Government of the People's Republic of Bangladesh
Bangladesh Water Development Board
Flood Plan Coordination Organisation

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

SPECIALIST STUDY

SURFACE WATER RESOURCES OF THE NORTHEAST REGION

Final Report
June 1995

SNC • Lavalin International
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services
Institute For Development Education and Action
Nature Conservation Movement

Canadian International Development Agency

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COVER PHOTO: A typical village in the deeply flooded area of the Northeast Region. The earthen village platform is created to keep the houses above water during the flood season which lasts for five to seven months of the year. The platform is threatened by erosion from wave action; bamboo fencing is used as bank protection but often proves ineffective. The single *hijal* tree in front of the village is all that remains of the past lowland forest. The houses on the platform are squeezed together leaving no space for courtyards, gardens or livestock. Water surrounding the platform is used as a source of drinking water and for waste disposal by the hanging latrines. Life in these crowded villages can become very stressful especially for the women, because of the isolation during the flood season. The only form of transport from the village is by small country boats seen in the picture. The Northeast Regional Water Management Plan aims to improve the quality of life for these people.

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ACRONYMS AND ABBREVIATIONS

BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CIDA	Canadian International Development Agency
FAP	Flood Action Plan
FCD	Flood Control and Drainage (only) Project
FCDI	Flood Control, Drainage and Irrigation Project
FPCO	Flood Plan Coordination Organization
GSB	Geological Survey of Bangladesh
GTS	Greater Triangulation (Survey) System Datum
IOH	Institute of Hydrology (United Kingdom)
JRC	(Indo-Bangladesh) Joint Rivers Commission
MPO	Master Plan Organization
NERP	Northeast Regional Water Management Project
NHC	Northwest Hydraulic Consultants
PMP	NERP Project Monitoring Programme
PWD	Public Works (Survey) Datum
SOB	Survey of Bangladesh
WARPO	Water Resources Planning Organization
WMO	World Meteorological Organization

NERP DOCUMENTS

The Northeast Regional Water Management Plan is comprised of various documents prepared by the NERP study team including specialist studies, the outcome of a series of public seminars held in the region, and pre-feasibility studies of the various initiatives. A complete set of the Northeast Regional Water Management Plan Documents consists of the following:

Northeast Regional Water Management Plan

Main Report
Appendix: Initial Environmental Evaluation

Specialist Studies

Participatory Development and the Role of NGOs
Population Characteristics and the State of Human Development
Fisheries Specialist Study
Wetland Resources Specialist Study
Agriculture in the Northeast Region
Ground Water Resources of the Northeast Region
Northeast Regional Model
Surface Water Resources of the Northeast Region
Regional Water Resources Development Status
River Sedimentation and Morphology
Study on Urbanization in the Northeast Region
Local Initiatives and People's Participation in the Management of Water Resources
Water Transport Study

Public Participation Documentation

Proceedings of the Moulvibazar Seminar
Proceedings of the Sylhet Seminar
Proceedings of the Sunamganj Seminar
Proceedings of the Sherpur Seminar
Proceedings of the Kishorganj Seminar
Proceedings of the Narsingdi Seminar
Proceedings of the Habiganj Seminar
Proceedings of the Netrokona Seminar
Proceedings of the Sylhet Fisheries Seminar

Pre-feasibility Studies

Jadukata/Rakti River Improvement Project
Baulai Dredging
Mrigi River Drainage Improvement Project
Kalni-Kushiyara River Improvement Project
Fisheries Management Programme
Fisheries Engineering Measures
Environmental Management, Research, and Education Project (EMREP)
Habiganj-Khowai Area Development
Development of Rural Settlements
Pond Aquaculture
Applied Research for Improved Farming Systems
Manu River Improvement Project
Narayanganj-Narsingdi Project Narsingdi District Development Project
Upper Kangsha River Basin Development
Upper Surma-Kushiyara Project
Surma Right Bank Project
Surma-Kushiyara-Baulai Basin Project
Kushiyara-Bijna Inter-Basin Development Project
Dharmapasha-Rui Beel Project
Updakhali River Project
Sarigoyain-Piyain Basin Development
Improved Flood Warning
Baulai River Improvement Project

FOREWORD

This report was first issued as a draft in May 1993. Following comments from FPCO, CIDA, BWDB and others, a second version was assembled in October 1994. Subsequently the second version was subjected to an internal review process. Following the review, the final version was prepared from selected parts of the two earlier versions with certain revisions, deletions and additions. Chapter 11 (Flood Frequencies) has been entirely re-written on the basis of revised analyses.

On the topics of geology, geomorphology, rainfall and runoff there is a certain amount of overlap between this report and the specialist report on River Sedimentation and Morphology. The partial duplication of coverage results in minor differences of opinion and interpretation. The opinions and conclusions expressed in the specialist reports are those of the authors; those of the project team are contained in the Regional Plan report.

Much use has been made of the hydrological data produced by the Bangladesh Water Development Board (BWDB) over the last three decades. Valuable inputs were also received from the UK Institute of Hydrology (IOH) regarding earlier rainfall data for gauges in the Northeast Region and adjacent tributary areas in India, from the Bangladesh Meteorological Department (BMD) regarding climate data, and from the Bangladesh Agricultural Research Council (BARC) regarding the production of potential evapotranspiration data.

The report consists of a Main Report with three Appendices, and two Annexes bound together in a separate volume.

EXECUTIVE SUMMARY

The report presents a quantitative evaluation of the surface water resources of the Northeast Region, as part of the Northeast Region Water management Project (FAP 6) under the national Flood Action Plan. Parallel studies covering other water resources topics, including groundwater and sedimentation, are listed under NERP Documents on page ii.

Chapter 1 describes the study framework and objectives, sources of data previous studies and the report arrangement. Chapter 2 describes the land and topography in relation to sources and distribution of water, with some reference to geological features. Chapter 3 described the climate in terms of annual and seasonal weather patterns that determine the availability of water. Chapter 4 describes rainfall and evapotranspiration, including spatial and temporal distributions of annual rainfall, seasonal distributions, water surpluses and deficits, and storm rainfall. The question of climatic change and long-term trends in rainfall statistics is considered, without definite conclusions.

Chapter 5 describes the river systems of the Region and the nature and limitations of available data on flows and water levels. Using data on rainfall, evapotranspiration and river flows, means annual water balances are established for the Region as a whole and for its constituent subregions. Using the results of the water balance studies, the relative significance of nine main rivers at sixteen locations is established in terms of mean annual flows.

Chapters 6 through 10 analyze the sequence the water resources of five main river systems—Barak, Kushiyara, Surma, Kangsha-Baulai and Old Brahmaputra-Megha—including their main stems and principal tributaries and distributaries. The geographical setting and gauging history of each stream are described briefly, and summary statistics are provided on historical and seasonal ranges of flows and water levels.

Chapter 11 analyzes flood frequencies in terms of four data series: annual maximum flows, pre-monsoon maximum flows, annual maximum water levels, and pre-monsoon maximum water levels. The nature and limitations of the available data are described, and methods of analysis and predictions are discussed. Maximum flows are analyzed for 30 stations and maximum water levels for 88 stations, results being shown graphically in appendices. Predicted maximum flows and water levels are tabulated for return periods ranging form 2 to 100 years.

GENERAL NOTES

1. River Names

River names may change along the course of a single river channel, and the same river name may occur several times in the Region even though the rivers are quite distinct. Particular examples are Dhalai and Dhaleshwari. In most cases the context and maps should clarify the situation.

2. Survey Datum

In this report all water levels are referred to the Public Works Datum (PWD), and expressed in metres.

The PWD is in use throughout the Northeast Region except on the Manu River Irrigation Project where, for unknown reasons, The Survey of Bangladesh's Greater Triangulation System (GTS) datum is used for all construction levels and for the river gauges at the barrage and pumping station; these levels are also given in feet. Levels in feet GTS are converted to mPWD using:

$$\text{mPWD} = \text{feet GTS}/3.2808 + 0.457 \text{ m}$$

The GTS datum is sometimes referred to also as the SOB (Survey of Bangladesh) datum, and it is identifiable with mean sea level. PWD elevations are 0.457 m (1.51 feet) higher than SOB elevations.

In 1993 and 1994 a second-order levelling program was conducted by Survey of Bangladesh as part of the Northeast Regional Water Management Project. It's purpose was to check the datum of the active water level gauges in the region and to install and survey a network of new benckmarks to second-order accuracy for use in future projects. Elevations were surveyed from existing SOB first-order benchmarks and were published in mGTS. For consistency with common practice these elevations have been converted to mPWD.

4. Availability of Indian Data

It was found difficult to obtain sufficient hydrological data for Indian basins tributary to the Northeast Region. This difficulty applies to all Indian hydrometeorlogical data of relevance to Bangladesh.

4. Definition of Seasons

Throughout this report the seasons are defined as follows:

Season	Calendar Period
Pre-monsoon	April and May
Monsoon	June through September
Post-Monsoon	October and November
Dry	December through March

5. Water Year

In Bangladesh climatological data are organized on a calendar year basis, but hydrological data are organized on a water year basis. The Bangladesh water year begins on 1 April and ends on 31 March, and so it runs 3 months later than the calendar year. This difference is apt to cause confusion when, say, comparing annual mean rainfalls to annual mean runoffs. Also, water leap years occur one year earlier than calendar leap years. Re-organization of the hydrological data base on a calendar year basis would be consistent with current international hydrological practice and with easier utilization of the data in conjunction with climatological and agricultural data.

6. Averaging

In this report monthly values are frequently averaged to obtain the corresponding mean annual value. This averaging is done on a day-weighted basis, taking account of the inequality in lengths of calendar months.

7. Period of Hydrometric Data

Chapters 1 through 10 were developed using data from 1964 to 1990 or 1991 (or less, depending on the gauge). The data base has subsequently been extended up to the end of July 1993 which effectively adds three years of data. Chapter 11 (the revised flood frequency analysis) and Annex B (Hydrological Data Summaries) have been updated to include the extended data base and second-order levelling adjustments. Chapters 1 through 10 are not materially affected by these changes.

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1. INTRODUCTION

1.1 Study Framework

Bangladesh has an area of 148,000 km^2 (BBS, 1992) of which 120,400 km^2, or 81%, lies within the world's largest delta, that of the Ganges, Brahmaputra and Meghna rivers (Figure 1.1). The lower Brahmaputra is generally known as the Jamuna in Bangladesh.

The delta floods every year during the monsoon season, and in some recent years the scale of the flooding has been disastrous (Figure 1.2A). Following the flooding of 1988 the Flood Action Plan (FAP) was initiated to develop improved water management. Work under the FAP is coordinated by the Flood Plan Coordination Organization (FPCO 1992) which has divided the work into components. Several of these components are concerned with water management at the regional level, and for this purpose the FPCO has divided the country into regions separated by its main rivers (Figure 1.2B). The Northeast Regional Water Management Project (NERP) is the sixth component of the FAP, or FAP 6, and its purpose is to plan improved water management for the Northeast Region of the country.

1.2 The Northeast Region

The Northeast Region is defined as the area east of the Old Brahmaputra/Lakhya river channel, and north of the Upper Meghna river channel and the Titas river basin (Figure 1.3). It comprises an area of 24,265 km^2, and constitutes 17% of the country and 20% of its deltaic sector. It can be divided conveniently into two distinct subregions, the larger Meghna Subregion in the east comprising 20,261 km^2 or 83.5% of the Region, and the smaller Old Brahmaputra Subregion in the west comprising 4,004 km^2 or 16.5% of the Region.

Although the two Subregions experience essentially the same climate and are similar geologically, they differ hydrologically. The Meghna Subregion receives many flash floods from the adjacent Indian states of Tripura which lies south of the Region, and Meghalaya which lies to the north; it also receives the substantial outflow of the Barak River basin which lies to the east and occupies parts of the Indian states of Assam, Mizoram and Manipur. In contrast, the Old Brahmaputra Subregion mainly receives flood waters spilling into it from the Brahmaputra River.

Characteristically, the Northeast Region is flood-affected during the wet season, and affected by soil moisture deficits in the dry season. Wet season flooding involves inundation of much of the Region particularly in the central part of the Meghna Subregion where the depth of inundation ranges up to about 7 metres in the lowest-lying areas. Irrigation is required during the dry season.

1.3 Study Purpose

The purpose of this study is to describe and assess the surface water resources of the Northeast Region. The specific objective is to quantify the surface water resources with particular reference to the land, the climate, rainfall and evapotranspiration, river discharges and water levels.

The present report covers surface water only. Ground water is dealt with in the NERP Specialist Report: Ground Water Resources of the Northeast Region.

1.4 Primary Data

Two sources of primary data on surface water exist in Bangladesh. The principal source is the Bangladesh Water Development Board (BWDB) which collects most primary data on river water discharges and water levels, and much data on rainfall and pan evaporation. The BWDB monitoring networks in the Northeast Region are quite extensive in terms of areal coverage but generally produce only daily daytime manual observations. The Bangladesh Meteorological Department (BMD) also collects data on daily rainfall and pan evaporation but from a much sparser monitoring network; it collects daily data on most other climatic variables entering into the estimation of potential evapotranspiration, but data on solar radiation are conspicuously lacking. The data are summarised in tabular form in the text, and more extended summaries are given in Annexes A and B.

1.5 Preceding Studies

The principal studies consulted were the National Water Plan originally drawn up by the Master Plan Organisation (MPO 1987, 1991), and the Pre-Feasibility Study for Northeast Rivers Flood Protection (NHC/SARM 1986).

There are also various reports by engineering consultants relating to specific water resource development projects in the Northeast Region. A few of those are referenced in Appendix C of the above-referenced Pre-Feasibility Study.

1.6 Arrangement of Report

Chapter 2 describes the land and topography of the Region in relation to its water resources. Chapter 3 discusses the climate in general terms, and Chapter 4 presents regional information on rainfall and evapotranspiration. Chapter 5 discusses the river systems, the available river gauging data, the results of water balance analyses, and the relative significance of the main rivers.

Chapters 6 through 10 respectively present analyses of the surface water resources of five designated river systems of the Region: Barak, Kushiyara, Surma, Kangsha-Baulai and Old Brahmaputra-Meghna. In each chapter, summary statistics on annual and seasonal flows and water levels are tabulated for each of the gauged channels of the system.

Chapter 11 describes frequency analyses of maximum annual and pre-monsoon flows and water levels. Summary tables present predicted annual maximum flows and water levels at selected return periods, for all gauging stations with sufficient length of record.

References and bibliography are listed at the end of the main text.

Appendix A contains a number of data and analysis tables, additional to the tables in the main text. Appendix B contains frequency plots for all analyzed maximum flows as summarized in Chapter 11. Appendix C contains similar plots for maximum water levels.

Appendix D contains the report Figures.

There are two Annexes in one separate volume. Annex A contains rainfall and evapotranspiration data, and Annex B contains data on river flows and water levels.

2. LAND AND TOPOGRAPHY

2.1 Introduction

The land of the Northeast Region (24,265 km^2), and of its adjacent tributary areas (another 45,574 km^2), plays an important role in determining the spatial distributions of rainfall, evapotranspiration, surface and ground waters within the Region. This role is asserted mainly by the varied topography of the land, but the underlying geological materials and the overlying vegetative covers also influence these distributions. The properties of the land, especially its topography, are in turn functions of the extremely complex geophysical/geological history of the region.

The processes which have led to the present form of the Region and its adjacent tributary areas are complex and still active. The activity manifests itself in two ways of concern to water resource development and management:

1) it is widely believed, though yet to be convincingly proven, that the Northeast Region is slowly subsiding, the subsidence being at a maximum along the Region's northern border;

2) it is definitely known that the Northeast Region is seismically active, earthquakes of recent decades having produced some unusual phenomena at the surface, in the form of surficial mounds of sediment squeezed up from subsurface fissures.

Both the subsidence and the seismicity impinge on the movement of surface and ground waters, and on the engineering of infrastructure, particularly flood protection works.

2.2 Topography and Geological Origins of Bangladesh

While Bangladesh, including its Northeast Region, is mostly located on the low-lying, relatively featureless deltaic plains of the Ganges/Brahmaputra/Meghna river system, more or less high land exists to the west, east and north of the country. These highlands exert a potent influence on the climate, weather and hydrology of Bangladesh.

The general topography is shown in Figure 2.1. To the west lies the Indian Shield, a region of moderate relief the northeastern extremity of which comprises the Rajmahal Hills of West Bengal; elevations in these hills range from 100 m to 1000 m. To the southeast lie the Indo-Burman Ranges which increase in peak elevation from about 80 m near Comilla in the west to over 2000 m near Kohima in the northeast. To the north lie, in southward order:

- the east-west oriented Himalayas wherein elevations increase rapidly northwards to around 8000 m, and reach 8848 m on Mt. Everest - the world's highest mountain.

- the east-west oriented valleys of the Middle Ganges in the west, and of the Middle Brahmaputra in the east; in these valleys elevations do not exceed 100 m except where two outliers of Pre-Cambrian age igneous rock occur just north of the Brahmaputra, opposite Goalpara, and form two groups of inselberg-like hills with elevations of up to 455 m and 525 m.

2d

- the east-west oriented Shillong Plateau, and the associated Tura Range in the west and Mikir Hills in the east; the maximum elevation on the Plateau is almost 2,000 m.

Between the Rajmahal Hills and the Tura Ranges lies the Rangpur Saddle - a relatively low topographical feature over which the Ganges and Brahmaputra rivers flow on entering Bangladesh.

2.3 Topography of the Northeast Region and Adjacent Tributary Areas

The Northeast Region and its adjacent tributary areas constitute the river basin of the Upper Meghna River. Within this river basin are five topographically and geologically very distinct areas (Figure 2.2):

1) the northern Indo-Burman Ranges lying to the southeast of the Northeast Region, but including the Region's Tripura border area - a strip of land some 30 km wide along the Region's southeastern border;

2) the southern slopes of the Shillong Plateau lying north of the Northeast Region, but towards the northeast;

3) the Tura Range lying north of the Northeast Region, but towards the northwest;

4) the Madhapur Tract lying to the southwest of the Northeast Region;

5) the Northeast Regional Plain comprised of the Northeast Region itself, except for its Tripura border area.

2.3.1 Indo-Burman Ranges

The Indo-Burman Ranges consist of a series of long, narrow north-south oriented anticlinal ridges. The most westerly of these ridges runs along the longitude of Comilla (91°E), and the rest occur at intervals of about 15 km eastwards at least to the longitude of Kohima (94° E). Maximum elevations of the ridges occur approximately along latitude 23° 30' N, and they increase eastwards from about 80 m near Comilla to around 2700 m near Kohima. The ridges plunge northwards from the latitude of their greatest elevation, and disappear beneath the Holocene sediments of the Northeast Region at a distance of about 30 km northwest of the Region's border with Tripura. They are known from seismic investigations to continue northwards beneath both the Northeast Region and the Cachar Plain, to the foot of the Shillong Plateau; some geologists believe that the ridges are deflected eastwards in this area (Johnson and Alam, 1991) but geophysical mapping (Rahman et al, 1990) does not support this belief.

The ridges are heavily eroded and present an almost knife-edge appearance in many places, particularly towards the east; the erosion products have filled the intervening synclinal valleys to a large extent and, as a result, the valleys are typically wide and flat-bottomed. From the latitude of maximum elevation of the ridges (23° 30' N) the valleys west of Tipaimukh fall and open northwards, and all the rivers draining these valleys flow northwards into either the Northeast Region or the Cachar Plain; east of Tipaimukh, however, the rivers predominantly flow southwards, apparently due to the intrusion of the Mt. Javpo volcano (now extinct) at the end of the Pliocene and the consequent uplifting of the ridges towards the northeast.

The rivers flowing between the Ranges often cut, always westward, from one synclinal valley to the next; river capture has, no doubt, been involved in this cutting but it has occurred where cross-faulting provided the rivers with exploitable zones of weakness in the bedrock. The existence of significant cross-faults in the Ranges is also suggested by other major topographical/hydrological features, notably Hail Haor, Kawadighi Haor and Hakaluki Haor.

2.3.2 Shillong Plateau

The Shillong Plateau rises to a height of 1975 m above sea level, and presents a very steep face towards the south. This face extends southwards from the edge of the Plateau surface to the Dauki Fault at its foot; thus most of the 2000 m rise from the plain of the Northeast Region to the top surface of the Shillong Plateau occurs in a very short distance, typically in the order of 15 km. The face is draped with Cretaceous limestone dipping at 55° to the south; many springs emerge from this limestone and sustain high waterfalls, some of which can easily be seen from the Bangladesh side of the border. One of those, in the Umium Valley, has been developed recently by India as a small hydropower project (Ahmad et al, 1994).

The southern face of the Shillong Plateau has been deeply incised by a number of rivers, most notably the Jadukata which drains much of the southwestern portion of the Plateau. The valleys of these rivers, together with the intervening ridges, comprise topographic "traps" in which moisture laden air from the south is forced to rise very rapidly before passing northwards over the Plateau. Not surprisingly, therefore, some of the world's heaviest rainfalls occur in these valleys; Cherrapunji, on the ridge between the Umium and Dhalai (N) rivers has long claimed the world's records for rainfalls of durations of 3 hours and more (Table A2.1), and even higher rainfalls are now claimed to occur at Mawsynram, some 30 km west of Cherrapunji on the ridge between the Umium and Jhalukhali rivers.

Corresponding to the steep land slopes on the southern face of the Shillong Plateau are steep river bed slopes. The steepness of the dendritic (convergent) river networks, coupled with the high rainfall, results in the generation of flash floods in all the valleys draining from the Plateau into Bangladesh.

2.3.3 Tura Range

The Tura Range consists of Eocene-age sediments, predominantly the Tura Sandstone, which have been folded into a prominent anticline (Khan, 1991). The Range runs west-northwest to east-southeast along the south-southwestern edge of the Shillong Plateau. As a result of erosion the Range is now quite narrow, sharp-crested, and has very steep slopes. Its maximum elevation (1413 m) occurs just east of the town of Tura in West Meghalaya; from there the crest of the range descends gradually towards the mouth of the Jadukata River where it terminates at the Dauki Fault. To the south-southwest the Range gives way to the Neogene plains of West Meghalaya; these plains feature inselberg-like low hills which are possibly the eroded remnants of lesser folds in the Eocene sediments running parallel to the Tura Range anticline.

The Tura Range is cut through by only one river, the Someswari, which flows along the north-northwestern foot of the Range for a considerable distance before passing through the Range at the Someswari gorge and on southwards into Bangladesh.

2.3.4. Madhapur Tract

The Madhapur Tract lies to the southwest of the Northeast Region between the Jamuna (present Brahmaputra) and Old Brahmaputra rivers. It consists of an extensive (4105 km^2) tabular slab of Holocene-age clay; although it is nowhere higher than 25 m PWD, it always remains above seasonal flood levels, although some ponding on its surface occurs locally.

Possibly as recently as 200 years ago, torsional movement on the inferred Dubri Fault, which underlies the present course of the Jamuna (Brahmaputra), resulted in the Madhapur Tract and its outliers being tilted slightly towards the north and the Barind Tract being tilted slightly towards the south (Morgan and McIntyre, 1959). Associated echelon faulting is seen in the Madhapur Tract, more particularly along its western side.

About 1790 a major earthquake caused a major change in the course of the Brahmaputra River. Formerly it had flowed around the western end of Meghalya, as it does today, but it had then followed the course of the present Old Brahmaputra to meet the Upper Meghna at Bhairab Bazar (Figure 1.3); in the process, it eroded away the eastward extension of the Madhapur Tract and replaced it with the extensive alluvial fan deposits which are seen today emanating from the vicinity of Bahadurabad southeastwards towards Bhairab Bazar. Subsequent to this earthquake the main flow of the Brahmaputra exploited the zone of weakened bedrock over the Dubri Fault to establish the present course of the Jamuna Brahmaputra, and it eroded away the Holocene clays which formerly joined the Barind and Madhupur Tracts. As a result, the former river course from Bahadurabad to Bhairab Bazar was largely abandoned; today it carries only about 3% of the Brahmaputra's flow (as spill), plus local runoff from the Madhapur Tract to the west and from the alluvial fan deposits to the east of the Old Brahmaputra. Abandonment of the lower course of the Old Brahmaputra, between Toke and Bhairab Bazar, was almost total; today flow occurs in this lower course only during the highest floods, and all other flows coming down the Old Brahmaputra pass into the Lakhya, which closely follows the eastern edge of the Madhapur Tract.

2.3.5 Northeast Regional Plain

The Northeast Region, except for its Tripura border area, consists of a deltaic plain which is basically a triangle in plan (Figure 1.3). The apices of this triangular area may be identified with:

- the bifurcation, just north of Bahadurabad in the northwest, of the Brahmaputra River into the Jamuna and Old Brahmaputra Rivers;
- the bifurcation, at Amalshid in the northeast, of the Barak River into the Kushiyara and Surma Rivers;
- the confluence, near Satnal in the south, of the Old Brahmaputra/Lakhya/ Dhaleshwari and Meghna Rivers.

The topography of this plain, all of which lies at elevations below approximately 25 m PWD, is characterized by low relief and by deltaic morphological features. The surface geology consists exclusively of alluvial and swamp sediments of late Holocene age. Throughout the plain the topography consists of a three-dimensional alternation of :

1) river channels;

2) natural river levees along the river channel banks;

3) inter-riverine depressions, known as *haors*, which occupy most of the area.

Channels

Characteristically, the river channels are of triangular (rather than trapezoidal) section, a reflection of the fact that they are continually meandering. Oxbows and old abandoned meander courses are frequently seen features of the landscape - especially on satellite photos of the Region; the frequency of such features increases southwestwards towards Bhairab Bazar on the Meghna River. The beds of these channels are below mean sea level over much of the lengths of the Meghna, Kushiyara and Surma Rivers. As a result, these river channels constitute the most natural and effective routes of access into the Region for navigation and fish migration. In colonial times steamers ran regularly along both the Meghna/Baulai/Surma/Barak and Meghna/Kushiyara/Barak routes to Silchar in India, serving such towns as Sylhet and Moulvi Bazar enroute. Small ocean-going cargo vessels still penetrate as far as Chhatak and Sylhet on the Baulai/Surma route but cannot penetrate far up the Kushiyara due to heavy deposition of sediments in this river in recent years. Among the many aquatic species using these channels are dolphins which are still commonly seen as far upstream on the Baulai/Surma as Sunamganj, and on the Kushiyara as far as Sherpur, and which feed on the larger species of migrant fish inhabiting the main rivers.

Levees

Natural levees (linear mounds of sediments deposited by the rivers when in flood) are found beside every river in the Northeast Region; they are a feature of current river channels and abandoned courses. The levee crests rarely exceed an elevation of about 10 m PWD and consequently are less apparent in the Meghalaya and Tripura border areas; they do, however, exist in these areas. The levees have great social significance because they provide the only relatively flood-free base upon which to found a village; characteristically, villages of the Northeast Region comprise linear developments on top of the levees. Where the levees are not high enough, villagers have placed earth on top of them to form a *kanda* (see cover picture).

Haors

Between the river channels are inter-riverine areas called *haors* which consist of dish-shaped depressions within a perimeter consisting of natural river levees. The haor lands include the lower external slopes of the levees, which merge at a central location to form an extensive inter-riverine depression. The haor lands lie, in general, at elevations between sea level and + 5 m PWD, and are flooded from the surrounding rivers every year during the monsoon whether they are still in their natural state or have been enclosed by submersible embankments.

Static water bodies, known as *beels*, are found at the centre of virtually every haor in the dry season. These beels are in contact with the ground water in the underlying sediments; where the water table remains above ground level in the dry season the beels are permanent, but where it falls below ground level the beels are seasonal. In many cases the beels are connected to nearby rivers by channels known as *khals*, but in some cases they are isolated from the river system. In the wet season, river floods overtop the levees and back up the khals until the haors are completely under water. At the peak of the monsoon season only the highest segments of the levees, on which the villages are mainly built, remain above water. As seen from the air in this season the central part of the Region is one large lake the perimeter of which runs roughly through Bhairab Bazar, Kishoreganj, Sunamganj, Chhatak, Sherpur, Habiganj, and back to Bhairab Bazar. Large areas are also flooded to the east of the central basin between Chhatak, Sylhet, Amalshid, and Moulvibazar. Smaller areas are flooded in the Kangsha basin which lies to west of the central basin. Figure 1.3 shows the approximate extent of flooding in 1988.

The haors comprise the prime agricultural land of the Region, but their seasonal inundation severely constrains agriculture. In most Haors a *boro* (dry season) rice crop only can be grown, and this is liable to damage by flash flooding usually in the pre-monsoon season, but also earlier as in February 1993 and 1994. The haors also comprise an important part of the Regional fisheries environment. When the haors flood over at the beginning of the monsoon fish migrate into them to feed and/or spawn, and as the haors drain in the post-monsoon period the fish migrate back into the main river system. Also, during the monsoon the haors are mostly navigable by country boats, and they offer commercial boatmen many advantageous short routes between local towns and villages.

Embankments of two types have been constructed around about half the haors in the Northeast Region. The most common type is the submersible embankment, intended to provide flood protection to the boro crop up to 15 May by when it is normally harvested. A few full-height embankments have also been constructed to provide year-round protection to all crops.

Submersible embankments normally contain one or several regulators, which are closed while the boro crop is on the land and then opened on 15 May to flood the haors before the embankment is over-topped by monsoon flooding. The purpose of flooding the haors via the regulators is to limit erosion of the embankments during over-topping by ensuring that the water level difference across the embankment does not exceed 30 cm when over-topping begins.

While the hoar embankments usually protect boro rice crops from flooding in the dry and pre-monsoon (harvest) seasons, the structures can cause problems. Farmers, fishermen and boatmen sometimes respond by cutting the embankments to enable land drainage in the post-monsoon period, to allow fish catches at the cuts (usually in the pre-monsoon period), and to provide shorter routes for country boats during the monsoon. If the cuts are not repaired during the dry season the boro crops are at risk of damage in the pre-monsoon season.

After transplantation of the boro crop in January, residual soil moisture can provide the crop water requirement for several weeks, but by late February it is usually necessary to irrigate. In the Northeast Region, about half the water for irrigation is obtained by pumping from the beels using low lift pumps. Haor regulators are usually partially closed in the post-monsoon season to retain water which would otherwise drain out of the haor, sufficient for this irrigation. The other half of the irrigation water requirement is obtained from wells, particularly in the western half of the Region.

3. CLIMATE

3.1 Introduction

Climate plays the main role in determining temporal distributions of rainfall, evapotranspiration, surface and ground waters. The Northeast Region is located entirely to the north of the Tropic of Cancer, hence its monsoon climate is described as sub-tropical. The sub-tropical monsoon climate tends to have more sharply defined seasons than the tropical one.

3.2 The Monsoons

The sub-tropical monsoon climate of the Northeast Region is characterised by a twice-yearly reversal of air movement over the region. For about four months in winter December through March) air flows from the northeast, while for about four months in summer (June through September) it flows from the southwest. These air flows are called monsoons, that of winter being the "northeast monsoon" while that of summer is the "southwest monsoon". Agricultural activity is closely linked to the monsoon periods, *rabi* crops (mainly *boro* rice) being cultivated with irrigation during the dry northeast monsoon, while *kharif* (almost exclusively *aus* and *aman* rice) are grown during the southwest monsoon when rainfall is abundant.

Southwest Monsoon (Wet Season)
The southwest monsoon brings moist air into the Northeast Region from the Bay of Bengal along a circular route over the Chittagong Region so that this air actually approaches the Region from the southeast. Rainfall in this season is abundant and it is often referred to as "the monsoon", meaning the rainy season. Typically, rainfall increases northeastwards across the Region and reaches a maximum on the southward-facing slopes of the Shillong Plateau in Meghalaya; Cherrapunji, on these slopes, is well known as the wettest place on Earth, its annual rainfall often exceeding 12 metres (Table A2.1). The distribution of the annual rainfall over the Region and adjacent tributary areas in India strongly reflects the interaction of the southwest monsoon with the regional topography, particularly the Shillong Plateau (Figure 3.1). Across the Northeast Region rainfall during the southwest monsoon ranges from around 1500 mm (about 64% of the annual total) in the southwest to around 4100 mm (about 74%) in the northeast at the border with Meghalaya (Figure 3.2). Floods occur frequently and the central part of the Region is always flooded to a depth of several metres.

Northeast Monsoon (Dry Season)
The northeast monsoon brings dry air directly into the Region from China. Dry season rainfall ranges from around 80 mm (4%) in the southwest of the Region to around 220 mm (3%) in the northeast (Figure 3.2). River discharges are greatly reduced.

Inter-Monsoon Transitions (Pre- and Post-Monsoon Seasons)
A reversal of the monsoons takes about two months. The first reversal occurs in April-May when the change of regional wind direction is from northeast to southwest via northwest, and the second occurs in October-November when the change is from southwest to northeast via southeast. These periods of changing wind direction are called the pre-monsoon and post-monsoon seasons.

The pre-monsoon season is characterised by increasing rainfall as the spring reversal progresses, the rainfall ranging from around 490 mm (24%) in the southwest to around 1290 mm (18%) in the northeast (Figure 3.2), and by flash floods of increasing frequency.

The post-monsoon season is characterised by decreasing and more sporadic rainfall, the rainfall ranging from around 170 mm (8%) in the southwest to around 320 mm (6%) in the northeast (Figure 3.2), and by the draining of flood water which has accumulated during the monsoon season.

Definition of the Seasons in Bangladesh
In Bangladesh the water year is defined as beginning on 1 April and ending on 31 March, and it is divided into four more or less distinct seasons:

Pre-Monsoon	:	April and May
Monsoon	:	June through September
Post-Monsoon	:	October and November
Dry Season	:	December through March

The seasons as defined above tie in with the normal dates of onset and withdrawal of the monsoon rains as indicated in Figure 3.3. These dates can depart from the normal by up to two weeks or so either way.

Associated Transient Weather Systems
During the two monsoon periods weather conditions are relatively stable. In contrast, during the spring and autumn reversals unstable weather conditions can arise and are mainly responsible for the occurrence of disasters. The severe weather conditions are basically of two types: tropical cyclones, known locally as "cyclones" or *tufan*, and the line squalls, know locally as "nor-westers" or *kalbaishakhi*.

Most rainfall in Bangladesh occurs during the southwest monsoon and is associated with the formation of tropical depressions in the Bay of Bengal and their movement from the Bay onto the sub-continental land mass (Figure 3.4B). These depressions may form anywhere in the Bay, and they often move northwestwards onto the east coast of India; the more southerly their place of formation, and the more southerly their track of movement, the less likely they are to affect Bangladesh.

The frequency with which tropical depressions affect Bangladesh is indicated in Figure 3.4A which shows that their frequency is low in April, rises sharply in May, then rises more steadily through the period of the southwest monsoon until it reaches a maximum in September; thereafter, the frequency declines rapidly through October to December to reach its minimum (zero) in March. The severity of the depressions also varies markedly on a seasonal basis, as also indicated in Figure 3.4A; in May, and in October through December, there are strong tendencies for the depressions to deepen and develop into tropical cyclones.

Tropical cyclones can occur during both the pre-monsoon and post-monsoon reversals and with more or less equal severity in both seasons (Figure 3.4A). The cyclone which struck Bangladesh on 29 April 1991 was a particularly severe example of a spring cyclone. The effects of cyclones on the Northeast Region, however, are not nearly as severe as in the southern parts of the country. This is due to the fact that the moisture supply which fuels a cyclone is cut off as soon as it moves over land. The Northeast Region, being some 300 km inland (Figure 1.2B) is spared the full force of cyclones. It is however, affected by the tropical depressions into which the cyclones degenerate after crossing the coastal areas; the remnant of the cyclone of 29 April 1991 entered Tripura and the Northeast Region, causing flooding on an unprecedented scale.

Nor-westers are particularly prevalent during the pre-monsoon reversal although they may also occur during the dry season. The one of 28 January 1992 caused a large dust-storm, and those in January and February 1993 and 1994 caused flash floods. Such flooding is particularly prevalent during the spring reversal when the most important crop, boro rice, is either still standing in the fields or under harvest. When, as in February 1993 and 1994, such floods occur just after the boro crop is transplanted, they cause considerable damage.

3.2.1 Driving Mechanisms of the Monsoons

Basically, the monsoon air flows are driven by the alternate heating and cooling of the Asian and Australian/Indonesian land masses, consequent upon the seasonal movement of the sun. Atmospheric circulation conditions in January and July are summarized below and illustrated in Figure 3.5.

January

The sun is farthest south on 22 December and nearest the Earth on 3 January. In January surface temperatures reach a minimum over western China, and a maximum over northern Australia/Indonesia. In China air descends in a massive high pressure system, and in Indonesia air ascends in a massive low pressure system. Since these pressure systems lie on opposite sides of the Equator, the near-ground circulations of air around them are clockwise in both cases. As a consequence cool dry air flows out of the Chinese high following a northeast to southwest track over Bangladesh, which then experiences its dry season; at the same time warm moist air flows into the Indonesian low following a west to east track over that country, which then experiences its wet season. A change in wind direction from northeast to west occurs over the eastern Indian Ocean; this change occurs rapidly between Sri Lanka and the Equator, where cool dry air from China is warmed and moistened prior to its entry into Indonesia. Within Indonesia this air is lifted within the Inter-Tropical Convergence Zone (ITCZ), in which winds of contrasting direction meet, and rainfall there is copious.

July

The sun is farthest north on 21 June and farthest from Earth on 5 July. In July surface temperatures reach a minimum over Australia, and a maximum over northwestern India. In Australia air descends in a massive high pressure system, and in India it ascends in a massive low pressure system. Since these pressure systems lie on opposite sides of the Equator, the near-ground circulations of air around them are anti-clockwise in both cases. Cool dry air flows out of the Australian high following a southeast to northwest track over Indonesia, which then experiences its dry season; at the same time warm moist air flows into the Indian low following a southeast to west track over Bangladesh and eastern India which then experience their wet season. These differences in wind direction imply a change in wind direction over the eastern Indian Ocean. This change involves a double change of direction from southeast to southwest near the Equator, and from southwest back to southeast near Bangladesh. While this monsoon approaches Bangladesh from the southwest, it veers rapidly in the Bay of Bengal/Burma. Surface winds over Bangladesh, particularly its Northeast Region, are then generally from the southeast. In its passage over the eastern Indian Ocean the cool, dry air from Australia is warmed and moistened prior to its entry into Bangladesh/India where it is then lifted in the ITCZ and yields abundant rainfall.

3.2.2 Inter-Seasonal and Intra-Seasonal Variations

There are significant differences between:

- the seasonal rainfalls of different years (inter-seasonal variations)
- rainfalls occurring during periods within a single season (intra-seasonal variations)

These variations, mainly apparent in but not confined to the monsoon season, have considerable impact on the success or otherwise of agricultural activities from year to year.

Inter-Seasonal Variations

Inter-seasonal variations in the rainfall derive from inter-annual variations in the monsoon circulation. These, in turn derive from movements of the so-called "Walker Circulation" - a series of major convective cells distributed around the Equator.

In normal years the Walker Circulation is characterized by ascending air flows and high rainfall over Africa, East Indonesia/Papua New Guinea, and South America - Figure 3.6(a). These are years of normal or above normal rainfall over Bangladesh.

Every 4 to 7 years on average, the Walker Circulation is disturbed by the so-called El Nino phenomenon - a major shift in the structure of ocean currents off South America. The whole Walker Circulation then shifts eastwards so that the areas of ascending air and maximum rainfall become located over the Western Indian Ocean and over the central Pacific and Atlantic Oceans - Figure 3.6(b). Rainfall over Bangladesh is reduced below normal.

Intra-Seasonal Variations

Within every monsoon season there are active and passive periods with respect to rainfall.

During active periods the main zone of upward movement in the atmosphere is located over Bangladesh, particularly its Northeast Region. During these active periods rainfall is particularly heavy as indicated in Figure 3.6 (c).

During passive periods the main zone of upward motion in the atmosphere is located south of Bangladesh, and rainfall over the country generally is somewhat diminished - Figure 3.6(d).

3.3 Severe Weather Disturbances

The severe weather disturbances, associated with the pre- and post-monsoon seasons, are tropical cyclones and nor-westers.

3.3.1 Tropical Cyclones

Tropical cyclones are the most energetic of the transient weather systems occurring in the tropics, and they normally have a devastating impact on coastal areas and islands lying in their path. The entire coast of Bangladesh, from the Sunderbans in the west to the Teknaf Peninsula in the southeast, is exposed to tropical cyclones and where they come ashore a huge loss of lives and extensive serious damages normally occur. The tropical cyclone of 29 April 1991 (Figure 3.7) caused the loss of 138,000 human lives, some 500,000 head of cattle and virtually all smaller livestock in a 20 km wide strip along the coast of the Chittagong Region (Figure 1.2A); in addition some 20,000 homes were destroyed and much infrastructure, particularly roads and power lines, was heavily damaged.

Tropical cyclones are referred to in the South Asian region simply as "cyclones". "Hurricane" and "typhoon" are terms used in the Caribbean and Far East to describe the same phenomenon. In Bengali the term *tufan*, derived from "typhoon" is used.

Tropical cyclones are characterised by:

1) a spiral cloud structure organised around a central core; the core features a circular "eye" of clear calm weather (no cloud or wind) surrounded by an annular "wall" of intense cloud and high winds; the diameter of the eye is typically about 50 km, the thickness of the wall 25 km, and the spiral "arms" may extend out from the wall to a distance of 1000 km or more.

2) extremely high winds which are at a maximum along the outer edge of the wall.

3) extremely low atmospheric pressure under the wall; called the central pressure, it is typically 900 mb or less; a consequence of this low pressure is a corresponding rise in sea level under the wall, and when the cyclone reaches its landfall a tidal wave is released onto the land.

4) extremely high rainfall in the vicinity of the wall; this high rainfall implies the release of a tremendous amount of latent heat of condensation, which drives and sustains the cyclone; however, rainfall decreases rapidly away from the wall (Table A3.1).

Tropical cyclones originate over tropical oceans where the following essential conditions must co-exist:

1) ocean water surface temperature exceeding 26° to 27° C

2) sufficient Coriolis force

3) a small change of wind speed with height

The high ocean surface temperatures are required to sustain a sufficient high flux of moisture into the cyclone. Such high temperatures rarely occur poleward of the Tropics so tropical cyclones do not form at latitudes greater than 23.5°; once formed, however, a tropical cyclone may penetrate over an ocean to latitudes as high as 40° as in the case of those reaching Japan. A sufficient Coriolis force is required to produce the strong rotation characteristic of a tropical cyclone; equatorward of latitudes 5° to 8° this force is not strong enough, and tropical cyclones cannot exist within this latitude range. A small amount of vertical wind shear is known to be essential if the cyclone is to survive; appropriately small amounts of wind shear occur in the pre-monsoon and post-monsoon seasons; during both the northeast and southwest monsoons the wind shear is so great that any cyclone structure developing is quickly disrupted.

In relation to Bangladesh these essential conditions are found, both in the pre-monsoon and post-monsoon seasons, in the southern part of the Bay of Bengal and in the adjacent Andaman Sea. Tropical cyclones forming in this area tend to travel northwestwards initially but they change direction, or "re-curve", between latitudes 15° to 20° N. Depending on the degree of recurvature they then follow one of three recognized paths (Figure 3.4B):

1) northeastward to the coast of Bangladesh

2) northward to the coast of West Bengal (in India)

3) northwestward to the coast of Orissa (in India)

Those reaching Bangladesh have travelled the greatest distance over the Bay of Bengal, have therefore taken in the greatest quantity of moisture, and have usually attained the greatest intensity as a result. Table ~~A3.2~~ presents the characteristics of some notable tropical cyclones which have affected Bangladesh. A.4

Once ashore, tropical cyclones are cut off from their oceanic source of moisture, and rapidly lose much of their kinetic energy. They then degenerate into intense tropical depressions which can move far inland and generate heavy rainfall and floods for up to two or three weeks before they "fill in" completely or move eastwards out of the affected area. Thus, after its landfall near Kutubdia Island, the tropical cyclone of 29 April 1991 degenerated into an intense depression which moved northeastwards over the Northeast Region; the resulting floods were the worst of recent memory in the Tripura border area of the Northeast Region, that of the Manu River having a frequency estimated at once in 100 years.

3.3.2 Nor-Westers

Nor-westers are caused by outbreaks of cold air from Central Asia which enter Bangladesh from the northwest. Nor-westers occur at the interface between the advancing cold air and the warm air already present in the region. The temperature difference across the interface is large enough to generate large-scale turbulence which, in turn, generates thunderstorms along the interface. High winds, even tornadoes, thunder and lightning, and rain and hail, mark the passage of a nor-wester which typically lasts only for an hour or two. Several tornadoes were experienced in the spring of 1992 in the vicinities of Mymensingh and Brahmanbaria where they caused localized damage. The high winds and hail frequently damage standing crops and homesteads over wider areas. More important, however, is the damage to crops, both standing and harvested, caused by flash floods generated by the intense rainfall associated with nor-westers.

4. RAINFALL AND EVAPOTRANSPIRATION

4.1 Introduction

Rainfall over the Northeast Region and adjacent tributary areas in India is characteristically extremely variable in both space and time. For water management purposes it is essential to define and understand the spatial and temporal variations in rainfall over the Region and its adjacent tributary areas. The question also arises of whether and how these variations may be changing as a result of global climate change.

4.2 Annual Rainfall Study

A study of annual rainfall data for the period 1901-90 was undertaken with the following objectives:

- to define and understand the spatial variation of rainfall;
- to define and understand the temporal variation of rainfall over the longest possible period of time;
- to detect and quantify any evidence of changing climatic conditions;
- to estimate the 1961-90 mean annual rainfalls over specific catchment areas.

4.2.1 Available Data

Annual rainfall data were assembled for 120 rainfall stations within the area of interest, but data for 69 of these stations could not be used, either because the station location was not defined or because the data were too few. None of the 51 stations used has a complete 90-year record, but the missing data could be estimated reliably by double-mass analysis. Of these 51 stations, 23 are located within Bangladesh and 28 within India. The spatial distribution of stations is generally adequate.

Data for the period 1891-1948 were obtained mainly from the UK Meteorological Office, Bracknell, accessed and processed for NERP by the UK Institute of Hydrology, Wallingford; the data relate to both the Bangladesh and Indian rainfall stations; in some cases the data were supplemented from the UNDP/FAO: AEZ Climate Data Base (FAO, 1988).

The availability of data for the 51 stations can be summarised as follows:

Pre-1901: Although the earliest rainfall data obtained go back as far as 1891, no use could be made of these in the context of this study; too few stations were operating, and the data are generally for less than 10 years;

1901-30: Data for this period are largely complete for both the Bangladesh and Indian stations; they provide a strong backbone for double mass analysis;

1931-60: Data for this period are relatively few for the Bangladesh stations, and not available at all for the Indian ones;

1961-90: Data for this period are relatively plentiful for the Bangladesh stations and were obtained from the BWDB; no data are available for the Indian stations.

4.2.2 Data Analysis

The basic approach involved the use of double-mass analysis to fill the gaps in annual data records, to adjust the records for any revealed inconsistencies due to changes in rain gauge exposure, and to extend the records forward in time as required to obtain 90 years of annual rainfalls for all 51 stations. On completion of this analysis, estimated 30-year means and standard deviations for the WMO Standard Periods 1901-30, 1931-60 and 1961-90 were available for all 51 stations individually and collectively.

The 30-year means for the individual stations were used to construct mean annual rainfall maps for each of the WMO Standard Periods. The 51-station means for each year were used to identify the wettest and driest years of record, and the individual station means for these years were used to construct annual rainfall maps for 1988 (the wettest year) and 1957 (the driest year). All of these maps were prepared using the SURFER software package.

The 51-station means for each year were also used to construct a 90-year time series for 1901-90. These means represent integrations of rainfall over an area of nearly 100,000 km^2 encompassing the Northeast Region and its adjacent tributary areas in India.

4.2.3 Spatial Distribution of Annual Rainfall

The patterns depicted in the three 30-year mean annual rainfall maps (Figure 3.1 shows one example) and in the annual rainfall maps for the wettest and driest years (Figures 4.1 and 4.2), are very similar in shape. The only significant difference is in the scale of the rainfall.

The rainfall pattern over the Northeast Region and its adjacent tributary areas in India is dominated by the island of high rainfall centred near Cherrapunji; from this centre rainfall decreases radially in all directions, but at a decreasing rate. Six rainfall zones can be delineated on the basis of the direction and magnitude of the rainfall gradient (Figure 4.3A).

4.2.4 Temporal Distribution of Annual Rainfall

The temporal distribution of the 51-station mean annual rainfalls over a 90-year period, depicted in Figure 4.3B, exhibits two unexpected features:

- a gradual increase in mean annual rainfall over the region
- a more marked increase in the variability of rainfall over the region.

These features of the 51-station series can be quantified in terms of 30-year means and standard deviations as shown in Table 4.1:

Table 4.1
Changes in Rainfall over the Northeast Region, 1901-90

Period	Mean		St. Deviation		Coeff. of Variation	
	Value (mm)	Ratio (%)	Value (mm)	Ratio (%)	Value (%)	Ratio (%)
1901-30	2871	100	270	100	9.4	100
1931-60	2987	104	339	126	11.3	120
1961-90	3166	110	580	215	18.3	195

The ratios given in Table 4.1 are based on the values for 1901-30. They suggest that the 30-year 51-station mean rainfall has increased 10% over the 90-year period, and that its variability has doubled. It is possible that the indicated trends may reflect only a rise to the peak of some long-term climatic cycle, but they may reflect a monoclinal rise due to global climatic change. However, caution should be exercised in interpreting these results, due to the relatively high proportion of synthetic data.

A change in climate would have significant implications for future water management in the Northeast Region, as elsewhere in the world. Whether such a change is in progress is the subject of intense investigation, but so far no firm conclusions have been reached; nevertheless, a growing number of meteorologists are becoming convinced that a global change in climate is in progress.

A recent paper by Chowdhury and Debsarma (1992) reports on a statistical review of climate in Bangladesh carried out by the Bangladesh Meteorology Department. It reaches no firm conclusion, but this may be due to the short period of record (1948-90) considered.

The possibility of climate change in Bangladesh has also been studied by FAP 25 in connection with a concern that hydrological data of the last 25-years (1965-89) may not be representative of long-term conditions. FAP 25 concluded, on the basis of:

- rainfall data for 16 stations in Bangladesh for the period 1902-89 (88 years)
- daily water levels of the Ganges at Hardinge Bridge from 1910 to 1989 (80 years)
- daily discharges of the Ganges at Hardinge Bridge from 1933 to 1989 (55 years)
- daily discharges of the Brahmaputra at Bahadurabad from 1956 to 1989 (33 years)

that "hydrometeorological conditions in Bangladesh during the last 25 years are fairly representative for the longer term". In fact, however, the data presented by FAP 25 suggest slight increases in all four of the data samples, and these increases might have been larger if the data had been analysed differently.

If increases in annual rainfall and its variability are parallelled by short-duration rainfall - which is not necessarily the case - some engineering implications of climate change in Bangladesh would be:

- flood protection works constructed in the last 25 years or so may have been under-designed as a result of their design being based on earlier hydrological data;

- flood protection works proposed for construction now may be at risk of being under-designed if apparent recent increases in rainfall and its variability are sustained.

In view of the upward trends indicated by Table 4.1, it is suggested that:

- hydrometeorological data for the last 25 years (1965-90) are more likely to be representative of hydrometeorological conditions in Bangladesh in the next 25 years than any earlier data.

- engineering designs should be based on these recent data until sufficient additional hydrometeorological data have accumulated to show whether the indicated trends are continuing upwards, levelling off, or reversing.

4.3 Seasonal Distribution of Rainfall

The seasonal distribution of rainfall over the Northeast Region has been studied for a representative sample consisting of 16 of the 54 rain gauges now operating. The seasonal rainfall at the sample stations is shown in Table 4.2:

Table 4.2
Seasonal Distribution of Rainfall over the Northeast Region, 1961-90

Gauge	Rainfall (mm)				
	Pre-Monsoon	Monsoon	Post-Monsoon	Dry Season	Year
Latitude 25° — 25°30′:					
Dewanganj	425	1555	199	53	2232
Nalitabari	445	1783	204	59	2491
Durgapur	598	2716	246	69	3629
Sunamganj	835	4284	287	125	5531
Bholaganj	978	4128	283	149	5538
Lallakhal	1287	4109	316	219	5931
Latitude 24°30'— 25°:					
Jamalpur	372	1617	159	57	2205
Mymensingh	459	1702	205	67	2433
Netrakona	545	2057	240	81	2923
Markuli	899	2354	169	107	3529
Sylhet	926	2841	270	172	4209
Zakiganj	969	2463	243	204	3879
Latitude 24° — 24°30′:					
Kishoreganj	491	1520	183	80	2274
Habiganj	670	1577	176	116	2539
Moulvi Bazar	689	1651	177	132	2649
Latitude 23°30′— 24°:					
Narsingdi	587	1759	221	90	2657

Monthly and seasonal distributions of the annual rainfall at those stations are shown in Figure 3.2. The proportions of rainfall occurring in each season are summarised in Table 4.3:

Table 4.3
Proportions of Seasonal Rainfall over the Northeast Region, 1961-90

Gauge	Percentage of Mean Annual Rainfall			
	Pre-Monsoon	Monsoon	Post-Monsoon	Dry Season
Latitude 25° — 25°30':				
Dewanganj	19	70	9	2
Nalitabari	18	72	8	2
Durgapur	16	75	7	2
Sunamganj	15	78	5	2
Bholaganj	18	74	5	3
Lallakhal	22	69	5	4
Mean	18.0	73.0	6.5	2.5
St.Deviation	2.5	3.3	1.8	0.8
Latitude 24°30'— 25°:				
Jamalpur	17	73	7	3
Mymensingh	19	70	8	3
Netrakona	19	70	8	3
Markuli	25	67	5	3
Sylhet	22	68	6	4
Zakiganj	25	64	6	5
Mean	21.2	68.7	6.7	3.5
St.Deviation	3.4	3.1	1.2	0.8
Latitude 24° — 24°30':				
Kishoreganj	21	67	8	4
Habiganj	26	62	7	5
Moulvi Bazar	26	62	7	5
Mean	24.3	63.7	7.3	4.7
St.Deviation	2.9	2.9	0.6	0.6
Latitude 23°30 — 24°:				
Narsingdi	22	66	9	3
Region:				
Mean	20.6	69.2	6.9	3.3
St.Deviation	3.6	4.5	1.4	1.1

Overall, the seasonal distribution of the annual rainfall is very stable, but the following slight trends are apparent:

Pre-Monsoon:

The pre-monsoon season's proportion of the mean annual rainfall decreases northwards from 24.3% in the south to 18.0% in the north.

Monsoon:

The monsoon season's proportion increases northwards from 63.7% in the south to 73.0% in the north.

Post-Monsoon:

The post-monsoon season's proportion decreases northwards from 7.3% in the south to 6.5% in the north.

Dry-Season:

The dry season's proportion decreases northwards from 4.7% in the south to 2.5% in the north.

4.4 Potential Evapotranspiration

NERP commissioned BARC in 1992 to extend and update the work of Karim and Akhand (1982) on potential evapotranspiration. The resulting 30-year sequence of monthly potential evapotranspiration values derived by the FAO Modified Penman method is given in Appendix A; the seasonal average values are given in Table 4.4:

Table 4.4
Seasonal Distribution of Potential Evapotranspiration over the Northeast Region, 1960-89

Season	30-Year Potential Evapotranspiration (mm)				
	Comilla	Dhaka	Mymensingh	Sylhet	Region
Pre-Monsoon	349	363	322	311	336
Monsoon	570	546	522	502	535
Post-Monsoon	244	246	229	243	241
Dry Season	481	499	433	495	477
Year	1644	1654	1506	1551	1589

4.4.1 Water Surpluses/Deficits

Comparing the seasonal regionally averaged potential evapotranspiration amounts of Table 4.4 with the seasonal rainfalls of Table 4.2 leads to the estimates of potential seasonal water surpluses/deficits given in Table 4.5:

Table 4.5
Seasonal Distribution of Water Surpluses/Deficits over the Northeast Region, 1961-90

Gauge	Potential Water Surplus/Deficit (mm)			
	Pre-Monsoon	Monsoon	Post - Monsoon	Dry Season
Latitude 25° - 25°30':				
Dewanganj (M)*	103	1033	-30	-380
Nalitabari (M)	123	1261	-25	-374
Durgapur (M)	276	2194	17	-364
Sunamganj (S)	524	3782	44	-370
Bhalaganj (S)	667	3626	40	-346
Lallakhal (S)	976	3607	73	-276
Mean	445	2584	20	-352
Latitude 24°30' - 25°:				
Jamalpur (M)	50	1095	-70	-376
Mymensingh (M)	137	1180	-24	-366
Netrakona (M)	223	1535	11	-352
Markuli (S)	588	1852	-74	-388
Sylhet (S)	615	2339	27	-323
Zakiganj (S)	658	1961	0	-291
Mean	379	1660	-22	-349
Latitude 24° - 24°30':				
Kishoreganj (M)	169	998	-46	-353
Habiganj (S)	359	1075	-67	-379
Moulvi Bazar (S)	378	1149	-66	-365
Mean	302	1074	-60	-365
Latitude 23°30' - 24°:				
Narsingdi (D)	224	1213	-25	-409

*The letter in brackets after each gauge name indicates the station for which potential evapotranspiration data was used in the calculation: M = Mymensingh; S = Sylhet; D = Dhaka.

The estimated surpluses/deficits given in Table 4.5 show that water deficits start to develop in the post-monsoon season in the south and northwest of the Region, where the largest deficits subsequently occur in the dry season.

4.5 Storm Rainfall

Analyses of 1-day and 5-day storm rainfalls were conducted as part of the NERP river modelling studies. Thirty-nine stations distributed throughout the region were used in the analysis.

Figure 4.4 shows time-series plots of annual maximum 1-day and 5-day rainfalls, averaged over the 39 stations, for the 30-year period 1964-93. High values seem to have been more prevalent in the last decade, but the evidence for a systematic trend is weak.

The station data were frequently analyzed using the EV1 (Gumbel) distribution, and estimates were derived for 2-year and 10-year maxima. Results are listed in Table 4.6 and are mapped approximately in Figures 4.5 and 4.6. There is a general trend for values to increase from southwest to northeast.

Table 4.6
Annual Maximum 1-day and 5-day Rainfall Statistics
(derived for 30-year period 1964-93)

Gauge	Location	1-day Maxima		5-day Maxima	
		2-yr return period mm	10-yr return period mm	2-yr return period mm	10-yr return period mm
R-061	Balitpur	150	232	294	445
R-062	Dewanganj	166	275	316	473
R-063	Durgapur	197	293	414	561
R-065	Gouripur	150	218	331	458
R-068	Jaria-Jhanjail	186	276	422	597
R-071	Kishoreganj	139	224	276	404
R-072	Muktagacha	158	253	309	457
R-073	Mymensingh	159	233	327	481
R-074	Nalitabari (Taragani)	167	267	332	499
R-077	Phulpur	149	257	334	582
R-078	Sherpur (Town)	159	261	282	415
R-101	Bhairab Bazar	138	213	283	408
R-102	Bholaganj	213	294	582	917
R-103	Brahmanbaria	151	221	296	464
R-104	Chandbagh	156	215	344	531
R-105	Chandpur Bagan	136	219	288	452
R-107	Chhatak	220	321	561	845
R-108	Dakshinbagh (Samanbag)	154	223	366	563
R-109	Gobindaganj	194	273	472	737
R-110	Habiganj	151	215	310	455
R-111	Itakhola (Baikunthapur)	155	244	299	449
R-112	Itna	143	206	356	499
R-113	Khailajuri	195	310	414	635
R-114	Kamalganj	140	208	289	460
R-116	Lallakhal	216	296	577	818
R-117	Langla	151	240	309	511
R-118	Latu	165	240	394	590
R-120	Markuli	132	197	402	607
R-121	Mohanganj	162	261	362	559
R-122	Moulvibazar	146	216	291	462
R-123	Netrokona	161	232	373	561
R-125	Sheola	204	284	445	685
R-126	Srimangal	148	241	280	422
R-127	Sunamganj	252	340	610	869
R-128	Sylhet	212	312	473	713
R-129	Talpur	202	297	417	650
R-130	Zabiganj	179	264	404	588
R-131	Sarail	140	211	273	406
R-132	Nasimagar	129	176	280	401

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5. RIVER SYSTEMS

5.1 Introduction

The catchment area of the Ganges, Brahmaputra and Meghna rivers totals 1,721,000 km^2 at the Bay of Bengal. Of this area 93%, or 1,601,000 km^2, lies upstream of Bangladesh (Figure 5.1). The outflow of water from this catchment into the Bay amounts on average to 1352 km^3/year, or 42,000 m^3/s. Of this flow 87%, or 1177 km^3/year, is generated upstream of Bangladesh while only 13%, or 175 km^3/s, is generated within the country (Figure 5.2). This inflow of water from India into Bangladesh is the main cause of flooding in its deltaic sector. Of this inflow, the Ganges contributes 36% or 426 km^3/year, the Brahmaputra 55% or 646 km^3/year, and the Meghna basin 9% or 105 km^3/year. The Northeast Region receives mainly the Meghna basin's contribution; it does, however, also receive a very small proportion of the Brahmaputra's contribution.

Water balance studies indicate that total inflow to the Northeast Region from India amounts to 126 km^3/year, equivalent to 3990 m^3/s, which represents 60.8% of the regional water supply. Of this amount 105 km^3/year, or 3330 m^3/s, is contributed by Meghna basin tributaries and 21 km^3/year, or 660 m^3/s, by the Brahmaputra as spill into its distributary, the Old Brahmaputra.

The upper catchment of the Meghna in India has an area of 45,574 km^2; this area is 1.88 times the area of the Northeast Region. It consists of:

- Catchment areas totalling 13,466 km^3 in the Indian state of Meghalaya which contribute 63 km^3/year, or 31% of the regional water supply.

- Catchment areas totalling 6,845 km^2 in the Indian state of Tripura which contribute 10 km^3/year, or 5% of the regional water supply.

- The Barak catchment, with an area of 25,263 km^3 in the Indian states of Assam, Manipur and Mizoram, which contributes 32 km^3/year, or 16% of the regional water supply.

Apart from the Brahmaputra's spill into the Old Brahmaputra the region is affected by the Ganges and Brahmaputra in two other significant ways:

- Overbank spill from the Brahmaputra causes flooding in the extreme northwest of the region.

- Backwater from the Ganges and Brahmaputra, when they are in flood, penetrates far upstream and contributes to flooding in the central part of the Meghna Subregion.

The flow contributions from Meghalaya and Tripura partly occur in the form of flash floods (Figure 5.3, A and B) which typically rise to a peak in a day, and recede in a day or two. The flood flows carry much sediment, can have disastrous effects on the region's agriculture and infrastructure, and could only be controlled by dams within India. The flood peaks are not diminished to any significant extent by attenuation in the Bangladesh reaches of the rivers. Since all the rivers tend to flood simultaneously, the hydrologic regimes of the main rivers of the region are also erratic, with large floods rising within a few days at most and receding in as little as a week (Figure 5.3, C and D). The lake which forms in the central part of the Meghna Subregion during the monsoon smooths out the fluctuations in discharge, but the Meghna River outflow from this lake at Bhairab Bazar still features substantial flood rises and recessions (Figure 5.3E). Discharges in the Old Brahmaputra, which result mainly as spill from floods in the Brahmaputra, also fluctuate quite rapidly (Figure 5.3F). Floods are therefore characteristic of the entire river system of the Northeast Region. Since there are no possibilities to control them by means of dams within Bangladesh, water management in the Northeast Region has always utilized embankments for flood protection.

5.2 Regional River Systems

The principal rivers of the Northeast Region and their more significant tributaries are shown in Figure 5.4. The principal rivers are:

- Barak
- Kushiyara
- Surma
- Kangsha
- Baulai
- Old Brahmaputra
- Lakhya
- Meghna

In some parts of the Region, particularly the topographic depression in the north-central area, changes in river locations and inter-connections are fairly frequent. Changes in channel locations and river connections within the historical period are discussed in the separate specialist study on River Sedimentation and Morphology.

For hydrological purposes it is convenient to deal with these rivers and their tributaries in terms of the following component systems of the river network.

- Barak System
- Kushiyara System
- Surma System
- Kangsha-Baulai System
- Meghna System
- Old Brahmaputra-Lakhya System

Salient hydrological features of these systems are as follows:

Barak System

The Barak is the principal headwater tributary to the Meghna system. It enters the Northeast Region at Amalshid where it bifurcates. From Amalshid about two-thirds of the average flow of the Barak passes into the Kushiyara, and the other third into the Surma. The Barak drains a substantial area in the Indo-Burman Ranges, within which a number of favourable dam sites exist. If India develops these dam sites the flow regimes of the Kushiyara and Surma would change significantly. The Barak system and its possible future changes are considered in Chapter 6.

Kushiyara System

The Kushiyara constitutes the principal link between the Barak and the Meghna. In addition to carrying two-thirds of the Barak's flows, it collects all outflows from Tripura and the Surma-Kushiyara Floodplain. The lower part of the Kushiyara is known as the Kalni. The Kushiyara System is considered in Chapter 7.

Surma System

The Surma is the second important link, via the Baulai, between the Barak and the Meghna. In addition to carrying one-third of the Barak's flow, it collects substantial outflows from eastern Meghalaya and delivers significant flows through man-made offtakes into the Surma-Kushiyara Floodplain. It joins the Baulai near Jamalganj. The Surma System is considered in Chapter 8.

The Surma was formerly connected to the Kushiyara via the Old Surma channel, but this channel was closed in the late 1980s.

Kangsha-Baulai System

The Kangsha collects substantial outflows from western Meghalaya, and delivers them into the Baulai which constitutes an extension of the Surma and also collects the flow of the Mogra. There are many past and present channel linkages between the Kangsha and its tributaries, and between the Kangsha and the Mogra. Hence it is advisable to consider the Kangsha, Mogra and Baulai as one system. The Baulai delivers substantially more water into the Meghna than the Kushiyara. The Kangsha-Baulai System is considered in Chapter 9.

Meghna System

Outflows from the Kushiyara and Kangsha-Baulai Systems converge at Dilalpur to form the Meghna. Downstream of Dilalpur the Meghna seems to cut through some hard material, possibly the Madhapur Tract in the subsurface, which appears to cause some congestion of the drainage. A large lake forms upstream in the monsoon season. Downstream of Bhairab Bazar the hydraulic gradient increases.

Old Brahmaputra-Lakhya System

Most of the flow in the Old Brahmaputra originates as spill from the Brahmaputra just upstream of Bahadurabad. The Old Brahmaputra bifurcates at Toke, where most of the flow passes to the Lakhya and thence via the Dhaleshwari to the lower Meghna near Satnal. The rest continues in the Old Brahmaputra channel to join the Meghna near Bhairab Bazar.

Information provided in Sections 6 through 11 for each significant river within these systems includes:

- A description of the salient features of the catchment area within India, including an estimate of the outflow at the Indo-Bangladesh border; these estimates are derived from the water balance studies summarised in Section 5.4.

- A description of the salient features of the river between the Indo-Bangladesh border and the confluence with the main receiving river.

- A summary of annual and seasonal discharges and water levels in the Bangladesh reach of the river; more information on recorded discharges and water levels is tabulated in Appendix A.

5.3 Available Data

Water level data are available for 85 river gauging stations in the Northeast Region, but discharge data are available for only 30 of these stations. A complete list of all gauging stations used in this report is given in Tables A5.1 through A5.5 of Appendix A. The locations of these gauging stations are shown in Figures 6.1, 7.1, 8.1, 9.1 and 10.1. Each of these figures covers a sector of the river system, and their relationship is shown in Figure 5.5.

Two very important points need to be made about the available data:

1) river discharge measurements pertain to flow *only in the main channel of the river*;

2) river water level observations pertain to *daytime* water levels.

There is no reason to think that discharge measurements are unreliable in the sense of having been made carelessly or with inadequate equipment; BWDB has adequate equipment and well-trained operators, many with years of experience. Many measurements do not, however, include flows by-passing the main channel or escaping from the basin, either over the adjacent floodplain or through secondary and distributary channels. Evidence from both modelling and water balance studies indicate that unmeasured by-pass flows are often substantial. This means that the higher flows are often consistently under-measured, which has created major difficulties in calibrating models and analysing flood frequencies. Most river water level observations can also be considered reasonably reliable. It is, however, only practical to observe river water levels on staff gauges during *daytime*; BWDB employs only one observer per staff gauge, and in many cases flow conditions are too hazardous for safe observation at night. In the case of the flash flood-prone rivers in the border areas of the Northeast Region, however, the maximum water level often occurs during the night, and may exceed the maximum levels observed on the preceding and following days by a substantial amount. Thus, the maximum daytime water levels may not be representative of true peak water levels; water level frequency curves tend to exhibit high curvature, partly due to the higher *observed* levels being lower than the real maxima.

Another difficulty with river data is the existence of time trends and discontinuities in the records for some stations these are the result of progressive embankment construction along the river, or naturally induced changes in channel capacity and junctions, or artificial closures of certain channels. The effect of embankment construction upstream of a station is generally to increase the measured flood flows, as more of the basin runoff is directed into the main channel; also, the consequent reduction of overbank storage results in less attenuation of flood peaks in the downstream direction. Changes in channel capacities and junctions, whether natural or manmade, may affect flow distributions at all levels.

The question of non-homogeneous record series is discussed further in Chapter 12, in connection with flood frequencies. River channel shifts and changes are analyzed in the specialist report on River Sedimentation and Morphology (NERP, 1994).

5.4 Water Balance Studies

While discharge data exist for some rivers in the Northeast Region, no such data are available for others, notably the Barak, the lower reaches of the Kushiyara and Surma, the Baulai, Mogra and Lakhya. To establish the relative significance of all the rivers of concern, water balance studies were conducted to estimate the mean annual discharges, as described below. In these studies, the above-noted data limitations were neglected as of minor significance with respect to mean annual flows.

Inflows from Tripura and Meghalaya

Mean annual discharges for gauged rivers were assembled together with catchment areas upstream of the gauging stations; the discharges were then expressed as mean annual runoffs in mm/year. Mean annual rainfalls for these catchments were derived from the mean annual rainfall map, and runoffs correlated with rainfalls. The data available for correlation are as follows:

Table 5.1
Data for Runoff-Rainfall Correlation

River	Station No.	Catchment	Mean Annual Discharge		Rainfall
		(km^2)	(m^3/s)	(mm/yr)	(mm/yr)
Sonai-Bardal	265	2256	141.1	1973	2885
Juri	135+135A	775	43.3	1762	2621
Manu	201	2235	84.0	1185	2212
Dhalai	67	774	29.2	1190	2257
Lungla	192	221	8.3	1185	2350
Khowai/Karangi	158.1+138	1282	43.2	1063	2221
Bhogai	34	479	37.2	2449	3116
Nitai	314	356	30.8	2729	3372
Someswari	263	2419	188.0	2451	4268
Piyain/Jaflong	233+233A	1003	194.6	6119	7073
Sarigowain	251	840	129.6	4866	6078
Lubha	326	771	110.6	4524	5662

Figure 5.6A shows the correlation plots based on these data. As a check on the reliability of these plots, two control curves were established:

- Control curve AB represents the upper limit of runoff; that is to say 100% of rainfall, which could only occur in a totally impervious catchments having no evapotranspiration loss. All data points must fall below this curve since runoff cannot exceed rainfall.

- Control curve CD results from subtracting potential evapotranspiration from rainfall. Data points should not fall below this curve since the actual evapotranspiration cannot in theory exceed the computed potential evapotranspiration.

The available data points follow two distinct linear trends, EF and GH. The data points associated with EF represent "lowland" catchments in Tripura and in Meghalaya southwest of the Tura Range, that is:

- Sonai-Bardal
- Juri
- Manu
- Dhalai
- Lungla
- Khowai/Karangi
- Bhogai
- Nitai

Data points associated with trend line GH represent "highland" catchments on the Shillong Plateau, that is:

- Someswari
- Piyain
- Sarigowain
- Lubha

These data sets can be represented by linear regression equations, as follows:

Lowland Rivers:

$$Y = 1.4218\ X - 2046 \qquad \text{(Eq 1)}$$

Highland Rivers:

$$Y = 1.0759\ X - 1621 \qquad \text{(Eq 2)}$$

where:

X = mean annual rainfall (mm/year)
Y = mean annual runoff (mm/year)

Equation 2 is the equation of the control curve CD which was selected to represent the highland catchments.

Equations (1) and (2) can be used to estimate mean annual discharges for all the rivers entering the Northeast Region from Meghalaya and Tripura, as follows:

Table 5.2
Estimated Mean Annual Discharges at the Indo-Bangladesh Border

River	Rainfall (mm/yr)	Runoff (mm/yr)	Catchment Area (km^2)	Mean Annual Discharge (m^3/s)	(km^3/yr)
TRIPURA RIVERS ENTERING KUSHIYARA:					
Sonai-Bardal	2885	2056	2256	147.0	4.6
Juri	2621	1681	609	34.6	1.1
Manu	2212	1098	2235	77.8	2.5
Dhalai	2257	1169	632	23.4	0.7
Khowai	2210	1094	1113	38.6	1.2
Sub-total			6845	321.4	10.1
Minor Areas			0	0.0	0.0
Totals			6845	321.4	10.1
EAST MEGHALAYA RIVERS ENTERING SURMA:					
Lubha	5662	4469	771	109.3	3.4
Sarigowain	6078	4917	840	131.0	4.1
Piyain	7073	5989	1003	190.5	6.0
Dhalai	8677	7715	340	83.2	2.6
Umium	7657	6617	431	90.4	2.9
Jhalukhali	8594	7626	591	142.9	4.5
Jadukata	5974	4807	2399	365.7	11.5
Sub-total		5505	6375	1113.0	35.0
Minor Areas		7715	1166	285.3	9.0
Totals			7541	1398.3	44.1
WEST MEGHALAYA RIVERS ENTERING KANGSHA:					
Bhugai	3116	2384	479	36.2	1.1
Nitai	3372	2747	356	31.0	1.0
Someswari	4268	3432	2419	263.3	8.3
Sub-total		3203	3254	330.5	10.4
Minor Areas		3203	2671	271.3	8.5
Totals			5925	601.8	19.0

Inflow from the Barak

No Indian discharge data are available for the Barak at Amalshid, so it is necessary to estimate the mean annual discharge from those of the Kushiyara at Sheola and of the Surma at Kanairghat, adjusting for inflows between Amalshid and these stations. Formerly, the Kushiyara used to receive inflow between Amalshid and Sheola from the Singla in India, to lose flow into the Sonai-Bardal through a man-made channel from Karimaganj in India; it is understood that these linkages were closed many years ago when India constructed the Kushiyara left embankment from Amalshid to where the river departs from the Indo-Bangladesh border about 5 km upstream of Sheola. Thus, it is assumed that:

$$\overline{Q}_{KA} = \overline{Q}_{KS} \tag{3}$$

where:

$\overline{Q}_{KA}$ = mean annual discharge of the Kushiyara at Amalshid
$\overline{Q}_{KS}$ = mean annual discharge of the Kushiyara at Sheola

Between Amalshid and Kanairghat, however, the Surma receives inflows from the Lubha, Gumra and Singhuri rivers so that:

$$\overline{Q}_{SA} = \overline{Q}_{SK} - (\overline{Q}_{L} + \overline{Q}_{G+S}) \tag{4}$$

$\overline{Q}_{SA}$ = mean annual flow of the Surma at Amalshid
$\overline{Q}_{SK}$ = mean annual flow of the Surma at Kanairghat
$\overline{Q}_{L}$ = mean annual flow of the Lubha at Lubhachara
$\overline{Q}_{G+S}$ = mean annual flow of the Gumra and Singhuri

The mean annual flow of the Barak at Amalshid is then:

$$\overline{Q}_{BA} = \overline{Q}_{KA} + \overline{Q}_{SA} \tag{5}$$

Values of $\overline{Q}_{KS}$ and $\overline{Q}_{SK}$ are available from BWDB records as follows:

$\overline{Q}_{KS} = 655.7\ m^3/s$
$\overline{Q}_{SK} = 524.3\ m^3/s$

The value of $\overline{Q}_{L}$ is available from the rainfall runoff study just described above as:

$\overline{Q}_{L} = 109.3\ m^3/s$

This value agrees closely with the correlation shown in Figure 5.6B.

The value of $\overline{Q}_{G+S}$ can be approximated from $\overline{Q}_{L}$ by adjusting it in the catchment area ratio ($442\ km^2/771\ km^2$); thus:

$\overline{Q}_{G+S} = 62.7\ m^3/s$

Substituting these values in equations (4) and (5) gives the mean annual discharge for the Barak at Amalshid:

$$\overline{Q}_{BA} = 1008 \text{ m}^3/\text{s} = 31.8 \text{ km}^3/\text{year}$$

5.5 Water Balance of the Meghna Subregion

Using the above estimates, the total inflow from India into the Meghna Subregion can be assessed as follows:

Table 5.3
Inflow to the Meghna Subregion from India

	Mean Annual Discharge (m^3/s)	(km^3/yr)
Total Inflow from Tripura	321	10.1
Total Inflow from Meghalaya	2000	63.1
Inflow from the Barak	1008	31.8
Total	3329	105.0

In order to establish the total water supply to the Meghna Subregion it is necessary to estimate the runoff generated within the subregion. Estimates of rainfall are available from the MPO for each of the following planning areas:

Table 5.4
Rainfall on the Meghna Subregion

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
21	2613	2820
22	2878	3190
23	1534	4520
24	2498	4870
25	1848	2670
26	2342	3160
27	2030	3900
28	1496	2850
29	3022	2720
Meghna Subregion	20261	3375

Rainfall on the Meghna Subregion thus amounts to 68.4 km^3/year, or 2169 m^3/s. The total water supply to the Meghna Subregion is then the inflow from India (105.0 km^3/yr) plus the rainfall on the subregion (68.4 km^3/yr); this amounts to 173.4 km^3/year, or 5498 m^3/s.

This total water supply is disposed of by evapotranspiration and by outflow through the Meghna and Titas at Bhairab Bazar. It is shown in Chapter 4 that the region is in a state of water deficit in the dry season, so that actual evapotranspiration will be less than potential. The mean annual potential evapotranspiration is 1589 mm, while the dry season portion is 478 mm; the mean annual actual evapotranspiration can be estimated as the difference of 1111 mm/year, or 22.5 km^3/year. The mean annual discharge of the Meghna at Bhairab Bazar is 4725 m^3/s, or 149.0 km^3/year. The total estimated loss of water from the subregion is 22.5 + 149.0 = 171.5 km^3/year, or 1.9 km^3/year less than the total subregional water supply as estimated above (173.3 km^3/yr). This residual (1.9 km^3/year) may lie within the accuracy of the water balance calculation but it may also represent flow which by-passes Bhairab Bazar via the Titas Basin. Sub-surface ground water discharge out of the subregion is known from MPO studies to be negligible.

The water balance of the Meghna Subregion can then be summarised as follows:

Table 5.5
Water Balance of the Meghna Subregion

	m^3/s	km^3/yr
Inflow from India	3314	105.0
Rainfall on Subregion	2158	68.4
Total Water Supply	5472	173.4
Outflow at Bhairab Bazar	4702	149.0
Actual Evapotranspiration	710	22.5
Outflow through Titas	60	1.9
Total Outflow	5472	173.4

5.6 Water Balance of the Old Brahmaputra Subregion

Rainfall on the Old Brahmaputra Subregion can be estimated in the same way as for the Meghna Subregion, as follows:

Table 5.6
Rainfall on the Old Brahmaputra Subregion

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
19	1161	2160
20	1419	2340
30	1410	2310
Total/Average	3990	2277
Adjustment	14	2270
Old Brahmaputra Subregion	4004	2270

The small adjustment of 14 km^2 allows for the fact that small parts of Planning Areas 19 and20 extend into the North Central Region while Planning Area 18 of that region extends into the Old Brahmaputra Subregion. Rainfall on the subregion then amounts to 9.1 km^3/year, or 288.2 m^3/s.

Discharge in the Old Brahmaputra has been measured at Nilukirchar at the downstream end of Planning Area 19. The mean annual discharge at Nilukirchar is 698 m^3/s, or 22.0 km^3/year. Rainfall on Planning Area 19 amounts to 2.5 km^3/year, and actual evapotranspiration, estimated on the same basis as for the Meghna Subregion, amounts to 1.3 km^3/year; hence the local runoff is 1.2 km^3/year. Subtracting this from the flow at Nilukirchar gives the mean annual spill discharge from the Brahmaputra as 20.8 km^3/year, or 660 m^3/s; which amounts to about 3% of the mean flow of the Brahmaputra. Total water supply to the subregion is the sum of the Brahmaputra spill (20.8 km^3/year) and rainfall (9.1 km^3/year); this amounts to 29.9 km^3/year, or 948 m^3/s.

Actual evapotranspiration from the subregion, again estimated on the same basis as for the Meghna Subregion, amounts to 4.5 km^3/year, or 141 m^3/s. Deducting this from the total water supply (29.9 km^3/year) gives the outflow into the Meghna as 25.4 km^3/year, or 807 m^3/s.

