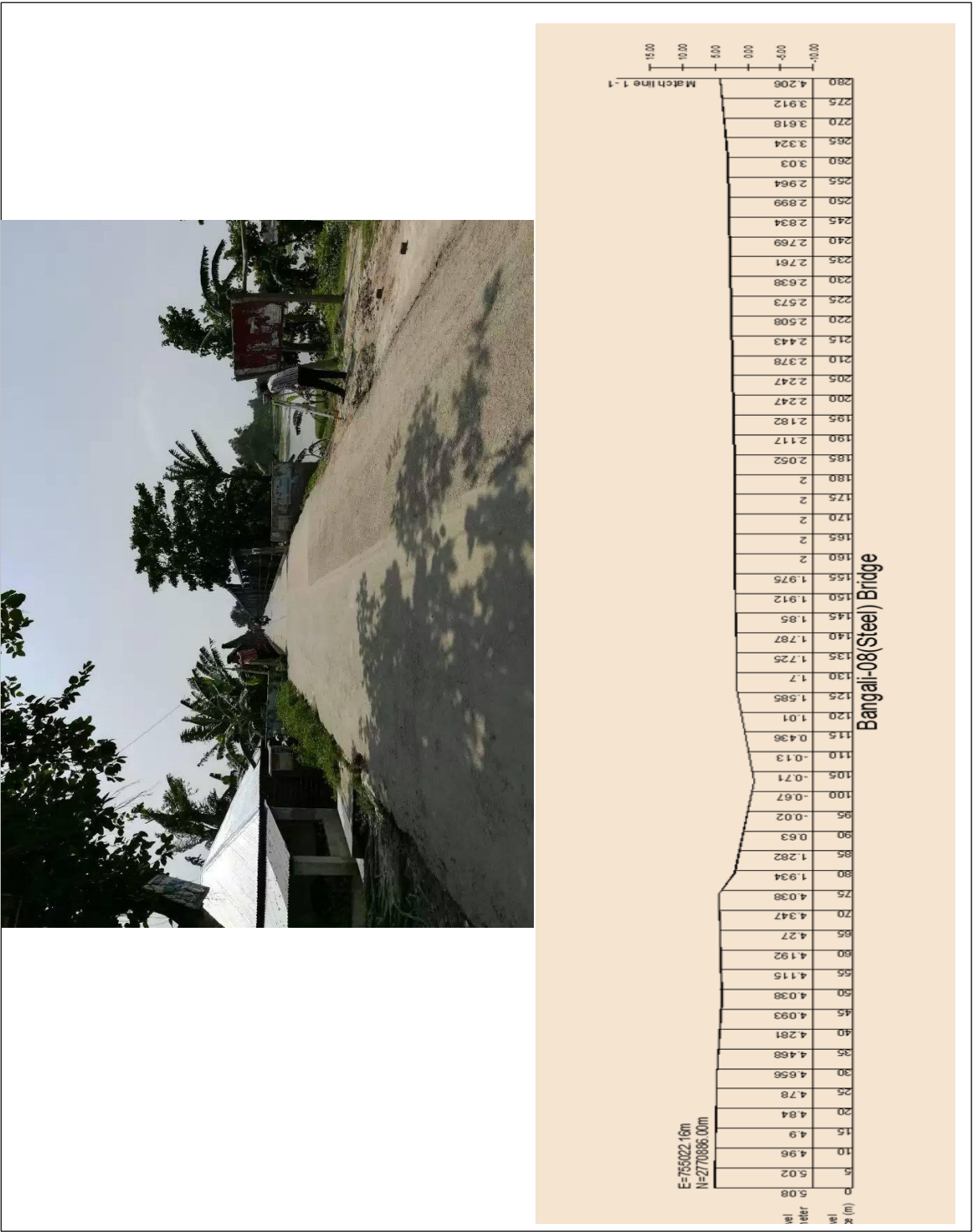
Topographic survey is required to understand the undulations on the ground surface. On a steep slope, the water flows quicker towards drainage bodies which are vice versa for a flat land. The digital 3D stereo imageries that have been collected as a measure of the survey works will be used to prepare a Digital Elevation Model (DEM) of the land.

**Map 3.1: Map showing the main drainage channels as identified at Saghata Upazila
under Gaibandha District**



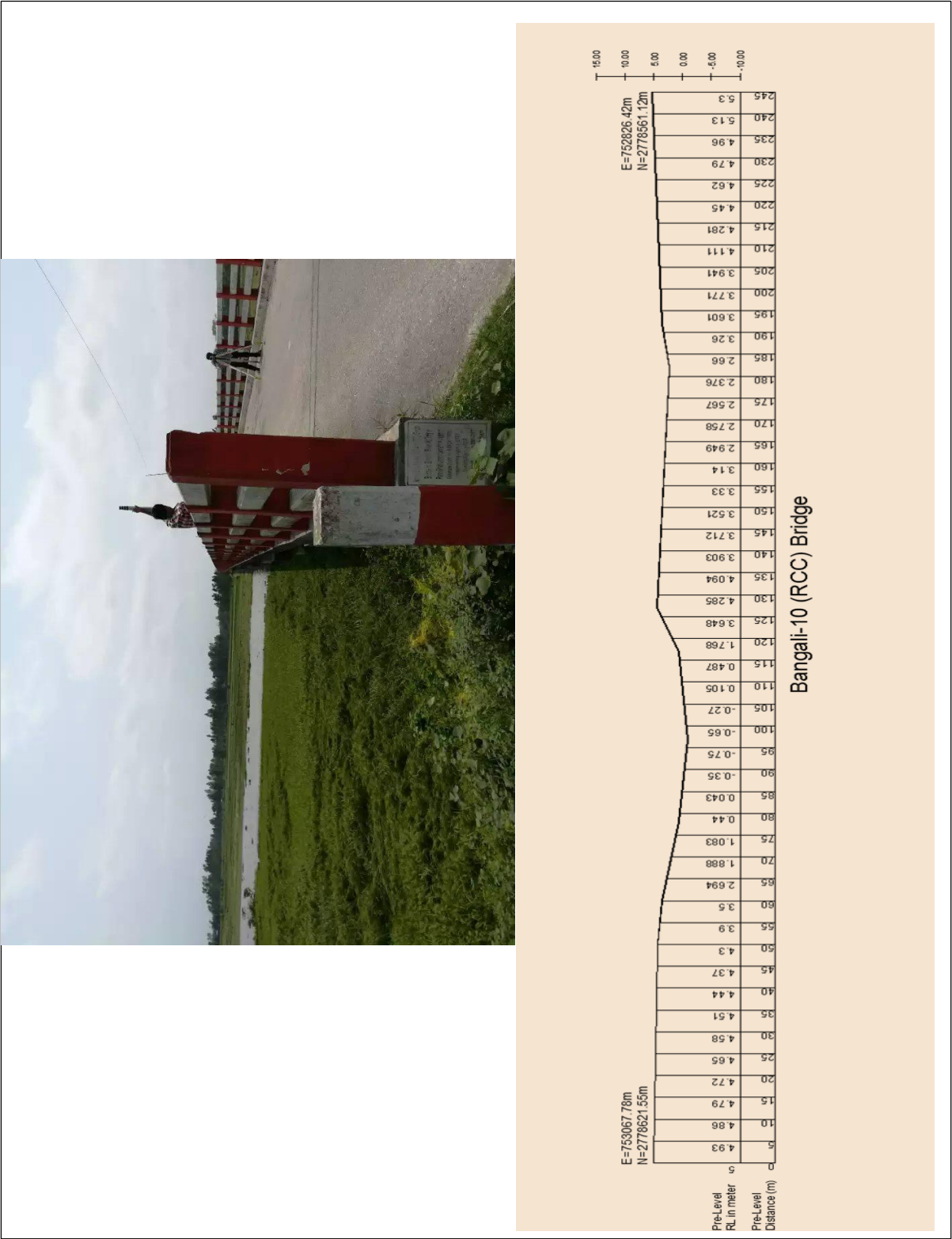
**Map 3.2: Map Showing the Main Drainage Channels as Identified at Saghata Upazila
under Gaibandha District**





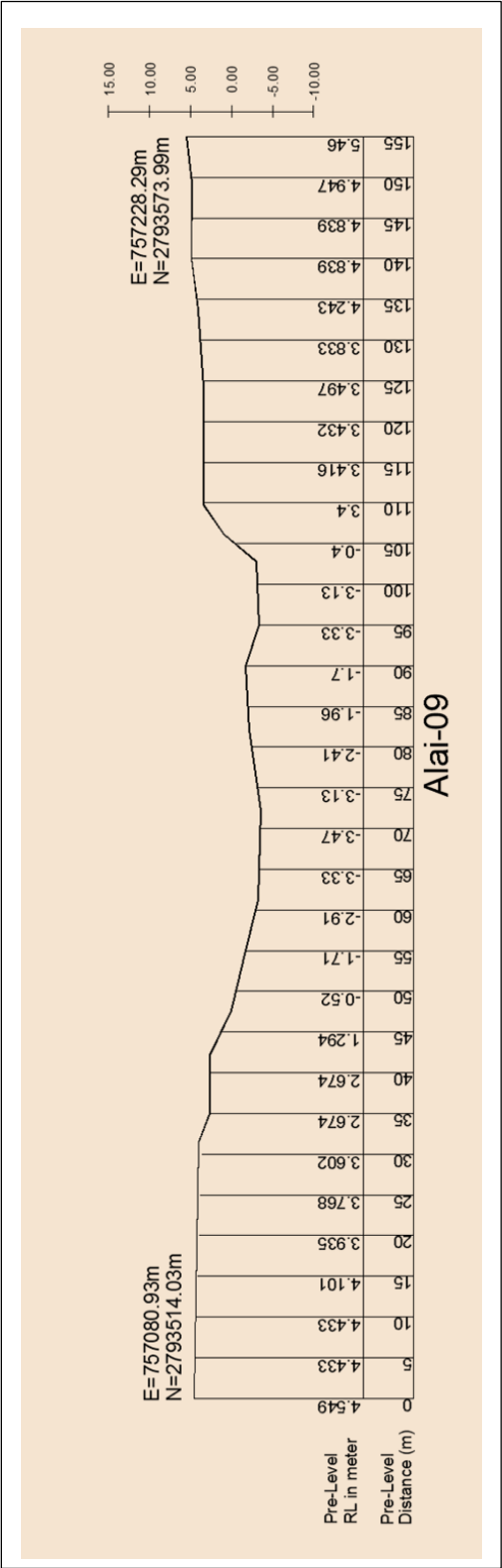
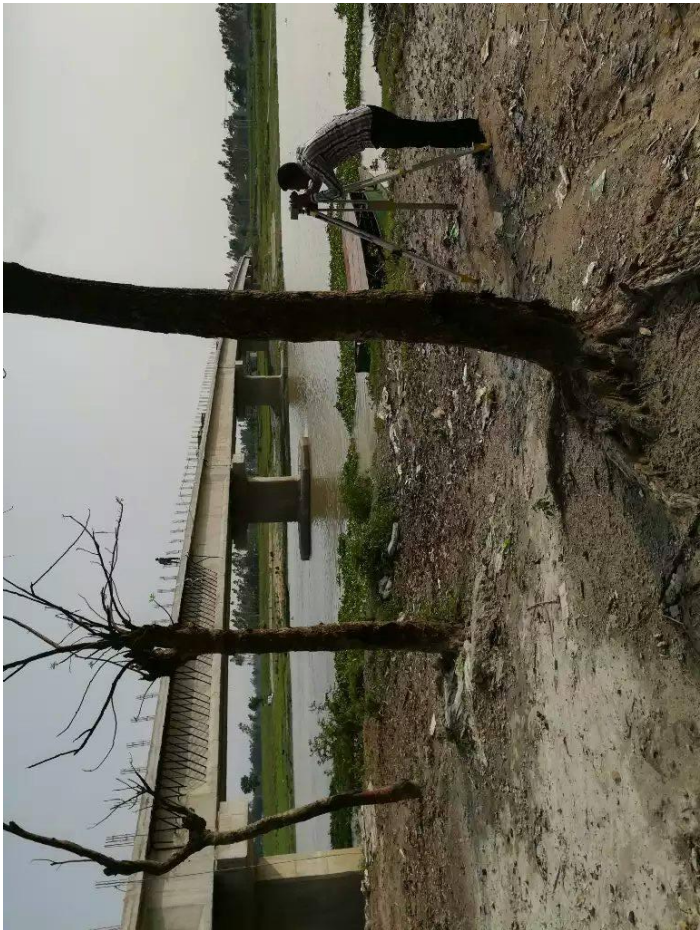
Source: Field Survey, 2017

Figure 3.1: Cross-Section of Banglai River at Chainage of N=2770886.00m and E=755022.1m as Surveyed



Source: Field Survey, 2017

Figure 3.2: Cross-Section of Banglai River at Chainage of N=2778621.55m and E=753067.78m as Surveyed



Source: Field Survey, 2017

Figure 3.3: Cross-Section of Banglai River at Chainage of N=27936514.93m and E=757080.93m as Surveyed

3.3 Survey of the Existing Drainage Systems

Information of existing drains at Saghata regarding depth and width, RL and GPS locations at different junction points, starting points and ending points are obtained. Names of roads alongside the drains are also collected. Lining conditions (Lined or Unlined) of the existing drains have been identified during the survey. This information would be used to prepare a drainage inventory to assess the capacity of the existing drainage system and with a view to that; a drainage improvement plan will be prepared.

