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)

MANU RIVER IMPROVEMENT PROJECT

Draft Final
December 1993

Shawinigan Lavalin (1991) Inc.
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

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ACRONYMS AND ABBREVIATIONS

BBS	Bangladesh Bureau of Statistics
BFRSS	Bangladesh Fisheries Resource System Survey
BRDB	Bangladesh Rural Development Board
BWDB	Bangladesh Water Development Board
DAE	Department of Agricultural Extension
DPHE	Department of Public Health Engineering
EIA	environmental impact assessment
EIRR	economic internal rate of return
EMP	Environmental Management Plan
EPWAPDA	East Pakistan Water and Power Development Agency
FAP	Flood Action Plan
FFW	Food for Work
FPCO	Flood Plan Coordination Organization
FW	future with project scenario
FWO	future without project scenario
GSB	Geological Survey of Bangladesh
HTW	hand tube well
HYV	high yielding variety
IBRD	International Bank for Reconstruction and Development
IEE	Initial Environmental Evaluation
ISPAN	Irrigation Support Project Asia Near East
LLP	low-lift pump
LT	local transplanted
MPO	Master Planning Organization
NERP	Northeast Regional Water Management Planning Organization
NGO	non-governmental organization
NHC	Northwest Hydraulic Consultants
NPV	net present value
PD	person-day
PWD	Pakistan Water Department
RCC	reinforced concrete
SLI	SNC-Lavalin International

US $1 = Tk 38

MPO Land Classification Terminology

Class F0	Land inundated to a depth of less than 0.3 m
Class F1	Land inundated to a depth of between 0.3 m - 0.9 m
Class F2	Land inundated to a depth of between 0.9 m - 1.8 m
Class F3	Land inundated to a depth of more than 1.8 m
Class F4	Land inundated to a depth of more than 1.8 m and on which deepwater aman cannot be grown

EXECUTIVE SUMMARY

The purpose of the project is to reduce the risk of flooding in Moulvibazar town; to reduce damage to Manu River Project infrastructure; to provide flood relief to the 30,000 people living between the Manu River and the Manu River Project embankment; and to reduce flooding in the Dhalai River basin.

In recent years, flooding of those parts of Moulvibazar district near the Manu River has increased in both frequency and extent despite the existence of a protective dyke on the right bank of the river (this increase appears to be correlated with increases in local rainfall and confinement effects from embankments). It has resulted in increased erosion of the river bank adjacent to Moulvibazar town, damage to property and infrastructure within Moulvibazar town, severing of the Dhaka - Sylhet road (part of the Dhaka-Sylhet corridor), damage to the Manu River Irrigation Project infrastructure, and damage to crops throughout the basin. A solution to flooding along the Manu River is thus considered the paramount water management issue in this area.

The most favourable option for addressing the problems in the Manu basin involves diverting peak monsoon flood flows from the Manu River into Hakaluki Haor. The Manu River presently experiences 100-year floods estimated at 1500 m^3/s. This reach can safely handle no more than 800 m^3/s. A 30 km diversion channel from Kotarkona (near Manu railway bridge) to Hakaluki Haor would, therefore, be designed to pass 700 m^3/s. Required infrastructure are: a major diversion structure, a 50 m wide embanked diversion channel (3 m high), and reconstruction of two road bridges and one railway bridge. The diversion would operate to 21 days during extreme flood years such as 1988 or 1991 and only 2 -3 days during low flood years. Impacts on Hakaluki Haor may be considerable and require further evaluation. An outstanding issue relates to whether more than 700 m^3/s should be diverted to Hakaluki Haor. Increasing the diversion volume would result in increase safety margins for the lower Manu system but may increase negative impacts on Hakaluki Haor and sedimentation in the lower Manu.

To eliminate overbank spills in the lower Dhalai River, a 3.0 m high embankment would be constructed for a length of 32 km on the right bank of the Dhalai upstream from the near its confluence with the Manu River.

The project would be implemented by the Bangladesh Water Development Board at an estimated cost of US $21.2 million

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 prefeasibility 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
- 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
- Kushiyara Dredging
- 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

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1. INTRODUCTION

1.1 General Information

BWDB Division	:	Moulvi Bazar O & M
District	:	Moulvi Bazar
Thana	:	Rajnagar, portions of Moulvi Bazar, Kamalganj and Kulaura
MPO Planning Area	:	25 and 26
Gross Area	:	90,000 ha (Basin); 52,300 ha (Project)
Net Area	:	49,200 ha (Basin); 40,800 ha (Project)

1.2 Scope and Methodology

This is a pre-feasibility study that was undertaken over a period of one month in early 1993. The field study team consisted of a water resources engineer, social anthropologist, agronomist, fisheries specialist and wetland resources specialist. Additional analytical support was provided by a hydrologist, environmental specialist, and an economist.

1.3 Data Base

Project analyses presented in this document was based mainly on secondary data supplemented by information obtained during field inspections and discussions with project area residents. Information and data sources used by the various analysts are as listed below.

Engineering analysis: Existing topographic maps, historic climatological and hydrological records, river and khal cross-sections surveyed by BWDB Morphology Directorate and by SWMC, BWDB reports, MPO Reports, personal field observations and interviews with beneficiaries, recommendations by BWDB officials and by local representatives.

Agricultural analysis: Data published in the "Land Resources Appraisal for Agricultural Development in Bangladesh" (AEZ Reports) for soils information, data published by the Water Resources Planning Organization (WARPO) for agricultural inputs, data assembled through the "Agriculture Specialist Study" by NERP, interviews with individuals and groups of farmers in different areas and on each land type, and hydrological data developed by the hydrology and engineering sections of the NERP.

Fisheries analysis: Topographic maps, BFRSS data, CIDA Inception Report, NERP Fisheries Specialist Study, field observations and local interviews, information provided by local representatives during field seminars held in Sylhet on June 26, 1992 and in Sunamganj on February 13, 1993.

Wetland analysis: Topographic maps, local revenue department records, personal field observations and interviews with local people, and the "Wetland Specialist Study" published by NERP.

Socio-economic analysis: Published BBS data on demographic features, education and agriculture; reports of the Directorate of Public Health and Engineering, and the NERP data base on Population and Human Development, personal field observation and field interviews with various cross-section of local people, the opinions and suggestions from various local level representatives including NGO personnel and the Honourable Members of the Parliament. In addition, information resulting from a case study (three month duration) was incorporated into the study.

1.4 Report Layout

A description of the biophysical features of the Manu River Basin is provided in Chapter 2. Chapter 3 describes the current status of development and resource management within the proposed Project Area including a summary of the types of problems faced by people living in these areas. Chapter 4 reviews previous studies directed towards management of the water resources in the Project Area and Chapter 5 lists trends which are occurring and which will continue if no interventions are made. Chapter 6 reviews water resource development options which were considered and recommended. Chapter 7 provides an analysis the recommended intervention and Chapter 8 flags an outstanding issue. The annexes provide more detailed information in support of the main body of the report.

2. BIOPHYSICAL DESCRIPTION

2.1 Basin Boundaries

The Manu River Basin is located in Moulvi Bazar District between latitude 24°08'N to 24°44'N and longitude 91°43'E to 92°0'E, and is bounded on the north by Kushiyara River, on the south by the international border, on the east by Bhatera Hills and Rajkandi and on the west by Bilasari Hills and Moulvi Bazar-Sylhet Highway (Annex D, Figure 1).

2.2 Climate

The Manu River Basin experiences the sub-tropical monsoon climate typical of Bangladesh, but with variations due to its location and topography. Rainfall is the most significant and variable aspect of the climate, causing severe floods and flooding in summer and an irrigation requirement in winter.

2.2.1 Variations in Annual Rainfall

The variation of annual rainfall over the Basin is best represented by data for 1961-90 for the six BWDB rain gauges in, or around its periphery. The locations of these rain gauges are given in Table A.1, and the data for 1961-90 in Table A.2.

The data show that annual rainfall increases from an average of 2447 mm/year in the south-southwest to 3168 mm/year in the north-northeast, or by 29% across the basin. This latitudinal increase is mainly attributable to the presence of the Shillong Plateau to the north (Figure 2), but the nearby low hills also contribute slightly to the increase.

A regional analysis of annual rainfalls (NERP, 1993a) has shown that mean annual rainfall for 1961-90 was 10% greater than that for 1901-30, and that the variability of annual rainfalls for 1961-90 was 1.95 times that for 1901-30. These disturbing trends have been reflected in increased floods and flooding in recent years, but it is not known whether they will continue into the future, level off, or be reversed. Climate modelling research being undertaken in the West suggests these trends, particularly that in variability of the annual rainfalls, will continue in the decades ahead.