Table 5.7
Water Balance of the Old Brahmaputra Subregion

	m^3/s	km^3/yr
Inflow from Brahmaputra	660	20.8
Rainfall on Subregion	288	9.1
Total Water Supply	948	29.9
Actual Evapotranspiration	141	4.5
Outflow to Meghna	807	25.4
Total Outflow	948	29.9

5.7 Water Balance of the Northeast Region

For the Northeast Region as a whole the water balance can be summarized as follows:

Table 5.8
Water Balance of the Northeast Region

	m^3/s	km^3/yr
Inflow from Tripura	321	10.1
Inflow from Meghalaya	2000	63.1
Inflow from Barak	1008	31.8
Inflow from Brahmaputra	660	20.8
Total Inflow from India	3989	125.8
Rainfall on Region	2457	77.5
Total Water Supply	6445	203.3
Outflow from Meghna Subregion	4782	150.9
Outflow from Old Brahmaputra Subregion	807	25.4
Actual Evapotranspiration	856	27.0
Total Outflow	6445	203.3

5.8 Relative Significance of the Main Rivers

The above water balance studies can be extended to estimate the mean annual discharges of the main rivers and their relative significance, as follows:

Kushiyara

The contribution of the Kushiyara to the Meghna at Dilalpur is made up of inflows from the Barak, from Tripura, and from local areas within the Northeast Region. It is shown in Chapter 6 that the Kushiyara receives on average 65% of the inflow from the Barak at Amalshid. It also collects all inflows from Tripura, and from regional lands between the Indian border and the Surma corresponding to MPO Planning Areas 25, 26, 27, 28, and part of 29. Local runoff from these areas can be estimated as follows:

Table 5.9
Rainfall on the Kushiyara System

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
25	1848	2670
26	2342	3160
27	2030	3900
28	1496	2850
33% of 29	1000	2720
Kushiyara System	8716	3125

Deducting an estimated actual evapotranspiration of 1111 mm/year gives the local runoff as 2014 mm/year, equivalent to 17.6 km^3/year or 557 m^3/s. The Kushiyara's contribution to the Meghna can then be estimated as follows:

Table 5.10
Contribution of Kushiyara to Meghna

Component	Mean Annual Discharge (m^3/s)	Mean Annual Discharge (km^3/yr)
65% of Barak Inflow (31.8 km^3/yr)	656	20.7
Inflows from Tripura	321	10.1
Local Runoff	557	17.7
Total	1534	48.4

Surma

The contribution of the Surma to the Baulai near Jamalganj is made up of inflows from the Barak, from East Meghlaya, and from local areas within the Northeast Region. It is shown in Chapter 6 that the Surma receives on average 35% of the inflow from the Barak at Amalshid. It also collects all inflows from East Meghalaya, and from regional lands between the Indian border and the Surma corresponding to MPO Planning Areas 23 and 24. Local runoff from these areas can be estimated as follows:

Table 5.11
Rainfall on the Surma System

MPO Planning Area #	Area (km²)	Rainfall (mm/yr)
23	1534	4520
24	2498	4870
Kushiyara System	4032	4737

Deducting 1111 mm/year for actual evapotranspiration gives the local runoff as 3626 mm/year, equivalent to 14.6 km^3/year or 464 m^3/s. The Surma's contribution to the Baulai can then be estimated as follows:

Table 5.12
Contribution of Surma to Baulai

Component	Mean Annual Discharge (m^3/s)	(km^3/yr)
35% of Barak Inflow (31.8 km^3/yr)	352	11.1
Inflows from East Meghalaya	1398	44.1
Local Runoff	464	14.6
Total	2214	69.8

Kangsha

The contribution of the Kangsha to the Baulai near Jamalganj is made up of inflows from West Meghalaya and from local areas within the Northeast Region, less the loss through the Thakuragaon-Atpara channel into the Mogra. It collects all inflows from West Meghalaya, and from regional lands between the border and the Kangsha-Mogra watershed corresponding to MPO Planning Area 21. Local runoff from this area can be estimated as follows:

Table 5.13
Rainfall on the Kangsha Subsystem

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
21	2613	2820

Deducting 1111 mm/year for actual evapotranspiration gives the local runoff as 1709 mm/year, equivalent to 4.5 km^3/year or 142 m^3/s. No data are available to support estimation of the loss through the Thakuragaon - Atpara channel but it is known to be substantial; here it is assumed to be 33% of the total inflow. The Kangsha's contribution to the Baulai can then be estimated as follows:

Table 5.14
Contribution of Kangsha to Baulai

Component	Mean Annual Discharge (m^3/s)	(km^3/yr)
Inflows from West Meghalaya	598	18.9
Local Runoff	142	4.5
Total Inflow	740	23.4
Outflow to Mogra (33%)	-244	-7.7
Net flow to Baulai near Jamalganj	496	15.7

Mogra

The contribution of the Mogra to the Baulai near Dilalpur is made up of inflow from the Kangsha Subsystem via the Thakuragaon-Atpara channel, and from the Mogra's catchment area which lies entirely within the region and corresponds to MPO Planning Area 22. Local runoff from this area can be estimated as follows:

Table 5.15
Rainfall on the Mogra Catchment

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
22	2878	3190

Deducting 1111 mm/year for actual evapotranspiration gives the local runoff as 2079 mm/year, equivalent to 6.0 km^3/year or 190 m^3/s. The Mogra's contribution to the Baulai can then be estimated as follows:

Table 5.16
Contribution of Mogra to Baulai

Component	Mean Annual Discharge (m^3/s)	(km^3/yr)
Inflow from Kangsha	244	7.7
Local Runoff	190	6.0
Total	434	13.7

Baulai

The contribution of the Baulai to the Meghna near Dilalpur is made up of the inflows from the Surma and Kangsha near Jamalganj, inflow from the Mogra, and local runoff from areas corresponding to 67% of MPO Planning Area 29. Local runoff can be estimated as follows:

Table 5.17
Rainfall on the Baulai Subsystem

MPO Planning Area #	Area (km^2)	Rainfall (mm/yr)
67% of 29	2022	2720

Deducting 1111 mm/year for actual evapotranspiration gives the local runoff as 1609 mm/year, equivalent to 3.3 km^3/year or 103 m^3/s. The Baulai's contribution to the Meghna can then be estimated as follows:

Table 5.18
Contribution of Baulai to Meghna

Component	Mean Annual Discharge (m^3/s)	Mean Annual Discharge (km^3/yr)
Inflow from Surma	2214	69.7
Inflow from Kangsha	496	15.7
Inflow from Mogra	434	13.7
Local Runoff	103	3.3
Total to Meghna	3247	102.4

Old Brahmaputra

The contribution of the Old Brahmaputra to the Meghna is made up of spill from the Brahmaputra and local runoff from the Old Brahmaputra Subregion. These components were estimated in Section 5.6. Since the Old Brahmaputra bifurcates at Toke, it is of interest to know how much of its flow is carried by the Lakhya and how much by the residual channel of the Old Brahmaputra. There are discharge data for the Lakhya at Demra and for the Old Brahmaputra at Bhairab Bazar, but the former include inflow through the Banar from the North Central Region and both records cover only the wet season. However, they suggest that the Lakhya carries 86% of the Old Brahmaputra flow. On this basis the contribution of the Old Brahmaputra to the Meghna can be estimated as follows:

Table 5.19
Contribution of Old Brahmaptura to Meghna

Component	Mean Annual Discharge (m^3/s)	Mean Annual Discharge (km^3/yr)
Lakhya (86% of 25.4 km^3/yr)	693	21.8
Old Brahmaputra (14% of 25.4 km^3/yr)	114	3.6
Total Outflow	807	25.4

Relative Significance

On the basis of the foregoing estimates the relative significance of the main rivers can be summarised as follows:

Table 5.20
Mean Discharges of Main Rivers

	Mean Annual Discharge (m^3/s)	Mean Annual Discharge (km^3/yr)
Meghna at Satnal	5589	176.3
Meghna at Nabinagar	4896	154.4
Meghna at Dilalpur	4781	150.8
Meghna at Bhairab Bazar	4725	149.0
Baulai at Dilalpur	3247	102.4
Baulai at Itna	2710	85.5
Surma at Jamalganj	2214	69.7
Kushiyara at Dilalpur	1534	48.4
Old Brahmaputra at Toke	807	25.4
Kangsha at Thakurakona	740	23.4
Lakhya at Narayanganj	693	21.8
Kushiyara at Amalshid	656	20.7
Mogra at Itna	434	13.7
Surma at Amalshid	352	11.1
Old Brahmaputra at Bhairab Bazar	114	3.6
Titas	60	1.9

6. BARAK SYSTEM

6.1 Introduction

Within India the Barak has a catchment area of 25,265 km^2, slightly larger than the Northeast Region (24,265 km^2). At Amalshid, where the Barak enters the region, its mean annual discharge is 32 km^3/year or 1008 m^3/s; this amounts to 18% of the regional water supply, and identifies the Barak as the most important river entering the region. The Barak bifurcates at Amalshid into the Kushiyara and Surma.

6.2 Barak Catchment in India

The Barak rises at an elevation of 2900 m on the south side of Mount Javpo on the Nagaland-Manipur border, and flows southwards between folds of the Indo-Burman Ranges for 250 km to Tipaimukh near the intersection of the borders of Assam, Manipur and Mizoram (Figure 6.1). At Tipaimukh the river breaks through the fold on its right in a deep gorge from where it flows northwards, again between two folds, for 60 km to Fulerthal. At Fulerthal the river cuts around the end of the fold on its left, and turns westwards into the Plain of Cachar across which it meanders for another 60 km to Amalshid. Across the Cachar Plain the Barak picks up flows from a number of tributaries:

Right Bank (Northern) Tributaries:

- Jiri
- Chiri
- Madura
- Jatinga
- Singhuri

Left Bank (Southern) Tributaries:

- Sonai-Rukni
- Gogra
- Kotakhal
- Dhaleshwari (I)

The right bank tributaries have short small catchments in the area where the Indo-Burman Ranges come up against the eastern end of the Shillong Plateau. The left bank tributaries have long larger catchments between folds of the Indo-Burman Ranges. Floods of the Barak and its tributaries regularly inundate large areas of the Cachar Plain.

6.3 Barak Bifurcation at Amalshid

At Amalshid the larger proportion of the Barak flow presently enters the Kushiyara. Any significant change in the bifurcation ratio could have far-reaching effects on flooding, drainage and irrigation, and inland navigation in the eastern half of the region. Such a change could result from a major flood event in the Barak system, or from river training works at Amalshid.

No Indian discharge data are available for the Barak at or near Amalshid; their nearest gauging station appears to be at Lakhpur where the catchment area is only 58% of the area at Amalshid. Discharge of the Barak at Amalshid has therefore been estimated from measured discharges of the Kushiyara and Surma at Sheola and Kanairghat. The Lubha, Gumra and Singhuri rivers join the Surma between Amalshid and Kanairghat. Monthly flows of the Surma at Amalshid were therefore calculated as:

$$Q_{SA} = Q_{SK} - (Q_L + Q_{G+S}) \qquad (1)$$

where:

Q_{SA} = monthly flow of the Surma at Amalshid
Q_{SK} = monthly flow of the Surma at Kanairghat
Q_L = monthly flow of the Lubha
Q_{G+S} = combined monthly flows of the Gumra and Singhuri

and:

$$Q_L = (\overline{Q}_L/\overline{Q}_{SK}) . Q_{SK} \qquad (2)$$

$$Q_{G+S} = (A_{G+S}/A_L) . Q_L \qquad (3)$$

where:

$\overline{Q}_L$ = mean annual flow of the Lubha
$\overline{Q}_{SK}$ = mean annual flow of the Surma at Kanairghat
A_{G+S} = combined catchment areas of the Gumra and Singhuri
A_L = catchment area of the Lubha

Relevant values of these quantities are:

$\overline{Q}_L$ = 109.3 m^3/s (from water balance studies)
$\overline{Q}_{SK}$ = 524.3 m^3/s (from records for 1969-89)
A_{G+S} = 442 km^2 (measured by NERP)
A_L = 771 km^2 (measured by SWMC)

Substituting these values in equations (2) and (3) gives:

$$Q_L = 0.2085\ Q_{SK} \qquad (2a)$$

$$Q_{G+S} = 0.5736\ Q_L \qquad (3a)$$

Monthly flows of the Barak at Amalshid were calculated at:

$$Q_{BA} = Q_{KS} + Q_{SA} \qquad (4)$$

where:

Q_{BA} = monthly flow of the Barak at Amalshid
Q_{KS} = monthly flow of the Kushiyara at Sheola
Q_{SA} = monthly flow of the Surma at Amalshid, as given by Eq. (1)

No adjustment of flows at Sheola is thought necessary because the left embankment of the Kushiyara precludes any inflows from the Langai and Singla between Amalshid and Sheola. Bifurcation coefficients were therefore calculated as:

(Surma) $B_S = Q_{SA}/Q_{BA}$ (5)
(Kushiyara) $B_K = Q_{KS}/Q_{BA}$ (6)

as shown on the following table:

Table 6.1
Calculation of Bifurcation Coefficients at Amalshid

Period	Q_{SK} (m^3/s)	Q_L (m^3/s)	Q_{G+S} (m^3/s)	Q_{SA} (m^3/s)	Q_{KS} (m^3/s)	Q_{BA} (m^3/s)	B_S (m^3/s)	B_K (m^3/s)
Apr	227.4	47.4	27.2	152.8	291.4	444.2	34.4	65.6
May	479.3	99.9	57.3	322.1	546.7	868.8	37.1	62.9
Jun	1064.6	222.0	127.3	715.3	1164.1	1879.4	38.1	61.9
Jul	1428.2	297.8	170.8	959.6	1609.6	2569.2	37.3	62.7
Aug	1273.5	265.5	152.3	855.7	1476.4	2332.1	36.7	63.3
Sep	1031.2	215.0	123.3	692.9	1258.2	1951.1	35.6	64.4
Oct	551.8	115.1	66.0	370.7	770.2	1140.9	32.5	67.5
Nov	119.2	24.9	14.3	80.0	279.7	359.7	22.2	77.8
Dec	25.0	5.2	3.0	16.8	141.8	158.6	10.6	89.4
Jan	8.6	1.8	1.0	5.8	95.9	101.7	5.7	94.3
Feb	6.4	1.3	0.8	4.3	80.0	84.3	5.1	94.9
Mar	37.5	7.8	4.5	25.2	111.0	136.2	18.5	81.5
Year	524.3	109.3	62.7	352.3	655.7	1008.0	35.0	65.0

On an annual basis, the Kushiyara carries almost twice as much Barak flow as the Surma.

The monthly bifurcation coefficients are plotted in Figure 6.2A as a function of flow in the Barak at Amalshid, which shows a markedly hysteretic variation: the proportion entering the Surma is greater when the Barak is rising to its seasonal peak than when it is receding. This hysteresis suggests that the bifurcation coefficients may be influenced by the hydraulic gradient across the sand bar in the entrance to the Surma. Monthly flow distributions between the Kushiyara and the Surma are shown in Figure 6.2B.

The above annual values of bifurcation coefficients were used in the water balance studies described in Chapter 5. Values taken from Figure 6.2A are used below in evaluating the effects of the proposed Tipaimukh Dam on flows in the Kushiyara and Surma.

6.4 Proposed Tipaimukh Dam and Hydropower Project

Many years ago India recognized the potential for a dam on the Barak at the Tipaimukh gorge. As originally proposed the dam was to provide flood control for the benefit of agriculture in the Cachar Plain and of the town of Silchar, but it was found that the flood control benefits would not justify the cost of the dam. Furthermore, the height of dam required for flood control alone was much less than the gorge can support. Subsequently, it was proposed to build the dam to the maximum height and use the head for hydropower generation. It is understood that the proposed funding is delayed pending resolution of various issues. On the basis of information from the Joint Rivers Commission (JRC), an evaluation is made here of the likely effects on flows in the Kushiyara and Surma.

As presently proposed (JRC, 1992) the Tipaimukh project will involve a 161 m high, 390 m long rockfill dam in Tipaimukh gorge, and an above ground powerhouse with an installed capacity of 1500 MW (10 x 150 MW units). The design flow per unit is 140 m^3/s, the design head 125 m, and the minimum and maximum operating heads 107 m and 127 m respectively. The live storage in the reservoir (between the minimum operating water level and the full supply water level) is given as 9.0 km^3. The annual energy production (input to the Indian grid) is projected at 3609 GWH, equivalent to a net power of 412 MW continuous.

The daily load factor is given as 0.25 which indicates that only two units will operate continuously; the other units will be brought in/taken out one by one during the day as the system load develops/recedes. Outflow from the powerhouse will then vary during the day from 280 m^3/s up to 1400 m^3/s in steps of 140 m^3/s. It is thought that such a daily variation in the river will have largely attenuated by the time it has reached Amalshid, which is some 225 km downstream of Tipaimukh.

On the basis of the information available, the effect of the Tipaimukh hydropower project (only) on average monthly discharges of the Barak at Amalshid has been estimated as shown in Table 6.2.

Table 6.2
Effect of Tipaimukh Dam and Hydropower Project (only) on Discharge of the Barak at Amalshid, 1964-91 Average Year Conditions

Period	Q_{BA} (m^3/s) (1)	Q_{BT} (m^3/s) (2)	Q_{IC} (m^3s) (3)	H (m) (4)	Q_P (m^3/s) (5)	P_N (MW) (6)	Q'_{BA} (m^3/s) (7)	dQ (m^3/s) (8)
Apr	520	254	266	110	670	475	936	416
May	1053	514	539	107	588	405	1127	74
Jun	2130	1040	1090	111	377	269	1467	-663
Jul	2740	1337	1403	115	249	184	1652	-1088
Aug	2540	1240	1300	119	334	256	1634	-906
Sep	2116	1033	1083	123	419	332	1502	-614
Oct	1301	635	666	127	505	413	1171	-130
Nov	415	203	212	124	578	462	790	375
Dec	183	90	93	121	640	499	733	550
Jan	118	57	61	118	702	533	763	645
Feb	103	50	53	116	763	570	816	713
Mar	157	77	80	113	753	548	833	676
Year	1121	547	574	117	547	412	1121	0

The explanation of Table 6.2 is as follows:

Column 1 (Q_{BA}): Mean monthly discharges of the Barak at Amalshid without project.

Column 2 (Q_{BT}): Mean monthly discharges into Tipaimukh reservoir.

Column 3 (Q_{IC}): Mean monthly discharges from the Barak catchment between Tipaimukh and Amalshid.

Column 4 (H): Mean monthly operating heads at Tipaimukh Dam assuming:

1) the maximum head (127 m) is attained in October

2) the minimum head (107 m) is attained in May

3) the head varies linearly in the intermediate periods

On this basis the mean annual head available is 117 m.

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Column 5 (Q_P): Mean monthly discharges through Tipaimukh powerhouse assuming no discharges over the spillway or through the bottom outlet; this is a reasonable assumption for the average year conditions. Under such perfect regulation the mean monthly powerhouse discharges must average the mean annual discharge of the river (547 m^3/s).

Column 6 (P_N)

This column contains the mean monthly net power output calculated as:

$$P_N(MW) = e_O \cdot \rho_W \cdot g \cdot Q_P \cdot H/10^6 \quad (6.19)$$

wherein:

e_O	=	overall efficiency; this allows for energy losses in the powerhouse intake, penstocks, turbines, generators, transformers and transmission lines; estimated as 0.656
ρ_W	=	density of water (1000 kg/m^3)
g	=	gravitational acceleration (9.81 m/s^2)
Q_P	=	powerhouse discharge (m^3/s)
H	=	operating head (m)

and 10^6 converts joules/second (watts) to megawatts.

Column 7 (Q_{BA}): Mean monthly discharges of the Barak at Amalshid, with project.

Column 8 (dQ): Changes in the mean monthly discharges of the Barak at Amalshid. These are calculated as:

$$dQ = Q'_{BA} - Q_{BA} \quad (6.21)$$

The results indicate that water will be stored in June through October and released in November through May.

The maximum discharge augmentation calculated here (713 m^3/s) occurs in February, when natural flows are at a minimum. This estimate is based on installation of the power project only. Indian statements indicate that *with planned irrigation of the Cachar Plain*, the maximum discharge augmentation will be 405 m^3/s.

On the basis of Table 6.2, calculated annual volumes of water stored in and released from Tipaimukh reservoir are as shown in Table 6.3.

Table 6.3
Effect of Tipaimukh Dam and Hydropower Project (only) on Volumes of Water Arriving at Amalshid

Period	Without Project (km^3)	Without Project %	With Project (km^3)	With Project %	Difference (km^3)
Wet Season	28.6	81	19.6	56	-9.0
Dry Season	6.7	19	15.7	44	+9.0
Year	35.3	100	35.3	100	0

A rating curve for the gauge at Amalshid can be approximated by comparing the mean monthly water levels at Amalshid (H_{BA}) with the values of Q_{BA} (without project). By re-entering this approximate rating curve (Figure 6.3) with the values of Q'_{BA} (with project) it is found that the changes in water level at Amalshid will be about:

- $dH_{(Jul)} = -2.6$ m
- $dH_{(Feb)} = +3.5$ m

Conclusions

Implementation of the Tipaimukh dam and hydropower project (only) by India would be of considerable hydrological benefit to the Northeast Region. At Amalshid, with the project and under average year conditions:

- peak flows in July would be reduced by 1088 m^3/s, or about 40%
- peak water levels in July would be reduced by about 2.6 m
- the volume of flood water during the monsoon would be reduced 9.0 km^3, or by about 31%
- low flows in February would be augmented by 713 m^3/s, or by a factor of about (816/103) = 7.9.
- low water levels in February would be raised by about 3.5 m
- the volume of water available during the dry season would be augmented by 9.0 km^3, or by a factor of about (15.7/6.7) = 2.3.

6.5 Cachar Plain Irrigation Project

Regulation of the Barak's flow by the Tipaimukh dam and hydropower project would allow irrigation of the Cachar Plain. As presently proposed the scheme involves a barrage on the Barak at Fulerthal, about 90 km downstream of Tipaimukh, where the Barak emerges from the Indo-Burman Ranges on to the Cachar Plain. From this barrage main canals will be constructed on both banks. The right bank (north) canal will be 89 km long, and the left bank (south) canal will be 110 km long. Together they will serve an area of 1680 km^2 (Figure 6.1).

It is stated with respect to the combined hydropower and irrigation project (JRC, 1992) that "The Project will augment the dry season flows by about 405 m^3/s. Availability of assured draft in the lean season will improve navigability of the Barak River, and will open up an inland navigation route between Calcutta and Silchar through Bangladesh". This statement is interpreted here to mean that the minimum (February) discharge of the Barak at Amalshid will be augmented by 405 m^3/s.

It is not stated how much water will be used for irrigation of the Cachar Plain, but it can be estimated from the cited discharge augmentation (405 m^3/s) in February, almost certainly a month of maximum or near-maximum irrigation demand. Comparing with the last column of Table 6.2, the discharge diverted at Fulerthal barrage for irrigation is then

$$713 - 405 = 308 \text{ m}^3/\text{s}$$

Neglecting return flow from irrigation in Cachar, mean monthly discharges at Amalshid with both projects can then be estimated as shown in Table 6.4.

Table 6.4

Effect of Tipaimukh Dam, Hydropower Project and Cachar Plain Irrigation Project, on Discharge of the Barak at Amalshid, 1964-91 Average Year Conditions

Period	Q'_{BA} (m^3/s) (1)	Q_{IW} (m^3/s) (2)	Q''_{BA} (m^3/s) (3)	Q_{BA} (m^3/s) (4)	dQ' (m^3/s) (5)
Apr	936	154	782	520	262
May	1127	-	1127	1053	74
Jun	1467	-	1467	2130	-663
Jul	1652	-	1652	2740	-1088
Aug	1634	-	1634	2540	-906
Sep	1502	-	1502	2116	-614
Oct	1171	-	1171	1301	-130
Nov	790	156	634	415	219
Dec	733	312	421	183	238
Jan	763	312	451	118	333
Feb	816	308	508	103	405
Mar	833	308	525	157	368
Year	1121	129	992	1121	-129

The explanation of Table 6.4 is as follows:

Column 1 (Q'_{BA}): Mean monthly flows of the Barak at Amalshid for the "with hydropower project only" case, established as Q'_{BA} in Table 6.2, Column 7.

Column 2 (Q_{IW}): Discharges diverted at Fulerthal barrage to meet the irrigation demand of the Cachar Plain. The monthly distribution of the irrigation diversion is not known but has been estimated on the basis of experience in Bangladesh.

Column 3 (Q_{BA}''): Mean monthly discharges of the Barak at Amalshid corresponding to the "with dam, hydropower project, and irrigation project" case, computed as:

$$Q''_{BA} = Q'_{BA} - Q_{IW} \tag{6.22}$$

Column 4 (Q_{BA}): Mean monthly discharges of the Barak at Amalshid corresponding to the "without projects" case, i.e: Q_{BA} from Table 6.2, Column 1.

Column 5 (dQ'): Changes in the mean monthly discharges of the Barak at Amalshid computed as:

$$dQ' = Q''_{BA} - Q_{BA} \tag{6.23}$$

From the values of dQ' it appears that flows in the Barak at Amalshid will be reduced during the monsoon season by the same amount as in the "with hydropower project only" case, but the increase in the dry season will not be as great. Estimated volumes of water arriving at Amalshid in the "with hydropower and irrigation projects" case are shown in Table 6.5:

Table 6.5
Effect of Tipaimukh Dam, Hydropower Project, and Cachar Plain Irrigation Project, on Volumes of Water Arriving at Amalshid

Period	Without Projects		With Projects		Difference
	(km^3)	(%)	(km^3)	(%)	(km^3)
Wet Season	28.6	81	19.6	55	-9.0
Dry Season	6.7	19	11.6	33	+4.9
Year	35.3	100	31.2	88	-4.1

The volume arriving at Amalshid during the wet season will still be reduced by 9.0 km^3, but the dry season volume will be increased by only 4.9 km^3; the loss to irrigation in the Cachar Plain (assuming no return flow) will be 4.1 km^3.

Utilising the approximate rating curve for the Barak at Amalshid (Figure 6.3), and re-entering it with values of Q''_{BA} (with both projects) it is found that the changes in water level at Amalshid will be:

$$dH'_{(Jul)} = -2.6 \text{ m}$$
$$dH'_{(Feb)} = +2.1 \text{ m}$$

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Conclusions

At Amalshid, with both the hydropower and irrigation projects and under average year conditions:

- peak flows in July would still be reduced by 1088 m^3/s, or about 40%
- peak water levels in July would still be reduced by about 2.6 m
- the volume of flood water during the monsoon would still be reduced by 9.0 km^3, or 31%

but:

- low flows in February would be augmented by only 405 m^3/s, representing a factor of (405/103) = 3.9.
- low water levels in February would be raised only about 2.1 m
- the volume of water available during the dry season would be augmented by only 4.91 km^3, representing a factor of about (11.6/6.7) = 1.7.

6.6 Effects on Flows in the Kushiyara and Surma

With Tipaimukh Dam in place, India would have no reason for not proceeding with irrigation of the Cachar Plain. The combined hydropower and irrigation situation will therefore be of primary concern to the Northeast Region of Bangladesh. For average year conditions, altered monthly flows in the Kushiyara and Surma are as shown in Table 6.6:

Table 6.6
Effect of Tipaimukh Dam, Hydropower Project and Cachar Plain Irrigation Project on Discharges in the Kushiyara and Surma Rivers

Period	Without Projects				With Projects			
	Q_{BA} (m^3/s)	B_S (%)	Q_{SA} (m^3/s)	Q_{KA} (m^3/s)	Q''_{BA} (m^3/s)	B''_S (%)	Q''_{SA} (m^3/s)	Q''_{KA} (m^3/s)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Apr	520	34.9	181	339	782	34.9	273	509
May	1053	37.6	396	657	1127	37.6	424	703
Jun	2130	38.5	820	1310	1467	38.5	565	902
Jul	2740	37.3	1022	1718	1652	37.3	616	1036
Aug	2540	37.0	940	1600	1634	37.0	605	1029
Sep	2116	35.7	755	1361	1502	35.7	536	966
Oct	1301	33.3	433	868	1171	33.3	390	781
Nov	415	23.2	96	319	634	23.2	147	487
Dec	183	11.4	21	162	421	11.4	48	373
Jan	118	6.7	8	110	451	6.7	30	421
Feb	103	5.7	6	97	508	5.7	29	479
Mar	157	19.1	30	127	525	19.1	100	425
Year	1121	35.3	396	725	992	35.3	315	677

<u>Column 1 (Q_{BA})</u>: Mean monthly flows of the Barak at Amalshid without projects.

<u>Column 2 (B_S)</u>: Surma bifurcation coefficients derived in Section 6.4.

<u>Column 3 (Q_{SA})</u>: Existing mean monthly flows of the Surma at Amalshid:

$$Q_{SA} = B_S . Q_{BA} \tag{6.24}$$

<u>Column 4 (Q_{KA})</u>: Existing mean monthly flows of the Kushiyara at Amalshid:

$$Q_{KA} = (1-B_S).Q_{BA} \tag{6.25}$$

<u>Column 5 (Q''_{BA})</u>: Mean monthly flows of the Barak at Amalshid in with hydropower and irrigation projects as derived in Section 6.6.

<u>Column 6 (B''_S)</u>: Forecast Surma bifurcation coefficients. It is assumed that their values will be essentially the same as at present.

<u>Column 7 (Q''_{SA})</u>: Forecast mean monthly flows of the Surma at Amalshid with hydropower and irrigation projects

$$Q''_{SA} = B''_S . Q''_{BA} \tag{6.25}$$

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Column 8 (Q''_{KA}): Forecast mean monthly flows of the Kushiyara at Sheola (which apply also at Amalshid) are computed as:

$$Q_{KA} = Q''_{BA} - Q''_{SA} \tag{6.26}$$

Figure 6.4A shows the effects of Tipaimukh Dam, Hydropower Project, and Cachar Plain Irrigation Project on discharges of the Barak at Amalshid. Figures 6.4B and C show the effects on discharges of the Kushiyara and Surma at Amalshid.

6.7 Other Indian Proposals

Other schemes under consideration for implementation at a later stage involve dams on the Sonai and on the Dhaleshwari (I) at Bhairabi and Sairang (Figure 6.1). These are all smaller than the Tipaimukh hydropower and irrigation projects, and their implementation seems remote in time. Nevertheless, progress on these schemes should be monitored.

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7. KUSHIYARA SYSTEM

7.1 Introduction

The Kushiyara, the second largest river of the Meghna Subregion, receives on average 65% of the Barak flow and also collects all inflows from a 6845 km^2 area in Tripura and in small parts of Mizoram and Assam (Figure 7.1). This area contains the Tripura Hills, a series of seven long, narrow, north-south anticlinal ridges separated by wide, low-lying, flat-bottomed synclinal valleys opening to the north. The ridges are about 15 km apart and penetrate up to 30 km into Bangladesh, where they are known as the Sylhet Hills. In southern Tripura the ridges, which are a northward extension of the Chittagong Hill Tracts, reach a maximum elevation of 938 m, but where they enter the Meghna Subregion they rarely exceed 300 m. At their northernmost extremity the ridges plunge beneath the Kushiyara-Surma flood-plain. The lower reaches of the valleys, particularly within Bangladesh, contain large beel complexes; notable among these are Son Beel in Assam, and Hakaluki Haor and Hail Haor in Bangladesh.

The Kushiyara has eight significant tributaries all originating in Tripura and entering it from the south; in downstream (east to west) order these are:

- Sonai-Bardal
- Juri
- Manu
- Dhalai
- Lungla
- Karangi
- Khowai
- Sutang

These tributaries do not all enter the Kushiyara directly; the Sonai-Bardal is a tributary of the Juri, the Dhalai is a tributary of the Manu, and the Karangi is a tributary of the Lungla. The Lungla, Karangi and Sutang rise in the Sylhet Hills, have little or no catchment area in Tripura, but drain the same synclinal valleys as the other tributaries.

The tributaries are not uniquely matched with the synclinal valleys, apparently as a result of river capture. Most of the tributaries traverse two or more valleys, escaping westwards either through gorges in the intervening ridges or around the northern extremities of the ridges (Figure 7.1). It is convenient for descriptive purposes to label the ridges and valleys in east to west order, as follows:

Ridge A	:	Cut around by Barak
Valley 1	:	Occupied by Singla and Son Beel, Langai, Sonai-Bardal
Ridge B	:	Cut around by Sonai-Bardal
Valley 2	:	Occupied by Manu, Juri and Hakaluki Haor, Sonai-Bardal
Ridge C	:	Cut through by Manu, and cut around by Juri
Valley 3	:	Occupied by Manu and Juri
Ridge D	:	Cut through by Manu
Valley 4	:	Occupied by Gumti, Khowai, Dhalai, Manu
Ridge E	:	Cut through by Gumti, Khowai
Ridge E1	:	Cut around by Manu

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Valley 5	:	Occupied by Lungla and Hail Haor
Ridge E2	:	Cut around by Lungla
Valley 6	:	Occupied by Gumti, Khowai, Karangi, Sutang, Lungla
Ridge F	:	Cut through by Gumti, and cut around by Lungla, Khowai, Sutang

Where the rivers cut through the ridges it appears possible to construct low dams. One such dam is known to exist on the Gumti where it cuts through Ridge E; a NOAA satellite photo of 8 October 1988 clearly shows the Gumti reservoir but shows no other reservoirs in Tripura.

An additional tributary from the north, Sada Khal, has a small drainage area between the Surma and Kushiyara but mainly carries flood spill from both rivers.

7.2 Kushiyara

The Kushiyara originates from the bifurcation of the Barak at Amalshid, from where it follows a southwesterly course to Dilalpur where it joins the Baulai. The lower reaches of the Kushiyara are known locally by different names: between Markuli and Madna it is called the Kalni, and between Madna and Dilalpur it is called the Dhaleshwari. Water balance studies indicate that the Kushiyara's contribution to the Upper Meghna amounts to 48.5 km^3/yr, or 1537 m^3/s.

The south bank tributaries listed in Section 7.1 together collect all the outflow from Tripura. Water balance studies indicate that these inflows total 10.2 km^3/year, or 5.9% of the total water supply to the Meghna Subregion, equivalent to a mean annual flow of 324 m^3/s. The inflows occur mainly in the monsoon season when flash floods occur with peak flows ranging up to 20 or more times average flows. In contrast, base flows towards the end of the dry season are very small, and may dry up completely. The Kushiyara also collects 65% of the Barak inflow.

Discharges in the Kushiyara have been measured by the BWDB at Sheola and Sherpur. The 27 years of record for Sheola indicate a mean annual discharge of 682 m^3/s, and a range of daily discharges from 27.7 m^3/s to 2960 m^3/s. The seasonal distribution of the runoff at Sheola is as follows:

Table 7.1
Seasonal Distribution of Runoff at Sheola

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	472	2487	11.5
Monsoon	1415	14,918	69.4
Post-Monsoon	555	2927	13.6
Dry Season	111	1162	5.5
Year	682	21494	100.0

The 10 years of record for Sherpur indicate a mean annual discharge of 1101 m^3/s, and a range of daily discharges from 45.6 m^3/s to 3950 m^3/s. The seasonal distribution of the runoff at Sherpur is as follows:

Table 7.2
Seasonal Distribution of Runoff at Sherpur

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	1152	6074	17.4
Monsoon	1952	20,577	59.0
Post-Monsoon	1175	6196	17.8
Dry Season	197	2058	5.8
Year	1101	34,906	100.0

Water levels in the Kushiyara have been observed by the BWDB at Amalshid, Sheola, Fenchuganj, Manumukh, Sherpur, Markuli, Ajmiriganj, Madna and Austagram. The indications of the record are as follows:

Table 7.3
Historical Water Level Summary for Kushiyara River

Gauge	Record (years)	Water Level Mean (mPWD)	Water Level Minimum (mPWD)	Water Level Maximum (mPWD)	Range (m)
Amalshid	27	10.73	5.94	17.91	11.97
Sheola	28	8.76	3.92	14.22	10.30
Fenchuganj	28	6.61	2.06	11.30	9.24
Manumukh	15	5.58	1.48	9.76	8.28
Sherpur	10	5.86	1.79	9.30	7.51
Markuli	20	4.85	1.34	8.50	7.16
Ajmiriganj	26	4.22	1.04	8.35	7.31
Madna	20	3.77	0.68	8.15	7.47
Austagram	22	3.52	0.28	7.97	7.69

Seasonal mean water levels are estimated as follows:

Table 7.4
Seasonal Water Level Summary for Kushiyara River

Season	Mean Water Levels (mPWD)				
	Amalshid	Sheola	Fenchuganj	Manumukh	Sherpur
Pre-Monsoon	9.97	8.23	6.23	5.07	5.83
Monsoon	14.60	12.35	9.65	8.31	8.12
Post-Monsoon	10.66	9.00	7.22	6.26	6.48
	7.15	5.30	3.44	2.73	3.30
Year	10.73	8.76	6.61	5.58	5.86
	Markuli	Ajmiriganj	Madna	Austagram	
Pre-Monsoon	4.44	3.38	2.70	2.44	
Monsoon	6.87	6.42	6.03	5.72	
Post-Monsoon	5.49	4.83	4.40	4.07	
Dry Season	2.69	2.12	1.72	1.56	
Year	4.85	4.22	3.77	3.52	

7.3 Sonai-Bardal

Within India, the Sonai-Bardal has a catchment area of 2256 km^2. It is formed in Assam from the confluence of the Langai and the Singla 5 km south of Karimganj. The Langai and the Singla both rise in Mizoram, in the same synclinal Valley 1, but are separated by a low ridge within the valley. The western tributary, the Langai, rises near a col in the valley at an elevation of 150 m, and follows a northerly course for 90 km to its confluence with the Singla in Assam. The eastern tributary, the Singla, rises at a similar elevation on Ridge A, and follows a parallel northerly course for 75 km, through the Son Beel complex, to its confluence with the Langai. From this confluence the Sonai-Bardal follows a westerly course for 10 km around the end of Ridge B to the Indo-Bangladesh border. There is evidence in satellite SPOT imagery of a channel running from the Singla into the Kushiyara at a point about halfway between Amalshid and Karimganj; it is reported that this channel has been abandoned by the Singla, and closed off by the Kushiyara left embankment in India. The imagery also shows a spill channel running from the Kushiyara at Karimganj southwestwards into the Sonai-Bardal; again, it is reported to be closed off by the Kushiyara left embankment at Karimganj. Thus, the Sonai-Bardal now carries the entire outflow of the Langai and the Singla, but no spill from the Kushiyara. Water balance studies indicate a mean annual outflow from the Sonai-Bardal catchment at the Indo-Bangladesh border of 147.0 m^3/s, equivalent to 4.6 km^3/year.

Within Bangladesh the Sonai-Bardal follows a southwesterly course for 25 km, through Jaldhup, to its confluence with the Juri within the Hakaluki Haor beel complex. From Hakaluki Haor the flow of the Sonai-Bardal is carried by the lower Juri into the Kushiyara at Fenchuganj.

Discharges in the Sonai-Bardal have been measured by the BWDB at Jaldhup. The 24 years of record indicate a mean annual discharge of 146 m^3/s, and a range in daily discharge from 1.3 m^3/s to 706 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.5
Seasonal Runoff Summary for Sonai-Bardal River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	123	650	14.2
Monsoon	297	3130	68.2
Post-Monsoon	127	667	14.5
Dry Season	14	143	3.1
Year	146	4591	100.0

Water levels in the Sonai-Bardal have also been observed by the BWDB at Jaldhup. The 27 years of record indicate a mean annual water level of 8.55 m PWD, a minimum of 5.46 m PWD, a maximum of 12.82 m PWD, and a range of 7.36 m. The seasonal distribution of water levels is as follows:

Table 7.6
Seasonal Water Level Summary for Sonai-Bardal River

Season	Mean Water Level (m PWD)
Pre-Monsoon	8.46
Monsoon	10.80
Post-Monsoon	8.61
Dry Season	6.30
Year	8.55

7.4 Juri

Within India, the Juri has a catchment area of 629 km^2. It rises in Valley 2 on the west side of Ridge B at an elevation of 300 m, and follows a northerly course for 45 km to the Indo-Bangladesh border. Water balance studies indicate a mean annual outflow at the border of 34.5 m^3/s, equivalent to 1.1 km^3/year.

Within Bangladesh, the Juri continues northwards for 8 km to its bifurcation at Silghat, about 5 km south of the railway line. From the bifurcation two channels continue northwards in parallel for another 8 km before merging in the Hakaluki Haor beel complex. During the dry season Hakaluki Haor consists of a group of about 20 beels of various sizes, but during the wet season the beels are flooded over to form one large shallow lake approximately 15 km in diameter and 200 km^2 in area. The Sonai-Bardal and the Pisang, possibly a distributary of the Manu, also flow into Hakaluki Haor where their flows merge with those of the Juri. From Hakaluki Haor the merged flows pass westwards through the lower Juri for 10 km to its confluence with the Kushiyara at Fenchuganj.

Discharges in the Juri have been measured by the BWDB at Juri Railway Bridge on the east distributary, and at Continala on the west distributary. The discharges at these two places, if appropriately added together, would represent the total outflow from the Juri catchment in Tripura. The 8 years of records for Juri Railway Bridge indicate a mean annual discharge into the east distributary of 13.2 m^3/s, and a range in daily discharge from 0 m^3/s to 91 m^3/s. The 9 years of records for Continala indicate a mean annual discharge into the west distributary of 30.1 m^3/s, and a range in daily discharge from 0 m^3/s to 234 m^3/s. The seasonal distribution of the runoff at Juri Railway Bridge is as follows:

Table 7.7
Seasonal Runoff Summary for Juri River at Railway Bridge

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6 m^3)	(%)
Pre-Monsoon	15.1	79.4	18.7
Monsoon	26.5	279.8	66.1
Post-Monsoon	8.0	42.1	9.9
Dry Season	2.2	22.5	5.3
Year	13.2	423.8	100.0

The seasonal distribution of the runoff at Continala is as follows:

Table 7.8
Seasonal Runoff Summary for Juri River at Continala

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	32.9	173.3	18.7
Monsoon	51.2	540.2	58.5
Post-Monsoon	15.5	81.6	8.8
Dry Season	12.4	129.4	14.0
Year	30.1	924.5	100.0

Water levels in the Juri have been observed by the BWDB at Juri Railway Bridge and Continala. The 15 years of records for Juri Railway Bridge indicate a mean annual water level of 8.93 m PWD, a minimum of 7.35 m PWD, a maximum of 11.65 m PWD and a range of 4.30 m. The 25 years of records for Continala indicate a mean water level of 8.97 m PWD, a minimum of 6.55 m PWD, a maximum of 11.55 m PWD, and a range of 5.00 m. The seasonal distribution of water levels is as follows:

Table 7.9
Seasonal Water Level Summary for Juri River

Season	Mean Water Level (m PWD)	
	Juri R.B	Continala
Pre-Monsoon	8.72	8.57
Monsoon	10.08	9.93
Post-Monsoon	8.61	8.53
Dry Season	8.15	8.42
Year	8.97	8.97

7.5 Manu

Within India, the Manu has a catchment area of 2235 km^2. It has two main headwater tributaries both rising at an elevation of 150 m. The western tributary rises in Valley 3 and flows northwards for 55 km to its confluence with the eastern tributary. The eastern tributary rises in Valley 2 and flows northwards for 55 km before cutting southwestwards for 8 km, through Ridge C, to join the western tributary. From the confluence of the two main tributaries the Manu continues northwards in Valley 3 for 20 km to the Indo-Bangladesh border. Water balance studies indicate a mean annual outflow from the Manu catchment at the Indo-Bangladesh border of 77.8 m^3/s, equivalent to 2.5 km^3/year.

Within Bangladesh, the Manu continues northwards in Valley 3 for 20 km before cutting through Ridge D at Kazir Chalk into Valley 4. From Kazir Chalk the Manu flows westwards for 10 km to its confluence with the Dhalai. About 2 km downstream of this confluence is the Manu Project barrage, a major structure used to divert water for irrigation within the Manu Project area located on the north side of the river. Between the barrage and Moulvi Bazar the Manu continues westwards for 5 km, cuts around the end of Ridge E1, passes through Moulvi Bazar, and then turns northwards for another 10 km before joining the Kushiyara at Manumukh. Embankments constructed along the Manu have considerably altered flood flow conditions in the river. On both banks embankments extend all the way from the border to where the Manu cuts through Ridge D; nevertheless, water escapes from this reach near the Manu Railway Bridge northeastwards through the Pisang to Hakaluki Haor. Downstream of Ridge D the right embankment, a component of the Manu Project, extends all the way down to the Kushiyara confluence, and the left bank is embanked from the Manu Project barrage upstream as far as the Dhalai confluence.

Discharges in the Manu have been measured by the BWDB at Manu Railway Bridge. The 27 years of record indicate a mean annual discharge of 86.8 m^3/s, and a range in daily discharge from 2.9 m^3/s to 875 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.10
Seasonal Runoff Summary for Mann River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	94.2	496.6	18.1
Monsoon	165.6	1745.2	63.6
Post-Monsoon	65.9	347.6	12.7
Dry Season	14.9	155.9	5.6
Year	86.8	2745.3	100.0

Water levels in the Manu have been observed by the BWDB at Manu Railway Bridge and Moulvi Bazar. The 28 years of records for Manu Railway Bridge indicate a mean water level of 14.05 m PWD, a minimum of 12.26 m PWD, a maximum of 18.92 m PWD, and a range of 6.66 m. The 27 years of records for Moulvi Bazar indicate a mean water level of 7.82 m PWD, a minimum of 5.34 m PWD, a maximum of 13.1 m PWD, and a range of 7.76 m. The seasonal distribution of water levels is as follows:

Table 7.11
Seasonal Water Level Summary for Manu River

Season	Mean Water Level (m PWD)	
	Juri R.B	Moulvi Bazar
Pre-Monsoon	14.05	7.66
Monsoon	15.19	9.41
Post-Monsoon	13.91	7.73
Dry Season	12.98	7.11
Year	14.05	7.82

7.6 Dhalai

Within India, the Dhalai has a catchment area of 632 km^2. It rises in Valley 4 at an elevation of 75 m, and flows northwards for 40 km to the Indo-Bangladesh border. Water balance studies indicate a mean annual outflow at the border of 23.4 m^3/s, equivalent to 0.7 km^3/year.

Within Bangladesh, the Dhalai continues northwards for 30 km, through Kamalganj, to its confluence with the Manu about 2 km upstream of the Manu Project barrage. A tributary of the Lungla in Valley 5 has cut back through Ridge E1 and is apparently close to capturing the Dhalai; a man-made connection between the Dhalai and this tributary may be accelerating the capture process.

Discharges in the Dhalai have been measured by the BWDB at Kamalganj. The 26 years of record indicate a mean annual discharge of 29.8 m^3/s, and a range in daily discharge from 0.6 m^3/s to 448 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.12
Seasonal Runoff Summary for Dhalai River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	34.4	181.1	19.2
Monsoon	55.6	586.5	62.0
Post-Monsoon	23.1	122.0	12.9
Dry Season	5.5	57.1	5.9
Year	29.8	946.7	100.0

Water levels in the Dhalai have also been observed by the BWDB at Kamalganj. The 28 years of records indicate a mean water level of 17.66 m PWD, a minimum of 16.69 m PWD, a maximum of 21.18 m PWD, and a range of 4.49 m. The seasonal distribution of water levels is as follows:

Table 7.13
Seasonal Water Level Summary for Manu River

Season	Mean Water Level (m PWD)
Pre-Monsoon	17.70
Monsoon	18.29
Post-Monsoon	17.57
Dry Season	17.05
Year	17.66

Time trends in Manu River data are discussed in the Specialist Study on River Sedimentation and Morphology.

7.7 Lungla

The Lungla has no catchment area in India. It rises just within Bangladesh at an elevation of 100 m where Ridge E splits into Ridges E1 and E2, and it flows northwards in Valley 5 for 20 km to the railway line at Motiganj, near Srimangal. From Motiganj it continues northwards in Valley 5 for 30 km, through Hail Haor into which numerous small tributaries converge from the flanks of Ridges E1 and E2, to Terapasha. One tributary which enters Hail Haor from the east has cut back into Ridge E1 and is apparently close to capturing the Dhalai; a man-made connection between the Dhalai and this tributary may be accelerating the capture process. Below Terapasha the Lungla, now called the Bijna, follows a southwesterly course for 20 km to its confluence with the Karangi, where it turns westwards and follows a rather circuitous route for 25 km to its confluence with the Kushiyara (Dhaleshwari reach) near Madna. Between Terapasha and the Karangi confluence numerous distributaries take off the Bijna into a complex network of minor channels which ultimately connect with the Kushiyara at various points between Manumukh and Madna.

Discharges in the Lungla have been measured by the BWDB at Motiganj. The 14 years of record indicate a mean annual discharge of 8.7 m^3/s, and a range in daily discharge from 0 to 333 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.14
Seasonal Runoff Summary for Lungla River

Season	Mean Discharge (m^3/s)	Mean Runoff ($10^6 m^3$)	Mean Runoff (%)
Pre-Monsoon	11.0	58.1	21.1
Monsoon	15.2	160.3	58.4
Post-Monsoon	7.1	37.2	13.6
Dry Season	1.8	18.7	6.9
Year	8.7	274.3	100.0

Water levels in the Lungla have also been observed by the BWDB at Motiganj. The 28 years of records indicate a mean water level of 7.28 m PWD, a minimum of 5.74 m PWD, a maximum of 9.19 m PWD, and a range of 3.45 m. The seasonal distribution of water levels is as follows:

Table 7.15
Seasonal Water Level Summary for Lungla River

Season	Mean Water Level (m PWD)
Pre-Monsoon	7.21
Monsoon	7.54
Post-Monsoon	7.19
Dry Season	7.12
Year	7.28

Recently, the SWMC has established a gauging station at Terapasha.

7.8 Karangi

Within India, the Karangi has a small catchment area of only 50 km^2. It rises on the western flank of Ridge E, and flows northwestwards in Valley 6 for 10 km to the Indo-Bangladesh border.

Within Bangladesh, the Karangi continues northwestwards for another 10 km before turning northwards for 8 km to intersect the railway line at Sofiabad. From Sofiabad it continues northwards for another 20 km to its confluence with the Lungla (Bijna) 7 km northeast of Habiganj. The Karangi has a few relatively insignificant tributaries, but one of them appears to collect a significant amount of spill from the adjacent Khowai river. All outflow from the catchment upstream of Sofiabad is constrained by the railway embankment to pass under the railway bridge.

Discharges in the Karangi have been measured by the BWDB at Sofiabad. The 23 years of records indicate a mean annual discharge of 8.1 m^3/s, and a range in daily discharge from 0 to 500 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.16
Seasonal Runoff Summary for Karangi River

Season	Mean Discharge (m^3/s)	Mean Runoff ($10^6 m^3$)	(%)
Pre-Monsoon	9.1	47.9	18.7
Monsoon	15.7	165.8	64.8
Post-Monsoon	5.6	29.3	11.5
Dry Season	1.3	13.1	5.0
Year	8.1	256.1	100.0

Water levels in the Karangi have also been observed by the BWDB at Sofiabad. The 28 years of records indicate a mean water level of 8.41 m PWD, a minimum of 7.44 m PWD, a maximum of 12.31 m PWD, and a range in water levels of 4.87 m. The seasonal distribution of water levels is as follows:

Table 7.17
Seasonal Water Level Summary for Karangi River

Season	Mean Water Level (m PWD)
Pre-Monsoon	8.52
Monsoon	8.95
Post-Monsoon	8.21
Dry Season	7.89
Year	8.41

Time trends in the Karangi data are discussed in the Specialist Study on River Sedimentation and Morphology. It appears that flood spills from the Khowai into the Karangi have increased in recent years.

7.9 Khowai

Within India, the Khowai has a catchment area of 1113 km^2. It rises at an elevation of 150 m on Ridge D, and flows westwards for 15 km, across Valley 4, before cutting through Ridge E into Valley 6. The gorge in Ridge E appears to offer the possibility of a water storage scheme similar to that on the Gumti further south in Valley 4, but a NOAA satellite photo of 8 October 1988 shows no dam. From the gorge the Khowai continues westwards for another 15 km across Valley 6 to the foot of Ridge F, where it turns sharply northwards for 30 km to the border at Ballah. Water balance studies indicate a mean annual outflow from the Khowai catchment at Ballah of 38.6 m^3/s, equivalent to 1.2 km^3/year.

Within Bangladesh, the Khowai flows northwestwards for 25 km through Chunarughat to Shaistaganj, where the Dhaka-Sylhet railway crosses over the river. From Shaistaganj the Khowai continues northwestwards for another 15 km through Habiganj, where it turns sharply westwards. From this turning point the Khowai, now called the Barak, flows westwards for 20 km to its confluence with the Kushiyara (Dhaleshwari reach) near Madna. The reach of the Khowai from Ballah to a point about 5 km downstream of the turning point has been embanked on both banks, which has considerably altered flood flow conditions. Both maps and SPOT imagery show a channel running northeastwards from the turning point to connect with the Lungla (Bijna reach); it is not clear in which direction this channel flowed, but it has been closed off recently by the downstream extension of the Khowai right embankment.

Discharges in the Khowai have been measured by the BWDB at Shaistaganj. The 27 years of record indicate a mean discharge of 36.4 m^3/s, and a range of daily discharges from 0.8 m^3/s to 1050 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.18
Seasonal Runoff Summary for Khowai River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	37.7	198.6	17.6
Monsoon	60.3	635.4	56.5
Post-Monsoon	32.6	171.6	15.3
Dry Season	11.5	120.5	10.6
Year	36.4	1126.1	100.0

Water levels in the Khowai have also been observed by BWDB at Ballah, Chunarughat, Shaistaganj and Habiganj. The indications of the records are as follows:

Table 7.19
Historical Water Level Summary for Khowai River

Gauge	Records (years)	Water Level Mean (m PWD)	Minimum (m PWD)	Maximum (mPWD)	Range (m)
Ballah	25	20.19	19.04	26.10	7.06
Chunarughat	27	13.64	12.45	18.17	5.72
Shaistaganj	27	9.36	8.12	15.05	6.93
Habiganj	28	6.75	4.76	10.96	6.20

The seasonal distribution of water levels is as follows:

Table 7.20
Seasonal Water Level Summary for Khowai River

Season	Mean Water Level (m PWD)			
	Ballah	Chunarughat	Shaistaganj	Habiganj
Pre-Monsoon	20.13	13.62	9.25	6.67
Monsoon	20.69	14.32	10.00	7.33
Post-Monsoon	20.16	13.60	9.32	6.70
Dry Season	19.75	13.11	8.75	6.24
Year	20.19	13.64	9.36	6.75

Time trends and inconsistencies in the Khowai data are discussed in the Specialist Study on River Sedimentation and Morphology.

7.10 Sutang

The Sutang has almost no catchment area in India. It rises in Valley 6 at a very low elevation, and very close to the Khowai; this suggests it was a distributary of the Khowai, the entrance having been closed off when the Khowai was embanked. From its point of origin near Chunarughat, the Sutang flows northwestwards for 25 km to where the Dhaka-Sylhet railway embankment runs right across its drainage basin. Flow in the Sutang appears to pass through this embankment entirely at Sutang Railway Bridge, but there may be some culverts through the embankment. From Sutang Railway Bridge the Sutang continues northwestwards for another 10 km before cutting around the end of Ridge F and turning southwestwards for 15 km to its confluence with the Kushiyara (Dhaleshwari reach) near Austagram.

Discharges in the Sutang have been measured by the BWDB at Sutang Railway Bridge. The 10 years of record indicate a mean discharge of 9.6 m^3/s, and a range of daily discharges from 0.1 m^3/s to 253 m^3/s. The seasonal distribution of the runoff is as follows:

Table 7.21
Seasonal Runoff Summary for Sutang River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	7.5	39.4	13.0
Monsoon	21.3	224.1	73.7
Post-Monsoon	6.1	32.2	10.6
Dry Season	0.8	8.3	2.7
Year	8.6	304.0	100.0

Water levels in the Sutang have been observed by the BWDB at Sutang Railway Bridge. The 28 years of record indicate a mean water level of 4.59 m PWD, and a range of daily water levels from 2.70 m PWD to 8.13 m PWD. The seasonal distribution of water levels is as follows:

Table 7.22
Seasonal Water Level Summary for Sutang River

Season	Mean Water Level (m PWD)
Pre-Monsoon	3.98
Monsoon	6.15
Post-Monsoon	4.62
Dry Season	3.32
Year	4.59

7.11 Sada Khal

Sada Khal has no catchment area within India. It originates between the Surma and Kushiyara rivers near Amalshid, and follows a southwesterly course parallel to these rivers for 33 km before entering the Kushiyara from the north, about 8 km downstream of Sheola. Its catchment area is only 354 km^2, and so the local runoff is not large. The hydrological significance of Sada Khal stems from the fact that it receives large quantities of water from the Surma and Kushiyara via openings in the Surma left embankment and the Kushiyara right embankment, and as spill over these embankments.

Discharges in Sada Khal have been measured by the BWDB near Sheola only during the wet season when it is carrying substantial spill from the Surma and Kushiyara, and there are only 8 years of such partial record. Monthly discharges vary greatly from one year to another. For what they are worth, these partial data indicate mean monthly discharges as shown in Table 7.1.

Table 7.23
Mean Monthly Discharges of Sada Khal at Sheola (m^3/s)

Jun	Jul	Aug	Sep	Oct	Nov
245.9	312.7	284.8	122.1	50.8	4.6

8. SURMA SYSTEM

8.1 Introduction

The Surma, the third largest river of the Meghna Subregion, receives on average 35% of the Barak flow and also collects inflows from the eastern 7540 km^2, or 56%, of the tributary area in Meghalaya (Figure 8.1). This area occupies most of the southern slopes of the Shillong Plateau, which rises to a maximum elevation of 2575 m and records the world's greatest annual rainfall.
The Surma has seven significant tributaries originating in Meghalaya and entering from the north; in downstream (east to west) order these are:

- Lubha
- Sarigowain
- Piyain
- Dhalai
- Umium
- Jhalukhali
- Jadukata

The Jadukata also drains the eastern part of the Tura Range. As seen from Bangladesh all these catchments appear to be covered by secondary forest.

8.2 Surma

The Surma originates from the bifurcation of the Barak at Amalshid from where it follows a westerly course until it joins the Baulai just north of Sukdevpur. Flow in the Surma has been measured by the BWDB in its upper reaches only, since the lower reaches are flooded over in the wet season. Water balance studies indicate that the Surma's contribution to the Baulai amounts to 2214 m^3/s, or 69.7 $km^3/year$.

Water balance studies indicate that inflows from the Meghalaya tributaries total 35.2 $km^3/year$, or 20.3% of the total water supply to the Meghna Subregion; this is equivalent to a mean annual flow of 1116 m^3/s. The inflows occur mainly in the monsoon season partly as flash floods with peak flows ranging up to 30 or more times average flows. Base flows in these rivers are very small by the end of the dry season, and may dry up completely. The Surma also collects 35% of the Barak inflow.

Discharges in the Surma been measured by the BWDB at Kanairghat and Sylhet. The 22 years of record for Kanairghat indicate a mean annual discharge of 549 m^3/s, and a range of daily discharges from 2.2 m^3/s to 2730 m^3/s. The seasonal distribution of the runoff at Kanairghat is as follows:

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Table 8.1
Seasonal Summary of Runoff at Kanairghat

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	404	2130	12.3
Monsoon	1235	13,018	75.3
Post-Monsoon	367	1935	11.2
Dry Season	21	216	1.2
Year	549	17299	100.0

The 22 years of record for Sylhet indicate a mean annual discharge of 563 m^3/s, and a range of daily discharges from 2.6 m^3/s to 2480 m^3/s. The seasonal distribution of the runoff at Sylhet is as follows:

Table 8.2
Seasonal Summary of Runoff at Sylhet

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	399	2104	11.9
Monsoon	1263	13312	75.0
Post-Monsoon	395	2082	11.7
Dry Season	23	245	1.4
Year	563	17742	100.0

Water levels in the Surma have been observed by the BWDB at Kanairghat, Sylhet, Chhatak and Sunamganj. The indications of the records are as follows:

Table 8.3
Historical Summary of Water Levels in Surma River

Gauge	Record (years)	Water Level: Mean (mPWD)	Water Level: Minimum (mPWD)	Water Level: Maximum (mPWD)	Water Level: Range (m)
Kanairghat	26	8.32	3.93	15.04	11.11
Sylhet	11	6.34	1.99	11.94	9.95
Chhatak	25	5.43	1.10	11.16	10.06
Sunamganj	27	5.23	1.34	9.46	8.12

The seasonal distribution of water levels is as follows:

Table 8.4
Seasonal Summary of Water Levels in Surma River

Season	Mean Water Level (m PWD)			
	Kanairghat	Sylhet	Chhatak	Sunamganj
Pre-Monsoon	7.81	6.10	5.19	5.06
Monsoon	12.27	9.74	8.32	7.68
Post-Monsoon	8.05	6.58	5.88	5.84
Dry Season	4.71	2.93	2.43	2.50
Year	8.32	6.34	5.43	5.22

8.3 Lubha

Within India, the Lubha has a catchment area of 771 km^2. The catchment is very steep, rising in a distance of 35 km from an elevation of 10 m at the border to an elevation of 1627 m on the plateau. The Lubha and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow from the catchment passes through a gorge on the Indian side of the border. Water balance studies indicate a mean annual outflow at the border of 109.3 m^3/s, or 3.4 km^3/year.

Within Bangladesh, the Lubha follows a southerly course for 7 km to its confluence with the Surma at Lubhachara. Just within the border a spill channel takes off from the right bank, but it is thought to be rarely active. About 3 km upstream of Lubhachara a small tributary enters at the right bank; when the Lubha is in flood, back flow into this tributary causes spill onto agricultural lands west of the Lubha. Under normal flow conditions Lubha water passes down the Surma through Kanairghat, but hydraulic conditions at the Lubha/Surma confluence are more complicated when one river is in high flood and the other is not. When the Lubha is in high flood and the Surma is not, some Lubha water flows up the Surma towards Amalshid and may even enter the Kushiyara. When the Surma is in high flood and the Lubha is not, Surma water backs up the Lubha at least as far as Lubhachara and possibly as far as the Indo-Bangladesh border.

Discharges in the Lubha have been measured by the BWDB at Lubhachara. Unfortunately, since the current meter measurements were made in the period 1971-80, and the water level observations in the period 1982-90, it is not possible to process the data into mean discharges since rating curves cannot be established. The 212 current meter measurements available for Lubhachara indicate a mean annual discharge of 124.2 m^3/s, a minimum discharge of 1.8 m^3/s, and a maximum discharge of 800 m^3/s.

Water levels have also been observed at Lubhachara. The 9 years of records indicate a mean water level of 8.82 m PWDB, a minimum of 4.61 m PWD, a maximum of 15.56 m PWD, and a range of 10.95 m. The seasonal distribution of water levels is follows:

Table 8.5
Seasonal Water Level Summary for Lubha River

Season	Mean Water Level (m PWD)
Pre-Monsoon	8.75
Monsoon	12.51
Post-Monsoon	8.48
Dry Season	5.32
Year	8.82

8.4 Sarigowain

Within India, the Sarigowain has a catchment area of 840 km^2. The catchment is very steep, rising in a distance of 35 km from an elevation of 10 m at the border to an elevation of 1405 m on the plateau. In the lower half of the catchment the Sarigowain and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow from the catchment passes through a gorge on the Indian side of the border. Water balance studies indicate a mean annual outflow at the border of 131.0 m^3/s, or 4.1 km^3/year.

Within Bangladesh, the Sarigowain follows a southwesterly course for about 60 km, through Sarighat, Gowainghat and Salutikar, to its confluence with the Surma about 10 km upstream of Chhatak. At the border, 7 km upstream of Sarighat, a spill channel takes off from the right bank of the Sarigowain, and follows a westerly course before re-joining the Sarigowain just upstream of Gowainghat. At Gowainghat the Sarigowain is joined by the Jaflong spill channel of the Piyain.

Discharges of the Sarigowain have been measured by the BWDB at Sarighat and Salutikar. The 26 years of record available for Sarighat indicate a mean annual discharge of 130 m^3/s, and a range in daily discharge from 2.5 m^3/s to 1730 m^3/s. The seasonal distribution of the runoff is as follows:

Table 8.6
Seasonal Runoff Summary for Sarigowain River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	109	572.6	14.0
Monsoon	294	3094.2	75.3
Post-Monsoon	63	329.7	8.1
Dry Season	11	109.4	2.6
Year	130	4105.9	100.0

The 11 years of record available for Salutikar are not sufficiently complete to indicate a mean annual discharge, or a range of discharges.

Water levels in the Sarigowain have been observed by the BWDB at Sarighat, Gowainghat and Salutikar. The indications of the records are as follows:

Table 8.7
Historical Water Level Summary for Sarigowain River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Sarighat	28	8.09	5.52	14.07	8.55
Gowainghat	27	6.34	1.83	12.43	10.60
Salutikar	28	5.80	1.18	11.22	10.04

The seasonal distribution of water levels is as follows:

Table 8.8
Seasonal Water Level Summary for Sarigowain River

Season	Mean Water Level (m PWD) Sarighat	Gowainghat	Salutikar
Pre-Monsoon	8.03	6.21	5.56
Monsoon	10.66	9.81	9.04
Post-Monsoon	7.44	6.40	6.20
Dry Season	5.79	2.86	2.45
Year	8.09	6.34	5.80

8.5 Piyain

Within India, the Piyain has a catchment area of 1003 km^2. The catchment is very steep, rising in a distance of 40 km from an elevation of 10 m at the border to an elevation of 1945 m on the plateau. In the lower half of the catchment the Piyain and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow from the catchment passes through a gorge on the Indian side of the border. Water balance studies indicate a mean annual outflow at the border of 190.5 m^3/s, or 6.0 km^3/year.

Within Bangladesh, the Piyain follows a southwesterly course for 35 km, through Ratnerbhanga and Companiganj, to its confluence with the Surma at Chhatak. At the border, 7 km upstream of Ratnerbhanga, a significant spill channel takes off from the left bank of the Piyain and follows a southerly course, through Jaflong, to join the Sarigowain at Gowainghat. At Companiganj the Piyain is joined by the Dhalai, and at Ambari it is joined by the main channel of the Umium.

Discharges of the Piyain have been measured by the BWDB in the main channel at Ratnerbhanga, and in the spill channel at Jaflong. The discharges at these two places, if appropriately added together, would represent the total outflow from the Piyain catchment in Meghalaya. The 5 years of record available for Ratnerbhanga indicate a mean annual discharge of 100 m^3/s, and a range in daily discharge from 1.8 m^3/s to 2730 m^3/s. The seasonal distribution of the runoff is as follows:

Table 8.9
Seasonal Runoff Summary for Piyain River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	Mean Runoff (%)
Pre-Monsoon	71	372.3	11.5
Monsoon	232	2445.6	76.1
Post-Monsoon	56	296.3	9.2
Dry Season	9	98.5	3.2
Year	100	3212.7	100.0

The 76 current meter measurements available for Jaflong indicate a mean annual discharge of 37.1 m^3/s.

Water levels in the Piyain have been observed by the BWDB at Ratnerbhanga and Companiganj. The 18 years of record for Ratnerbhanga indicate a mean water level of 10.25 m PWD, a minimum of 8.84 m PWD, a maximum of 15.33 m PWD, and a range of 6.49 m. The 25 years of records for Companiganj indicate a mean water level of 7.68 m PWD, a minimum of 6.02 m PWD, a maximum of 12.04 m PWD, and a range of 6.02 m. The seasonal distribution of water levels is as follows:

Table 8.10
Seasonal Water Level Summary for Piyain River

Season	Mean Water Level (m PWD) Ratnerbhanga	Companiganj
Pre-Monsoon	10.00	7.34
Monsoon	11.29	9.24
Post-Monsoon	10.02	7.28
Dry Season	9.45	6.47
Year	10.25	7.68

8.6 Dhalai

Within India, the Dhalai has a catchment area of 340 km^2. The catchment is very steep, rising in a distance of 30 km from an elevation of 10 m at the border to a maximum elevation of 1892 m on the plateau. Throughout the catchment the Dhalai and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow passes through a gorge on the Indian side of the border. From the gorge the Dhalai follows a southwesterly course for about 2 km before it enters Bangladesh at Islampur. Water balance studies indicate a mean annual outflow at the border of 83.2 m^3/s, or 2.6 $km^3/year$. Cherrapunji, site of the world's greatest annual rainfall, is located on the western watershed of the catchment.

Within Bangladesh, the Dhalai follows a southerly course for about 10 km from Islampur to its confluence with the Piyain at Companiganj.

The BWDB opened a gauging station on the Dhalai at Islampur in 1990.

8.7 Umium

Within India, the Umium has a catchment area of 431 km^2. The catchment is very steep, rising in a distance of 50 km from an elevation of 10 m at the border to a maximum elevation of 1965 m on the plateau. Except in their highest reaches, the Umium and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow passes through a gorge on the Indian side of the border. From the gorge the Umium follows a southeasterly course for about 8 km across a fairly extensive alluvial area before it enters Bangladesh at Chelasonapur. Within this alluvial area the Umium bifurcates twice, so that the outflow enters Bangladesh through a main channel and two spill channels. The first bifurcation occurs immediately downstream of the gorge from where a spill channel takes off westwards towards the border. The second bifurcation occurs in the centre of the alluvial area, from where a major spill channel, the Nawagang, takes off southwestwards to enter Bangladesh at Urugoan. Water balance studies indicate a mean annual outflow at the border of 90.4 m^3/s, or 2.9 $km^3/year$. Cherrapunji, site of the world's largest annual rainfall, is located on the eastern watershed of the catchment, while Mawsynram with comparable rainfall is located on its western watershed.

Within Bangladesh, the Umium turns south at Chelasonapur and maintains a southerly course for 10 km to its confluence with the Surma at Chhatak. At Urugoan the Nawagang also turns south, maintaining this course for 8 km to its confluence with the Surma at Dohalia. Between Urugoan and Dohalia the Nawagang is joined by the first spill channel and several streams coming off the lower slopes of the plateau.

The BWDB opened gauging stations on the Umium at Chelasonapur and on the Nawagang at Urugoan in 1990.

8.8 Jhalukhali

Within India, the Jhalukhali has a catchment area of 591 km^2. The catchment is very steep, rising in a distance of 40 km from an elevation of 10 m at the border to a maximum elevation of 1885 m on the plateau. Throughout the catchment the Jhalukhali and its tributaries are deeply incised into the southern slope of the plateau, and the entire outflow passes through a gorge on the Indian side of the border. From the gorge the Jhalukhali follows a southerly course for about 5 km across an extensive alluvial area before it enters Bangladesh at Dulura. Within this area the Jhalukhali bifurcates twice, so that the outflow enters Bangladesh through a main channel and two spill channels. The first bifurcation occurs about 2 km inside India, and the second at the border. Water balance studies indicate a mean annual outflow at the border of 142.9 m^3/s, or 4.5 $km^3/year$.

Within Bangladesh, the Jhalukhali follows a southerly course for 10 km from Dulura, through Muslimpur, to its confluence with the Surma at Sunamganj. The two spill channels follow more westerly courses to join the Jadukata near Tahirpur and Satepur; their flows are finally discharged into the Surma through the Jadukata, (or Rakti, as it is known in this lowest reach) at Durlabpur, near Jamalganj.

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The BWDB opened a gauging station on the Jhalukhali at Muslimpur in 1988, and the SWMC opened one at Dulura in 1990.

8.9 Jadukata

Within India, the Jadukata has a catchment area of 2399 km^2. This large catchment drains most of the southwestern slope of the plateau. The catchment is very steep, rising in a distance of 45 km from an elevation of 10 m at the border to a maximum elevation of 1925 m on the plateau. The lower reach of the Jadukata in India follows a southeasterly course through a narrow valley separating the southwestern slope of the Shillong Plateau from the eastern end of the Tura Range. Its upper reach, and its tributaries, all originate on the southwestern slope of the plateau and follow southwesterly courses to their confluence with the lower reach. At the border the Jadukata turns south and enters Bangladesh at Lorergarh. Water balance studies indicate a mean annual outflow at the border of 365.7 m^3/s, or 11.5 km^3/year.

Within Bangladesh, the Jadukata follows a southerly course for 25 km to its confluence with the Surma at Durlabpur, near Jamalganj; the lower stretch of this reach, south of Tahirpur, is called the Rakti. Between Lorergarh and Durlabpur the Jakukata bifurcates three times. The first bifurcation occurs 1 km south of Lorergarh where the Patni takes off westwards for 10 km before turning south to its confluence with the Baulai west of Tahirpur. The second bifurcation occurs 10 km south of Lorergarh where the Baulai takes off westwards, through Tahirpur. The third bifurcation occurs 15 km south of Lorergarh where the Nawa takes off westwards through Beheli, to join the Baulai at Ramjibanpur.

Discharges in the Jadukata have not been measured.

Water levels in the Jadukata have been observed by the BWDB at Saktiakhola, about halfway between the first and second bifurcations. The 27 years of record for Saktiakhola indicate a mean water level of 5.80 m PWD, a minimum of 3.46 m PWD, a maximum of 9.67 m PWD, and a range of 6.21 m. The seasonal distribution of water levels is follows:

Table 8.11
Seasonal Water Level Summary for Jadukata River

Season	Mean Water Level (m PWD)
Pre-Monsoon	5.20
Monsoon	7.40
Post-Monsoon	5.88
Dry Season	4.45
Year	5.80

Recently, SWMC started water level observations at Lorergarh, upstream of the first bifurcation.

8.10 Distributaries

Numerous distributaries, all resulting from interventions by man, take off from the Surma's left bank downstream of Sylhet. The purpose of the interventions was generally to provide water for dry season irrigation of the Surma-Kushiyara floodplain. The more significant of these distributaries are:

- Bahia
- Khajanchi
- Bhattakhal
- Madhabpur

These four distributaries, for which partial discharge records exist, take off the Surma between Sylhet and Chhatak. There are others downstream of Chhatak whose significance cannot be assessed on the basis of recorded discharge data. All of these distributaries break up into several channels on the floodplain, but the water diverted from the Surma, less losses on the floodplain, eventually finds its way into the Kushiyara between Sherpur and Ajmiriganj.

Old Surma

The Old Surma channel takes off from the Surma River south of Sunamganj and connects to the Kushiyara River at Markuli. As indicated in the Specialist Study on River Sedimentation and Morphology, this was the main course of the Surma River in the 18th century. By 1952 it was a distributary. In 1987 the channel was blocked by an embankment near its upstream end and in 1992 it was closed near its downstream end.

9. KANGSHA-BAULAI SYSTEM

9.1 Introduction

The Kangsha-Baulai system, which includes the outflow from the Surma system (Chapter 8), joins the Kushiyara system in the southwest part of the Region to form the Meghna system.

The Kangsha River collects inflows from the western 5925 km^2, or 44%, of the area in Meghalaya tributary to the Meghna Subregion (Figure 9.1). This area contains the Tura Range of western Meghalaya, and the extensive plains extending from it towards the southwest. The Kangsha has five significant tributaries all originating in Meghalaya and entering it from the north; in downstream (west to east) order these are:

- Malijhee
- Chelakhali
- Bhogai
- Nitai
- Someswari

Except for the Someswari, these tributaries all rise on, or near, the southwestern slope of the Tura Range. The Someswari drains most of the northeastern slope of the Tura Range and the western slopes of the Shillong Plateau: part of its flow is tributary to the Baulai. The Kangsha also appears to receive some spill flow from the Old Brahmaputra.

The Baulai River has three principal tributaries:

- Surma
- Kangsha
- Mogra

The Surma which enters the Baulai from the east, and the Kangsha which enters it from the west, together collect all the inflow from Meghalaya. The Surma also collects 35% of the Barak inflow. The lower reach of the Surma is known locally as the Nawa.

9.2 Kangsha

The Kangsha collects outflow from the Bhogai, Chelakhali and Malijhee near Nalitabari, from where it follows an easterly course until it joins the Baulai just south of Sukdevpur. Flow in the Kangsha has been measured by the BWDB in mid-reach at Jaria Jhanjail only. Water balance studies indicate that the Kangsha's contribution to the Baulai amounts to 740 m^3/s, or 23.4 $km^3/year$; this includes 244 m^3/s, or 7.7 $km^3/year$ estimated passing into the Mogra via the Thakurakona-Atpara channel.

The Kangsha tributaries listed in 9.1 above collect 44% of the inflow to the Region from Meghalaya. Water balance studies indicate that their inflows total 18.9 $km^3/year$, equivalent to a mean annual flow of 598 m^3/s. The inflows occur mainly in the monsoon season and include flash floods with peak flows ranging up to 30 or more times average flows. In contrast, base flows are very small by the end of the dry season, and may dry up altogether.

Discharges in the Kangsha have been measured by the BWDB at Jaria Jhanjail. The 25 years of record indicate a mean annual discharge of 281 m^3/s, and a range of daily discharges from 0 to 1430 m^3/s. The seasonal distribution of the runoff is as follows:

Table 9.1
Seasonal Runoff Summary for Kangsha River

Season	Mean Discharge (m^3s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	111	587.0	6.6
Monsoon	626	6602.2	74.5
Post-Monsoon	252	1327.5	15.0
Dry Season	33	344.1	3.9
Year	281	8860.8	100.0

Water levels in the Kangsha have been observed by the BWDB at Sarchapur, Jaria Jhanjail, and Mohanganj. The indications of the records are as follows:

Table 9.2
Historical Water Level Summary for Kangsha River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Sarchapur	27	9.71	5.96	14.28	8.32
Jaria Jhanjail	28	6.80	3.60	11.48	7.88
Mohanganj	26	5.00	2.20	8.72	6.52

The seasonal distribution of water levels is as follows:

Table 9.3
Seasonal Water Level Summary for Kangsha River

Season	Sarchapur (mPWD)	Jaria Jhanjail (mPWD)	Mohanganj (mPWD)
Pre-Monsoon	8.65	5.53	4.22
Monsoon	11.83	9.48	6.87
Post-Monsoon	9.79	7.06	5.40
Dry Season	8.04	4.59	3.32
Year	9.07	6.80	5.00

9.3 Baulai

The Baulai originates from the bifurcation of the Jadukata near Tahirpur, from where it follows a westerly course for 12 km and then a southerly course for 100 km to Dilalpur on the Upper Meghna, receiving major inflows from the Someswari, Surma (Nawa), Kangsha and Mogra. The flow of the Baulai has never been measured by the BWDB: during the wet season its channel is at the bottom of the lake which forms in the centre of the subregion. Water balance studies indicate that its total contribution to the Upper Meghna amounts to 102 km^3/yr, or 3247 m^3/s.

Water levels in the Baulai have been observed by the BWDB at Sukdevpur, Kaliajuri, Itna and Dilalpur. The indications of the records are as follows:

Table 9.4
Historical Water Level Summary for Baulai River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Sukdevepur	10	4.44	0.80	8.08	7.28
Kaliajuri	25	4.66	0.98	8.99	8.01
Itna	27	4.39	1.20	8.69	7.49
Dilalpur	27	3.83	1.02	8.15	7.13

The seasonal distribution of water levels is as follows:

Table 9.5
Seasonal Water Level Summary for Baulai River

Season	Mean Water Levels (m PWD) Sukdevepur	Kaliajuri	Itna	Dilalpur
Pre-Monsoon	4.22	3.77	3.39	2.79
Monsoon	6.48	6.93	6.68	6.02
Post-Monsoon	5.21	5.42	5.13	4.33
Dry-Season	2.12	2.43	2.21	1.88
Year	4.44	4.66	4.39	3.83

9.4 Malijhee

Within India, the Malijhee has a catchment area of 78 km^2. The catchment is very flat, rising in a distance of 25 km from an elevation of 10 m at the border to a maximum elevation of 150 m at the foot of the Tura Range. From the foot of the Tura Range the Malijhee follows a southerly course for about 25 km through a long, relatively narrow valley, apparently devoid of any significant tributaries, before it enters Bangladesh near Gazni. Water balance studies indicate a mean annual outflow at the border of 5.5 m^3/s, based on an assumed runoff of 70 l/s/km^2.

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Within Bangladesh, the Malijhee continues southwards, collects a small tributary rising to the west in Meghalaya, and then passes through a series of beels to the north of Sherpur. Outflow from this series of beels is variously shown on different maps as entering the Kangsha west of Nalitabari, or entering the Old Brahamaputra downstream of Jamalpur.

No water level nor discharge data are available.

9.5 Chelakhali

Within India, the Chelakhali has a catchment area of 80 km^2. The catchment is very flat rising in a distance of 25 km from an elevation of 25 m at the border to a maximum elevation of 150 m at the foot of the Tura Range. From the foot of the Tura Range the Chelakhali follows a southerly course for about 25 km through a long, relatively narrow valley, apparently devoid of any significant tributaries, before entering Bangladesh at Bathkuchi. Water balance studies indicate a mean annual outflow at the border of 5.6 m^3/s, based on an assumed runoff of 70 $l/s/km^2$.

Within Bangladesh, the Chelakhali continues southwards passing through a series of beels southwest of Nalitabari. Outflow enters the Kangsha at its confluence with the Bhogai south of Nalitabari.

No discharge data are available. Water levels have been observed by the BWDB at Bathkuchi. The 27 years of record indicate a mean water level of 24.00 m PWD, a minimum of 23.10 m PWD, a maximum of 27.70 m PWD, and a range of 4.60 m. The seasonal distribution of water levels is follows:

Table 9.6
Seasonal Water Level Summary for Chelakhali River

Season	Mean Water Levels (m PWD)
Pre-Monsoon	23.87
Monsoon	24.29
Post-Monsoon	23.99
Dry Season	23.79
Year	24.00

9.6 Bhogai

Within India, the Bhogai has a catchment area of 479 km^2. It rises at an elevation of 1412 m on the southwest slope of the Tura Range, and the upper third of its catchment is located on this steep slope. The lower two-thirds of the catchment are located on a broad expanse of flat land containing several outliers of higher land. From the crest of the Tura Range the Bhogai follows a southerly course for 30 km before entering Bangladesh at Nakuagaon. Water balance studies indicate a mean annual outflow of 36.2 m^3/s, or 1.1 km^3/year.

Within Bangladesh, the Bhogai continues on a southerly course for 20 km from Nakuagaon to join the Kangsha 5 km south of Nalitabari. A distributary takes off southeastwards from the left bank of the Bhogai near Nakuagaon and enters an extensive area of interconnecting channels and beels between the Bhogai, Kangsha and Nitai rivers.

Discharges in the Bhogai have been measured by the BWDB at Nakuagaon. The 24 years of record indicate a mean annual discharge of 38.0 m^3/s, and a range of daily discharges from 0.6 m^3/s to 1240 m^3/s. The seasonal distribution of the runoff is as follows:

Table 9.7
Seasonal Runoff Summary for Bhogai River

Season	Mean Discharge (m^3/s)	Mean Runoff (MCM)	Mean Runoff (%)
Pre-Monsoon	13.5	71.3	5.9
Monsoon	89.5	943.9	78.8
Post-Monsoon	25.8	136.2	11.4
Dry Season	4.4	46.2	3.9
Year	38.0	1197.6	100.0

Water levels have been observed by the BWDB at Nakuagaon and Nalitabari. The 26 years of record for Nakuagoan indicate a mean water level of 20.79 m PWD, a minimum of 19.82 m PWD, a maximum of 25.38 m PWD, and a range of 5.56 m. The 27 years of record for Nalitabari indicate a mean water level of 14.97 m PWD, a minimum of 14.06 m PWD, a maximum of 18.15 m PWD, and a range of 4.09 m. The seasonal distribution of water levels is as follows:

Table 9.8
Seasonal Water Level Summary for Bhogai River

Season	Mean Water Levels (m PWD) Nakuagoan	Mean Water Levels (m PWD) Nalitabari
Pre-Monsoon	20.43	14.61
Monsoon	21.56	15.75
Post-Monsoon	20.71	14.89
Dry Season	20.25	14.40
Year	20.79	14.97

9.7 Nitai

Within India, the Nitai has a catchment area of 365 km^2. It rises at an elevation of 1360 m on the southwest slope of the Tura Range, and the upper third of its catchment is located on this steep slope. The lower two-thirds of the catchment are located on a broad expanse of flat land with several outliers of higher land. From the crest of the Tura Range the Nitai follows a southerly course for 30 km before entering Bangladesh at Ghosegaon. Water balance studies indicate a mean annual outflow of 31.0 m^3/s, or 1.0 km^3/year.

Within Bangladesh, the Nitai follows a southwesterly course for 15 km from Ghosegaon into a extensive area of interconnecting channels and beels between the Bhogai, Kangsha and Nitai rivers. The Nitai picks up the outflow from this area which includes the flow of the Bhogai's left distributary and of several other streams entering from India. The Nitai then turns eastwards for 15 km before joining the Kangsha 10 km upstream of Jaria Jhanjail.

Discharges have been measured by the BWDB at Ghosegaon. The 24 years of record indicate a mean annual discharge of 32.3 m^3/s, and a range of daily discharges from 0 m^3/s to 981 m^3/s. The seasonal distribution of the runoff is as follows:

Table 9.9
Seasonal Runoff Summary for Nitai River

Season	Mean Discharge (m^3/s)	Mean Runoff (MCM)	Mean Runoff (%)
Pre-Monsoon	12.4	65.2	6.5
Monsoon	76.0	801.1	79.4
Post-Monsoon	20.1	106.2	10.5
Dry Season	3.5	36.3	3.6
Year	32.3	1008.8	100.0

Water levels have also been observed the BWDB at Ghosegaon. The 22 years of record indicate a mean water level of 13.15 m PWD, a minimum of 11.65 m PWD, a maximum of 17.43 m PWD, and a range of 5.78 m. The seasonal distribution of water levels is as follows:

Table 9.10
Seasonal Water Level Summary for Nitai River

Season	Mean Water Level (m PWD)
Pre-Monsoon	12.99
Monsoon	13.80
Post-Monsoon	12.80
Dry Season	12.76
Year	13.15

9.8 Someswari

Within India, the Someswari has a catchment area of 2419 km^2. The upper two-thirds of this area are located northeast and the lower third southwest of the Tura Range. The river rises at an elevation of 1412 m on the northeastern slope at a point about 10 km east of Tura, and flows northeastwards for 15 km to the foot of this steep slope where the elevation is only 300 m. At the foot of the slope the river turns southeastwards and flows between the Tura Range and the Shillong Plateau for 30 km. At the end of this reach the Someswari is joined from the north by a major tributary which drains the western end of the Shillong Plateau, and it turns southwestwards for 20 km cutting through the Tura Range in a gorge. At the entrance to the gorge the river is joined from the southeast by a tributary draining the remainder of the northeast slope of the Tura Range. Downstream of the gorge the Someswari follows a more southerly course, and is joined by several tributaries draining the southwestern slope of the Tura Range before it enters Bangladesh at Bagmara. Water balance studies indicate a mean annual outflow of 263.3 m^3/s, or 8.3 km^3/year.

Within Bangladesh, the Someswari continues southwards for 5 km from Bagmara to Durgapur where it bifurcates. Prior to 1974 the Someswari flowed mainly eastwards into the left distributary which extends for 45 km through Kalmakanda and Madhyanagar to join the Baulai near Sukdevpur; in this period the right distributary, which follows a southerly course to the Kangsha just upstream of Jaria Jhanjail, carried the lesser portion of the flow. In 1974 a major flood changed the bifurcation ratio and since then the larger portion of the flow has passed down the right distributary to the Kangsha.

Discharges in the Someswari have been measured by the BWDB at Durgapur. Prior to 1974 the discharge was measured sporadically in both distributaries, but since 1974 it has been measured in the right distributary only. Consequently, common periods of record, representative of the total flow of the Someswari, are available for only 5 years. The measurement point on the right distributary is here referred to as Durgapur A, and that on the left distributary as Durgapur B. The 5 years of record (prior to 1974) for Durgapur B indicate a mean annual discharge in the left distributary of 47.1 m^3/s. The 19 years of record (spanning 1964 to 1989) for Durgapur A indicate as mean annual discharge of 151 m^3/s, and a range of daily discharges from 2 m^3/s to 2490 m^3/s. The 5 years of common records for Durgapur A and B (1966, 1969, 1970, 1972 and 1973) indicate a total mean annual discharge of 188 m^3/s, and a range of daily discharges from 8.5 m^3/s to 4415 m^3/s. The seasonal distribution of the runoff for these 5 years is as follows:

Table 9.11
Seasonal Runoff Summary for Someswai River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	57	299.5	5.1
Monsoon	447	4709.8	79.5
Post-Monsoon	111	587.4	9.9
Dry Season	31	325.9	5.5
Year	188	5922.6	100.0

Water levels in the Someswari have been observed by the BWDB at Bagmara, Durgapur, Kalmakanda and Madhyanagar. The data for Madhyanagar are unreliable. The indications of the records are as follows:

Table 9.12
Historical Water Level Summary for Someswari River

Gauge	Record (years)	Mean (mPWD)	Water Level Minimum (mPWD)	Maximum (mPWD)	Range (m PWD)
Bagmara	25	13.88	12.67	18.38	5.71
Durgapur	28	10.84	9.34	14.98	5.64
Kalmakanda	26	4.75	0.61	9.27	8.66

The seasonal distribution of water levels is as follows:

Table 9.13
Seasonal Water Level Summary for Someswari River

Season	Mean Water Levels (m PWD) Bagmara	Durgapur	Kalmakanda
Pre-Monsoon	13.47	10.47	4.05
Monsoon	14.70	11.65	6.90
Post-Monsoon	14.06	10.81	5.46
Dry Season	13.26	10.24	2.57
Year	13.88	10.84	4.75

9.9 Mogra

The Mogra rises near Phulpur on the plains north of Mymensingh from where it follows a southeasterly course to its confluence with the Baulai about halfway between Itna and Dilalpur. Flow in the Mogra has never been measured by the BWDB; its upper reaches carry little water and its lower reaches are flooded over in the wet season. Water balance studies indicate that the Mogra's contribution to the Baulai amounts to 13.7 km^3/yr, or 434 m^3/s; this includes 244 m^3/s, or 7.7 km^3/year, of spill from the Kangsha via the Thakurakona-Atpara channel.