3.4 Samples of Collected Data

The BWDB Water Level, Discharge and Rainfall gauge stations of which the data has been collected are shown on Figure 3.4. The sample data are charted on Table 3.1 and 3.2.

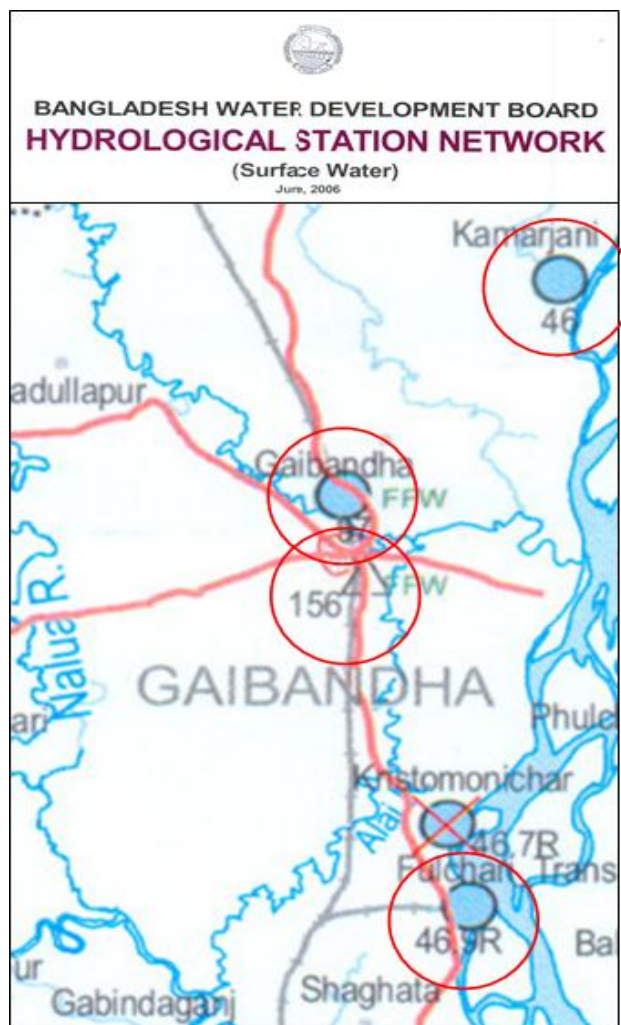


Figure 3.4: Locations of BWDB Water Level, Discharge and Rainfall gauge stations in and around Saghata, Gaibandha, of which the data has been collected (SW 46, SW 46.9R, SW 97, SW 155, CL 156)

Table 3.1: Sample of Collected water level data of BWDB station SW 46, SW 46.9R and SW 97

RiverName	StationName	StationID	Date	MDWL	RIVER_NAME	StationID	Station Name	Date	MDWL	RiverName	StationName	StationID	Date	MDWL
Brahmaputra-Jamuna	Kamarjani	SW46	01-01-81	16.05	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	01-04-2003	13.19	Ghagot	Gaibandha	SW97	01-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	02-01-81	16.03	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	02-04-2003	13.20	Ghagot	Gaibandha	SW97	02-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	03-01-81	16.01	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	03-04-2003	13.20	Ghagot	Gaibandha	SW97	03-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	04-01-81	16.00	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	04-04-2003	13.22	Ghagot	Gaibandha	SW97	04-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	05-01-81	15.98	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	05-04-2003	13.26	Ghagot	Gaibandha	SW97	05-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	06-01-81	15.98	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	06-04-2003	13.28	Ghagot	Gaibandha	SW97	06-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	07-01-81	15.97	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	07-04-2003	13.31	Ghagot	Gaibandha	SW97	07-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	08-01-81	15.97	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	08-04-2003	13.31	Ghagot	Gaibandha	SW97	08-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	09-01-81	15.95	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	09-04-2003	13.34	Ghagot	Gaibandha	SW97	09-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	10-01-81	15.95	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	10-04-2003	13.39	Ghagot	Gaibandha	SW97	10-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	11-01-81	15.94	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	11-04-2003	13.52	Ghagot	Gaibandha	SW97	11-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	12-01-81	15.94	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	12-04-2003	13.63	Ghagot	Gaibandha	SW97	12-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	13-01-81	15.93	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	13-04-2003	13.64	Ghagot	Gaibandha	SW97	13-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	14-01-81	15.93	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	14-04-2003	13.68	Ghagot	Gaibandha	SW97	14-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	15-01-81	15.90	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	15-04-2003	13.73	Ghagot	Gaibandha	SW97	15-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	16-01-81	15.88	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	16-04-2003	13.79	Ghagot	Gaibandha	SW97	16-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	17-01-81	15.86	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	17-04-2003	13.83	Ghagot	Gaibandha	SW97	17-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	18-01-81	15.85	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	18-04-2003	13.90	Ghagot	Gaibandha	SW97	18-01-81	18.36
Brahmaputra-Jamuna	Kamarjani	SW46	19-01-81	15.84	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	19-04-2003	14.00	Ghagot	Gaibandha	SW97	19-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	20-01-81	15.82	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	20-04-2003	14.21	Ghagot	Gaibandha	SW97	20-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	21-01-81	15.81	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	21-04-2003	14.29	Ghagot	Gaibandha	SW97	21-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	22-01-81	15.79	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	22-04-2003	14.43	Ghagot	Gaibandha	SW97	22-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	23-01-81	15.77	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	23-04-2003	14.52	Ghagot	Gaibandha	SW97	23-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	24-01-81	15.76	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	24-04-2003	14.66	Ghagot	Gaibandha	SW97	24-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	25-01-81	15.74	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	25-04-2003	14.88	Ghagot	Gaibandha	SW97	25-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	26-01-81	15.73	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	26-04-2003	15.00	Ghagot	Gaibandha	SW97	26-01-81	18.35
Brahmaputra-Jamuna	Kamarjani	SW46	27-01-81	15.71	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	27-04-2003	15.04	Ghagot	Gaibandha	SW97	27-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	28-01-81	15.69	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	28-04-2003	15.08	Ghagot	Gaibandha	SW97	28-01-81	18.33
Brahmaputra-Jamuna	Kamarjani	SW46	29-01-81	15.68	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	29-04-2003	15.26	Ghagot	Gaibandha	SW97	29-01-81	18.32
Brahmaputra-Jamuna	Kamarjani	SW46	30-01-81	15.68	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	30-04-2003	15.39	Ghagot	Gaibandha	SW97	30-01-81	18.32
Brahmaputra-Jamuna	Kamarjani	SW46	31-01-81	15.66	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	01-05-2003	15.22	Ghagot	Gaibandha	SW97	31-01-81	18.32
Brahmaputra-Jamuna	Kamarjani	SW46	01-02-81	15.66	Brahmaputra-Jamuna	SW46.9R	Fulchari_Transit	02-05-2003	15.15	Ghagot	Gaibandha	SW97	01-02-81	18.31

Table 3.2: Sample of Collected water level and discharge data of BWDB station SW 155 and rainfall data of BWDB station CL 156

RiverName	StationName	StationID	Date	MDWL	RIVER_NAME	Station_ID	Name	Date	WL(m)	Disch.(m) ³ /s	Max_Vel	District	StationID	StationName	DateTime	Rainfall
Katakhal	Mohimaganj Railway Crossi	SW155	01-01-81	14.69	Katakhal	SW155	Mohimaganj Railway Crossi	11-01-1990	14.73	42.50		Gaibandha	CL156	Gaibandha(Bhawaniganj)	01-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	02-01-81	14.69	Katakhal	SW155	Mohimaganj Railway Crossi	29-01-1990	14.64	40.40		Gaibandha	CL156	Gaibandha(Bhawaniganj)	02-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	03-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	08-02-1990	14.54	37.90		Gaibandha	CL156	Gaibandha(Bhawaniganj)	03-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	04-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	22-02-1990	14.43	34.70		Gaibandha	CL156	Gaibandha(Bhawaniganj)	04-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	05-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	08-03-1990	14.26	31.80		Gaibandha	CL156	Gaibandha(Bhawaniganj)	05-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	06-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	23-03-1990	14.17	30.50		Gaibandha	CL156	Gaibandha(Bhawaniganj)	06-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	07-01-81	14.69	Katakhal	SW155	Mohimaganj Railway Crossi	04-04-1990	14.15	29.60		Gaibandha	CL156	Gaibandha(Bhawaniganj)	07-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	08-01-81	14.71	Katakhal	SW155	Mohimaganj Railway Crossi	18-04-1990	14.19	30.60		Gaibandha	CL156	Gaibandha(Bhawaniganj)	08-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	09-01-81	14.72	Katakhal	SW155	Mohimaganj Railway Crossi	02-05-1990	14.28	32.50		Gaibandha	CL156	Gaibandha(Bhawaniganj)	09-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	10-01-81	14.72	Katakhal	SW155	Mohimaganj Railway Crossi	16-05-1990	14.95	85.80		Gaibandha	CL156	Gaibandha(Bhawaniganj)	10-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	11-01-81	14.72	Katakhal	SW155	Mohimaganj Railway Crossi	30-05-1990	15.82	117.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	11-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	12-01-81	14.70	Katakhal	SW155	Mohimaganj Railway Crossi	13-06-1990	17.26	237.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	12-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	13-01-81	14.69	Katakhal	SW155	Mohimaganj Railway Crossi	27-06-1990	17.31	235.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	13-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	14-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	12-07-1990	17.77	285.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	14-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	15-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	25-07-1990	17.67	267.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	15-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	16-01-81	14.68	Katakhal	SW155	Mohimaganj Railway Crossi	09-08-1990	17.38	225.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	16-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	17-01-81	14.66	Katakhal	SW155	Mohimaganj Railway Crossi	22-08-1990	17.34	199.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	17-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	18-01-81	14.66	Katakhal	SW155	Mohimaganj Railway Crossi	08-09-1990	16.93	146.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	18-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	19-01-81	14.65	Katakhal	SW155	Mohimaganj Railway Crossi	19-09-1990	16.64	85.20		Gaibandha	CL156	Gaibandha(Bhawaniganj)	19-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	20-01-81	14.63	Katakhal	SW155	Mohimaganj Railway Crossi	04-10-1990	17.55	250.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	20-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	21-01-81	14.63	Katakhal	SW155	Mohimaganj Railway Crossi	17-10-1990	18.44	454.00	1.00	Gaibandha	CL156	Gaibandha(Bhawaniganj)	21-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	22-01-81	14.63	Katakhal	SW155	Mohimaganj Railway Crossi	31-10-1990	16.45	105.00		Gaibandha	CL156	Gaibandha(Bhawaniganj)	22-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	23-01-81	14.61	Katakhal	SW155	Mohimaganj Railway Crossi	15-11-1990	15.20	98.30		Gaibandha	CL156	Gaibandha(Bhawaniganj)	23-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	24-01-81	14.61	Katakhal	SW155	Mohimaganj Railway Crossi	28-11-1990	15.03	87.80		Gaibandha	CL156	Gaibandha(Bhawaniganj)	24-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	25-01-81	14.61	Katakhal	SW155	Mohimaganj Railway Crossi	12-12-1990	14.89	68.40		Gaibandha	CL156	Gaibandha(Bhawaniganj)	25-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	26-01-81	14.61	Katakhal	SW155	Mohimaganj Railway Crossi	26-12-1990	14.80	60.50		Gaibandha	CL156	Gaibandha(Bhawaniganj)	26-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	27-01-81	14.61	Katakhal	SW155	Mohimaganj Railway Crossi	23-01-1991	14.69	50.10		Gaibandha	CL156	Gaibandha(Bhawaniganj)	27-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	28-01-81	14.60	Katakhal	SW155	Mohimaganj Railway Crossi	07-02-1991	14.54	46.50		Gaibandha	CL156	Gaibandha(Bhawaniganj)	28-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	29-01-81	14.60	Katakhal	SW155	Mohimaganj Railway Crossi	20-02-1991	14.34	41.40		Gaibandha	CL156	Gaibandha(Bhawaniganj)	29-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	30-01-81	14.60	Katakhal	SW155	Mohimaganj Railway Crossi	06-03-1991	14.18	36.20		Gaibandha	CL156	Gaibandha(Bhawaniganj)	30-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	31-01-81	14.60	Katakhal	SW155	Mohimaganj Railway Crossi	20-03-1991	14.06	32.90		Gaibandha	CL156	Gaibandha(Bhawaniganj)	31-Jan-81	0.00
Katakhal	Mohimaganj Railway Crossi	SW155	01-02-81	14.59	Katakhal	SW155	Mohimaganj Railway Crossi	03-04-1991	13.98	29.10		Gaibandha	CL156	Gaibandha(Bhawaniganj)	01-Feb-81	0.00

CHAPTER FOUR: HYDROLOGIC DATA ANALYSIS

4.0 Analysis of Hydrological Data

4.1 Estimation of Design Discharge and Water Level

Estimation of both flood discharges and high water levels are necessary for bank protection design. Careful estimation of discharge and water level is important for all sites with erodible banks. This section describes the methods of assessing flood discharge and water level at the site under consideration. The design discharge and water level are determined for selected probability of exceedance or return period.