There are four more or less distinct seasons in the project area relative to the annual cycle of water resource activity which reflects the seasonal distribution of the annual rainfall; these are identified in Table 2.1.

The most distinctive climatic events of the year are the onset and withdrawal of the monsoon. In the project area onset occurs on average on 1 June plus or minus about 4 days, and withdrawal occurs on average on 7 October plus or minus about 14 days. The average duration of the monsoon is 122 days, but it has varied from 112 days to 139 days.

Table 2.1: Definition of Climate Seasons in the Manu Basin

Season	Activity	Calendar Period
Dry	Irrigation	December through March
Pre-Monsoon	Flash Floods	April and May
Monsoon	Flooding	June through September
Post-Monsoon	Drainage	October and November

The seasonal distribution of the annual rainfall is shown in Table 2.2, which shows that the rainfall is heavily concentrated in the monsoon season, but more so in the north than in the south, and that the dry season is slightly more intense in the north than in the south.

2.2.2 Seasonal Climatic Variations

The climate of the Basin as a whole is best represented by data for Srimangal, the nearest BMD climatological station, located a short distance southwest of the project area. Data are available for 1948-91 (44 years). The averages are given in Table A.3, and the extremes of record in Table A.4.

Annual sunshine hours average 6.2 hours/day, and average monthly sunshine hours range from a minimum of 4.2 hours/day in July to a maximum of 8.1 hours/day in February. No radiation data are available.

The mean annual temperature is 24.9°C, and average monthly temperatures range from a minimum of 17.6°C in January to a maximum of 28.7°C in August.

Monthly mean minimum temperatures range from 9.3°C in January to 25.1°C in July/August, and extreme minimum temperatures of record range from 2.8°C in February to 21.2°C in August.

Monthly mean maximum temperatures range from 25.6°C in January to 33.2°C in April, and extreme maximum temperatures have ranged from 31.1°C in January to 43.4°C in April.

The annual mean humidity is 81%, and monthly averages range from 73% in April to 88% in August/September.

The annual mean windspeed is 7.3 km/hour from the south-southwest. Monthly average wind

Table 2.2: Seasonal Distribution of Rainfall in the Basin

Season	Percent of Annual Rainfall in the Basin	
	South (Srimangal)	North (Chandbagh)
Dry	5	4
Pre-Monsoon	28	26
Monsoon	59	62
Post-Monsoon	8	8
Year	100	100

speeds range from 5.7 km/hour to 9.9 km/hour, but the extreme gust of record is 167 km/hour. Winds are generally from the south-southeast during the monsoon season, and vary between south-southwest and southeast in the other seasons.

The mean annual rainfall is 2431 mm. Average monthly rainfalls range from 6 mm in December to 483 mm in June, and monthly rainfalls have ranged from 0 mm in November through April to as much as 1285 mm in June. The extreme daily rainfall of record is 514 mm.

Potential evapotranspiration averages 1460 mm/year, and ranges from 141 mm (4.7 mm/day) in September to 243 mm (8.1 mm/day) in April.

The surface water balance shows an annual excess of 971 mm which runs off into the river system or recharges the aquifers. The monthly water balance is positive in May through September and ranges up to 324 mm/month in June, but during October through April the balance is negative, reaching as low as -139 mm in January. The winter surface moisture deficit is generally met from residual soil moisture until February after which a demand for irrigation normally arises.

2.3 Land (Physiography)

2.3.1 General Description

The Manu River Basin comprises the floodplains on the right and left banks of the Manu River, the flood plains on the right and left banks of the Dhalai River, and the low hills which surround these river systems.

The Manu River Irrigation Project is located on the right bank of the mid and lower reaches of the Manu River. It is square in plan and focused on Kawadighi Haor, a large shallow depression with a central elevation of 5 m PWD which contains a number of beels (permanent or seasonal lakes). The bathymetry of this haor is given in Figure 3. To the east, it is bounded by the Bhatera Hills which attain a maximum elevation of 145 m PWD. To the north it is bounded by the left bank levee of the Kushiyara River, and to the south and west by the right bank levee of the Manu River. Streams within the basin drain radially inwards to Kawadighi Haor, and extend eastwards into the Bhatera Hills. Kawadighi Haor itself drains northwards to the Kushiyara River through the Koradair and Machuakhali Khals.

The Dhalai system is elongate and triangular in plan and focused in the north on Daldala Haor, a relatively small shallow depression with a central elevation of 12 m PWD which contains a few beels. The bathymetry of this haor is given in Figure 4. To the southeast it is bounded by the Rajkandi Hills which attain a maximum elevation of 198 m PWD. To the north it is bounded by the left bank levee of the Manu River, and to the west by the right bank levee of the Dhalai River — the main tributary of the Manu River. Streams within the basin drain northwards to Daldala Haor, and extend southeastwards into the Rajkandi Hills. Daldala Haor itself drains northwards to the Manu River through Kalkalia Khal.

Hakaluki Haor could be affected by interventions in the Manu Basin. It is a very large depression lying east of the Bhatera Hills, and containing a number of large beels. The area of the haor is about 32,000 ha, and it has a central elevation of 4 m PWD. The bathymetry of this haor is given in Figure 5. To the west the haor is bounded by the Bhatera Hills, and to the east it is bounded by the Patharia Hills. To the north it is bounded by the Kushiyara River, and to the south by the international border. Two rivers, the Sonai-Bardal and the Juri, enter the haor from the east and southeast respectively, and a number of smaller rivers and streams, including the Phanai River, enter the haor from the southwest. Hakaluki Haor itself drains northwards to the Kushiyara River through the lower Juri River.

Another potential reservoir for floods from the Manu River system is Hail Haor. It is also a very large depression lying southwest of Moulvi Bazar. This haor is very flat and beels are not a distinctive feature; rather, it tends to form a single huge swamp when flooded. The area of the haor is about 25,000 ha, and it has a central elevation of 4 m PWD. The bathymetry of this haor is given in Figure 6. To the west the haor is bounded by the Rashidpur Hills, and to the east by the Balisiri Hills. To the north it is bounded by a very low east-west levee-like ridge, and to the south by the Dhaka - Sylhet Railway line. The Langla River is the main tributary to the haor, but many streams enter it from the hills to the west and east. Hail Haor itself is drained by the Langla River which runs right through it, and passes into the Bijna River.

2.3.2 Geology, Soils and Aquifers

Tectonics and Subsidence

Much of the basin lies within the Sylhet Trough, one of the major tectonic structures of Bangladesh. The basement of the Trough slopes northwards at great depth, and passes beneath the Shillong Plateau from which it is separated by the Dauki Fault (Figure 7).

As a result of northward thrusting of the Trough basement beneath the Plateau, the Plateau is rising and the Trough is subsiding. Tectonic subsidence during the Pliocene/Pleistocene period has been estimated at 2 cm/century, and this rate is considered still applicable. The great thickness of sediments which have accumulated in the Trough have amplified the tectonic subsidence. It has been estimated that this sedimentary subsidence was 4.5 cm/century during the Pliocene/Pleistocene period, but this rate is considered no longer applicable. Based on the present sediment budget of the Trough it is considered that the present rate of sedimentary subsidence is 3 cm/century, and the present rate of total subsidence is thus thought to be 5 cm/century. This is an average total rate for the Trough, and it is considered that rates across the Trough will vary from about 3 cm/century in the south of the Northeast Region to about 7 cm/century in the north. Since the project area is located in the south, relatively far from the Dauki Fault, it is considered that the rate of total subsidence in Basin is about 3 cm/century.

The implications of this rate of subsidence are that:

- Embankments may need to be raised about 3 cm every century.
- The river bed gradients of the northward flowing Manu and Dhalai Rivers may increase about 1% every century.

It is concluded from these estimates that subsidence will not pose a serious problem for embankments or other major structures in the project area, and that drainage of the project area may improve slightly over time.

Structures and Seismicity
The vast thickness of sediments filling the Sylhet Trough were folded in the Late Miocene period to form the Indo-Burman ranges, a sequence of north-trending anticlines extending from 91°E eastwards into Burma. The anticlines increase in amplitude eastwards, and plunge northwards into the Trough where they are submerged beneath the more recent sediments. In the north, however, submergence of the anticlines has been resisted, and they are exposed as outliers at Chhatak and Sylhet. The presence of the submerged portions of the anticlines has been detected by both seismic and geomagnetic surveys.