The Mogra has no significant tributaries. There is, however, an important cross-connection, believed to be man-made, between the Kangsha and the Mogra, the Dhanai Khal, which is now a main source of water in the Mogra. The Dhanai Khal joins the Mogra at Atpara, and the reach of the Mogra downstream of Atpara is called the Dhanu.

Discharge data are not available for the Mogra.

Water levels been observed by the BWDB at Netrokona and Atpara. The indications of the records are as follows:

Table 9.14
Historical Water Level Summary for Mogra River

Gauge	Record	Water Level			
		Mean	Minimum	Maximum	Range
	(years)	(mPWD)	(mPWD)	(mPWD)	(m)
Netrokona	13	5.58	2.79	10.05	7.26
Atpara	9	5.42	2.60	8.60	6.00

The seasonal distribution of water levels is as follows:

Table 9.15
Seasonal Water Level Summary for Mogra River

Season	Mean Water Levels (m PWD)	
	Netrokona	Atpara
Pre-Monsoon	4.39	4.59
Monsoon	7.82	7.29
Post-Monsoon	5.99	5.99
Dry-Season	3.73	3.66
Year	5.58	5.42

10. OLD BRAHMAPUTRA-MEGHNA SYSTEM

10.1 Introduction

The Meghna is the main drain of the entire Northeast Region (Figure 10.1). All drainage from the Meghna Subregion passes into the Meghna, which is formed by the confluence of the Baulai and Kushiyara (Kalni) at Dilalpur. All drainage from the Old Brahmaputra Subregion enters the Meghna between Bhairab Bazar and Satnal. The Titas, which lies east of the Regional boundary, forms a by-pass around Bhairab Bazar. There is some minor inflow to the Meghna from the Southeast Region, partly via the Titas.

The concentration of the entire Meghna Subregion outflow at Bhairab Bazar is a significant feature of the river network. A vast lake forms every wet season in the central part of the Meghna Subregion, possibly in part because outflow is somewhat constricted at Bhairab Bazar. It appears possible that harder sediments in the Meghna river channel at or near Bhairab Bazar form a sill over which the Meghna must pass. This harder material may be the Madhupur Tract which, while not evident at the surface at Bhairab Bazar, is probably present in the Meghna river bed: outliers are present to the west of Bhairab Bazar, and south of the Meghna at Comilla.

The principal tributaries of the Meghna, in downstream order, are the Baulai and Kushiyara, Old Brahmaputra, Titas, Lakhya and Dhaleswari. The Baulai and Kushiyara systems are covered in Chapters 9 and 7 respectively. The seasonal lake which covers most of the Meghna Subregion during the monsoon is described in Section 10.8 herein.

10.2 Brahmaputra/Jamuna

The Brahmaputra/Jamuna flows along the western edge of the Northeast Region for a distance of about 70 km (Figure 1.3), and contributes flow to the region in two ways:

- Overbank spill from the Brahmaputra causes flooding in the extreme northwest of the region, particularly in the area extending northwards from Boalmari (Figure 9.1).
- Spill from the Brahmaputra, amounting to about 3% of its mean annual flow, enters its distributary the Old Brahmaputra near Boalmari (Figure 9.1).

Discharges in the Brahmaputra/Jamuna downstream of the Old Brahmaputra offtake have been measured by the BWDB at Bahadurabad. The 26 years of record indicate a mean annual discharge of 20,444 m^3/s, and a range of daily discharges from 2860 m^3/s to 109,000 m^3/s. The seasonal distribution of the runoff is as follows:

Table 10.1
Seasonal Runoff Summary for Brahmaputra/Jamuna River

Season	Mean Discharge (m^3/s)	Mean Runoff (MCM)	(%)
Pre-Monsoon	11,845	62,440	9.7
Monsoon	40,782	429,875	66.7
Post-Monsoon	18,367	96,821	15.0
Dry Season	5,312	55,531	8.6
Year	20,444	644,667	100.0

Water levels in the Brahmaputra/Jamuna have been observed by the BWDB at Chilmari, Kamarjani, Kholabarichar, and Bahadurabad. The indications of the record are as follows:

Table 10.2
Historical Water Level Summary for Brahmaputra/Jamuna River

Gauge	Record	Water Level			
	(years)	Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Chilmari	25	19.89	16.02	25.04	9.02
Kamarjani	26	18.26	14.05	23.92	9.87
Kholabarichar	28	16.90	13.08	21.67	8.59
Bahadurabad	27	15.94	12.89	10.61	7.72

The seasonal distribution of water levels is as follows:

Table 10.3
Seasonal Water Level Summary for Brahmaputra/Jamuna River

Season	Mean Water Level (m PWD)			
	Chilmari	Kamarjani	Kholabarichar	Bahadurabad
Pre-Monsoon	19.09	17.46	16.03	15.20
Monsoon	22.54	20.91	19.32	18.46
Post-Monsoon	20.17	18.41	17.13	16.22
Dry Season	17.47	15.91	14.78	13.66
Year	19.89	18.26	16.90	15.94

10.3 Old Brahmaputra

The Old Brahmaputra follows the course of a former main channel and is presently a distributary of the Brahmaputra. It offtakes north of Bahadurabad and follows an east-southeasterly course to Mymensingh, from where it follows a southeasterly course to Toke and Bhairab Bazar. At Toke the river bifurcates into the lower reach of the Old Brahmaputra which discharges into the

Upper Meghna at Bhairab Bazar, and the Lakhya which carries most of the flow from the upper reach and discharges into the Dhaleshwari at Narayanganj. The Dhaleshwari, which drains most of the North Central Region, carries the Lakhya flow into the Upper Meghna just north of Satnal.

The Old Brahmaputra has no significant tributaries. There are three man-made diversions from the upper reach for irrigation in the North Central Region:

- Bangshi Offtake
- Sirkhali Offtake
- Sutia Offtake

The lower reach has two significant natural distributaries:

- Lakhya
- Arial Khan

Discharges in the upper Old Brahmaputra have been measured by the BWDB at Nilukirchar. The 25 years of record indicate a mean annual discharge of 697 m^3/s, and a range of daily discharges from 6.0 m^3/s to 4890 m^3/s. The seasonal distribution of the runoff is as follows:

Table 10.4
Seasonal Runoff Summary for Old Brahmaputra River

Season	Mean Discharge (m^3/s)	Mean Runoff ($10^6 m^3$)	Mean Runoff (%)
Pre-Monsoon	162	855.3	3.9
Monsoon	1688	17796.0	81.1
Post-Monsoon	563	2965.4	13.5
Dry Season	35	365.6	1.5
Year	697	21982.3	100.0

Water levels in the Old Brahmaputra have been observed by the BWDB at Goal Khanda, Jamalpur, Sirkhali Offtake, Sutia Offtake, Mymensingh, Nilukirchar, Toke, Motkhola and Bhairab Bazar.

Table 10.5
Historical Water Level Summary for Old Brahmaputra River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Goal Khanda	28	19.24	16.68	23.64	6.96
Jamalpur	28	13.42	11.34	17.81	6.47
Sirkhali Offtake	20	10.34	7.64	14.77	7.13
Sutia Offtake	26	9.10	6.51	14.88	8.37
Mymensingh	20	8.63	6.36	13.47	7.11
Nilukirchar	24	8.52	6.29	13.70	7.41
Toke	24	3.96	0.84	9.81	8.97
Motkhola	5	4.13	1.01	9.72	8.71
Bhairab Bazar	24	3.46	0.71	7.66	6.95

10.4 Lakhya

The Lakhya originates from the bifurcation of the Old Brahmaputra at Toke from where it follows a westerly course to its confluence with the Banar, a river of the North Central Region, at Trimohini. From Trimohini the Lakhya follows a southerly course to its confluence with the Dhaleshwari, another river of the North Central Region, at Narayanganj.

The Lakhya has no significant tributaries or distributaries from or into the Northeast Region.

Discharges in the Lakhya have been measured by the BWDB at Demra, but no complete years of record are available.

Water levels have been observed by the BWDB at Trimohini, Lakhpur, Ghorasal, Demra and Narayanganj. The indications of the records are as follows:

Table 10.6
Historical Water Level Summary for Lakhya River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Trimohini	24	3.76	0.79	9.08	8.29
Lakhpur	22	3.43	0.71	7.84	7.13
Ghorasal	15	3.22	0.61	7.19	6.58
Demra	25	3.02	0.48	6.60	6.12
Narayanganj	16	2.84	0.62	6.23	5.61

10.5 Dhaleshwari

The Dhaleshwari flows along the southern edge of the Northeast Region for a distance of about 10 km. It originates in the North Central Region for which it is the main drainage outlet. It intersects the southern boundary of the Old Brahmaputra Subregion at Narayanganj where it collects the flow of the Lakhya, and joins the Meghna about 10 km upstream of Satnal. When in flood the Dhaleshwari may contribute to backwater in the Meghna.

Water levels have been observed by the BWDB at Rekabi Bazar and Kalagachia. The indications of the record are as follows:

Table 10.7
Historical Water Level Summary for Dhaleshwari River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Rekabi Bazar	19	2.82	0.47	6.43	5.96
Kalagachia	21	2.71	0.34	5.99	5.65

The seasonal distribution of water levels is as follows:

Table 10.8
Seasonal Water Level Summary for Dhaleshwari River

Season	Mean Water Level (m PWD) Rekabi Bazar	Kalagachia
Pre-Monsoon	2.09	1.96
Monsoon	4.46	4.30
Post-Monsoon	3.17	3.06
Dry-Season	1.37	1.30
Year	2.82	2.71

10.6 Meghna

The Meghna is formed by the confluence of the Baulai and the Kalni (Kushiyara) at Dilalpur (Figure 10.1). From Dilalpur it follows a semi-circular course for 20 km to Bhairab Bazar, where the flow is closely confined to the river channel. Between Dilalpur and Bhairab Bazar overbank spill occurs into the Titas Basin, and at Ajabpur, 10 km downstream of Dilalpur, the Titas river channel takes off into the Titas Basin. Both the overbank spill and the flow in the Titas channel are normally returned to the Meghna at Nabinagar, 15 km downstream of Bhairab Bazar. Some spill occurs from the Titas into the Southeast Region.

BWDB records indicate the mean annual discharge of the Meghna at Bhairab Bazar is 4725 m^3/s, or 149.0 km^3/year. Between Bhairab Bazar and Nabinagar the Meghna is joined by the residual channel of the Old Brahmaputra; a distributary of this residual channel, the Arial Khan, may also deliver some flow into the Meghna at Narsingdi, 30 km downstream of Nabinagar. From Narsingdi the Meghna flows for another 40 km to its confluence with the Dhaleshwari between Meghna Ferry Ghat and Satnal. At Meghna Ferry Ghat it is joined from the Southeast Region by the Gumti.

Discharges have been measured by the BWDB at Bhairab Bazar. The 21 years of record indicate a mean annual discharge of 4725 m^3/s, and a range of daily discharges from 2.0 to 19800 m^3/s. The seasonal distribution of the runoff is as follows:

Table 10.9
Seasonal Runoff Summary for Meghna River

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6m^3)	(%)
Pre-Monsoon	1955	10,304	6.9
Monsoon	9852	103,852	69.7
Post-Monsoon	5674	29,908	20.1
Dry Season	484	5,055	3.3
Year	4725	149,120	100.0

Water levels have been observed by the BWDB at Bhairab Bazar, Narsingdi, Badyer Bazar, Meghna Ferry Ghat and Satnal. The indications of the records are as follows:

Table 10.10
Historical Water Level Summary for Meghna River

Gauge	Record	Water Level			
	(years)	Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Bhairab Bazar	25	3.49	0.74	7.66	6.92
Narsingdi	26	3.08	0.64	6.90	6.26
Badyer Bazar	25	2.87	NA	6.98	NA
Meghna Ferry Ghat	22	2.87	0.49	6.19	5.70
Satnal	26	2.64	0.27	6.04	5.77

The seasonal distribution of water levels is as follows:

Table 10.11
Seasonal Water Level Summary for Meghna River

Season	Mean Water Level (m PWD)				
	Bhairab Bazar	Narsingdi	Badyer Bazar	Meghna F.G.	Satnal
Pre-Monsoon	2.50	2.21	2.11	2.11	1.96
Monsoon	5.57	4.90	4.51	4.51	4.15
Post-Monsoon	4.00	3.52	3.52	3.21	2.95
Dry-Season	1.63	1.45	1.45	1.43	1.32
Year	3.49	3.08	3.08	2.87	2.64

10.7 Titas

The Titas takes off from the Meghna at Ajabpur (Figure 10.1) and follows a looping course for 60 km, through Akhaura and Gobarnaghat, to Nabinagar where it re-joins the Meghna. Between Ajabpur and Akhaura the Titas is joined by the Sonai, and south of Akhaura it is joined by the Hawrah.

Water levels in the Titas have been observed by the BWDB at Ajabpur, Akhaura, Gokarnaghat and Nabinagar. The indications of the records are as follows:

Table 10.12
Historical Water Level Summary for Titas River

Gauge	Record (years)	Water Level Mean (mPWD)	Minimum (mPWD)	Maximum (mPWD)	Range (m)
Ajabpur	22	3.58	0.66	7.89	7.23
Akhaura	26	3.58	0.81	7.77	6.96
Gokarnaghat	24	3.39	0.67	7.50	6.83
Nabinagar	24	3.31	0.70	7.34	6.64

The seasonal distribution of water levels is as follows:

Table 10.13
Seasonal Water Level Summary for Titas River

Season	Mean Water Level (m PWD) Ajabpur	Akhaura	Gokarnaghat	Nabinagar
Pre-Monsoon	2.57	2.62	2.45	2.35
Monsoon	5.70	5.59	5.38	5.28
Post-Monsoon	4.14	4.23	3.89	3.80
Dry-Season	1.67	1.72	1.61	1.55
Year	3.58	3.58	3.39	3.31

10.8 Seasonal Monsoon Lake

Every year, the haors of the Meghna Subregion fill with flood water from the adjacent rivers until their levees/embankments are submerged and a single huge lake is formed in the centre of the Subregion with its outlet at Bhairab Bazar. This seasonal lake begins to form in the pre-monsoon season, fills rapidly during the first half of the monsoon season, and remains more or less full until the end of the monsoon season. It empties mainly during the post-monsoon season, but the dry season may be well advanced before it has drained away completely.

In 1988 unprecedented floods occurred in Bangladesh. The monsoon lake in the Meghna Subregion attained a maximum extent in September. A satellite image of 8 October 1988 indicated a lake area of 13,900 km^2 or 68% of the Meghna Subregion. Subsequent studies have shown that the corresponding volume of water was 24.6 km^3 and the maximum depth was 5.2 m.

Water level data indicate that in 1988 the lake began to form in early April, reached a first peak level in mid- July, drained slightly through August, but reached a second higher peak in September. It is estimated that at the time of this second peak the lake had an area of 18,700 km^2 or 92% of the Meghna Subregion, and a volume of 45.3 km^3 of water.

The flooding situation in 1993 is believed to have been worse than in 1988. Preliminary estimates indicate a maximum area of 19,800 km^2 or 98% of the Meghna Subregion, a volume of about 46 km^3, and a maximum depth of 7.0 m.

11. FLOOD FREQUENCIES

11.1 Introduction

Data on annual maximum discharges, that can be analyzed to estimate the magnitude of floods at specified frequencies or return periods, are available for approximately 40 gauging stations on rivers and khals. Data on annual maximum water levels that can be used for similar analyses are available for approximately 90 stations.

Periods of record at the various stations range from only a year or two to 30 years. The longest records used herein cover the period 1964-93, and the shortest the period 1989-93. For a few stations, data on discharges or water levels or both have been rejected because of reliability problems. In some other cases, only the more recent part of the record has been used because flow conditions have changed during the period of record as a result of engineering works, morphologic changes or other causes.

Predicted flood discharges or high water levels for specific return periods, as tabulated herein, are based on statistical analysis of the available data series and the fitting of a mathematical probability distribution, which is then used to estimate the predicted values. A predicted value at a specified return period - for example, 1240 m^3/s at 25 years - means that a discharge of 1240 m^3/s or greater is predicted to occur once every 25 years on the average. Another way of expressing the result is that the probability of 1240 m^3/s being attained or exceeded in any one year is 1/25, or 0.04.

The maximum length of return period for which predictions can reasonably be made depends on the period of record and other factors. Predictions are not tabulated herein for return periods exceeding 4 times the period of record. Even with this limitation, the reliability of predictions for the longer return periods is likely to be low.

11.2 Data Availability and Limitations

11.2.1 Availability

Data series on annual maximum discharges and water levels were first compiled for all stations where data exist. The 30-year period 1964-93 was used where possible, otherwise whatever period was available within it. Annual maxima always occur during the monsoon season. For most stations, data series were also compiled for pre-monsoon maxima.

Discontinued stations were included in the analysis. For some discontinued stations, the available data may not be representative of present conditions because of engineering or morphologic changes.

The original data used for analyses are included in Annex B, Hydrological Data Summaries. Frequency plots for discharges and water levels are shown in Appendices B and C respectively. These include plots of both annual maxima and pre-monsoon maxima.

11.2.2 Limitations

Certain limitations of available data were discussed in Appendix C of the Pre-feasibility Study (NHC/SARM 1986) and are further identified in Section 5.3 of this report. Key limitations can be listed as follows:

1. Where floodplains and secondary channels carry parts of the total flood flow in a river, gauge discharge measurements usually represent flows in the main channel only, discounting those out-of-channel flows. As a result, many of the discharge data series are truncated and their frequency curves tend towards upper asymptotes. In such cases, flood frequency predictions underestimate the true flood potential that could develop if overbank spills are prevented by embankments.

2. Water levels are normally observed during daytime hours only. Reported maximum discharges are computed by applying a rating curve to observed water levels. As a result, many annual maxima of both discharge and water level are under-reported, because the real maxima occurred at night.

3. Reported annual maximum discharges and water levels are so-called "mean daily" values, theoretically averages over a 24-hour period but actually based on averaging five daytime readings. In the case of rivers subject to flash floods, instantaneous maximum discharges may be higher by a substantial margin, perhaps 30% or more. In the case of the larger lowland rivers, the differences between daily and instantaneous maxima are relatively small.

4. Most data series are relatively short: the longest records cover 30 years and a considerable number cover 10 years or less. This means that even when no statistical abnormalities are evident, predictions for the longer return periods tend to be of low reliability.

5. Data series for many stations, especially in the border areas, are non-homogeneous or non-stationary - that is, the data do not reflect consistent physical conditions of flood generation. For the longer records, such inconsistencies can often be detected by statistical tests. The usual reasons are construction or breaching of dikes and embankments, or natural or manmade changes to river morphology or connections. In such cases, flood frequency estimates derived from the whole record represent an average of historic conditions and are not necessarily applicable to present or future conditions. This problem has been addressed in some cases by analyzing a partial series considered to represent present conditions. However, in some cases where the effects of changes are believed to be relatively small, it has been thought preferable to used the whole series rather than a short partial series with its attendant problem of extrapolation.

6. Peak discharges at many stations are unreliable because rating curves have been extrapolated well beyond the range of discharge measurements. This problem is particularly acute in the border rivers subject to flash floods.

After reviewing statistical and other peculiarities that arose out of these limitations, a few of the initial flood frequency relationships were rejected and notes were attached to others. The analyses presented herein are intended for planning purposes. More detailed analyses should be conducted for specific design projects.

11.3 Methods of Analysis and Prediction

11.3.1 Statistical tests of data sets

Before analyzing frequencies, most of the data sets were subjected to statistical tests for randomness, independence, stationarity and homogeneity. A considerable number of sets did not satisfy normally accepted standards for stationarity and/or homogeneity, presumably for reasons referred to in 12.1 above. Logically, single frequency curves should not be fitted to the data in such cases. However, a number of such plots have been retained with qualifying comments, where violations of the criteria did not appear excessive.

11.3.2 Plotting empirical distributions

For plotting the data series on probability paper, plotting positions were calculated using the Cunnane formula:

$$p_e = 1/\text{return period} = (m-0.4)/(N+0.2)$$

where p_e = probability of exceedance

m = rank of data point in series, with highest = 1, and
N = number of data points in series.

The plots presented in Appendices B and C are labelled not with probability of exceedance, but with cumulative probability (less than) = 1 - p_e. Return periods are also shown.

11.3.3 Fitting probability distributions

All data series were analyzed using two forms of mathematical probability: 3-Parameter LogNormal (3PLN), and General Extreme Value (GEV) using the maximum likelihood fitting procedure. In most cases and with appropriate selection of parameters, both distributions appeared to fit the data reasonably well. The GEV results have been adopted for the majority of discharge and water level predictions presented herein. The 3PLN results have been substituted where they appeared to give a more reasonable fit or curve shape.

An in-house computer program FREQ was used for the statistical analyses.

11.3.4 Predicted values

Values of discharge and water level for specific return periods were computed from the fitted probability distributions. Tables 11.1 and 11.2 consolidate results for annual maximum discharges and annual maximum water levels respectively. All values are rounded to three or four significant digits. Values are not shown for return periods exceeding 4 times the period of record, as such extrapolations are considered to be too unreliable.

Results are not tabulated for pre-monsoon maxima, but can be approximated from the curves presented in Appendices B and C. In some cases the mathematically fitted curves for pre-monsoon maxima tend to intersect the annual maximum curves if extrapolated beyond the actual record period. As this is physically impossible, caution should be exercised when using the pre-monsoon analyses.

In Tables 11.1 and 11.2, stations for which partial data series were used because of problems of non-homogeneity etc. are denoted by (R) after the station number.

11.4 Comments on Specific Stations

The following comments refer to certain stations where special data or analysis problems were encountered. Stations for which partial series are indicated in Tables 11.1 and 11.2, as described above, are not included in this list unless there are other problems.

11.4.1 Discharges (Table 11.1)

34, Bhogai River at Nakuagaon. There has been some increase in recent flood flows due to embankments, but predictions are based on the whole record period because of uncertainty as to how to split the record.

67, Dhalai River at Kamalganj. Flood flows have increased in recent years due to embankments, however predictions are based on the whole record period because of statistical problems with a short partial series.

135/135A, Juri River (2 branches). These stations are not included because data are unreliable, due to effects of Kushiyara River backwater on the rating curve.

138, Karangi River at Sofiabad. The data are non-homogeneous due to large overbank spills in some years from the Khowai River, however predictions are based on the whole record period.

158.1, Khowai River at Shaistaganj. Not included because of several problems with data reliability and consistency.

192(R), Lungla River at Motiganj. An anomalously high reported maximum in 1989 was reduced on the basis of a revised rating curve.

201, Manu River at railway bridge. Flows have increased due to embankments, however predictions are based on the whole record period because a partial series gave similar results.

227(R), Sutia offtake from Old Brahmaputra. Anomalously high reported flows in 1982 were corrected for unit error.

233, Piyain River at Ratnerbhanga. Not included because of shortness of record and morphologic changes.

263A, Shibganjdhala River at Durgapur (main branch of Someswari). Not included because of morphologic changes and unreliable data.

263B, Someswari River at Durgapur. Same comment.

266, Surma River at Kanairghat. There has been some increase in flood flows due to embankments, however predictions are based on the whole record.

280, Sutang River at railway bridge. Not included because of several data problems.

11.4.2 Water levels (Table 11.2)

34, Bhogai. As for discharges, see above.
67, Dhalai. Same.
201, Manu. Same.
233, Piyain. Same

269, Surma River at Sunamganj. Data are believed to be non-stationary due to slight changes since 1980, however predictions are based on the whole record period.

314(R), Nitai. Pre-monsoon data are affected by winter cross-damming.

11.5 Suggestions for Improved Monitoring of Flood Flows

There is a need for improved flood flow data in some areas, especially in the border streams. Suggestions are made here for both general and local improvements.

11.5.1 General improvements

Measurement of peak discharges:

Most locations have adequate data at low-to-medium stages but few have sufficient data at high stages to define the rating curves for peak flow conditions. These data are difficult to collect at the right time due to the flashy nature of the border streams and difficulty of travelling during flood conditions. An intensive short-term discharge measurement program could be implemented at the critical locations and when a discharge gauge is first installed. A hydrometric crew could be stationed on site for one to three months and would make daily or more frequent measurements until a significant peak was sampled. Such programs were conducted in 1994 at the Ballah/Rema Began gauge on the Khowai River and the Bijoypur gauge on the Someswari River and were reasonably successful.

Re-location of gauging stations upstream of overbank spills:

Many gauge locations are subject to overbank spills or embankment breaches which bypass the gauge and therefore are not included in peak flow estimates. Wherever possible these gauges should be re-located farther upstream. Considerable improvement has been made in this respect since 1991, but some of the new gauges have been discontinued.

Improved documentation of gauge operation:

Up-to-date large-scale location maps showing the exact gauge location, location and elevations of benchmarks and their elevations, location of gauging section, and a summary of the gauge record should be maintained. All re-locations of the gauge and changes to benchmarks and their elevations should be systematically recorded in a centralized data base.

Improved temporal resolution:

Water levels are measured at most locations every three hours from 6AM to 6PM only. This is not adequate for the flashy border tributaries. A significant improvement could be made by making one measurement at midnight, or by making three overnight measurements. Alternatively, the over-night peak water level could be measured with a simple crest stage device. Another solution would be to install recorders to give a continuous record, but past experience with maintaining such recorders under local conditions is not encouraging.

11.5.2 Specific locations

Discharge monitoring - specific locations:

Station 53, Chelakhali River at Bathkuchi. The scatter in available data is too great to permit a reliable rating curve to be developed. The reasons for this variability should be determined and if necessary the gauge should be re-located or abandoned.

Station 262, Someswari at Bijoypur. This location should be continued as a discharge measurement site in order to better define the peak flows in the Someswari River. Previously the only measurements were made at Durgapur (see below). Bijoypur is a relatively stable location and is upstream of the avulsion and channel shifting which occurs at Durgapur. An intensive program in 1994 helped to define the rating curve for peak flows, but more data are needed to monitor changes in the future and to confirm peak flows.

Station 263, Durgapur. The Someswari splits into three channels at this location and is unstable due to morphological changes. Discharge measurements should be continued to define the flow split, but the discharges should be calculated and published separately for each branch. The practice in this regard has been inconsistent in the past - sometimes discharges have been published for the Old Someswari, sometimes for the Shibganjdhala, and more recently for the sum of the three channels. Measurements at peak stages are required, as there are almost no data with which to define the peak flows.

Jadukata River at Lorergarh (SWMC gauge). Discharge measurements should be continued at this site as it represents one of the largest catchments and has few discharge data. A water level recorder was established in 1994 and will provide peak water level data.

Jhalukhali River at Duluria (SWMC gauge). This gauge should be continued as a discharge measuring site, as it is representative of the four smaller catchments which drain the Shillong Plateau in the central Mehgalaya region. Available discharge measurements show this site to be better than those available in the three other streams.

Station 233, Piyain River at Ratnerbhanga. The gauge should be re-located upstream to near the bifurcation of the Jaflong, upstream of the variability due to channel shifting and avulsion. This may be difficult as the site is near the Indian border.

Lubha River at Lubhachara. Water levels are governed by backwater from the Surma River and there is no practical way to develop a rating curve at this location. Discharges can be estimated reasonably from the adjacent Sarigowain catchment, which has good records and is comparable in size, physiography, and climate.

Station 172B, Barak River at Amalshid. Discharge measurements should be continued in the Kushiyara River and Surma River at Amalshid, which together define the inflows from the Barak River, the single largest tributary to the Northeast region. Existing sites at Sheola and Kanairghat farther downstream are bypassed by overbank spills through embankment breaches during high flows.

Station 135, Juri River. The discharge measurement sites at Continala and Silghat are dominated by backwater from the Kushiyara River during the monsoon season and should be relocated upstream of the backwater zone. Two locations are planned for monitoring in NERP's flood forecasting program and should be considered for future extension, depending on the results of the program.

Station 201, Manu River. Discharges should be measured near the border, upstream of embankment breaches that bypass the existing Railway Bridge gauge. Discharge measurement should also be taken at Maulvi Bazar, downstream of other inflows and significant embankment breaches, to help define the overbank spills through embankment breaches and confirm the design flow in this reach. In view of the importance of the Manu Project and the probability of remedial work, such additional monitoring represents a small investment for a more secure project.

Station 157/158, Khowai River. Discharge measurements should be continued at Ballah which is located at the border and upstream of major overbank spills. The existing gauge at Shaistaganj is located in an unstable reach, downstream of overbank spills and periodic embankment breaches, but should be continued to help define the magnitude of these spills. High-flow measurements should be taken as there are none presently available. The HD model can be used to help verify the computed discharges and rating curves.

Station 280, Sutang River at Railway Bridge. This gauge is affected by backwater from the Kalni River and should be moved upstream. Existing discharge data are not reliable.

Table 11.1
Results of Flood Frequency Analysis
Predicted Annual Maximum (Daily) Discharges, m^3/s

Gauge no.	Stream/location	No. of years	Discharge estimates, Return period, years					Type of disbn.
			2	10	25	50	100	
3A	Anderson K./ Brahmanbaria Rly. Br.	6	264	330				GEV
6	Bahia R./Surma Offtake	11	204	246	267			GEV
33	Bhattahkali R. /Gobindaganj	13	742	953	1032	1082		GEV
34	Bhogai R./Nakuagaon	26	506	906	1145	1340	1552	GEV
35-5	Kangsha R./Sarchapur	8	286	356	378			GEV
36(R)	Kangsha R./Jariajanjail	11	1324	1440	1461			GEV
46-9 L	Brahmaputra R./Bahadurabad	26	64640	84710	96580	106300	116700	GEV
67	Dhalai R./Kamalganj	25	243	346	398	436	475	GEV
123(R)	Hawrah R./Gangasagar Rly. Br.	7	42	62	67			GEV
138	Karangi R./Sofiabad	24	87	193	301	423		GEV
157	Khowai R./Ballah	8	535	1071	1354			GEV
172B	Barak R./Amalshid	28	4673	5349	5539	5640	5716	GEV
173(R)	Kushiyara R./Sheola	12	2599	3080	3310			GEV
173A	Sada K./Sheola	7	543	1553	2434			GEV
175-5	Kushiyara R./Sherpur	11	2632	3493	3969			GEV
179	Lakhya R./Demra	17	2094	2441	2575	2660		GEV
192(R)	Lungla R./Motiganj	16	79	133	151	163		GEV
201	Manu R./Manu Rly. Br.	29	616	768	819	850	878	3-PLN
227(R)	Sutia Offtake from Old Brahmaputra	13	38	88	121	150		GEV
228-5	Old Brahmaputra R./Mymensingh	24	2945	4003	4517	4891		GEV
230-1(R)	Old Brahmaputra R./Bhairab Bazar	12	445	610	665			3-PLN
251	Sarigowain R./Sarighat	27	1064	1381	1500	1577	1647	3-PLN
252-1	Sarigowain R./Salutikar	11	1340	1750	1953			3-PLN
262	Someswari R./Bijoypur	8	3182	4096	4374			3-PLN
265	Sonaibardal R./Jaldhup	22	441	556	602	632		GEV
266	Surma R./Kanairghat	24	2193	2573	2706	2791		3-PLN
267	Surma R./Sylhet	24	2067	2312	2386	2429		3-PLN
273	Meghna R./Bhairab Bazar	20	13240	17120	19630	21790		GEV
314(R)	Nitai R./Ghosegaon	10	467	723	904			GEV
315	Madhabpur K./Chhatak	5	266	607				GEV

NOTE: (R) after gauge no. indicates that estimates are based on a revised partial series considered to represent present conditions.

Table 11.2
Results of Flood Frequency Analysis
Predicted Annual Maximum (Daily) Water Levels, m

Gauge no.	Stream/location	No. of years	Water level estimates — Return period, years					Type of disbn.
			2	10	25	50	100	
3	Anderson K./ Brahmanbaria Rly. Br.	14	6.43	7.14	7.50	7.77		GEV
3A	Anderson K./Brahmanbaria	26	6.48	7.18	7.48	7.69	7.88	GEV
6	Bahia R./Surma Offtake	11	10.81	11.18	11.36			GEV
9.5	Banar R./Trimohini	24	8.05	8.75	9.01	9.17		GEV
33	Bhattakhal/Gobindaganga	17	10.20	10.81	11.04	11.19		GEV
34	Bhogai R./Nakuagaon	29	24.63	25.03	25.15	25.21	25.25	GEV
35	Bhogai R./Nalitabari	29	18.18	18.34	18.39	18.42	18.45	GEV
35.5	Kangsha R./Sarchapur	29	13.40	13.99	14.22	14.36	14.49	GEV
36	Kangsha R./Jaria Jhanjail	30	10.90	11.25	11.36	11.43	11.49	GEV
36.1	Kangsha R./Mohanganj	29	7.60	8.13	8.38	8.55	8.72	GEV
45.5	Brahmaputra R./Chilmari	25	23.95	24.50	24.71	24.85	24.98	GEV
46	Brahmaputra R./Kamarjani	26	22.34	23.34	23.73	23.98	24.20	GEV
46.7 L	Brahmaputra R./Kholabarichar	28	20.72	21.29	21.49	21.60	21.69	GEV
46.9 L	Brahmaputra R./Bahadurabad	26	19.76	20.21	20.40	20.52	20.63	GEV
53(R)	Chelakhali R/Bathkuchi	10	26.57	27.56	27.89			GEV
67	Dhalai R./Kamalganj	29	20.68	20.99	21.11	21.19	21.26	GEV
71	Dhaleswari R./Kalagachia	22	5.32	5.90	6.15	6.31		GEV
71A	Dhaleswari R./Rekabi Bazar	19	5.52	6.10	6.33	6.48		GEV
72	Baulai R./Kaliajuri	27	7.27	7.96	8.22	8.39	8.53	GEV
72B	Baulai R./Sukdebpur	12	7.33	7.98	8.19			GEV
73	Baulai R./Itna	29	7.12	7.76	8.01	8.17	8.30	GEV
74	Ghorautra R./Dilalpur	27	6.77	7.49	7.73	7.88	8.00	GEV
115	Gumti R./Daudkandi	22	5.44	6.03	6.32	6.52		GEV
123	Hawrah R./Gangasagar Rly. Br.	25	6.14	6.75	7.03	7.22	7.41	GEV
131	Jadukata R./Saktiarkhola	26	9.26	9.61	9.67	9.69	9.71	GEV
135	Juri R. (Juri Branch)/Continala	14	11.00	11.46	11.65	11.78		GEV
135A	Juri R. (Continala Branch)/Continala	25	10.94	11.50	11.73	11.89		GEV
138	Karangi R./Sofiabad	30	11.89	12.18	12.25	12.28	12.31	3-PLN
157	Khowai R./Ballah	29	24.25	25.62	26.02	26.24	26.40	GEV
158	Khowai R./Chunarghat	29	17.51	18.13	18.30	18.39	18.46	3-PLN
158.1(R)	Khowai R./Shaistaganj	9	13.70	14.38	14.55			3-PLN
159(R)	Khowai R./Habiganj	9	10.18	10.76	10.92			3-PLN
172	Kushiyara R./Amalshid	28	17.35	17.77	17.89	17.96	18.02	3-PLN

Table 11.2 continued

Gauge no.	Stream/location	No. of years	Water level estimates Return period, years					Type of disbn.
			2	10	25	50	100	
173	Kushiyara R./Sheola	30	13.94	14.19	14.27	14.31	14.35	3-PLN
173A	Sada K./Sheola	13	13.10	13.70	14.00	14.22		3-PLN
174	Kushiyara R./Fenchuganj	30	10.63	11.08	11.27	11.40	11.52	GEV
175	Kushiyara R./Manumukh	14	9.15	9.59	9.82	10.00		GEV
175.5	Kushiyara R./Sherpur	12	8.97	9.31	9.42			GEV
177	Lakhya R./Lakhpur	23	6.87	7.49	7.72	7.87		GEV
178	Lakhya R./Ghorasal	15	6.47	6.95	7.13	7.25		GEV
179	Lakhya R./Demra	25	5.73	6.30	6.53	6.69		GEV
180	Lakhya R./Narayanganj	17	5.50	6.05	6.31	6.49		GEV
192(R)	Langla R./Motiganj	10	8.84	9.09	9.22			GEV
199	Mahasingh R./Mahasingh Ferryghat	13	7.86	8.64	9.06	9.38		GEV
201	Manu R./Manu Rly. Br.	29	18.69	19.00	19.07	19.11	19.14	GEV
202(R)	Manu R./Maulavi Bazar	12	12.70	13.11	13.18			3-PLN
223	Old Brahmaputra R./Goal Khanda	28	22.70	23.28	23.45	23.54	23.61	GEV
225	Old Brahmaputra R./Jamalpur	28	17.04	17.52	17.62	17.67	17.71	GEV
226	Old Brahmaputra R./Sirkhali Offitake	21	14.43	14.77	14.83	14.85	14.87	GEV
227	Old Brahmaputra R./Sutia Offtake	26	13.35	14.12	14.42	14.61	14.78	3-PLN
228.5	Old Brahmaputra R./Mymensingh	24	12.32	13.08	13.38	13.58		GEV
229	Old Brahmaputra R./Toke	24	8.50	9.32	9.61	9.78		GEV
230	Old Brahmaputra R./Motkhola	16	8.45	9.10	9.40	9.61		GEV
230.1	Old Brahmaputra R./Bhairab Bazar	24	6.47	7.16	7.43	7.60		GEV
233	Piyain R./Ratnerbhanga	20	13.82	14.73	15.08	15.30		GEV
234	Piyain R./Companyganj	26	10.66	11.36	11.59	11.73	11.85	GEV
251	Sarigowain R./Sharighat	27	13.93	14.35	14.46	14.52	14.56	GEV
252	Sarigowain R./Gowainghat	27	11.74	12.17	12.27	12.31	12.34	GEV
252.1	Sarigowain R./Salutikar	27	10.67	11.08	11.20	11.27	11.32	3-PLN
262	Someswari R./Bagmara (Bijoypur)	28	17.13	17.90	18.16	18.32	18.44	GEV
263	Someswari R./Durgapur	30	14.11	14.71	14.96	15.12	15.27	GEV
263.1	Someswari R./Kalmakanda	28	7.93	8.76	9.29	9.74	10.25	GEV
264	Sonai R./Madhabpur	10	6.66	7.44	7.84			GEV
265	Sonaibardal R./Jaldhup	28	12.07	12.63	12.84	12.97	13.08	GEV
266	Surma R./Kanairghat	28	14.85	15.15	15.20	15.22	15.23	GEV
267	Surma R./Sylhet	29	11.21	11.63	11.77	11.86	11.94	3-PLN
268	Surma R./Chhatak	27	10.02	10.69	10.94	11.10	11.25	3-PLN
269	Surma R./Sunamganj	30	8.64	9.06	9.25	9.38	9.51	3-PLN
270	Kusiyara R./Markuli	25	7.43	7.90	8.14	8.32	8.51	GEV

Table 11.2 continued

Gauge no.	Stream/location	No. of years	Water level estimates Return period, years					Type of disbn.
			2	10	25	50	100	
271	Kalni R./Ajmiriganj	27	7.12	7.78	8.03	8.20	8.34	GEV
272	Kalni R./Madna	26	6.95	7.63	7.87	8.02	8.14	GEV
272.1	Dhaleswari R./Austagram	26	6.81	7.56	7.85	8.03	8.20	GEV
273	Meghna R./Bhairab Bazar	28	6.50	7.18	7.42	7.57	7.69	GEV
274	Meghna R./Narsingdi	28	5.92	6.70	7.11	7.42	7.74	GEV
275	Meghna R./Badyar Bazar	26	5.49	6.06	6.38	6.62	6.87	GEV
275.5	Meghna R./Meghna Ferry Ghat	23	5.45	5.93	6.12	6.25	6.36	GEV
276	Meghna R./Satnal	27	5.18	5.68	5.90	6.05	6.19	GEV
280	Sutang R./Sutang Rly. Br.	28	7.57	8.06	8.15	8.19	8.22	GEV
295	Titas R./Ajabpur	25	6.66	7.37	7.64	7.81	7.95	GEV
296	Titas R./Akhaura	25	6.43	7.13	7.41	7.61	7.78	GEV
297	Titas R./Gokarnaghat	24	6.29	6.97	7.29	7.51	7.72	GEV
298	Titas R./Nabinagar	25	6.24	6.91	7.21	7.42	7.62	GEV
308	Khajanchi Nadi/Khajanchigaon Rly. Br.	10	10.27	10.64	10.78			GEV
310	Mogra R./Netrokona	15	8.97	9.58	9.80	9.93		GEV
311	Mogra R./Atpara	11	7.77	8.23	8.41			GEV
314(R)	Nitai R./Ghosegaon	11	17.27	17.55	17.71			GEV
326	Lubachara R./Outfall	9	15.28	15.47	15.53			3-PLN
327	Jinjiram R./Boalmari	10	24.32	26.44	27.86			GEV

NOTES: Abbreviations R. = River; K = Khal
(R) after gauge no. indicates that estimates are based on a revised partial series considered to represent present conditions

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APPENDIX A
Additional Tables

APPENDIX A - Additional Tables

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Table A1
World Record Rainfalls at Cherrapunji, India

Duration	Depth (mm)	Date
3 days	2,759	Sept. 12 - 14, 1974
4 days	3,721	Sept. 12 - 15, 1974
15 days	4,798	June 24 - July 8, 1931
31 days	9,300	July 1861
2 months	12,767	June - July, 1861
3 months	16,369	May - July, 1881
4 months	18,738	April - July, 1861
5 months	20,412	April - August, 1861
6 months	22,454	April - September, 1861
11 months	22,990	January - November, 1861
1 year	26,461	August 1860 - July 1861
2 years	40,768	1860 - 1861

Source: WMO, 1986

Table A2

Selected Earthquakes Affecting The Northeast Region

Date	Epicentre		Location Location	Magnitude
	°N	°E		
10 Jan 1869	?	?	Cachar	7.5
14 Jul 1885	?	?	Sirajganj	6.5
12 Jun 1897	?	?	Shillong	8.7
08 Jul 1918	24.3	91.7	NER/Srimangal	7.6
15 Aug 1920	22.2	93.2	Burma	6.0
09 Sep 1923	25.2	91.0	NER/Tangua Haor	7.1
15 Mar 1927	24.5	95.0	Burma	6.5
02 Jul 1930	25.8	90.2	NW Meghalaya	7.1
15 Jan 1934	26.6	86.8	Nepal	8.2
27 May 1939	24.3	94.1	Manipur	6.7
24 Dec 1944	24.7	92.2	NER/HakalukiHaor	6.0
29 Jul 1947	28.8	93.7	China	7.7
15 Aug 1950	28.7	96.6	China	8.5
15 Jan 1952	23.8	94.5	Burma	6.0
21 Mar 1954	24.2	95.1	Burma	7.2
14 Jun 1961	24.7	94.8	Burma	5.7
14 Nov 1967	24.0	91.5	NER/Khowai	5.1
27 Dec 1968	24.1	91.6	NER/Khowai	5.2
25 Jan 1969	22.9	92.3	Chittagong	5.4
02 Feb 1971	23.6	91.8	Tripura	5.5

NER = Northeast Region
Source: Khan, 1991

Table A3
Rainfall Distribution in a Tropical Cyclone

Distance Range From Centre (km)	**Daily Rainfall**	
	(mm)	**(%)**
0 - 50 (Core)	863	79
50-100	160	15
100-150	54	5
150-200	15	1
Totals	1092	100

Source: Riehl, 1954

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Table A4
Tropical Cyclones of Record in Bangladesh, 1876-1991

Date	Landfall Area	Central Pressure (mb)	Maximum Windspeed		Storm Surge	
			(knots)	(kph)	(ft)	(m)
01 Nov 1876	Noakhali	?	?	?	10-45	3-14
11 Oct 1960	Chittagong	?	87	160	15	5
31 Oct 1960	Chittagong	?	104	193	20	6
09 May 1961	Chittagong	?	87	160	8-10	2-3
30 May 1961	Feni	?	87	160	6-15	2-5
28 May 1963	Chittagong/ Cox's Bazar	?	113	209	8-12	2-4
11 May 1965	Chittagong/ Barisal	?	87	160	12	4
05 Nov 1965	Chittagong	?	87	160	8-12	2-4
15 Dec 1965	Cox's Bazar	?	114	210	8-10	2-3
01 Nov 1966	Chittagong	?	65	120	20-22	6-7
23 Oct 1970	Khulna/ Barisal	?	88	163	?	?
12 Nov 1970	Chittagong	?	121	224	10-33	3-10
28 Nov 1974	Cox's Bazar/ Chittagong	?	88	163	9-17	3-5
12 Dec 1981	Khulna	989	65	120	7-15	2-5
15 Oct 1983	Chittagong	995	50	93	?	?
09 Nov 1983	Cox's Bazar	986	73	136	5	2
24 May 1985	Chittagong	982	83	154	15	5
29 Nov 1988	Khulna	983	87	160	2-14.5	0.6-4.4
18 Dec 1990	Cox's Bazar	995	62	115	5-7	1.5-2.1
29 Apr 1991	Chittagong/ Cox's Bazar	940	122	225	12-22	3.7-6.7

Source : BMD

Notes : Maximum windspeeds are calculated using

$$V = 14.4(P_o - P_c)^{1/2}$$

Wherein : V = maximum windspeed in knots
P_o = outside pressure in millibars
P_c = central pressure in millibars

: Storm surges reported prior to 1988 are possibly exaggerated; compare 12 Nov 1970 with 29 Apr 1991.

Table A5
Catchment Areas and Mean Annual Catchment Rainfalls - Barak River Basin

River	Stretch/Outfall	Area (km^2)	Standard Period Rainfall (mm/yr)	
			1961-90 (WMO)	1964-91 (NERP)[2,3]
Barak (upper)	Tipaimukh Dam	7973	2386	2586
Tuvai	Tipaimukh Dam	4921	3686	3995
Barak	Tipaimukh Dam	12894	2882	3123
Barak	Tipaimukh to Fulerthal	745	3500	3793
Jiri	Barak River	983	3013	3265
Barak	Fulerthal/Lakhipur	14622	2922	3167
Chiri	Barak River	437	3683	3991
Sonai	Sonai Dam	1716	3560	3858
Sonai	Sonai Dam to Rukni	367	3394	3678
Rukni	Sonai River	891	3307	3584
Sonai-Rukni	Sonai to Rukni	179	3500	3793
Sonai-Rukni	Barak River	3153	3466	3756
Barak	Fulerthal to Silchar	348	3632	3936
Madhura	Barak River/Silchar	317	3737	4050
Barak	Silchar	18877	3057	3313
Jatinga	Barak River	504	3875	4199
Singhuri	Barak River	330	4251	4607
Gogra	Barak River	526	3477	3768
Katakhal	Barak River	224	3445	3733
Dhaleshwari	Sairang Dam	1052	2674	2898
Dhaleshwari	Sairang to Bhairabi	1640	2471	2678
Dhaleshwari	Bhairabi Dam	2692	2550	2763
Dhaleshwari	Bhairabi to Barak	1995	2791	3025
Dhaleshwari	Swamp Area	75	3214	3483
Dhaleshwari	Barak River	4762	2661	2884
Barak	Silchar to Amalshid	269	3904	4231
Barak	Amalshid (IBB)[1]	25492	3036	3290

[1] Indo-Bangladesh border
[2] 1964-91 (NERP) Standard Period excludes 1971
[3] 1964-91 (NERP) Rainfall = 1.0837 (1961-90(WMO) Rainfall)

Table A6
Catchment Areas and Mean Annual Catchment Rainfalls - Tripura Basins

River	Outfall	Area (km^2)	Standard Period Rainfall (mm/yr)	
			1961-90 (WMO)	1964-91 (NERP)[2,3]
Sada Khal	Sheola	354	4400	4768
Sonai-Bardal	IBB	2334	3092	3351
Juri	IBB	635	2915	3159
Manu	IBB	2233	2319	2513
Dhalai (S)	IBB	579	2343	2539
Lungla	Motiganj	237	2450	2665
Karangi	Sofiabad	213	2400	2601
Khowai	IBB	1111	2299	2491
Sutang	Sutang RB	257	2350	2547
Tripura	IBB	6892	2634	2854

[1] IBB = Indo-Bangladesh border
[2] 1964-91 (NERP) Standards Period excludes 1971
[3] 1964-91 (NERP) Rainfall = 1.0837 (1961-90 (WMO) Rainfall)

Table A7
Catchment Areas and Mean Annual Catchment Rainfalls - East Meghalaya Basins

River	Outfall[1]	Area (km2) (mm/yr)	Standard Period Rainfall (mm/yr)	
			1961-90 (WMO)	1964-91 (NERP)[2,3]
Minor Streams	IBB	85	4711	5105
Minor Streams	IBB	13	4865	5272
Minor Streams	IBB	90	5023	5443
Minor Streams	IBB	148	5665	6139
Jadukata	IBB	2514	5474	5932
Minor Streams	IBB	56	6515	7060
Jhalukhali	IBB	447	6996	7582
Minor Streams	IBB	339	7529	8159
Umium	Nodal Point in	518	6637	7193
Dhalai (N)	IBB	342	6450	6990
Minor Streams	IBB	193	6384	6918
Piyain	IBB	808	4549	4930
Minor Streams	IBB	55	5274	5715
Minor Streams	IBB	63	5423	5877
Sarigowain	IBB	810	4592	4976
Minor Streams	IBB	44	4973	5389
Lubha	IBB	724	4469	4843
Lubha	Lubhachara	771	4469	4843
Minor Streams	IBB	152	4561	4943
Minor Streams	IBB/Surma River	77	4442	4814
Minor Streams	IBB/Surma River	86	4449	4821
East Meghalaya	IBB	7564	5465	5922

[1] IBB = Indo-Bangladesh border
[2] 1964-91 (NERP) Standard Period
[3] 1964-91 (NERP) Rainfall = 1.0837(1961-90)(WMO) Rainfall)

$A_{MRS} = (152 + 77 + 86) = 315 \text{ km}^2$
$\overline{R}_{MRS} = (152 \times 4943 + 77 \times 4814 + 86 \times 4821)/315 = 4878 \text{ mm}$

Table A8
Catchment Areas and Mean Annual Catchment Rainfalls - West Meghalaya Basins

River	Outfall[1]	Area (km²)	Standard Period Rainfall (mm/yr)	
			1961-90 (WMO)	1964-91 (NERP)[2,3]
Dorong	IBB	161	2934	3180
Malijhee	IBB	123	3052	3307
Chillakhali	IBB	117	3112	3372
Bhogai	IBB	455	3348	3628
Minor Streams	IBB	123	3316	3594
Nitai	IBB	381	3607	3909
Minor Streams	IBB	48	3783	4100
Someswari	IBB	2129	4065	4405
Minor Streams	IBB	61	4158	4506
Minor Streams	IBB	84	4438	4809
Minor Streams	IBB	23	4441	4813
Minor Streams	IBB	48	4614	5000
West Meghalaya	IBB	3753	3811	4130

[1] IBB = Indo-Bangladesh border
[2] 1964-91 (NERP) Standard Period excludes 1971
[3] 1964-91 (NERP) Rainfall = 1.0837 (1961-90) (WMO) Rainfall)

Table A9
51-Station Mean Individual Year Rainfalls

Year	1961-90	1964-90	Year	1961-90	1964-90
1961	2327		1976	3063	3063
1962	2643		1977	3436	3436
1963	1719		1978	3331	3331
1964	3890	3890	1979	2947	2947
1965	2791	2791	1980	3458	3458
1966	3124	3124	1981	2903	2903
1967	2946	2946	1982	2324	2324
1968	3178	3178	1983	3602	3602
1969	3829	2829	1984	3971	3971
1970	2698	2698	1985	2481	2481
1971	3240		1986	3707	3707
1972	2438	2438	1987	2837	2837
1973	4357	4357	1988	4747	4747
1974	3607	3607	1989	2889	2889
1975	3074	3074	1990	3433	3433
Means				3008	3233

Ratio (1964-90)/(1961-90) = 3233/3008 = 1.0748

Table A10
Ratios of 1964-91/1961-90 Mean Annual Rainfalls

Rain Gauge	Ratio	Rain Gauge	Ratio
Bajitpur	1.0127	Kishoreganj	1.0018
Bhairab Bazar	1.0127	Lallakhal	1.0015
Bholaganj	0.9960	Langla	1.0098
Brahmanbaria	1.0109	Latu	1.0073
Chandbagh	1.0100	Markuli	1.0032
Chandpur Bagan	1.0088	Mohanganj	1.0095
Chhatak	1.0073	Muktagacha	1.0100
Dakshinbagh	1.0047	Mymensingh	1.0235
Dewanganj	0.9965	Netrakona	1.0143
Durgapur	1.0079	Sarail	1.0121
Gobindaganj	1.0033	Sheola	1.0120
Gouripur	1.0034	Sherpur	1.0067
Habiganj	1.0146	Srimangal	1.0162
Itakhola	1.0129	Sunamganj	1.0077
Itna	1.0093	Sylhet	1.0066
Jaria Jhanjail	1.0044	Tajpur	0.9968
Kamalganj	1.0126	Zakiganj	1.0090
Khaliajuri	1.0166		

Mean Ratio = 1.0083

Table A11
Estimated Inflows at the Indo-Bangladesh Border, 1964-91

River	Catchment Area (km^2)	Mean Annual Values, 1964-91				
		$\overline{RF}$ (mm/yr)	$\overline{RO}$ (mm/yr)	$\overline{AET}$ (mm/yr)	$\overline{Q}$ m^3/s)	V (km^3/yr)
Part 1: TRIPURA RIVERS ENTERING THE KUSHIYARA						
Sonai-Bardal	2334	3351	2280	1071	168.7	5.32
Juri	635	3159	1997	1162	40.2	1.26
Manu	2233	2513	1045	1468	74	2.33
Dhalai (S)	579	2539	1083	1456	19.9	0.63
Khowai	1111	2491	1012	1479	35.7	1.12
Total	6892				338.5	10.66

Table A11 (cont)
Estimated Inflows at the Indo-Bangladesh Border, 1964-91

River	Catchment Area (km^2)	Mean Annual Values, 1964-91				
		$\overline{RF}$ (mm/yr)	$\overline{RO}$ (mm/yr)	$\overline{AET}$ (mm/yr)	$\overline{Q}$ (m^3/s)	V (km^3/yr)
PART 2: EAST MEGHALAYA RIVERS ENTERING THE SURMA						
Minor Streams	86	4821	4447	374	12.1	0.38
Minor Streams	77	4814	4436	378	10.8	0.34
Minor Streams	152	4943	4626	317	22.3	0.70
Lubha	724	4843	4479	364	102.8	3.24
Minor Streams	44	5389	5127	262	7.2	0.23
Sarigowain	810	4976	4675	301	120.1	3.79
Minor Streams	63	5877	5615	262	11.2	0.35
Minor Streams	55	5715	5453	262	9.5	0.30
Piyain	808	4930	4607	323	118.0	3.72
Minor Streams	193	6918	6656	262	40.7	1.29
Dhalai (N)	342	6990	6728	262	73.0	2.30
Umium	518	7193	6931	262	113.8	3.59
Minor Streams	339	8159	7897	262	84.9	2.68
Jhalukhali	447	7582	7320	262	103.8	3.27
Minor Streams	56	7060	6798	262	12.1	0.38
Jadukata	2514	5932	5670	262	452.0	14.26
Minor Streams	148	6139	5877	262	27.6	0.87
Minor Streams	90	5443	5181	262	14.8	0.47
Minor Streams	13	5272	5010	262	2.1	0.07
Minor Streams	85	5105	4843	262	13.1	0.41
Total	7564				1351.9	42.64

Table A11 (cont.)
Estimated Inflows at the Indo-Bangladesh Border, 1964-91

River	Catchment Area (km^2)	Mean Annual Values, 1964-91				
		$\overline{RF}$ (mm/yr)	$\overline{RO}$ (mm/yr)	$\overline{AET}$ (mm/yr)	$\overline{Q}$ (m^3/s)	V (km^3/yr)
PART 3: WEST MEGHALAYA RIVERS ENTERING THE KANGSHA						
Dorong	161	3180	2028	1152	10.4	0.33
Malijhee	123	3307	2215	1092	8.6	0.27
Chillakhali	117	3372	2311	1061	8.6	0.27
Bhogai	455	3628	2688	940	38.8	1.22
Minor Streams	123	3594	2638	956	10.3	0.33
Nitai	381	3909	3102	807	37.5	1.18
Minor Streams	48	4100	3384	716	5.2	0.16
Someswari	2129	4405	3834	571	258.8	8.16
Minor Streams	61	4506	3982	524	7.7	0.24
Minor Streams	84	4809	4429	380	11.8	0.37
Minor Streams	23	4813	4435	378	3.2	0.10
Minor Streams	48	5000	4711	289	7.2	0.23
Total	3753				408.1	12.86

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Table A12
Annual Discharges of Barak River at Lakhipur, Assam, 1956-71

Year	Annual Discharge		
	acre-ft/year(1)	km^3/year(2)	m^3/s(3)
1956	12,158,112	15.0	475.4
1957	11,117,130	13.7	434.7
1958	15,770,004	19.4	616.6
1959	15,176,874	18.7	593.4
1960	11,824,334	14.6	462.3
1961	16,443,048	20.3	642.9
1962	12,593,772	15.5	492.4
1963	14,855,784	18.3	580.8
1964	17,063,628	21.0	667.2
1965	7,730,000	9.5	302.2
1966	19,800,000	24.4	774.1
1967	10,900,000	13.4	426.2
1968	14,700,000	18.1	574.7
1969	12,000,000	14.8	469.2
1970	12,350,000	15.2	482.9
1971	15,500,000	19.1	606.0
16-Year Average	13,748,918	17.0	537.6

(1) As reported by India

(2) km^3 = acre-ft x $1233/10^{-9}$

(3) m^3/s = (km^3/year) x 31.7098

Note: $\overline{Q}_{BL\ (64\text{-}70)}$ = 528.1 m^3/s

Table A13
Water Balance of the Kushiyara between Sheola and Sherpur, 1964-91

Water Year	Kushiyara/ Sheola	Sada Khal/ Sheola	Sonai-Bardal/ Jaldhup	Manu/ Manu RB	Dhalai/ Kamalganj	Total Inflows		Kushiyara at Sherpur		
						Gauged	Ungauged	Total	Main Channel	By-Pass
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1964	638.4	100.6	165.9	106.8	37.6	1049.3	275.1	1324.4	889.8	434.6
1965	512.2	80.7	119.6	66.5	23.3	802.3	210.4	1012.7	710.1	302.6
1966	568.7	89.6	161.5	93.7	40.8	954.3	250.2	1204.5	790.6	413.9
1967	505.4	79.7	117.0	64.8	27.1	794.0	208.2	1002.2	700.4	301.8
1968	586.6	92.4	151.9	86.4	35.6	952.9	249.9	1202.8	816.0	386.8
1969	549.2	86.6	132.7	58.1	22.4	849.0	222.6	1071.6	762.8	308.8
1970	643.7	101.4	135.7	61.9	18.7	961.4	252.1	1213.5	897.4	316.1
1971										
1972	468.6	73.9	105.0	44.0	12.6	704.1	184.6	888.7	648.0	240.7
1973	745.6	117.5	143.3	123.9	43.5	1173.8	307.8	1481.6	1042.5	439.1
1974	760.6	119.9	155.7	104.7	35.6	1176.5	308.5	1485.0	1063.8	421.2
1975	665.0	104.8	129.4	66.8	18.0	984.0	258.0	1242.0	927.7	314.3
1976	692.4	109.1	158.0	103.3	35.3	1098.1	287.9	1386.0	966.7	419.3
1977	740.4	116.7	177.8	119.7	37.7	1192.3	312.6	1504.9	1035.1	469.8
1978	605.1	95.4	116.3	97.2	31.4	945.4	247.9	1193.3	842.4	350.9
1979	471.7	74.2	91.6	48.5	14.2	700.2	183.6	883.8	652.4	231.4
1980	691.5	109.0	130.3	77.1	34.8	1042.7	273.4	1316.1	965.4	350.7
1981	563.8	88.9	126.6	72.9	25.5	877.7	230.1	1107.8	783.6	324.2
1982	607.0	95.7	133.6	67.1	23.5	926.9	243.0	1169.9	822.8	347.1
1983	913.6	144.0	183.9	108.1	36.0	1385.6	363.3	1748.9	1281.7	467.2
1984	640.4	100.9	139.1	92.2	27.6	1000.2	262.3	1262.5	902.4	360.1
1985	790.6	124.6	163.7	86.0	30.1	1195.0	313.3	1508.3	1106.6	401.7
1986	600.1	94.6	107.7	73.3	25.3	901.0	236.2	1137.2	872.1	265.1
1987	709.2	111.8	142.8	57.2	24.1	1045.1	274.0	1319.1	963.6	355.5
1988	834.2	131.5	171.8	117.9	36.1	1291.5	338.6	1630.1	1189.7	440.4
1989	882.1	139.0	183.6	90.7	27.1	1322.5	346.8	1669.3	1193.1	476.2
1990	1008.3	158.9	183.4	113.5	39.8	1503.9	394.3	1898.2	1402.3	495.9
1991	1001.5	157.8	209.0	129.6	53.5	1551.4	406.8	1958.2	1446.6	511.6
Mean	681.3	107.4	145.8	86.4	30.3	1051.2	275.6	1326.8	950.9	375.8

APPENDIX B
Frequency Plots of Maximum Discharges

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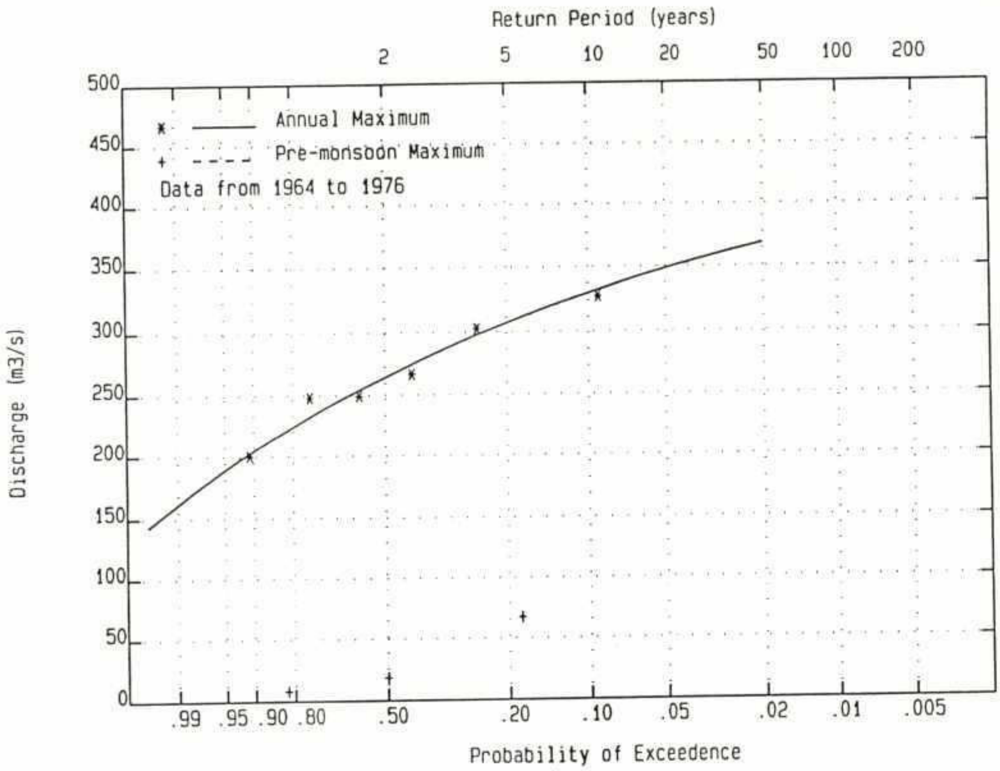
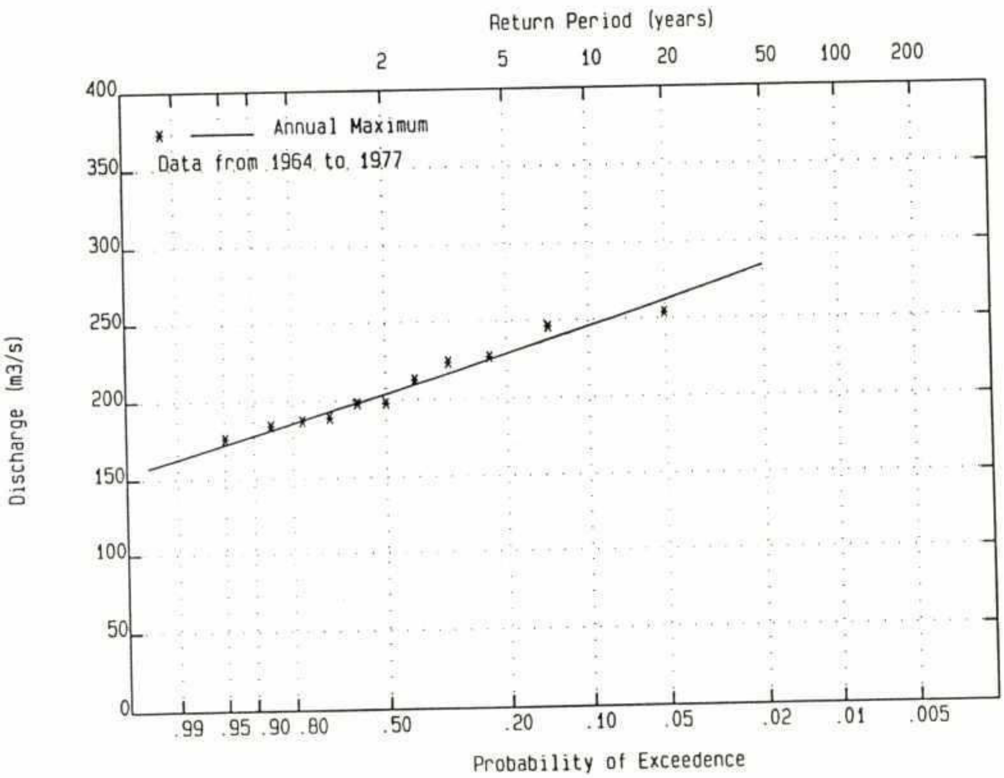
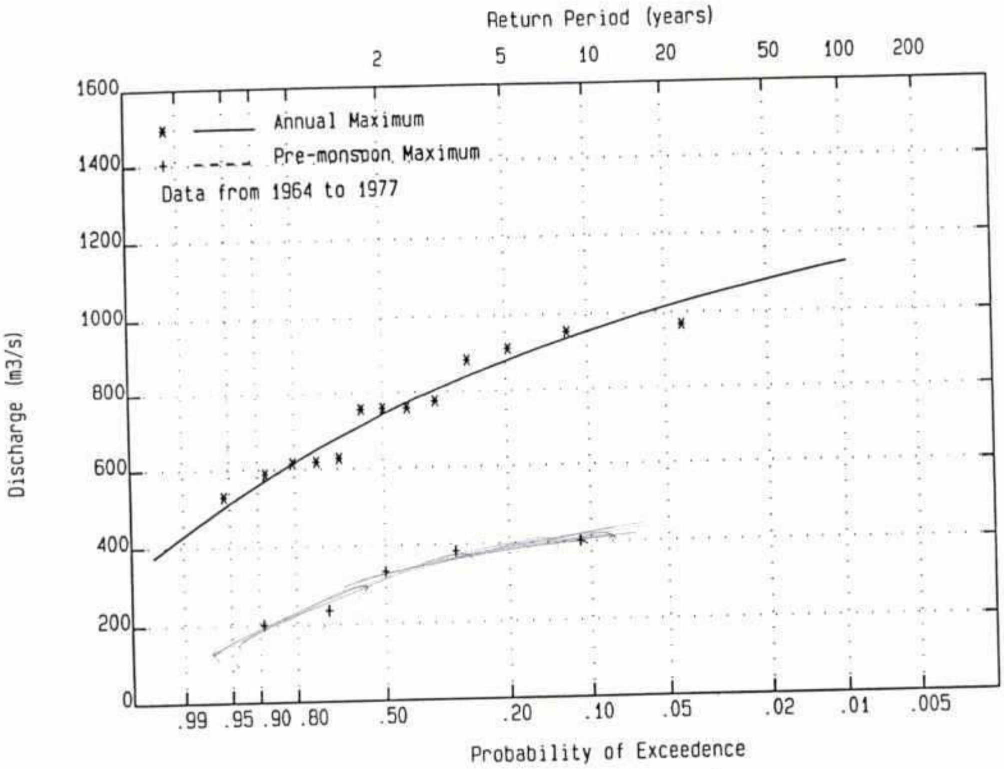


Gauge 3A Anderson Khal at Brahmanbaria Rly. Bridge
General Extreme Value Distribution

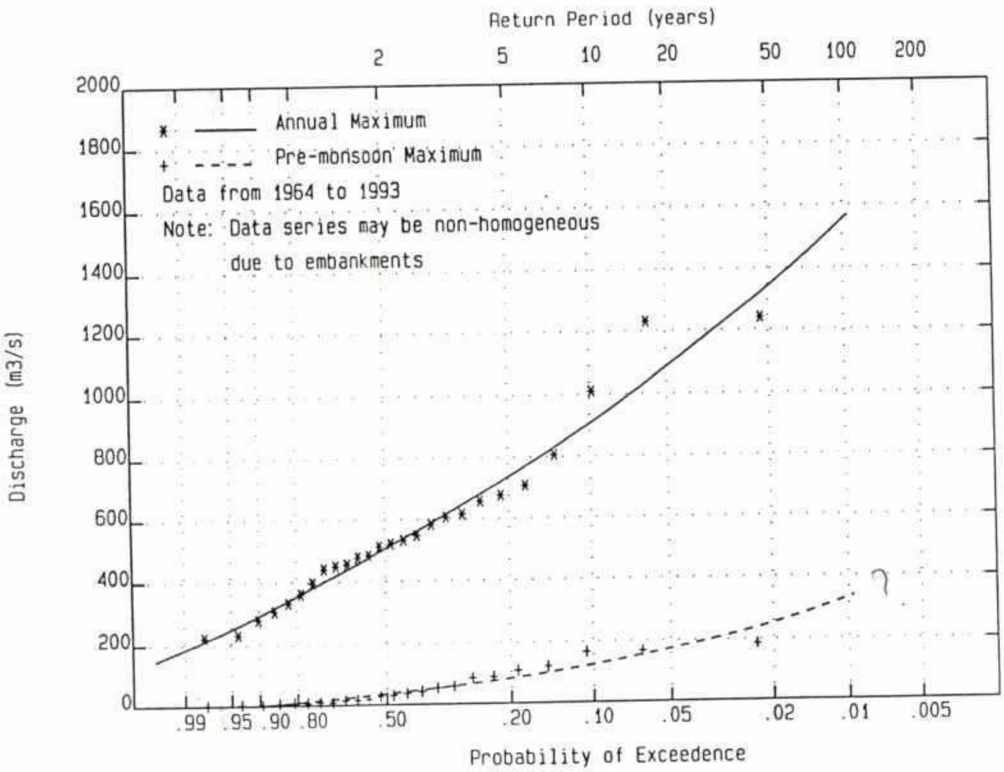


Gauge 6 Bahia River at Surma Offtake
General Extreme Value Distribution

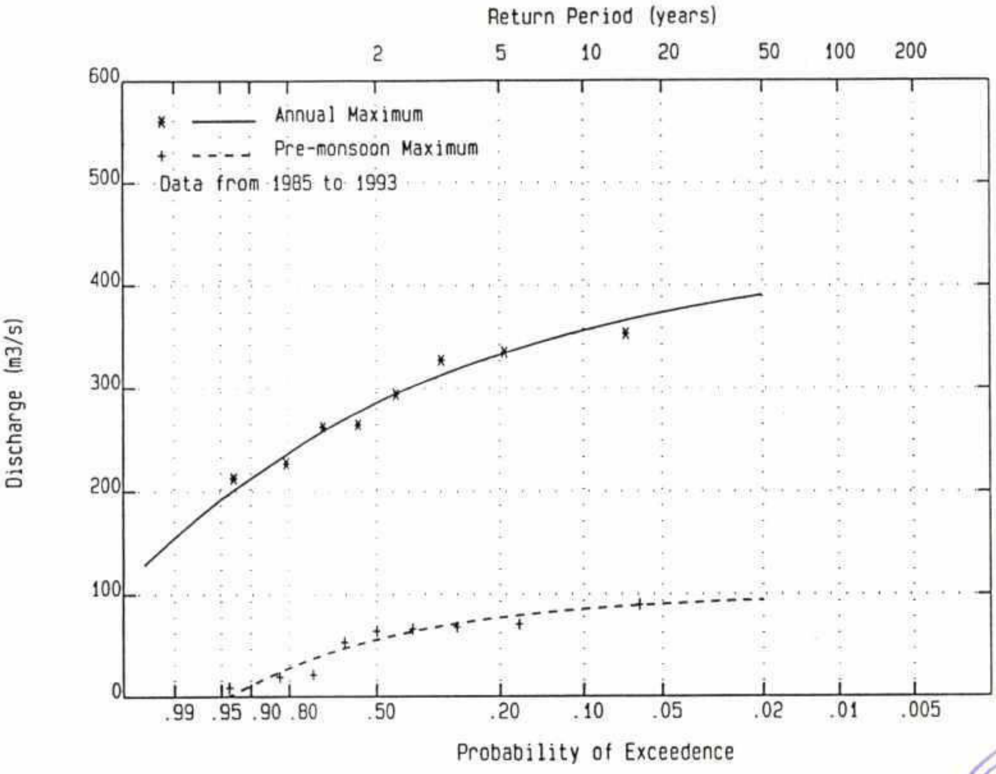
208



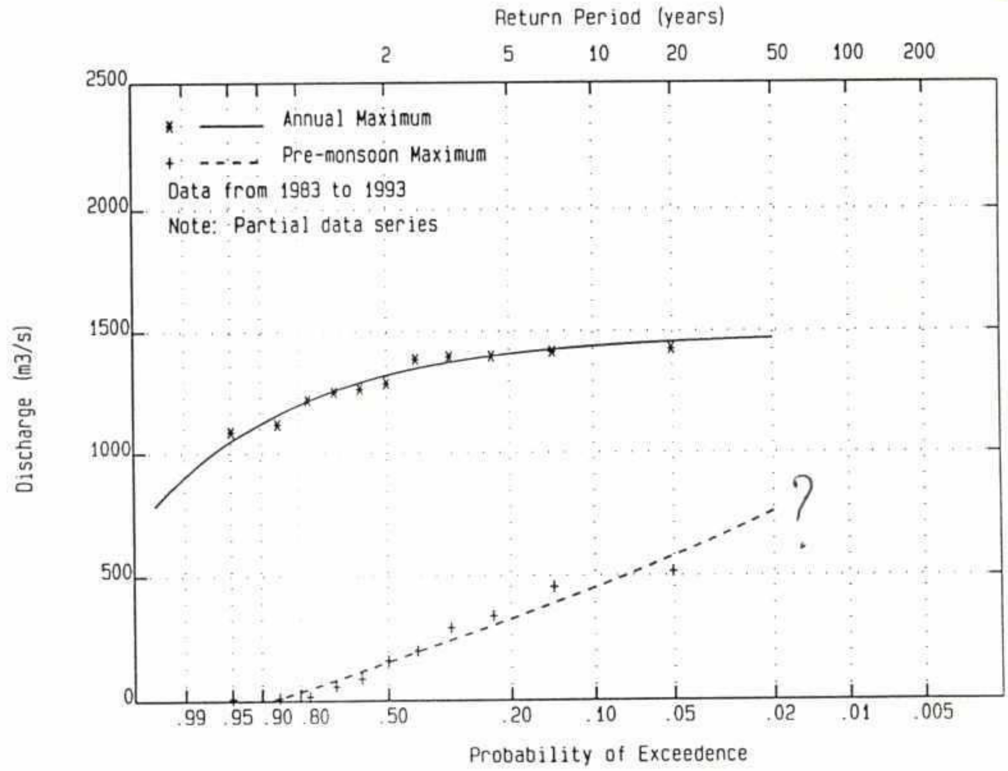
Gauge 33 Bhattakhali River at Gobindaganj
General Extreme Value Distribution



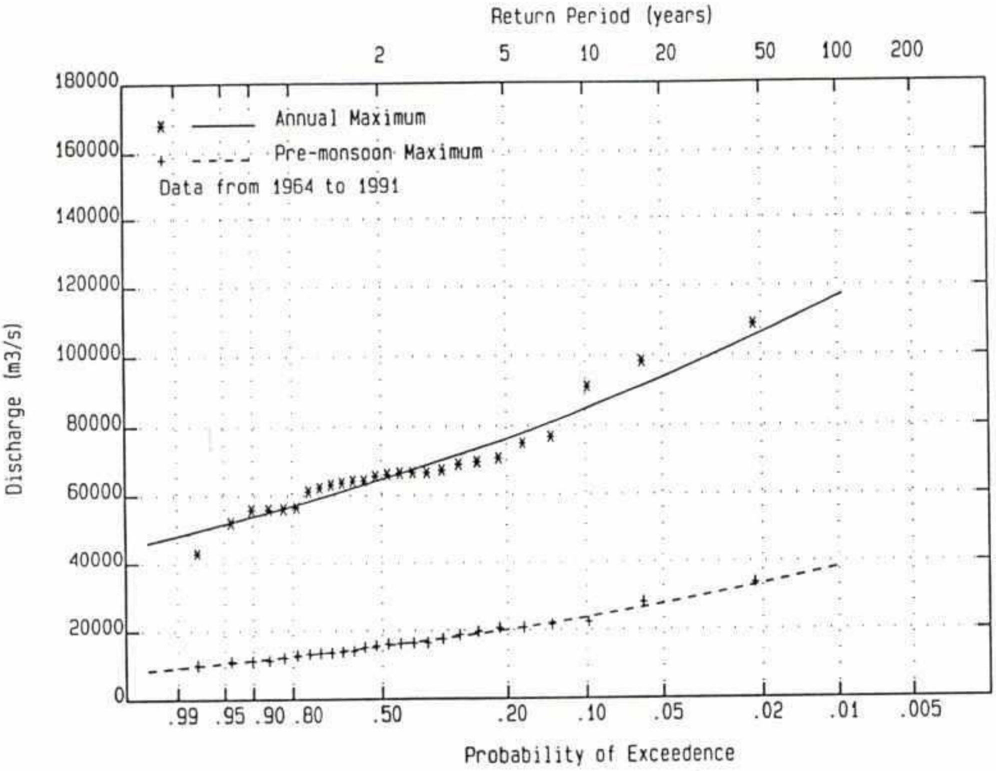
Gauge 34 Bhogai River at Nakuagaon
General Extreme Value Distribution



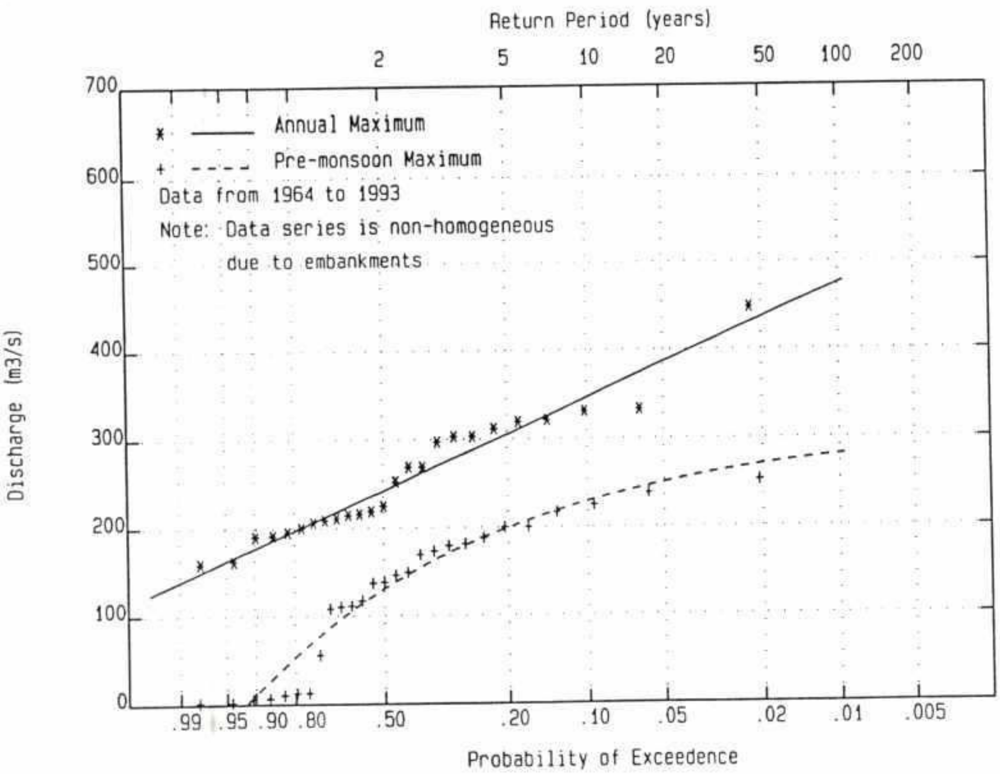
Gauge 35-5 Kangsha River at Sarchapur
General Extreme Value Distribution



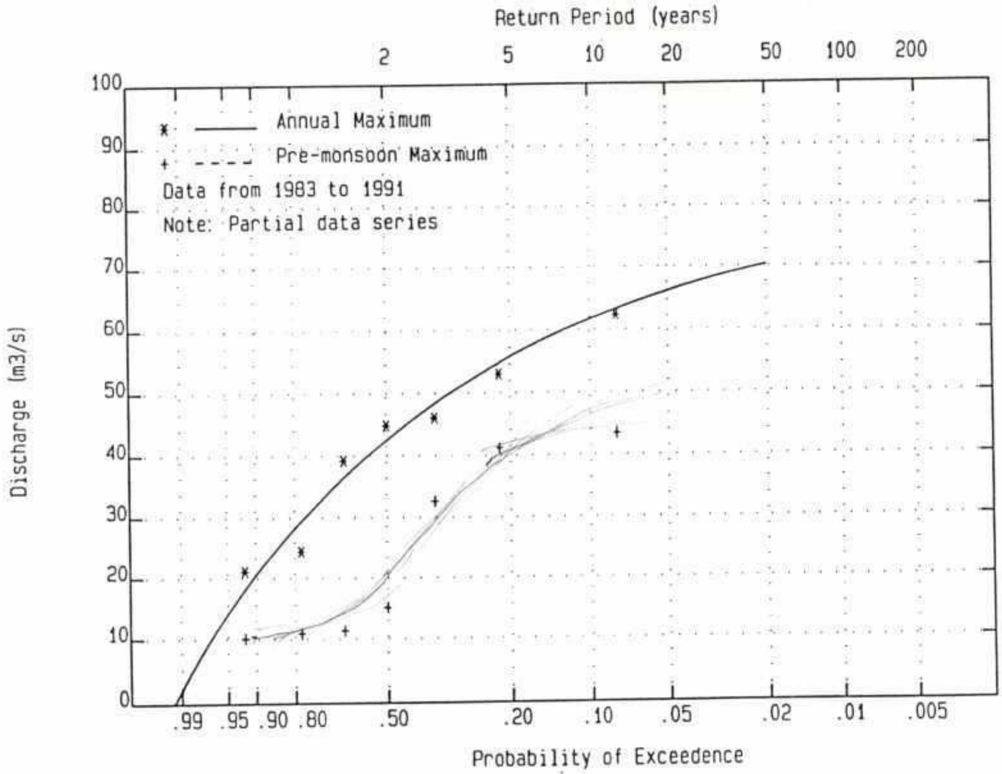
Gauge 36(A) Kangsha River at Jariajanjail
General Extreme Value Distribution