The design discharge and water level arising from floods should be selected after due consideration of the following:

- The maximum historical discharge as recorded at the site, or as calculated on the basis of recorded water level at the site, or as calculated on the basis of measured discharge at other points on the river from which corresponding site discharge can reasonably be inferred.
- The discharge derived from a frequency analysis using a probability of exceedance or return period which is appropriate to the importance and value of the protection work.
- The maximum historical water level as recorded at the site, or as inferred from observed or recorded water level at other points on the river from which level can reasonably be transferred to the site in question.
- The water level derived from a frequency analysis using a probability of exceedance or return period which is appropriate to the importance and value of the protection work.

In estimating high flows, primary reliance should be placed on careful field investigations, local enquiries and searches of historical records. Data so obtained should be compared with recorded data for hydrometric stations, and supplemented by analytical procedure using stage-discharge curves. At most hydrometric gauging stations reasonably stable relationship exists between water level and discharge. At some sites, however, the stage discharge curve may be quite unstable because of aggradation or degradation at channel bed or backwater effect from downstream, and may change drastically during major floods. A persistent trend of rising or lowering of curve indicates progressive channel aggradation or degradation. The stage corresponding to design flood which exceeds any recorded flow obtained by extrapolating the stage-discharge relationships.

The most commonly used method for estimating design discharge and water level examines the observed discharge and water level to arrive at suitable estimates. The method, known as frequency analysis, is founded on statistical analyses of discharge and water level records. For locations where records of stream flows are available, or where flows from another basin can be transported to the design location, design flood magnitude and water level can be estimated directly from those records by means of frequency analysis.

4.2 Frequency Analysis

Frequency of a hydrological event, such as the annual peak flow is the probability that a value will be equaled or exceeded in any year. This is more appropriately called the exceedance probability, $P(F)$. The reciprocal of the exceedance probability is the return period T in years, that is, $T = 1/P(F)$. The length of record should be sufficient to justify extrapolating the frequency relationship. For example, it might be reasonable to estimate a 50-year flood on the basis of a 30-year record, but to estimate a 100-year flood on the basis of a 10-year record would normally be absurd (Neill 1973)⁽¹⁾. Viessman and Lewis (1996)⁽²⁾ noted that as a general rule, frequency analysis is cautioned when working with shorter records and estimating frequencies of hydrological events greater than twice the record length.

Frequency analysis can be conducted in two ways: one is the analytical approach and the other is the graphical technique in which flood magnitudes are usually plotted against probability of exceedance.

Here in the following sections, procedures are given mostly for discharge frequency analysis; the similar procedures can also be followed for water level frequency analysis.

4.3 Analytical Frequency Analysis

Analytical frequency analysis is based on fitting theoretical probability distributions to given data. Numerous distributions have been suggested on the basis of their ability to 'fit' the plotted data from streams (Linsley et al. 1982)⁽³⁾. The Log-Pearson Type III (LP3) has been adopted for use in the United States Federal Agencies for flood analysis. The first asymptotic distribution of extreme values (EV1), commonly called Gumbel Distribution has been widely used and is recommended in the United Kingdom. For this project, all the collected data will be analyzed using Normal distribution, Log-Normal distribution, Log-Pearson III distribution and Extreme Variable Distribution and the best fit distribution will be adopted for analysis.

4.3.1 Extreme Value Distributions

Distributions of the extreme values selected from sets of samples of any probability distribution converge to any one of three forms of Extreme Value Distributions, called Type I, II, and III, respectively, when the number of selected extreme values is large. The three limiting forms are special cases of a single distribution called Generalized Extreme Value (GEV) Distribution (Chow et al. 1988) ⁽⁴⁾. The cumulative distribution function for the GEV is:

$$F(x) = \exp \left[- \left(1 - \kappa \frac{x-u}{\alpha} \right)^{1/\kappa} \right] \quad (1)$$

Here κ , u , and α are parameters to be determined. For EVI Distribution x is unbounded, while for EVII, x is bounded from below, and for EVIII, x is bounded from above. The EVI and EVII Distributions are also known as the Gumbel and Frechet Distributions, respectively.

The Extreme Value Type I (EVI) cumulative distribution function is:

$$F(x) = \exp \left[- \exp \left(- \frac{x-u}{\alpha} \right) \right] \quad -\infty \leq x \leq \infty \quad (2)$$

The parameters are estimated by

$$\alpha = \frac{\sqrt{6}}{\pi} s \quad \text{and} \quad u = \bar{x} - 0.5772\alpha \quad (3)$$

Eq (2) can be expressed as

$$F(x) = e^{-e^{-y}} \quad (4)$$

Where y is the reduced variate defined as

$$y = \frac{x-u}{\alpha} \quad (5)$$

Solving Eq (4) for y :

$$y = -\ln \left[\ln \left(\frac{1}{F(x)} \right) \right] \quad (6)$$

Noting that the probability of occurrence of an event $x \geq x_T$ is the inverse of its return period T , we can write

$$\frac{1}{T} = P(x \geq x_T) = 1 - P(x \leq x_T) = 1 - F(x_T)$$

So,

$$F(x_T) = 1 - \frac{1}{T}$$

Substituting for $F(x_T)$ into Eq (6)

$$y_T = -\ln \left[\ln \left(\frac{T}{T-1} \right) \right] \quad (7)$$

For a given return period x_T is related to y_T by Eq (5), or

$$x_T = u + \alpha y_T \quad (8)$$

4.3.2 Frequency Analysis using Frequency Factors

Calculating the magnitudes of extreme events by the method outlined in the above example requires that the probability distribution function be invertible, that is, given a value of T or $F(x_T) = 1 - \frac{1}{T}$, the corresponding value of x_T can be determined. Some probability distribution functions are not readily invertible, like the Normal and Pearson Type III Distributions. Thus an alternative method based on frequency factor is used for calculating the magnitudes of extreme events. Chow (1951) ⁽⁵⁾ has shown that most frequency functions can be generalized to

$$x_T = \bar{x} + K_T s \quad (9)$$

where x_T is a flood of specified probability or return period T , \bar{x} is the mean of the flood series, s is the standard deviation of the series; and K_T is the frequency factor and is a function of return period and type of probability distribution, as well as coefficient of skewness for skewed distributions, such as LP3.

In the event that the variable analyzed is $y = \log x$, for example as in Lognormal and LP3 Distributions, the same method is applied to the statistics for the logarithms of data using $y_T = \bar{y} + K_T s_y$, and the required value of x_T is found taking antilog of y_T .

Chow (1951) ⁽⁵⁾ proposed the frequency factor as in Eq (9), and it is applicable to many probability distributions used in hydrological frequency analysis. The K-T relationship can be expressed in mathematical terms or by a table.

Normal Distribution: From Eq (9) the frequency factor can be expressed as

$$K_T = \frac{x_T - \bar{x}}{s} = z \quad (10)$$

Thus, for Normal Distribution K_T is the same as the standard normal variable z . The value of z and hence K_T can be obtained from Table 1 in ANNEXURE – I(a).

Lognormal Distribution: The recommended procedure for use of the Lognormal Distribution is to convert the data series to logarithms and compute:

- 1) $y_i = \log x_i$
- 2) Compute the mean, \bar{y} and standard deviation s_y
- 3) Compute $y_T = \bar{y} + K_T s_y$

$$K_T = \frac{y_T - \bar{y}}{s_y} = z$$

So, K_T can be taken from Table 1 in ANNEXURE – I(a).

- 4) Finally compute $x_T = \text{anti log } y_T$

Log-Pearson Type III (LP3) Distribution: The recommended procedure for use of the LP3 Distribution is to convert the data series to logarithms and compute:

- 1) $y_i = \log x_i$
- 2) Compute the mean, \bar{y} and standard deviation s_y
- 3) Compute coefficient of skewness

$$C_s = \frac{n \sum (y_i - \bar{y})^3}{(n-1)(n-2)s_y^3}$$

- 4) Compute $y_T = \bar{y} + K_T s_y$ (11)

Where K_T is taken from Table 2 in ANNEXURE – I(a)..

- 5) Finally compute $x_T = \text{anti log } y_T$

Table 3 in ANNEXURE – I(a) gives values of the frequency factors for the LP3 Distribution for various values of return period and coefficient of skewness, C_s . When $C_s = 0$, the frequency factor is equal to the standard normal variable z (Table 1 in ANNEXURE – I(a)).

Extreme Value I (EVI) Distribution: Chow (1951) ⁽⁵⁾ derived the following expression for frequency factor for the EVI Distribution

$$K_T = -\frac{\sqrt{6}}{\pi} \left[0.5772 + \ln \left\{ \ln \left(\frac{T}{T-1} \right) \right\} \right] \quad (12)$$

When $x_T = \mu$, Eq (9) (in population term) gives $K_T = 0$ and Eq (12) gives $T=2.33$ years. This is the return period of the mean of the EVI Distribution.

Table of frequency factors for the EVI Distribution, given in Table 3 in ANNEXURE – I(a), is taken from Haan (1977) ⁽⁶⁾. The values computed from the above equation are equivalent to an infinite sample size in Table 3.

4.3.3 Goodness of Fit Test

The goodness of fit of a probability distribution can be tested by comparing the theoretical and sample values of the relative frequency or the cumulative frequency function. In the case of the relative frequency function, the χ^2 – test is used and with cumulative frequency function the Kolmogorov-Smirnov test is used.

Chi-Square Test: The test statistic is given by

$$\chi^2 = \sum_{i=1}^k \frac{n[f_s(x_i) - p(x_i)]^2}{p(x_i)} \quad (13)$$

Where, k is the number of intervals; the sample value of the relative frequency of interval i is, $f_s(x_i) = n_i/n$; the theoretical value of the relative frequency function (also called incremental probability function) is $p(x_i) = F(x_i) - F(x_{i-1})$. It may be noted that $nf_s(x_i) = n_i$, the observed number of occurrences in interval i , and $np(x_i)$ is the corresponding expected number of occurrences in interval i .

To describe the χ^2 test, the χ^2 probability distribution must be defined. A χ^2 distribution with $v = k-l-1$ degrees of freedom (l is the number of parameters used in fitting the proposed distribution) is the distribution for the sum of squares of v independent standard normal random variables z_i . The critical χ^2 distribution function is tabulated (in Table 4 in ANNEXURE – I(a)) from Haan (1977) ⁽⁶⁾. A confidence level is chosen for the test; it is often expressed as $1-\alpha$, where α is termed the significance level.

Kolmogorov-Smirnov Test: The theoretical and sample values of the cumulative frequency are compared with the Kolmogorov-Smirnov (S-K) test. The test statistic D , which is based on deviations of the sample distribution function $P(x)$ from the completely specified continuous hypothetical distribution function $P_o(x)$, such that:

$$D = \max |P(x) - P_o(x)|$$

Developed by Kolmogorov (Kite 1988) ⁽⁷⁾ in 1933, the test requires that the value of D computed from the sample distribution be less than the tabulated value of D (Table 5) at the required confidence level. Kolmogorov-Smirnov test for Gumbel's Extremal Distribution gives better result in Bangladesh.