The project area lies within the southern part of the Trough where the anticlines are exposed as low hill ranges. The following topographic features of the project area and its surroundings are identifiable with some of the anticlines and intervening synclines:

Rashidpur Hills/Chhatak Hill	Anticline
Hail Haor	Syncline
Balisiri Hills	Anticline
Kawadighi Haor/Daidala Haor	Syncline
Rajkandi and Bhatera Hills	Anticline
Hakaluki Haor	Syncline
Patharia Hills	Anticline

Both seismic and geomagnetic surveys have shown that the anticlines and synclines have been faulted quite extensively although only two faults are exposed at the surface. The exposed faults trend northwards on the eastern edge of the Rashidpur Hills, and through the Patharia Hills. Faults inferred from the geomagnetic survey suggest such faults also exist on the western edge of the Balisiri Hills, the western and eastern edges of the Bhatera Hills, and on the western edge of the Patharia Hills; those associated with the Balisiri and Bhatera Hills may have some significance for the project if encountered during construction. Of greater significance for the project, however, is an inferred fault trending southeastwards through Moulvi Bazar, and down-thrown to the north. Various surface features tend to confirm the existence of this fault, the Moulvi Bazar Fault:

- The northern rim of Hail Haor is in line with this fault, and the haor may owe its existence to it.

- The northward termination of the Balisiri Hills is on the line of this fault; this may explain the apparent absence of any continuation of this anticline north of the Manu River, and the existence of Kawadighi Haor instead.

- A surveyed profile of the Dhalai River shows a sudden step, downwards to the north, of 2 m just upstream of the river's confluence with the Manu River.

- The existence of this fault would explain the present course of the Manu River from Sharifpur to Moulvi Bazar, and the existence of Daldala Haor.

The Manu River clearly flowed into the Hakaluki Haor area in earlier geological times, and its present route westwards from Sharifpur to Moulvi Bazar must reflect its interception by the fault, and its subsequent exploitation of the weakened fault zone. The large gap between the Rajkandi and Bhatera Hills indicates that this fault zone has considerable width. This fault may be encountered during excavation for the project floodway. It was not, apparently, encountered during excavations for the bridges over the Manu River at Kotarkona and Moulvi Bazar, or for the Manu Irrigation Project barrage, but excavation for these structures would have been very limited in comparison to that required for the floodway.

Seismicity is associated with the existence of faults, and the project area and its surroundings are certainly prone to earthquakes. The earthquake which occurred on 8 July 1918 at Srimangal is the fourth largest of record in the region and had a magnitude of 7.6 on the Richter scale. While this earthquake was probably on a much more deep-seated fault than those just described above, its occurrence would likely have caused some movement on these faults. There are well-documented descriptions of ground liquefactions, land sliding, rapid subsidence, ejection of ground water at the surface, collapse of river banks, and changes in river courses resulting from past earthquakes in the region.

The project area lies within "Seismic Zone 1" of Bangladesh, defined by the GSB as the most active seismic zone in the country and subject to earthquakes of intensity IX on the modified Mercalli scale. Major project structures, especially those located on or near the Moulvi Bazar Fault, probably ought to be designed for an acceleration of 0.4 g.

Haors and Beels

Haors are natural depressions of considerable areal extent lying between the main rivers of the Northeast Region. Two such depressions, Kawadighi Haor and Daldala Haor, lie within the Basin and two others of concern, Hail Haor and Hakaluki Haor, lie in adjacent structural valleys. Some haors, and it is the case with all these four, have formed as a result of peripheral faulting leading to depression of the haor area. In other cases, and more generally in the Northeast Region, haors have formed simply as a result of river levees building up around inter-riverine areas, and this process also applies to the structural depressions in the Basin.

Beels are shallow lakes, sometimes perennial but more often seasonal, which form in the lowest parts of the haors. There is little doubt, regional ground water table levels being everywhere close to the ground surface throughout most of the Northeast Region, that beel water surfaces are contiguous with the ground water table and that beels are sustained from ground water to a large extent. Surface water does, of course, also collect in the beels during the wet season, often spilling out of them into the main river system through natural connecting channels known as khals.

Surface Sediments and Soils

Surface sediments in the Basin and its surroundings consist of:

Paludal marsh clays and peats	:	Unit Ppc
Alluvial silts and clays	:	Unit Asc
Valley alluvium and colluvium	:	Unit Ava
Dihing and Dupi Tila formations	:	Unit QTdd

The first three of these units are found in the synclines, and the fourth on the anticlines. The first three are identifiable with paddy-field agriculture, the fourth with tea gardens.

Unit Ppc is found in the lowest-lying areas of Hail Haor, Kawadighi Haor, and Hakaluki Haor. It consists of bluish grey clay, herbaceous peat, and yellowish-grey silt. Alternating beds of peat and peaty clay are common in these large structurally controlled depressions, and in the beels; peat is thickest in the deeper parts. Soils associated with this unit are grey heavy silty clays of low permeability, with some peat. The water table is close to the surface, and these soils are well-suited to rice culture.

Unit Asc is found in the next higher-lying areas of the three haors. It consists of grey silt to clay, with some peat and other organic matter. Soils associated with this unit are grey heavy silty clay loams of poor permeability but with a strong ploughpan. The water table is fairly close to the surface in these areas, and they are well-suited to rice culture.

Unit Ava is found in the highest parts of the synclines south of Hail Haor, Daldala Haor and Hakaluki Haor. It consists of grey-brown silt, clayey silt, and fine to medium sand; locally it contains coarse debris derived from local bedrock and organic matter. Soils are loams or clays of poor to moderate permeability. The water table is some distance below the surface, and the existence of a strong plough pan is essential for rice culture. While generally suitable for rice culture, other cultures are possible on these soils.

Unit QTdd is found on the nearby Balisiri, Rajkandi and Bhatera Hills, the Dihing Formation overlying the Dupi Tila Formation where the former exists. The Dihing Formation consists of yellowish-grey, massive, fine to medium grained, poorly consolidated sandstone and clayey sand stone, with pebble and clay beds locally, and it is highly weathered. The Dupi Tila consists of variously coloured sandstone, siltstone, and conglomerate; sandstone predominates in the upper part. Soils are sandy loams, and apparently well-suited to tea culture; there are tea gardens throughout the hills where this unit occurs.

Near Surface Sediments and Aquifers

Near surface sediments in the project area within which exploitable aquifers may exist are Units Ava and Asc, the characteristics of which have been outlined in the preceding sub-section. Unit Ava is closely identifiable with the Dhalai River Area, and Unit Asc with the Manu River Irrigation Project area. The two units, perhaps significantly, lie on opposite sides of the inferred Moulvi Bazar Fault.

Relatively few wells have been drilled and logged in the project area but the evidence suggests the sediments in both units are variable and poorly-sorted, with frequent occurrences and substantial thicknesses of non-aquiferous sediments within the exploitable section. This lithologic condition is reflected in generally low permeabilities ranging from 10 m/day to 25 m/day, and in the low probability of encountering screenable aquifer which is only 55% at depths to about 50 m. It is thought that the aquifers lack continuity, and that semi-confined or confined aquifer conditions may prevail.

2.4 Water (Hydrology)

The Manu River basin discharges into the Kushiyara River at Manumukh. The Manu River and its main tributary, the Dhalai River, rise in the Indian State of Tripura, and their catchment areas mostly lie within this state. The confluence of the two rivers occurs within Bangladesh about 10 km upstream of Moulvi Bazar. Between their catchments lies a third small but significant catchment, that of the Kalkalia Khal which enters the Manu River about 2 km upstream of its confluence with the Dhalai River.

Catchment Areas
The catchment areas of the Manu and Dhalai Rivers lie in a region of folded and faulted Neogene sediments the topography of which is characterised by a series of long north-south trending anticlinal ridges and synclinal valleys (Figure 8). Within Bangladesh the Manu River cuts westward across the ridges separating these valleys, following the line of the inferred Moulvi Bazar Fault.

The configurations of these rivers and their catchment areas are shown in Figure 9, and the areas of the catchments are given in Table A.5.