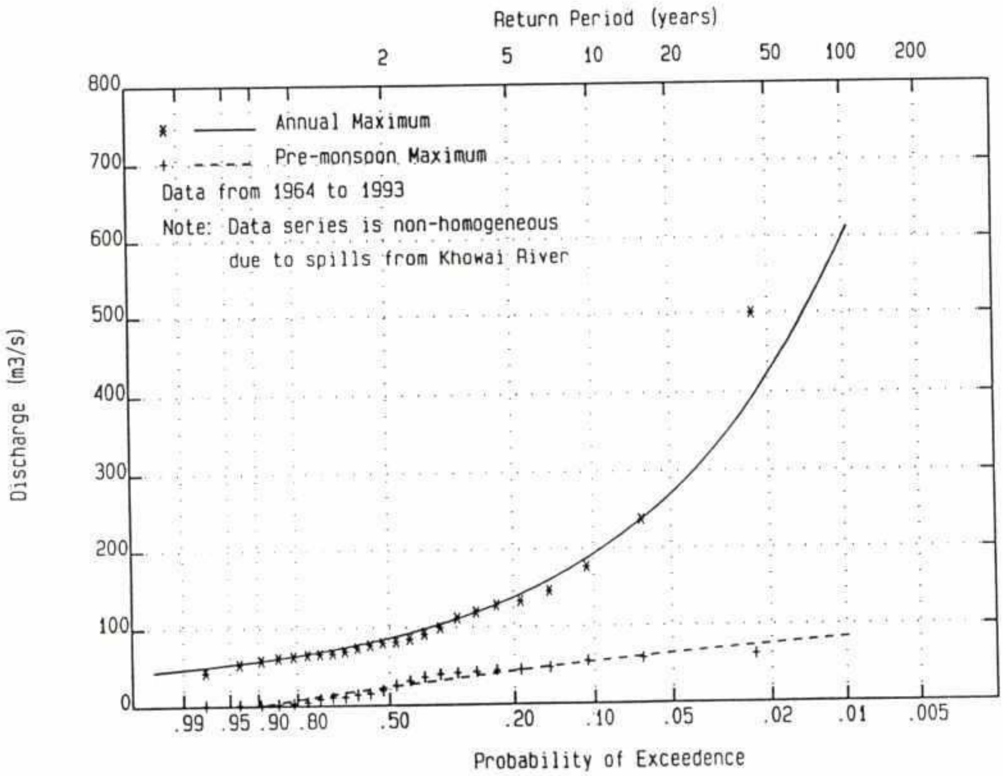
Gauge 46-9 L Brahmaputra River at Bahadurabad
General Extreme Value Distribution



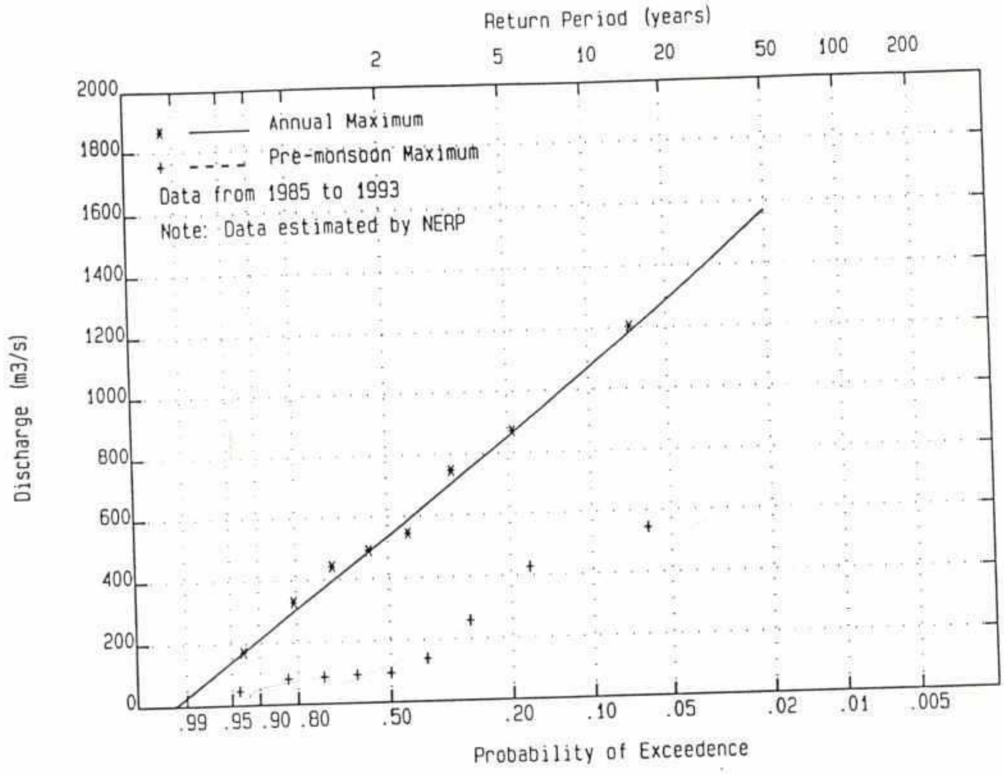
Gauge 67 Dhalai River at Kamalganj
General Extreme Value Distribution



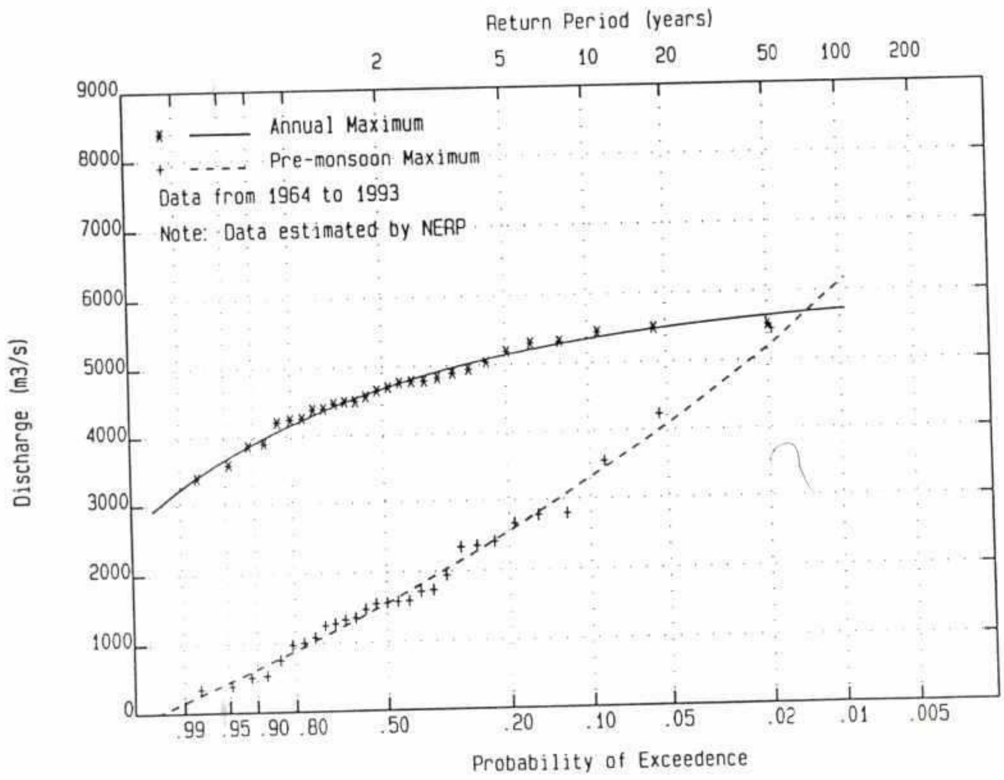
Gauge 123(R) Hawrah River at Gangasagar Rly. B.
General Extreme Value Distribution



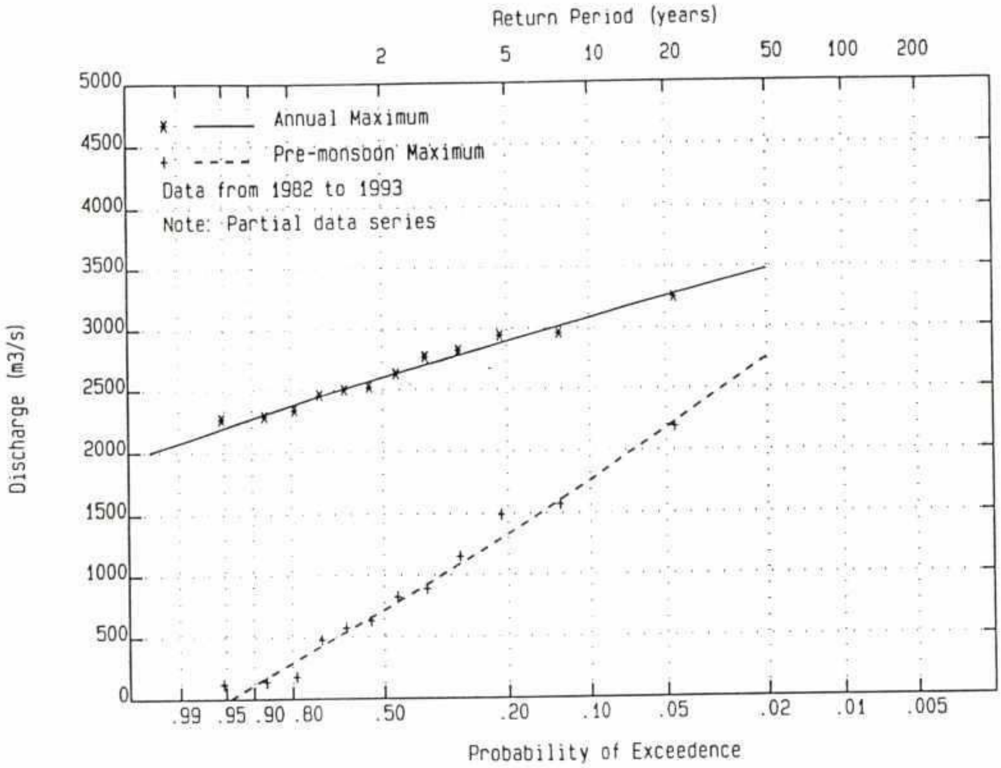
Gauge 138 Karangi River at Sofiabad
General Extreme Value Distribution



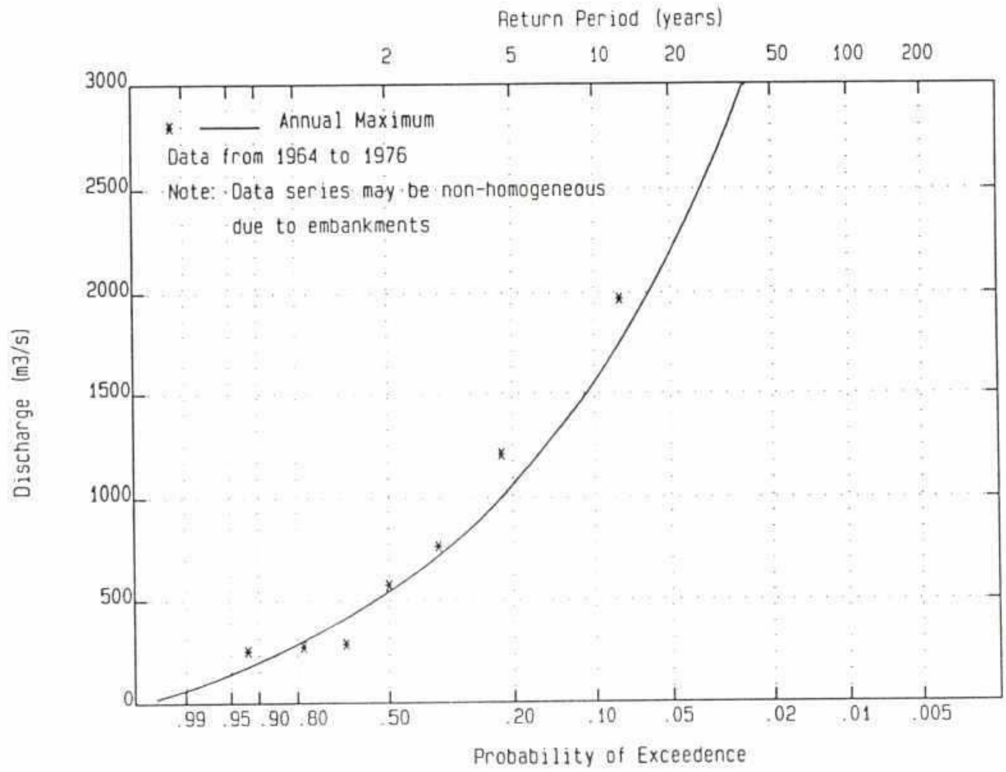
Gauge 157 Khowai River at Ballah
General Extreme Value Distribution



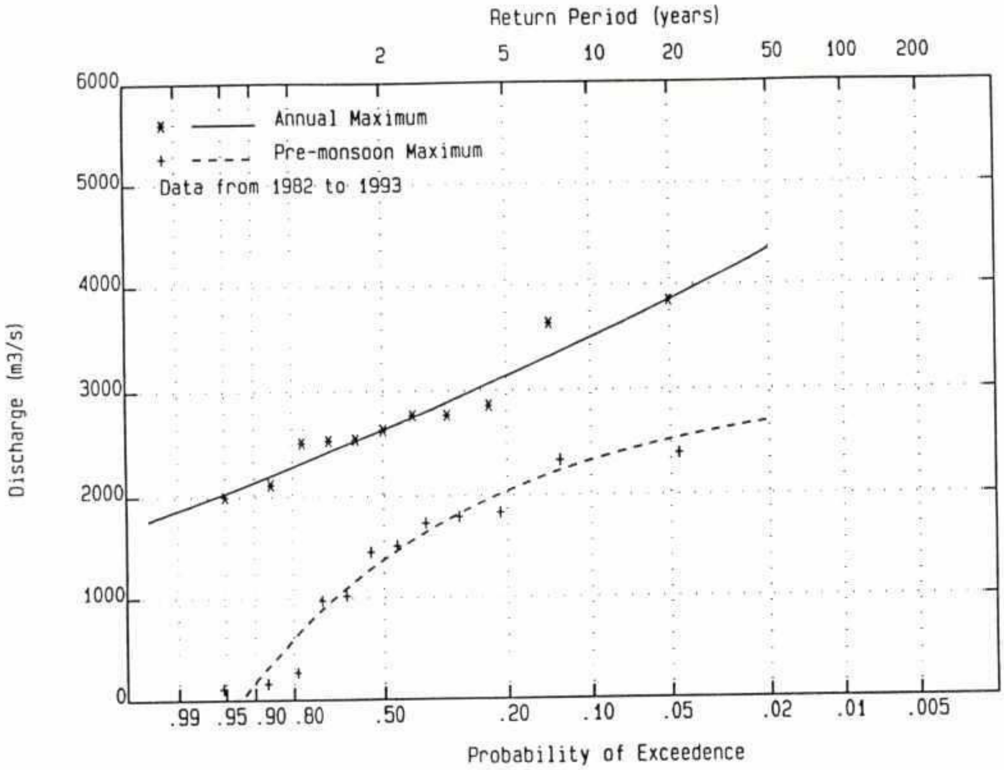
Gauge 172B Barak River at Amalshid
General Extreme Value Distribution



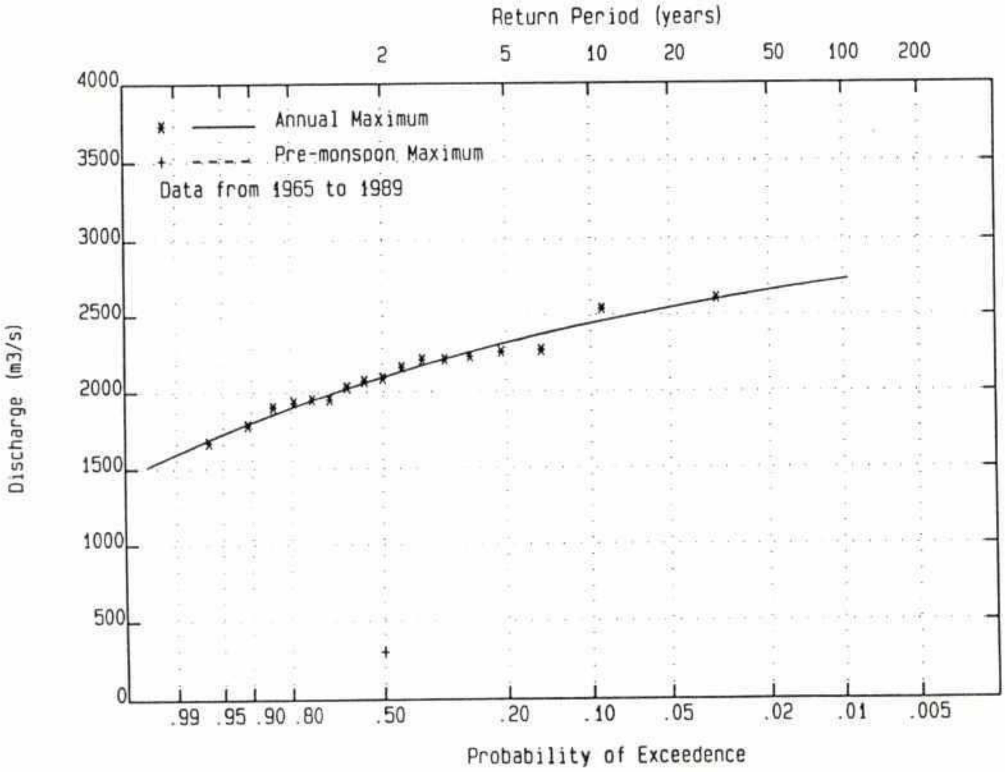
Gauge 173(R) Kushiyara River at Sheola
General Extreme Value Distribution



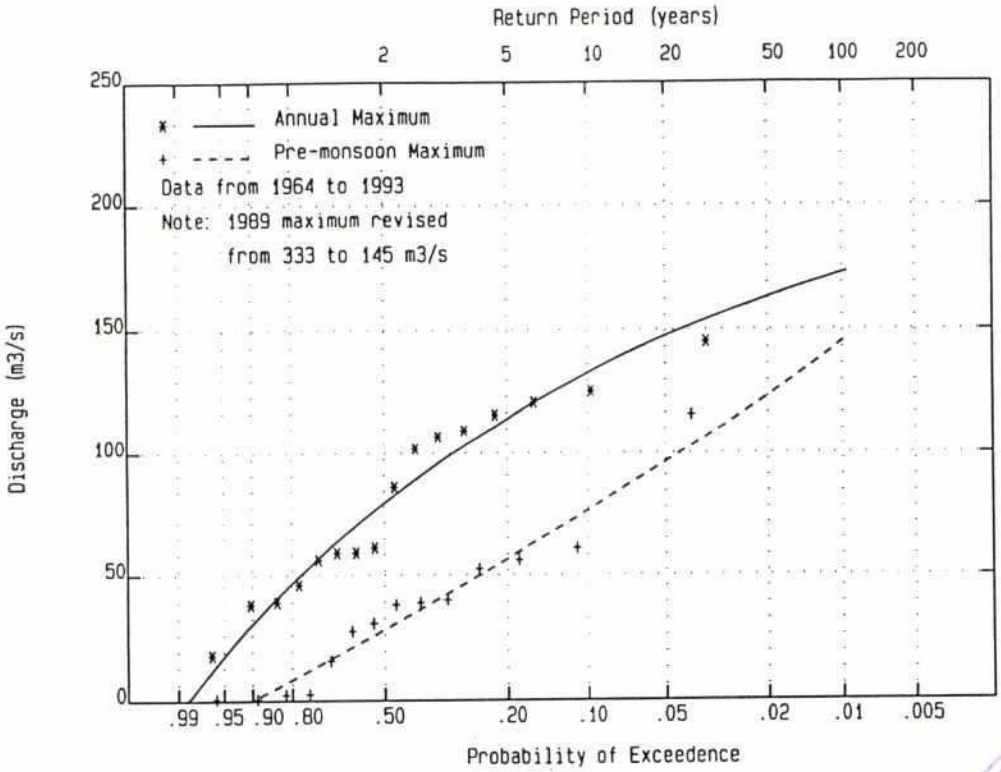
Gauge 173A Sada Khal at Sheola
General Extreme Value Distribution



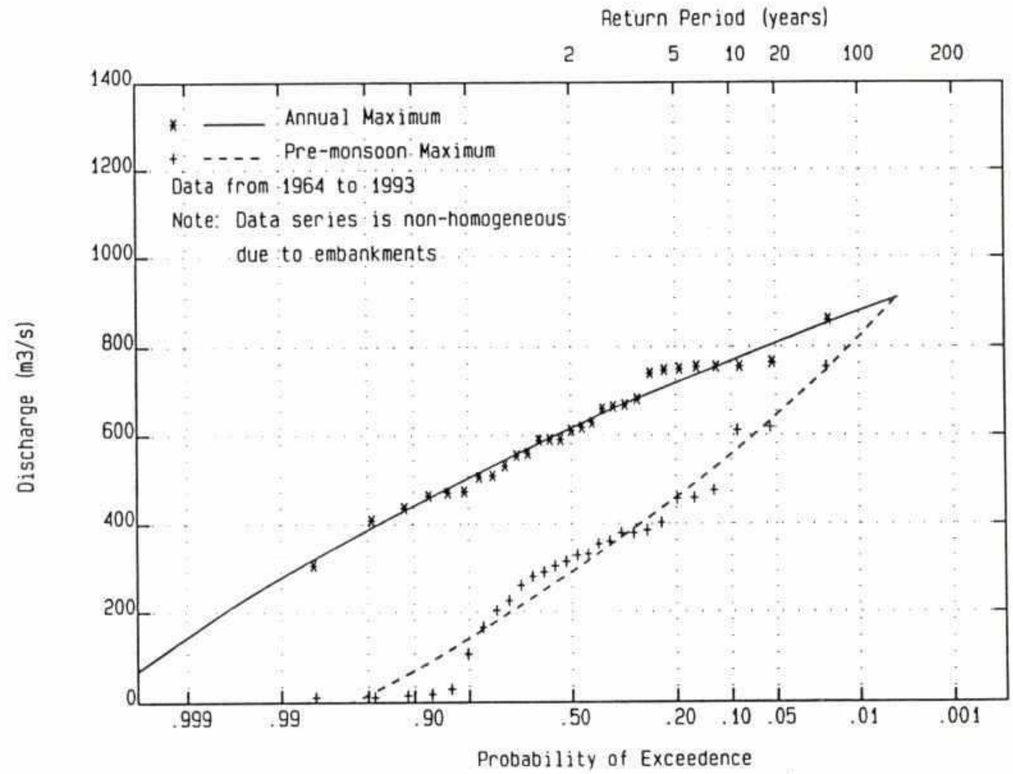
Gauge 175-5 Kushiyara River at Sherpur
General Extreme Value Distribution



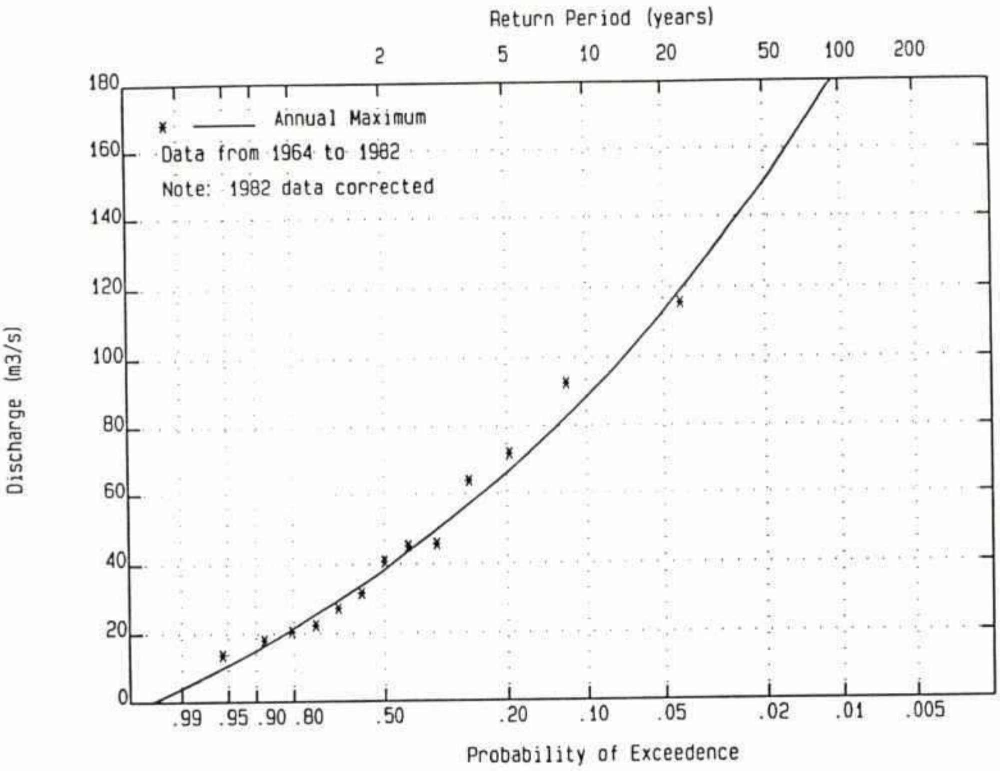
Gauge 179 Lakhya River at Demra
General Extreme Value Distribution



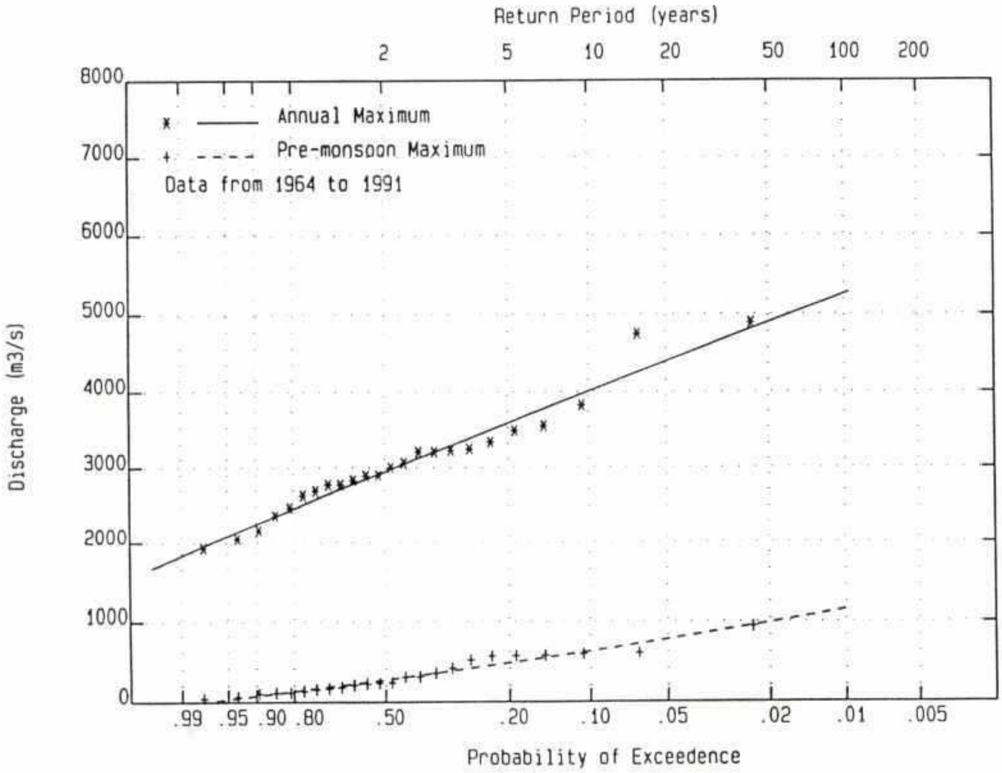
Gauge 192(R) Lungla River at Motiganj
General Extreme Value Distribution



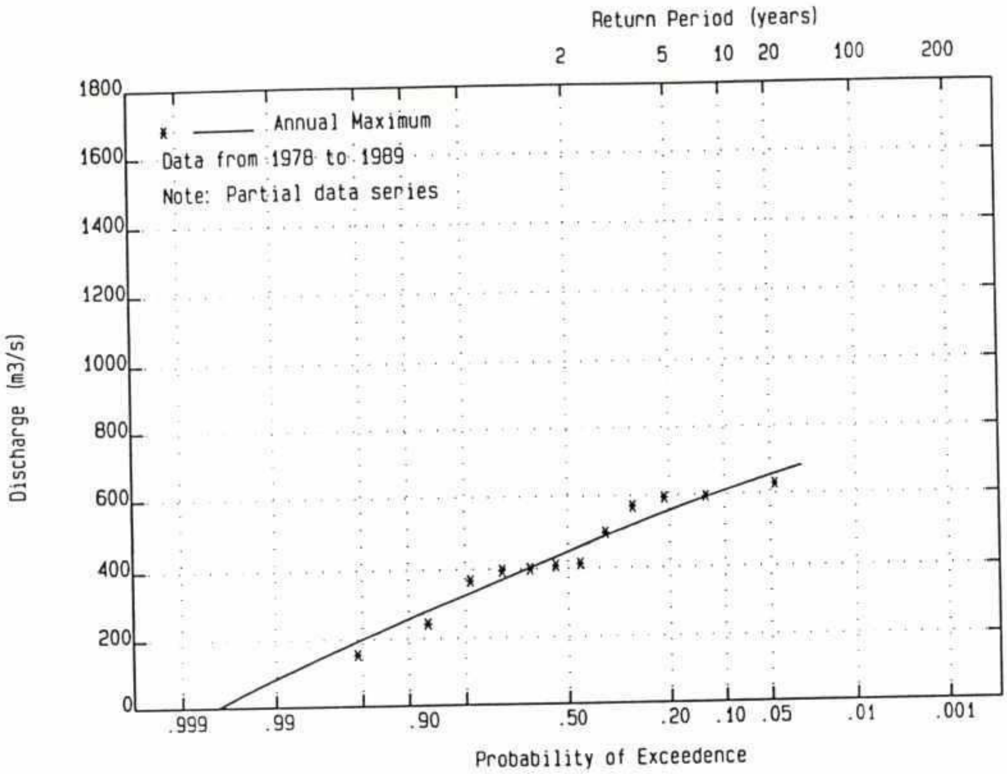
Gauge 201 Manu River at Manu Rly. Bridge
3-Parameter Log Normal Distribution



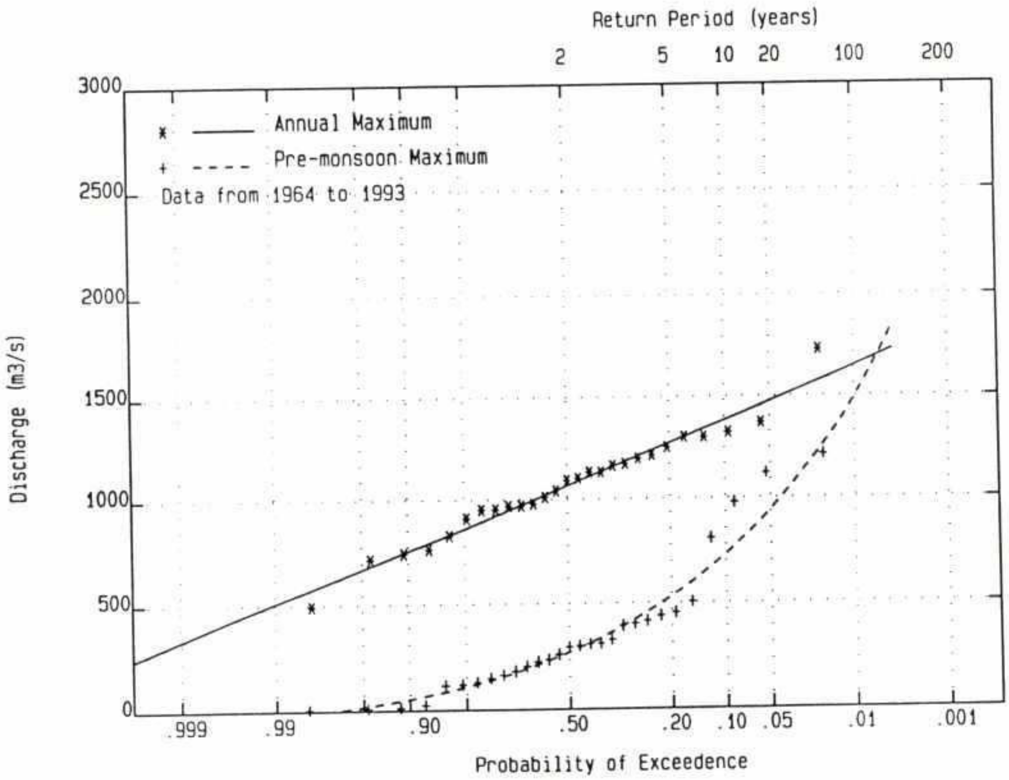
Gauge 227(R) Sutia Offtake from Old Bramahputra River
General Extreme Value Distribution



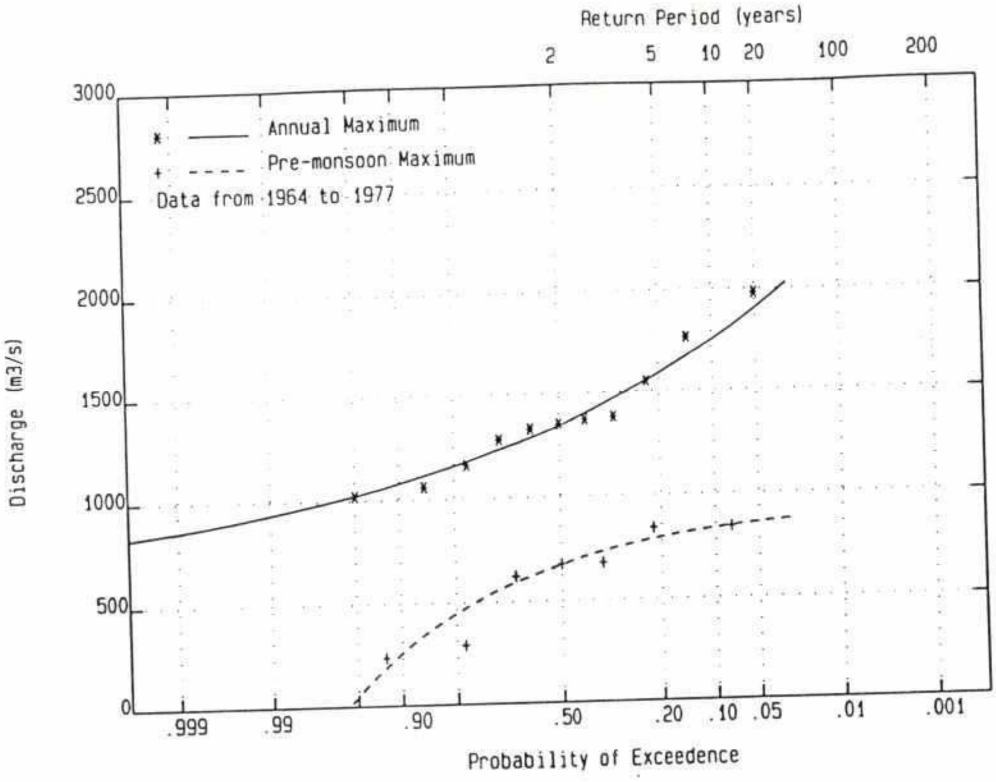
Gauge 228-5 Old Bramahputra R. at Mymensingh (Nilukirchar)
General Extreme Value Distribution



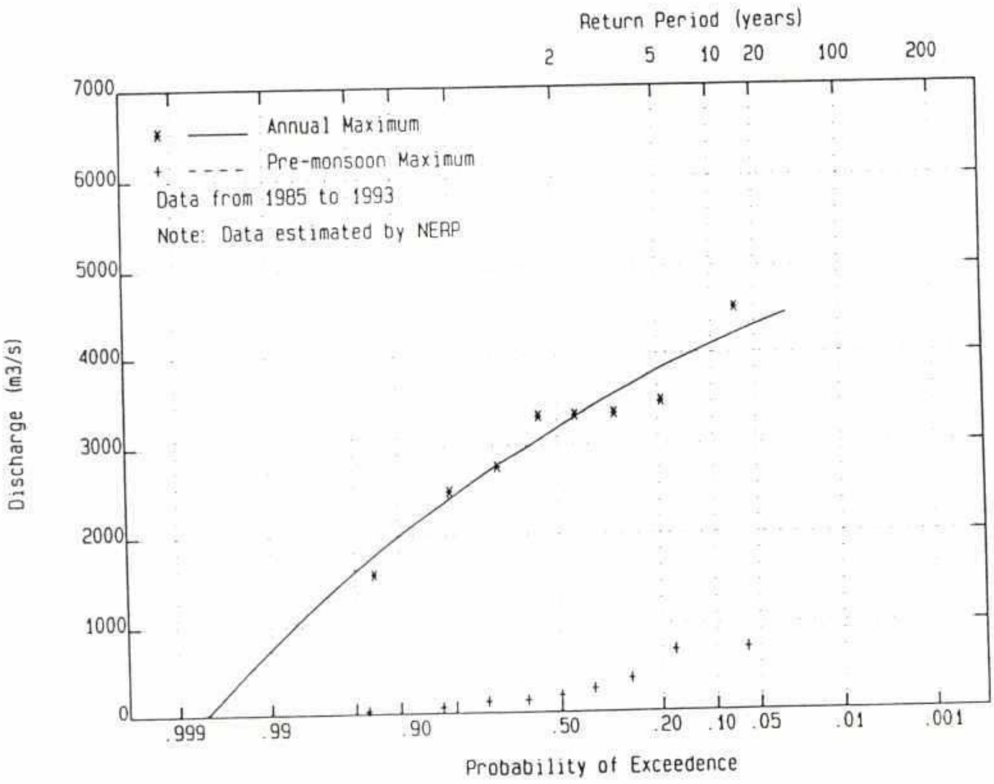
Gauge 230-1(A) Old Bramahputra River at Bhairab Bazar
3-Parameter Log Normal Distribution



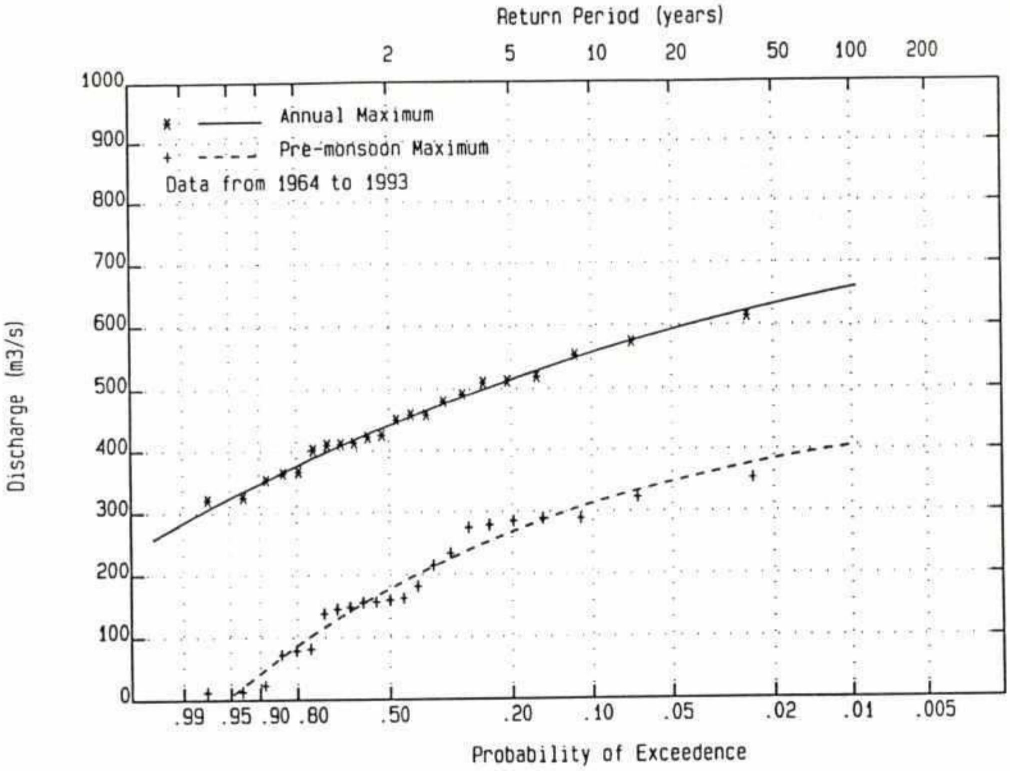
Gauge 251 Sarigowain River at Sarighat
3-Parameter Log Normal Distribution



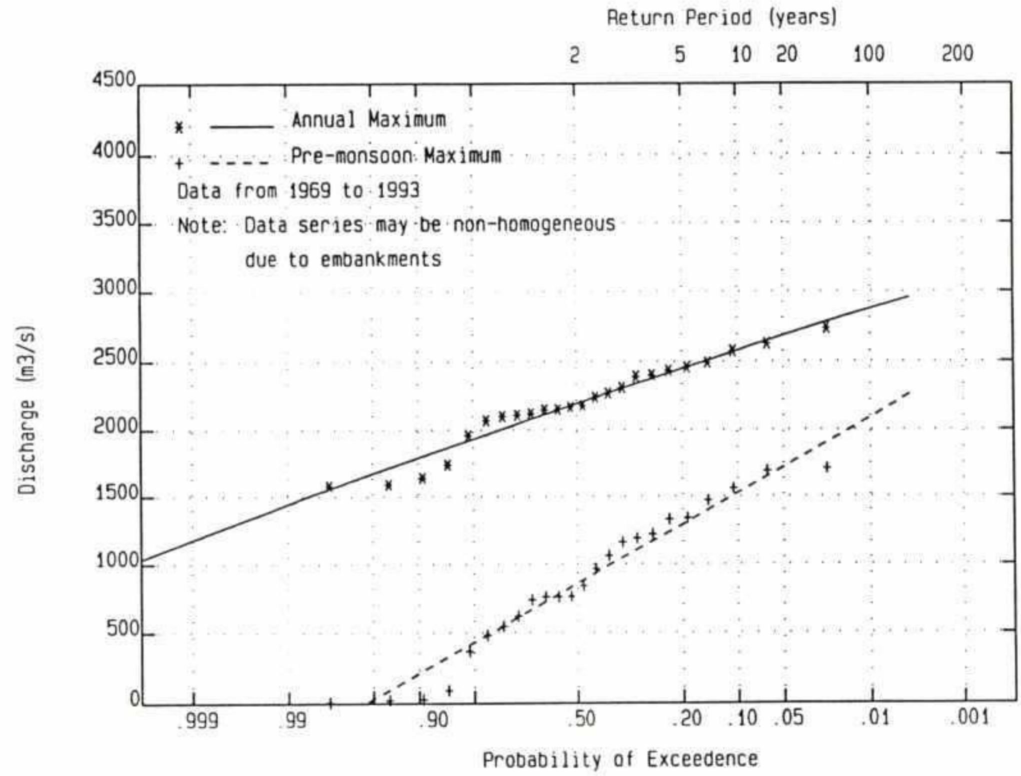
Gauge 252-1 Sarigowain River at Salutikar
3-Parameter Log Normal Distribution



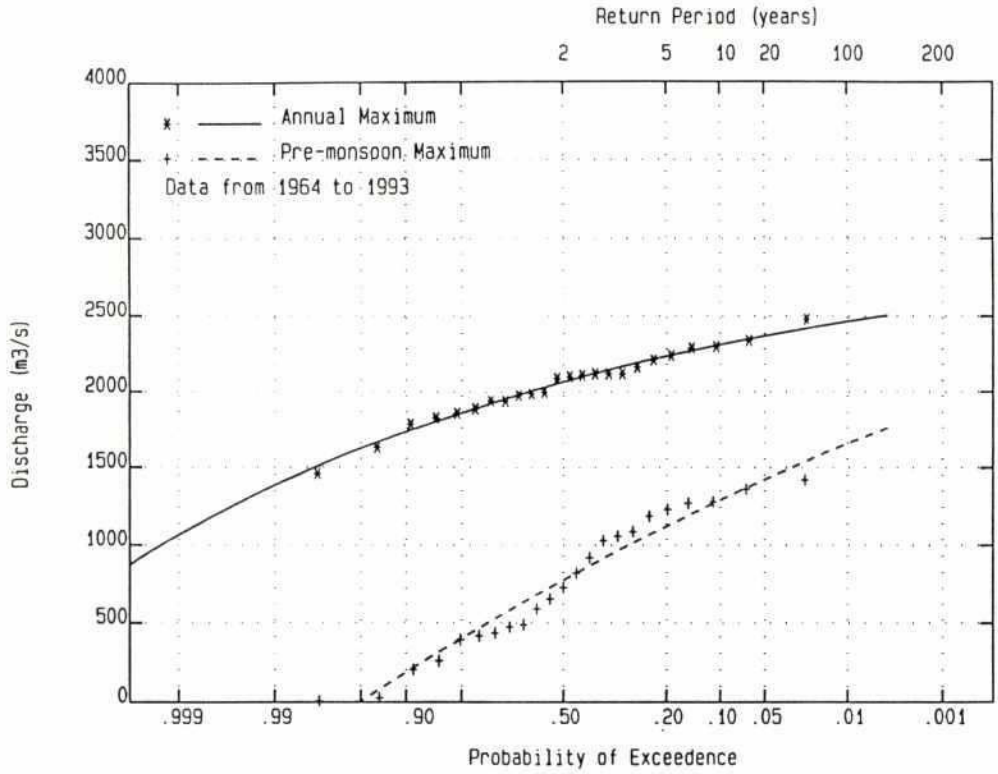
Gauge 262 Someswari River at Bijoypur
3-Parameter Log Normal Distribution



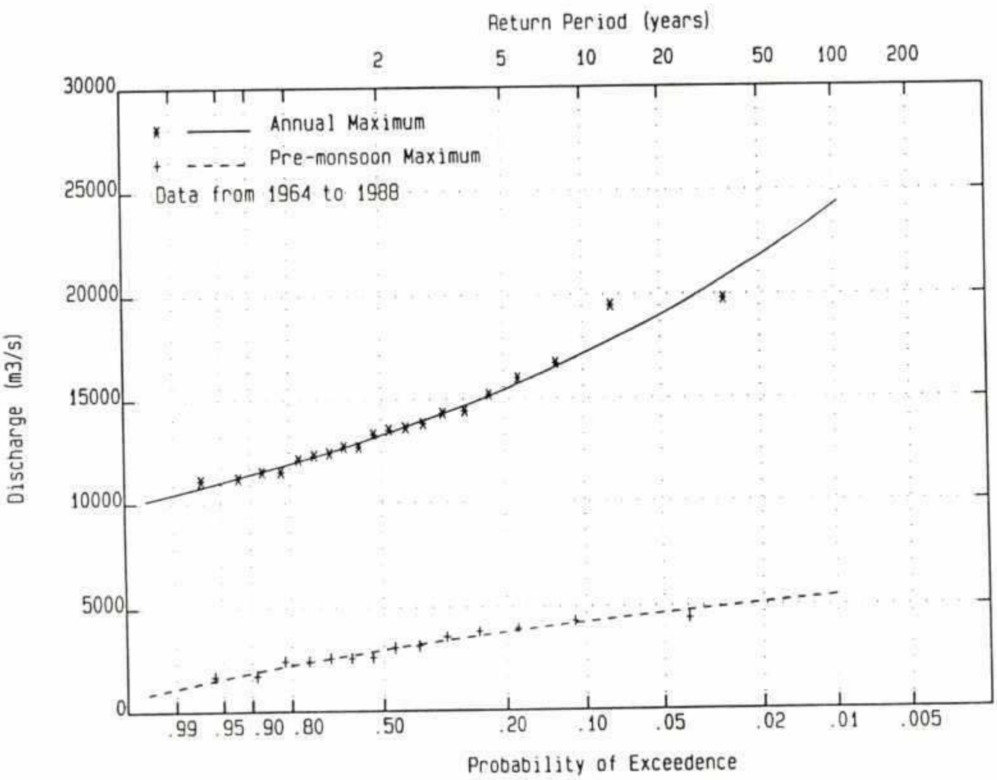
Gauge 265 Sonaibardal River at Jaldhup
General Extreme Value Distribution



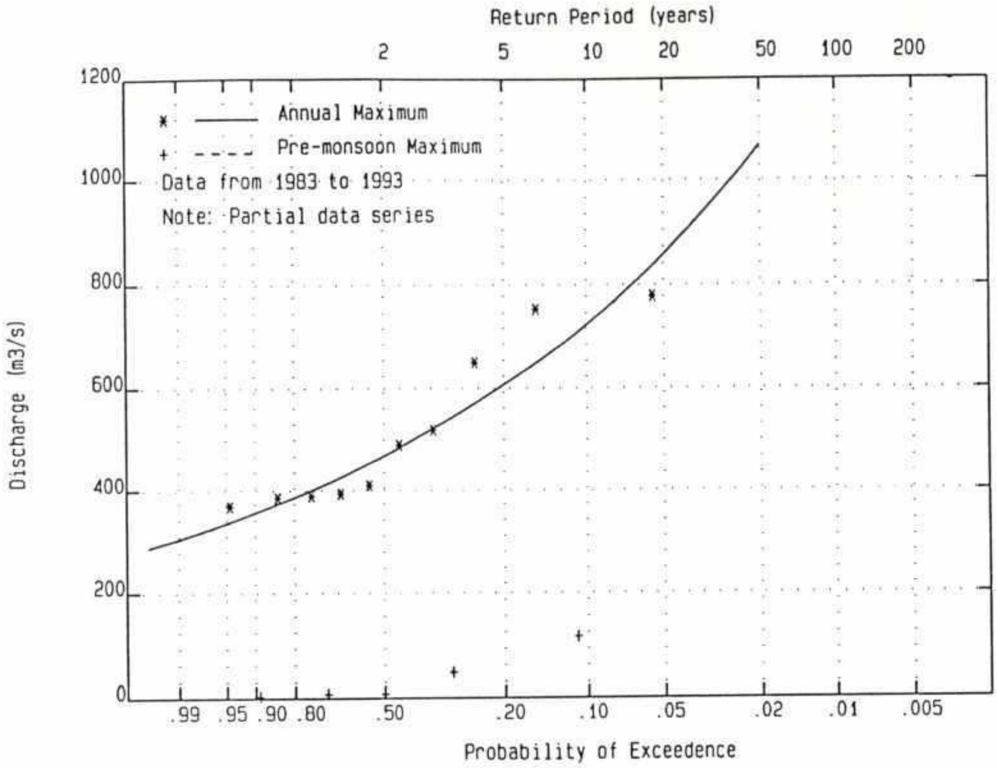
Gauge 266 Surma River at Kanairghat
3-Parameter Log Normal Distribution



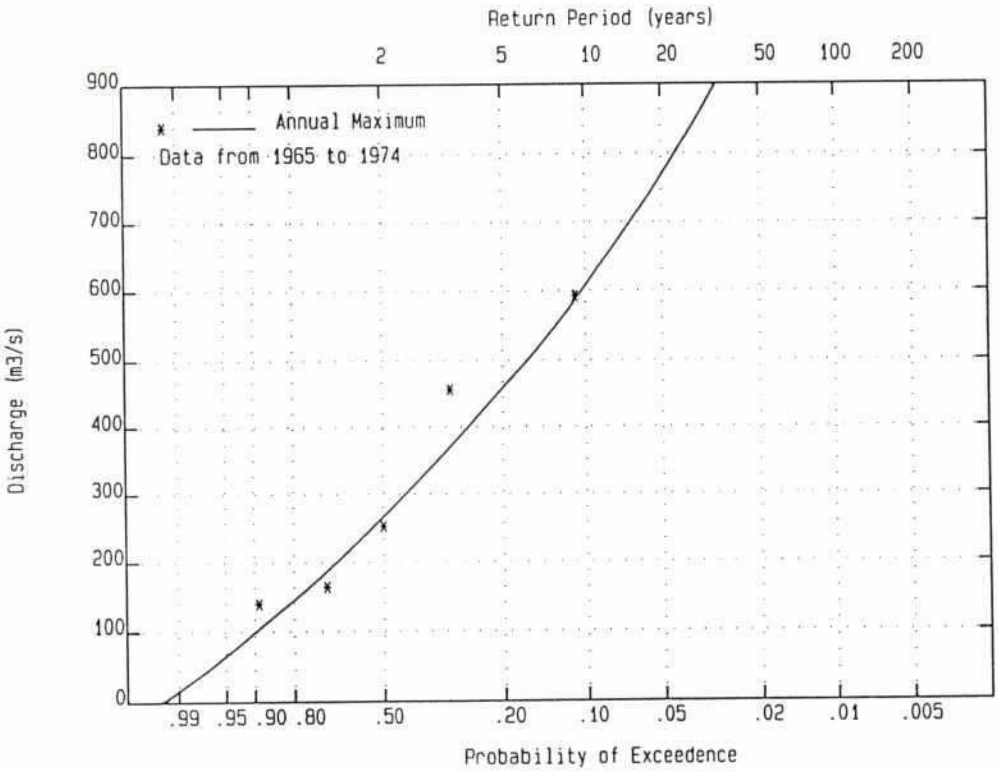
Gauge 267 Surma River at Sylhet
3-Parameter Log Normal Distribution



Gauge 273 Meghna River at Bhairab Bazar
General Extreme Value Distribution



Gauge 314(R) Nitai River at Ghosegaon
General Extreme Value Distribution



Gauge 315 Madhabpur Khal at Chhatak
General Extreme Value Distribution

APPENDIX C

Frequency Plots of Maximum Water Levels

APPENDIX C

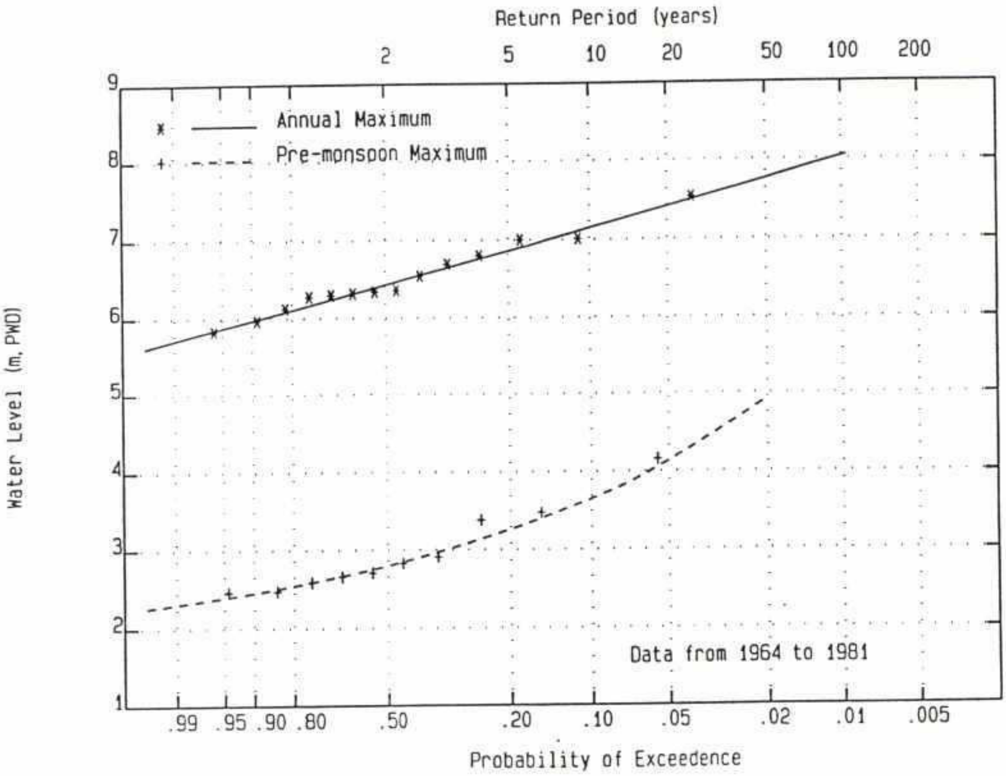
Frequency Plots of Maximum Water Levels

Note regarding gauge datum:

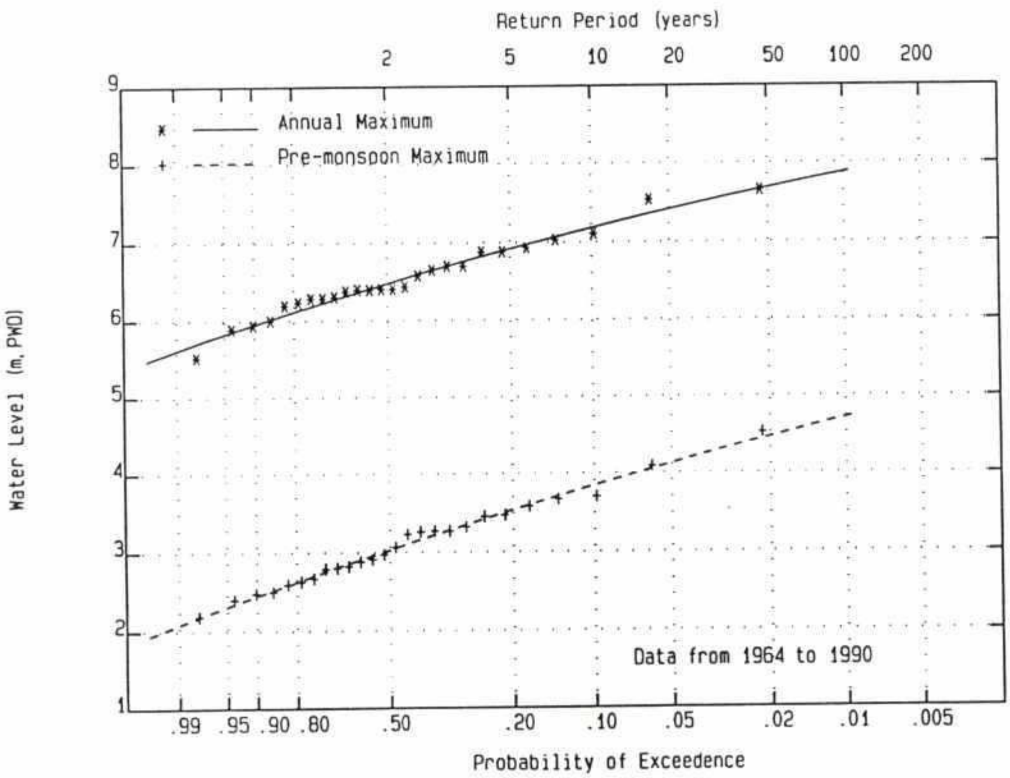
Water levels for the flood frequency analysis have been corrected for gauge datum corrections resulting from the second-order levelling program conducted in 1993 and 1994 by Survey of Bangladesh as part of the Northeast Regional Water Management Project. It's purpose was to check the datum of the active water level gauges in the region and to install and survey a network of new benchmarks to second-order accuracy for use in future projects.

Datum corrections apply to active gauges only - discontinued gauges could not be surveyed or checked. A small number of non-critical gauges which are located some distance from the survey route were not surveyed and are therefore uncorrected.

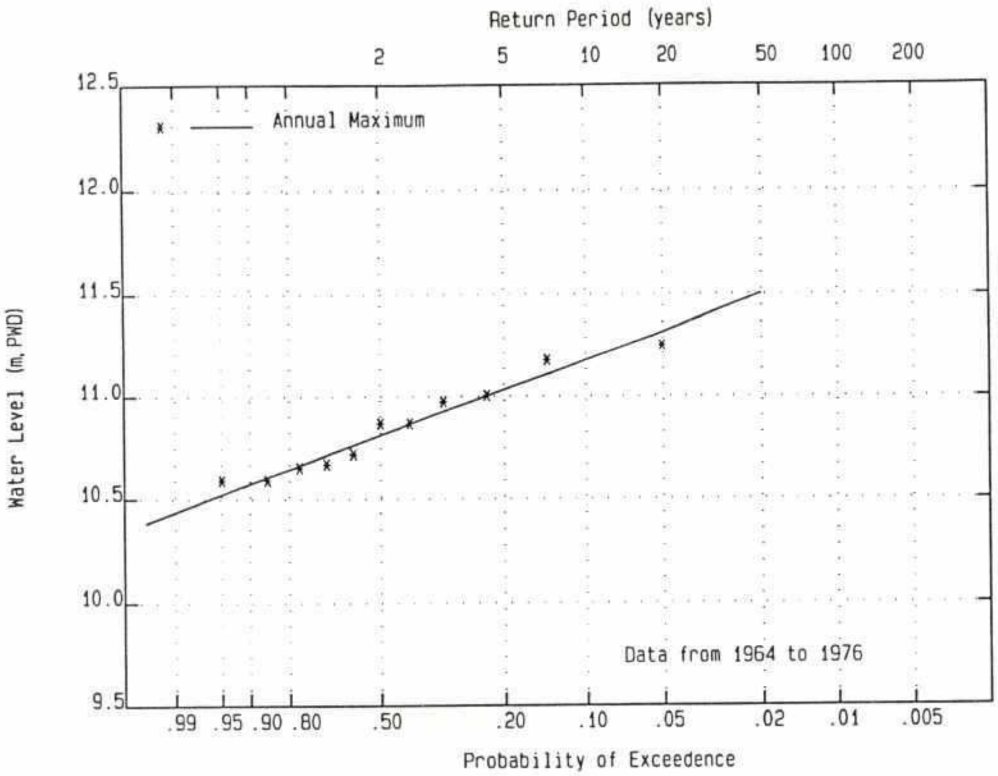
All elevations are relative to PWD datum.



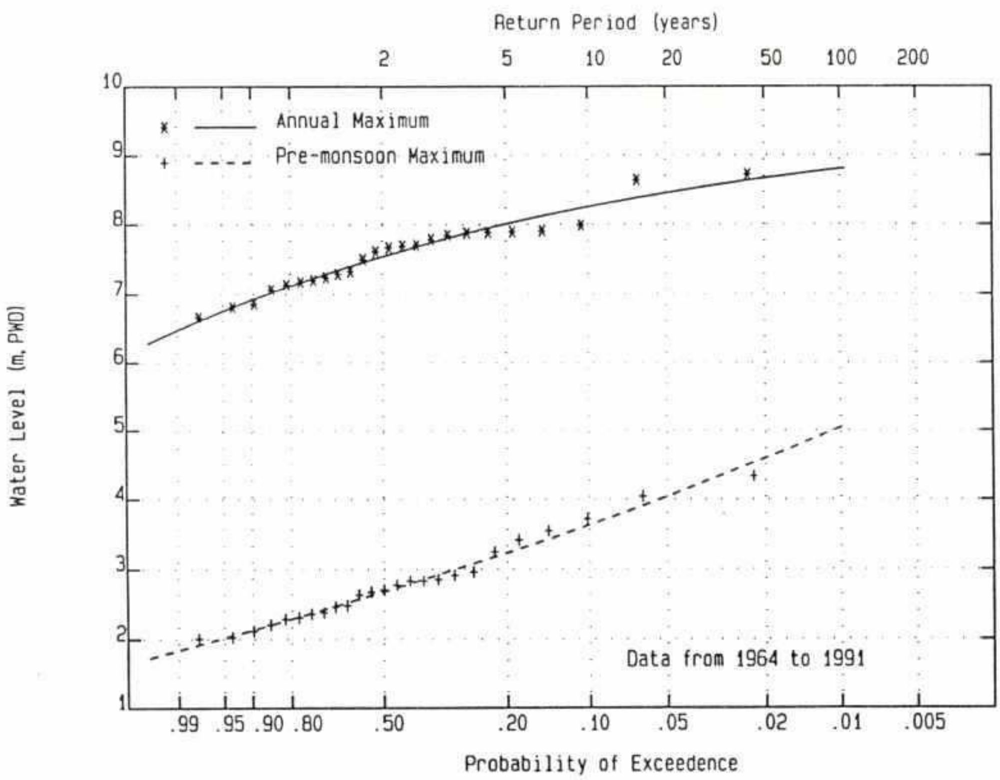
Gauge 3 Anderson khal at Brahamabaria Rly. Bridge
General Extreme Value Distribution



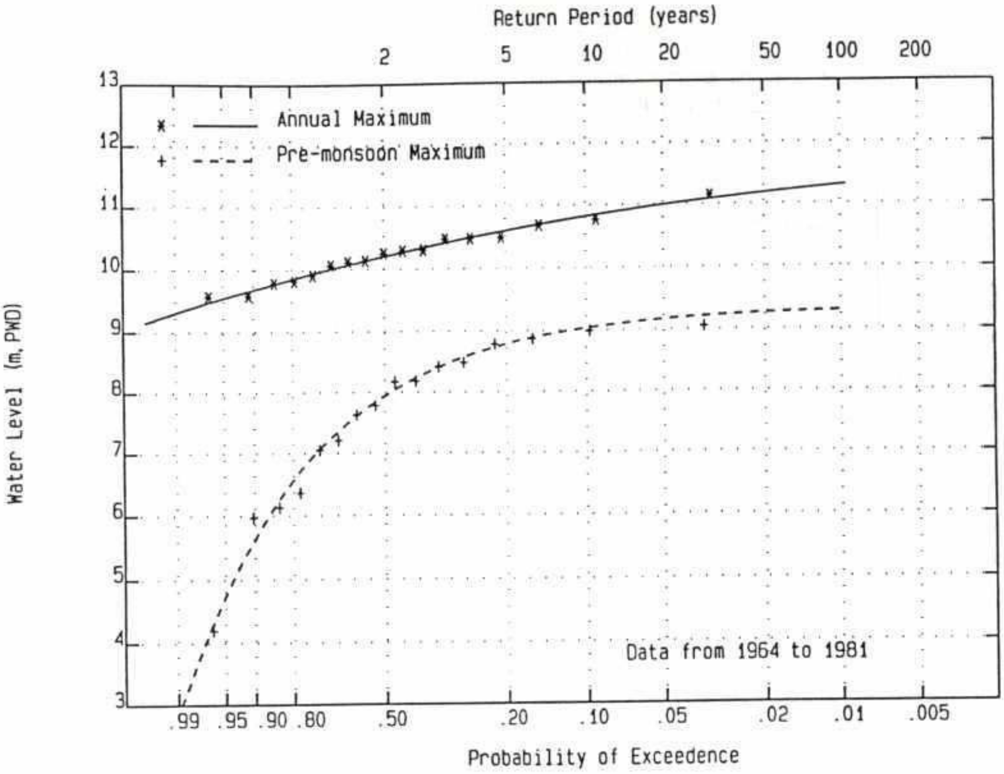
Gauge 3A Anderson khal at Brahamabaria
General Extreme Value Distribution



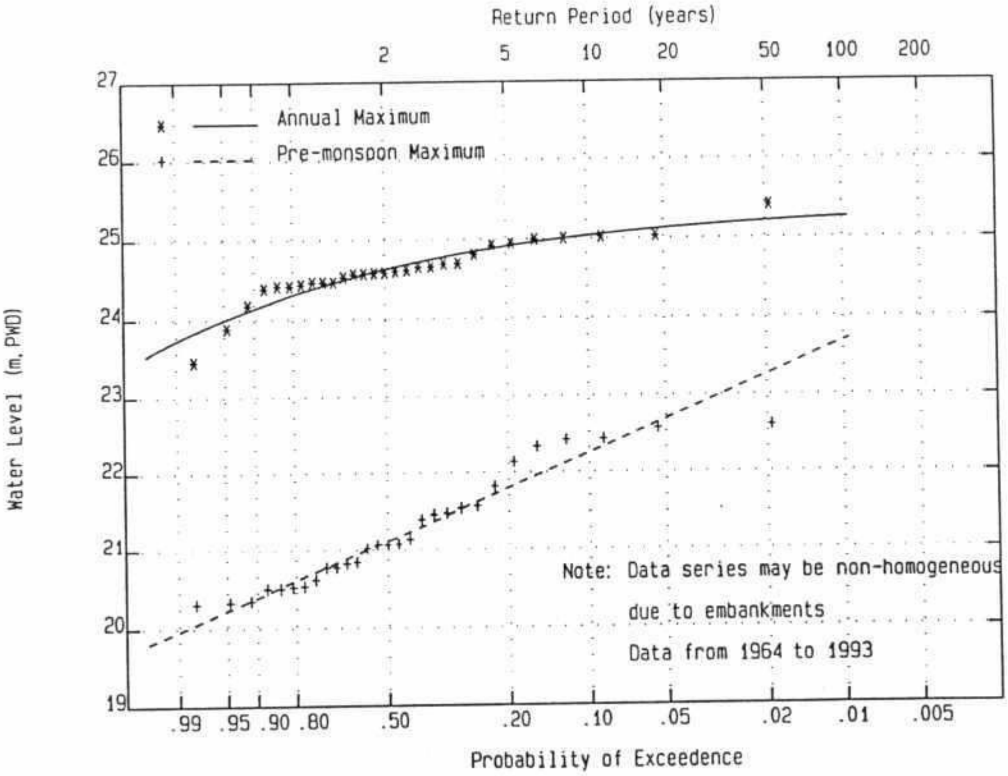
Gauge 6 Bahia River at Surma Offtake
General Extreme Value Distribution



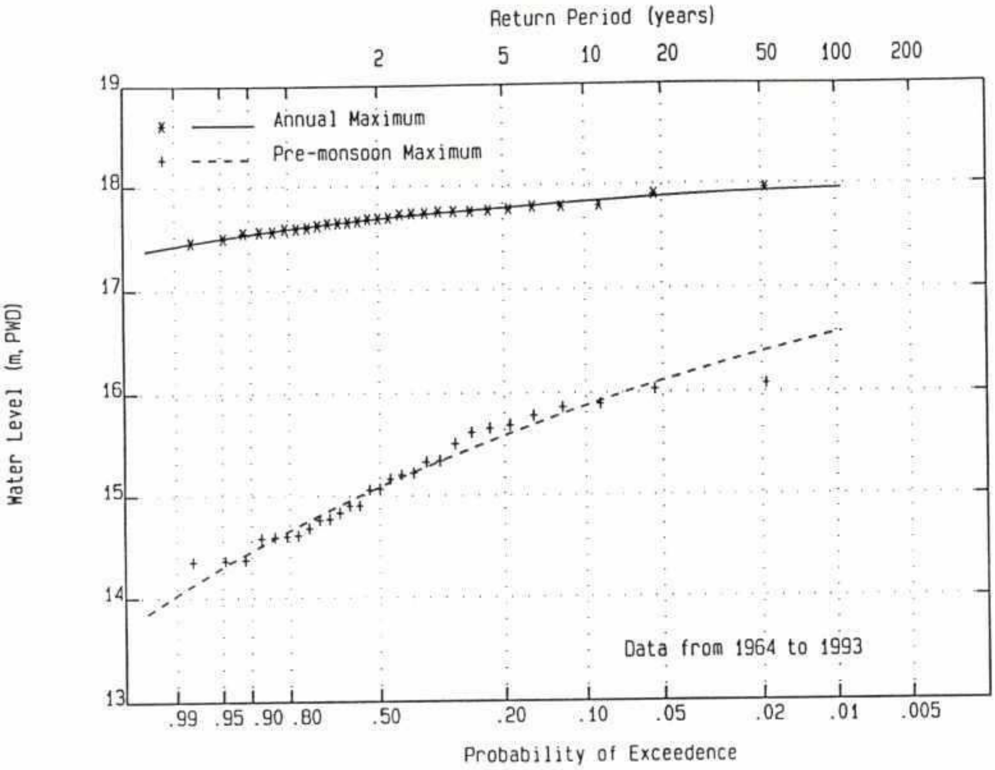
Gauge 9.5 Banar River at Trimohini
General Extreme Value Distribution



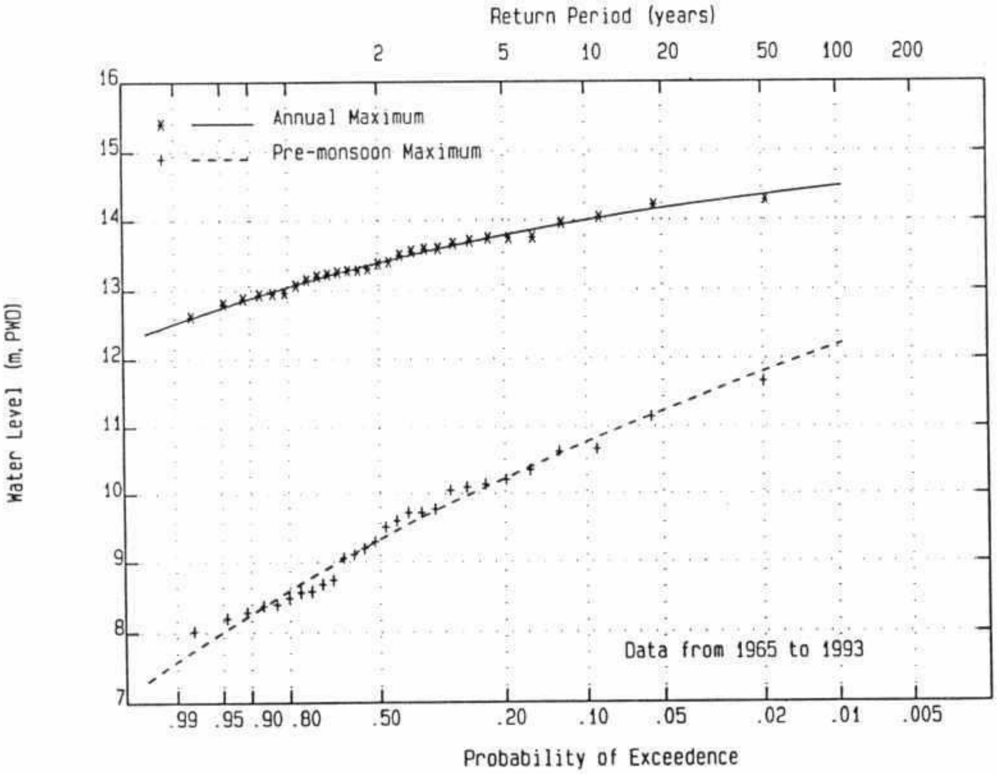
Gauge 33 Bhattakhal at Gobindaganga
General Extreme Value Distribution



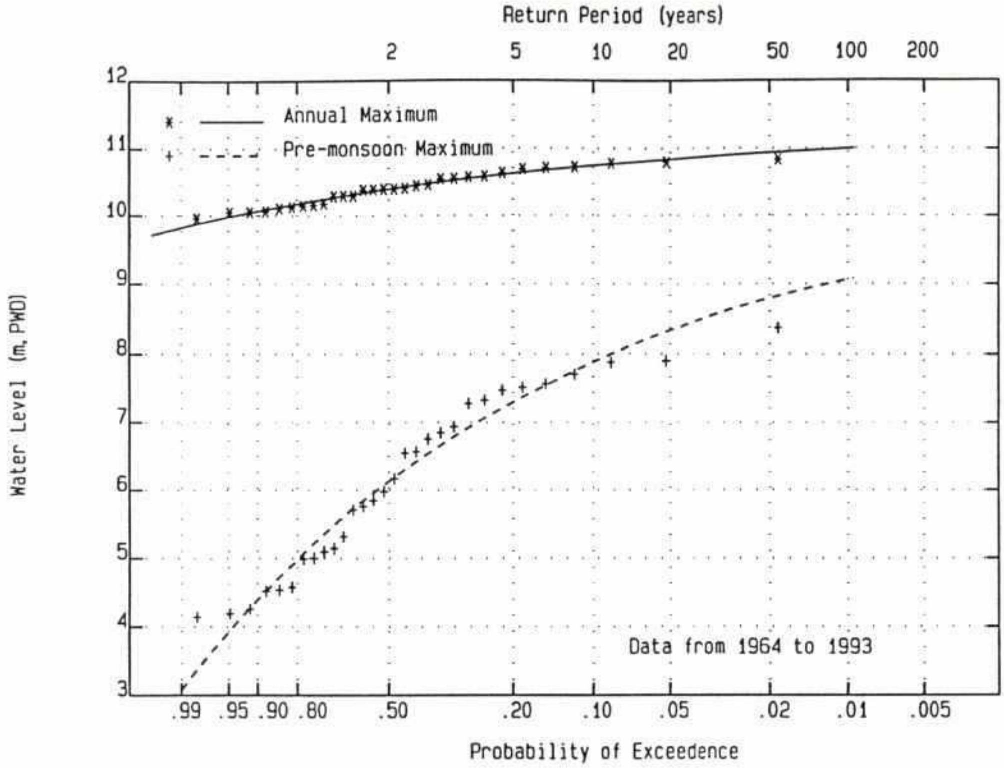
Gauge 34 Bhogai River at Nakuagaon
General Extreme Value Distribution



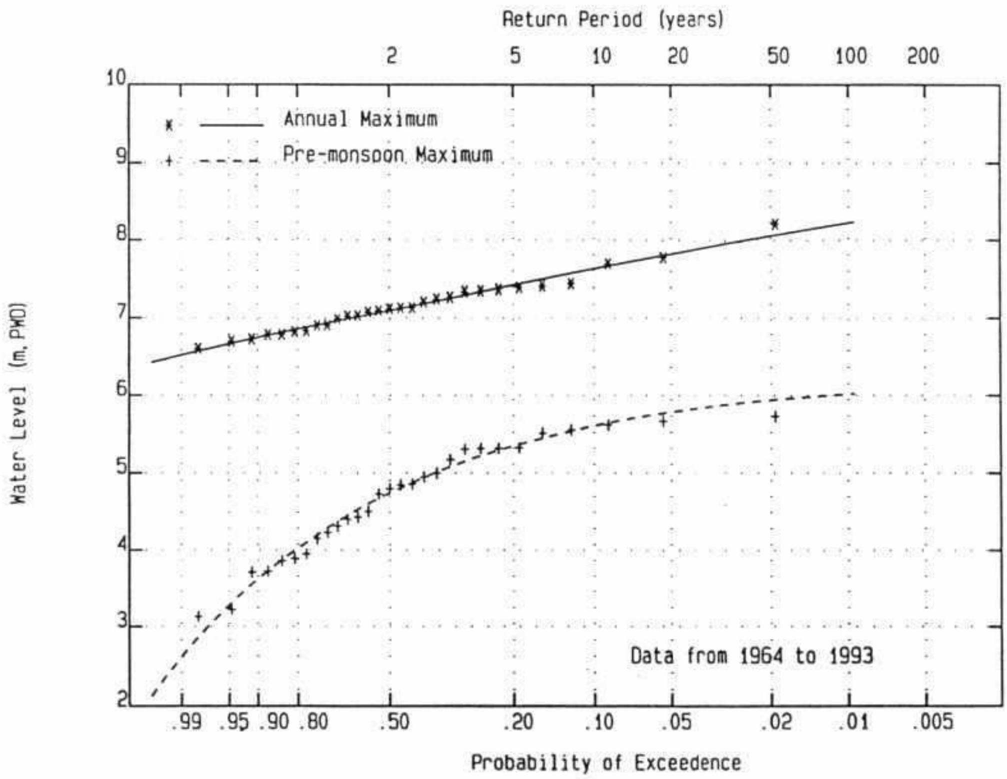
Gauge 35 Bhogai River at Nalitabari
General Extreme Value Distribution



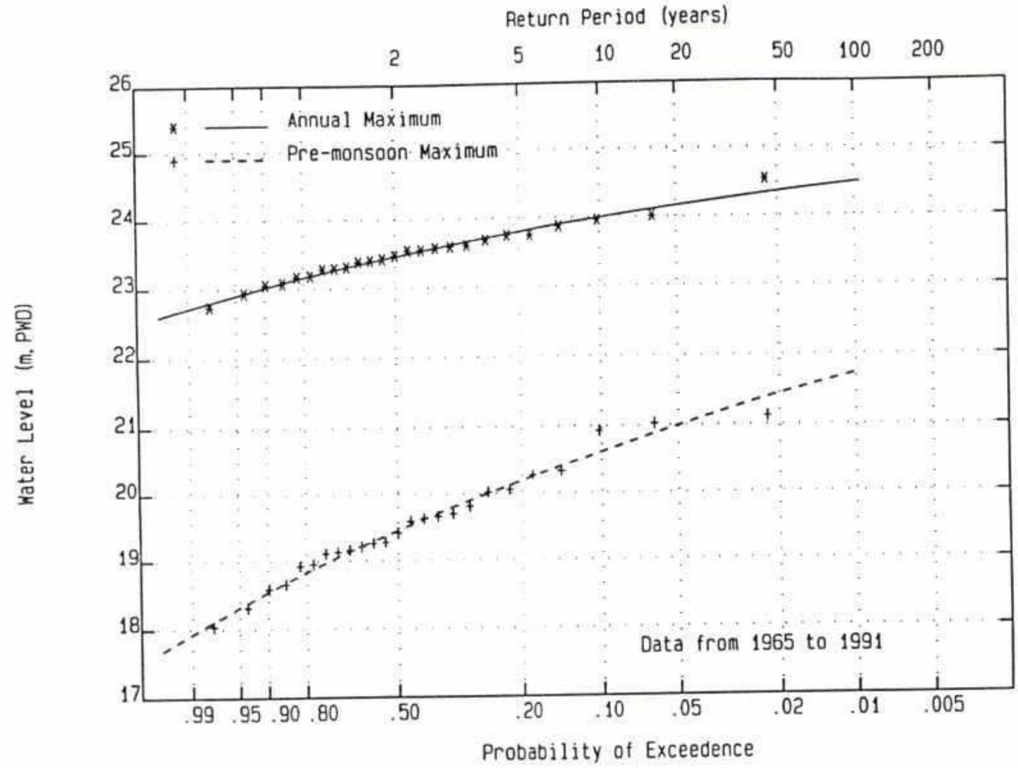
Gauge 35.5 Kangsha River at Sarchapur
General Extreme Value Distribution



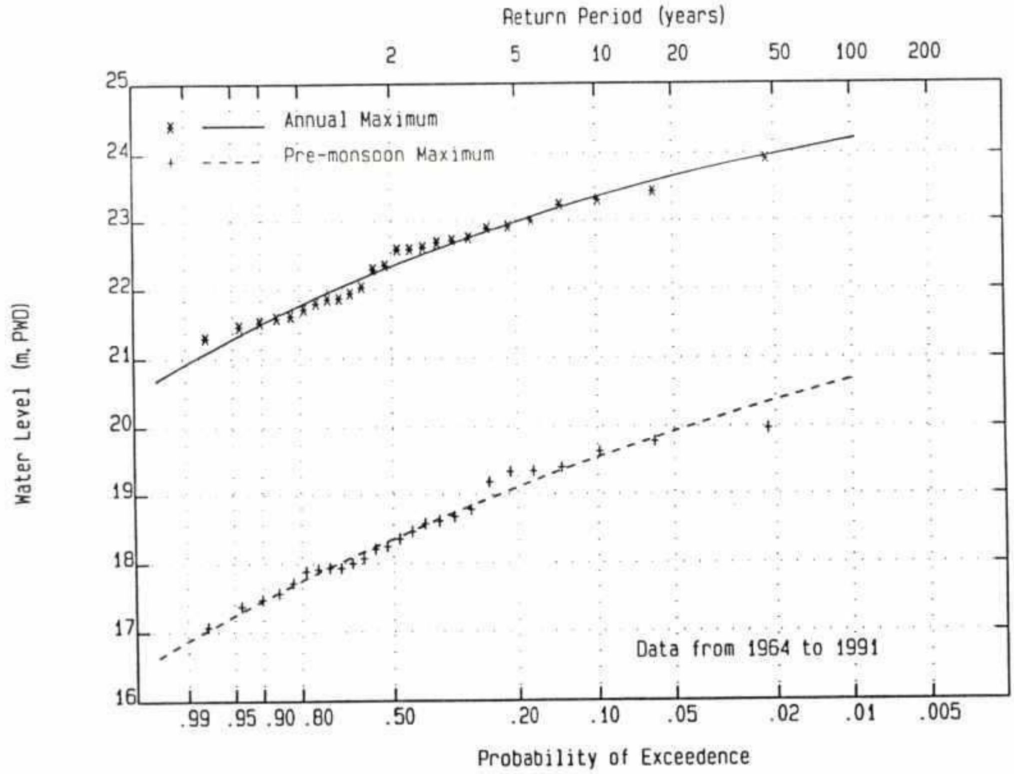
Gauge 36 Kangsha River at Jaria Jhanjail
General Extreme Value Distribution