4.4 Disaggregation of Daily Rainfall Data

4.4.1 Rainfall Cascade Disaggregation Model

Cascade level refers to the time series at a certain resolution. The transition from one cascade level to the higher one, corresponding to a doubling of resolution, is called *modulation*. A time interval at an arbitrary cascade level (i.e. time scale) is termed a *box*, which is characterized by an associated precipitation amount (0 if dry, >0 if wet). The break-up of a wet box into two equally sized sub-boxes is denoted *branching*. In one branching, the total amount is redistributed according to two multiplicative weights, $0 \leq W_1 \leq 1$ and $0 \leq W_2 \leq 1$ ($W_1 + W_2 = 1$). The model is a multiplicative random cascade of branching number 2 with exact conservation of mass (micro canonical property as opposed to canonical cascades where the volume is only approximately conserved). The model divides daily precipitation into non overlapping time intervals. If the precipitation in a day is P_d , $P_1 = P_d W_1$ is the precipitation amount assigned to the first half of the day, and $P_2 = P_d W_2$ the amount assigned to the second half. Similarly, each half is then branched to a doubled resolution, and so on. The implementation of cascade – based model allows the conversion of daily amount into 12-hourly (1 steps), 6-hourly (2 steps), and 3-hourly (3 steps) values. The short-time intensity disaggregation model (Connolly et al. 1998) ⁽⁸⁾, is used to have three fine-resolution time interval that are 1-hour, 1/2-hour and 10-minutes. A single Poisson distribution parameter represents the number of events, N , on a rainy day. The density function of the Poisson distribution (adjusted so that $N \geq 1$) has the form:

$$f(N) = \frac{\eta^{N-1} \cdot e^{-\eta}}{(N-1)!} \quad (14)$$

Where η is a fitted coefficient. Mean (μ_N) and variance (σ_N^2) are given as:

$$\mu_N = \eta + 1 \quad (15)$$

$$\sigma_N^2 = \eta \quad (16)$$

The simulated number of event N is the lowest integer to satisfy:

$$\sum_{i=1}^N \frac{\eta^{i-1} \cdot e^{-\eta}}{(i-1)!} \geq U \quad N \geq 1 \quad (17)$$

Where U is a uniform random number in the range 0–1.

The duration of each event, D , is represented with a gamma distribution. The scale parameter of the gamma distribution, α , has to be estimated and the shape parameter, β , is set held at 2. It results the following density function:

$$f(D) = \alpha^2 \cdot D \cdot e^{-\alpha \cdot D} \quad (18)$$

A uniform random number in the range 0–1, U , is generated and the event duration is simulated by solving the cumulative density function of the gamma distribution using Newton's method:

$$1 - (1 + \alpha \cdot D) \cdot e^{-\alpha \cdot D} = U \quad (19)$$

With these estimated point (10'-30'-1 h, 3 h, 6 h, 12 h and 24 h) following the procedures for the frequency distribution, it is possible to define the rainfall probability curves.

Using the above equations, daily and monthly basis analysis of water level data have been prepared which is shown in Annexure I (b).

CHAPTER FIVE: DESIGNING STORM SEWER

5.0 Capacity Estimate and Designing Drain Sections (Prismatic)

5.1 Manning's Formula

The Manning's formula is a widely used formula around the world to estimate capacity of an open channel or design required section. The formula is also known as Gauckler-Manning-Strickler formula. It is an empirical formula to estimate the average velocity of water flowing through an open channel. The Manning's equation is as follows:

$$V = \frac{K_n}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (20)$$

Where, V = average velocity of flow (SI unit: m/s; Imperial: ft/s)

K_n = Unit conversion factor (1.00 for SI unit and 1.49 for Imperial unit)

R = Hydraulic Radius = $\frac{P}{A}$ (SI unit: m, Imperial: ft)

Here, P = Wetted Perimeter (SI unit: m, Imperial: ft)

A = Cross-sectional area of flow (SI unit: m², Imperial: ft²)

s = hydraulic gradient of flow (SI unit: m/m, Imperial: ft/ft)

n = Manning's dimensionless roughness coefficient

Manning's roughness coefficient may be selected using the following.

Table 5.1: Manning's n for Channels (Chow (1951)) ⁽⁵⁾

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at flood stage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
b. same as above, but more stones and weeds	0.03	0.035	0.04
c. clean, winding, some pools and shoals	0.033	0.04	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.05
e. same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. same as "d" with more stones	0.045	0.05	0.06
g. sluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. very weedy reaches, deep pools, or floodways	0.075	0.1	0.15

Type of Channel and Description	Minimum	Normal	Maximum
with heavy stand of timber and underbrush			
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
b. bottom: cobbles with large boulders	0.04	0.05	0.07
3. Floodplains			
a. Pasture, no brush			
1. short grass	0.025	0.03	0.035
2. high grass	0.03	0.035	0.05
b. Cultivated areas			
1. no crop	0.02	0.03	0.04
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.03	0.04	0.05
c. Brush			
1. scattered brush, heavy weeds	0.035	0.05	0.07
2. light brush and trees, in winter	0.035	0.05	0.06
3. light brush and trees, in summer	0.04	0.06	0.08
4. medium to dense brush, in winter	0.045	0.07	0.11
5. medium to dense brush, in summer	0.07	0.1	0.16
d. Trees			
1. dense willows, summer, straight	0.11	0.15	0.2
2. cleared land with tree stumps, no sprouts	0.03	0.04	0.05
3. same as above, but with heavy growth of sprouts	0.05	0.06	0.08
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.08	0.1	0.12
5. Same as 4. with flood stage reaching branches	0.1	0.12	0.16
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.02
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.03
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.03
2. grass, some weeds	0.025	0.03	0.033
3. dense weeds or aquatic plants in deep channels	0.03	0.035	0.04
4. earth bottom and rubble sides	0.028	0.03	0.035
5. stony bottom and weedy banks	0.025	0.035	0.04

Type of Channel and Description	Minimum	Normal	Maximum
6. cobble bottom and clean sides	0.03	0.04	0.05
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.05	0.06
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.04
2. jagged and irregular	0.035	0.04	0.05
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.05	0.08	0.12
2. clean bottom, brush on sides	0.04	0.05	0.08
3. same as above, highest stage of flow	0.045	0.07	0.11
4. dense brush, high stage	0.08	0.1	0.14
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.01	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.01	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. un-planed	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.01	0.014	0.017
c. Concrete			
1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.02
4. unfinished	0.014	0.017	0.02
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.02	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.02
2. random stone in mortar	0.017	0.02	0.024
3. cement rubble masonry, plastered	0.016	0.02	0.024
4. cement rubble masonry	0.02	0.025	0.03
5. dry rubble or riprap	0.02	0.03	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.02	0.025

Type of Channel and Description	Minimum	Normal	Maximum
2. random stone mortar	0.02	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. glazed	0.011	0.013	0.015
2. in cement mortar	0.012	0.015	0.018
g. Masonry			
1. cemented rubble	0.017	0.025	0.03
2. dry rubble	0.023	0.032	0.035
h. Dressed ashlar/stone paving	0.013	0.015	0.017
i. Asphalt			
1. smooth	0.013	0.013	
2. rough	0.016	0.016	
j. Vegetal lining	0.03		0.5

Estimation of capacity of the existing drains and drainage channels will be estimated using Manning's formula. Design sections of the proposed sections will also be calculated using this formula.

CHAPTER SIX: CONCLUSION

6.0 Conclusion

The findings and the collected data during the survey works will be used in the subsequent planning stage of the project, “Preparation of Development Plan for Fourteen Upazilas”. The prepared DEM will be used for delineation of catchment area and preparing contours of the project area. The collected water level, rainfall and discharge data will be analyzed and tested for fitness with observed data and successively used to predict the respective data for different time periods. These are going to be incorporated in the final planning report. The results should assist in preparing a development plan that will be sustainable from the hydrologic point of view. The surveyed cross sections, drainage inventories and list of the road name along the drains will be updated after accumulation and processing of physical feature data.

REFERENCES/BIBLIOGRAPHY

1. O'Neill ADJ and Gray DM; Proceedings of Banff Symposium on Role of snow and Ice in Hydrology; 1973.
2. Warren Viessman and Garry L. Lewis; Introduction to Hydrology^{ed/4}, Harper Collins (1996).
3. Linsley, R. K., M. A. Kohler and J. L. H. Paulhus; Hydrology for engineers^{ed/3}, McGraw-Hill (1982).
4. Ven Te Chow, David Maidment, and Larry Hays; Applied Hydrology^{ed/1}, McGraw-Hill (1988).
5. VT Chow; Open-Channel Hydraulics, McGraw-Hill, New York (1959)
6. Charles T Haan; Statistical Methods in Hydrology, The Iowa State University Press (1977).
7. Khaled Hamed, A. Ramachandro. Rao; Flood Frequency Analysis, CRC press.
8. Stephan Pauleit, Adrien Coly, Sandra Fohlmeister, Paolo Gasparini, Gertrud Jørgensen, Sigrun Kabisch, Wilbard J. Kombe, Sarah Lindley, Ingo Simonis, Kumelachew Yeshitela; Urban Vulnerability and Climate Change in Africa: A Multidisciplinary Approach, Springer.

ANNEXURE

Annexure-I (a)

Table 1: Cumulative Probability of the Standard Normal Distribution
Cumulative probability of the standard normal distribution

<i>z</i>	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Source: Grant, E. L., and R. S. Leavenworth, *Statistical Quality and Control*, Table A, p.643, McGraw-Hill, New York, 1972. Used with permission.

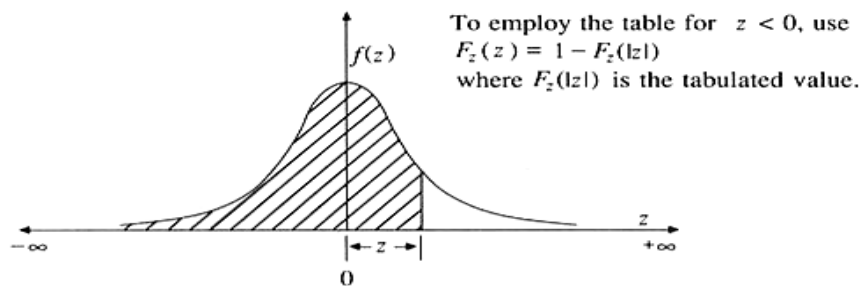


Table 2: Frequency Factors for Pearson Type III Distribution

K_T values for Pearson Type III distribution (positive skew)

Skew coefficient C_s or C_w	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
	0.50	0.20	0.10	0.04	0.02	0.01	0.005
3.0	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	-0.017	0.836	1.292	1.785	2.107	2.400	2.670
0.0	0	0.842	1.282	1.751	2.054	2.326	2.576

Table 2: Frequency Factors for Pearson Type III Distribution (Continued...)

K_T values for Pearson Type III distribution (negative skew)

Skew coefficient C_s or C_w	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
	0.50	0.20	0.10	0.04	0.02	0.01	0.005
-0.1	0.017	0.846	1.270	1.716	2.000	2.252	2.482
-0.2	0.033	0.850	1.258	1.680	1.945	2.178	2.388
-0.3	0.050	0.853	1.245	1.643	1.890	2.104	2.294
-0.4	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	0.099	0.857	1.200	1.528	1.720	1.880	2.016
-0.7	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	0.148	0.854	1.147	1.407	1.549	1.660	1.749
-1.0	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	0.180	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	0.210	0.838	1.064	1.240	1.324	1.383	1.424
-1.4	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.5	0.240	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	0.268	0.808	0.970	1.075	1.116	1.140	1.155
-1.8	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	0.294	0.788	0.920	0.996	1.023	1.037	1.044
-2.0	0.307	0.777	0.895	0.959	0.980	0.990	0.995
-2.1	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	0.330	0.752	0.844	0.888	0.900	0.905	0.907
-2.3	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	0.351	0.725	0.795	0.823	0.830	0.832	0.833
-2.5	0.360	0.711	0.771	0.793	0.798	0.799	0.800
-2.6	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	0.376	0.681	0.724	0.738	0.740	0.740	0.741
-2.8	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	0.390	0.651	0.681	0.683	0.689	0.690	0.690
-3.0	0.396	0.636	0.666	0.666	0.666	0.667	0.667

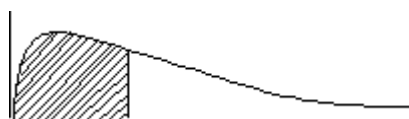
Source: U. S. Water Resources Council (1981).