River Gauging Stations and Records
Within the Manu River basin there are two river gauging stations where both discharge and water level are gauged:

Manu River at Manu Railway Bridge (Station No. 201)
Dhalai River at Kamalganj (Station No. 67)

These are located well upstream of the Manu-Dhalai confluence and Moulvi Bazar. Records of both discharge and water level exist for 1964-91 for both stations, and are summarised in Tables A.6 and A.7 (discharges) and Tables A.8 and A.9 (water levels). Also within the Manu River Basin water levels only are gauged at:

Manu River at Moulvi Bazar (Station No. 202)
Manu River at Kazir Chalk (NERP Station)

The water level records for Moulvi Bazar exist for 1964-90, and are summarised in Table A.10. Records for Kazir Chalk exist only for 1992-93.

Outside the Manu River basin, but of relevance are two gauging stations where both discharge and water level are gauged:

Kushiyara River at Sheola (Station No. 173)
Kushiyara River at Sherpur (Station No. 175.5)

These are located well upstream (Sheola) and downstream (Sherpur) of the reach of the Kushiyara River which forms the northern boundary of the Manu River Irrigation Project. Records exist for Sheola for 1964-91, and for Sherpur for 1982-91; these are summarised in Tables A.11 through A.14. Also on the Kushiyara River water levels only are gauged at:

Kushiyara River at Fenchuganj (Station No. 174).
Kushiyara River at Manumukh (Station No. 175).

The water level records for Fenchuganj exist for 1964-91 and are summarised in Table A.15. Records for Manumukh exist for 1964-78 only; these are summarised in Table A.16.

The locations of all these gauging stations are shown in Figure 9.

Annual Peak Discharges and Water Levels

Based on the available records of discharge and water level, flood frequency curves have been developed for the Manu River basin stations by the method of L-Moments as described in Appendix B. All of the annual series are apparently well fitted by the EV III distribution, although reservations attach to the goodness of fit; sample testing has shown that the samples exhibit dependence, non-stationarity, and heterogeneity due mainly to the construction of embankment works within the period of record, but changing the distribution will not improve the goodness of fit, except fortuitously. The 100-year flood discharges and water levels are given in Table 2.3.

Table 2.3: 100-Year Annual Discharges and Water Levels

River	Station	Discharge (m^3/s)	Water Level (mPWD)
Manu	Manu Railway Bridge	873	19.05
	Moulvi Bazar*	1577	13.62
Dhalai	Kamalganj	506	21.21
Kushiyara	Sheola	3448	14.29
	Fenchuganj	-	11.47
	Manumukh	-	10.18
	Sherpur	5252	9.57

Note: * *Based on synthesised data - see Appendix B.*

2.4.4 Water Bodies

Open water bodies

The Basin contains approximately 2600 ha of beels and channels. Of all the open water bodies in the area, Kawadighi Haor is the most prominent and lies within Manu River Irrigation Project. Prior to project construction, this beel was known to be carp spawning ground.

Closed water bodies

There are some 11,120 ponds and 2000 ditches covering an area of 1330 ha within the Basin. These ponds and ditches are suitable for aquaculture and are presented, by Thana, in Table A.17.

2.4.5 Surface Water Availability

The Manu River Irrigation Project presently holds full rights to the dry season flow of the Manu River so,unless the water rights are changed or flood water can be stored in small reservoirs in the Balisiri and Rajkandi Hills, there will be no surface water available for irrigation in the floodplain of the Dhalai River. For this reason, the interventions considered in the Dhalai basin relate mainly to flood control.

Irrigation in the Manu River Irrigation Project was developed on the basis of the dependable dry season flows of the Manu River. These flows are given in Table 2.4 for return periods of 2 years (50% probability), 5 years (80% probability), and 10 years (90% probability).

The irrigation water requirements adopted in design of the rehabilitation of the Manu River Irrigation Project are given in Table 2.5 in which they are also compared to the 80% dependable flows of the Manu River. This comparison suggests there is a deficiency lasting throughout March, on average once in 5 years.

Table 2.4: Dependable Dry Season Flows of the Manu and Dhalai Rivers

Station Number	Station Name	River Name	Month	Decade	Dependable discharge (m³/sec) 2-yr	5-yr	10-yr
201	Manu Railway Bridge	Manu	February	I	10.07	7.90	7.6
				II	9.49	7.90	7.54
				III	10.04	7.59	6.75
			March	I	9.72	6.98	6.07
				II	8.30	5.91	5.50
				III	9.07	6.33	5.32
67	Kamalganj	Dhalai	February	I	3.85	2.36	1.97
				II	3.22	2.36	2.16
				III	3.06	2.33	2.11
			March	I	2.94	2.30	2.07
				II	2.60	2.12	1.90
				III	3.64	2.03	1.96

Table 2.5: Manu River Irrigation Project Diversion Requirements and Manu River Discharges

Month	Decade	Diversion Requirement* (m^3/sec)	80% Dependable Flows (m^3/sec)	Surplus or Deficiency (m^3/sec)	Dependable/ Requirement (%)
Feb	I	8.00	10.26	+2.26	128
	II	8.00	10.26	+2.26	128
	III	8.00	9.92	+1.92	124
Mar	I	10.0	9.28	-0.72	93
	II	14.20	8.03	-6.17	57
	III	13.10	8.36	-4.74	64

Source: BWDB System Rehabilitation Project, Draft Feasibility Report, Manu River Irrigation Project, Dec. 1992

A similar comparison to the 50% dependable flows suggests there is a deficiency in March II and III (20 days), on average once in 2 years. Whether these indicated deficiencies are as serious as they appear depends, however, on the irrigation efficiency assumed in design when the diversion requirements were determined. In Table 2.6 the surface water deficits given in Table A.3 have been converted to crop water requirements (1 l/s/ha = 8.64 mm/day) and these, in turn, to irrigation field requirements assuming a reasonable field application efficiency of 60%.

Table 2.6: Crop and Field Water Requirements of the Manu River Irrigation Project

Month/ Decade		Surface Deficit (mm/day)	Crop Water Requirement (l/s/ha)	Field Requirement (m^3/s)	80% Dependable Flow (m^3/s)	Dependable/ Requirement (%)
Feb	I	4.53	0.52	10.49	10.26	98
	II	4.32	0.50	10.00	10.26	103
	III	4.43	0.51	10.25	9.92	97
Mar	I	4.10	0.47	9.49	9.28	98
	II	4.19	0.48	9.70	8.03	83
	III	2.87	0.33	6.64	8.36	126

Notes: 1) Field Application Efficiency = 60%
2) Command Area = 12000 ha

Comparison of these field requirements with the 80% dependable flows suggests the latter are basically adequate, that the inadequacies suggested by the design requirements are due to the assumption by the designers of a low irrigation distribution system efficiency, and that if there really is a deficiency it could be rectified by maintenance on the canal system.

2.4.6 Ground Water

Usable and available groundwater recharge computed from the thana ground water resources estimated by WARPO are given in Table 2.7. The data show that there is little prospect for groundwater development, especially for irrigation, due to aquifer constraints. It is considered that the meagre remaining exploitable ground water should be reserved for domestic use.

Table 2.7: Usable and Available Ground Water Recharge in the Manu River Irrigation Project

Usable Recharge (Mm^3)			Available Recharge (Mm^3)		
STW	DSSTW	DTW	STW	DSSTW	DTW
0.00	5.0	97.0	0.0	2.0	38.0

2.5 Land/Water Interactions

2.5.1 Siltation and River Erosion

Comparison of recent SPOT imagery with earlier topographic maps suggests there has been increased erosion and sediment yield in the headwaters of the Manu and Dhalai River over the last 30 years. These changes have not had much impact on the morphology of the Manu River that is within Bangladesh to-date. However, continued increases in sediment yields from the headwaters will almost certainly affect the stability of the main river in the long-term.

Within Bangladesh, the Manu River can be divided into three main reaches:

- Indian border to Kazir Chalk
- Kazir Chalk to Dhalai River confluence
- Dhalai River confluence to Kushiyara River at Manumukh

The river bed in the reach between the Indian border and Kazir Chalk is composed primarily of medium sand, and there is evidence of substantial sand transport in the form of large point bars throughout this reach. Analysis of stage - discharge rating curves at the Manu Railway Bridge (situated 6 km upstream of Kazir Chalk) suggests the river has degraded by about 0.5 m over the last 25 years.

Between Kazir Chalk and the Dhalai River confluence, the river slope flattens out during high water and the river spills into haors north and south of the channel. In this reach, channel velocities decrease and the bed is composed primarily of fine sand and silt, which suggests this is a depositional reach.