Gauge 36.1 Kangsha River at Mohanganj
General Extreme Value Distribution

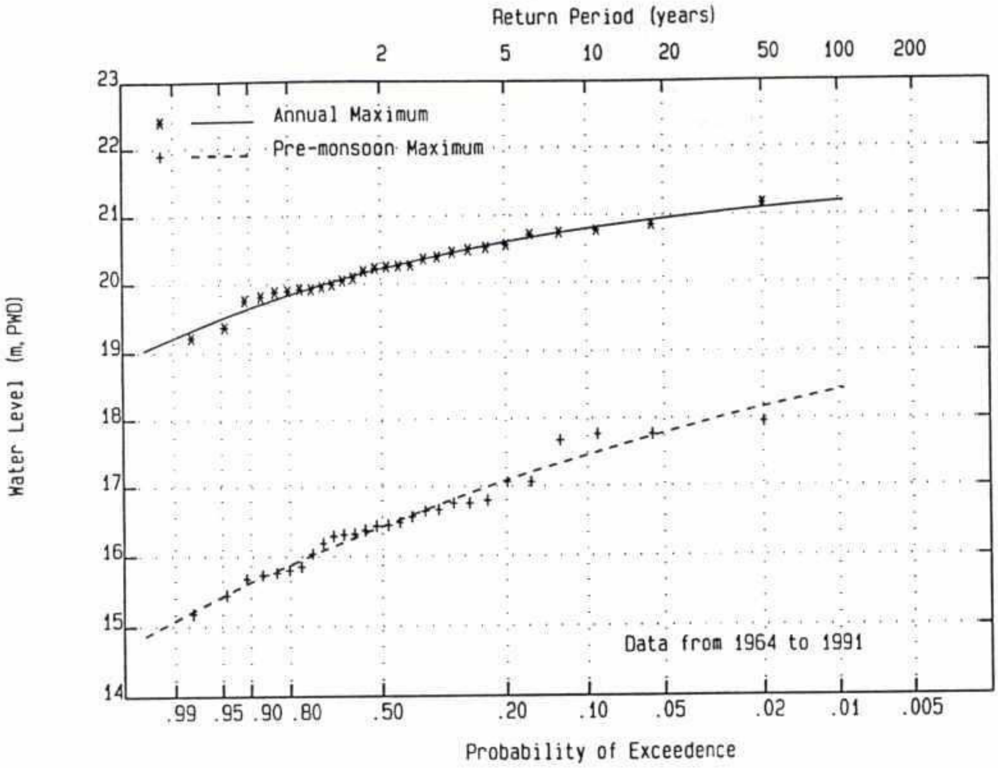


Gauge 45.5 Brahmaputra River at Chilmari
General Extreme Value Distribution

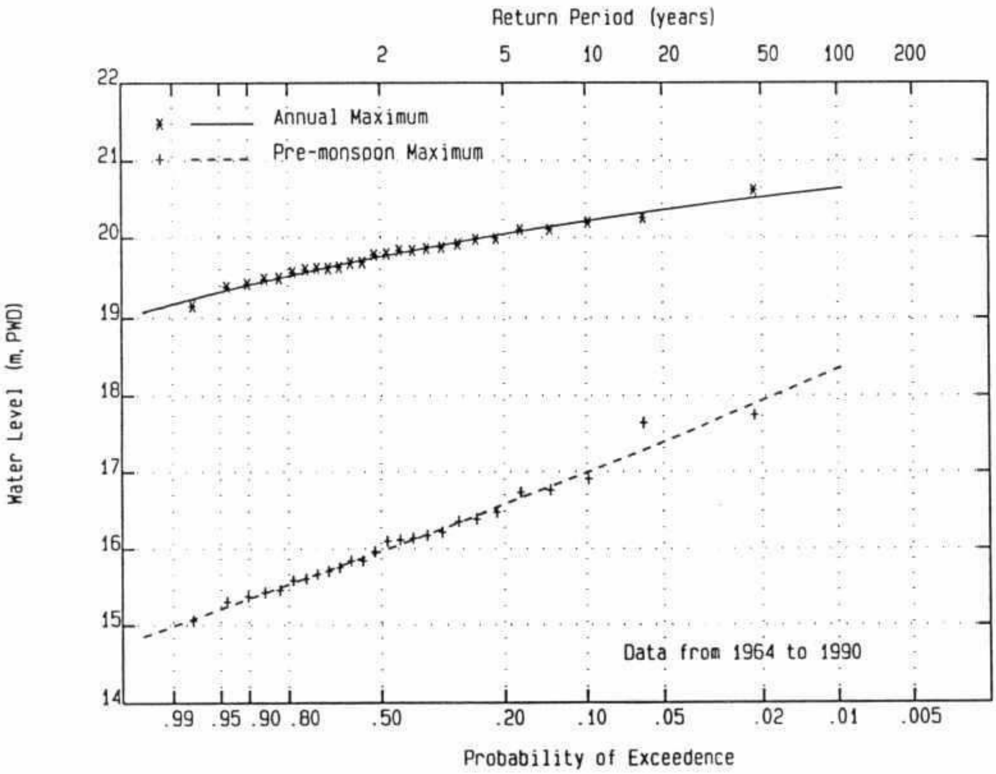


Gauge 46 Brahmaputra River at Kamarjani
General Extreme Value Distribution

394

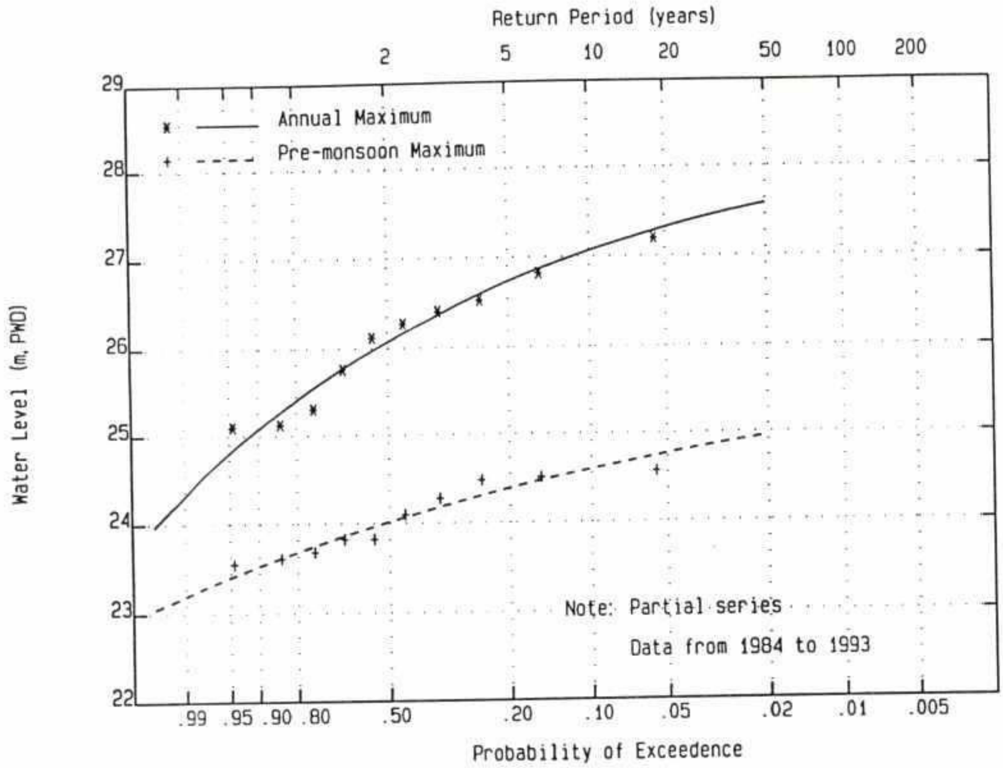


Gauge 46.7 L Brahmaputra River at Kholabarichar
General Extreme Value Distribution

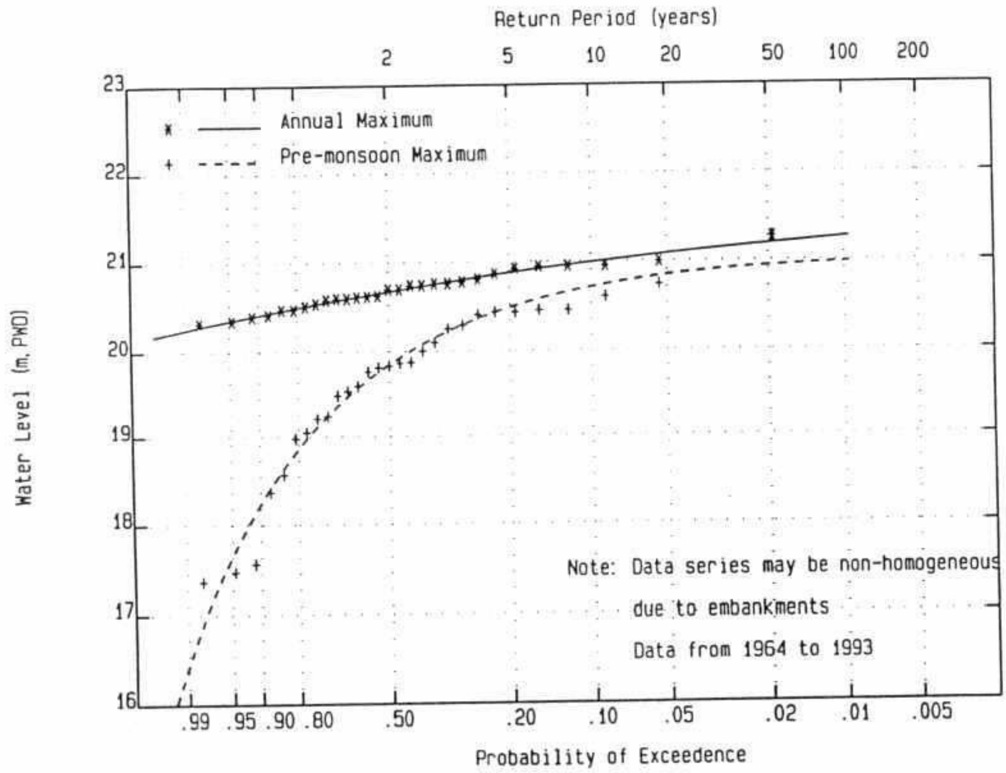


Gauge 46.9 L Brahmaputra River at Bahadurabad
General Extreme Value Distribution

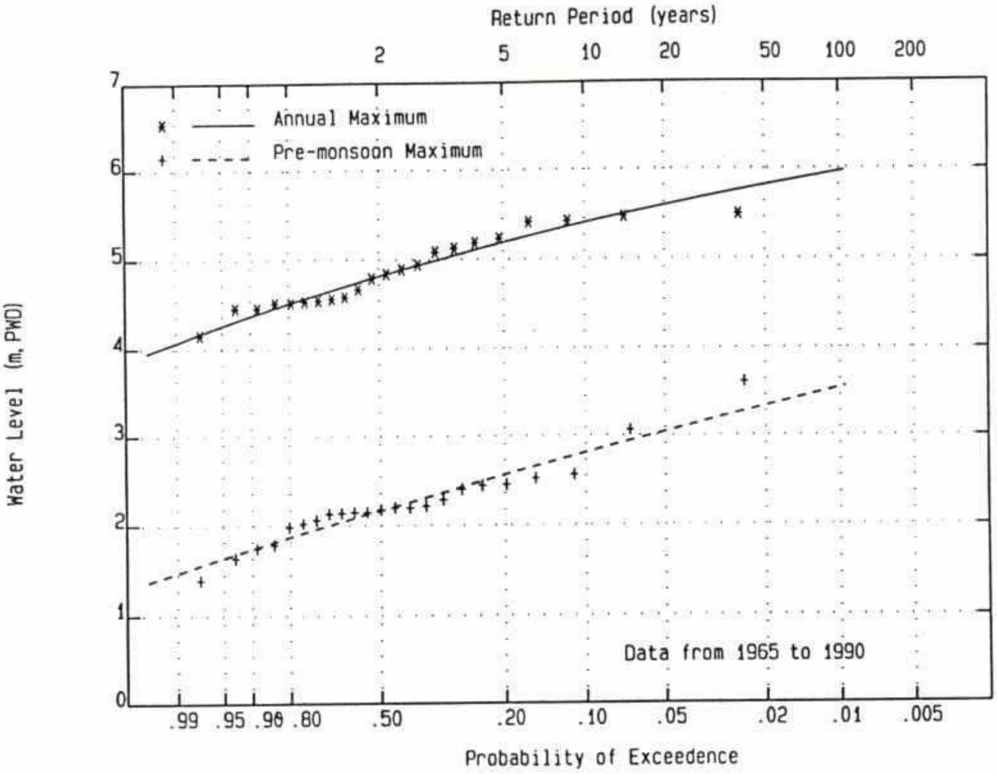
397



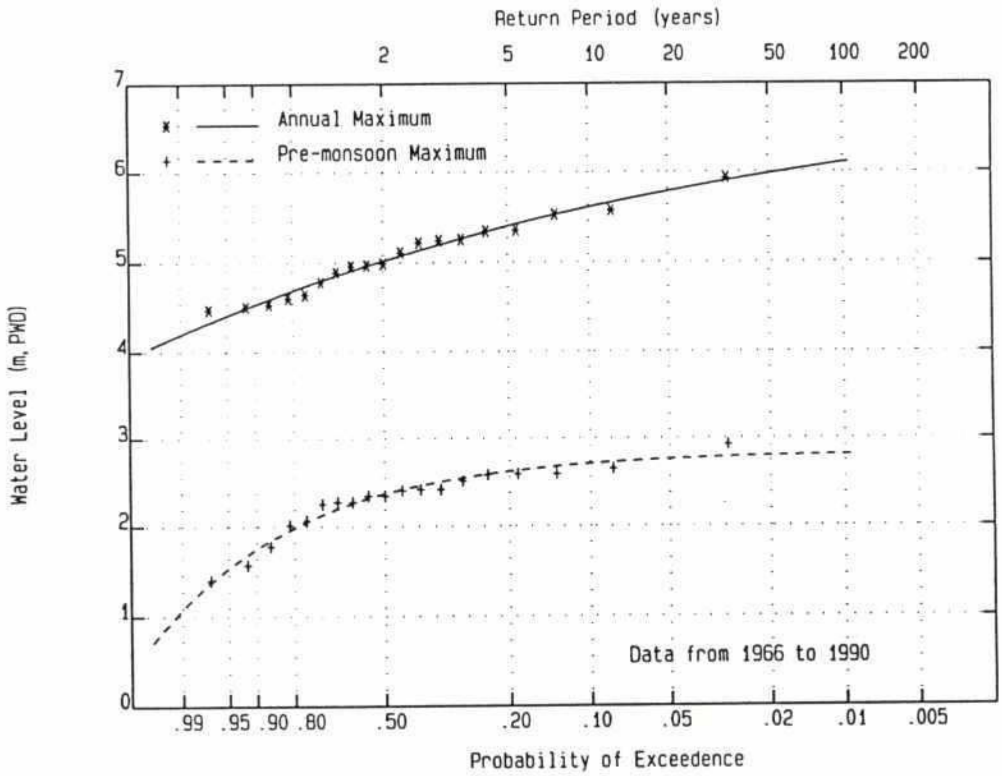
Gauge 53(A) Chelakhali River at Bathkuchi
General Extreme Value Distribution



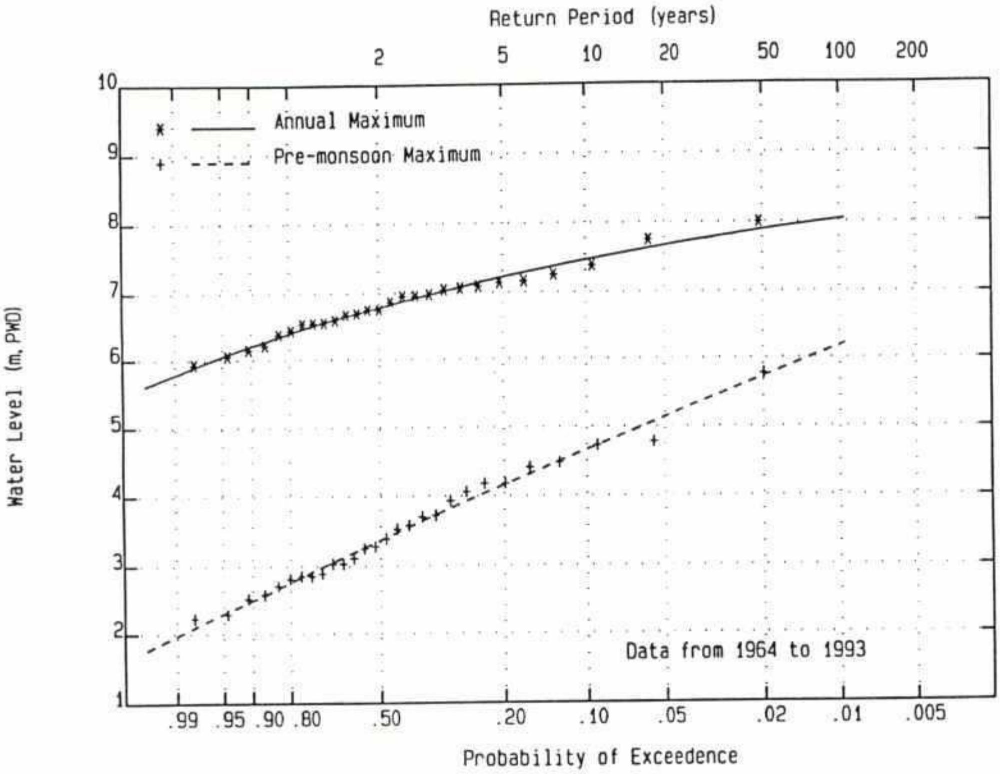
Gauge 67 Dhalai River at Kamalganj
General Extreme Value Distribution



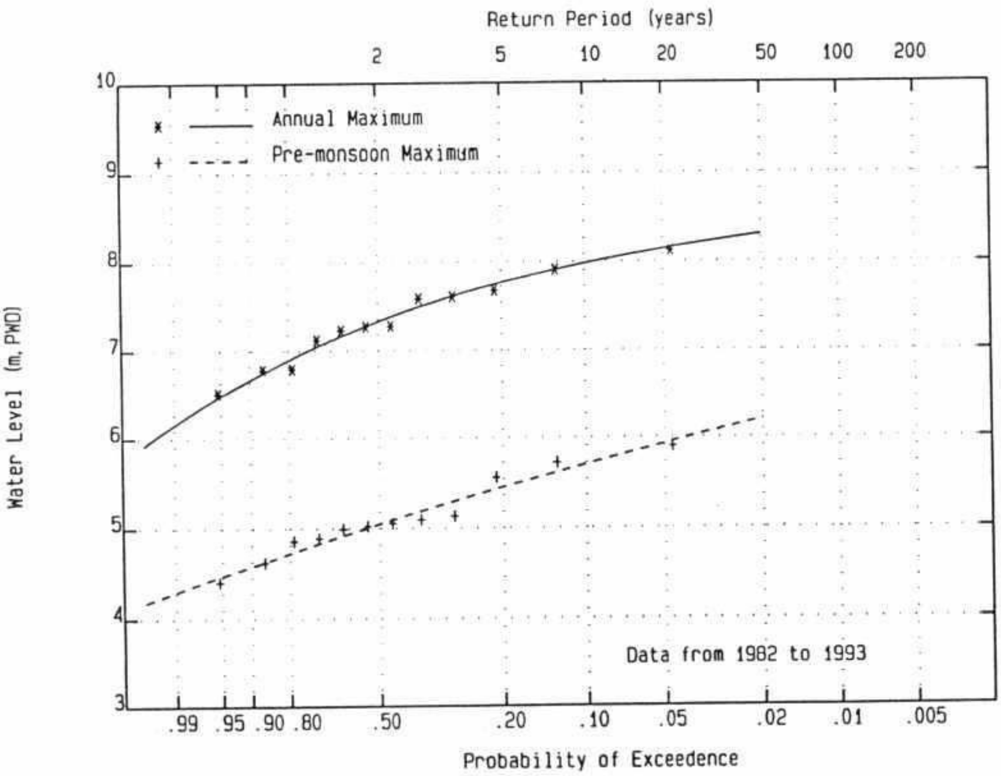
Gauge 71 Dhaleswari River at Kalagachia
General Extreme Value Distribution



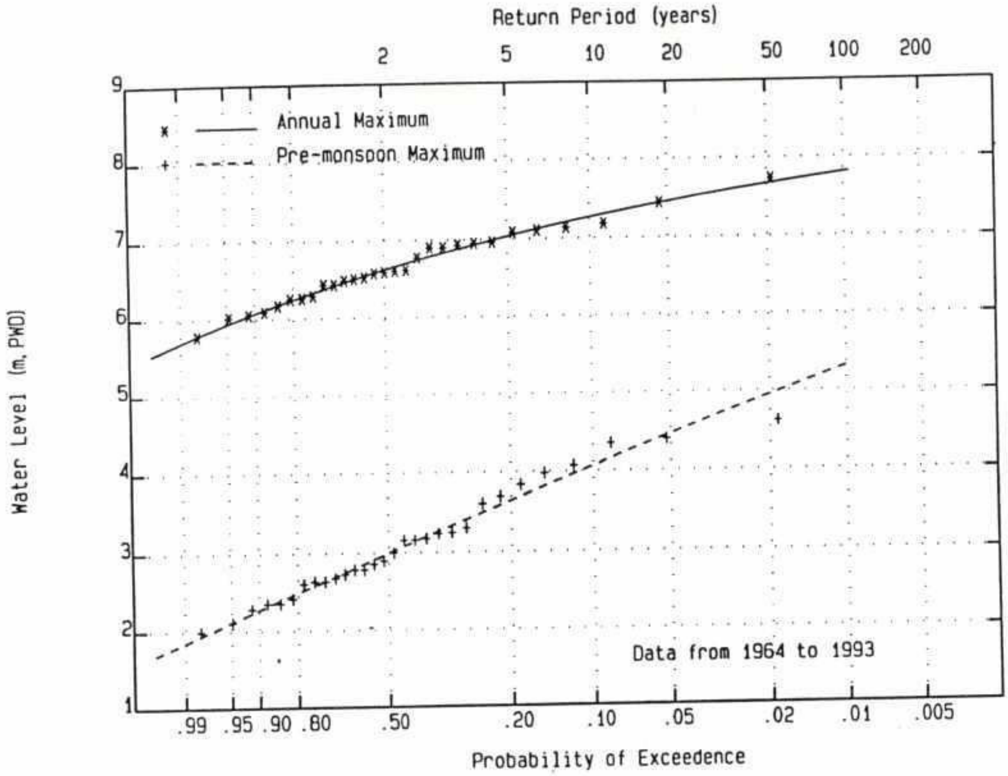
Gauge 71A Dhaleswari River at Rekabi Bazar
General Extreme Value Distribution



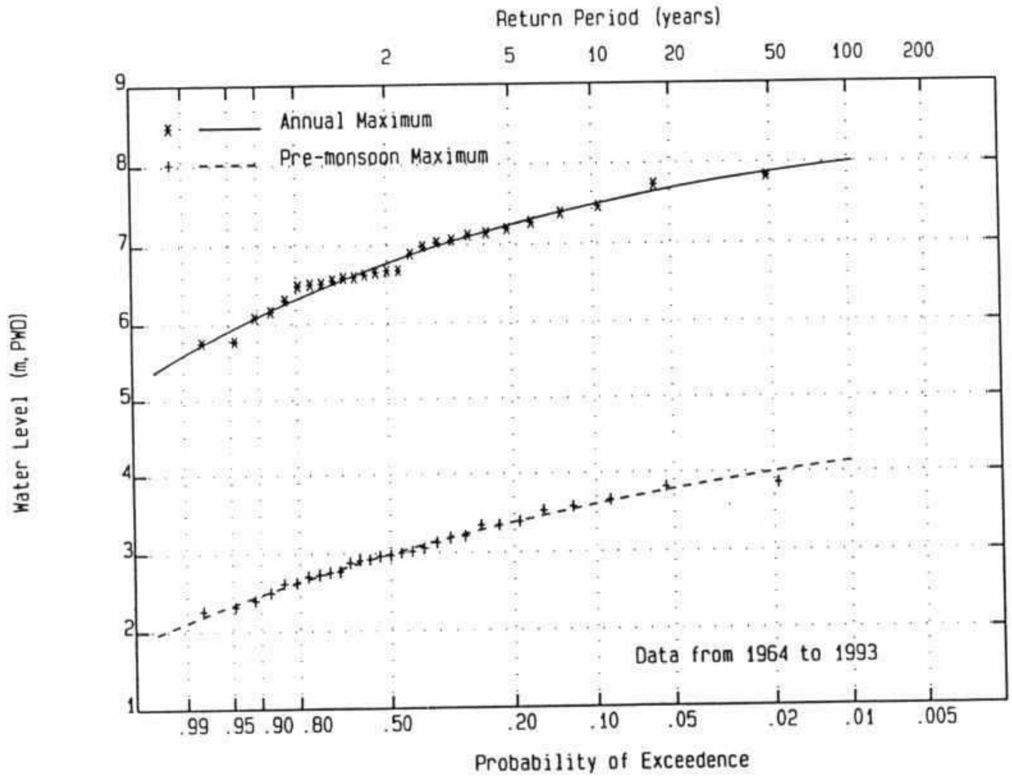
Gauge 72 Baulai River at Kaliajuri
General Extreme Value Distribution



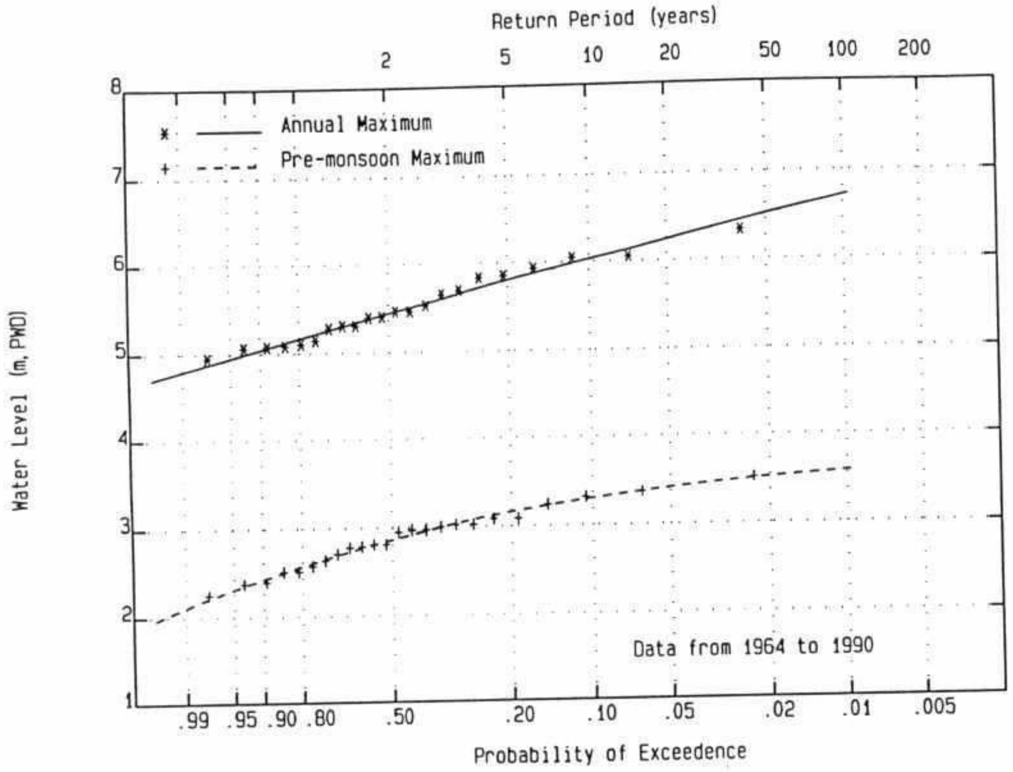
Gauge 72B Baulai River at Sukdebpur
General Extreme Value Distribution



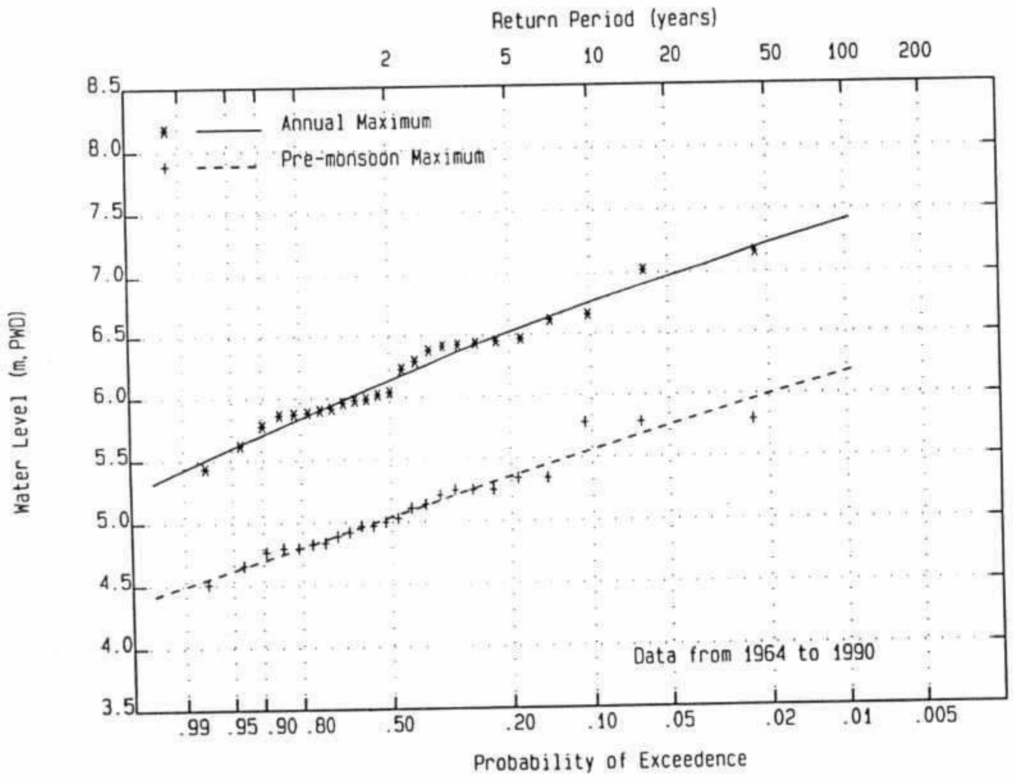
Gauge 73 Baulai River at Itna
General Extreme Value Distribution



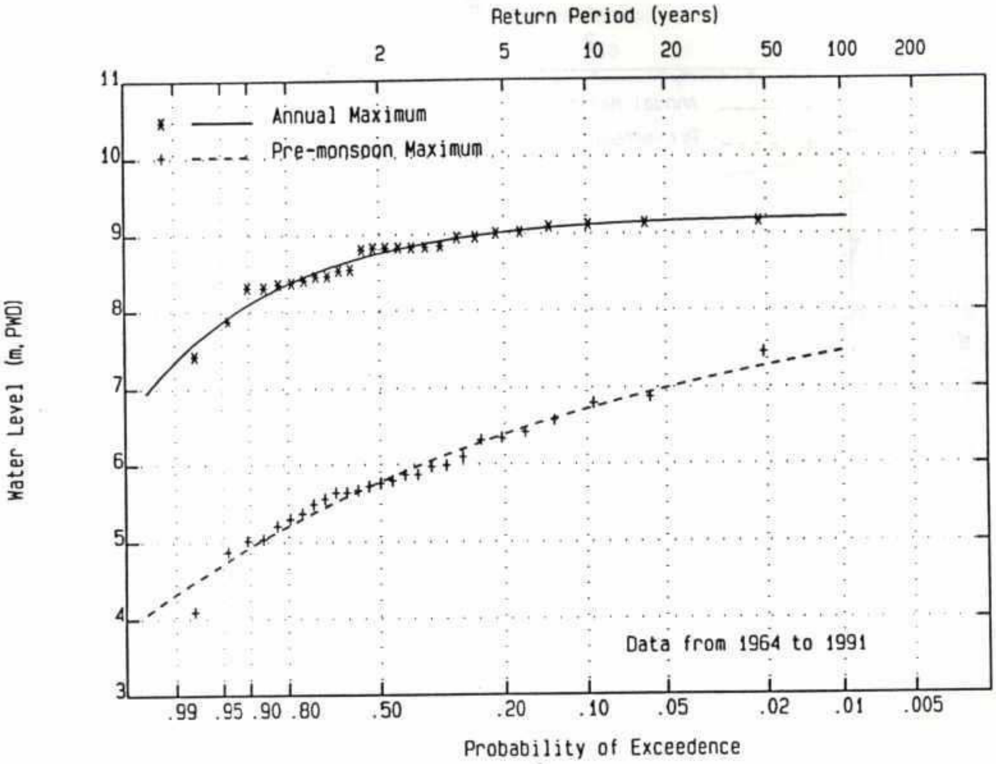
Gauge 74 Ghorautra River at Dilalpur
General Extreme Value Distribution



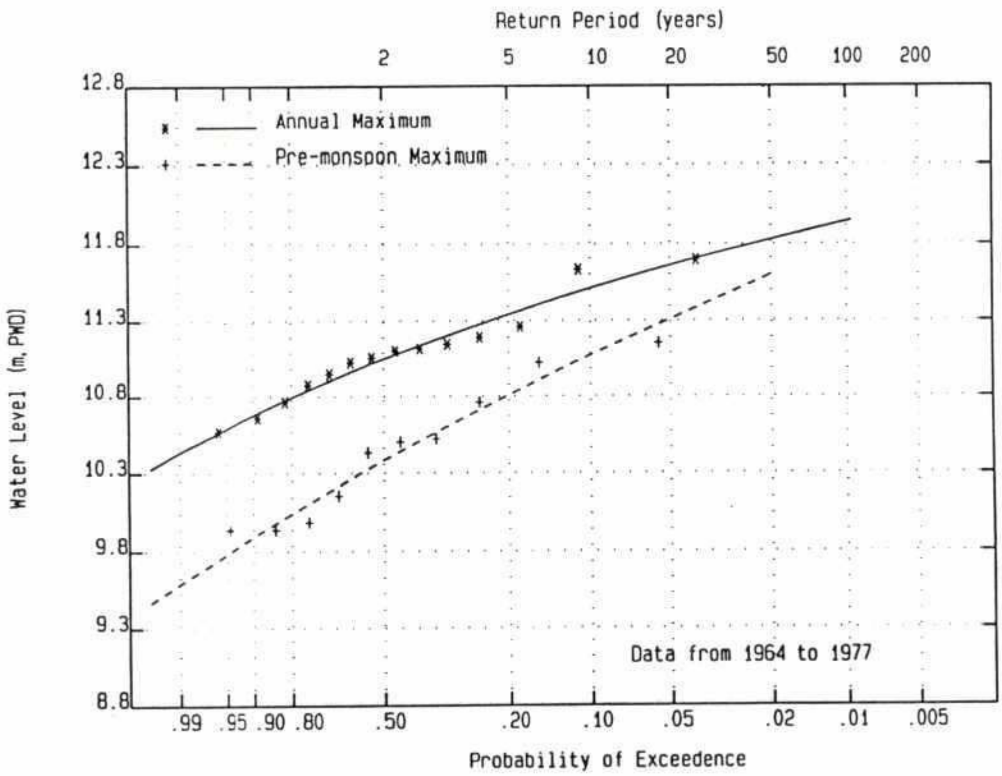
Gauge 115 Gumti River at Daudkandi
General Extreme Value Distribution



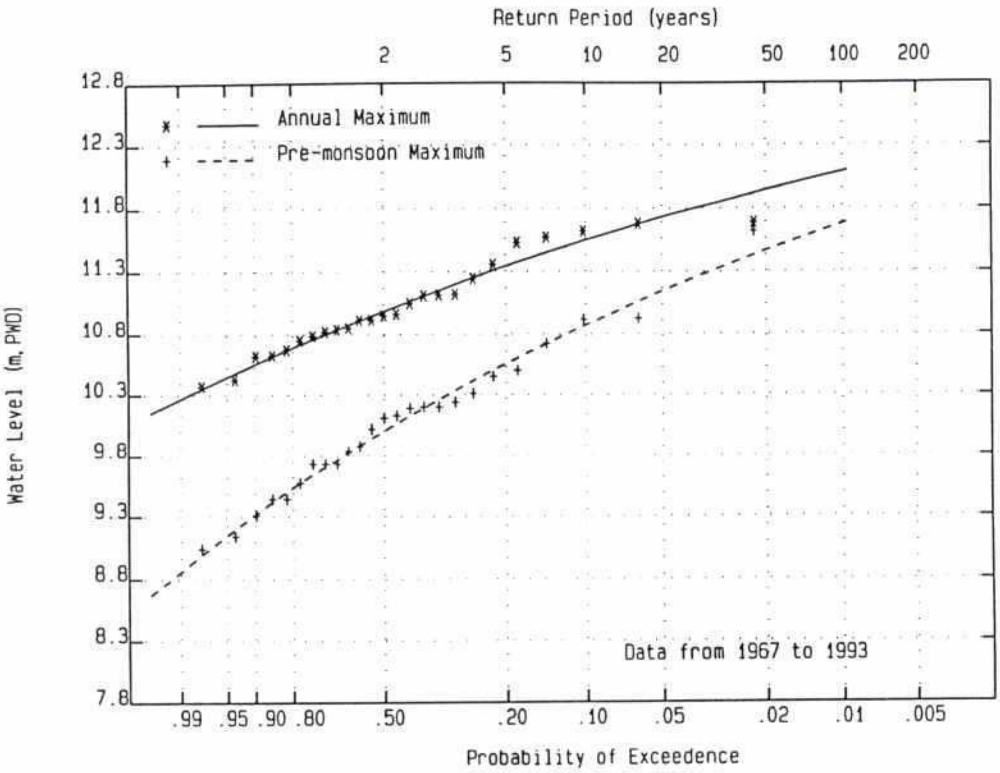
Gauge 123 Hawrah River at Gangasagar Rly. Bridge
General Extreme Value Distribution



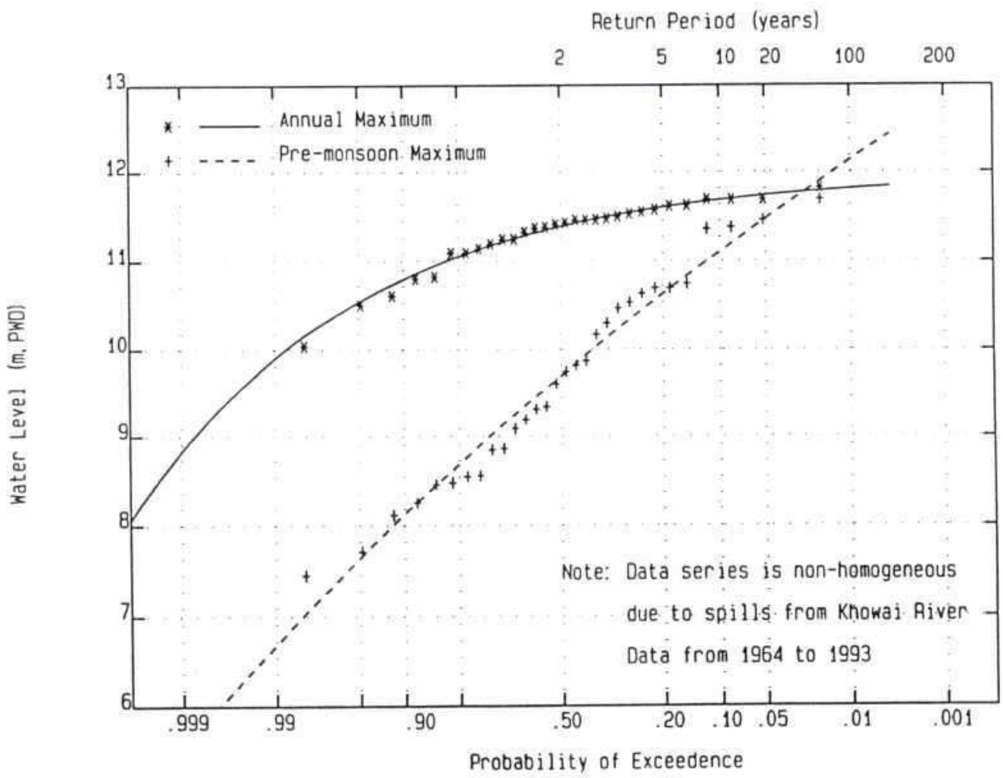
Gauge 131 Jadukata River at Saktiarkhola
General Extreme Value Distribution



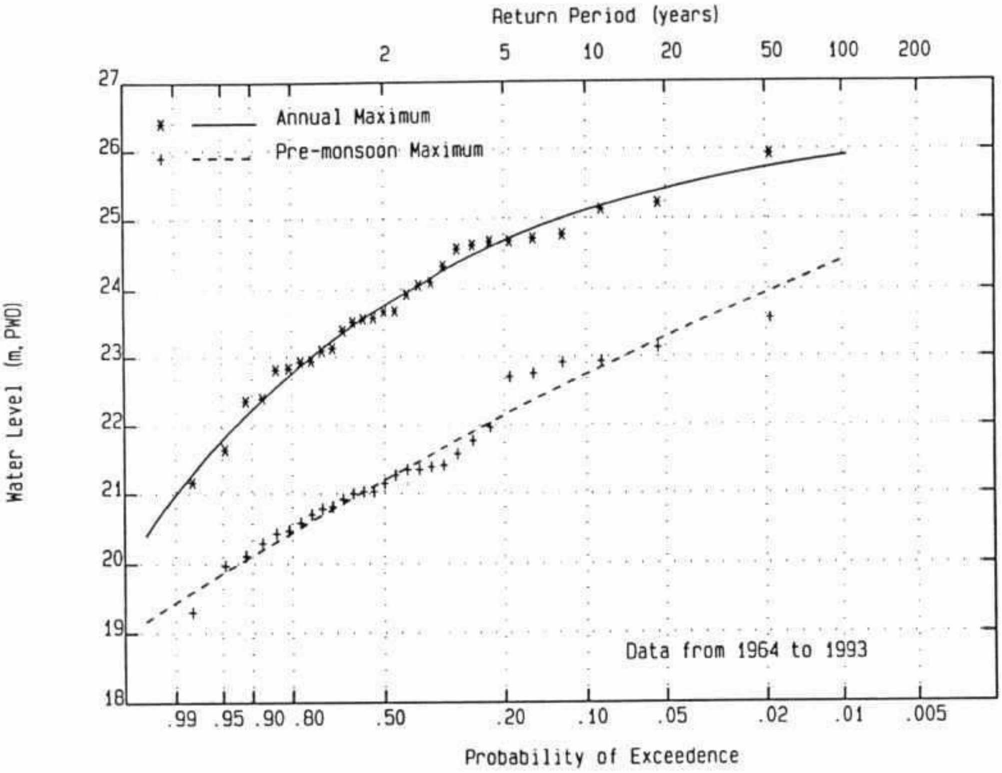
Gauge 135 Juri River (Juri Branch) at Continala
General Extreme Value Distribution



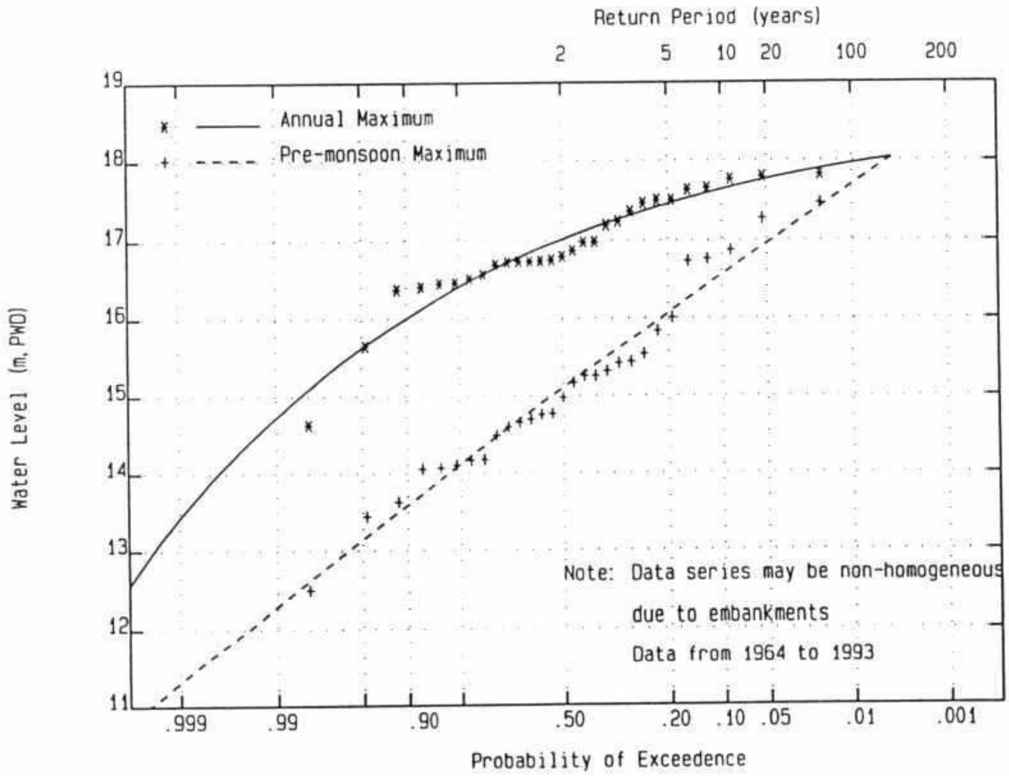
Gauge 135A Juri River (Continala Branch) at Continala
General Extreme Value Distribution



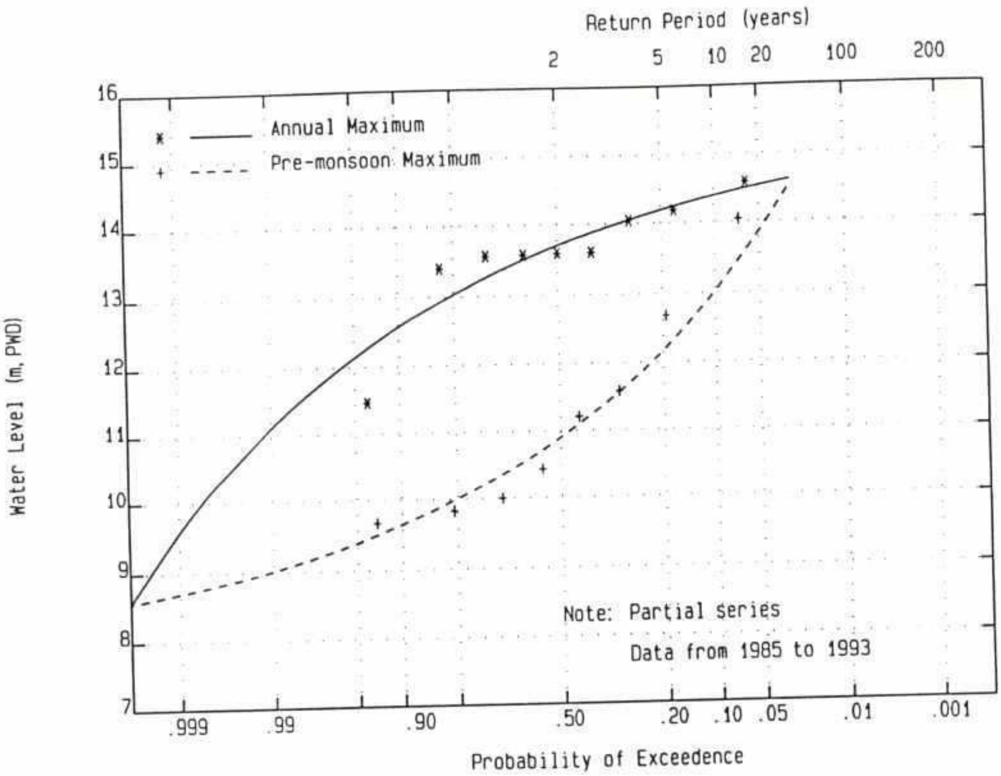
Gauge 138 Karangi River at Sofiabad
3-Parameter Log Normal Distribution



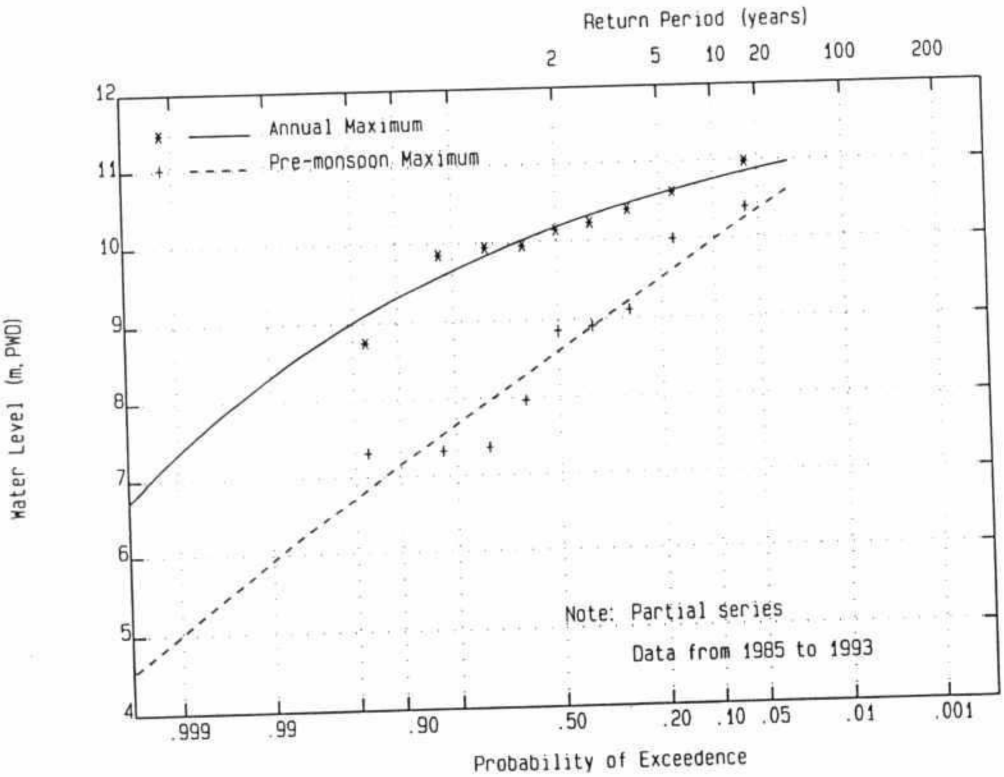
Gauge 157 Khowai River at Ballah
General Extreme Value Distribution



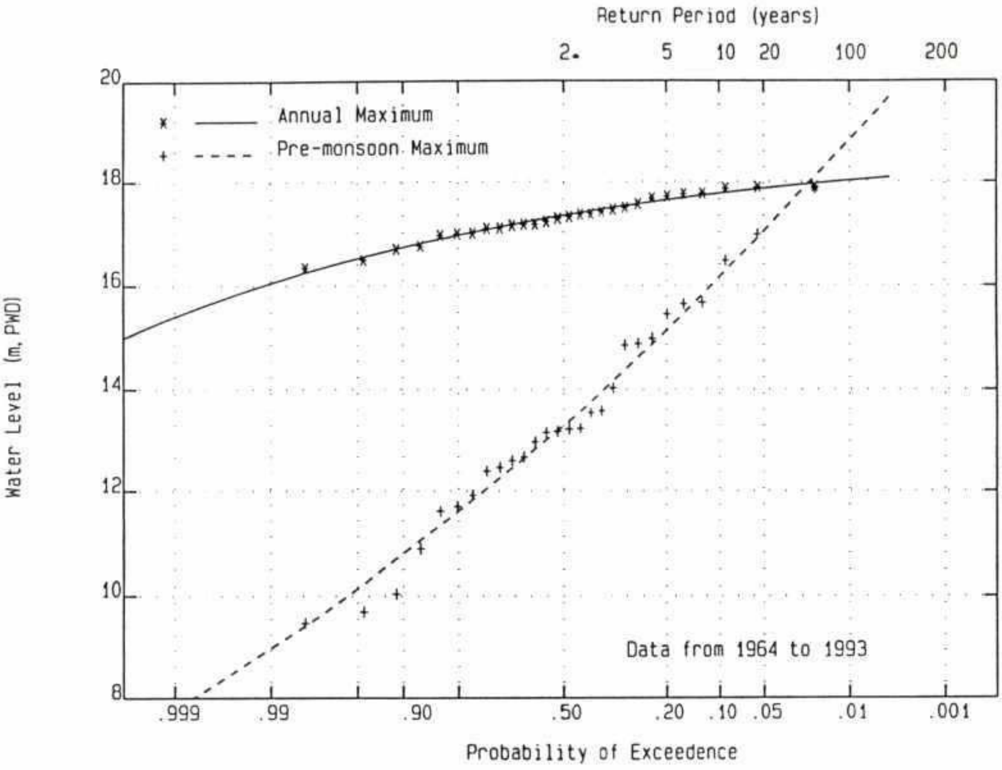
Gauge 158 Khowai River at Chunarghat
3-Parameter Log Normal Distribution



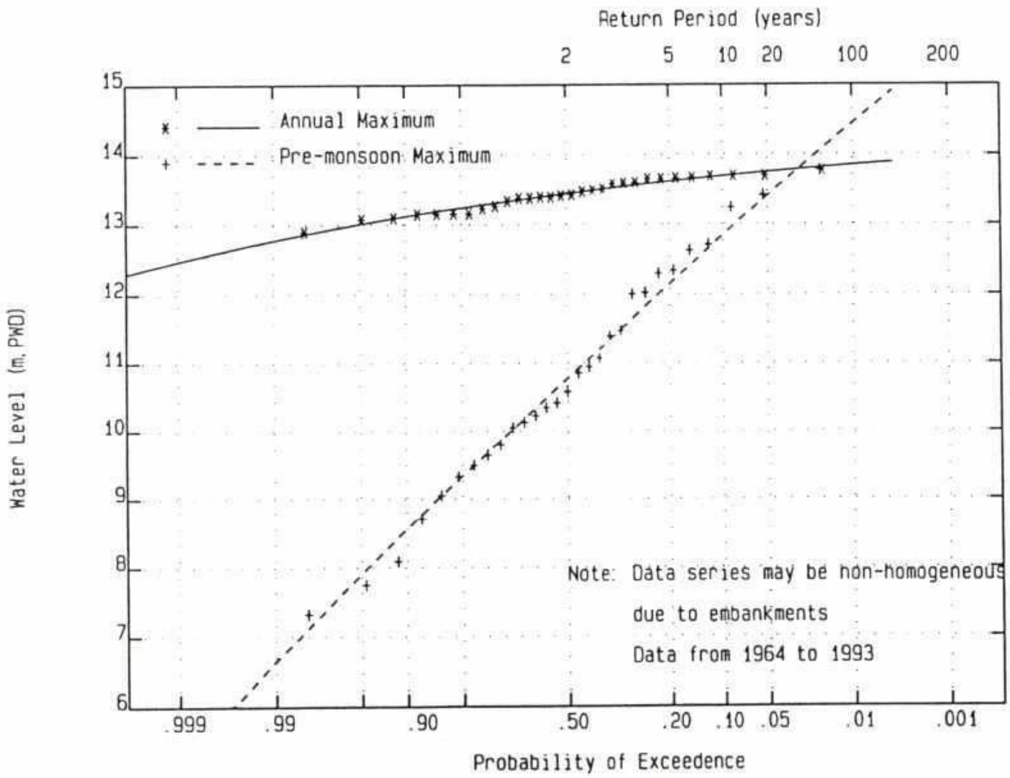
Gauge 158.1(R) Khowai River at Shaistaganj
3-Parameter Log Normal Distribution



Gauge 159(R) Khowai River at Habiganj
3-Parameter Log Normal Distribution

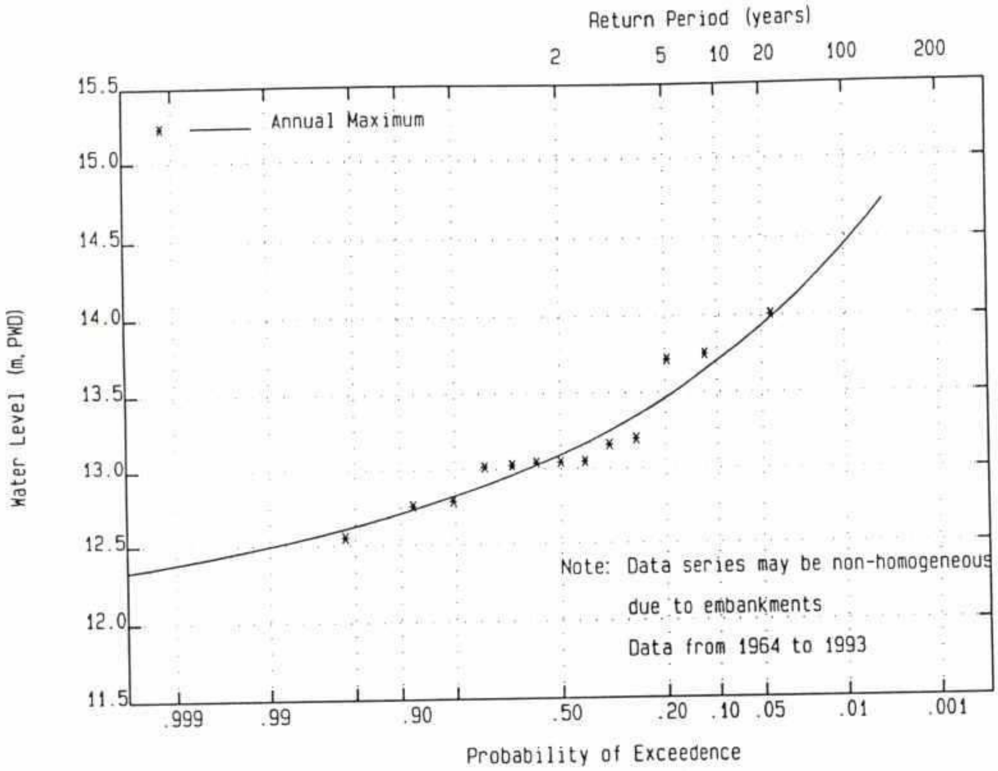


Gauge 172 Kushiyara River at Amalshid
3-Parameter Log Normal Distribution

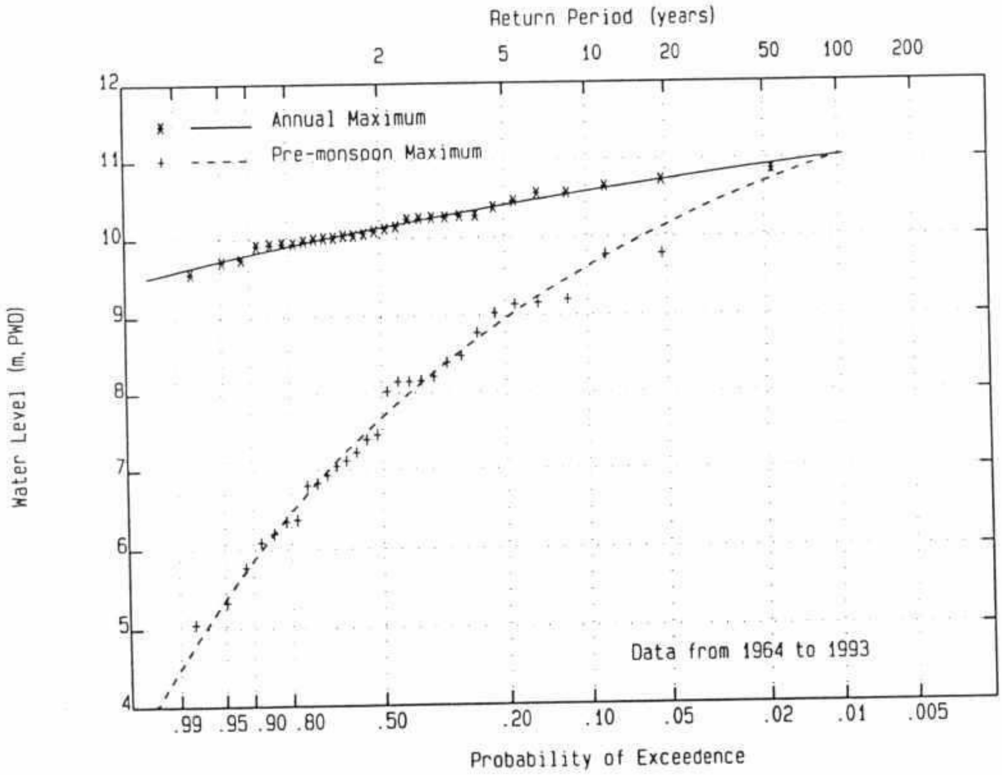


Gauge 173 Kushiyara River at Sheola
3-Parameter Log Normal Distribution

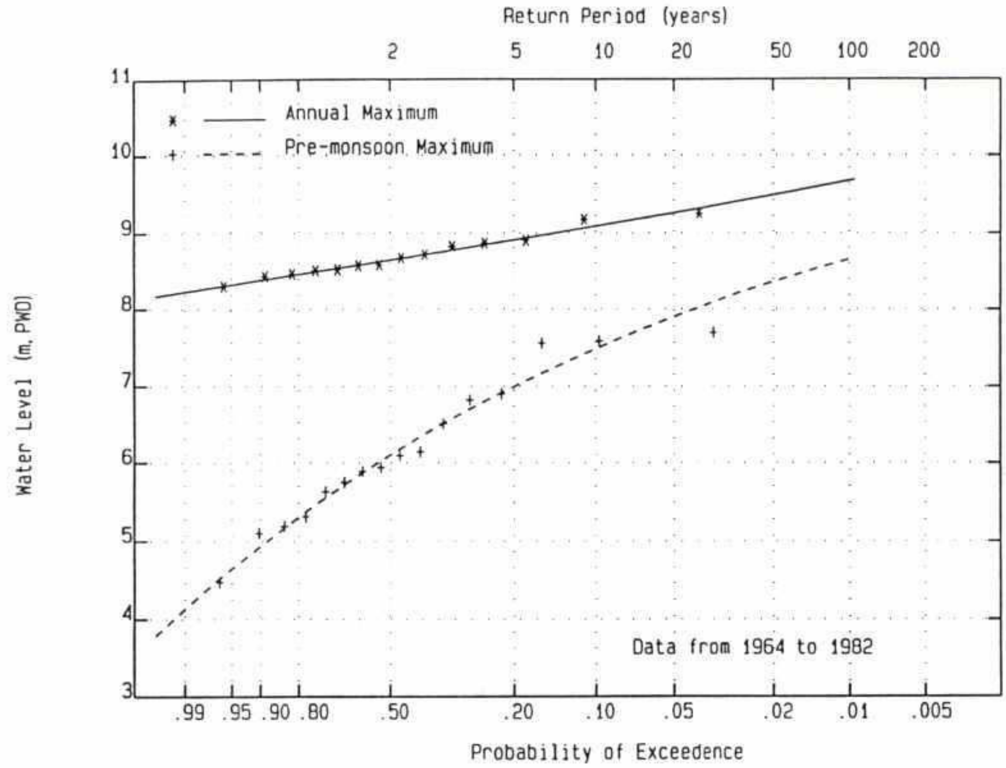
269



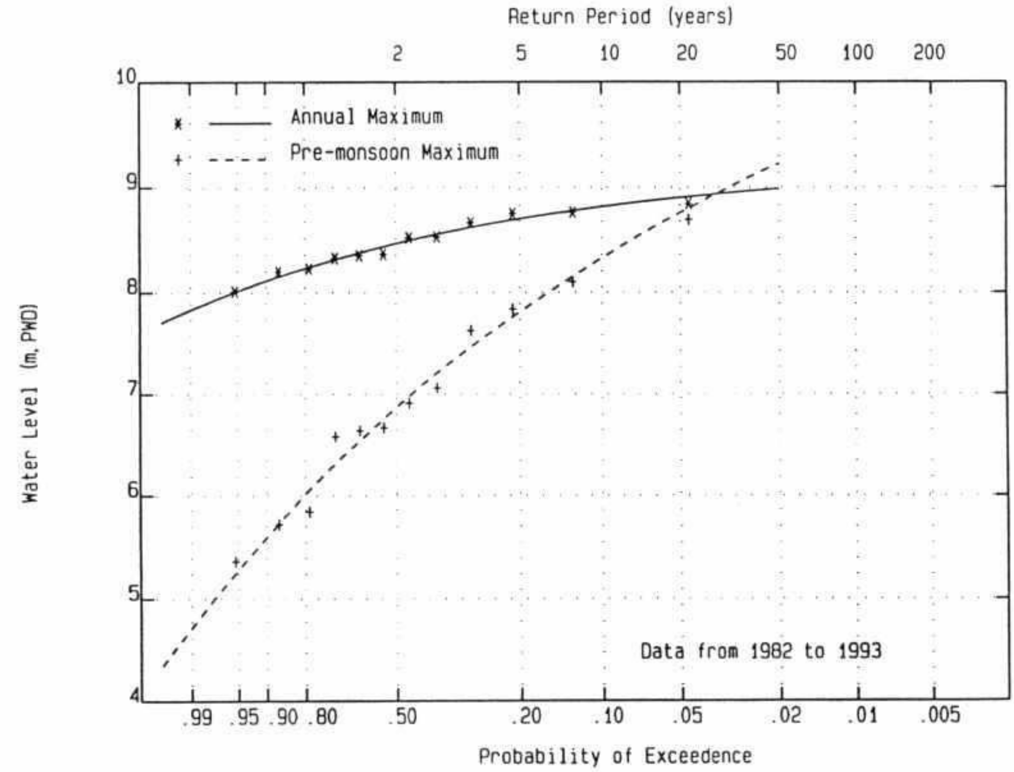
Gauge 173A Sada Khal at Sheola
3-Parameter Log Normal Distribution



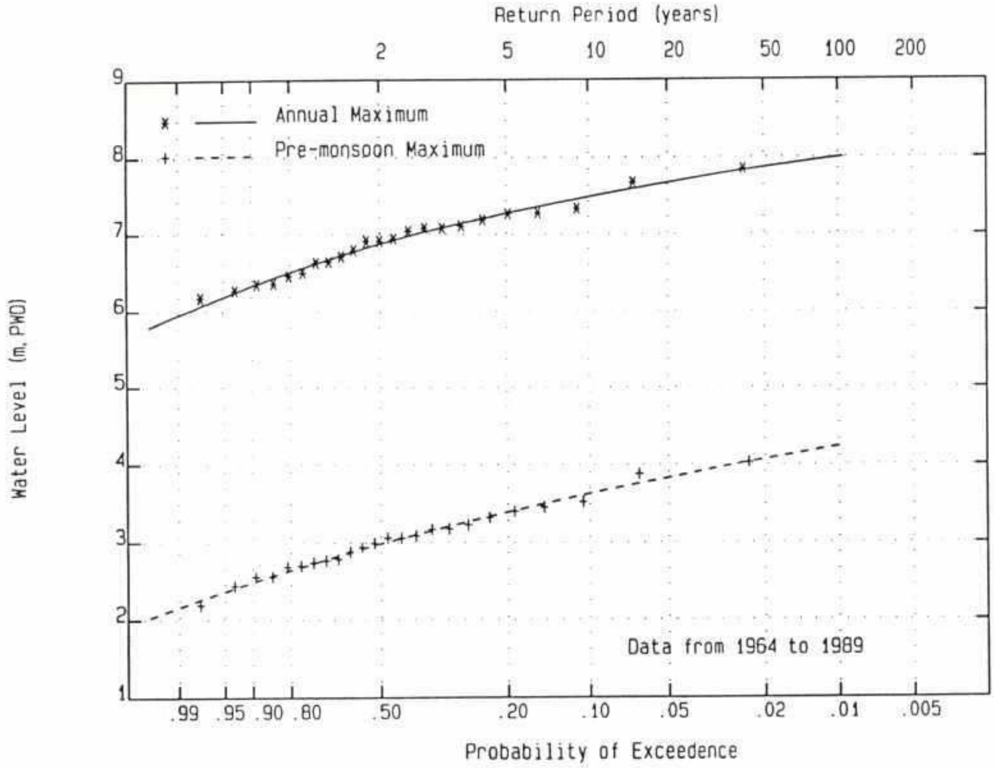
Gauge 174 Kushiyara River at Fenchuganj
General Extreme Value Distribution



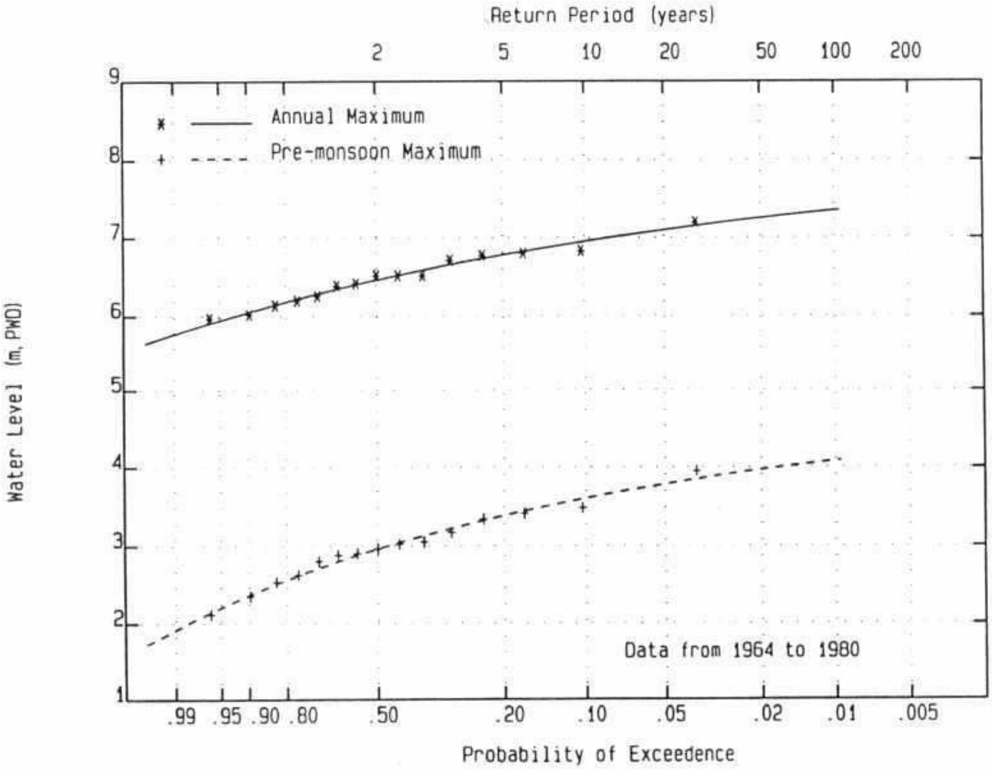
Gauge 175 Kushiyara River at Manumukh
General Extreme Value Distribution



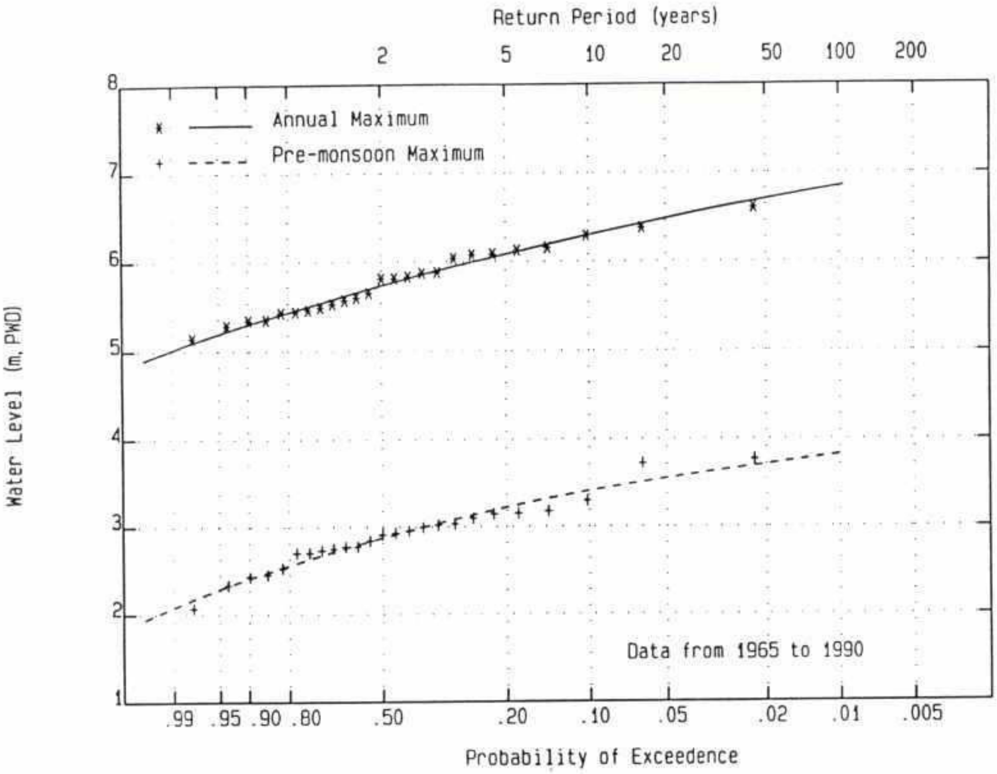
Gauge 175.5 Kushiyara River at Sherpur
General Extreme Value Distribution



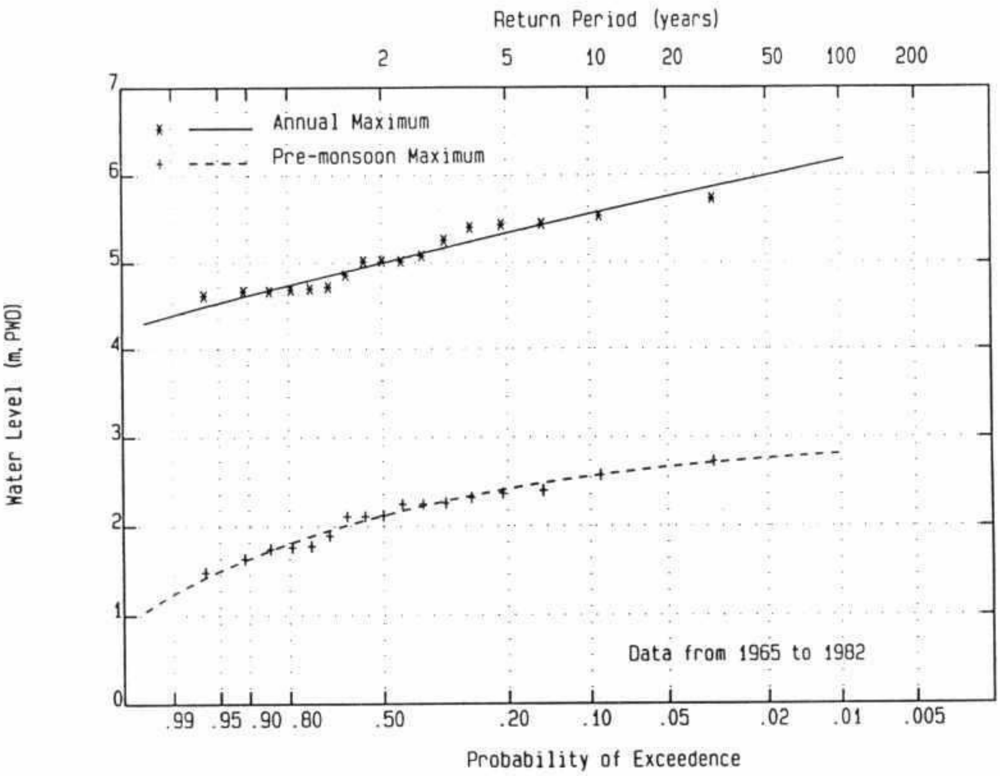
Gauge 177 Lakhya River at Lakhpur
General Extreme Value Distribution



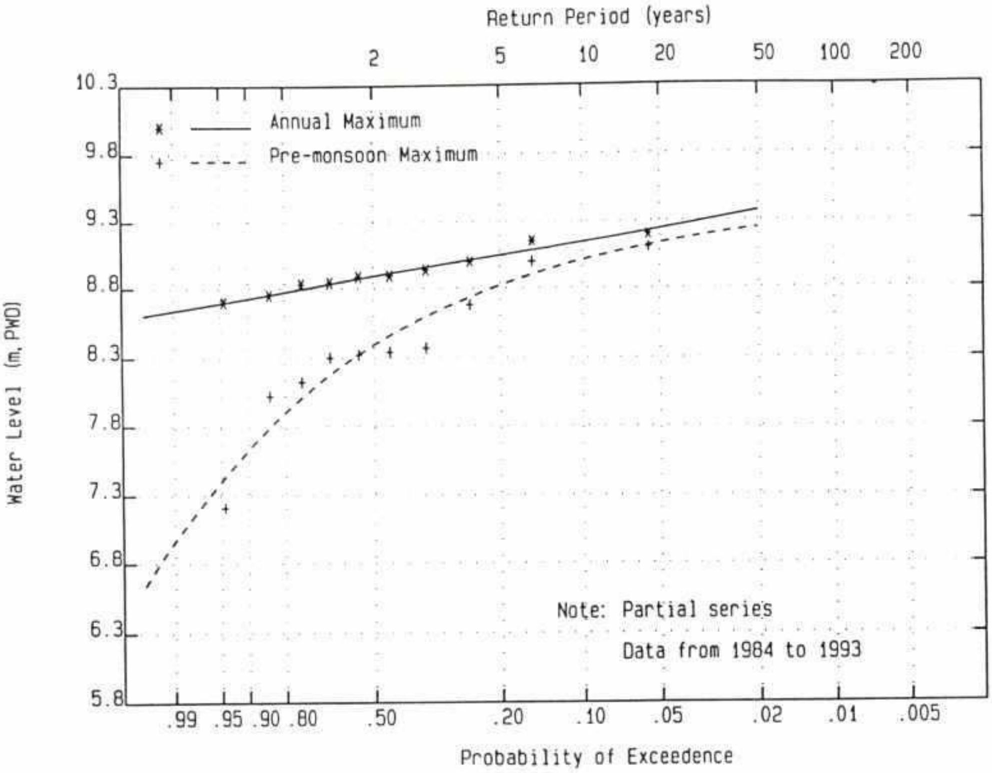
Gauge 178 Lakhya River at Ghorasal
General Extreme Value Distribution



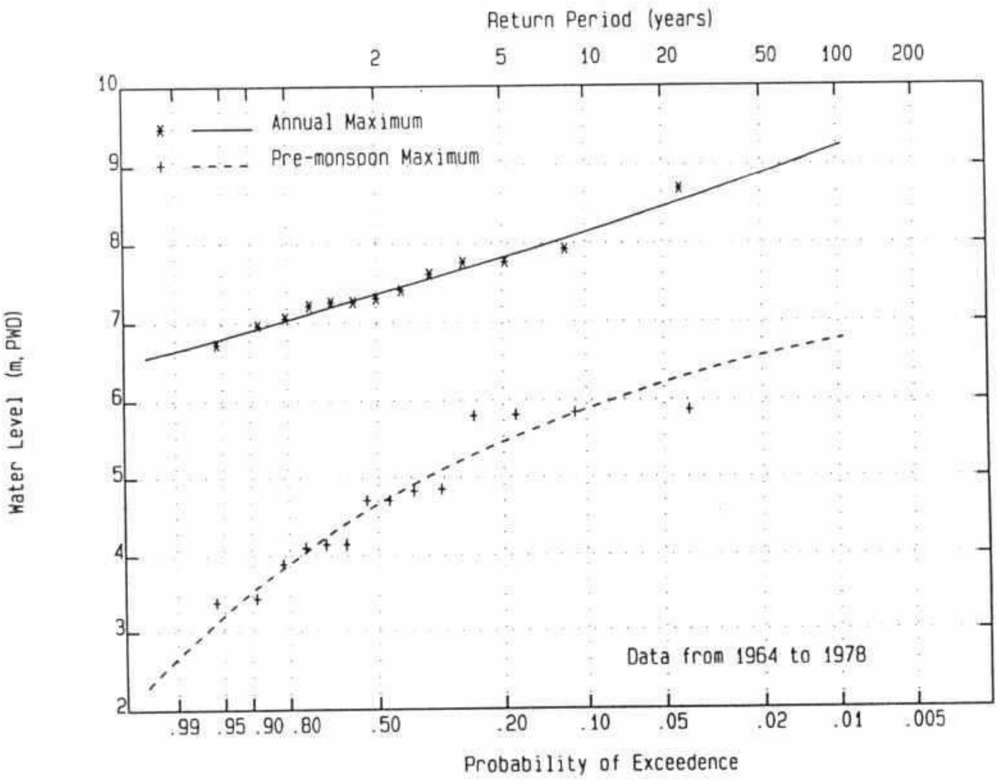
Gauge 179 Lakhya River at Demra
General Extreme Value Distribution



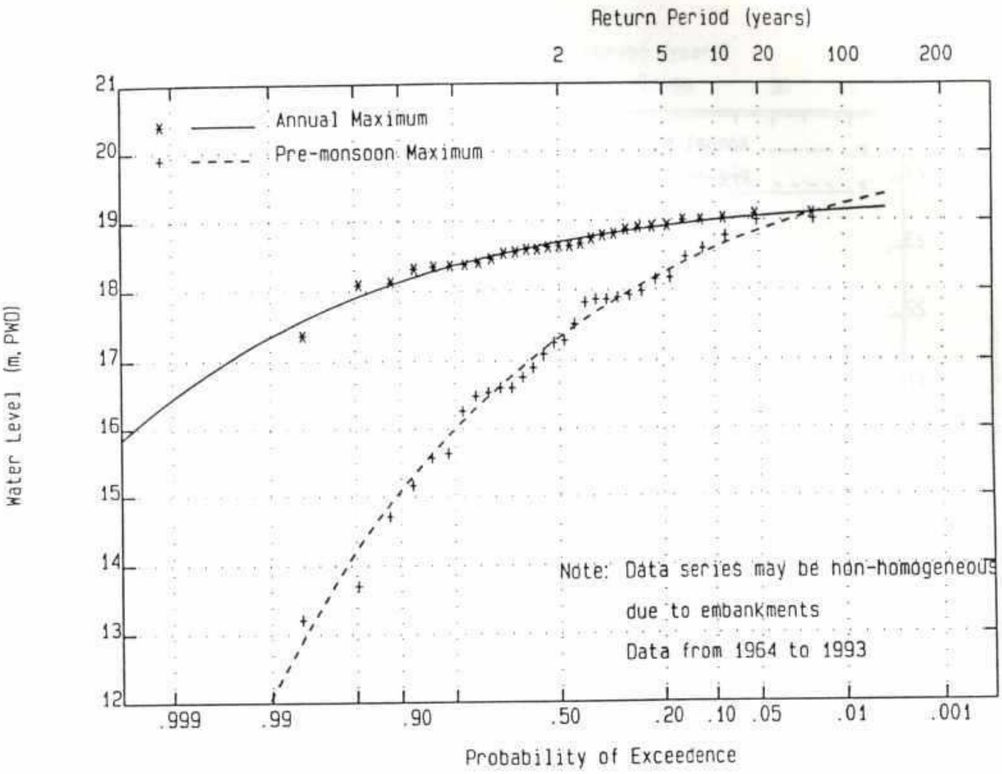
Gauge 180 Lakhya River at Narayanganj
General Extreme Value Distribution



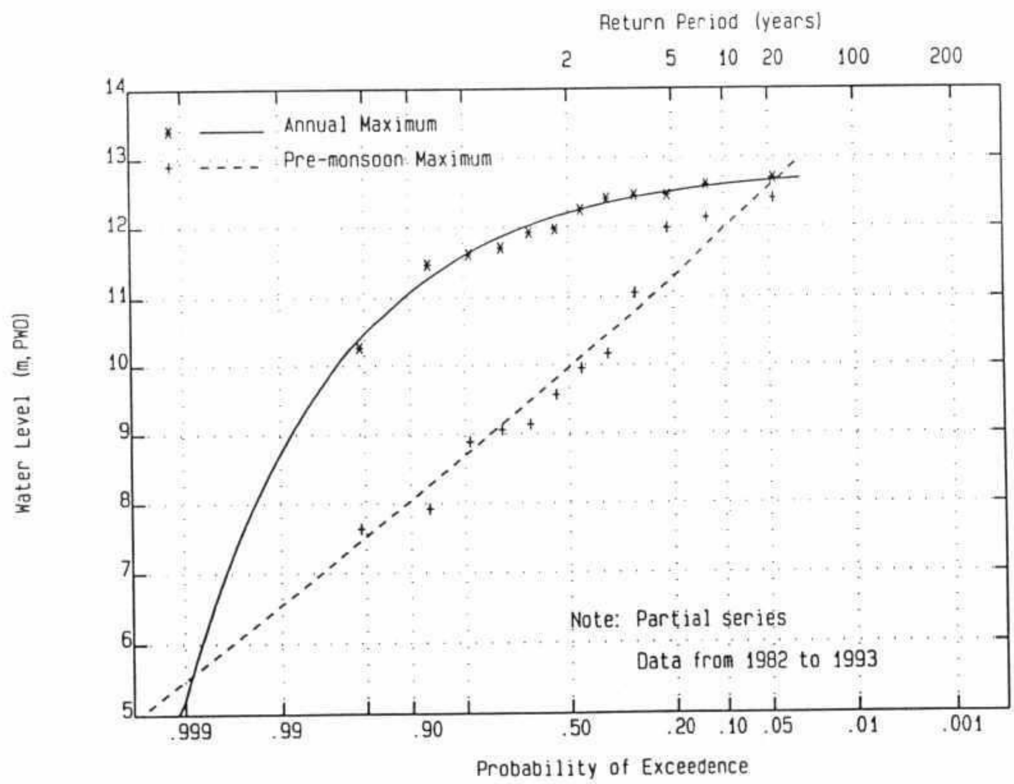
Gauge 192(R) Langla River at Motiganj
General Extreme Value Distribution