Table 3: Frequency Factors for Pearson Type III Distribution

Sample Size (n)	Return Period								
	5	10	15	20	25	50	75	100	1000
15	0.967	1.703	2.117	2.410	2.632	3.321	3.721	4.005	6.265
20	0.919	1.625	2.023	2.302	2.517	3.179	3.563	3.836	6.006
25	0.888	1.575	1.963	2.235	2.444	3.088	3.463	3.729	5.842
30	0.866	1.541	1.922	2.188	2.393	3.026	3.393	3.653	5.727
35	0.851	1.516	1.891	2.152	2.354	2.979	3.341	3.598	
40	0.838	1.495	1.866	2.126	2.326	2.943	3.301	3.554	5.576
45	0.829	1.478	1.847	2.104	2.303	2.913	3.268	3.520	
50	0.820	1.466	1.831	2.086	2.283	2.889	3.241	3.491	5.478
55	0.813	1.455	1.818	2.071	2.267	2.869	3.219	3.467	
60	0.807	1.446	1.806	2.059	2.253	2.852	3.200	3.446	
65	0.801	1.437	1.796	2.048	2.241	2.837	3.183	3.429	
70	0.797	1.430	1.788	2.038	2.230	2.824	3.169	3.413	5.359
75	0.972	1.423	1.780	2.029	2.220	2.812	3.155	3.400	
80	0.788	1.417	1.773	2.020	2.212	2.802	3.145	3.387	
85	0.785	1.413	1.767	2.013	2.205	2.793	3.135	3.376	
90	0.782	1.409	1.762	2.007	2.198	2.785	3.125	3.367	
95	0.780	1.405	1.757	2.002	2.193	2.777	3.116	3.357	
100	0.779	1.401	1.752	1.998	2.187	2.770	3.109	3.349	5.261
α	0.719	1.305	1.635	1.866	2.044	2.592	2.911	3.137	4.936

Source: Journal American Statistical Association 47:425-441, 1952.Z.W. Birnbaum

Table 4: χ^2 Distribution



$X^2_{\alpha, v}$

DOF v	$\chi^2_{.995}$	$\chi^2_{.99}$	$\chi^2_{.975}$	$\chi^2_{.95}$	$\chi^2_{.90}$	$\chi^2_{.75}$	$\chi^2_{.50}$	$\chi^2_{.25}$	$\chi^2_{.10}$	$\chi^2_{.05}$	$\chi^2_{.025}$	$\chi^2_{.01}$	$\chi^2_{.005}$
1	7.88	6.63	5.02	3.84	2.71	1.32	0.455	0.102	0.0158	0.0039	0.0010	0.0002	0.0000
2	10.6	9.21	7.38	5.99	4.61	2.77	1.39	0.575	.211	.103	.0506	.0201	.0100
3	12.8	11.3	9.35	7.81	6.25	4.11	2.37	1.21	.584	.352	.216	.115	.072

DOF v	$\chi^2_{.995}$	$\chi^2_{.99}$	$\chi^2_{.975}$	$\chi^2_{.95}$	$\chi^2_{.90}$	$\chi^2_{.75}$	$\chi^2_{.50}$	$\chi^2_{.25}$	$\chi^2_{.10}$	$\chi^2_{.05}$	$\chi^2_{.025}$	$\chi^2_{.01}$	$\chi^2_{.005}$
4	14.9	13.3	11.1	9.49	7.78	5.39	3.36	1.92	1.06	.711	.484	.297	.207
5	16.7	15.1	12.8	11.1	9.24	6.63	4.35	2.67	1.61	1.15	.831	.554	.412
6	18.5	16.8	14.4	12.6	10.6	7.84	5.35	3.45	2.20	1.64	1.24	.872	.676
7	20.3	18.5	16.0	14.1	12.0	9.04	6.35	4.25	2.83	2.17	1.69	1.24	.989
8	22.0	20.1	17.5	15.5	13.4	10.2	7.34	5.07	3.49	2.73	2.18	1.65	1.34
9	23.6	21.7	19.0	16.9	14.7	11.4	8.34	5.90	4.17	3.33	2.70	2.09	1.73
10	25.2	23.2	20.5	18.3	16.0	12.5	9.34	6.74	4.87	3.94	3.25	2.56	2.16
11	26.8	24.7	21.9	19.7	17.3	13.7	10.3	7.58	5.58	4.57	3.82	3.05	2.60
12	28.3	26.2	23.3	21.0	18.5	14.8	11.3	8.44	6.30	5.23	4.40	3.57	3.07
13	29.8	27.7	24.7	22.4	19.8	16.0	12.3	9.30	7.04	5.89	5.01	4.11	3.57
14	31.3	29.1	26.1	23.7	21.1	17.1	13.3	10.2	7.79	6.57	5.63	4.66	4.07
15	32.8	30.6	27.5	25.0	22.3	18.2	14.3	11.0	8.55	7.26	6.26	5.23	4.60
16	34.3	32.0	28.8	26.3	23.5	19.4	15.3	11.9	9.31	7.96	6.91	5.81	5.14
17	35.7	33.4	30.2	27.6	24.8	20.5	16.3	12.8	10.1	8.67	7.56	6.41	5.70
18	37.2	34.8	31.5	28.9	26.0	21.6	17.3	13.7	10.9	9.39	8.23	7.01	6.26
19	38.6	36.2	32.9	30.1	27.2	22.7	18.3	14.6	11.7	10.1	8.91	7.63	6.84
20	40.0	37.6	34.2	31.4	28.4	23.8	19.3	15.5	12.4	10.9	9.59	8.26	7.43
21	41.4	38.9	35.5	32.7	29.6	24.9	20.3	16.3	13.2	11.6	10.3	8.90	8.03
22	42.8	40.3	36.8	33.9	30.8	26.0	21.3	17.2	14.0	12.3	11.0	9.54	8.64
23	44.2	41.6	38.1	35.2	32.0	27.1	22.3	18.1	14.8	13.1	11.7	10.2	9.26
24	45.6	43.0	39.4	36.4	33.2	28.2	23.3	19.0	15.7	13.8	12.4	10.9	9.89
25	46.9	44.3	40.6	37.7	34.4	29.3	24.3	19.9	16.5	14.6	13.1	11.5	10.5
26	48.3	45.6	41.9	38.9	35.6	30.4	25.3	20.8	17.3	15.4	13.8	12.2	11.2
27	49.6	47.0	43.2	40.1	36.7	31.5	26.3	21.7	18.1	16.2	14.6	12.9	11.8
28	51.0	48.3	44.5	41.3	37.9	32.6	27.3	22.7	18.9	16.9	15.3	13.6	12.5
29	52.3	49.6	45.7	42.6	39.1	33.7	28.3	23.6	19.8	17.7	16.0	14.3	13.1
30	53.7	50.9	47.0	43.8	40.3	34.8	29.3	24.5	20.6	18.5	16.8	15.0	13.8
40	66.8	63.7	59.3	55.8	51.8	45.6	39.3	33.7	29.1	26.5	24.4	22.2	20.7
50	79.5	76.2	71.4	67.5	63.2	56.3	49.3	42.9	37.7	34.8	32.4	29.7	28.0
60	92.0	88.4	83.3	79.1	74.4	67.0	59.3	52.3	46.5	43.2	40.5	37.5	35.5
70	104.2	100.4	95.0	90.5	85.5	77.6	69.3	61.7	55.3	51.7	48.8	45.4	43.3
80	116.3	112.3	106.6	101.9	96.6	88.1	79.3	71.1	64.3	60.4	57.2	53.5	51.2
90	128.3	124.1	118.1	113.1	107.6	98.6	89.3	80.6	73.3	69.1	65.6	61.8	59.2
100	140.2	135.8	129.6	124.3	118.5	109.1	99.3	90.1	82.4	77.9	74.2	70.1	67.3

Source: Catherine M. Thompson, Table of percentage points of the χ^2 distribution, Biometrika, Vol. 32 (1941), by permission of the author and publisher

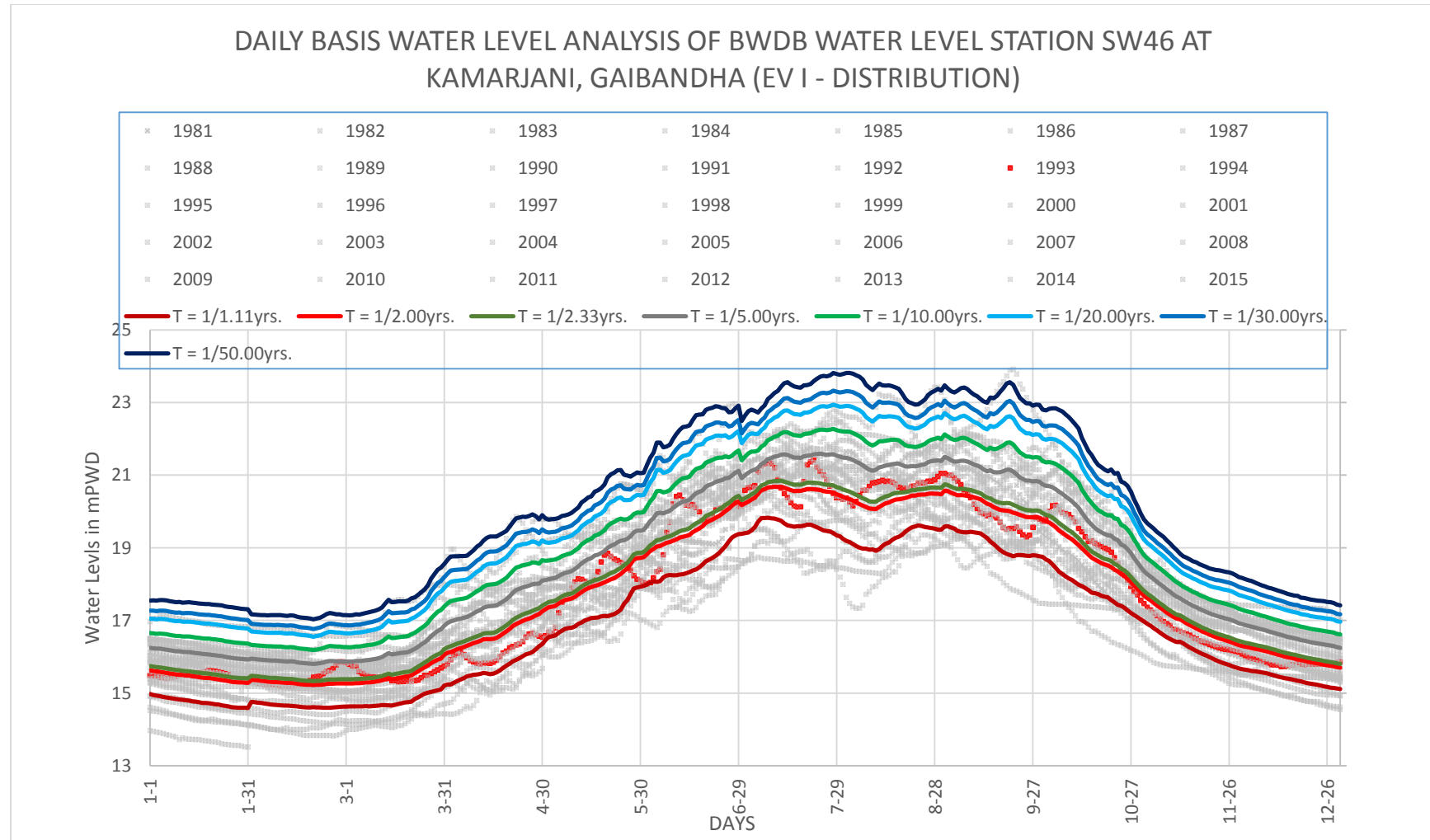
Table 5: Kolmogorov-Smirnov Distribution

Sample Size (n)		Significance Level			
	.20	0.15	0.10	0.05	0.01
1	.900	.925	.950	.975	.995
2	.684	.726	.776	.842	.929
3	.565	.597	.642	.708	.829
4	.494	.725	.564	.624	.734
5	.446	.474	.510	.563	.669
6	.410	.436	.470	.521	.618
7	.381	.405	.438	.486	.577
8	.358	.381	.411	.457	.543
9	.339	.360	.388	.432	.514
10	.322	.342	.368	.409	.486
11	.307	.326	.352	.391	.468
12	.295	.313	.338	.375	.450
13	.284	.302	.325	.361	.433
14	.274	.292	.314	.349	.418
15	.266	.283	.304	.338	.404
16	.258	.274	.295	.328	.391
17	.250	.266	.286	.318	.380
18	.244	.259	.278	.309	.370
19	.237	.252	.272	.301	.361
20	.231	.246	.264	.294	.352
25	.21	.22	.24	.264	.32
30	.19	.20	.22	.242	.29
35	.18	.19	.21	.23	.27
40				.21	.25
50				.19	.23
60				.17	.21
70				.16	.19
80				.15	.18
90				.14	
100				.14	
Asymptotic Formula	$\frac{1.70}{\sqrt{n}}$	$\frac{1.14}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