Downstream of the Dhalai River, the river bed coarsens again and the slope steepens. During flood conditions, large quantities of sand are transported as bed load and in suspension. Hydrographic surveys during a major flood event in June 1993 revealed very large dunes (up to 3 m in height and 100 m in length) moving along the river bed downstream of the bridge in Moulvibazar. These dunes persisted all the way down to the confluence with the Kushiyara River. A comparison of historic and recent cross sections indicated there has been relatively minor channel changes over the last 10 years downstream of the barrage, and no evidence of overall channel aggradation in this reach. The main morphologic change has been a slight increase in the channel width and cross sectional area. This net degradation has probably been caused by the high flood flows in recent years and by the encroachment from flood control embankments.

2.5.2 Crop Damage

Substantial crop damages occur in the project area due to natural flooding of the lower lands, and to floods and flooding resulting from public cutting of embankments and, much less frequently, from natural breaching of locally constructed public dykes. Localised crop damage also occurs during occasional hailstorms and high winds.

Within the Manu River Irrigation Project
The pumping station of the Manu River Irrigation Project is intended to cope only with local runoff generated within the Project area, and the runoff entering this area from the Bhatera Hills. In recent years this runoff has been unusually high, leading to some overloading of the pumping station.

Public cutting of the embankments adds substantially to the volume of water which the pumping station is required to dispose of; peak flows through a single one of these cuts in June 1993 was estimated at about 200 m^3/s. Such flows rapidly spread over the F0 and F1 land dashing the crops and leaving the paddy-fields brim full of water after their passage. There is little damage experienced on either F2 or F3 lands since these are usually fallow during the Kharif II season.

Within the Dhalai River Floodplain
Crops in the Dhalai River Floodplain are inundated by spill from the left bank of the Manu River and/or from the right bank of the Dhalai River. These spills tend to occur in the early or mid-monsoon and damage aus and t aman crops.

2.6 Wetlands and Swamp Forest

2.6.1 Natural Wetlands

There are two wetland areas within the Basin. They are characteristically quite different from each other and thus described separately. The first is the Kawadighi Haor and the second is the wetlands in the Dhalai River floodplain (Dhaldala Haor). The Hakaluki Haor, though not within the Manu Basin, is being considered as a possible reservoir for peak Manu River discharges so is also characterized here.

Kawadighi Haor
The Kawadighi Haor consists of several perennial beels with an area of about 1090 ha. This is one of the more prominent wetlands situated within the Manu River basin. The Haor is surrounded by Manu and Kushiyara River in south west and north and by Rajnagar and Battera Hills in the east. It is a large sized, flat-shallow wetland having some deeper pockets (beels).

The shallower regions provide a very good habitat for numerous submerged rooted floating plant communities in the monsoon. The most dominant submerged plants are Hydrilla verticillata, Ottelia alismoides, Aponogeton sp. and Ceratophyllum sp. The most dominant rooted floating species are Echinochloa colonum, Nymphaea sp., Nymphiodes sp. and Trapa maximowiczii.

The deeper sections are less densely crowded with vegetation and rooted floating Echinichloa colonum and Trapa maximowiczii are the dominant species. Clinigyne dichotoma which is one of the more economically important wetland plant species of this area grows at the border of the haor around homesteads.

This wetland serves as an important stopover for a large number of migratory waterfowl, particularly ducks. In January 1993 as many as 12,000 waterfowl from more than 35 species were counted. Many resident waterfowl use this wetland as their nesting habitat. It is one of the main nesting grounds of the Whiskered Tern in Bangladesh.

The threatened Smooth Indian Otter still inhabits this Haor. Rana temporalis, a very rare amphibian is also reported inhabiting this wetland.

Since this wetland is located inside a full flood control project (the Manu River Irrigation Project) the water levels are now lower in the pre-monsoon than prior to project implementation. As a result, a heavy growth of aquatic weeds has been induced. This is causing eutrophication during the post monsoon period. The highly eutrophic condition is not healthy for fish or any other aquatic animals.

Daldala Haor

The wetland areas of this Haor are not as important as the Kawadghi Haor, mainly because the beels are fewer and smaller; the total beel area of these beels is about 130 ha and most of them are shallow and seasonal.

Owing to rapid fluctuations in water levels in these wetlands, aquatic vegetation does not flourish. The rooted-floating Nymphaea and Nymphoides are the most prevalent plants.

Waterfowls do not visit these wetlands due to the small number and size of these beels, and the higher level of human activity around them. Other wildlife fauna are also not very common.

Hakaluki Haor

Hakaluki Haor one of the largest and the best known haor in Bangladesh. It consists of a complex of more than 80 interconnecting *beels* in a shallow basin with the Patharia and Madhab Hills to the east and the Bhatera Hills to the west. The important *beels* are Chatla, Pinglarkona, Dulla, Sakua, Barajalla, Pioula, Balijuri, Lamba, Tekonia, Haorkhal, Tural, Baghalkuri, Chinaura and so on. The total area of this wetland is about 18,000 ha of which 4,400 ha retain water perennially. During the monsoon, the entire haor is flooded and over 60% of the area is inundated by more than 2.5 m but as the water level falls during the dry season the beels become differentiated from one another. Some of the land between the *beels* is cultivated though most of the land remains fallow and serves as pasture land.

The ecological characteristics, particularly of the vegetation patterns, differs sharply between the permanent water bodies and the seasonal ones. Within the permanent water bodies, vegetation is less dense in the monsoon than during the winter since the vegetation becomes submerged and does not thrive without light. However, the aquatic vegetation that exists, begins germinating just after the start of the monsoon floods. The dominant species found in the perennial beels are Vallisnaria spiralis, Hydrilla verticillata, Ceratophyllum sp., Najas sp., Nymphoides indicum, Aponogeton sp. and Nymphaea sp.

In the recent past, the haor contained a very dense forest. Deforestation and the lack of conservation practices has virtually destroyed the forest within the last two decades. Unfortunately, the process continues so that even natural regenerated saplings are harvested regularly for household fuel.

Hakaluki Haor is very important for the migratory waterfowl. In January 1993, 64,000 waterfowl were counted in Haorkhal and 15,000 waterfowl were counted in Chatla Beel. The most interesting species observed was the Barheaded Goose which is now very rare in fresh water wetlands. Other important species were Adjutant Stork, Bear's Pochard, Falcated Teal, Broadbill Sandpiper, Spotted Redshank, Nordmann's Greenshank, Temminck's Stint, Steppe Eagle and

Osprey. High human interference due mostly to fishing and poaching making are steadily making the area unsuitable for birds.

Wildlife is not very common in the haor proper except some otters. De-watering for fishing has rapidly depleted the turtle population .

2.6.2 Swamp Forest Trees

There is no swamp forest within the Manu Basin, but two small patches of swamp forest are present in the Hakaluki Haor area. One is in Chatla beel and another is near the village of Kalikrishnapur. The plants which are common in this type of forest are also found in homestead groves. With the exception of these two swamp forest patches, the vegetation surrounding Hakaluki Haor is unique since it includes both swamp forest as well as mixed evergreen rain forest.

3. SETTLEMENT, DEVELOPMENT, AND RESOURCE MANAGEMENT

The previous chapter contained a biophysical description of the Bangladesh portion of the Manu River Basin. The current chapter, and those which follow, refer mainly to the project area — the area(s) which will be affected by interventions in the Basin. (see Figure 1). All statistics and analysis will, therefore, be based on the impacted area(s) unless otherwise specified.

3.1 Human Resources

3.1.1 Land Use and Settlement Pattern

Land Use
Current land use is summarized in Table 3.1.

Table 3.1: Current Land Use

Use	Area[3] (ha)
Cultivated (F0+F1+F2+F3)	40,800
Homesteads	4,020
Beels	1,220
Ponds	820
Channels	1,040
Hills	-
Fallow[1]	1,200
Infrastructure[2]	1,300
Total	52,300

[1] Multi-use land, wetlands, grazing lands, village grounds. Includes F4 land.
[2] Government-owned land not appearing elsewhere.
[3] Includes impacted area along the Dhalai and the Manu Rivers.

Settlements
The district headquarters of Moulvi Bazar is situated on the left bank of the Manu River.

Villages (an estimated 385 within the Project Area) are located on the higher lands but are not restricted either to the hills or to the river levees. The majority of villages tend to be located between the foot of the hills and the normal maximum flooding level in the haors; in such locations the villagers are normally free of flooding and practicably close to their farmlands.

Flood Damage to Housing
It is estimated that about 24% of Moulvi Bazar town is affected by flooding; this involves an estimated 8500 residents as well as numerous retail outlets and small manufacturing and repair shops located in this flooded zone.