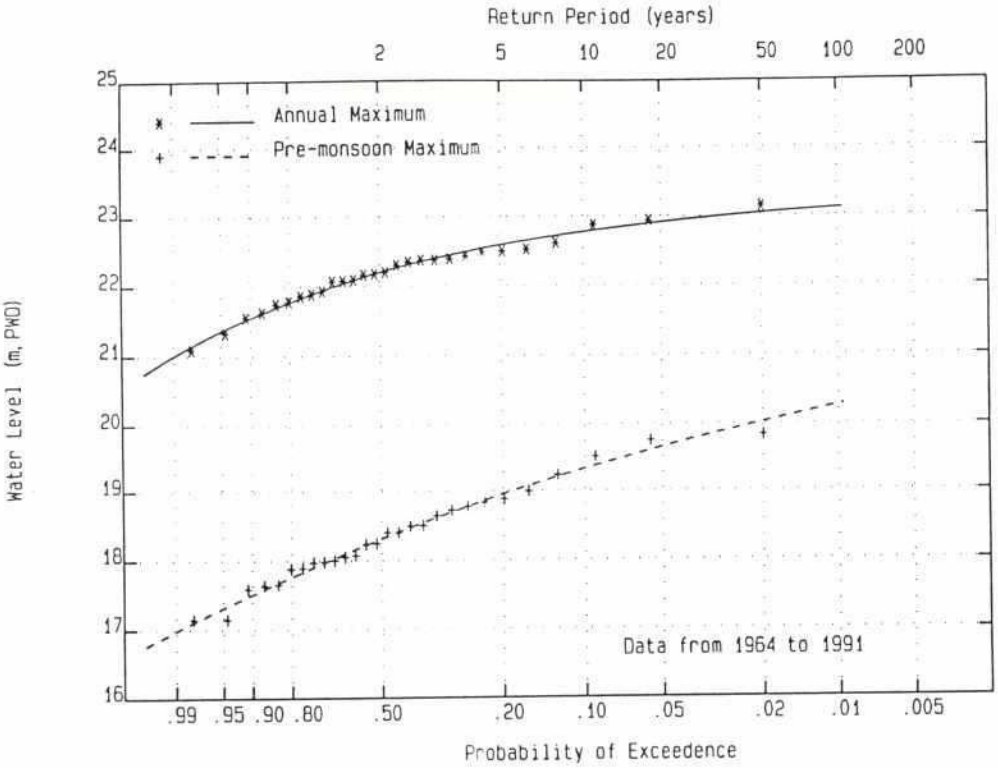
Gauge 199 Mahasingh River at Mahasingh Ferryghat
General Extreme Value Distribution



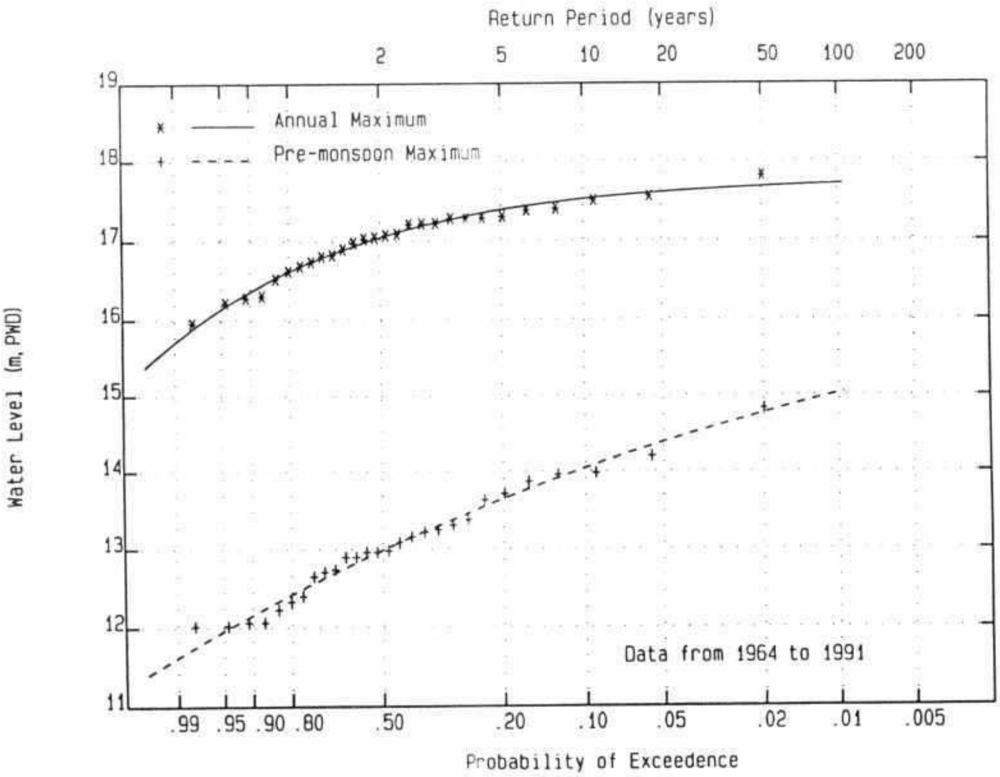
Gauge 201 Manu River at Manu Rly. Bridge
3-Parameter Log Normal Distribution



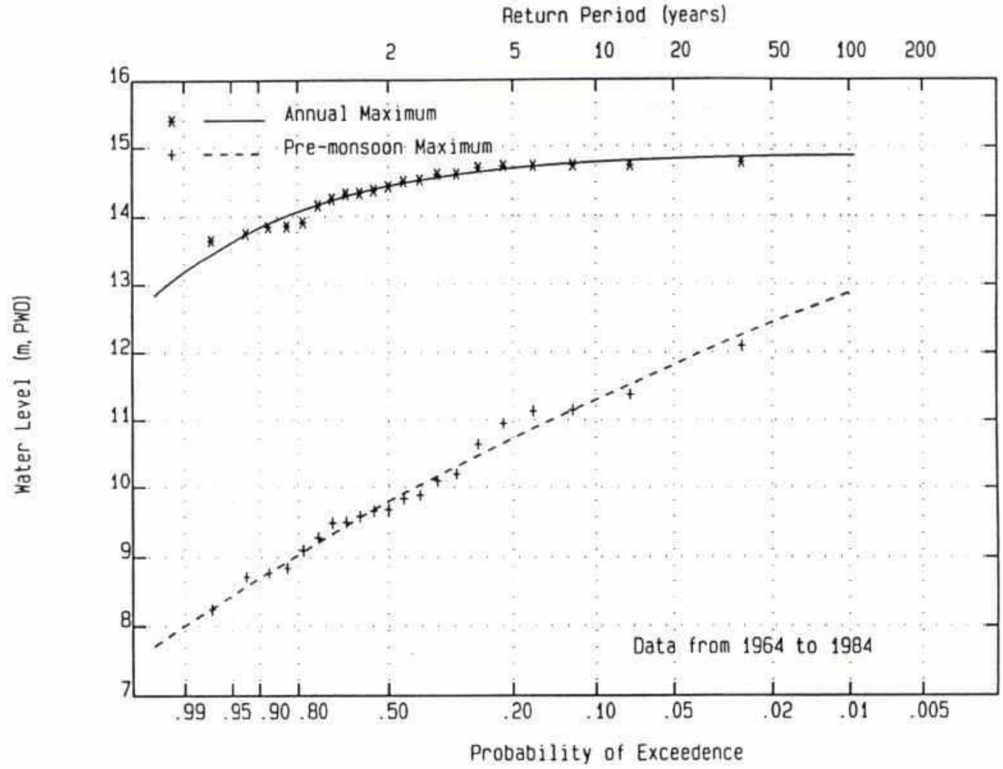
Gauge 202(R) Manu River at Maulavi Bazar
3-Parameter Log Normal Distribution



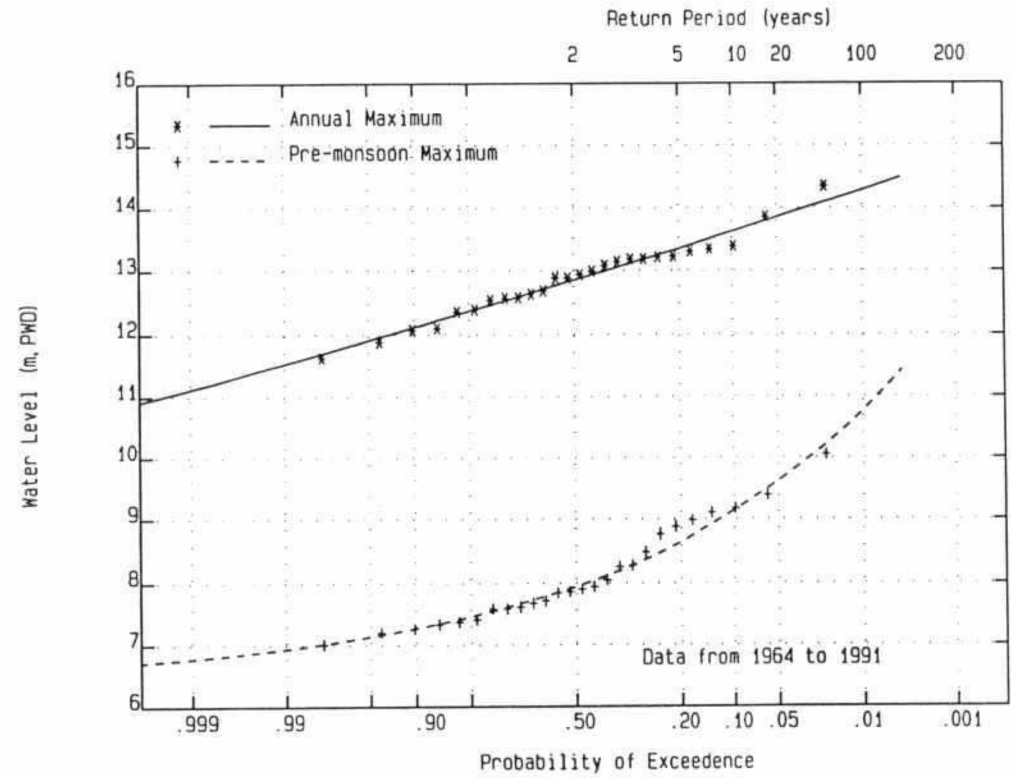
Gauge 223 Old Brahmaputra River at Goal Khanda
General Extreme Value Distribution



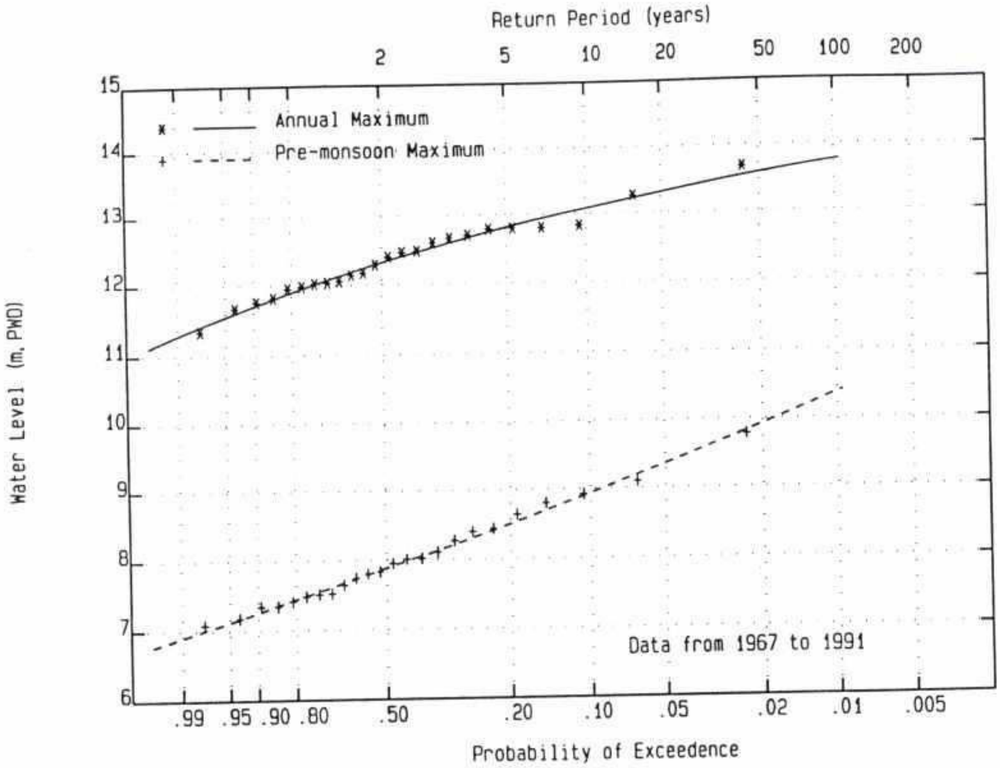
Gauge 225 Old Brahmaputra River at Jamalpur
General Extreme Value Distribution



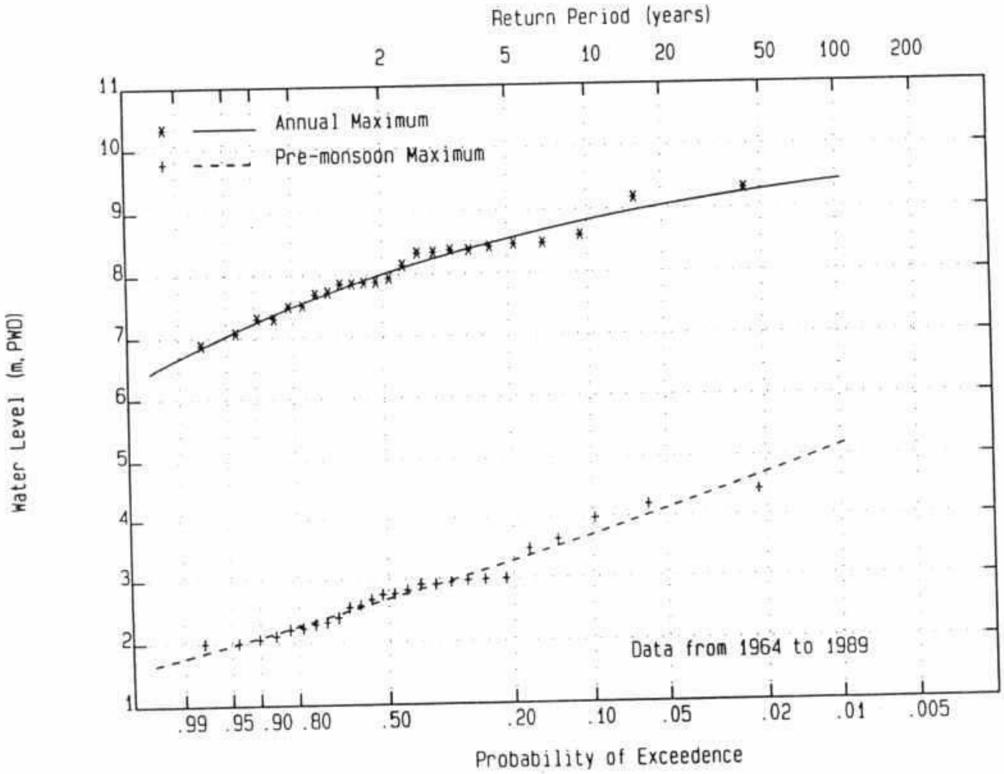
Gauge 226 Old Brahmaputra River at Sirkhali offtake
General Extreme Value Distribution



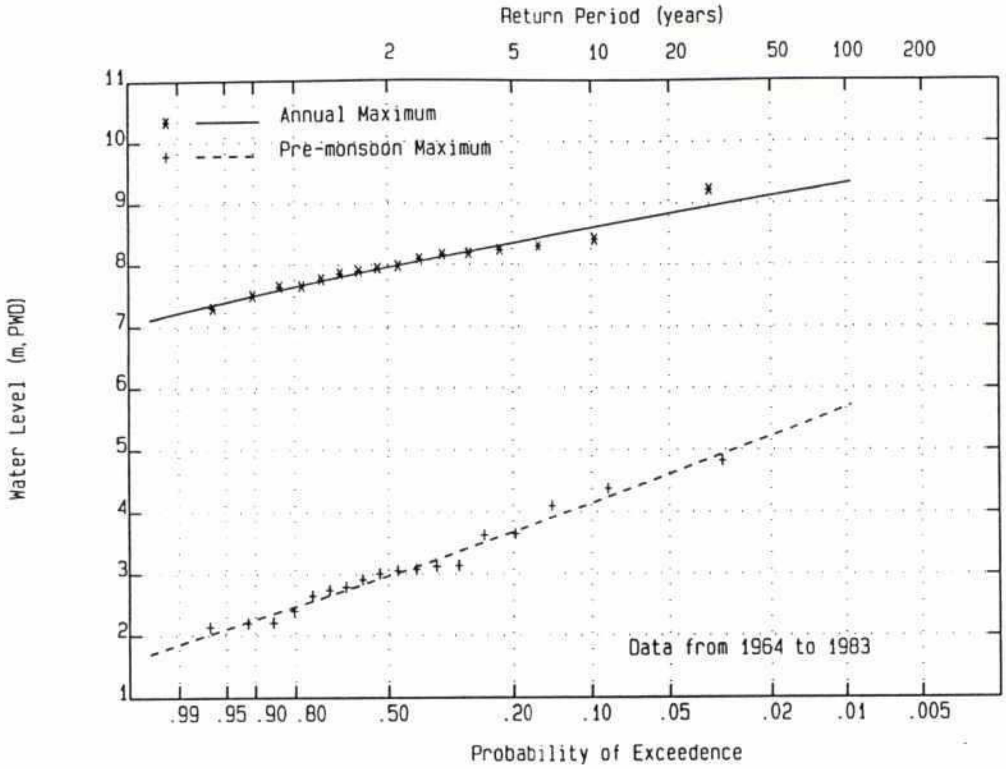
Gauge 227 Old Brahmaputra River at Sutia Offtake
3-Parameter Log Normal Distribution



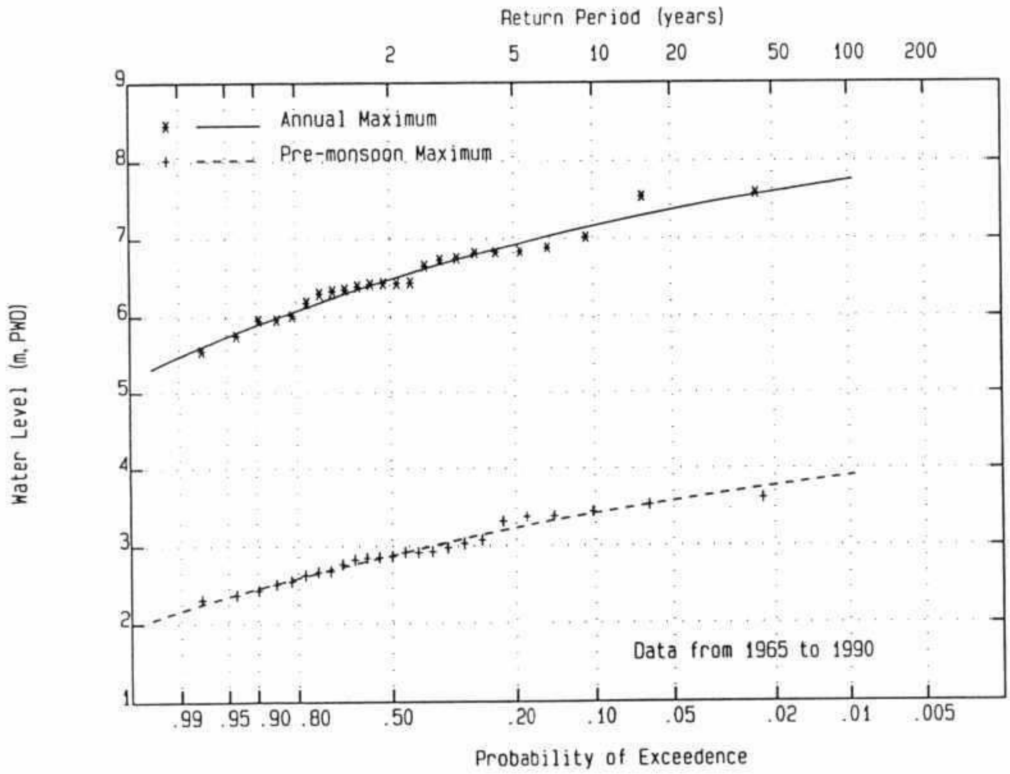
Gauge 228.5 Old Brahmaputra River at Mymenshingh
General Extreme Value Distribution



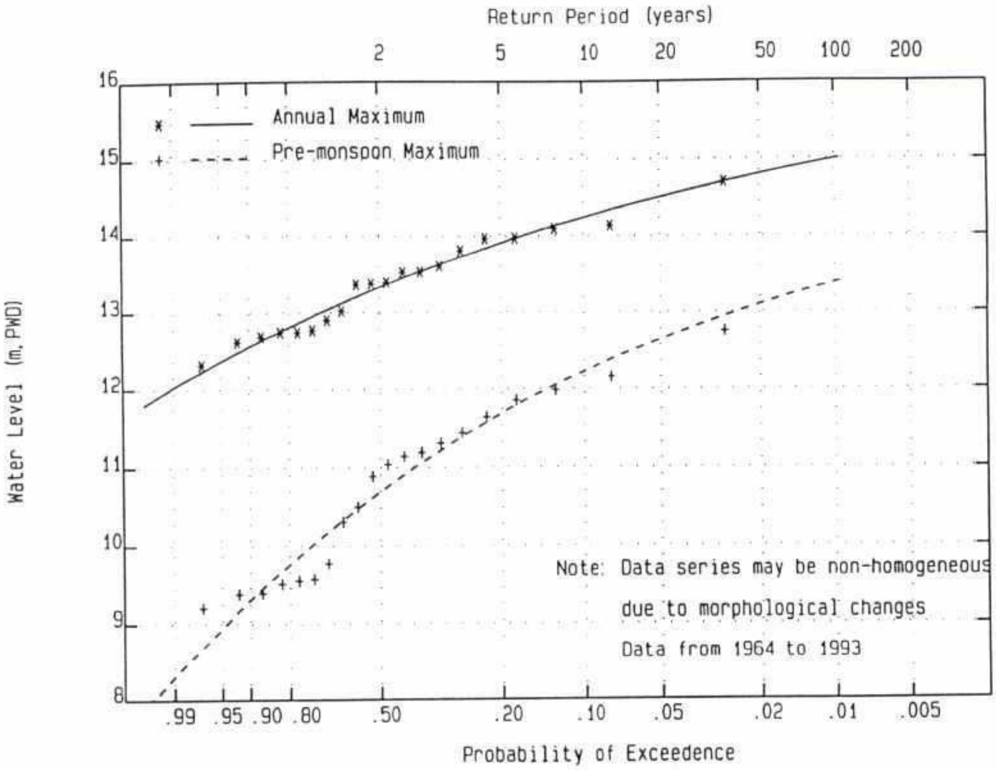
Gauge 229 Old Brahmaputra River at Toke
General Extreme Value Distribution



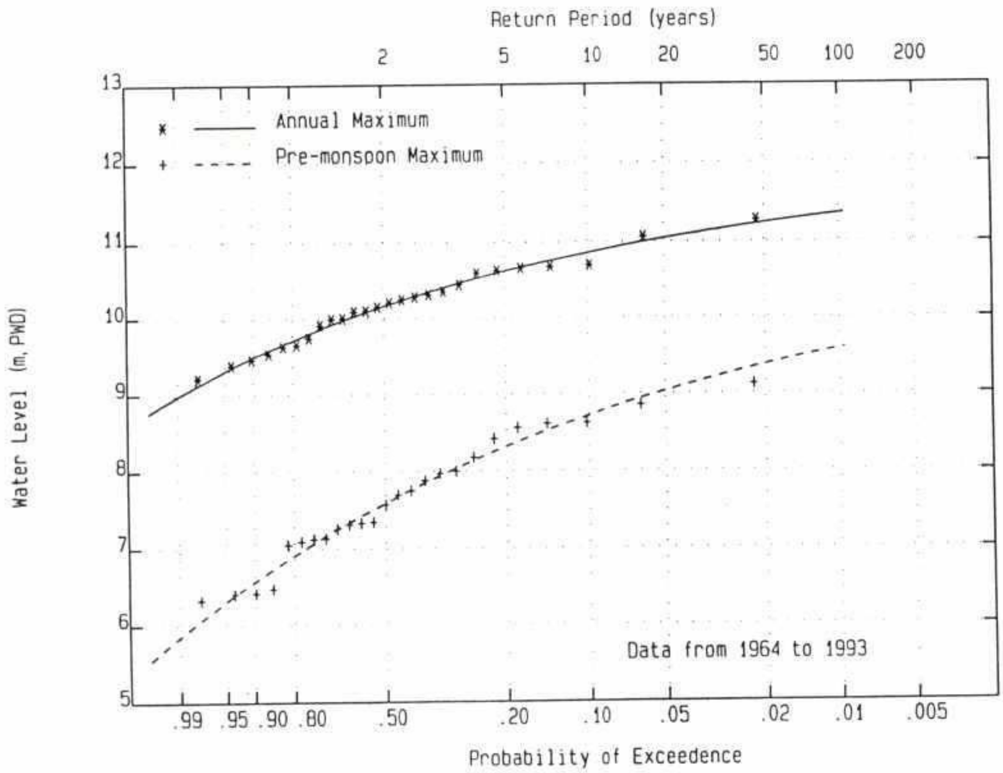
Gauge 230 Old Brahmaputra River at Motkhola
General Extreme Value Distribution



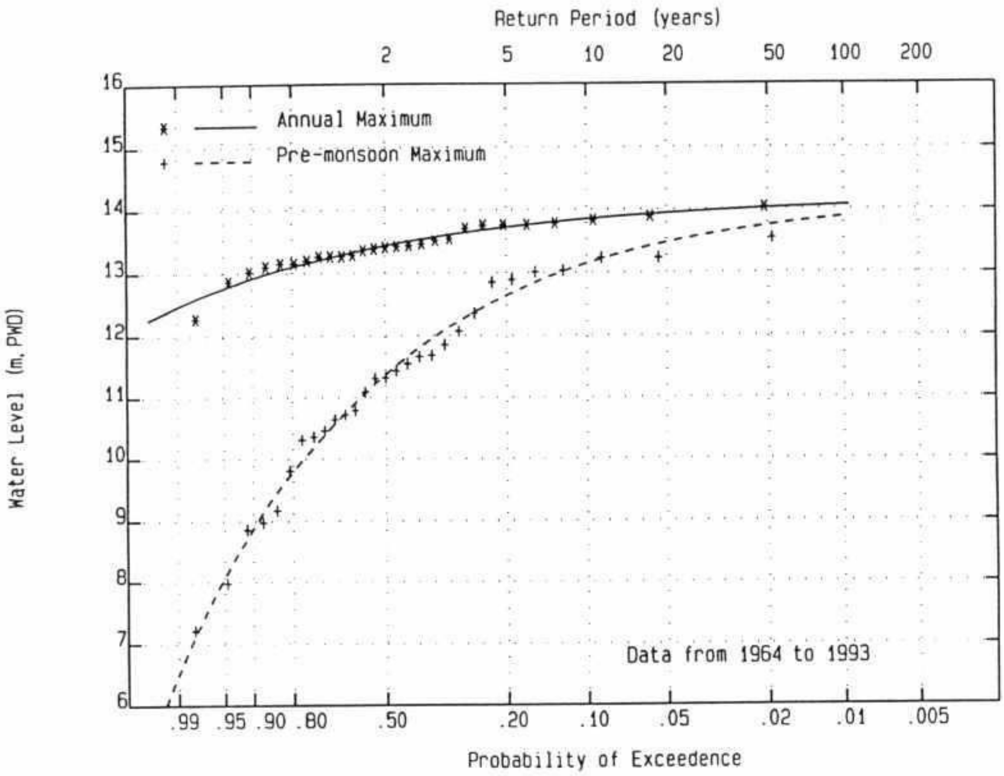
Gauge 230.1 Old Brahmaputra River at Bhairab Bazar
General Extreme Value Distribution



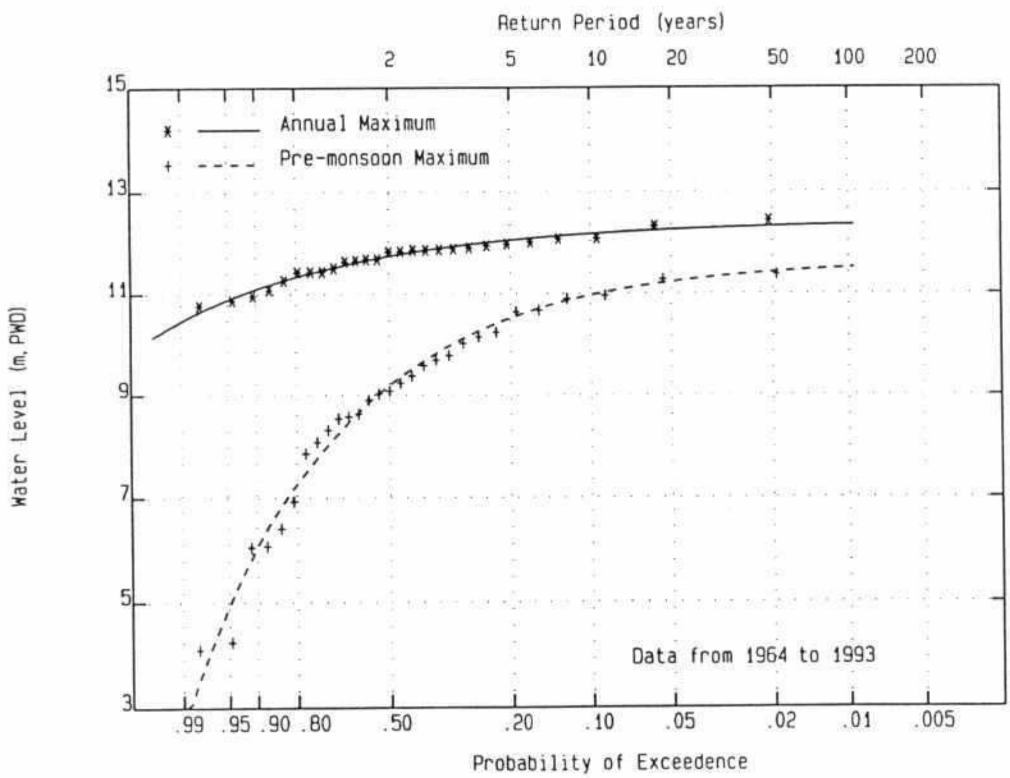
Gauge 233 Piyain River at Ratnerbhanga
General Extreme Value Distribution



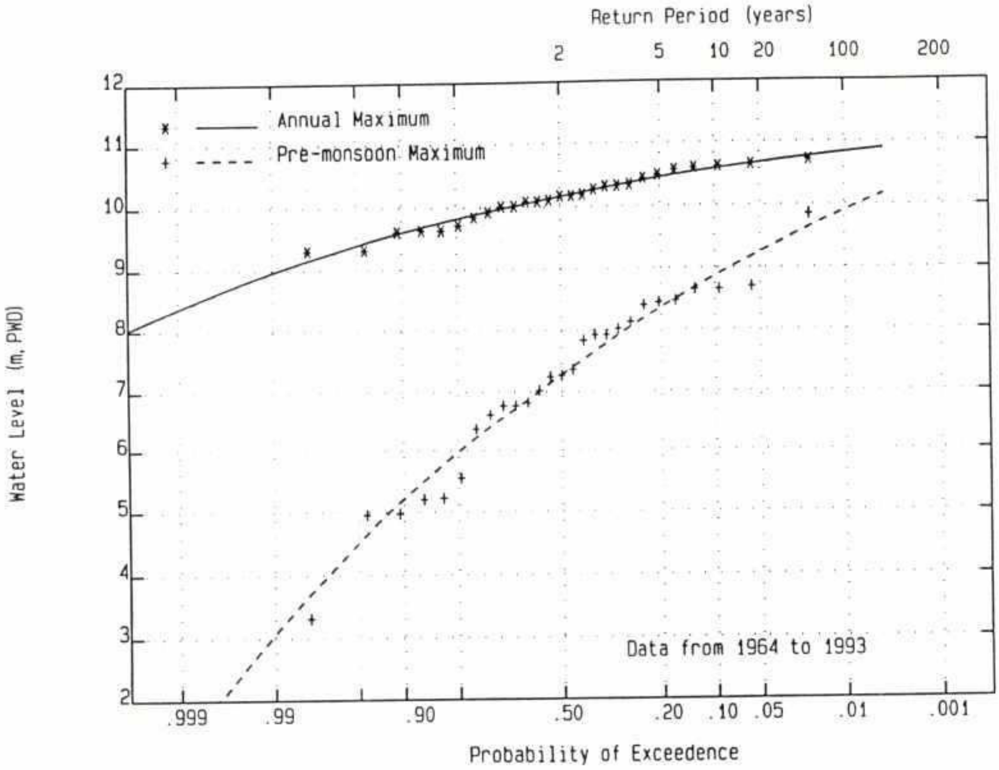
Gauge 234 Piyain River at Companyganj
General Extreme Value Distribution



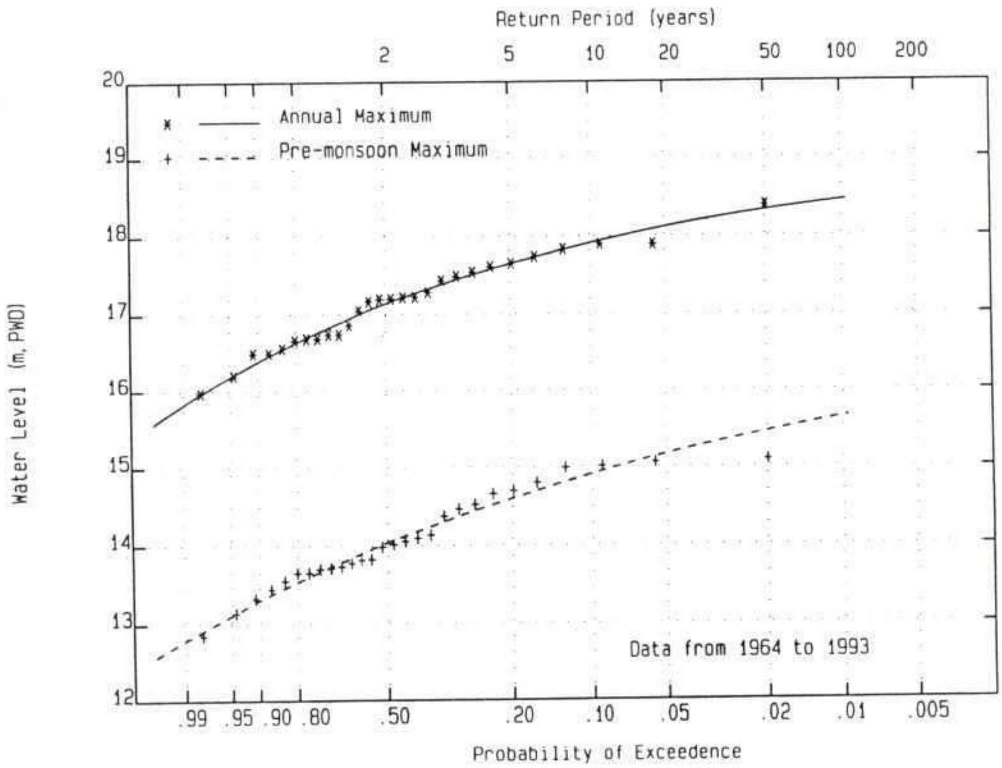
Gauge 251 Sarigowain River at Sharighat
General Extreme Value Distribution



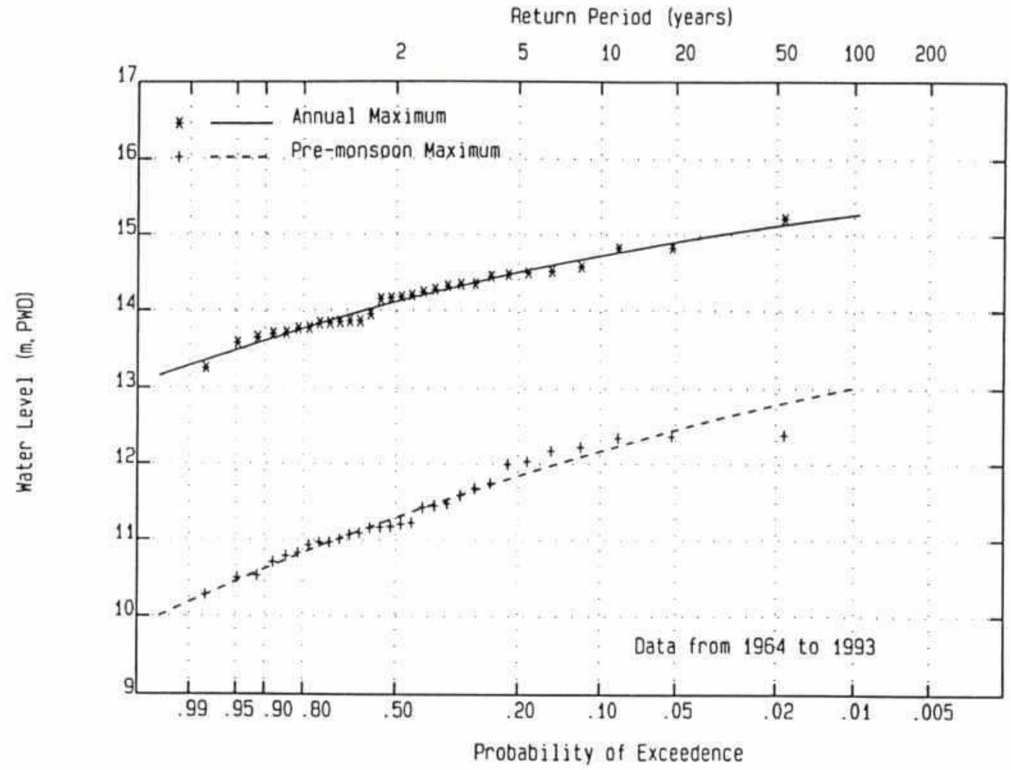
Gauge 252 Sarigowain River at Gowainghat
General Extreme Value Distribution



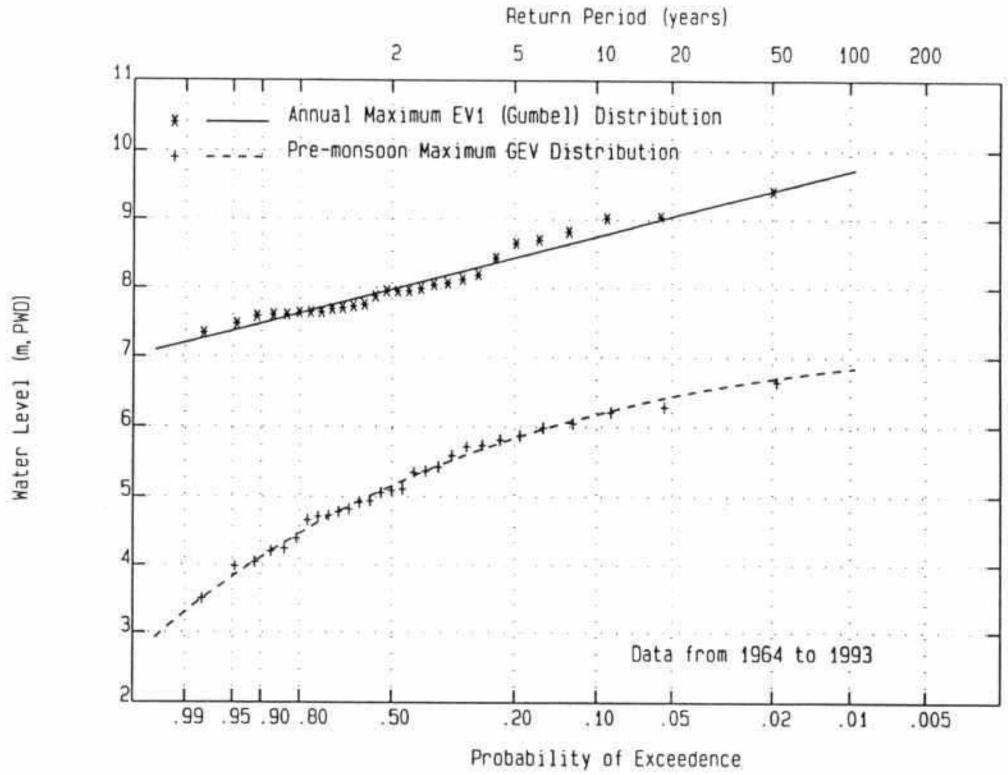
Gauge 252.1 Sarigowain River at Salutikar
3-Parameter Log Normal Distribution



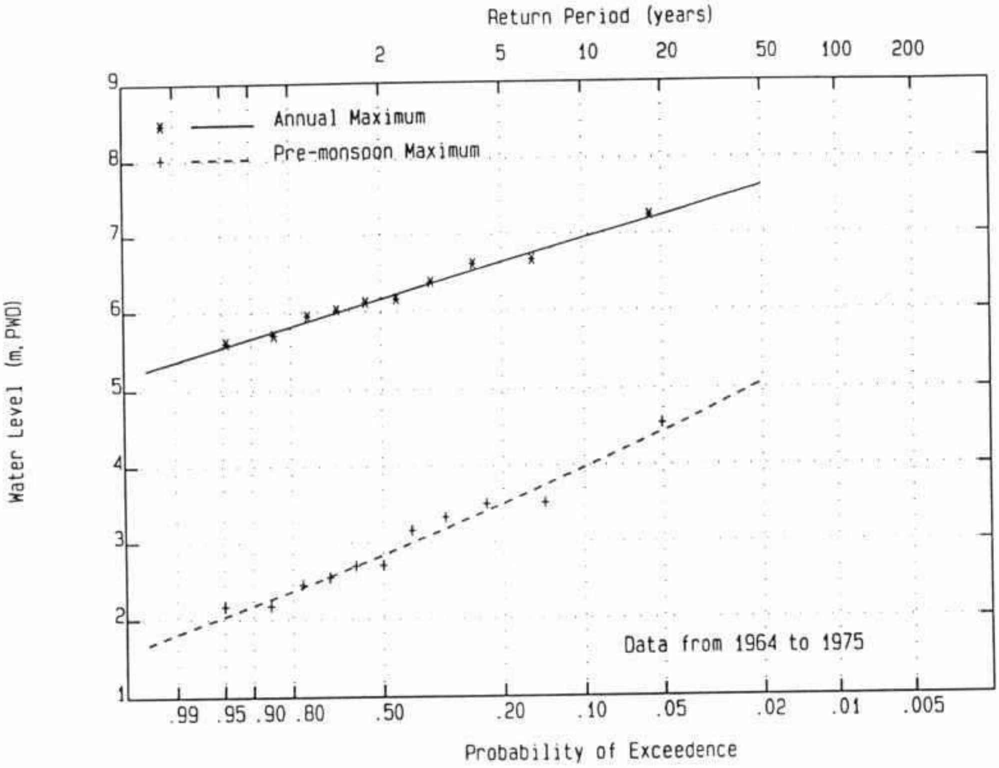
Gauge 262 Someswari River at Bagmara (Bijoypur)
General Extreme Value Distribution



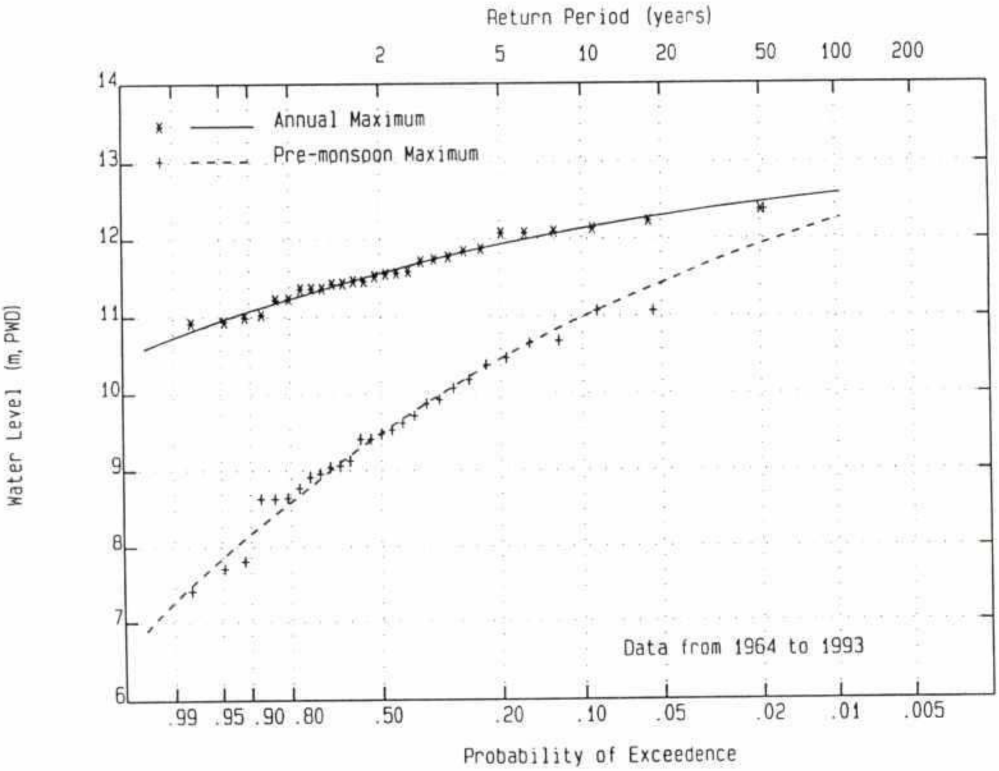
Gauge 263 Someswari River at Durgapur
General Extreme Value Distribution



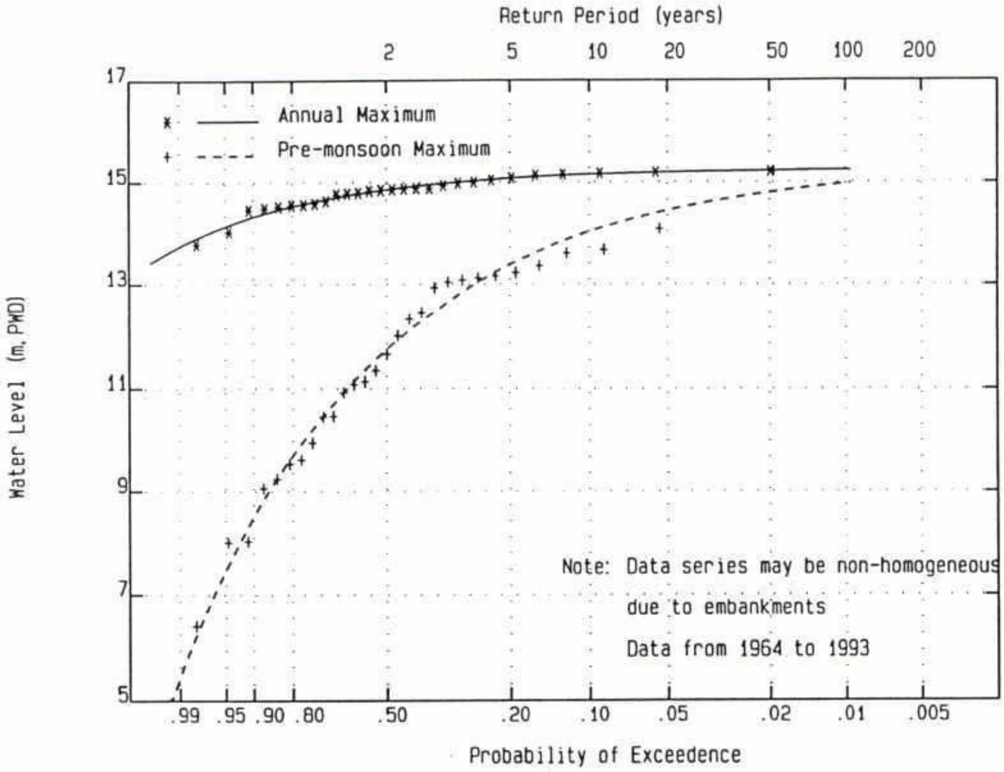
Gauge 263.1 Someswari River at Kalmakanda
Extreme Value Distributions



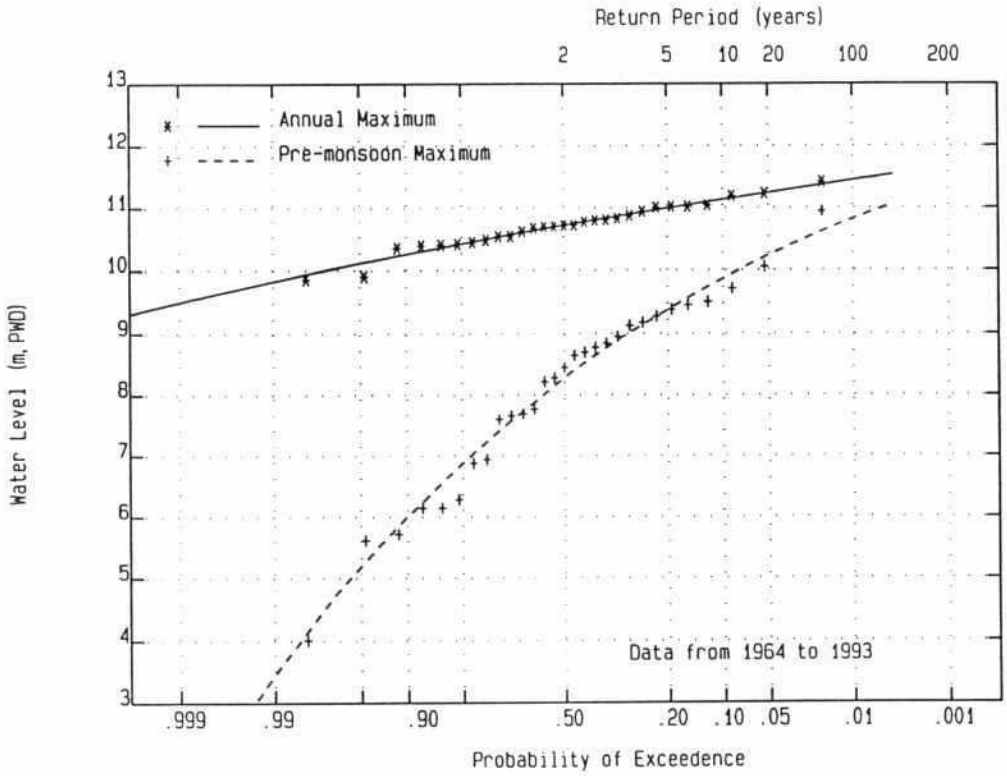
Gauge 264 Sonai River at Madhabpur
General Extreme Value Distribution



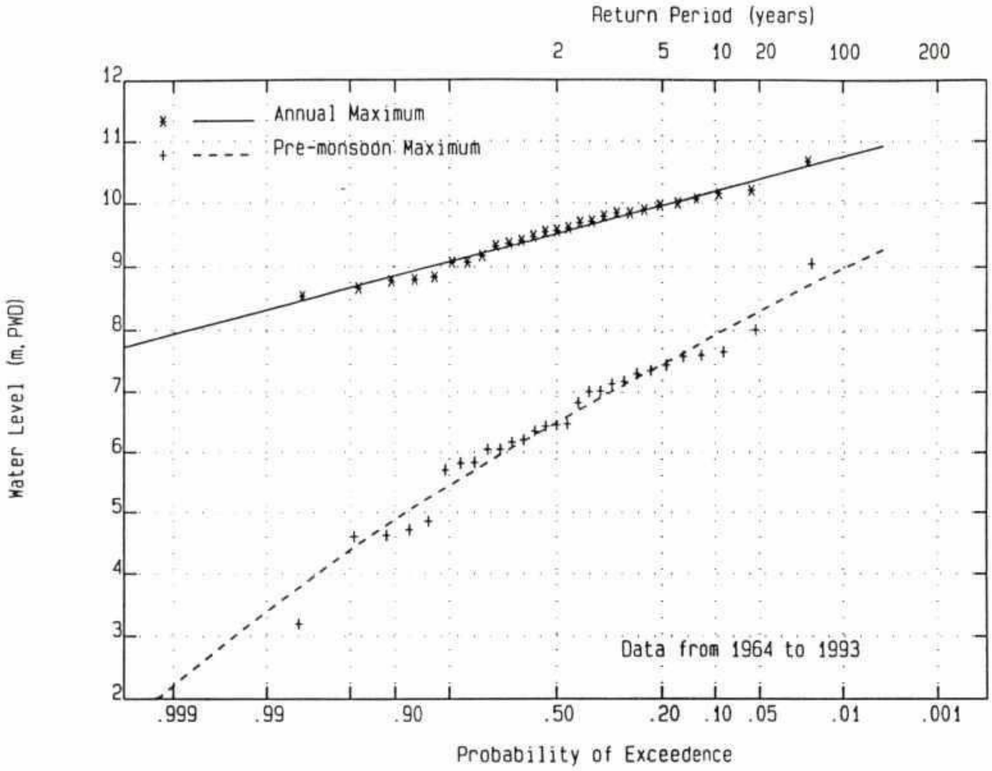
Gauge 265 Sonaibardal River at Jaldhup
General Extreme Value Distribution



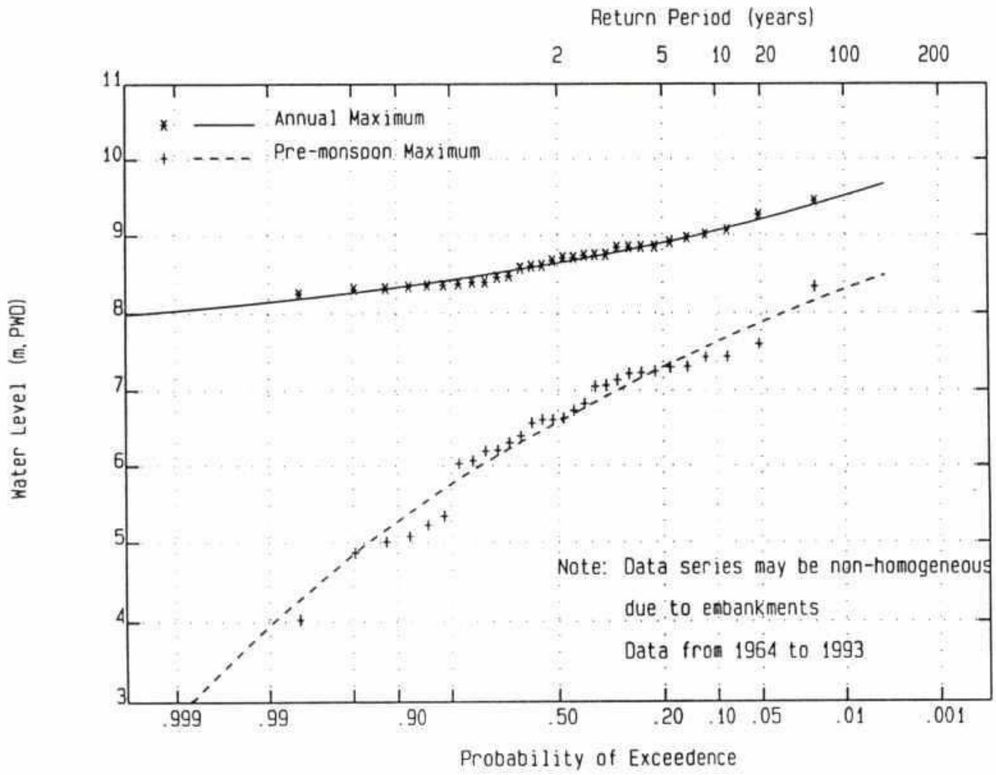
Gauge 266 Surma River at Kanairghat
General Extreme Value Distribution



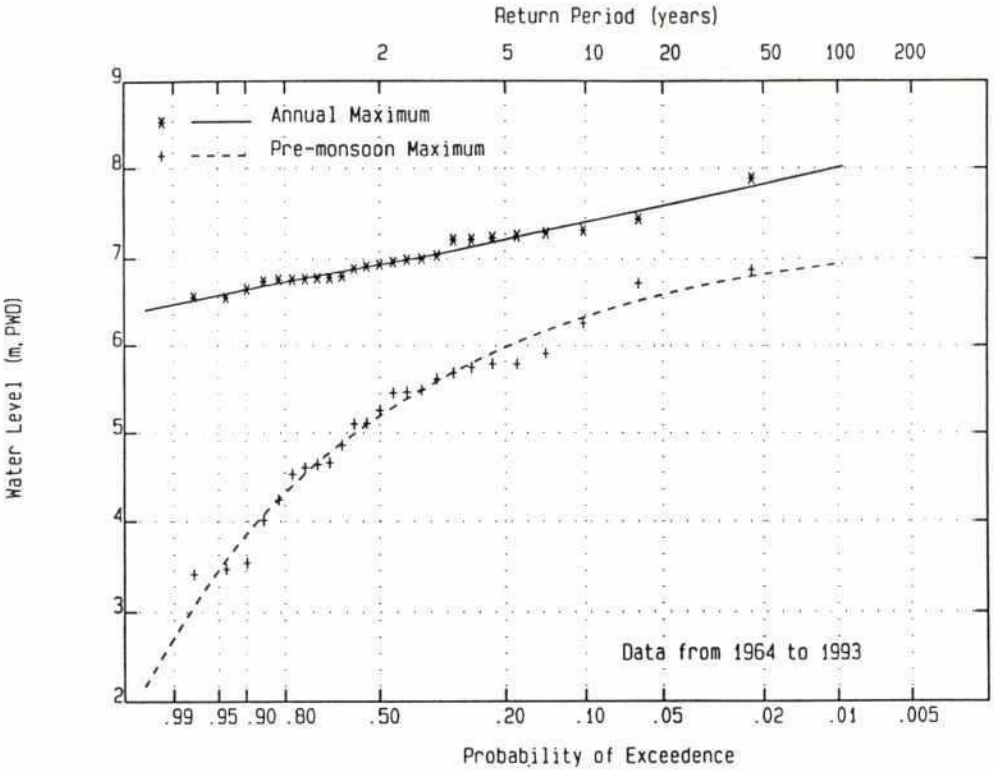
Gauge 267 Surma River at Sylhet
3-Parameter Log Normal Distribution



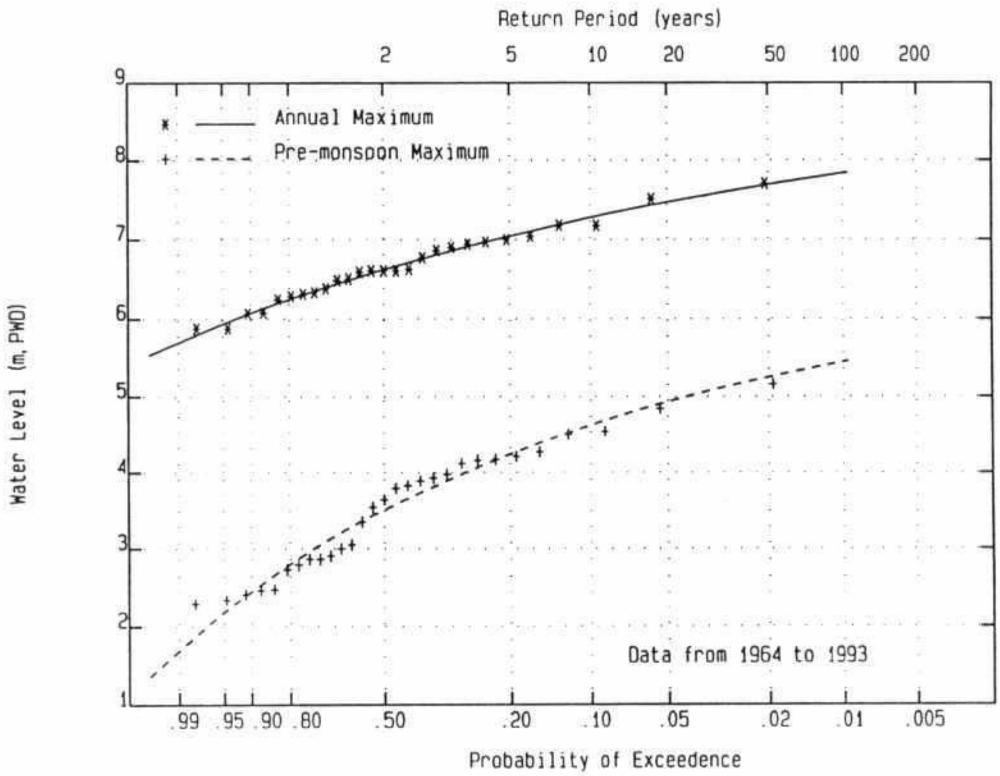
Gauge 268 Surma River at Chhatak
3-Parameter Log Normal Distribution



Gauge 269 Surma River at Sunamganj
3-Parameter Log Normal Distribution

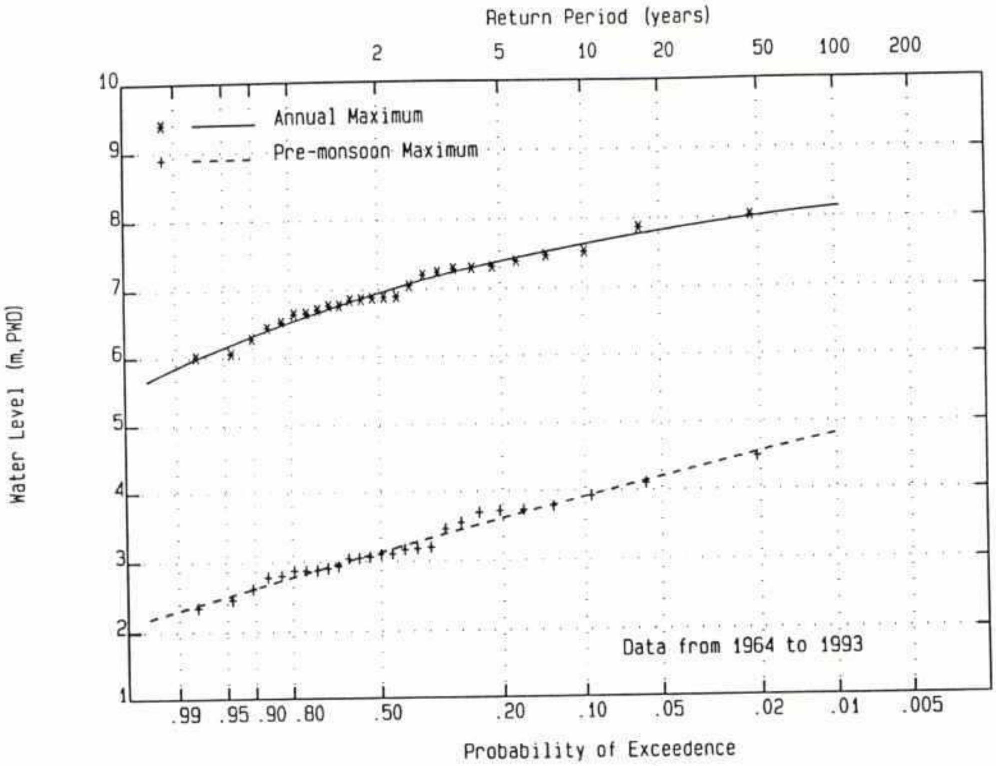


Gauge 270 Kusiyara River at Markuli
General Extreme Value Distribution

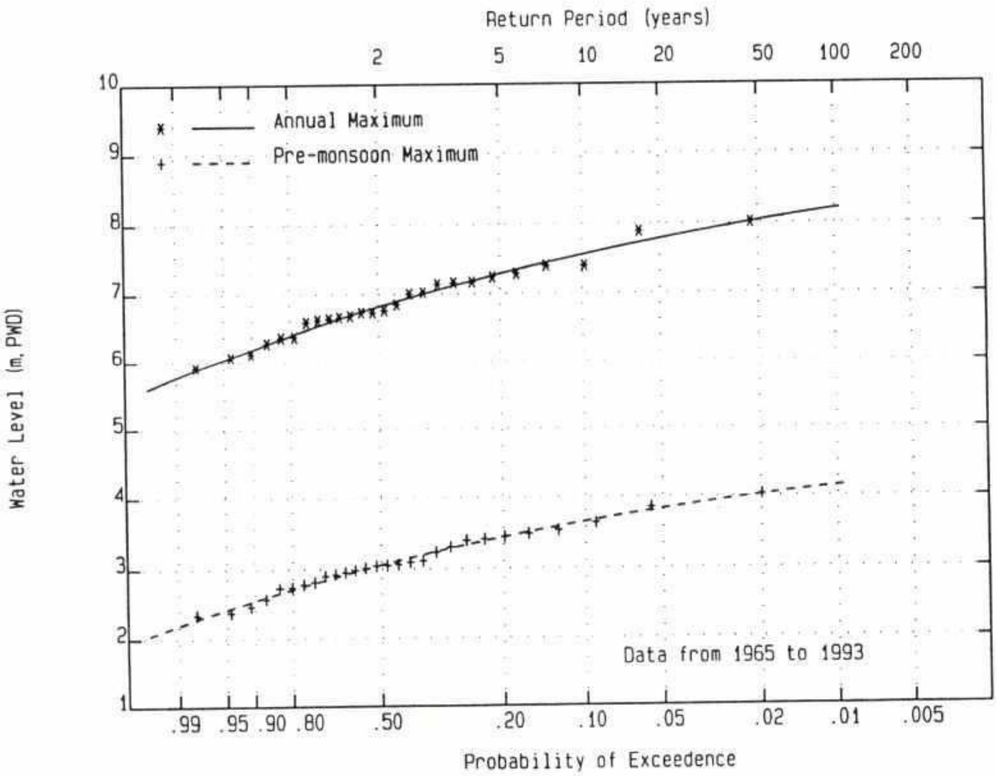


Gauge 271 Kalni River at Ajmiriganj
General Extreme Value Distribution

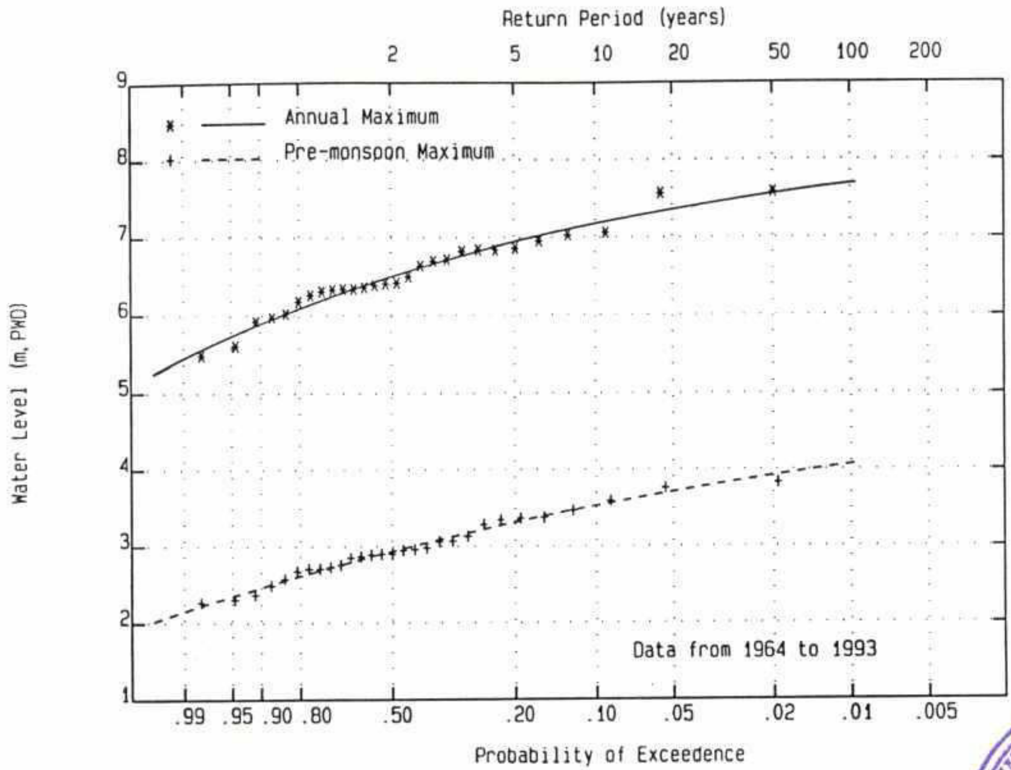
208



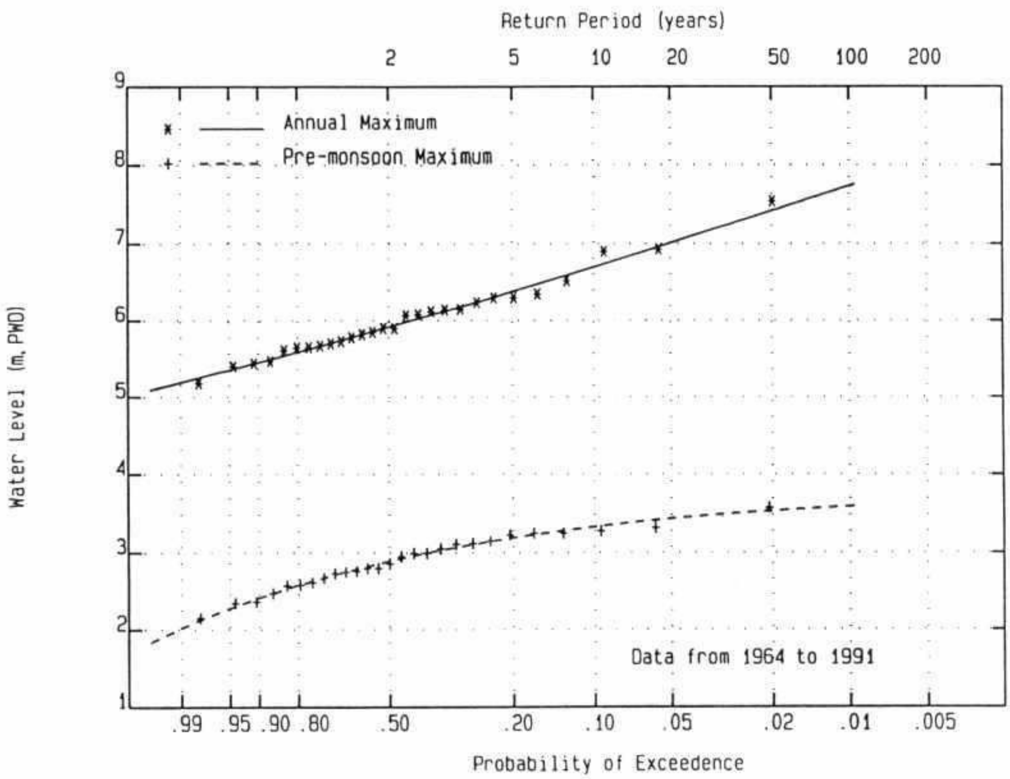
Gauge 272 Kalni River at Madna
General Extreme Value Distribution



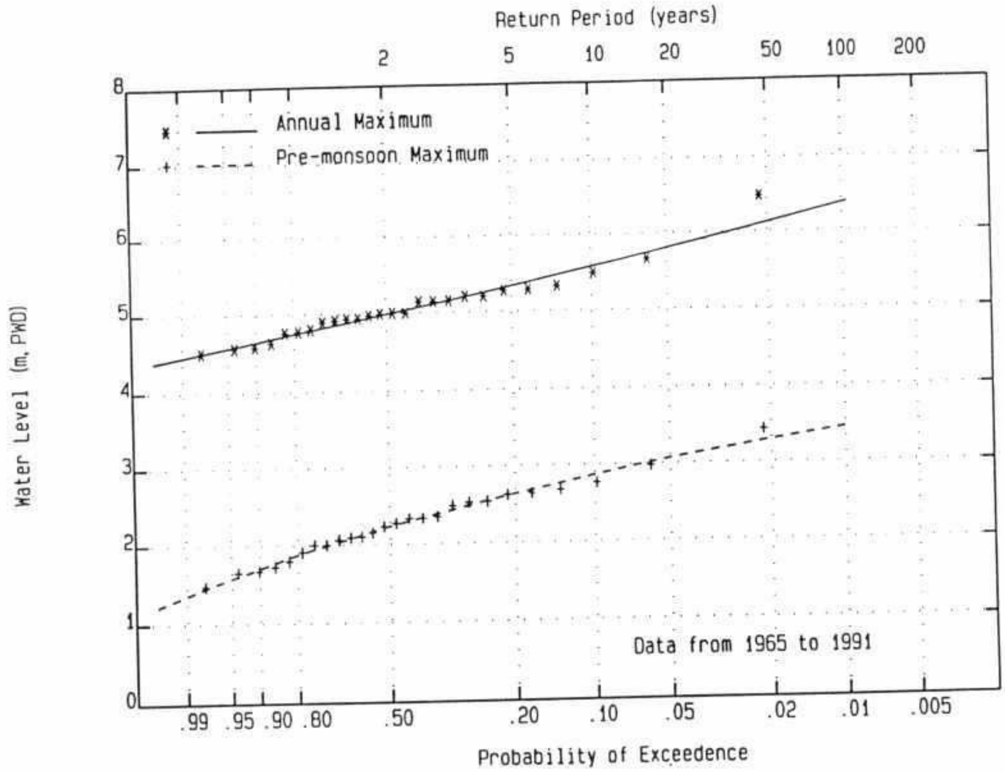
Gauge 272.1 Dhaleswari River at Austagram
General Extreme Value Distribution



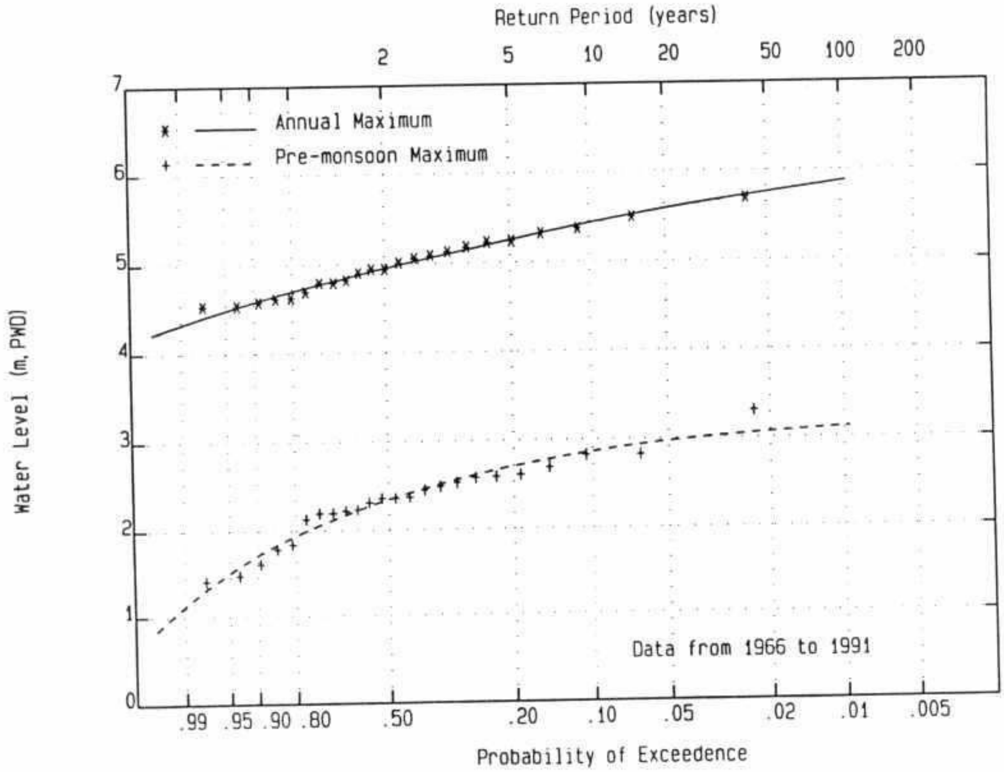
Gauge 273 Meghna River at Bhairab Bazar
General Extreme Value Distribution



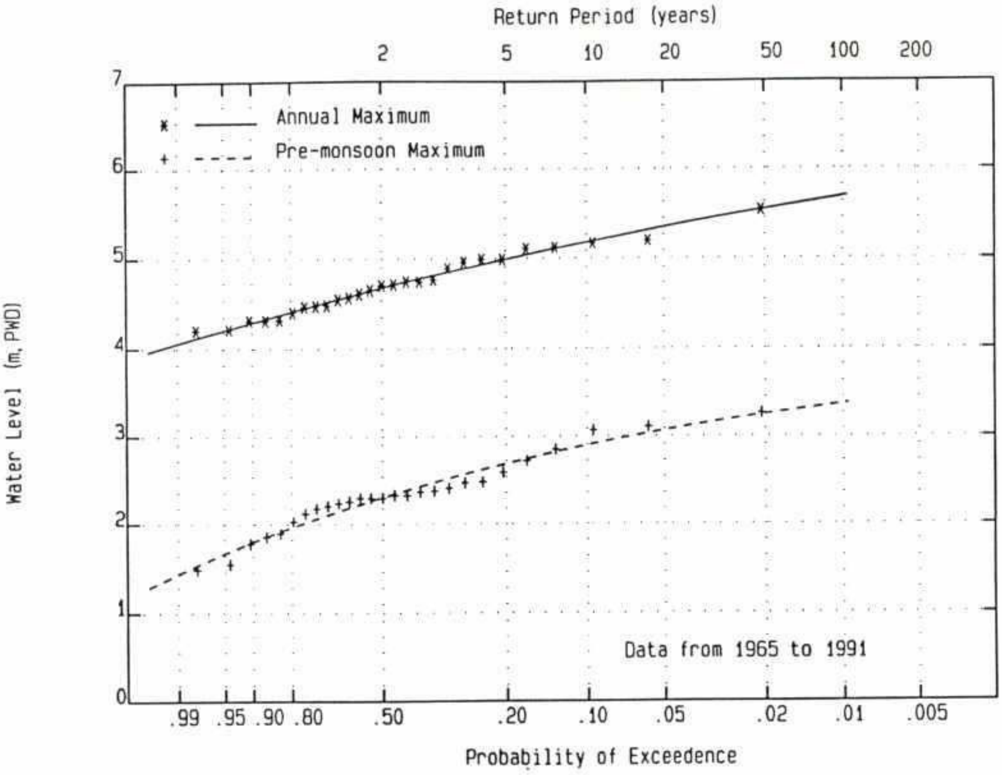
Gauge 274 Meghna River at Narsingdi
General Extreme Value Distribution



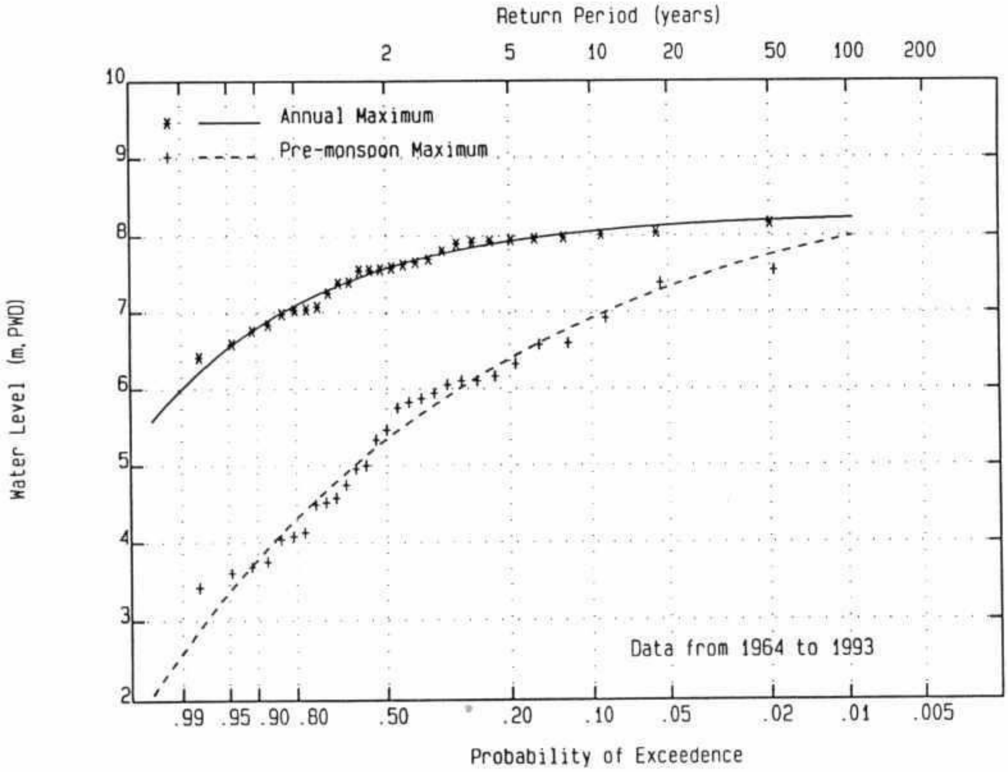
Gauge 275 Meghna River at Badyar Bazar
General Extreme Value Distribution



Gauge 275.5 Meghna River at Meghna Ferry Ghat
General Extreme Value Distribution



Gauge 276 Meghna River at Satnal
General Extreme Value Distribution



Gauge 280 Sutang River at Sutang Rly. Bridge
General Extreme Value Distribution

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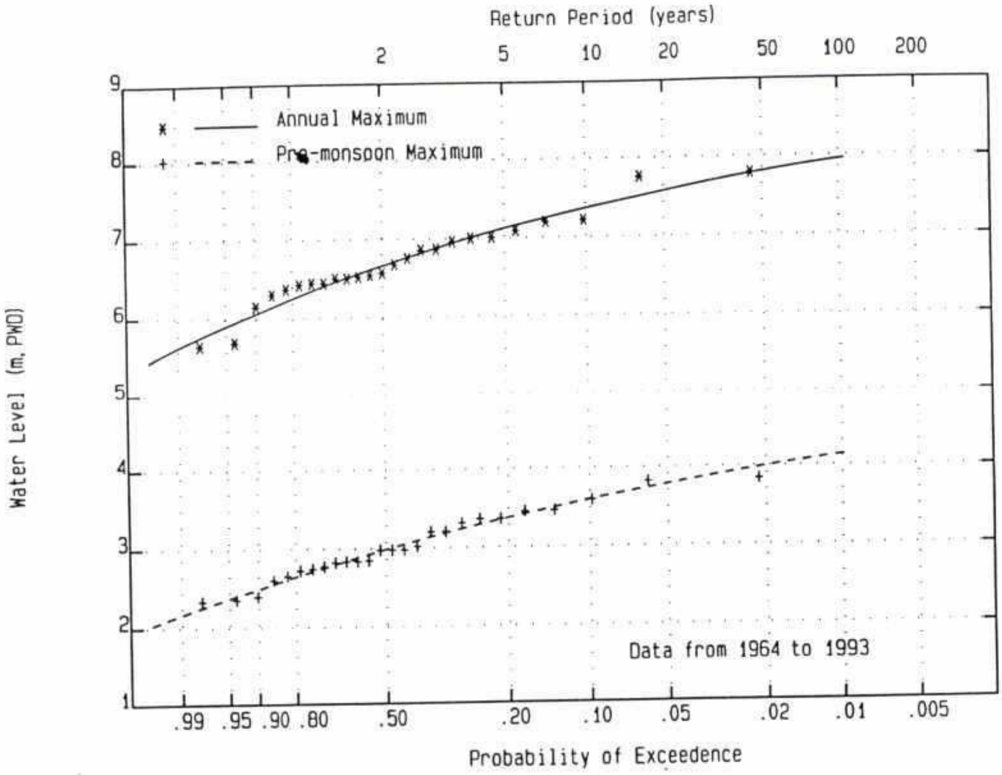
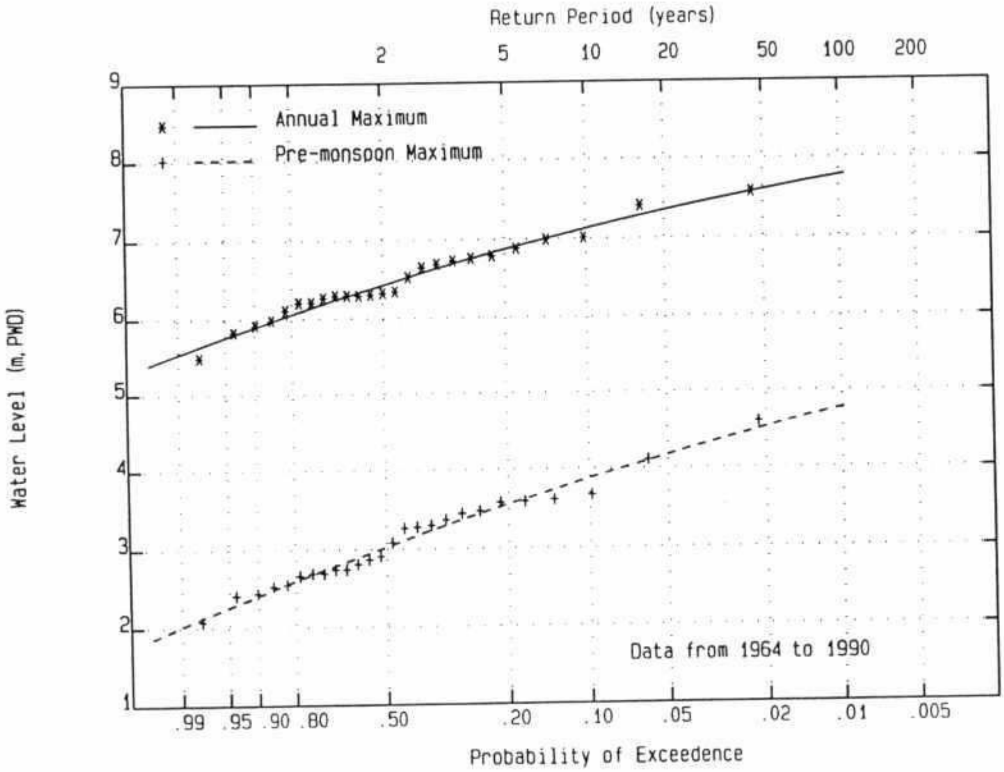
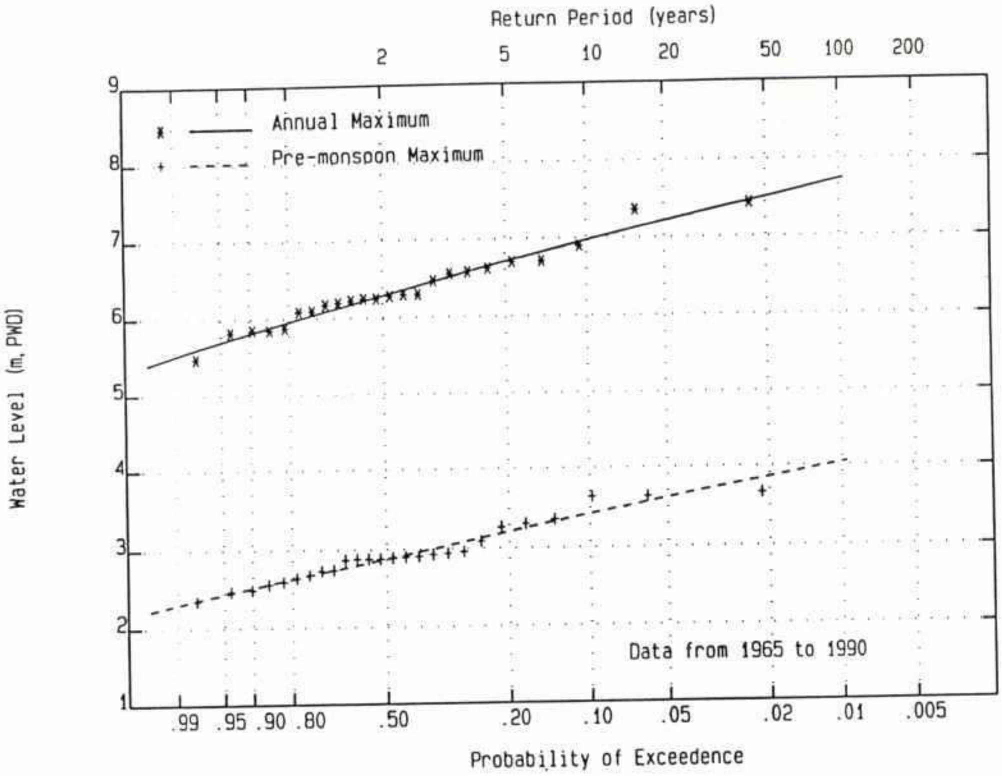