Source: Journal American Statistical Association 47:425-441, 1952.Z.W. Birnbaum

Annexure-I (b)

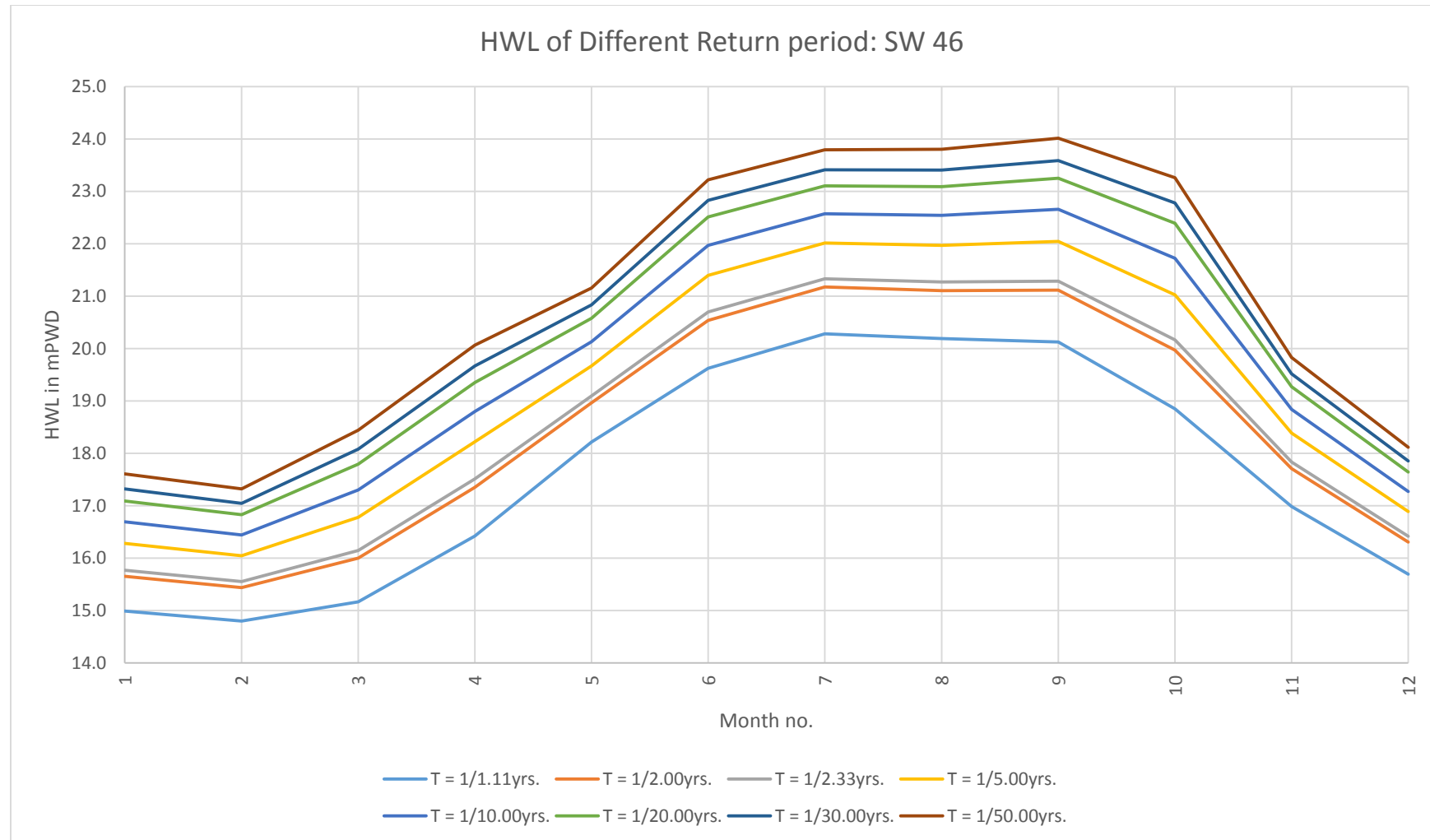
A.1b.1: Analyzed Results of BWDB Water Level Gauge Station SW 46 on the Brahmaputra River



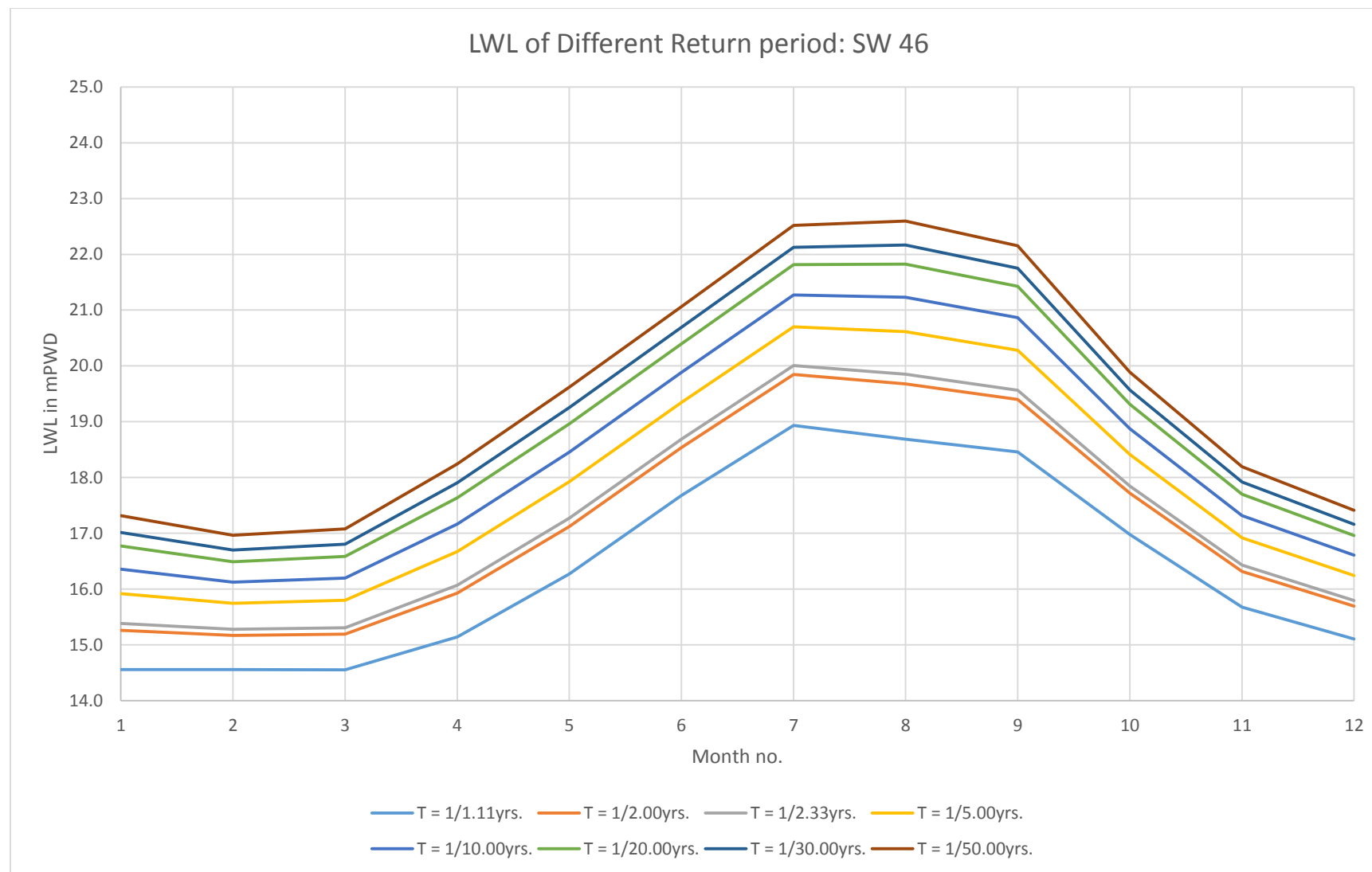
Monthly Basis Analysis of Data of Water Level Gauge Station SW 46