Generally, homesteads are not regularly affected by flooding. However, those homesteads situated in the floodway between the Manu River and the flood control embankment of the Manu River Irrigation Project are threatened every year with inundation. A combination of river confinement and increased discharges in the Manu River system has exposed these homesteads and parts of Moulvi Bazar town to the threat of annual flooding.

During the more severe flood events homesteads and most land types (except the highest lands) are inundated. During June 1993, most homesteads in unions such as Akailkura, Fatehpur, Panchgaon, and Akatona were inundated to depths ranging from one to two meters. Even on higher land, water rose to the plinth level of the homesteads. Damages included: loss of homestead buildings and any of the contents which had not been removed, destruction of the homestead platform, loss of livestock, destruction of homestead gardens, destruction of some trees, ponds used for aquaculture were inundated and the fish disappeared. In addition, commerce was interrupted since village markets were inundated and infrastructure such as roads were not passable.

Coping Strategies
People living in the floodway (between the Manu River and the Manu River Irrigation Project embankment) consider that by cutting the embankment and releasing flood water into the Manu Irrigation Project they can reduce water levels. While this measure is not highly effective, it is adopted regularly.

The government establishes relief centres for people whose homes have been inundated to the point that they are forced to move out — these relief centres are located in schools, union parishad offices, and on the premises of houses located on higher lands. These locations generally have inadequate sanitation facilities to accommodate large groups of people though drinking water is usually in sufficient supply from tube wells. Food is made available but quantities are insufficient. In general, the relief centres did not meet the demands placed upon them.

While wealthier families generally have their homesteads on higher land and are not usually subjected to flooding, those that are have several options. If the flooding is not too severe, they will build raised platforms inside their homes and store their belongings above flood level. If they need to move out, they do not go to the relief centres but rather will either move into the city (Moulvibazar) or will move in with relatives who are living on higher land.

In some places, where flooding is severe and regular, such as the villages of Fatehpur, Antohori, Akailkora, Baliakandi, Dheupasha, and Jahidpur, people have moved their homesteads onto the embankment. People also relocate themselves and their belongings onto country boats.

Where flooding is not too severe (less than 30 cm above the homestead platform) people will raise the sheds containing the livestock by placing water hyacinth or straw barriers. The best option that people have is to shift their belongings (including livestock) to dry ground though this option mainly exists for those with more resources.

3.1.2 Demographic Characteristics

The present (1991) population of Moulvi Bazar District is estimated to be 1,446,134, on the basis of the 1981 Census and a rate of increase of 23.4% over the past decade. The distribution of this population among the thanas, and the estimated populations within each thana which are included within the Project Area are given in Table 3.2.

Moulvi Bazar and Srimangal towns are the only urban centres in the District of Moulvi Bazar, and Moulvi Bazar town is the only urban centre partially within the project area; it has a population 35,371, of which 8,500 are estimated to live within the Manu flood affected part of the town. Srimangal has a population of 19,868. (NERP, 1993: Population Characteristics and State of Human Development, Table 2.12). Subtracting these urban populations from the total District population leads to an estimate of 1,390,895 for the rural population of the District.

Statistics on the age and gender distributions of the population are available only for the District of Moulvi Bazar, but these are thought to be well representative of the distributions among the population within the Project area.

3.1.3 Quality of Life Indicators

Quality of life is usually assessed by several key indicators. Those used here are literacy, school attendance, and access to health, sanitation, and pure drinking water facilities.

Literacy
The literacy rate in the project area varies. According to the 1981 census, the literacy of the population at 5 years of age and above varied from 21.4% in Rajnagar Thana to 26.8% in Moulvi Bazar Sadar Thana. The corresponding figures for females were 15.3% and 20.5% respectively for the same thanas. The rate appears to have increased over the last 10 years. According to the 1991 census, the literacy rate for all people of Moulvi Bazar District is recorded as 23.06% for both male and female.

Table 3.2: Thana Populations within the Project Area

Thana	Total Population	Project Area Population
Moulvi Bazar	251,928	48,000
Srimangal	224,256	0
Kamalganj	208,083	83,000
Kulaura	362,217	7,000
Rajnagar	190,416	140,000
Barlekha	209,235	0
Total	1,446,134	278,000

Source: NERP, 1993: Population Characteristics and State of Human Development, Table 2.1

Notes:

(1) Computed as Thana Population x Area Percentage.
(2) Includes 8,500 persons living within the 24% of Moulvi Bazar town affected by Manu River flooding, and 8,000 persons living on the lower Manu River floodplain, or a total of 16,500 persons.
(3) Includes 6,000 persons living on the upper Manu floodplain
(4) Includes 5,000 persons living on the upper Manu floodplain
(6) Includes 15,000 persons living on the upper Manu floodplain.

Table 3.3: Age and Gender Distributions in the District of Moulvi Bazar

Age Group	Males (%)	Females (%)	Total (%)	Gender Ratio
Children (< 15 years)	44.0	44.8	44.3	98
Adults (15 to 59 years)	51.0	50.0	50.6	102
Elderly (≥ 60 years)	6.7	5.3	5.9	126
Total/Average	100.0	100.0	100.0	109

Source: NERP, 1993: Population Characteristics and State of Human Development, Table 2.6

School Attendance
The average number of primary schools per 10,000 population is estimated to be 5.7 for Moulvi Bazar District (BANBEIS, 1990). Many villages, especially in Rajnagar Thana, have no primary school.

According to the 1981 census, school attendance in the project area for all children five to nine years of age varies from 22.9% in Rajnagar Thana to 29.3% in Moulvi Bazar Thana. Attendance for females in this age group in these two thanas varies from 21.0% to 27.2% respectively. Attendance for all youths between the ages of five and 24 is 19.5% and 23.4% for these thanas while the corresponding attendance for females is 15.6% and 20.1%. The situation is worse for the rural poor; they cannot afford to send their children to school.

Access to Health Services
Moulvi Bazar, the district headquarters, has a hospital, and all the thanas have hospital facilities located at their headquarters. According to the Directorate General of Health Services (1992), there is one hospital for every 241,022 persons, and one doctor for every 28,356 persons, in the District of Moulvi Bazar; there is one hospital bed for 7,054 people.

Immunization coverage of children below two years of age is high for the project area, the rate varying from 42% in Kamalganj Thana to 57% in Kulaura Thana (1990). However, access to health services is generally limited for rural villagers, and is out of reach of the poor.

Rural Water Supply
Detailed information on access to safe drinking water is not available for the project area. However, for rural areas of the District of Moulvi Bazar, the Department of Public Health Engineering reports the availability of one working tube well for 122 persons. In 1990, 62% of households had access to safe drinking water in the district. It is noted that most tube wells are located in the houses of the rich, and this means the poor have very limited access to safe drinking water.

Sanitation
Specific information on sanitation facilities is not available at the project level. Sanitary latrines are uncommon in the villages, except for the very well-off and educated families. During field reconnaissance, it was noted that open space defecation is a common practice in the villages, particularly for males. Women generally use kutcha latrines, or defecate at an allotted place protected by banana or betel nut leaves.

3.1.4 Agriculture Employment and Wage Rates

Village employment opportunities are mainly in agriculture. The major crops in the area are Aus and Aman. Employment for men mainly consists of transplanting t. aman which occurs between June and August, and harvesting which occurs in July-August (for aus) and November-December (for t. aman). Employment during Boro cultivation is limited to labourers living in low areas, especially in Kawadighi Haor.

Wages rates for male agricultural labourers vary from Tk 40 to Tk 60, with two meals per day during months of peak agricultural activity. During months when there is no agricultural work, the wage rate varies from Tk 20 to Tk 40.

During months when employment opportunities in agriculture are limited, some poor people migrate to Moulvi Bazar and Sylhet to work as rickshaw pullers, construction workers, or household servants.

Migration overseas, particularly to the UK, is very common in the project area. There is a seasonal in-migration to the project area, mainly from Noakhali, Dhaka, Mymensingh and Comilla Districts, to work on harvesting the rice crops and on earthworks.

3.1.5 Land Ownership Pattern

Land ownership categories have been defined by the BBS as shown in Table 3.4. Estimated land holdings per household are given in Table 3.5. Although only approximate, the estimates indicate that 15,014 Category V land owners, comprising 39% of all households, own 93% of the cultivable land.