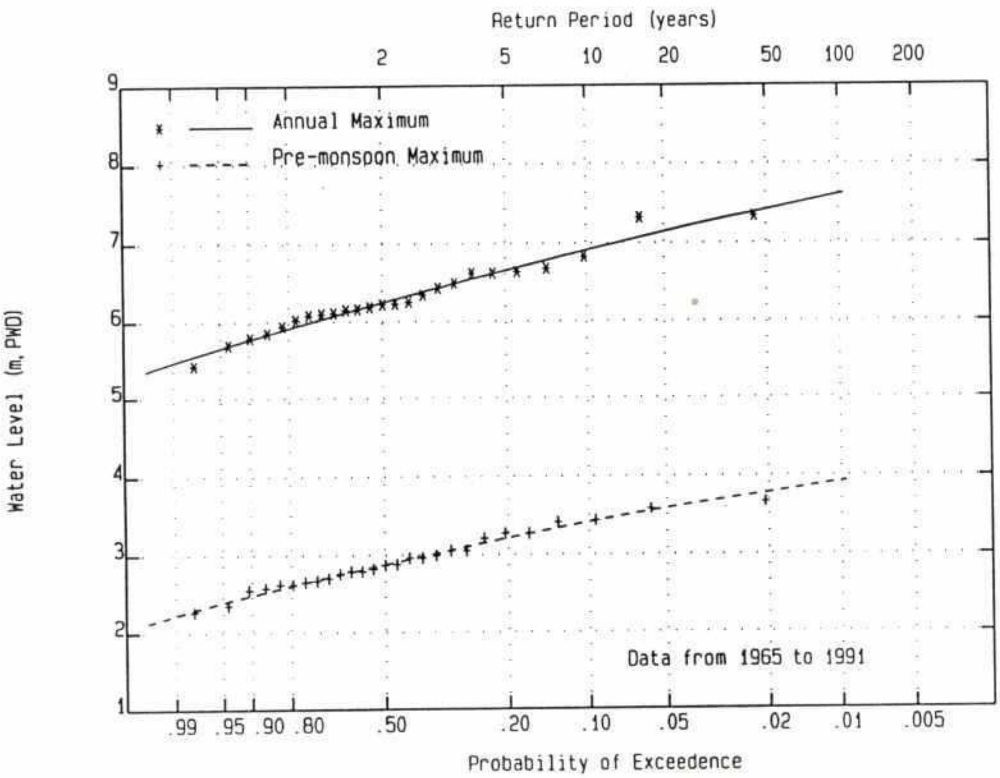
Gauge 295 Titas River at Ajabpur
General Extreme Value Distribution



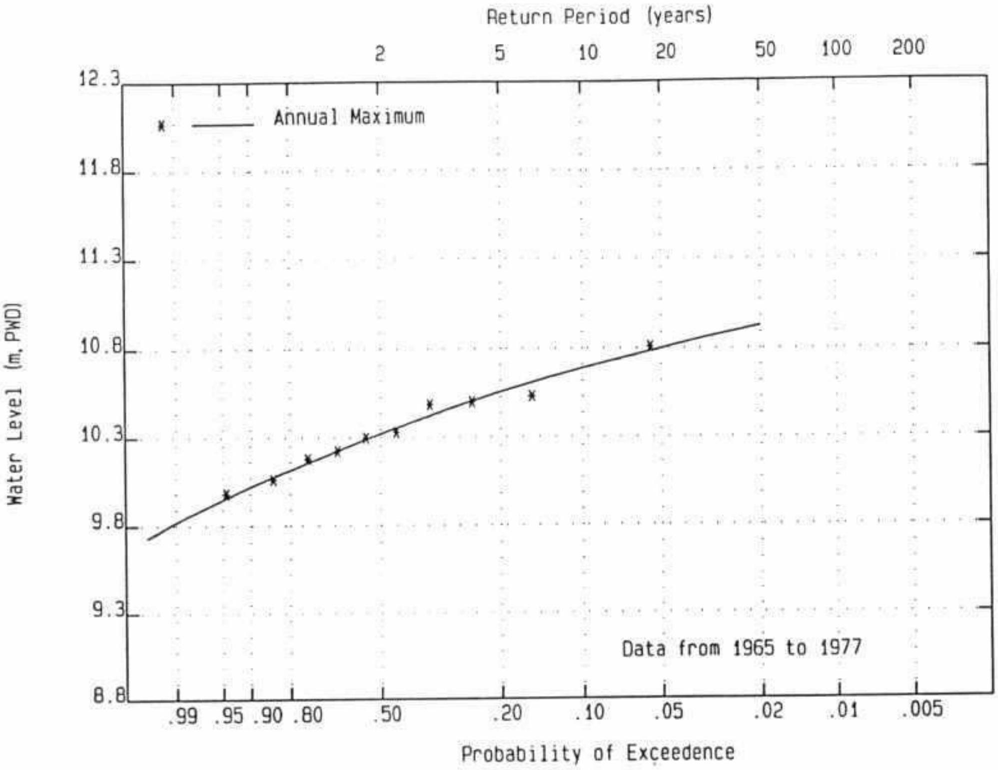
Gauge 296 Titas River at Akhaura
General Extreme Value Distribution



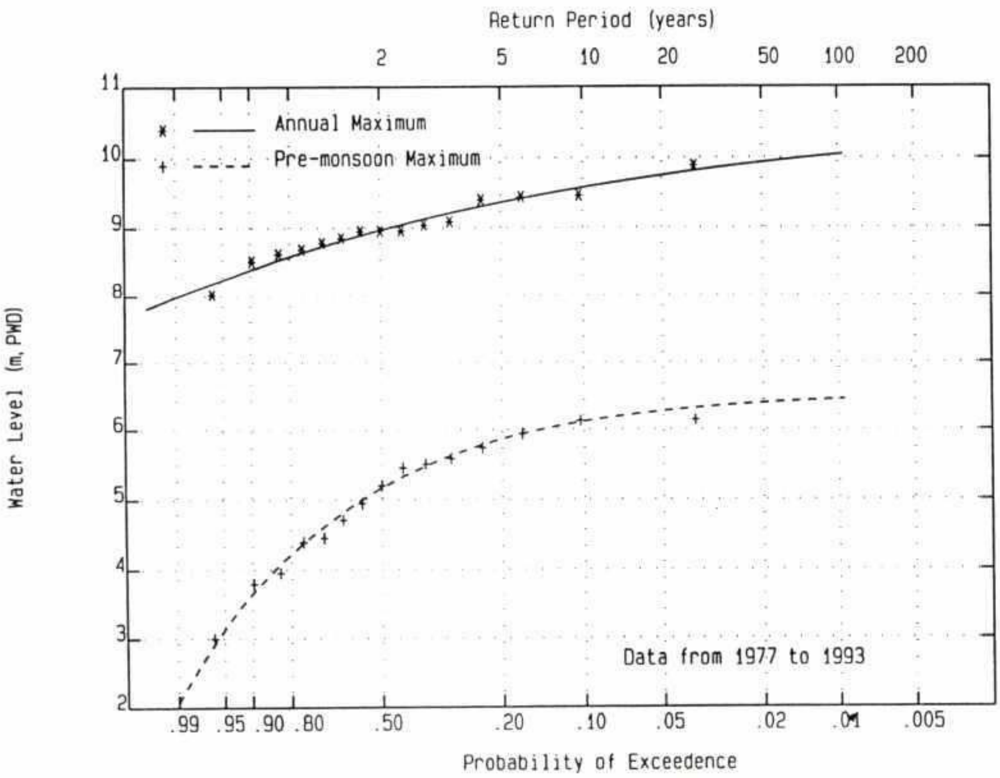
Gauge 297 Titas River at Gokarnaghat
General Extreme Value Distribution



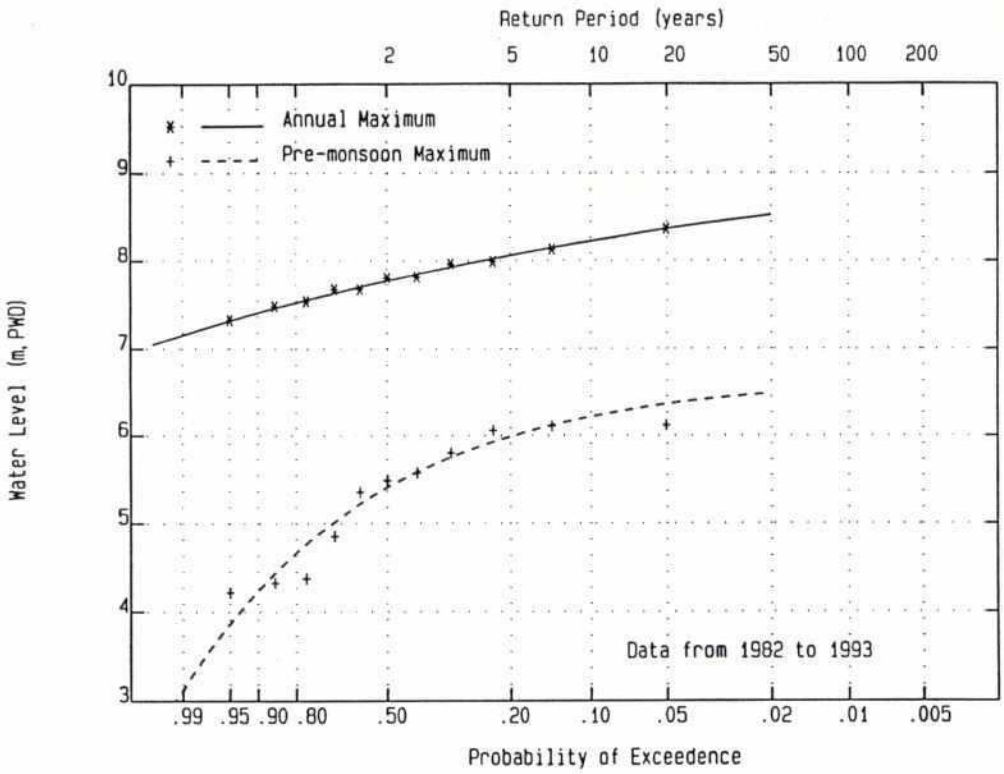
Gauge 298 Titas River at Nabinagar
General Extreme Value Distribution



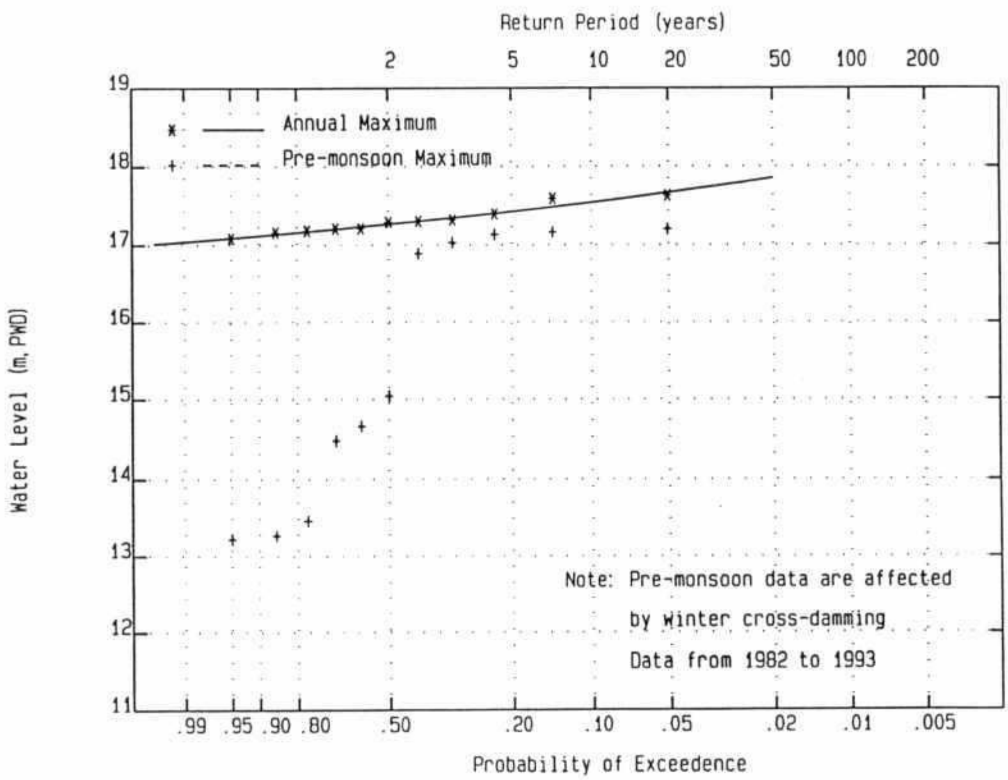
Gauge 308 Khajanchi Nadi at Khajanchigaon Rly. Bridge
General Extreme Value Distribution



Gauge 310 Mogra River at Netrokona
General Extreme Value Distribution

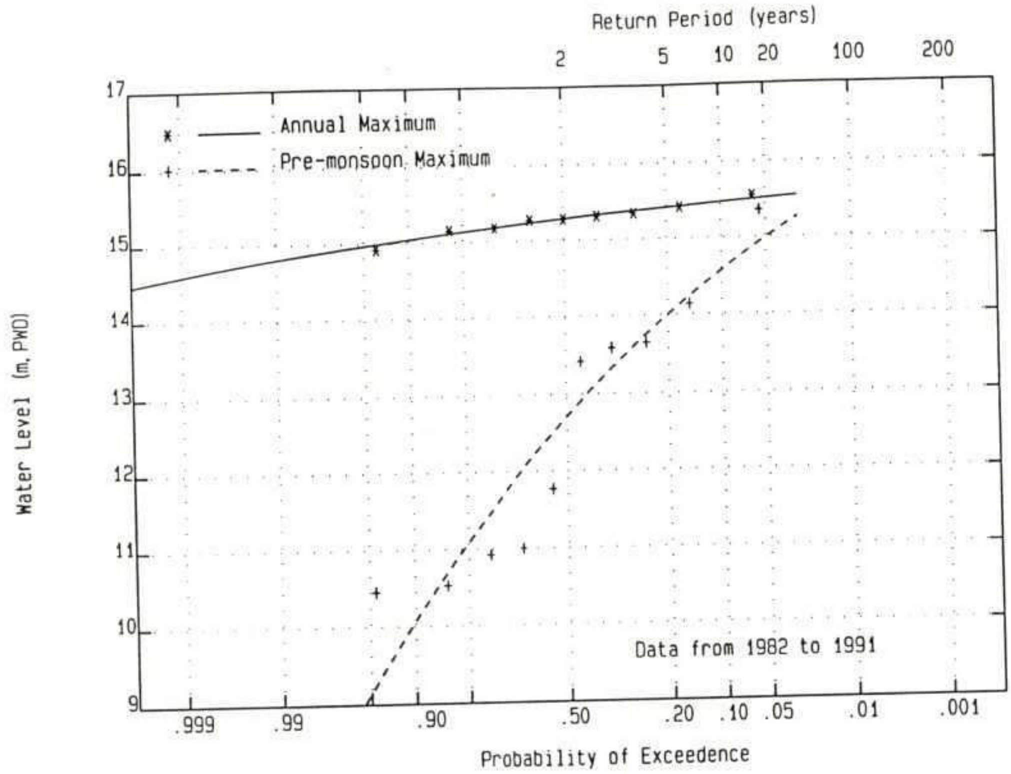


Gauge 311 Mogra River at Atpara
General Extreme Value Distribution

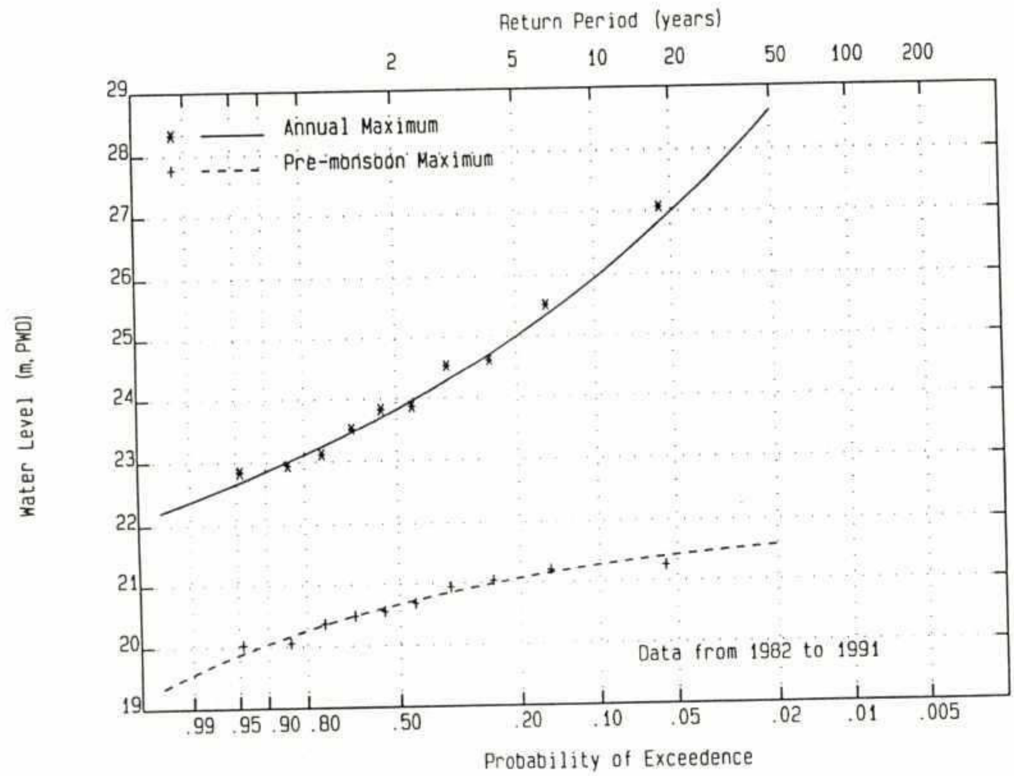


Gauge 314(R) Nitai River at Ghosegaon
General Extreme Value Distribution

२२७

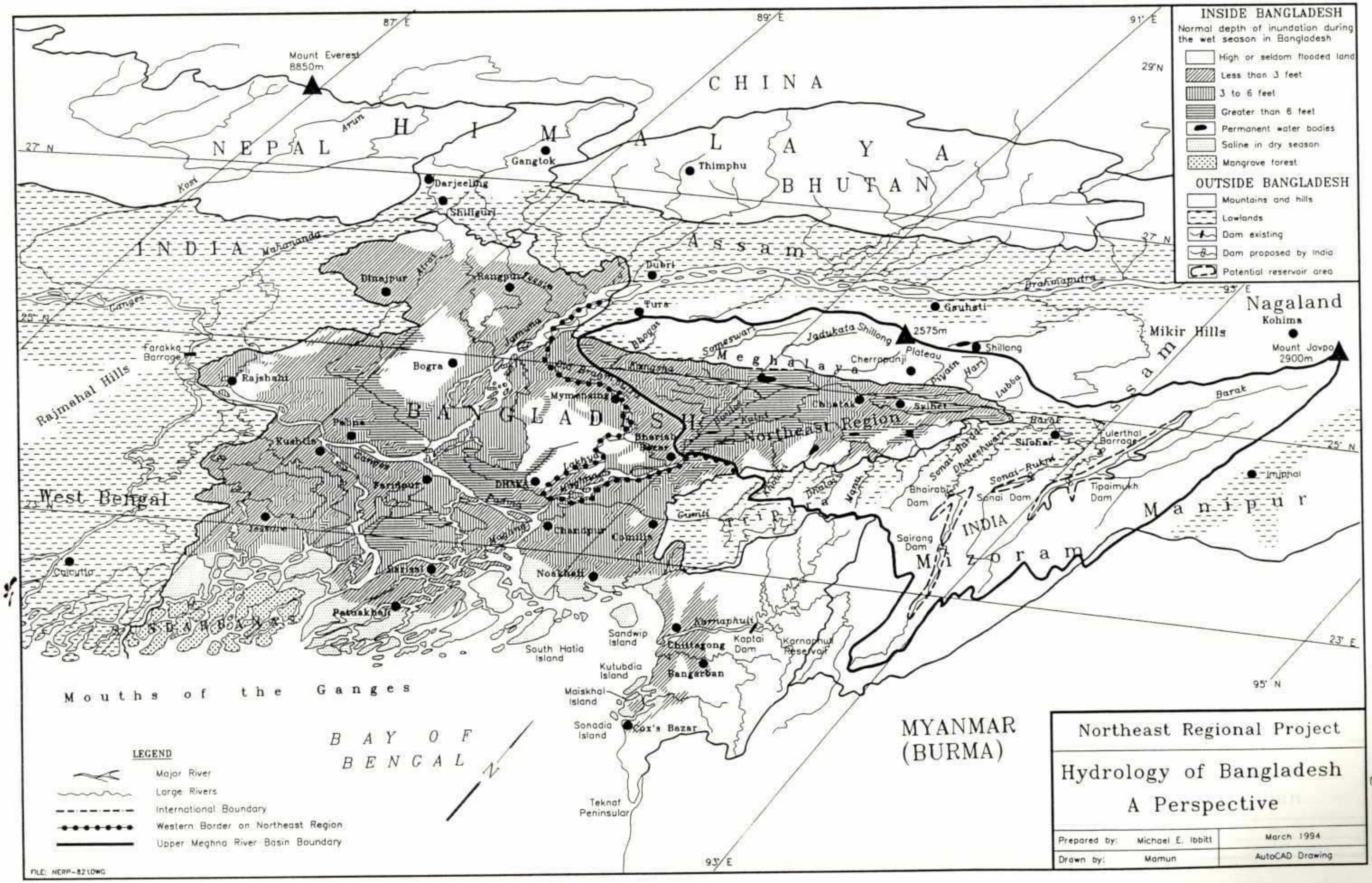


Gauge 326 Lubachara River at Outfall
3-Parameter Log Normal Distribution



Gauge 327 Jinjiram River at Boalmari
General Extreme Value Distribution

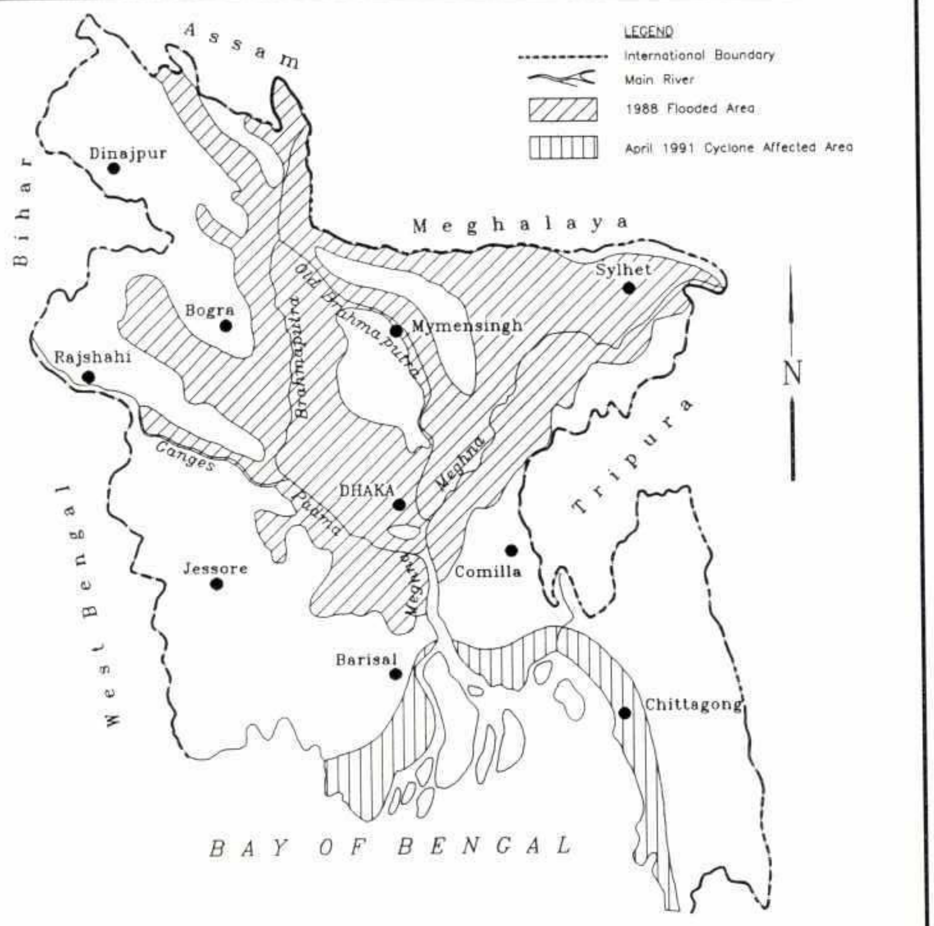
APPENDIX D
Figures



INSIDE BANGLADESH
Normal depth of inundation during the wet season in Bangladesh
High or seldom flooded land
Less than 3 feet
3 to 6 feet
Greater than 6 feet
Permanent water bodies
Saline in dry season
Mangrove forest
OUTSIDE BANGLADESH
Mountains and hills
Lowlands
Dam existing
Dam proposed by India
Potential reservoir area
CHINA
NEPAL
HIMALAYA
BHUTAN
INDIA
Assam
Meghalaya
Nagaland
Manipur
Mizoram
BANGLADESH
Northeast Region
West Bengal
MYANMAR (BURMA)
Mount Everest 8850m
Mount Japvo 2900m
2575m
Mikir Hills
Rajmahal Hills
Shillong Plateau
Farakka Barrage
Mouths of the Ganges
BAY OF BENGAL
N
LEGEND
Major River
Large Rivers
International Boundary
Western Border on Northeast Region
Upper Meghna River Basin Boundary
Northeast Regional Project
Hydrology of Bangladesh
A Perspective
Prepared by: Michael E. Ibbitt
March 1994
Drawn by: Mamun
AutoCAD Drawing
FILE: NERP-821DWG

Figure 1.1

Figure 1.2

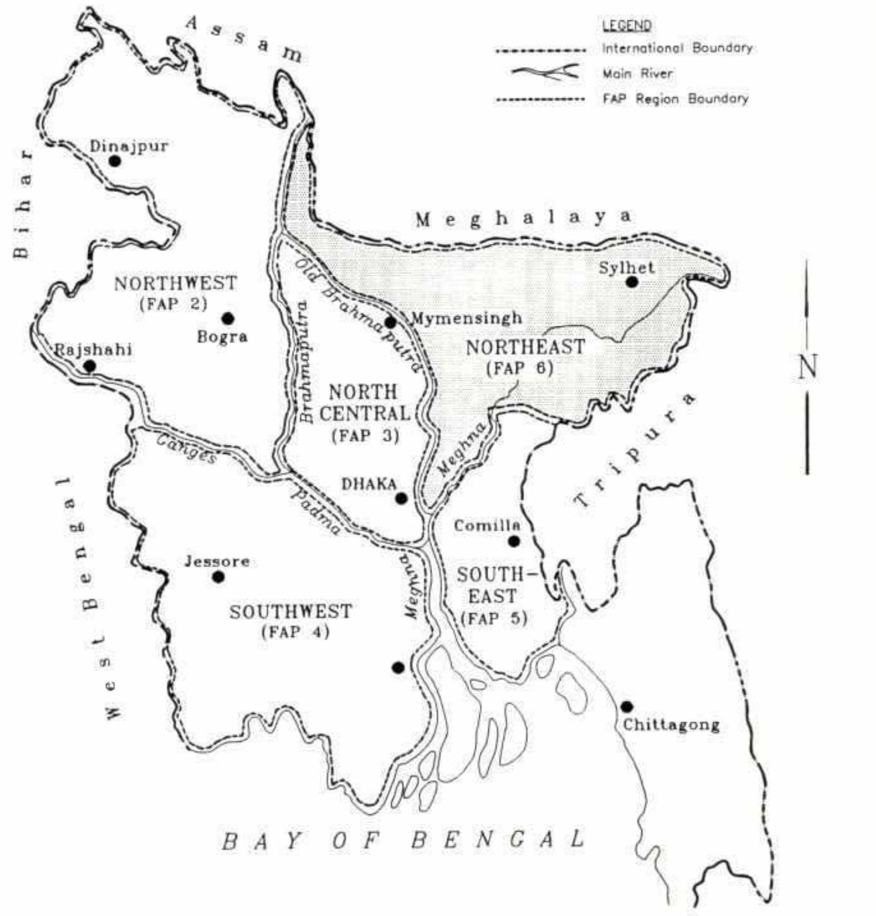


(A) Extent of Flooding in Bangladesh

Source: FPCO+SMEC

Scale 50km 0 50km

FILE: NERP-587.DWG



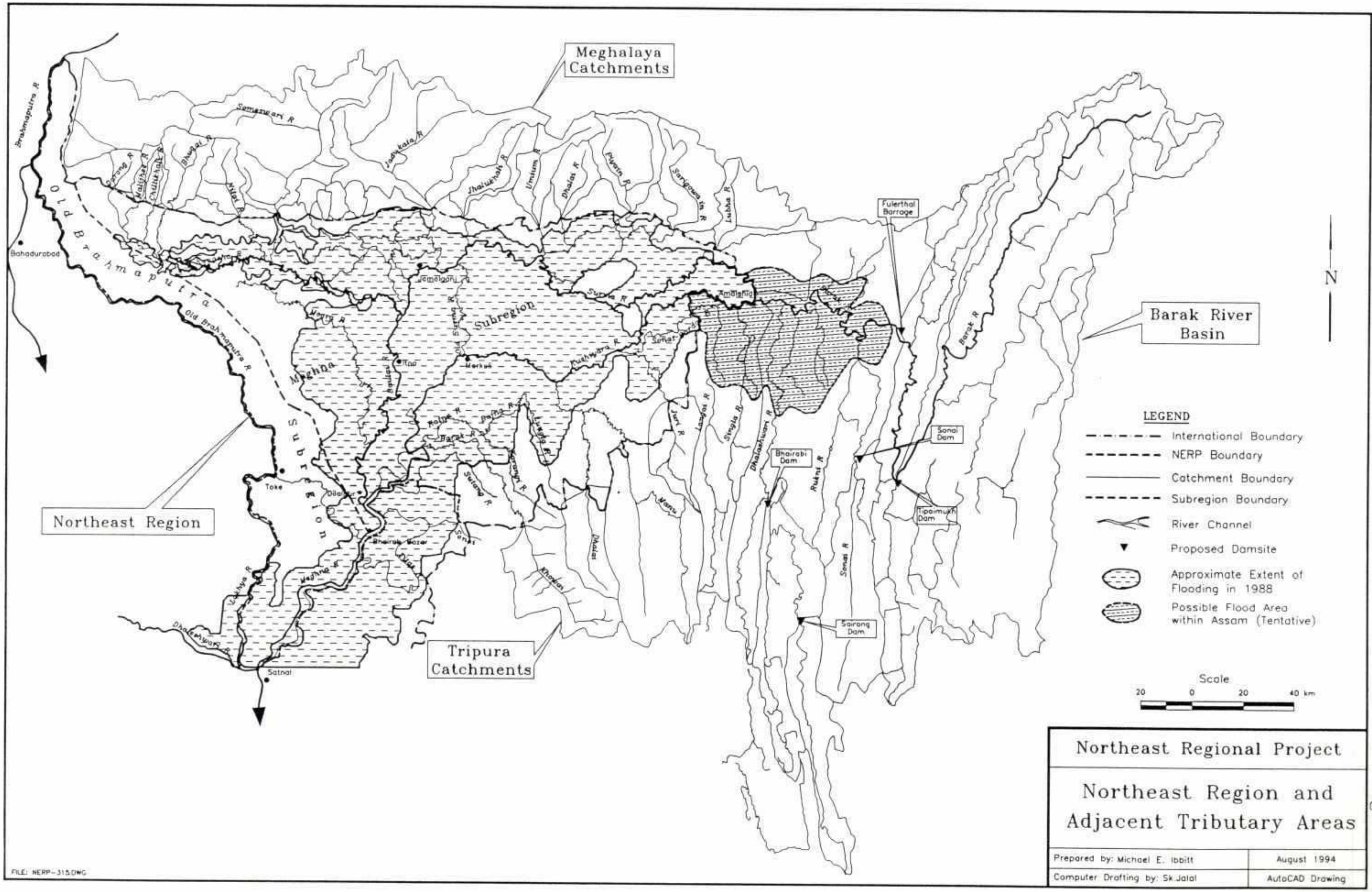
(B) Flood Action Plan Regions

Scale 50km 0 50km

Source: FPCO

Northeast Regional Project			
Flooding and the Flood Action Plan			
Prepared by:	Michael E. Ibbitt	May 1993	
Drawn by:	Mamun	AutoCAD Drawing	

Figure 1.3



Meghalaya Catchments
Barak River Basin
Northeast Region
Tripura Catchments
Old Brahmaputra
Subregion
Meghna
N
Brahmaputra R
Old Brahmaputra R
Bahadurabad
Toke
Satnal
Fulerthal Barrage
Sonai Dam
Tipaimukh Dam
Bhairabi Dam
Sairang Dam
Barak R
Sonai R
Rukni R
Dhaleshwari R
Singla R
Langai R
Juri R
Manu
Dhalai
Khowai
Sutang R
Kushiyara R
Surma R
Lubha R
Sarigowain R
Piyain R
Dhalai R
Umium R
Jhalukhali R
Jadukata R
Someswari R
Bhugai R
Nitai R
Markuli
LEGEND
International Boundary
NERP Boundary
Catchment Boundary
Subregion Boundary
River Channel
Proposed Damsite
Approximate Extent of Flooding in 1988
Possible Flood Area within Assam (Tentative)
Scale
20 0 20 40 km
Northeast Regional Project
Northeast Region and Adjacent Tributary Areas
Prepared by: Michael E. Ibbitt
August 1994
Computer Drafting by: Sk.Jalal
AutoCAD Drawing
FILE: NERP-315.DWG

Figure 2.1

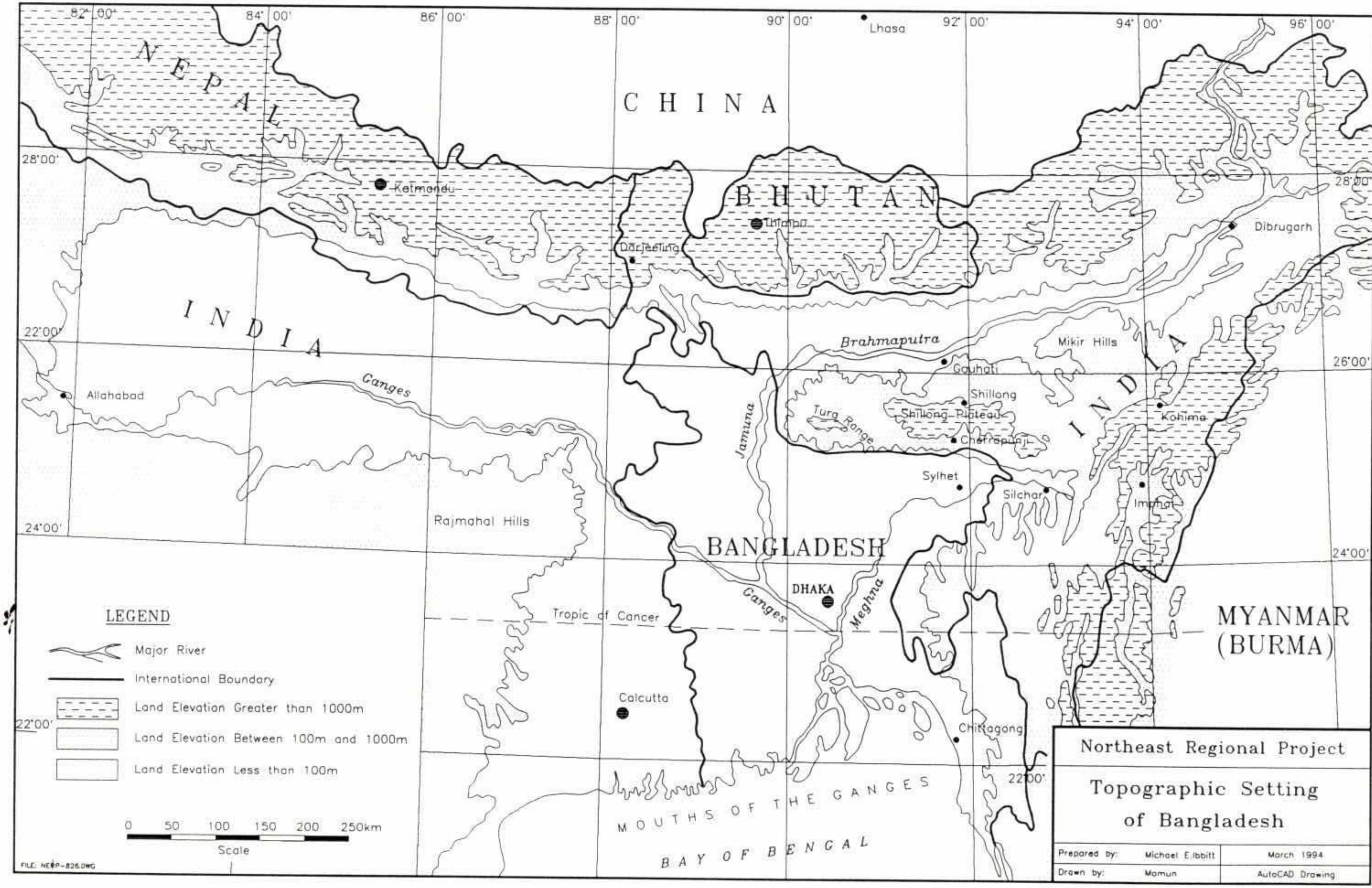
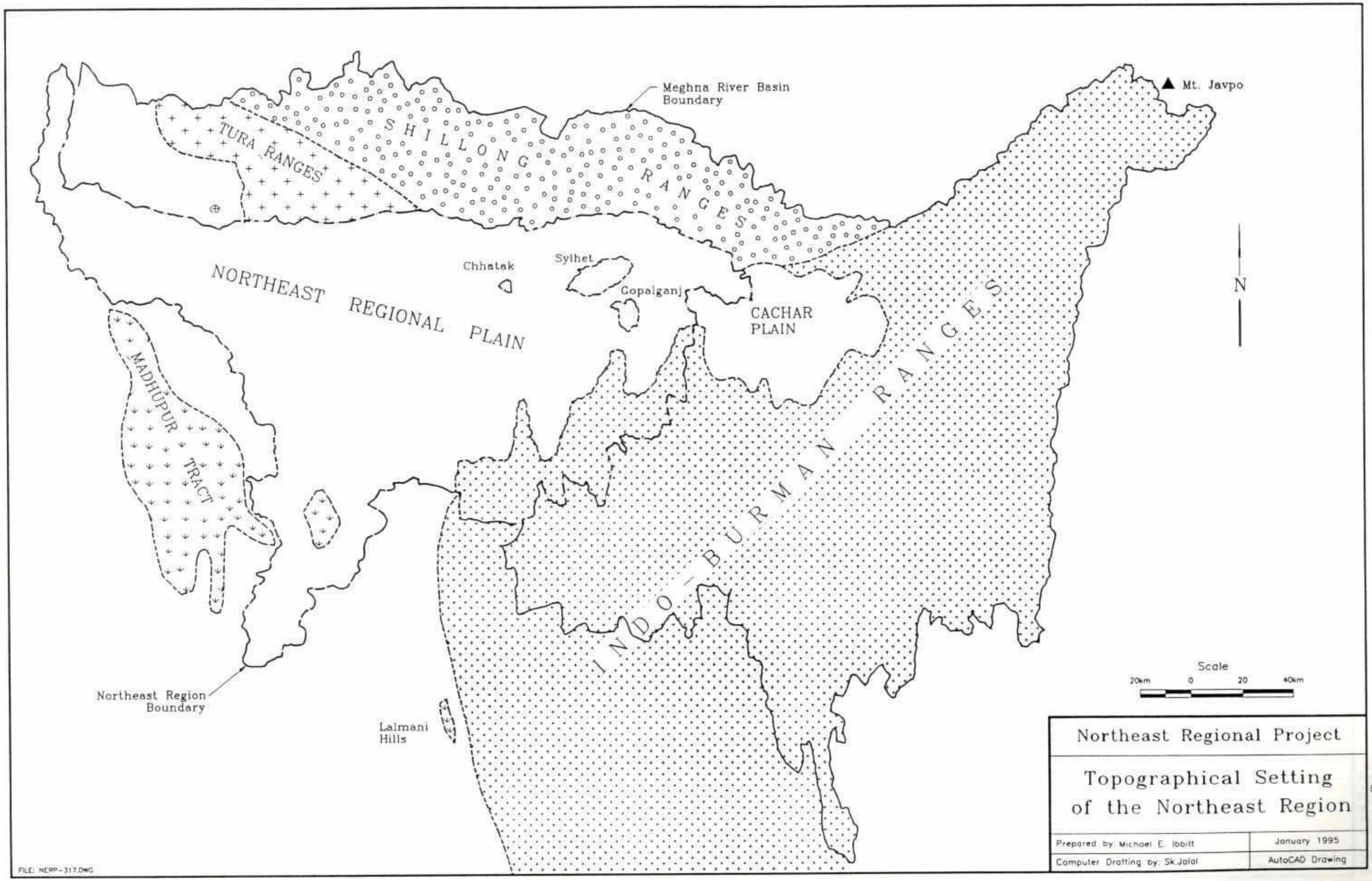
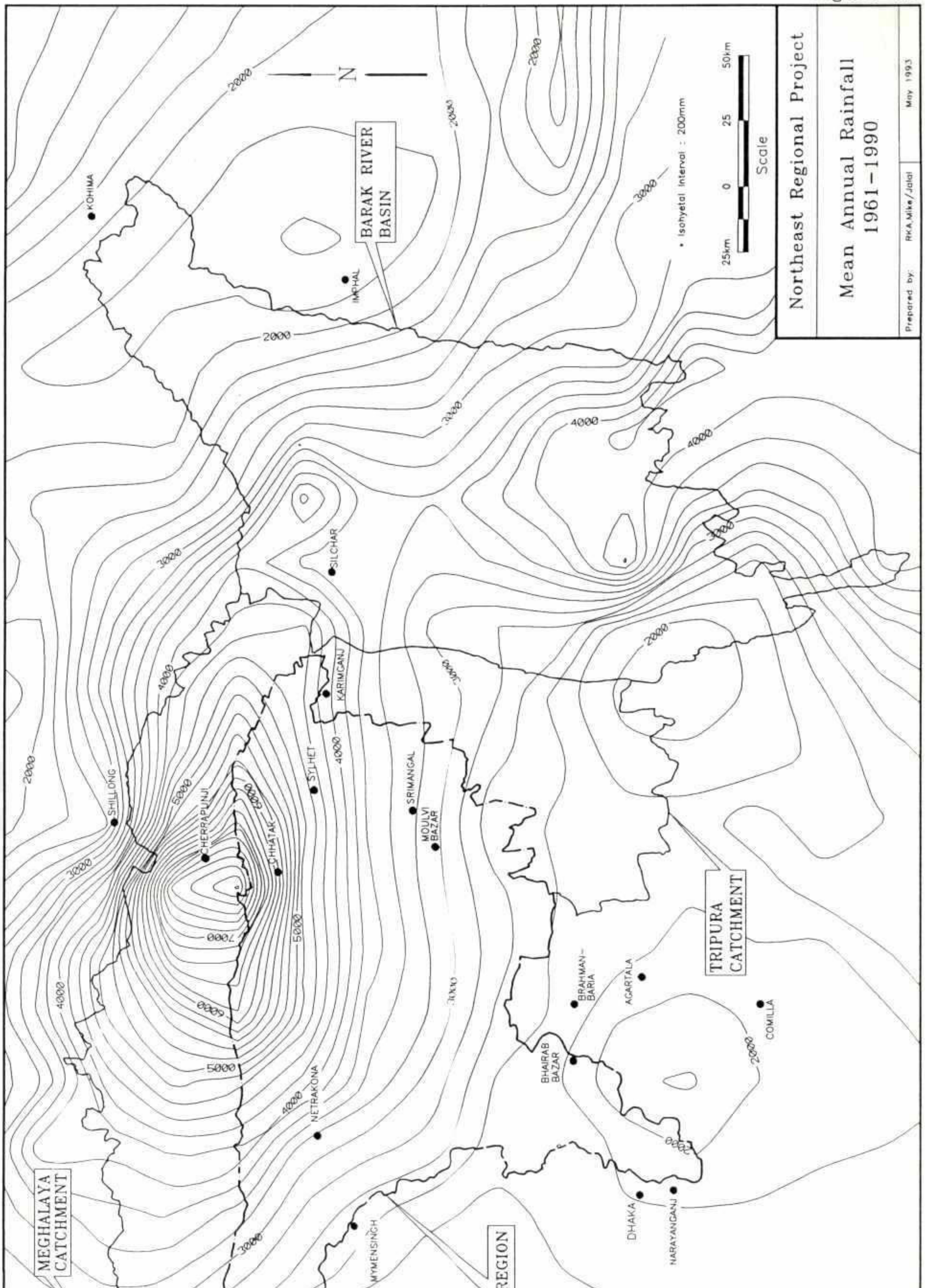

NEPAL
CHINA
BHUTAN
INDIA
BANGLADESH
MYANMAR (BURMA)
Lhasa
Katmandu
Darjeeling
Thimpu
Dibrugarh
Allahabad
Ganges
Brahmaputra
Mikir Hills
Gauhati
Shillong
Shillong Plateau
Cherrapunji
Kohima
Tura Range
Jamuna
Sylhet
Silchar
Imphal
Rajmahal Hills
DHAKA
Meghna
Tropic of Cancer
Calcutta
Chittagong
MOUTHS OF THE GANGES
BAY OF BENGAL
82° 00'
84° 00'
86° 00'
88° 00'
90° 00'
92° 00'
94° 00'
96° 00'
28°00'
26°00'
24°00'
22°00'
LEGEND
Major River
International Boundary
Land Elevation Greater than 1000m
Land Elevation Between 100m and 1000m
Land Elevation Less than 100m
0 50 100 150 200 250km
Scale
Northeast Regional Project
Topographic Setting of Bangladesh
Prepared by: Michael E.Ibbitt
March 1994
Drawn by: Mamun
AutoCAD Drawing

Figure 2.2



Mt. Javpo
Meghna River Basin Boundary
TURA RANGES
SHILLONG RANGES
NORTHEAST REGIONAL PLAIN
Chhatak
Sylhet
Gopalganj
CACHAR PLAIN
MADHUPUR TRACT
INDO-BURMAN RANGES
N
Scale
20km 0 20 40km
Northeast Region Boundary
Lalmani Hills
Northeast Regional Project
Topographical Setting of the Northeast Region
Prepared by: Michael E. Ibbitt
January 1995
Computer Drafting by: Sk.Jalal
AutoCAD Drawing
FILE: NERP-317.DWG

Figure 3.1



Northeast Regional Project
Mean Annual Rainfall
1961-1990
Prepared by: RKA,Mike/Jalal
May 1993
Scale
25km 0 25 50km
• Isohyetal Interval : 200mm
N
BARAK RIVER BASIN
MEGHALAYA CATCHMENT
NORTHEAST REGION
TRIPURA CATCHMENT
KOHIMA
IMPHAL
SILCHAR
KARIMGANJ
SYLHET
SHILLONG
CHERRAPUNJI
CHHATAK
SRIMANGAL
MOULVI BAZAR
BRAHMAN-BARIA
AGARTALA
COMILLA
BHAIRAB BAZAR
NETRAKONA
DHAKA
NARAYANGANJ
MYMENSINGH
JAMALPUR
FILE: NERP-120.DWG

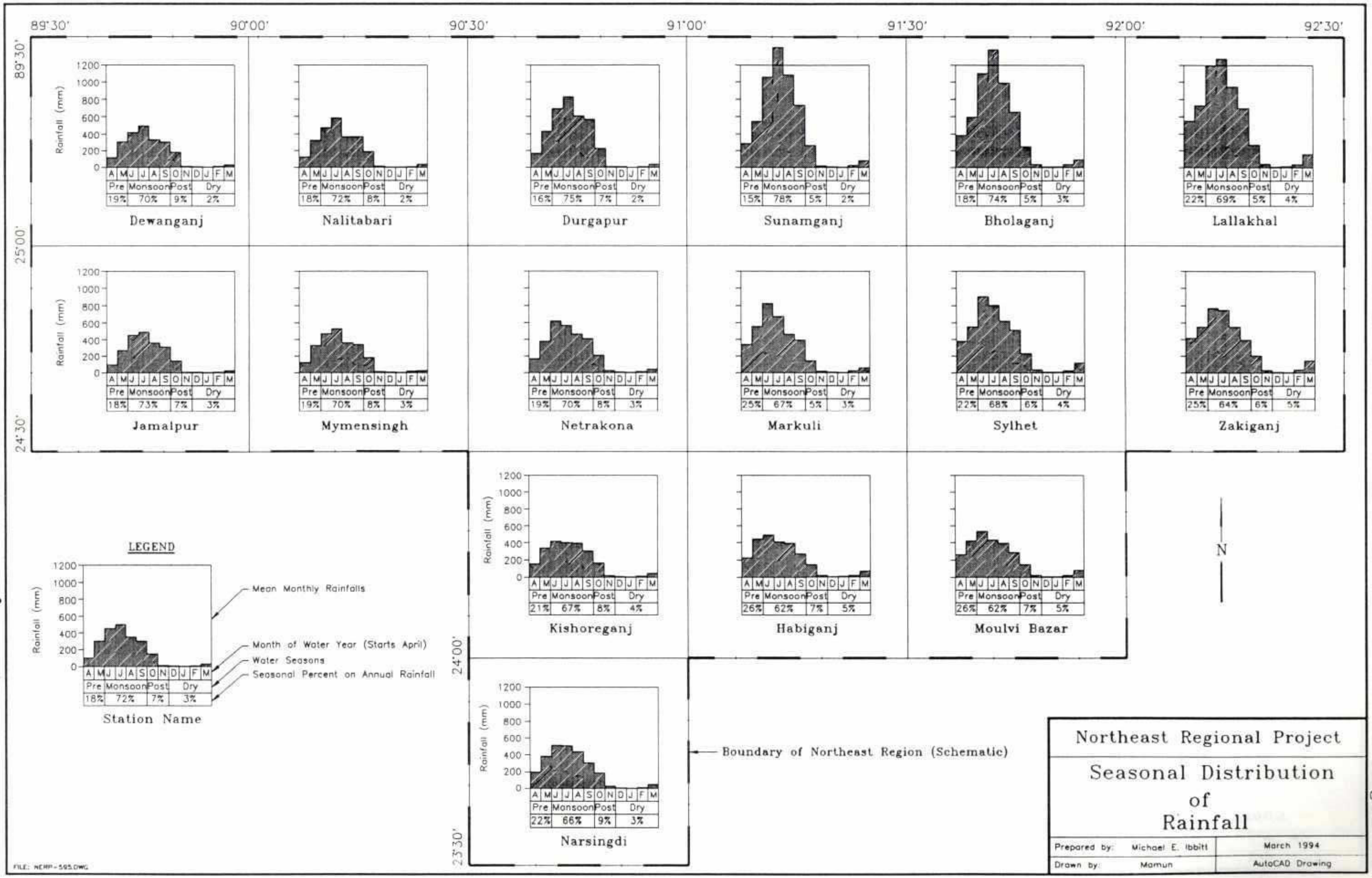
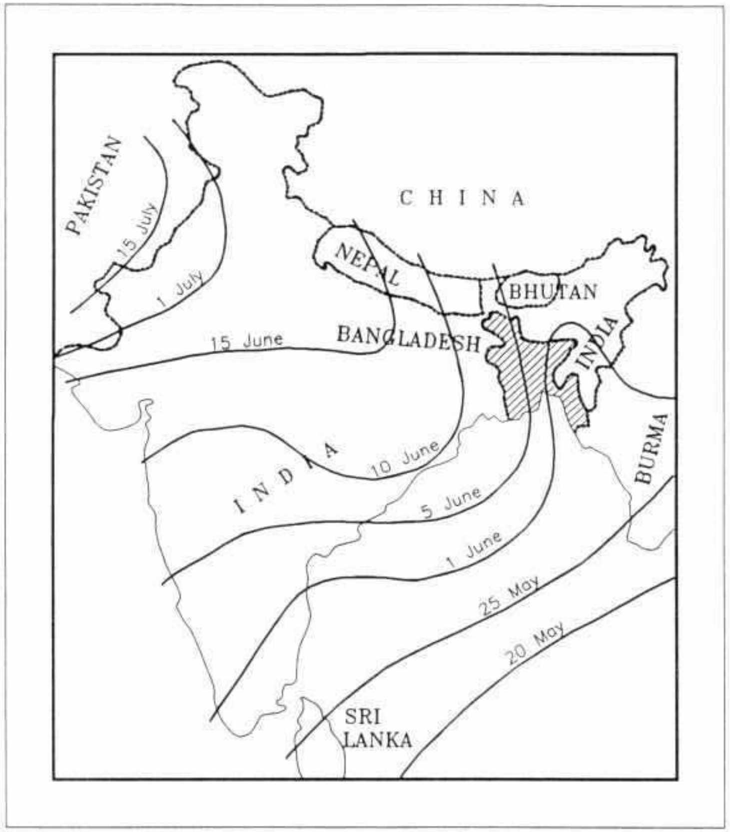

89°30'
90°00'
90°30'
91°00'
91°30'
92°00'
92°30'
25°00'
24°30'
24°00'
23°30'
Rainfall (mm)
1200
1000
800
600
400
200
0
A M J J A S O N D J F M
Pre Monsoon Post Dry
Dewanganj 19% 70% 9% 2%
Nalitabari 18% 72% 8% 2%
Durgapur 16% 75% 7% 2%
Sunamganj 15% 78% 5% 2%
Bholaganj 18% 74% 5% 3%
Lallakhal 22% 69% 5% 4%
Jamalpur 18% 73% 7% 3%
Mymensingh 19% 70% 8% 3%
Netrakona 19% 70% 8% 3%
Markuli 25% 67% 5% 3%
Sylhet 22% 68% 6% 4%
Zakiganj 25% 64% 6% 5%
Kishoreganj 21% 67% 8% 4%
Habiganj 26% 62% 7% 5%
Moulvi Bazar 26% 62% 7% 5%
Narsingdi 22% 66% 9% 3%
LEGEND
Mean Monthly Rainfalls
Month of Water Year (Starts April)
Water Seasons
Seasonal Percent on Annual Rainfall
18% 72% 7% 3%
Station Name
N
Boundary of Northeast Region (Schematic)
Northeast Regional Project
Seasonal Distribution of Rainfall
Prepared by: Michael E. Ibbitt
March 1994
Drawn by: Mamun
AutoCAD Drawing
FILE: NERP-595.DWG

Figure 3.2

Figure 3.3



Normal Dates of Onset of the Summer Monsoon

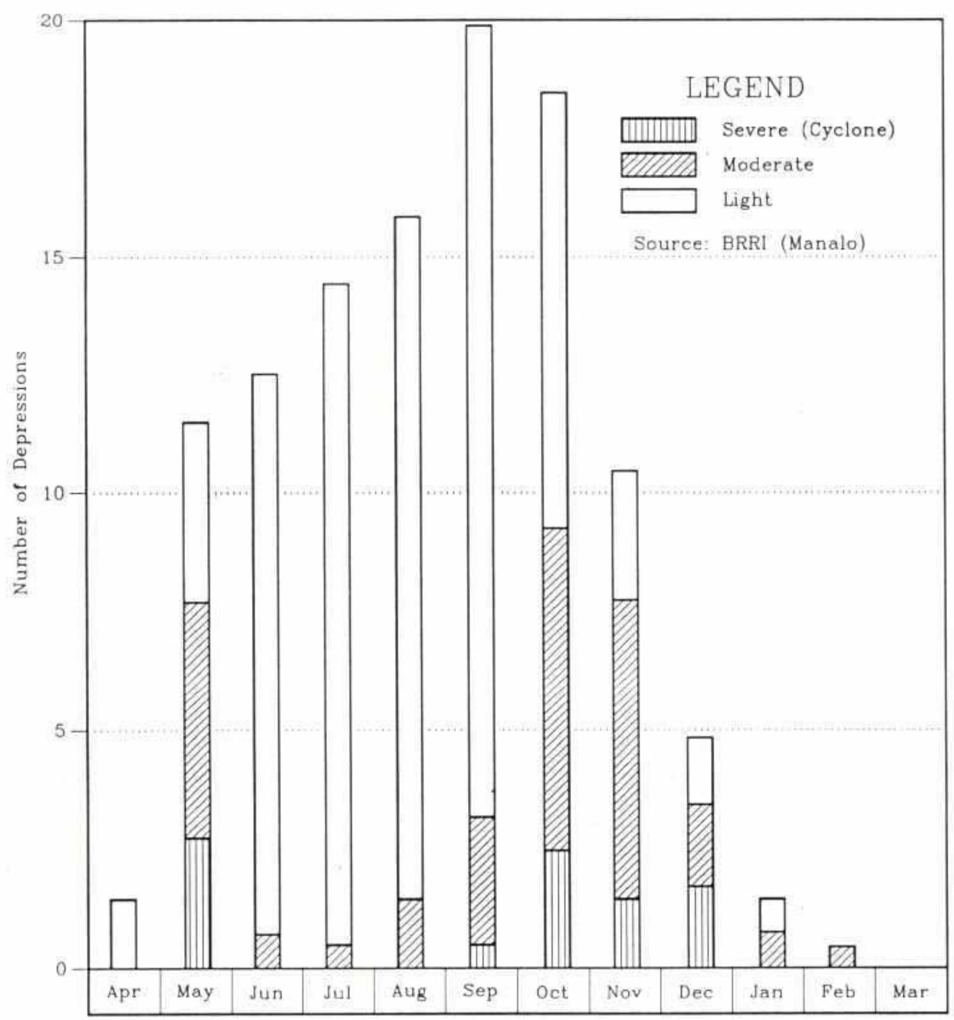
Normal Dates of Withdrawal of the Summer Monsoon

Source : Fein & Stephens, "Monsoons" 1987

Northeast Regional Project			
Onset and Withdrawal of the Summer Monsoon			
Prepared by:	Michael E. Ibbitt	May 1993	
Drawn by:	Mamun	AutoCAD Drawing	

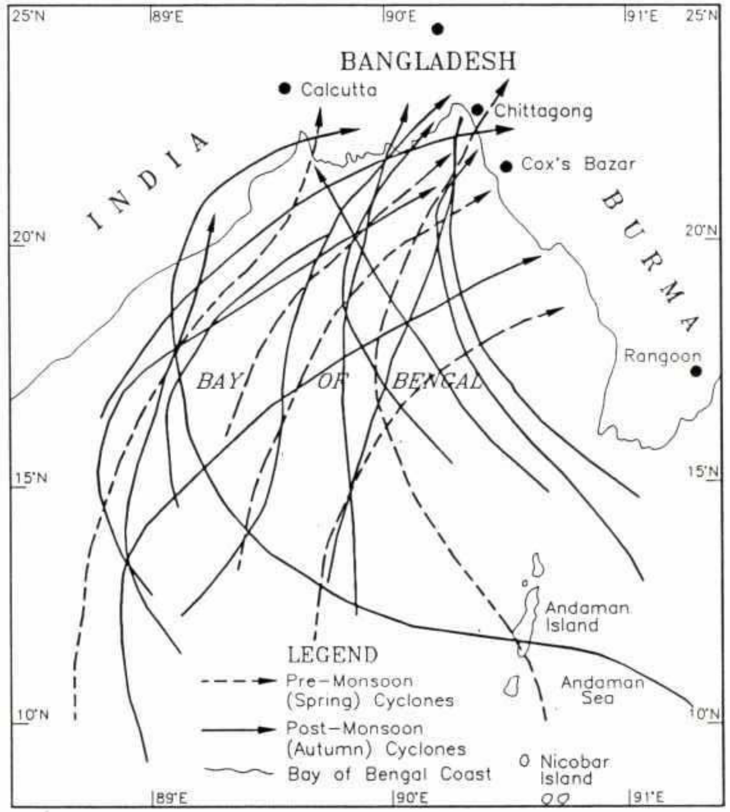
FILE: NERP-600.DWG

Figure 3.4



Average Number of Tropical Depressions in Ten Years

(A)



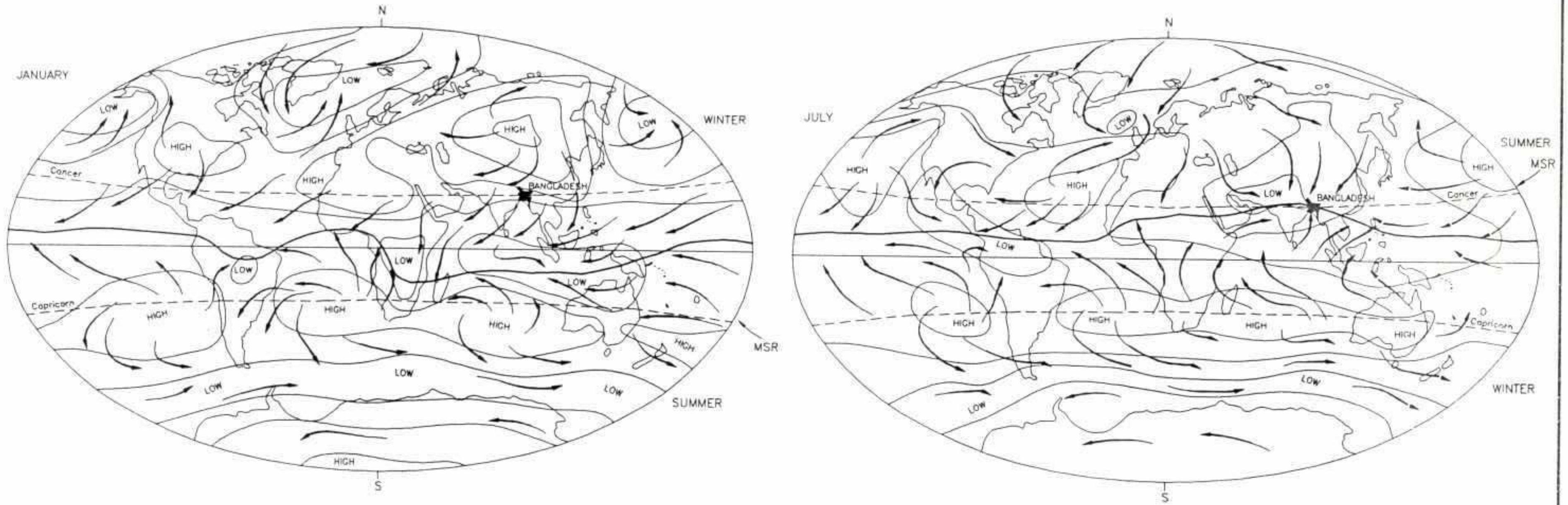
Cyclone Storm Tracks in the Bay of Bengal 1960-90

(B)

Northeast Regional Project	
Frequency of Tropical Depressions and Tracks of Tropical Cyclones	
Prepared by: Michael E. Ibbitt	January 1995
Computer Drafting by: Jalal	AutoCAD Drawing

FILE: NERP-592.DWG

Figure 3.5



(A) JANUARY

(B) JULY

Legend

- Pressure
- Surface Wind
- ITCZ
- MSR Maximum Solar Radiation

Northeast Regional Project	
General Circulation of the Lower Atmosphere	
Prepared by: Michael E. Ibbitt	March 1995
Computer Drafting by: Sk.Jalal	AutoCAD Drawing

FILE: NERP-330.DWG

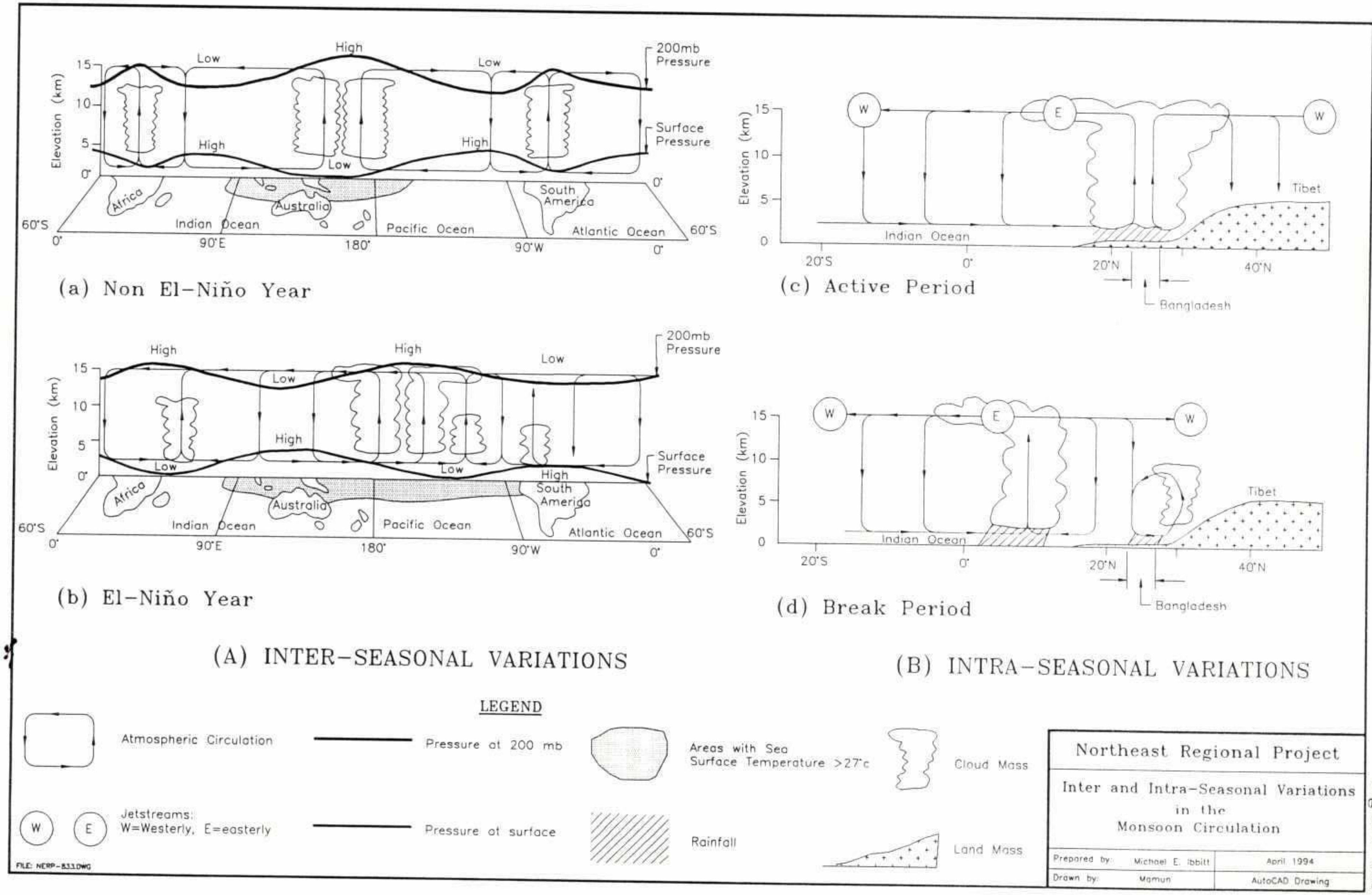
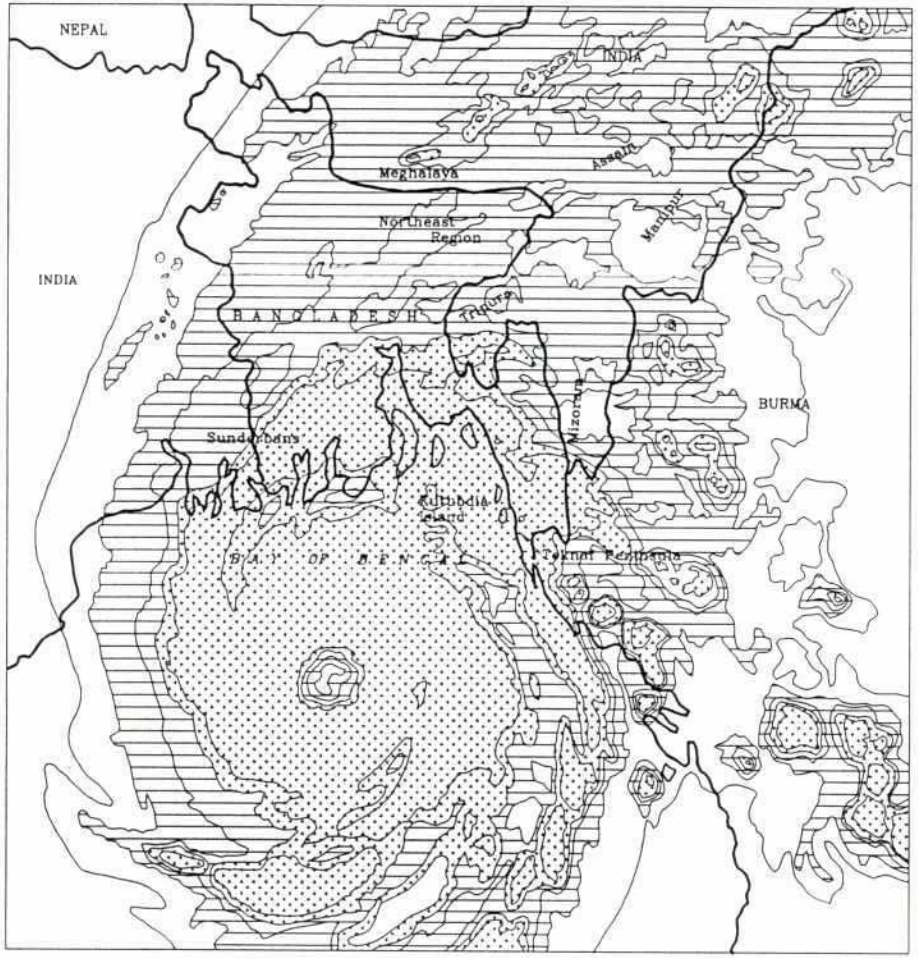

15
10
5
0°
Elevation (km)
Low
High
Low
High
High
Low
Low
High
200mb Pressure
Surface Pressure
Africa
Australia
South America
Indian Ocean
Pacific Ocean
Atlantic Ocean
60°S
0°
90°E
180°
90°W
(a) Non El-Niño Year
High
Low
High
High
Low
Low
Low
High
200mb Pressure
Surface Pressure
(b) El-Niño Year
(A) INTER-SEASONAL VARIATIONS
W
E
Tibet
Indian Ocean
20°S
0°
20°N
40°N
Bangladesh
(c) Active Period
(d) Break Period
(B) INTRA-SEASONAL VARIATIONS
LEGEND
Atmospheric Circulation
Pressure at 200 mb
Areas with Sea Surface Temperature >27°c
Cloud Mass
Jetstreams: W=Westerly, E=easterly
Pressure at surface
Rainfall
Land Mass
FILE: NERP-833.DWG
Northeast Regional Project
Inter and Intra-Seasonal Variations in the Monsoon Circulation
Prepared by: Michael E. Ibbitt
April 1994
Drawn by: Mamun
AutoCAD Drawing

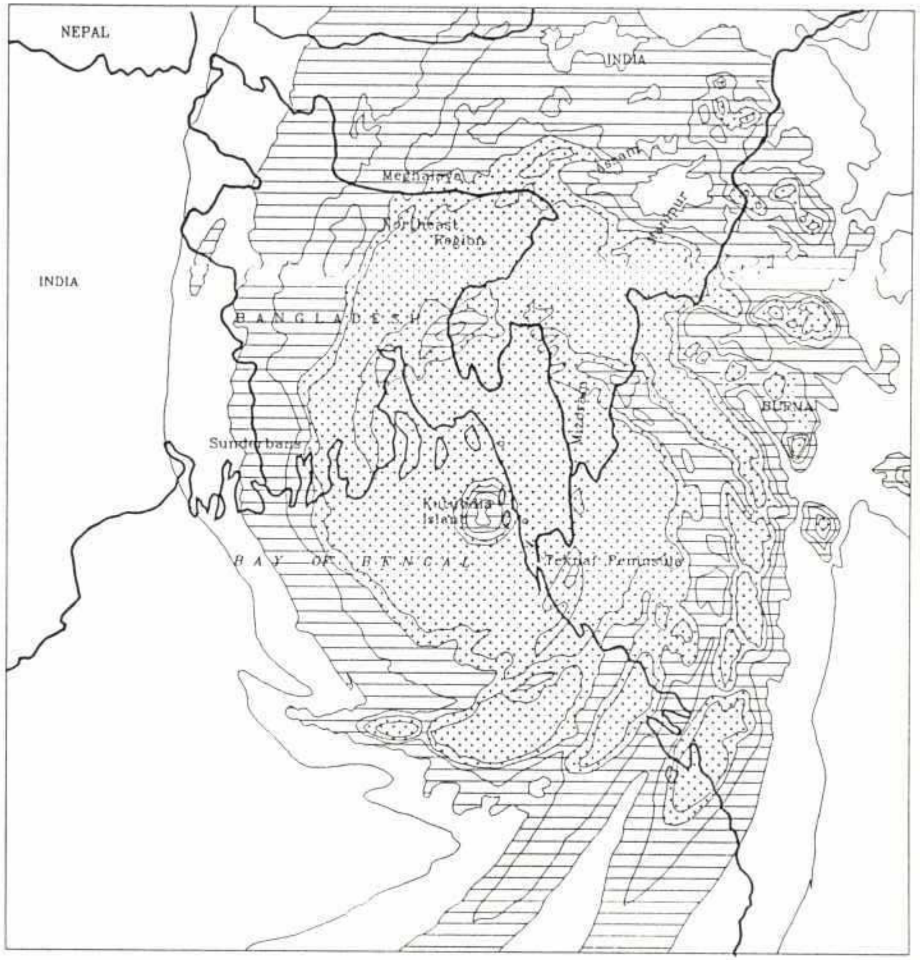
Figure 3.6



A) SATELLITE VIEW PRIOR TO LAND FALL
This view shows the cyclone as it actually was when still 300km offshore. The circulation is anti-clockwise. Notice how air is streaming into the cyclone, across the Northeast Region, from the northeast and the thunderstorms in this stream over Meghalaya.

Source: NOAA

CLOUD TOP TEMPERATURE
Warmest Coldest



B) TRANSPOSED SATELLITE VIEW AT LANDFALL
This view shows the cyclone as it might have been at the time of landfall on Kutubdia island. Notice how air would stream into the Northeast Region from the southeast giving rise to widespread intense rainfall over the Region.