Monthly Data			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WL		Year	Monthly Maximum WL (mPWD)													Monthly Minimum WL (mPWD)											
		1981	16.05	15.66	16.35	17.25	17.98	20.89	21.76	21.79	21.64	19.37	17.12	15.97		15.66	15.62	15.57	16.33	17.26	18.10	20.88	20.82	19.45	17.16	16.00	15.48
		1982	15.96	15.48	15.48											15.48	15.38	15.24									
		1983				17.84	19.34	20.60	21.13	21.13	21.94	21.58	18.77	17.09					16.19	17.91	19.25	20.53	20.54	20.69	18.86	17.10	16.52
		1984	16.50	16.15	16.39	17.90	20.75	21.00	22.45	22.47	23.92	22.44	18.39	17.08		16.15	15.85	15.85	16.42	17.36	20.25	20.65	21.53	21.97	18.41	17.10	16.50
		1985	16.49	16.06	16.65	18.13	18.84	21.58	22.59	22.33	22.07	21.11	18.26	16.94		16.08	15.70	15.69	16.67	18.13	19.15	21.67	20.77	21.08	18.34	16.98	16.40
		1986	16.35	15.84	16.08	18.03	18.36	21.45	21.45	21.57	21.86	20.80	18.54	17.05		15.85	15.72	15.65	15.98	17.86	17.91	20.55	19.97	20.55	18.73	17.07	16.25
		1987	16.23	15.73	16.19	17.81	18.99	21.23	22.81	23.23	22.11	21.84	18.80	17.11		15.73	15.68	15.71	16.20	17.48	18.77	21.53	21.30	21.28	18.93	17.15	16.14
		1988	16.11	15.92	16.82	17.12	18.72	18.99	22.15	23.43	23.07	21.00	18.25	16.80		15.93	15.66	15.60	16.62	17.09	17.38	18.64	20.88	20.03	18.38	16.70	16.04
		1989	16.01	15.81	15.67	17.48	19.65	20.63	21.46	20.96	21.09	20.67	18.67	17.08		15.54	15.46	15.48	15.66	17.26	19.10	20.21	19.87	20.06	18.77	17.12	16.35
		1990	16.35	16.06	15.84	18.21	19.01	21.20	21.27	21.06	21.30	21.29	18.47	16.73		16.09	15.47	15.64	15.87	17.80	19.02	20.42	19.87	20.49	18.57	16.75	15.96
		1991	15.93	15.52	16.08	17.71	19.81	21.27	21.70	20.83	20.38	19.52	17.20	15.51		15.53	15.41	15.42	16.14	16.81	19.07	19.92	19.73	19.42	17.26	15.53	14.93
		1992	14.91	14.57	15.86	16.87	17.54	21.08	21.31	21.17	20.88	19.91	18.11	16.18		14.55	14.40	14.45	15.60	16.31	16.81	20.22	20.00	19.60	18.22	16.23	15.52
		1993	15.62	15.86	15.86	16.65	18.84	20.45	21.41	21.05	21.05	20.17	17.46	16.08		15.34	15.19	15.31	15.74	16.54	18.01	20.12	20.16	19.30	17.55	16.13	15.73
		1994	15.87	15.75	17.63	17.58	18.58	20.00	19.95	19.55	19.13	18.56	16.52	15.21		15.73	15.53	15.49	16.66	16.63	18.12	18.30	18.60	18.45	16.62	15.22	14.55
		1995	14.52	14.27	14.68	16.16	19.40	20.55	21.48	21.00	20.49	20.31	16.61	15.29		14.14	14.00	14.20	14.70	16.31	18.37	19.76	19.38	18.94	16.73	15.31	14.62
		1996	14.61	14.10	15.43	17.21	19.39	19.97	21.74	20.81	20.63	19.98	18.67	16.25		14.10	13.82	13.91	14.94	16.46	17.86	20.09	19.65	18.88	17.56	16.27	15.33
		1997	15.30	14.94	16.57	16.53	18.75	21.10	22.24	21.05	21.30	20.90	17.23	16.18		14.82	14.70	14.76	15.87	16.00	18.35	19.86	19.44	19.29	17.28	16.18	15.63
		1998	15.58	15.18	15.30	16.00	19.09	21.38	22.02	21.93	22.15	19.13	18.09	15.89		15.18	15.05	14.54	15.10	16.06	18.68	21.21	21.23	19.13	17.57	15.76	14.94
		1999	14.92	14.42	14.51	15.58	18.11	20.10	20.47	20.65	20.19	18.60	17.70	15.95		14.44	14.15	14.13	14.41	15.68	17.50	19.35	18.60	18.60	17.85	15.50	15.30
		2000	15.28													14.80											
		2001										21.08	17.88	16.17											17.97	16.27	15.44
		2002	15.39	15.26	15.36	17.29	18.15	20.73								14.79	14.84	14.80	15.46	16.60	17.64						
		2003	13.97				19.89	20.79	21.95	21.96	20.29	19.26	17.90	17.42		13.51				19.17	19.90	20.84	20.39	19.13	17.92	17.43	17.01
		2004	17.16	16.83	18.18	19.86	20.76	22.97			21.25	21.01	18.69	17.08		16.83	16.57	16.56	18.03	18.18	19.98			19.56	18.81	17.12	16.52
		2005	16.52	16.91	17.99	17.99	18.80	20.50			22.75	21.35	18.60	16.72		16.31	16.07	16.70	17.69	17.86	18.79			19.80	18.83	16.74	15.94
		2006	15.89	15.51	16.58	18.75	19.78	22.15	20.93	20.41	20.66	20.06	17.92	17.21		15.40	15.22	15.52	16.97	18.31	20.03	20.23	18.78	19.28	17.96	17.12	16.48
		2007	16.48	16.20	16.40	17.57	20.00	21.58						15.95		16.09	16.06	16.13	16.45	17.53	20.00						15.84
		2008	15.84	15.30	15.93	17.73	19.30	20.24	21.33	21.73	21.88	18.37	17.12	15.52		15.47	15.07	15.04	15.98	17.75	19.39	20.23	20.57	18.42	16.93	15.52	15.41
		2009	15.41	15.32	15.15	16.67	18.99	18.62	18.75	19.87	19.80	17.47	17.26	16.74		15.33	15.07	15.06	15.16	16.78	18.44	18.45	18.29	17.47	17.26	16.74	15.72
		2010	15.71	15.31	16.99	19.79	19.80	19.96	20.41	19.76	20.64	19.62	17.27	16.95		15.32	15.01	15.03	17.09	19.31	19.59	19.68	18.75	19.09	17.32	16.96	16.39
		2011	16.38	15.93	15.91	17.09	17.99	18.48	20.98							15.93	15.80	15.80	15.91	17.14	17.80	18.57					
		2012																									
		2013																									
		2014																									
		2015							19.53	20.68	20.97	19.10	16.02	15.54								18.19	17.34	18.68	16.06	15.55	15.37
		MAX	17.16	16.91	18.18	19.86	20.76	22.97	22.81	23.43	23.92	22.44	18.80	17.42		16.83	16.57	16.70	18.03	19.31	20.25	21.67	21.53	21.97	18.93	17.43	17.01
		MIN	13.97	14.10	14.51	15.58	17.54	18.48	18.75	19.55	19.13	17.47	16.02	15.21		13.51	13.82	13.91	14.41	15.68	16.81	18.19	17.34	17.47	16.06	15.22	14.55
		N	29	27	27	27	28	28	25	24	26	27	27	28		29	27	27	27	28	28	25	24	26	27	27	28
		Ave	15.77	15.55	16.14	17.51	19.09	20.70	21.33	21.27	21.29	20.17	17.83	16.42		15.38	15.28	15.31	16.07	17.27	18.69	20.00	19.85	19.56	17.85	16.43	15.80
		σ	00.71	00.68	00.89	00.99	00.80	00.97	00.95	00.98	01.05	01.19	00.77	00.66		00.75	00.65	00.68	00.84	00.91	00.92	00.97	01.06	01.00	00.79	00.68	00.62
ANALYSED DATA:																											
		T = 1/1.11yrs. K _{1.11}	=	-1.10												14.56	14.56	14.55	15.14	16.27	17.68	18.94	18.69	18.46	16.98	15.68	15.11
		T = 1/2.00yrs. K _{2.00}	=	-0.16												15.26	15.17	15.19	15.93	17.12	18.54	19.85	19.68	19.40	17.72	16.32	15.69
		T = 1/2.33yrs. K _{2.33}	=	0.00												15.38	15.28	15.31	16.07	17.27	18.69	20.01	19.85	19.56	17.85	16.43	15.80
		T = 1/5.00yrs. K _{5.00}	=	0.72												15.92	15.75	15.80	16.67	17.92	19.35	20.70	20.61	20.28	18.41	16.92	16.25
		T = 1/10.00yrs. K _{10.00}	=	1.30												16.36	16.13	16.20	17.16	18.45	19.88	21.27	21.23	20.87	18.87	17.32	16.61
		T = 1/20.00yrs. K _{20.00}	=	1.87												16.77	16.49	16.58	17.64	18.96	20.40	21.81	21.83	21.43	19.31	17.70	16.96
		T = 1/30.00yrs. K _{30.00}	=	2.19												17.02	16.70	16.81	17.91								

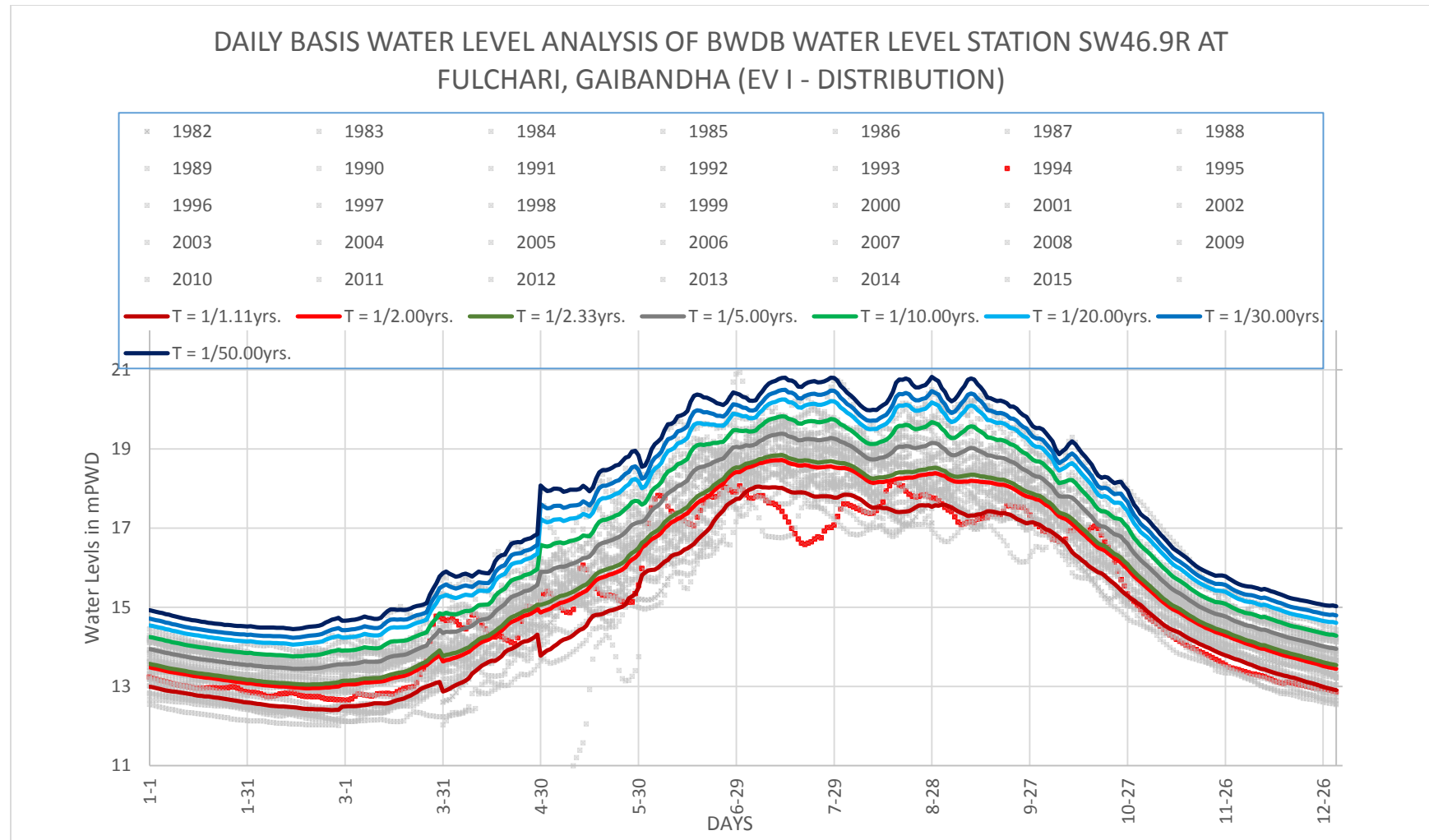
Monthly Basis Analysis of Data of Water Level Gauge Station SW 46



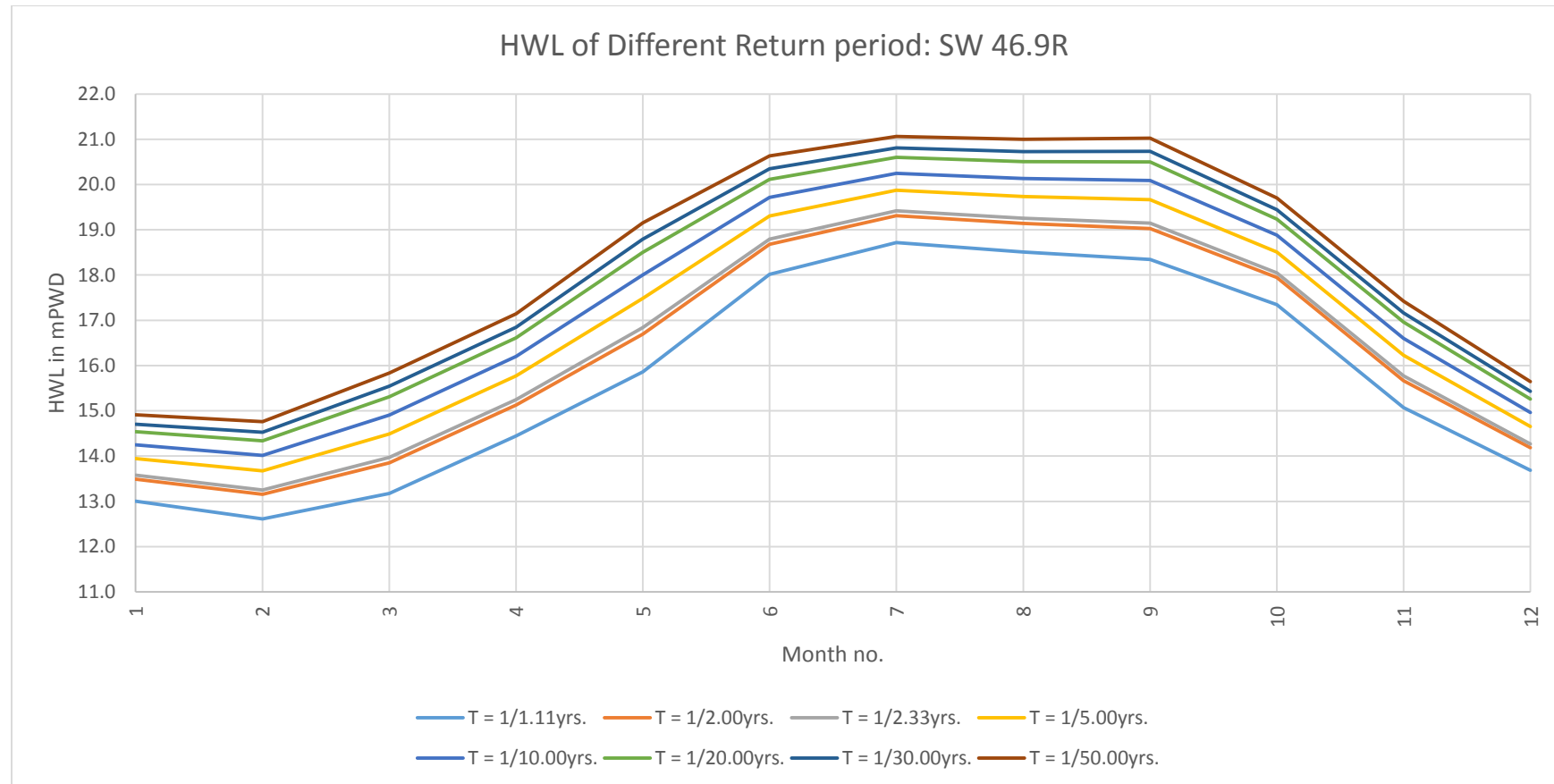
Monthly Basis Analysis of Data of Water Level Gauge Station SW 46