3.1.6 Land Tenure

Large landowners, particularly those living in Moulvi Bazar, use tenant farmers to farm the land, and the crop is shared equally between the owner and the tenant. Under this share cropping system the owner provides no inputs if the crop is a local variety, but if it is a high yielding variety, the owner provides 50% of the inputs.

Other large landowners lease their lands under the *pattani* system. In this case the landowner leases the land for one crop season for cash in advance, and the tenant provides all inputs and keeps all of the crop. The rate for such leases aries from Tk 600 per bigha to Tk 1000 per bigha (1 bigha = 0.12 ha). Landless people have very little access to land under this tenurial system, being unable to afford both the cash advance and the inputs.

The leasing of land under the *chukti* system is virtually non-existent in the project area.

Medium landowners farm their own land with the assistance of agricultural labourers, but small owners farm their land without assistance.

3.1.7 Fishermen

Fishing is an activity of considerable importance in the project area, and competition for the fish resources is increasing every day as more and more people have to depend on fishing for a living and the fish resources decline.

Table 3.4: Land Ownership Categories

Category	Status
I	Own no homestead
II	Own homestead but no cultivable land
III	Own homestead and up to 0.2 ha of cultivable land
IV	Own homestead and from 0.2 ha to 0.4 ha of cultivable land
V	Own homestead and more than 0.4 ha of cultivable land

Table 3.5: Estimated Land Holdings per Household in the Project Area

Land Owner Category	Households			Land Areas Owned				
	No	%	Σ%	Homestead		Cultivable Land		Total ha/HH
				ha/HH	ha	ha/HH	ha	
I	808	2	2	0.0	0	0	0	0
II	4997	13	15	~0.1	540	0	0	~0.1
III	12130	32	47	~0.1	1305	~0.1	1213	~0.2
IV	5238	14	61	~0.1	565	~0.3	1571	~0.4
V	15014	39	100	~0.1	1610	~2.6	39216	~2.7
Total	38187	100	100	-	4020	-	42000	-

Commercial fishing is carried on by two groups of fishermen, so called "traditional" and "non-traditional" fishermen. Casual fishing for family consumption is growing but is severely restricted by the leasing arrangements.

Traditional fishermen live off fishing, and have been engaged in it for generations. Their cooperatives hold the Jalmohal leases, either directly or under sub-lease from rich fishermen who can individually afford a Jalmohal lease. The rich fishermen appropriate most of the catch profit while the poorer ones, who fish on a regular basis, have to sell their catch to repay the rich and to survive.

Non-traditional fishermen are an emerging group consisting of the poorer farmers and the landless. They fish in un-leased water bodies during the monsoon season, and sell their catch to survive. About 25% to 30% of households fall into this group at present, but their number is increasing day by day.

Another group of people not called as "fishermen" but "common residents of the area" catch fish not for sale but for their own family consumption. Sometimes, the rich among the jalmohal leases lease the jalmohals for earning profit from the catch and also act as financiers for the fishermen cooperatives.

3.1.8 Situation of Women

Women's role in agricultural production is important, especially in the post-harvesting phase which involves the drying, winnowing, par-boiling and storing of rice, but it tends to be devalued and under-reported.

Most women prefer working in homestead gardens, and raising poultry/duck, in addition to doing their house work. Though women generally do not work in the fields, some poor women are reported to be working outside their homes, mainly for the Road Maintenance Programme of CARE, and on such activities as gathering wild vegetables and collecting fuel.

3.1.9 People's Perception

Problems
Local people's perceptions of their problems related to water and its impact on their livelihood, and their suggestions as to the nature of interventions which might solve these problems, were sought through meetings, group discussions, and personal interviews during 1993. The problems identified were as follows:

Flash Flooding. This is described as the major problem in the project area. It is perceived as a threat to the existence of Moulvi Bazar and of many villages along the Manu and Dhalai Rivers, and as the cause of much crop damage. The following aspects of this problem were noted:

a) Flash floods of the Manu River on entering Bangladesh cause many breaches in the embankments of the Sharifpur FCD Project, and of the Manu River FCD Sub-Project, as a result of which there is extensive damage to aus and aman rice crops in Kulaura and Kamalganj Thanas.

b) These floods also cause many breaches in the right bank dyke along the Manu River through and downstream of Moulvi Bazar. Flood water entering through these breaches is trapped by the Manu River Irrigation Project embankment which local residents cut in an effort to prevent inundation of their homesteads. There is extensive damage to housing, and to Aus and Aman rice crops both in the area between the dyke and the embankment, and within the Manu River Irrigation Project as a result of the embankment cuts.

c) Similar floods in the Dhalai River spill over the river banks significantly damaging rice crops including aus, aman and boro. Such damages are referred to as a regular feature of recent years. The floods typically last for five to seven days, and there are three to five such occurrences in every year.

River Erosion. River erosion of the banks of the Manu River is perceived as a problem. It was stated to be particularly serious in Akhailkura Union of Moulvi Bazar Thana.

River Siltation. Both the Manu and Dhalai Rivers carry large amounts of silt and sand, deposition of which on the river beds is perceived as a serious contributing factor in causing high water levels in both rivers. It was also stated that this siltation has accelerated downstream of the Manu barrage since it was constructed, and that the siltation renders difficult the movement of boats and bamboo rafts along the river.

Obstruction of Water Transport. Although obstruction of water transport is not perceived as a serious problem in the project area some people complain about difficulties in moving boats and bamboo rafts through the Manu barrage.

Obstruction of Fish Movements. It is perceived that the Manu River Irrigation Project embankments particularly, but also other embankments, obstruct the movement of fish between the rivers and the haors, and this has lead to a substantial reduction in fish production. The reduction in Kawadighi Haor was referred to as extreme.

Jalmohal Fishing Practices. Poor fishermen stated that fish production, especially in Kawadighi Haor, had greatly decreased due to the jalmohal lease-holder's practice of de-watering the haors.

Suggestions
Suggestions for remedial action to solve the flooding problems were as follows:

a) Strengthen the dyke on the right bank of the Manu River, and extend it downstream to the river's outfall at Manumukh.

b) Divert flood water of the Manu River to Hakaluki and/or Hail Haor, but with careful study to minimise effects on other areas.

c) Try dredging the Kushiyara River before diverting Manu/Dhalai floodwater to Hakaluki Haor; it might work, and so eliminate the need for the diversion.

d) Re-excavate the channels of the Manu and Dhalai Rivers to reduce water levels in these rivers.

Suggestions for remedial actions to solve the fisheries problems were as follows:

e) Stop Jalmohal leaseholders de-watering of the beels, especially those of Kawadighi Haor, and hence stop overfishing of the beels.

f) Declare a number of beels, in both Kawadighi Haor, and Daldala Haor to be fish sanctuaries, and stop fishing in those beels completely.

g) Improve fish habitats by planting water-resistant trees (hizal and koroch) around the habitats.

h) Allow local fishermen to catch fish in the beels leased as jalmohals, or let them take the lease.

Recommendations of Moulvi Bazar Seminar
A Seminar was held at Moulvi Bazar in July 1993 for the purpose of soliciting the views of responsible area representatives and officials concerning problems in the project area, and solutions which ought to be considered. The Seminar was attended by

Members of Parliament for Moulvi Bazar District
District Commissioner of Moulvi Bazar District
District and Thana Officials
Union Parishad Chairmen
Villages Representatives
NGO Representatives

Recommendations emerging from the Seminar[1] were that consideration should be given to:

1) Dredging the Kushiyara River in the vicinity of Markuli where its channel is heavily silted.

2) Dredging particular reaches of the Manu and Dhalai Rivers where their channels are silted.

3) Diverting floods of the Manu and Dhalai Rivers to Hakaluki Haor and/or Hail Haor.

4) Provision of embankments on both banks of the Manu River from the downstream end of the Manu River FCD Sub-Project to the Manu Barrage.

5) If (4) is not possible, strengthening of the existing dyke on the right bank of the Manu River from Hashimpur to Palpur, or relocation elsewhere of the residents living behind the dyke.

3.1.10 Local Initiatives

There are numerous examples of local initiative within the project area. These include local community initiatives in irrigation at the foot of the Bhatera Hills. They also include initiatives within the Manu River Irrigation Project. In many places, the project irrigation canals stop short of the land farmers wish to cultivate and they build small dams and canals which extend the project irrigation canal network. In 1992-1993, there were 43 dams, each with a set of canals to bring irrigation to individual plots. All were built and managed under local initiatives.