Scale
0 250km

Northeast Regional Project

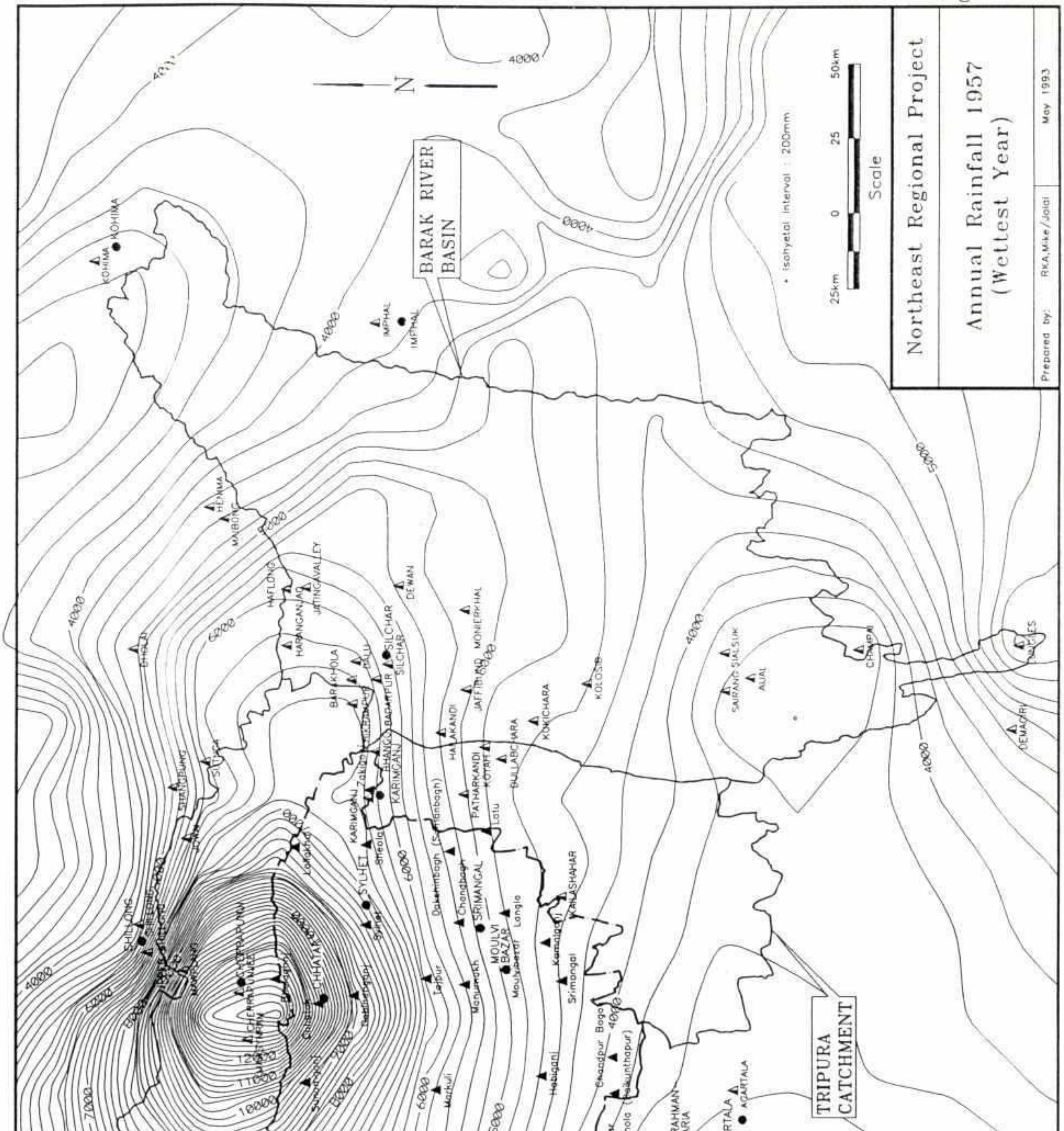
Cyclone of April 1991

Prepared by: Michael E. Ibbitt	April 1994
Computer Drafting by: Sk Jalal	AutoCAD Drawing

FILE: NERP-265.DWG

229

Figure 4.1



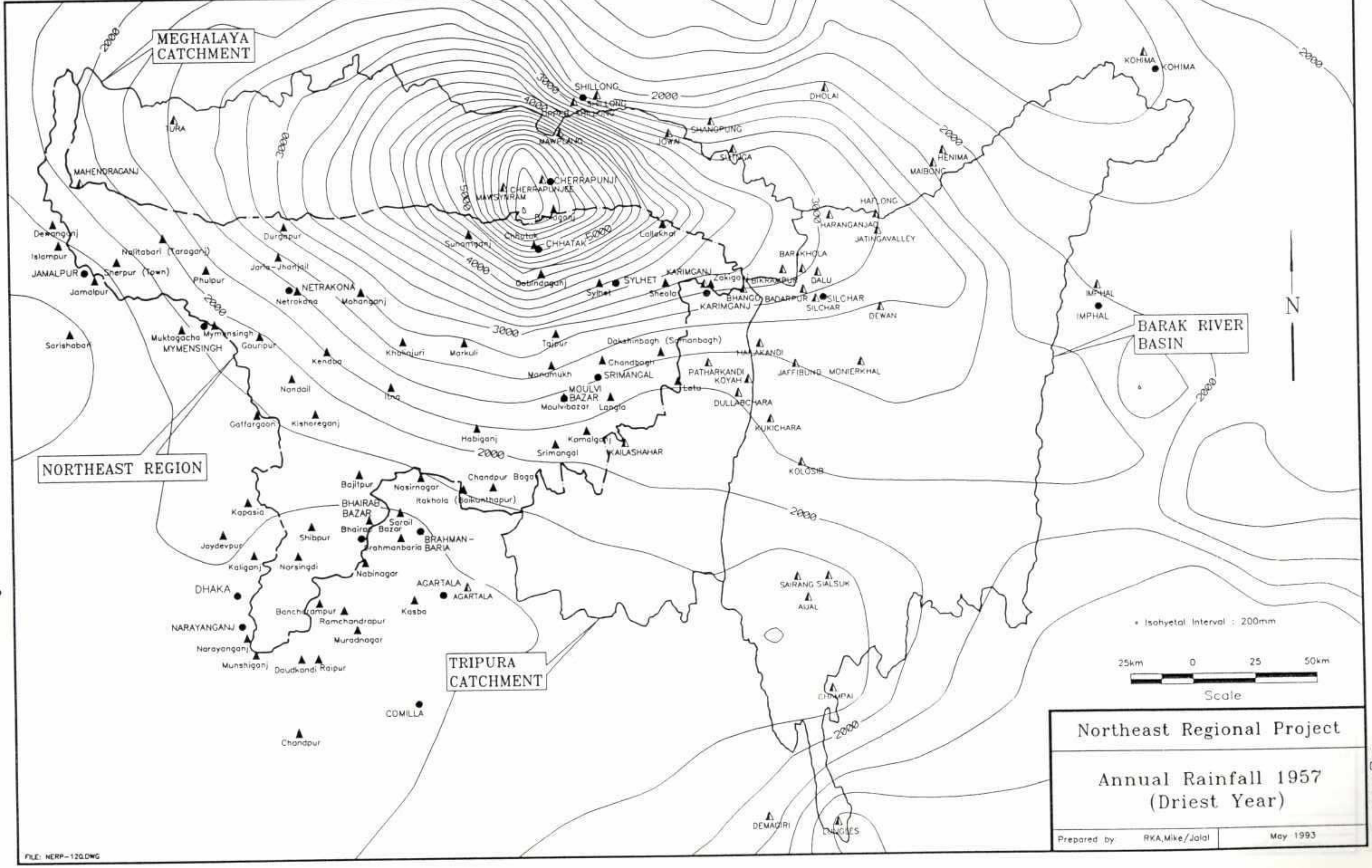
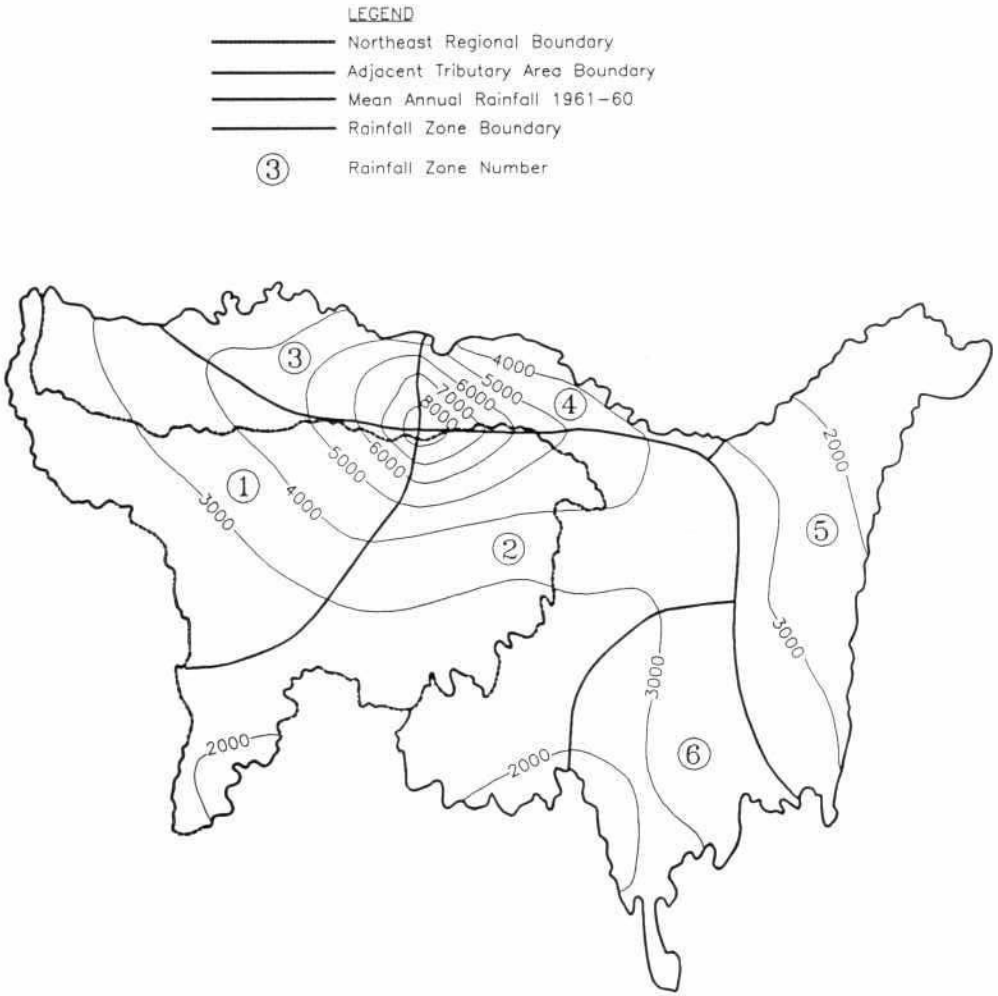
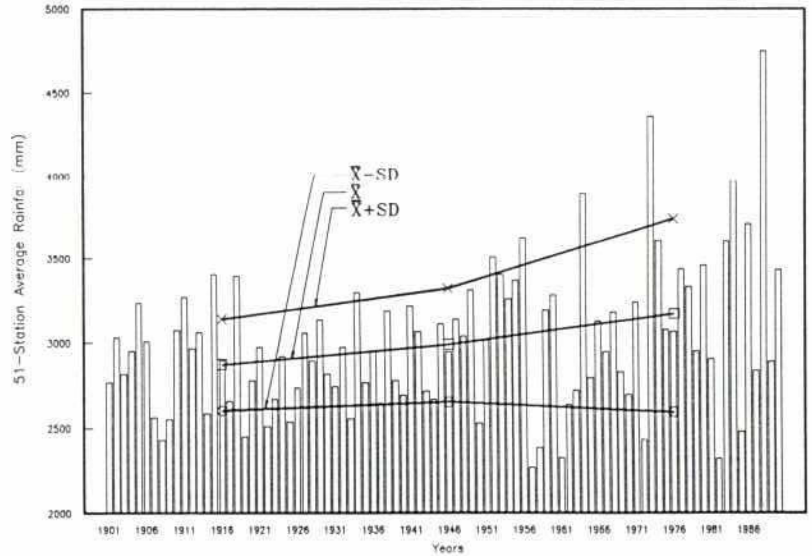

MEGHALAYA CATCHMENT
NORTHEAST REGION
TRIPURA CATCHMENT
BARAK RIVER BASIN
N
SHILLONG
CHERRAPUNJI
SYLHET
SILCHAR
IMPHAL
KOHIMA
AGARTALA
DHAKA
COMILLA
MYMENSINGH
JAMALPUR
NETRAKONA
SRIMANGAL
MOULVI BAZAR
KARIMGANJ
NARAYANGANJ
BRAHMAN-BARIA
BHAIRAB BAZAR
CHHATAK
2000
3000
4000
5000
* Isohyetal Interval : 200mm
25km 0 25 50km
Scale
Northeast Regional Project
Annual Rainfall 1957
(Driest Year)
Prepared by RKA,Mike/Jalal
May 1993
FILE: NERP-120.DWG

Figure 4.2



Rainfall Zones of the Northeast Region
and Adjacent Tributary Areas

(A)



Time Variation of the 51-Station Average Rainfall

NOTE

X= mean of 30 years of 51-station average annual rainfalls

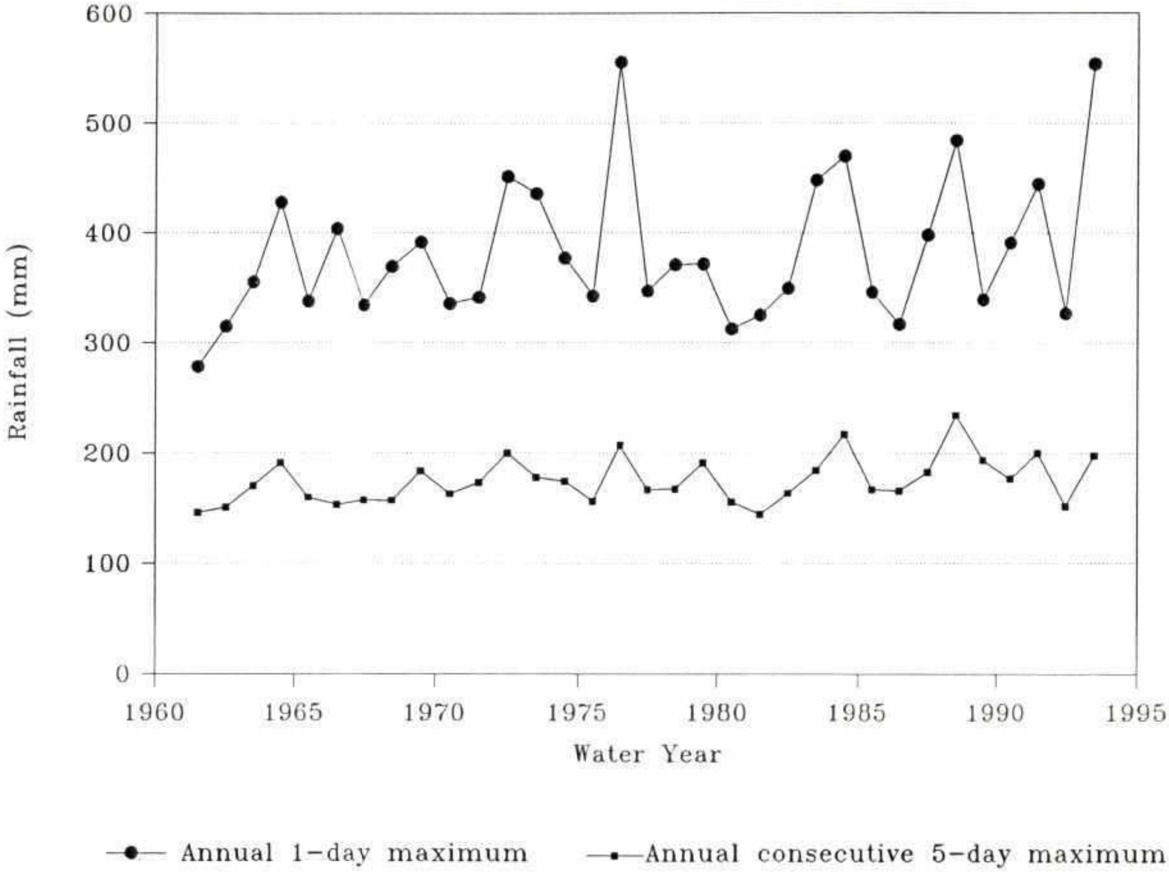
SD= standard deviation of 30 years of 51-station average annual rainfalls

(B)

Northeast Regional Project	
Spatial and Temporal Distributions of Mean Annual Rainfall	
Prepared by: Michael E. Ibbitt	May 1993
Drawn by: Mamun	AutoCAD Drawing

FILE: NERP-593.DWG

Figure 4.3

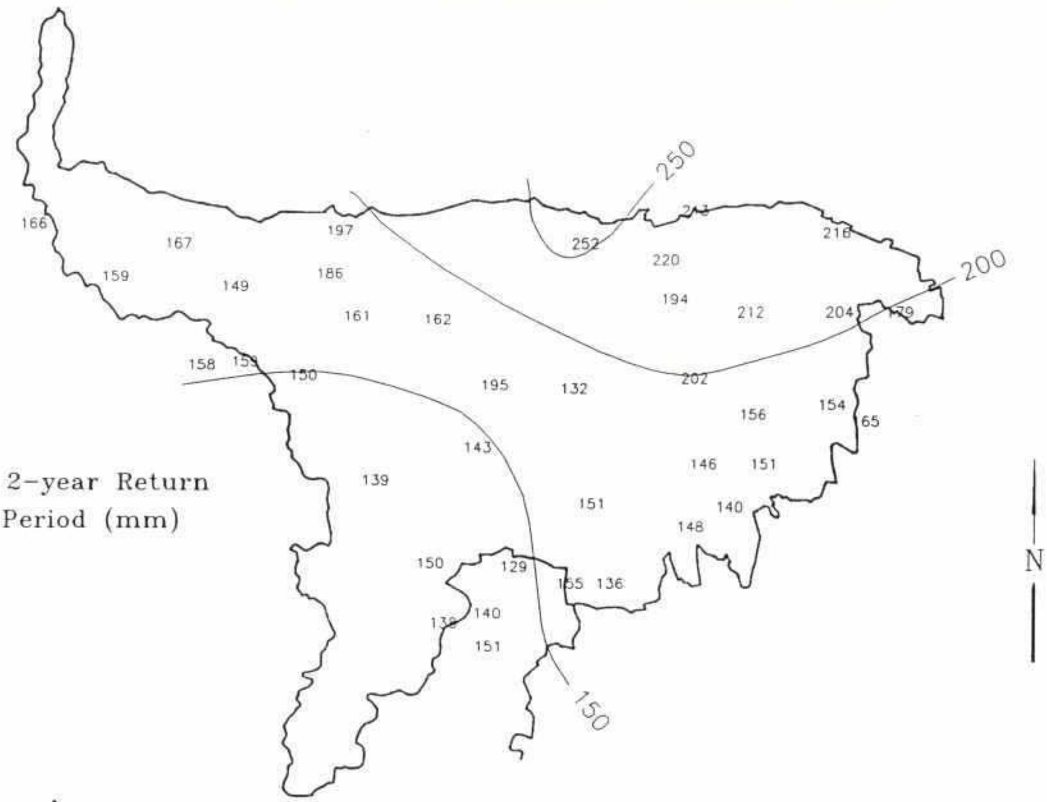


Regional averages of 39 stations

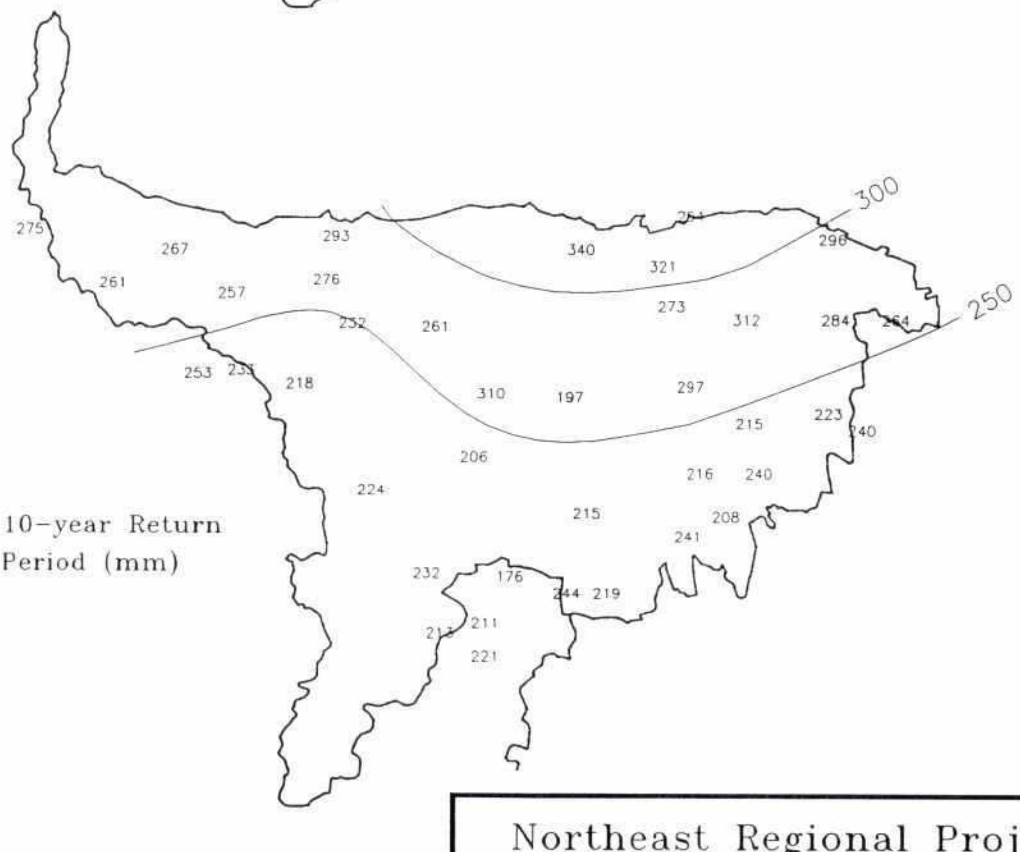
Northeast Regional Project	
Time Series of Annual Maximum 1-day and 5-day Rainfalls	
Prepared by: Larry	June 1995
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-960.DWG

Figure 4.5



(a) 2-year Return Period (mm)



(b) 10-year Return Period (mm)

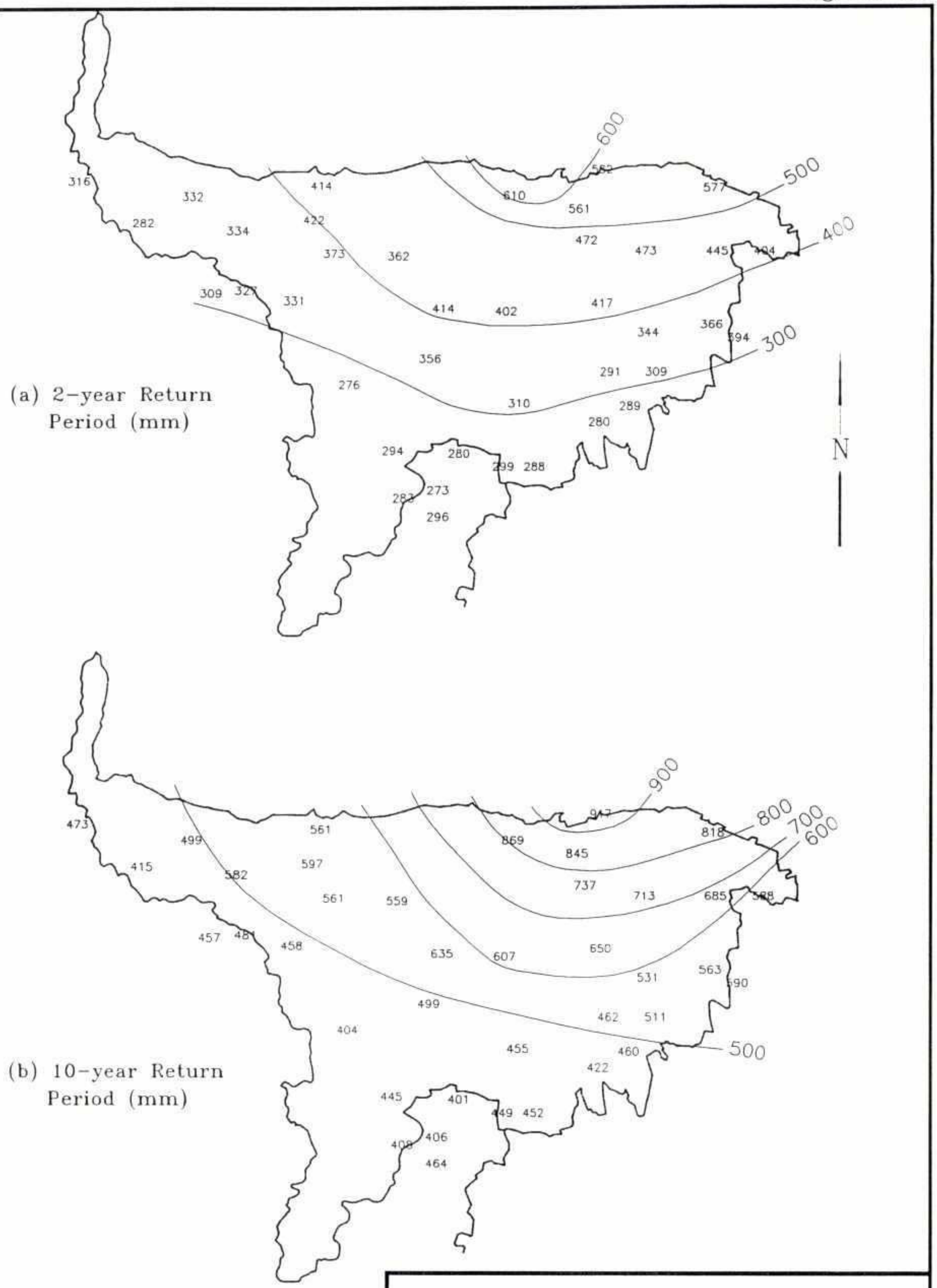
Northeast Regional Project

Mapping of 2 and 10-year Maximum 1-day Rainfall

Prepared by: Larry	June 1995
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-958.DWG

Figure 4.6



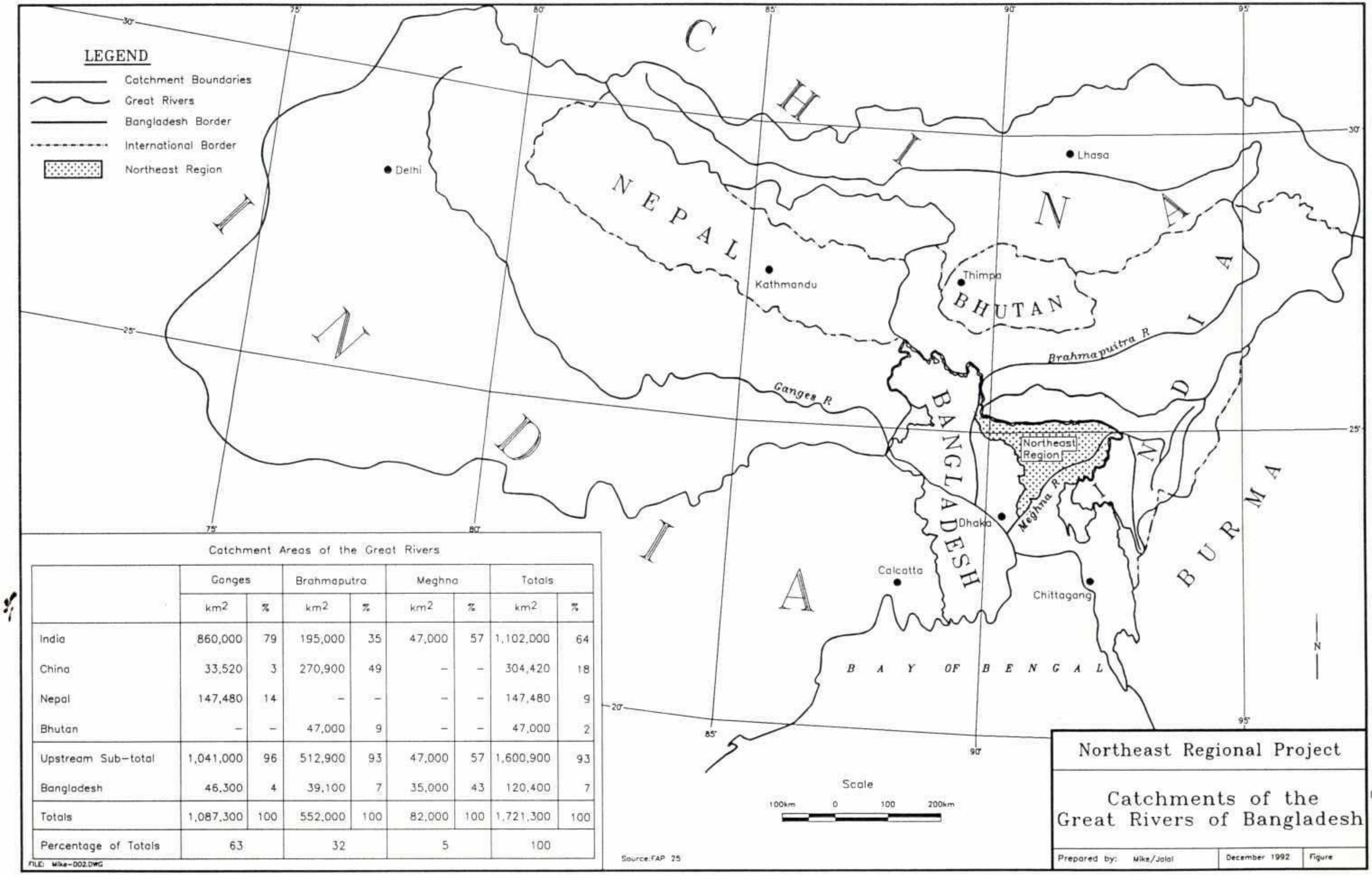
Northeast Regional Project

Mapping of 2 and 10 year Maximum 5-day Rainfall

Prepared by: Larry	June 1995
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-959.DWG

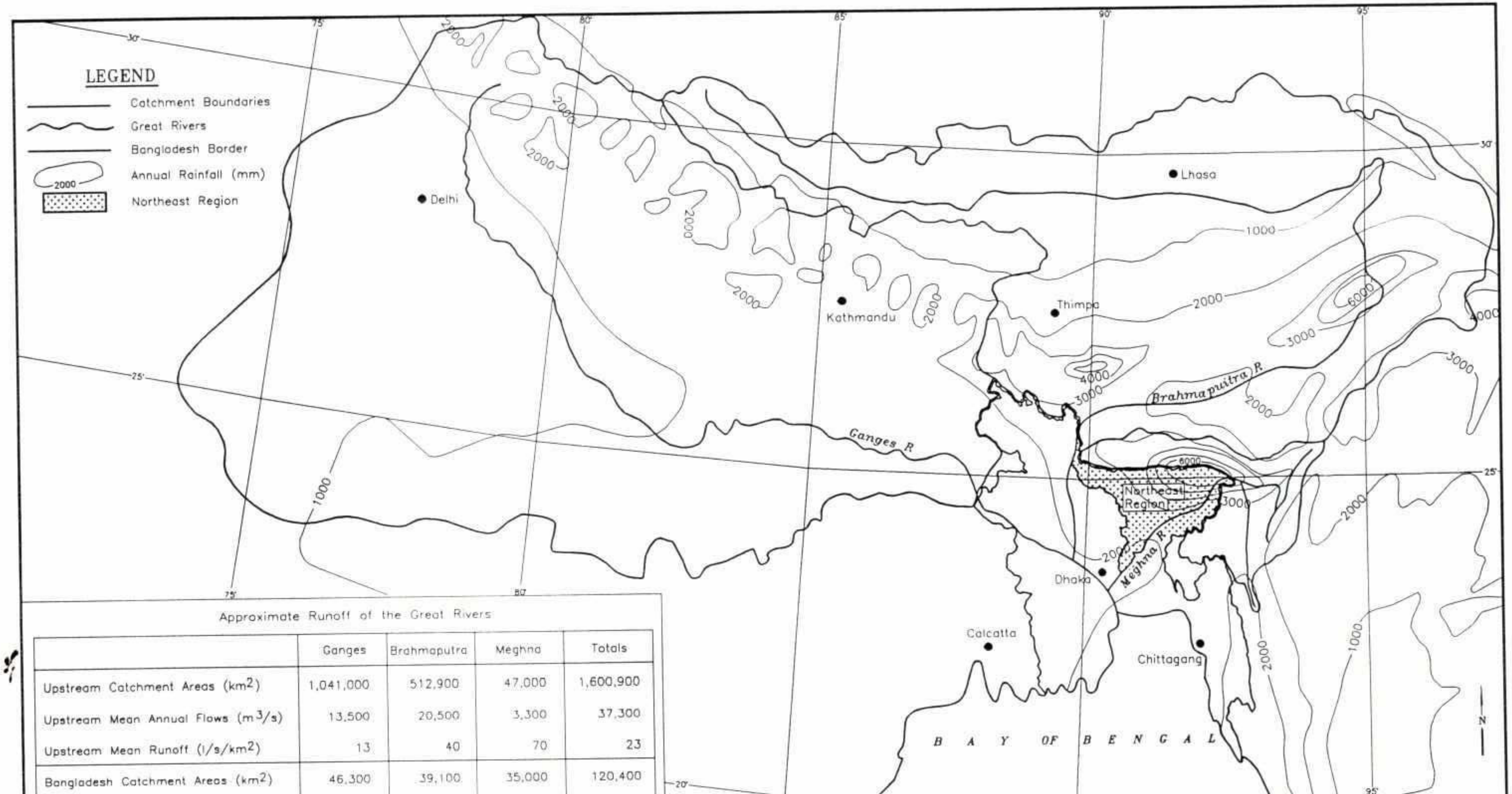
Figure 5.1



Catchment Areas of the Great Rivers

	Ganges		Brahmaputra		Meghna		Totals	
	km2	%	km2	%	km2	%	km2	%
India	860,000	79	195,000	35	47,000	57	1,102,000	64
China	33,520	3	270,900	49	–	–	304,420	18
Nepal	147,480	14	–	–	–	–	147,480	9
Bhutan	–	–	47,000	9	–	–	47,000	2
Upstream Sub-total	1,041,000	96	512,900	93	47,000	57	1,600,900	93
Bangladesh	46,300	4	39,100	7	35,000	43	120,400	7
Totals	1,087,300	100	552,000	100	82,000	100	1,721,300	100
Percentage of Totals	63		32		5		100	

Figure 5.2



Approximate Runoff of the Great Rivers

	Ganges	Brahmaputra	Meghna	Totals
Upstream Catchment Areas (km^2)	1,041,000	512,900	47,000	1,600,900
Upstream Mean Annual Flows (m^3/s)	13,500	20,500	3,300	37,300
Upstream Mean Runoff ($l/s/km^2$)	13	40	70	23
Bangladesh Catchment Areas (km^2)	46,300	39,100	35,000	120,400
Bangladesh Mean Annual Flows (m^3/s)	600	1,600	2,500	4,700
Total Catchment Areas (km^2)	1,087,300	552,000	82,000	1,721,300
Total Mean Annual Flows (m^3/s)	14,100	22,100	5,800	42,000
Inflows/Total Inflows (%)	36	55	9	100
Outflows/Total Outflows (%)	33	53	14	100

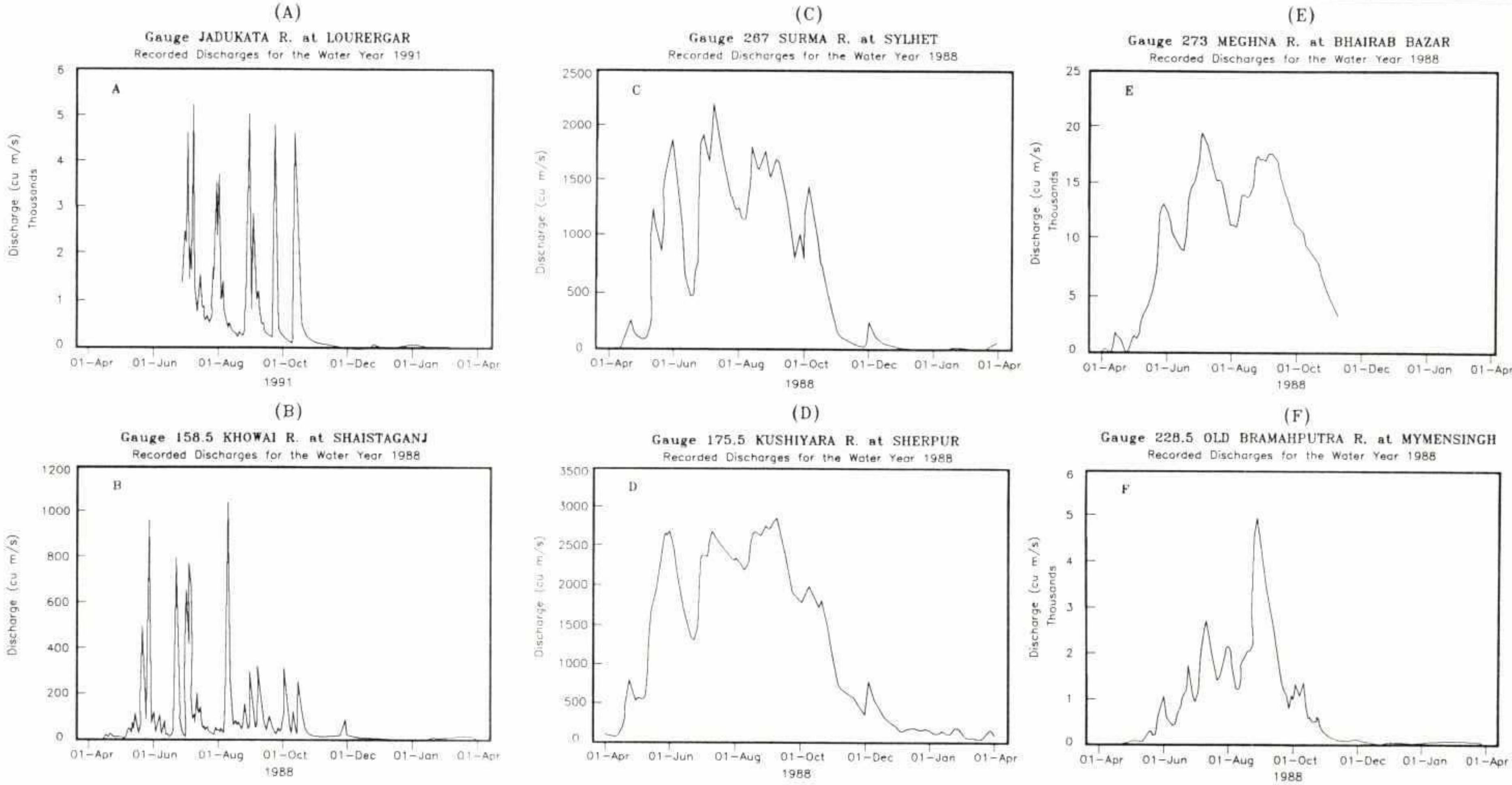
FILE: Mike-001DWG

Source: FAP 25+BWDB

Northeast Regional Project

Rainfall and Runoff of the Great Rivers

Prepared by: Mike/Jalal | December 1992



Northeast Regional Project

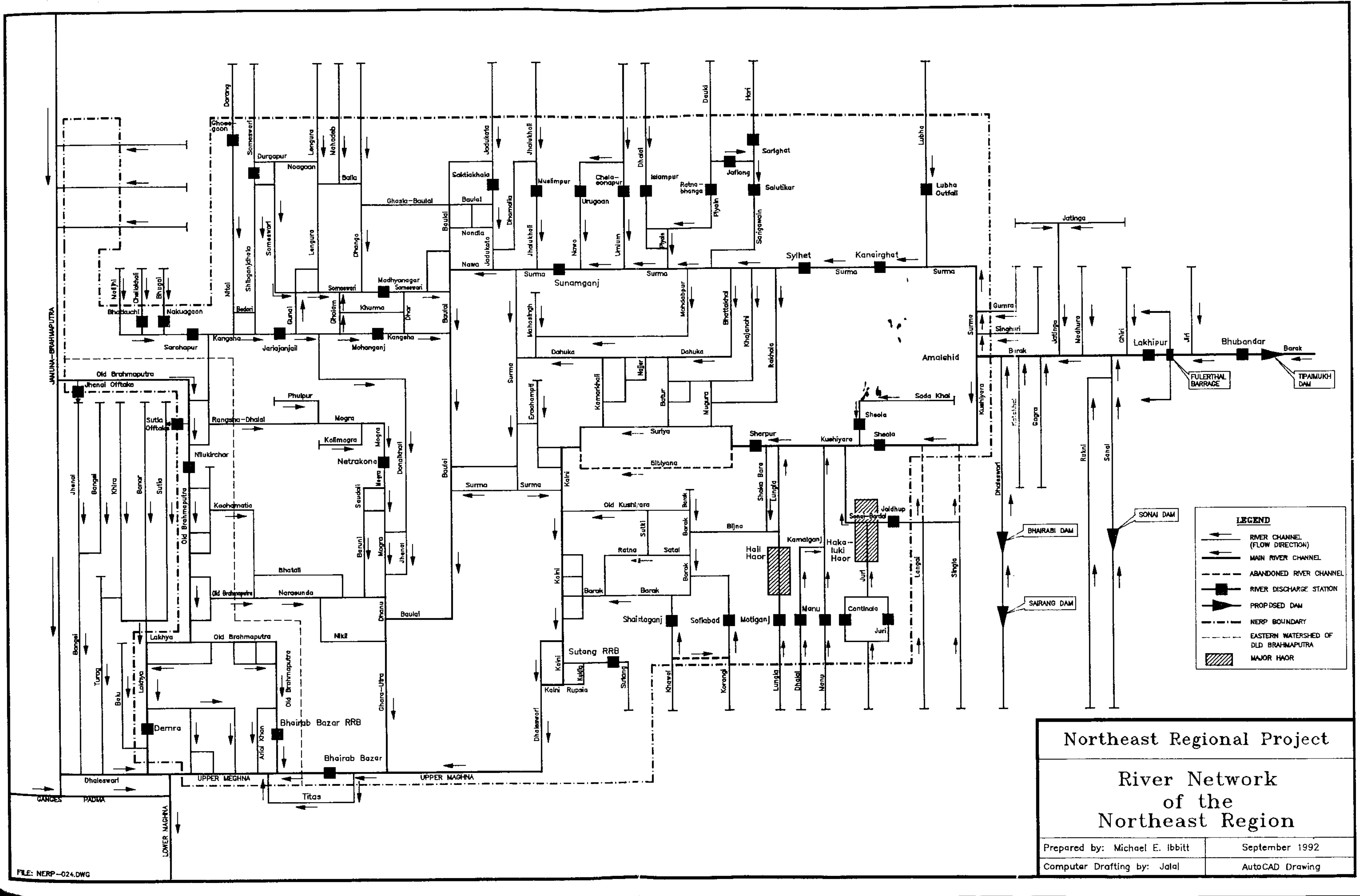
Representative Hydrographs of Regional Rivers

Prepared by: Mike | April 1995
Computer Drafting by: Mamun | AutoCAD Drawing

FILE: NERP-594.DWG

Figure 5.3

Figure 5.4


JAMUNA-BRAHMAPUTRA
GANGES
PADMA
LOWER MAGHNA
UPPER MEGHNA
Old Brahmaputra
Jhenai Offtake
Sutla Offtake
Demra
Bhairab Bazar RRB
Bhairab Bazar
Titas
Netrakona
Sunamganj
Sylhet
Kanairghat
Surma
Kushiyara
Sherpur
Sheola
Amalshid
Sutang RRB
Shaistaganj
Sofiabad
Motiganj
Hail Haor
Haka-luki Haor
Lakhipur
Bhubandar
Barak
FULERTHAL BARRAGE
TIPAIMUKH DAM
BHAIRABI DAM
SAIRANG DAM
SONAI DAM
LEGEND
RIVER CHANNEL (FLOW DIRECTION)
MAIN RIVER CHANNEL
ABANDONED RIVER CHANNEL
RIVER DISCHARGE STATION
PROPOSED DAM
NERP BOUNDARY
EASTERN WATERSHED OF OLD BRAHMAPUTRA
MAJOR HAOR
FILE: NERP-024.DWG
Northeast Regional Project
River Network of the Northeast Region
Prepared by: Michael E. Ibbitt
September 1992
Computer Drafting by: Jalal
AutoCAD Drawing

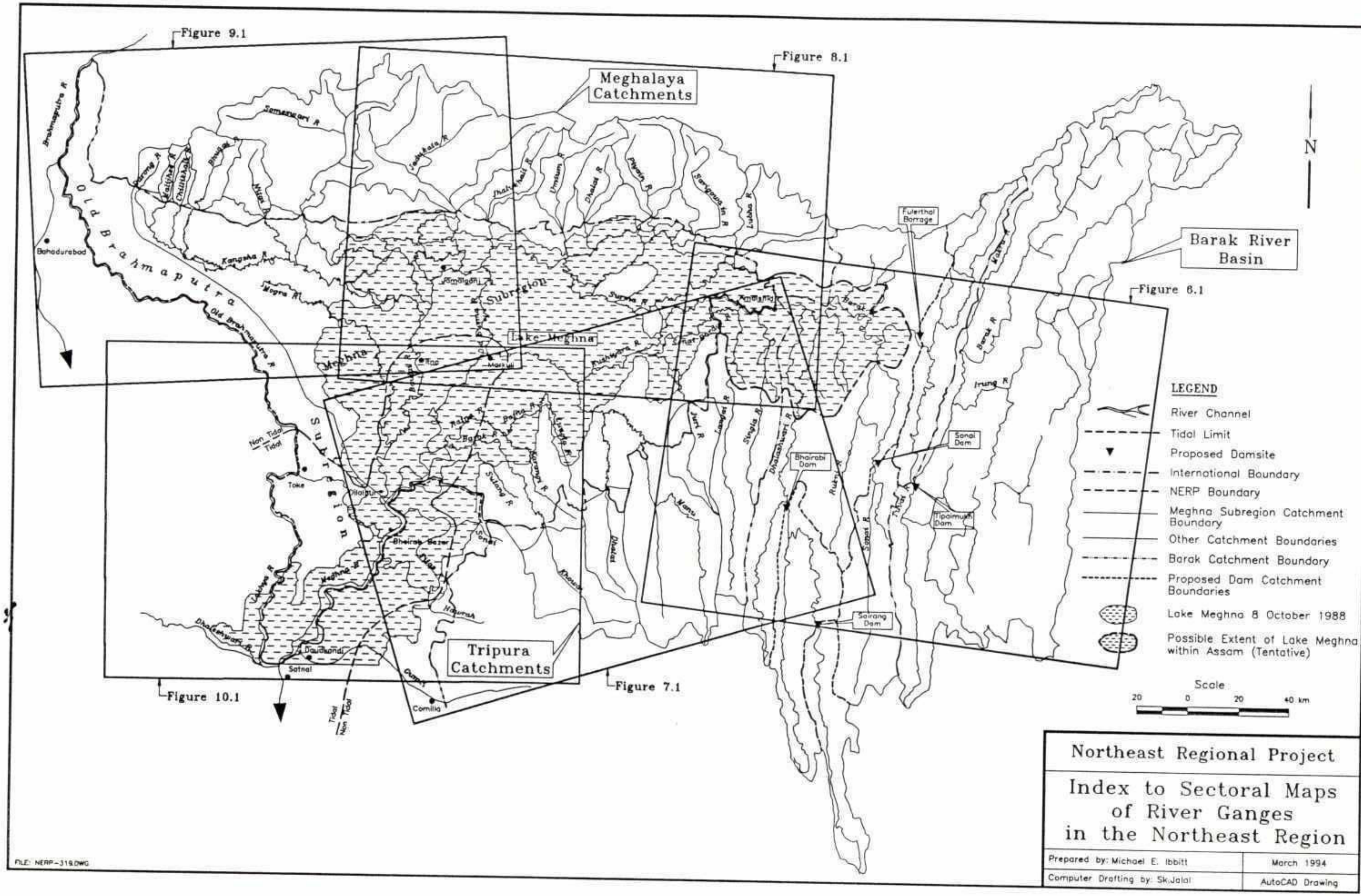
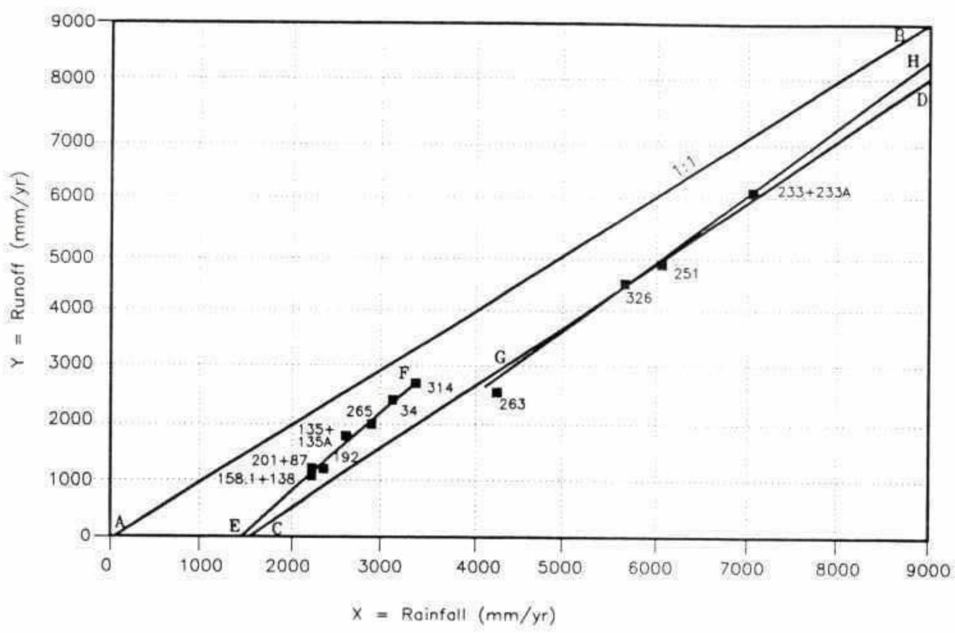


Figure 9.1
Figure 8.1
Meghalaya Catchments
Barak River Basin
Figure 6.1
Lake Meghna
Subregion
Tripura Catchments
Figure 10.1
Figure 7.1
Old Brahmaputra
Brahmaputra R
Bahadurabad
Somesswari R
Kangsha R
Mogra R
Old Brahmaputra R
Non Tidal
Tidal
Toke
Bhairab Bazar
Satnal
Daudkandi
Comilla
Sonai
Haorah
Dhaleswari R
Dhalai
Juri R
Manu
Surma R
Kushiyara R
Barak R
Irung R
Fulerthal Barrage
Sonai Dam
Tipaimukh Dam
Bhairabi Dam
Sairang Dam
Sonai R
Lubha R
Umium R
Dhalai R
Piyain R
Jadukata R
Sutang R
Khowai
LEGEND
River Channel
Tidal Limit
Proposed Damsite
International Boundary
NERP Boundary
Meghna Subregion Catchment Boundary
Other Catchment Boundaries
Barak Catchment Boundary
Proposed Dam Catchment Boundaries
Lake Meghna 8 October 1988
Possible Extent of Lake Meghna within Assam (Tentative)
Scale
20 0 20 40 km
N
Northeast Regional Project
Index to Sectoral Maps of River Ganges in the Northeast Region
Prepared by: Michael E. Ibbitt
March 1994
Computer Drafting by: Sk.Jalal
AutoCAD Drawing
FILE: NERP-319.DWG

Figure 5.5

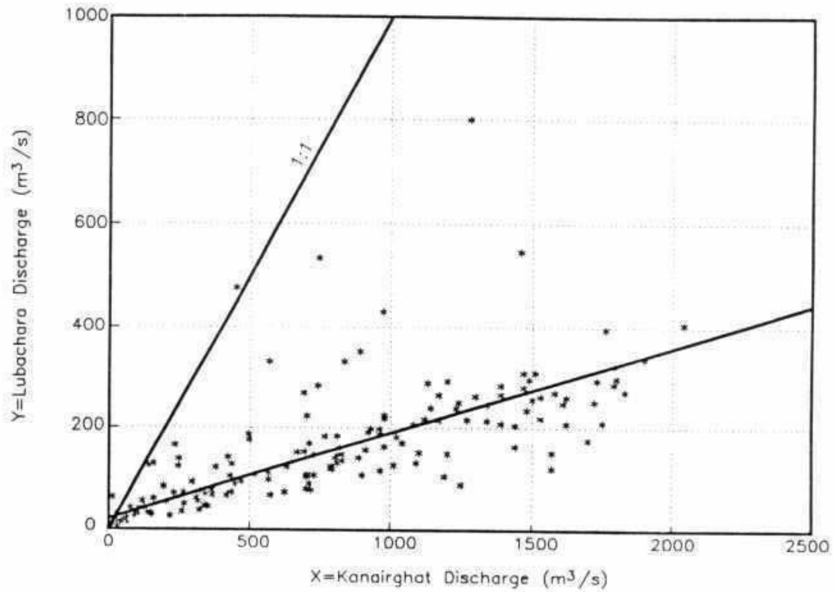
Figure 5.6



Correlation equation for lowland rivers (EF) : Y=1.4218X−2046,r=.99
Correlation equation for highland rivers (GH) : Y=1.1539X−2067,r=.99
Control curves (AB) : Y = X
(CD) : Y = 1.0759X−1621

LONG TERM CATCHMENT RAINFALLS AND RUNOFFS

(A)



Best fit equation Y = 0.16866X + 22.167
Correlation coefficent r = 0.79
Outliers not rejected

CORRELATION OF DISCHARGES BETWEEN LUBACHARA AND KANAIRGHAT,1970−1980

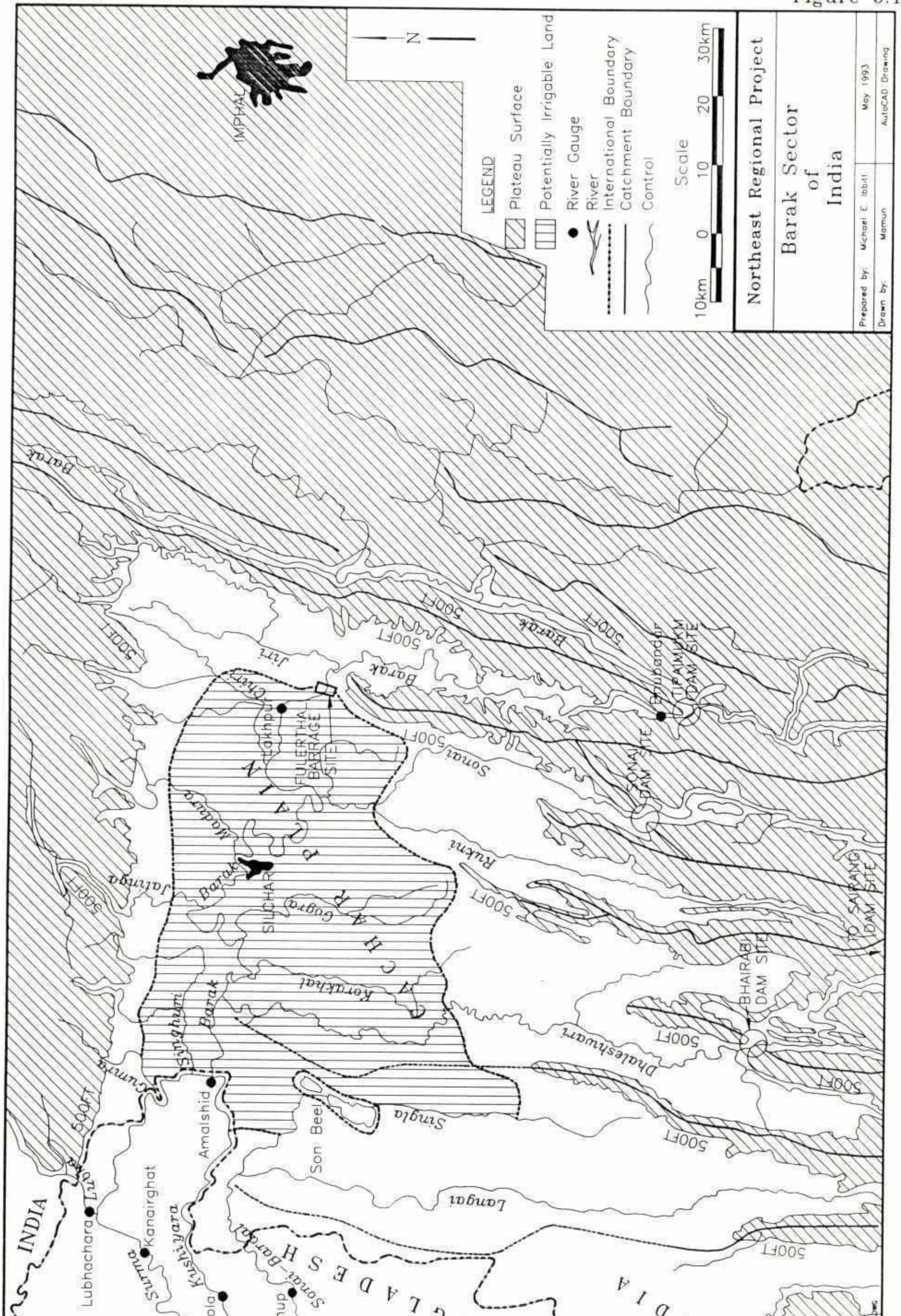
(B)

Northeast Regional Project			
Hydrological Correlations			
Prepared by:	Michael E. Ibbitt	May 1993	
Drawn by:	Mamun	AutoCAD Drawing	

FILE: NERP-597.DWG

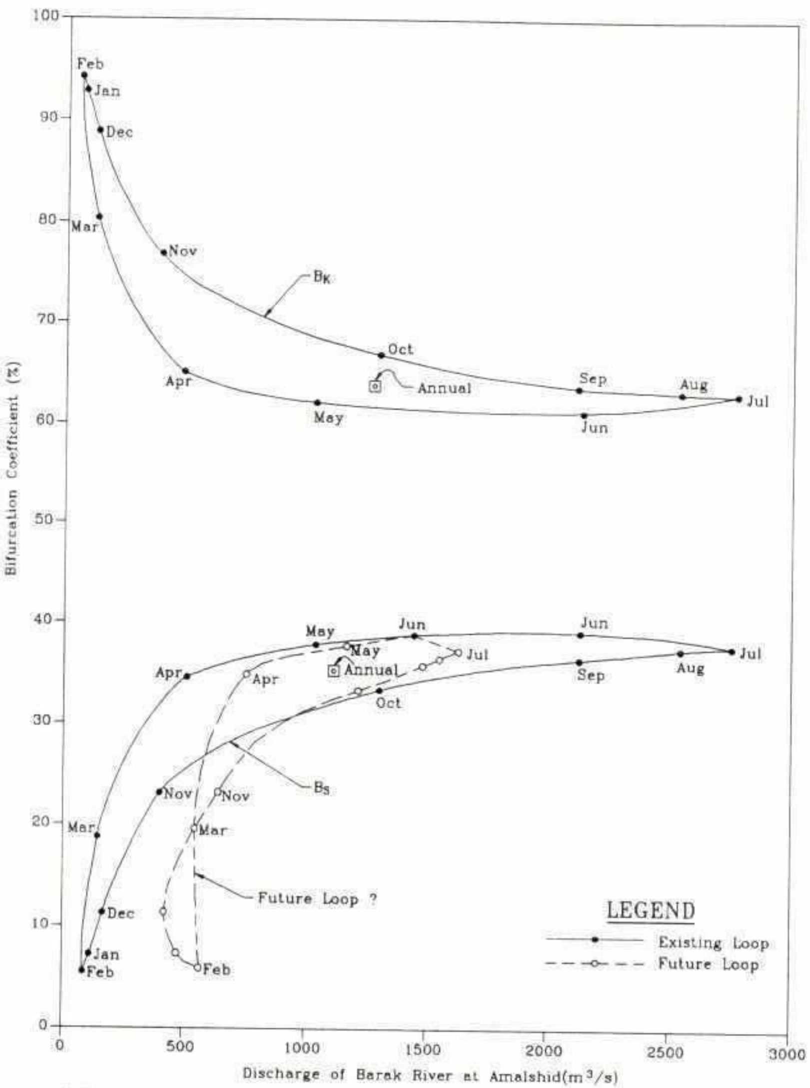
26১

Figure 6.1

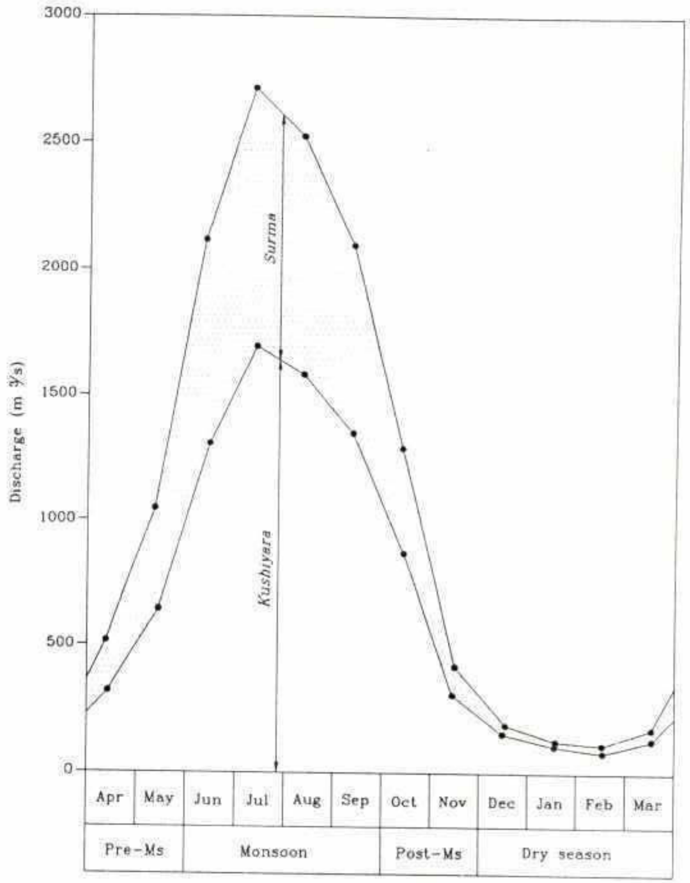


LEGEND
Plateau Surface
Potentially Irrigable Land
River Gauge
River
International Boundary
Catchment Boundary
Control
Scale
10km 0 10 20 30km
N
Northeast Regional Project
Barak Sector of India
Prepared by: Michael E. Ibbitt
May 1993
Drawn by: Mamun
AutoCAD Drawing
IMPHAL
INDIA
BANGLADESH
CACHAR PLAIN
SILCHAR
Lakhpur
FULERTHAL BARRAGE SITE
Bhubandar
TIPAIMUKH DAM SITE
SONAI DAM SITE
BHAIRABI DAM SITE
TO SAIRANG DAM SITE
Amalshid
Kanairghat
Lubhachara
Sheola
Jaldhup
Son Beel
Barak
Jiri
Chiri
Madhura
Jatinga
Katakhal
Sonai
Rukni
Dhaleshwari
Singla
Langai
Surma
Kushiyara
Lubha
500FT

Figure 6.2



A) Existing Bifurcation Coefficients for Kushiyara and Surma Rivers

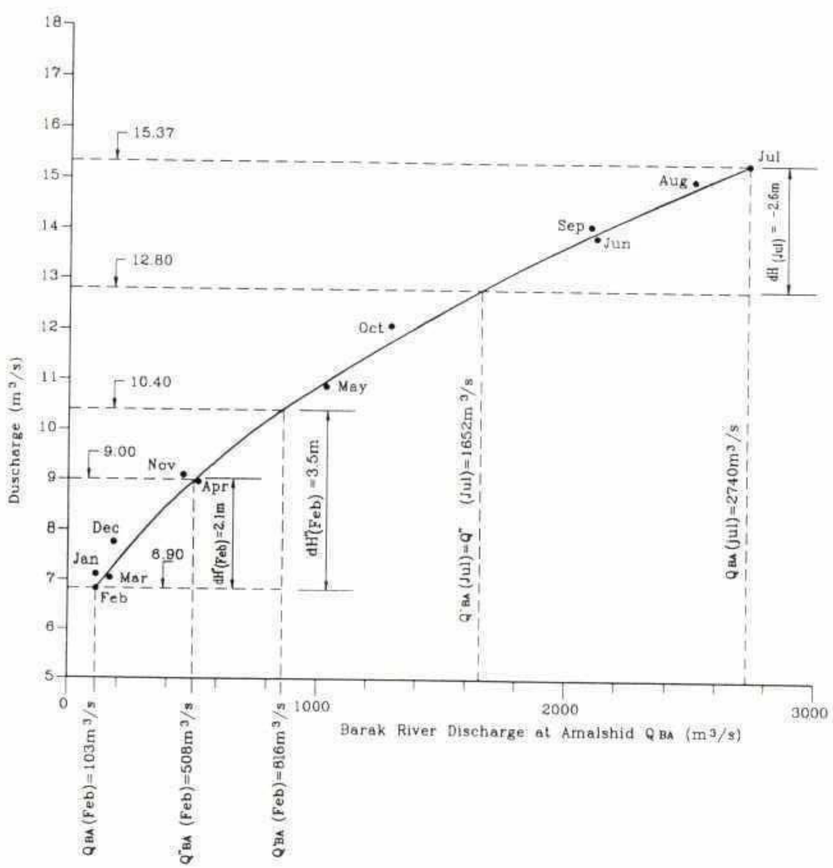


B) Existing Division of Barak Discharge at Amalshid

Northeast Regional Project	
Existing Division of Barak Discharge at Amalshid	
Prepared by: Mike E Ibbitt	January 1995
Computer Drafting by: Jalal	AutoCAD Drawing

FILE: NERP-308.DWG

A) APPROXIMATE RATING CURVE FOR BARAK AT AMALSHID



B) RATING DATA FOR BARAK RIVER AT AMALSHID*

Month	H_{BA}	Q_{BA}	Q'_{BA}	Q''_{BA}
	(m PWD)	(m^3/s)	(m^3/s)	(m^3/s)
Apr	9.06	520	936	782
May	10.86	1053	1127	1127
Jun	13.89	2130	1464	1467
Jul	15.37	2740	1652	1652
Aug	14.97	2540	1634	1634
Sep	14.14	2116	1502	1502
Oct	12.11	1301	1171	1171
Nov	9.16	415	790	834
Dec	7.81	183	733	421
Jan	7.11	118	763	451
Feb	6.90	103	816	508
Mar	7.12	157	833	525

* See tables in Chapter b for Q_{BA}, Q'_{BA} and Q''_{BA}
See Annex B for H_{BA}

Northeast Regional Project

Assessment of Water Level Changes in the Barak at Amalshid with Tipaimukh Hydropower and Cachar Plain Projects in Place

Prepared by:	Mike E. Ibbitt	January 1995
Computer Drafting by:	Jalal	AutoCAD Drawing

Figure 6.3

FILE: NERP-309.DWG

Figure 6.4

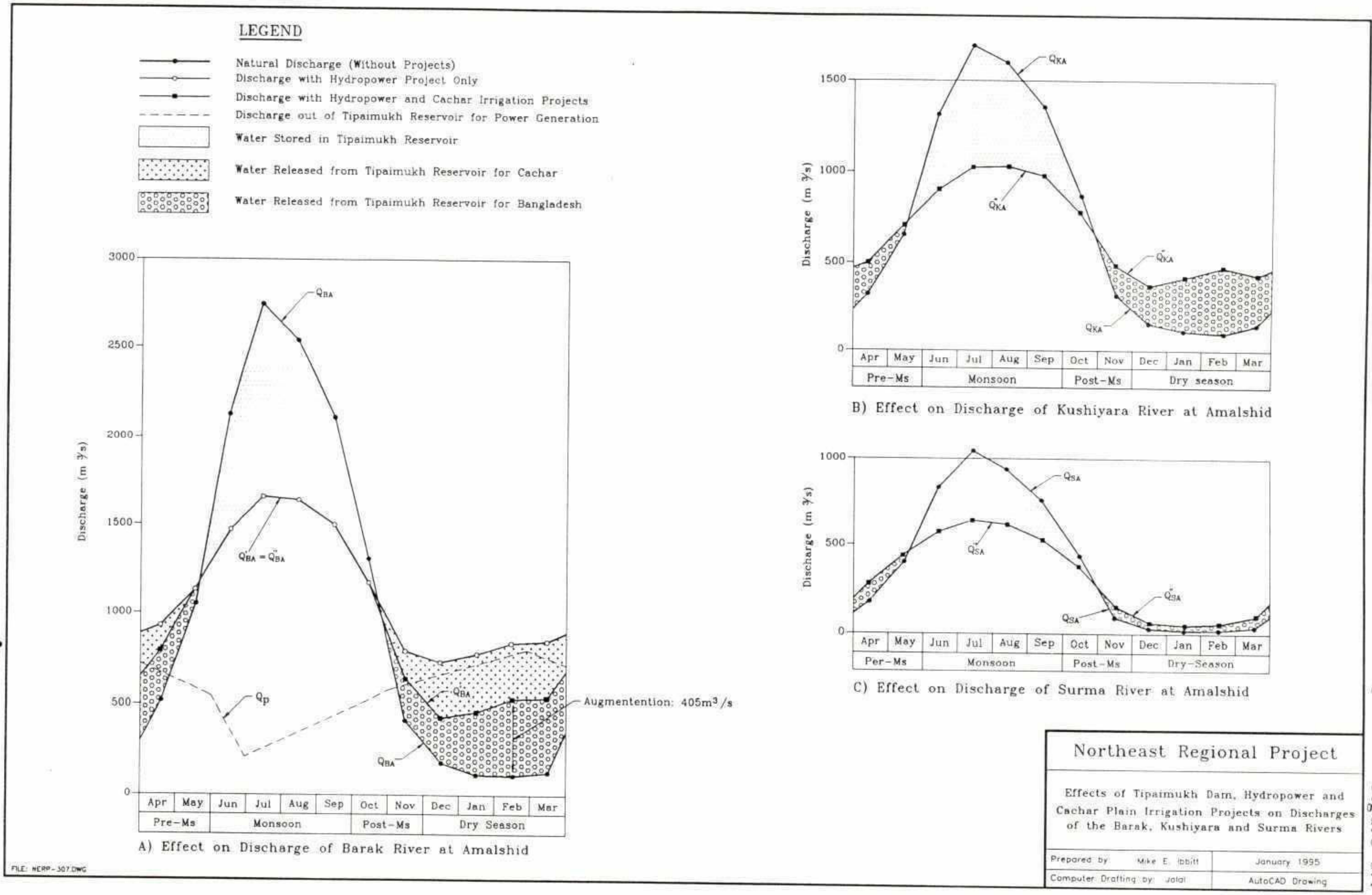
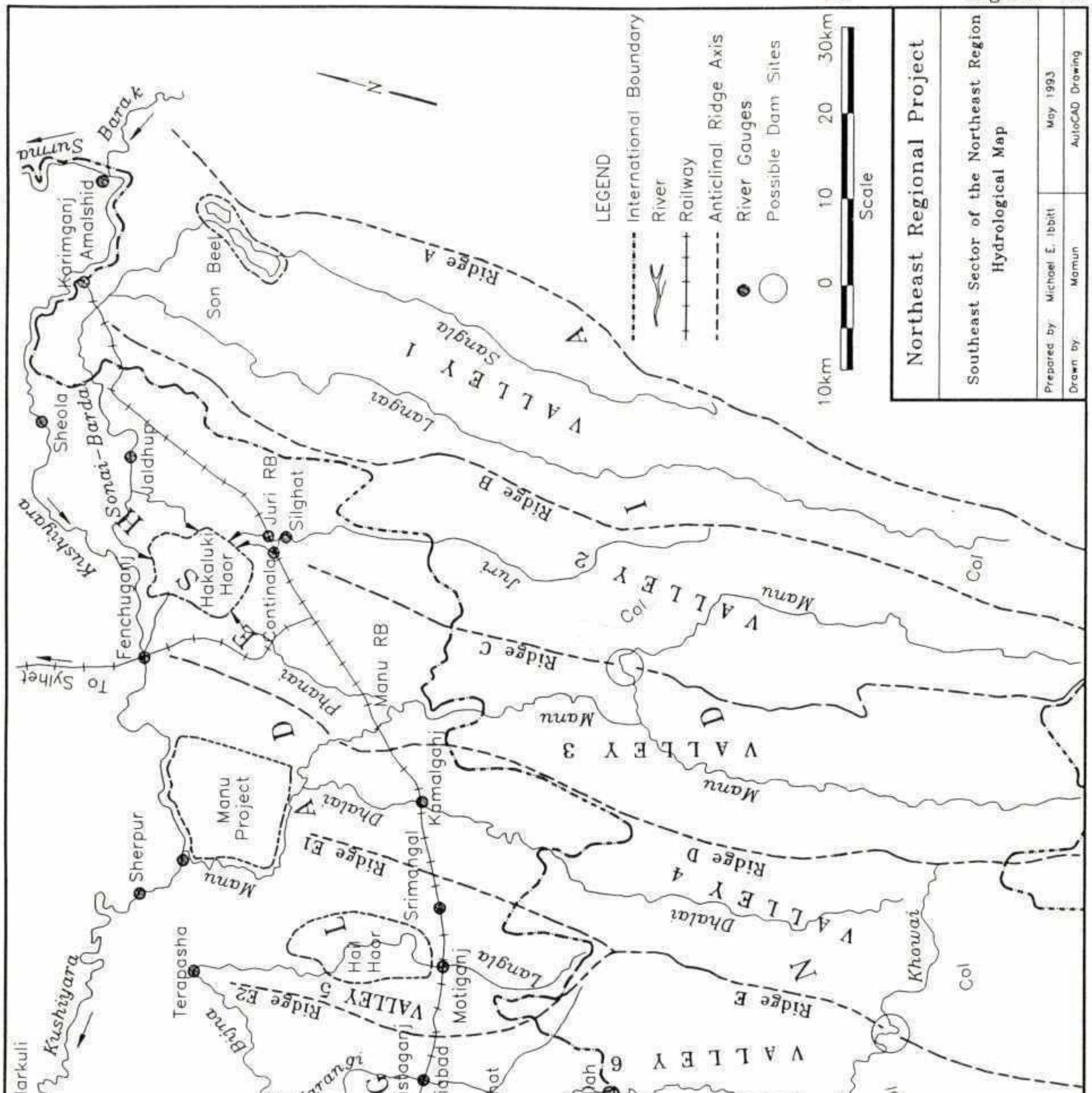

LEGEND
Natural Discharge (Without Projects)
Discharge with Hydropower Project Only
Discharge with Hydropower and Cachar Irrigation Projects
Discharge out of Tipaimukh Reservoir for Power Generation
Water Stored in Tipaimukh Reservoir
Water Released from Tipaimukh Reservoir for Cachar
Water Released from Tipaimukh Reservoir for Bangladesh
Discharge (m³/s)
Augmententio n: 405m³/s
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar
Pre-Ms Monsoon Post-Ms Dry Season
A) Effect on Discharge of Barak River at Amalshid
B) Effect on Discharge of Kushiyara River at Amalshid
C) Effect on Discharge of Surma River at Amalshid
Northeast Regional Project
Effects of Tipaimukh Dam, Hydropower and Cachar Plain Irrigation Projects on Discharges of the Barak, Kushiyara and Surma Rivers
Prepared by Mike E. Ibbitt
January 1995
Computer Drafting by: Jalal
AutoCAD Drawing
FILE: NERP-307.DWG

Figure 7.1


Northeast Regional Project
Southeast Sector of the Northeast Region
Hydrological Map
Prepared by Michael E. Ibbitt
May 1993
Drawn by Mamun
AutoCAD Drawing
FILE: NERP-585.DWG
LEGEND
International Boundary
River
Railway
Anticlinal Ridge Axis
River Gauges
Possible Dam Sites
0 10 20 30km
10km
Scale
N
BANGLADESH
INDIA
VALLEY 1
VALLEY 2
VALLEY 3
VALLEY 4
VALLEY 5
VALLEY 6
Ridge A
Ridge B
Ridge C
Ridge D
Ridge E
Ridge E1
Ridge E2
Ridge F
Col
Surma
Barak
Karimganj
Amalshid
Son Beel
Sangla
Langai
Sheola
Sonai-Barda
Jaldhup
Juri RB
Silghat
Juri
Kushiyara
Fenchuganj
Hakaluki Haor
Contination
Manu RB
Manu
To Sylhet
Phanai
Manu Project
Kamalganj
Dhalai
Sherpur
Srimangal
Hail Haor
Motiganj
Langla
Terapasha
Bijna
Markuli
Karangi
Shaistaganj
Sofiabad
Chunarughat
Khowai
Habiganj
Sutang
Sutang RB
Balloh
Ajmiriganj
Kushiyara (Kalni)
Kushiyara (Dhaleshwari)
Madna
Baulai
Mogra
Austagram
Titas
Agartala
Kishoreganj
Dilalpur
Bhairab Bazar
Meghna
Comilla

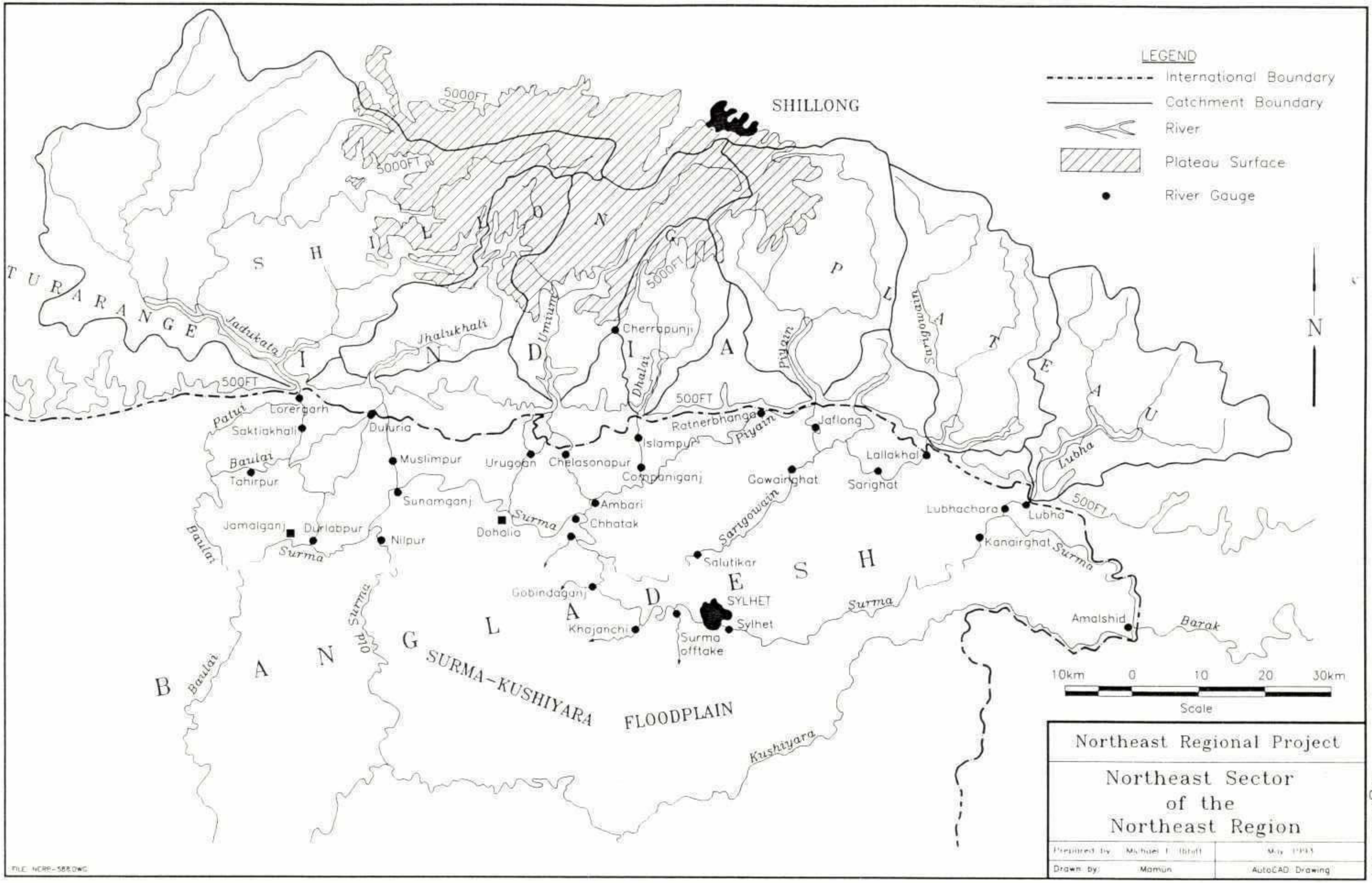
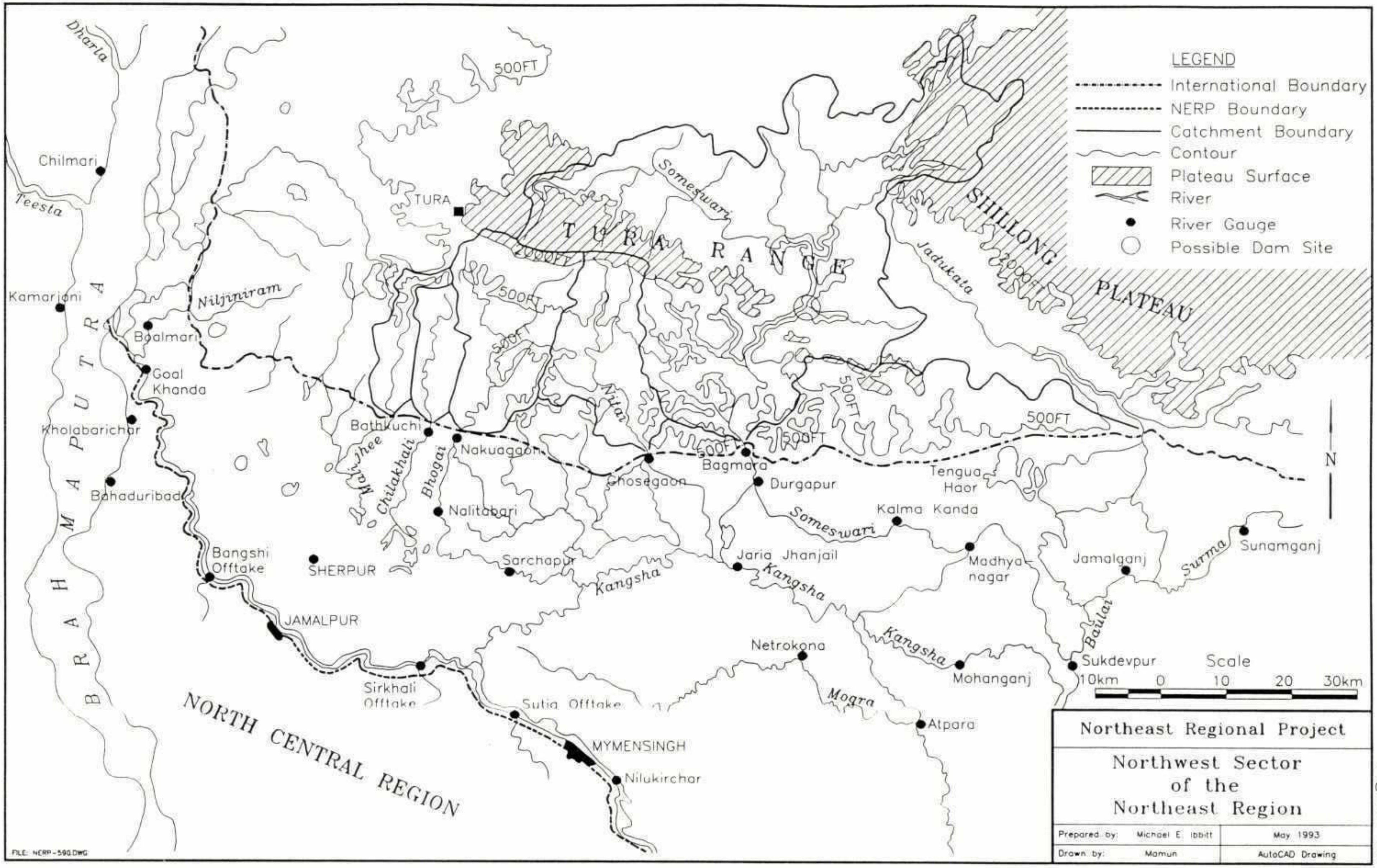

LEGEND
International Boundary
Catchment Boundary
River
Plateau Surface
River Gauge
SHILLONG
SHILLONG PLATEAU
TURA RANGE
INDIA
BANGLADESH
SURMA-KUSHIYARA FLOODPLAIN
5000FT
500FT
N
Jadukata
Jhalukhali
Umium
Dhalai
Piyain
Sarigowain
Lubha
Patui
Baulai
Surma
Old Surma
Kushiyara
Barak
Loreragarh
Saktiakhali
Tahirpur
Duluria
Muslimpur
Sunamganj
Jamalganj
Durlabpur
Nilpur
Urugoan
Chelasonapur
Dohalia
Ambari
Chhatak
Cherrapunji
Islampur
Companiganj
Ratnerbhanga
Jaflong
Gowainghat
Lallakhal
Sarighat
Salutikar
Gobindaganj
Khajanchi
SYLHET
Sylhet
Surma offtake
Lubhachara
Lubha
Kanairghat
Amalshid
10km
0
10
20
30km
Scale
Northeast Regional Project
Northeast Sector
of the
Northeast Region
Drawn by:
Mamun
AutoCAD Drawing
FILE: NERP-588.DWG

Figure 8.1

Figure 9.1


LEGEND
International Boundary
NERP Boundary
Catchment Boundary
Contour
Plateau Surface
River
River Gauge
Possible Dam Site
SHILLONG PLATEAU
TURA RANGE
TURA
500FT
2000FT
Dharla
Teesta
Chilmari
Kamarjani
BRAHMAPUTRA
Boalmari
Goal Khanda
Kholabarichar
Bahaduribad
Niljiniram
Bathkuchi
Nakuagaon
Malijhee
Chilakhali
Bhogai
Nalitabari
Someswari
Nitai
Ghosegaon
Bagmara
Durgapur
Jadukata
Tengua Haor
Kalma Kanda
Madhya-nagar
Jamalganj
Surma
Sunamganj
Sarchapur
Kangsha
Jaria Jhanjail
Bangshi Offtake
SHERPUR
JAMALPUR
Sirkhali Offtake
Sutia Offtake
MYMENSINGH
Nilukirchar
Netrokona
Mogra
Atpara
Mohanganj
Baulai
Sukdevpur
N
Scale
10km 0 10 20 30km
NORTH CENTRAL REGION
Northeast Regional Project
Northwest Sector of the Northeast Region
Prepared by: Michael E. Ibbitt
May 1993
Drawn by: Mamun
AutoCAD Drawing
FILE: NERP-590.DWG

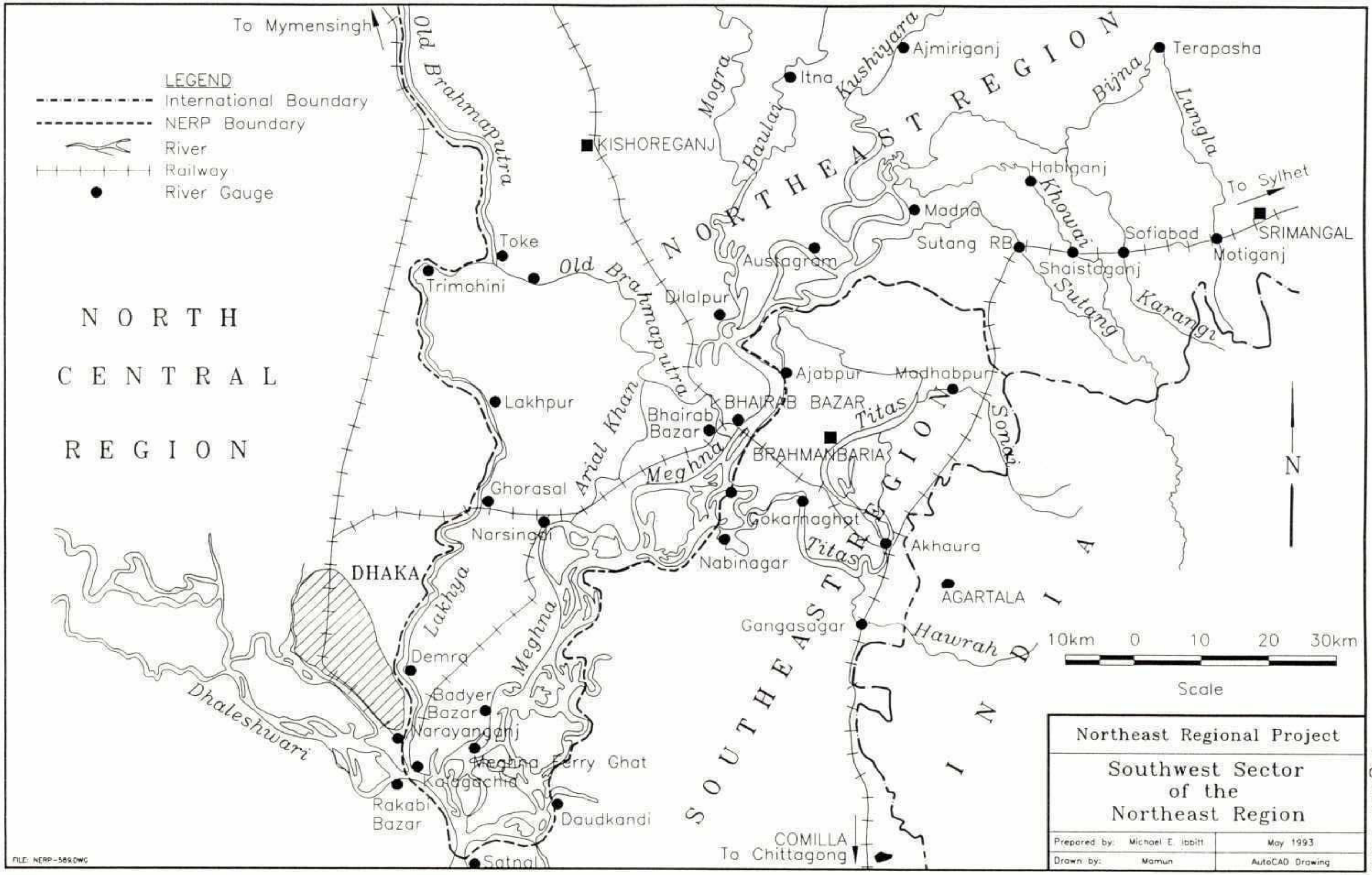

To Mymensingh
LEGEND
International Boundary
NERP Boundary
River
Railway
River Gauge
NORTH CENTRAL REGION
NORTHEAST REGION
SOUTHEAST REGION
INDIA
Old Brahmaputra
KISHOREGANJ
Mogra
Baulai
Itna
Kushiyara
Ajmiriganj
Bijna
Terapasha
Lungla
Habiganj
Khowai
Madna
To Sylhet
SRIMANGAL
Sofiabad
Motiganj
Sutang RB
Shaistaganj
Sutang
Karangi
Toke
Trimohini
Austagram
Dilalpur
Ajabpur
Madhabpur
BHAIRAB BAZAR
Bhairab Bazar
Titas
BRAHMANBARIA
Sonai
Lakhpur
Arial Khan
Meghna
Ghorasal
Narsingdi
Gokarnaghat
Nabinagar
Akhaura
AGARTALA
Gangasagar
Hawrah
DHAKA
Lakhya
Demra
Badyer Bazar
Narayanganj
Meghna Ferry Ghat
Kalagachia
Rakabi Bazar
Daudkandi
Satnal
Dhaleshwari
COMILLA
To Chittagong
N
10km 0 10 20 30km
Scale
Northeast Regional Project
Southwest Sector of the Northeast Region
Prepared by: Michael E. Ibbitt
May 1993
Drawn by: Mamun
AutoCAD Drawing
FILE: NERP-589.DWG

Figure 10.1