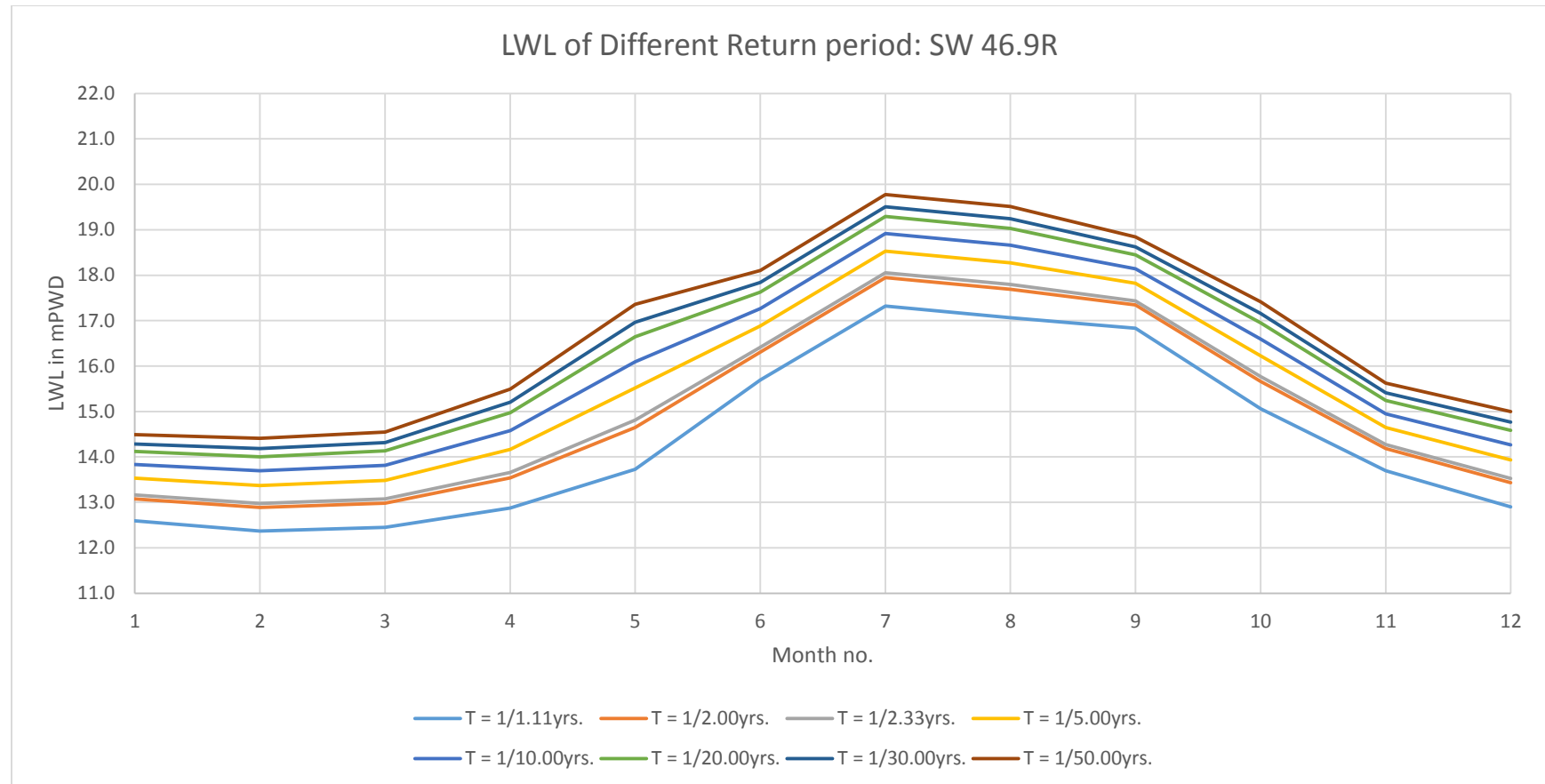
A.1b.2: Analyzed Results of BWDB Water Level Gauge Station SW 46.9R on the Brahmaputra River



Monthly Basis Analysis of Data of Water Level Gauge Station SW 46.9R



Monthly Basis Analysis of Data of Water Level Gauge Station SW 46.9R



Annexure-II: Instructions to Surveyors

Information to Be Collected During Bathymetric Survey and Physical Feature Survey:

1. During survey works, information regarding water levels should be collected. Information should include: a. Notable highest flood level (HFL) and lowest flood level (LFL) in the past. (ASK LOCALS) b. Notable Highest tide level (HTL) and lowest tide level (LTL) in the past. (ASK LOCALS) c. Present water level (PWL) during survey at the point of surveyed section should be measured.
2. Cross-sections should be collected at entry and exit of a bends of rivers, at centers of riffles of rivers at junctions with tributaries and distributaries and mouths of rivers, near locations of water level gauges and at locations of hydraulic structures.
3. GPS location of the surveyed section should be collected.
4. Local names of the rivers being surveyed and their tributaries (If any) should be collected. (ASK LOCALS)
5. Information regarding hydraulic structures has to be collected consulting with the government agencies likes BWDB, BADC, LGED and RHD. Information should include: a. Sill level of regulators, rubber dams, weirs and culverts. b. Opening of the structures. c. Storage level of water retention structures and dams. d. Information of the projects that funded the construction of the structures if possible to collect.
6. Consulting with the local people, information regarding flash flood has to be collected. Information should include: a. Number of incident(s) of flash flood in a year. b. Probable time(s) of flash flood(s) to occur. c. Duration(s) of flash flood(s). d. Areas that are more prone to damage inflicted by flash flood.
7. Information regarding water logging should be collected. Local people should be consulted in this regard. Information should include: a. Name of the areas experiencing frequent water logging problems. b. Duration of water logging. c. Local idea about cause of water logging.
8. Information regarding drains should include: a. Size of drains: (Depth X Width) b. RL of drains at different locations. c. Construction type of drains: i. Lined / Unlined ii. Man-made / Natural d. Method of connection of households to the drains. e. Location of different point of the drains: i. Starting points ii. Junction points iii. End points f. Name of roads alongside the drains, ward no. / name of village. g. Use of drains: i. Sewer ii. Storm-sewer iii. Mixed
9. Information regarding encroachment of drains and natural channels should be collected.

Table A2.1: Dumpy Level Reading Sheet

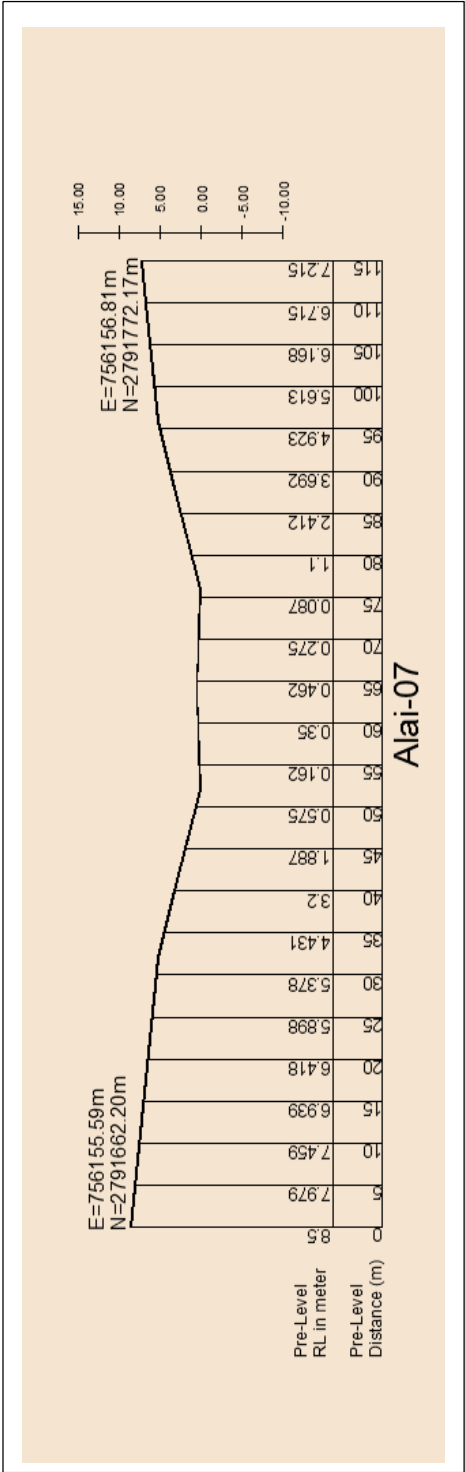
Ch.	Distance (m)		Staff Reading			Height of Instrument	RL	Remarks
(m)	(m)	(m)	BR (m)	IS (m)	FR (m)	(m)	(m)	

Table A2.2: Drainage Inventory

Upazila	Ward no.	By road	Reach	GPS location		RL (mPWD)		Reach Length	Depth	Width	Type
				Start	End	Start	End	(m)	(mm)	(mm)	

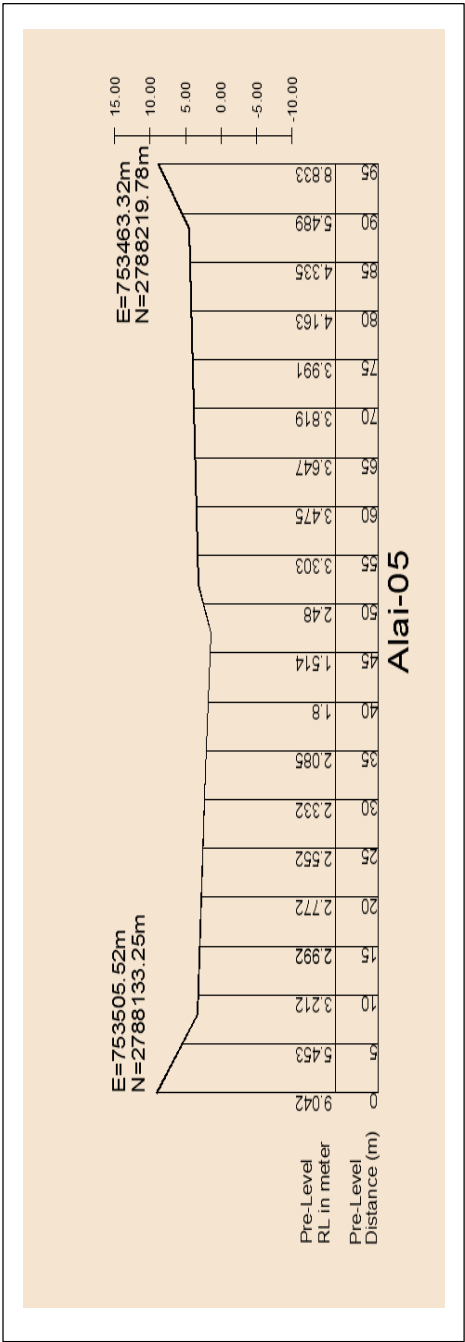
Cross-Sections of Rivers and Channels as Surveyed

Figure 1: Cross-Section of Alai River at Chainage of N=2791662.20m and E=756155.59m as Surveyed



Source: Field Survey, 2017

Figure 2: Cross-Section of Bangali River at Chainage of N=2788133.25m and E=753505.52m as Surveyed



Source: Field Survey, 2017

Annexure-III: Comments and Corrections of TMC Meeting Dated on 07.06.2017

Serial No.	Comments from TMC Members	Corrections Done by the Consultant of MEPC (Package-4)
1	In TMC meeting, an honorable TMC member raised a question about cross section either completed or postponed according to <i>Section 3.1: Survey of Main Rivers</i> of Hydrological Report for Saghata Upazila.	<p>Required correction has been revised by consultants of Modern Engineers Planners & Consultant Ltd and replaced in Page no 7 of the report.</p> <p>It also has been replaced the <i>Table of Content (page: iv)</i> and <i>Executive Summary (page: ii)</i> as these were correlated with the correction of page no. 7.</p>