Another form of local initiative, though less palatable since it engenders conflict and destruction, is the public cuts made in the Manu River Irrigation Project embankment. The embankment was cut in 1984, 1985, 1988, 1990, 1991 and 1993.

In general, people within the Project Area organize themselves to counteract crisis situations or to efficiently utilize available resources.

3.2 Water Resources Development

3.2.1 Flood Control and Drainage.

Within the Project Area, BWDB has implemented the several projects. These are summarized in Table 3.6 and shown in Figure 10. The projects are intended to provide full flood control improvement to a gross area of 46,419 ha and gravity irrigation to 12,000 ha.

[1] These recommendations overlapped to a certain extent (as would be expected) with those suggestions obtained from the field interviews which are recorded in the previous section of this document.

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Table 3.6: Existing Projects

Project Name and Type	Gross Area (ha)	Project Components
Manu River Irrigation Project; FCD/I	24,800 (FCD) 12,000 (Irr)	About 60.0 km of peripheral flood embankment 64 cross-drainage structures 2 drainage regulators One drainage pumping plant (34.0 m3/sec) 86 meter long R.C.C diversion barrage Irrigation canals lengths more than 100 km More than 240 irrigation structures
Sharifpur FCD Sub-Project; FCD	1,460	10 km of flood embankment along right bank of Manu River; 4 drainage sluices
Hamhami Chara Sub-Project; FCD	2,544	10 kilometre of flood embankment along left bank of Manu and Dhalai Rivers; 4 drainage regulators on various drainage channels.
Manu River FCD Sub-Project	1,615	37 km of flood embankment along both banks of Manu River 12 drainage structures at different locations.
Manu River Left Flood Embankment; FCD	16,000	17 km of flood embankment along left bank of Manu River from Moulvi Bazar to Manumukh; One pipe sluice at Balikandi.

3.2.2 Irrigation

Surface Water

As indicated above, 12,000 ha of Manu River Project area is targeted for irrigation by diverting Manu River flow at Moulvi Bazar. In 1988-89, however, the coverage was about 8250 ha. At full development, the Manu River Project requires 14.2 m^3/sec whereas the available flow at Moulvi Bazar is 8.03 m^3/sec (see section 2.4.5).

According to AST 1991 Irrigation Census, LLPs and traditional technologies irrigated 525 ha and 7300 ha respectively of boro rice.

Groundwater
According to AST 1991 census, about 10 ha of land was irrigated by STW and 30 ha by DTW in the area

3.3 Other Infrastructure

Roads
Moulvi Bazar town is the focal point of the road network in the District. The main roads leading from the town are:

Moulvi Bazar - Dhaka, via Srimangal
Moulvi Bazar - Sylhet, via Sherpur
Moulvi Bazar - Sylhet, via Kamalpur and Fenchuganj (new)
Moulvi Bazar - Kamalganj
Moulvi Bazar - Kulaura, via Kotarkona

Two bridges in Moulvi Bazar connect the first two of these roads to the third one, the second bridge presently being under construction. There are no other large road bridges in the project area or its surroundings, and river crossings are made by passenger ferry, or by fording the rivers in the dry season.

The road links between Moulvi Bazar and Sylhet are vulnerable to inundation during floods. The road links are becoming increasingly important to further development in the region as the region's economy monetises and becomes less agriculturally oriented in relative terms and thus the protection of these road networks is considered an important priority for development of improved water management in the Project Area.

Railways
The District of Moulvi Bazar is served by the Dhaka - Sylhet line of Bangladesh Railways, but the line does not pass through Moulvi Bazar town. Srimangal, Kamalganj and Kulaura are on the railway line which, beyond Kulaura leads to Sylhet via Fenchuganj, and to Barlekha.

Rail traffic is also disrupted during flooding. While this is of some concern, the railways handle considerable fewer passengers and much less freight than either the road network or the river system.

3.4 Agriculture

The Project Area includes land within the Manu River Irrigation Project and land within the Dhalai River Basin. Net cultivated is about 78% of the gross Project Area. About 60% of the cultivated area is flooded by less than 30 cm (F0 land type). Another 11% of the cultivated area is flooded between 30 to 90 cm (F1 land type). The area flooded between 90 to 180 cm (F2 land type) is 13% of the cultivated area and the remaining 16% of the cultivated area is flooded by more than 180 cm (F3 land type). The present cropping intensity is 164% with single, double and triple cropping being practiced on 38%, 60% and 2% respectively of the cultivated area.

Table 3.7: Present Crop Patterns in Project Area

Crop Pattern	F0		F1		F2		F3		Total Area (ha)
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
b aman-fallow					780	15.3	2240	34	3020
fallow-l boro					650	12.8	3945	60	4595
fallow-hyv boro	337	1.4	100	2.2	130	2.5	390	6	956
b aus-potato			60	1.3					60
b aus-lt aman	3264	13.3	712	15.6	994	19.5			4970
b aus-lt aman-rabi			255	5.6	373	7.3			629
b aus-hyv aman	4882	19.9	256	5.6					5138
b aus-hyv aman-potato			128	2.8					128
jute-lt aman					26	.5			26
hyv aus			400	8.9					400
hyv aus-potato			128	2.8					128
hyv aus-rabi	420	1.7	128	2.8	124	2.4			672
hyv aus-lt aman	5309	21.6	1396	30.6	497	9.8			7202
hyv aus-hyv aman	924	3.							924
lt aman-fallow	3235	13.2	128	2.8	832	16.4			4195
lt aman-hyv boro	840	3.4	740	16.2	601	11.8			2181
hyv aman-fallow	2426	9.9	127	2.8					2553
hyv aman-rabi	840	3.4							841
hyv aman-hyv boro	2102	8.6							2102
b aman-hyv boro					80	1.6			80
TOTAL	24580		4560		5085		6575		40800

Source: NERP estimates

High yielding varieties of rice dominate the present cropping patterns on F0 and F1 land types. Local and high yielding varieties of transplanted aman, are grown in the kharif II season on 76% of cultivated area and this is the major crop. Local and high yielding varieties of aus rice are grown in the kharif I season on 27 and 23 percent respectively of the cultivated area.

On the F2 and F3 land types, broadcast aman is the dominant crop. It is grown on about 8% of the total cultivated area during both kharif seasons. In the winter season, local and high yielding varieties of boro rice are grown on 24% of the cultivated area.

Non-rice crops are grown on all land types and include pulses, oilseeds, spices, vegetables, potato, etc. They are produced on 6% of the cultivated area in the rabi season. The present crop patterns in the Project Area are presented in Table 3.7.

Information with respect to average cropped areas and yields under damaged and damage free conditions were obtained from discussions with farmers. The information was synthesized with secondary sources and analyzed to obtain the production figures presented in Table 3.8.

Table 3.8: Present Crop Production in the Project Area

Crop	Damage Free Area			Damaged Area			Total Production (t)
	Area (ha)	Yield (t/ha)	Total (t)	Area (ha)	Yield (t/ha)	Total (t)	
b aus	4972	1.5	7,458.00	5953	1.1	6,548.3	14,006.30
hyv aus	4702	4	18,808.00	4625	3.2	14,800.0	33,608.00
b aman	746	1.8	1,342.80	2354	1.3	3,060.2	4,403.00
lt aman	15484	2.2	34,064.80	3719	1.8	6,694.2	40,759.00
hyv aman	8672	4	34,688.00	3014	3.4	10,247.6	44,935.60
l boro	4361	2.3	10,030.30	234	2.1	491.4	10,521.70
hyv boro	4350	4.6	20,010.00	969	4.2	4,069.8	24,079.80
Total Rice			126,401.90	20,868.0	17.1	45,911.5	172,313.40
potato	316	12	3,792.00				3,792.00
pulses	321	0.85	272.85				272.85
oilseeds	1071	0.75	803.25				803.25
spices	107	2.25	240.75				240.75
vegetables	642	8	5,136.00				5,136.00
jute	26	1.65	42.90				42.90

3.5 Fisheries

3.5.1 Floodplain fishery

Fisheries in the project area are associated mainly with beels, but some with khal reaches. Fishing rights in these beels and khals are almost all leased, for a period of one to three years at a time, to the highest bidder under the Jalmohal leasing system. A listing of Jalmohals in the project area which are renowned for their high fish production is given in Table A.18. A few beels only, notably Burijuri Beel, come under the Government's Nitamala scheme.

The Jalmohal lease-holders are rich influential, mainly local, persons who appropriate the profits from fishing in the beel or khal they have leased. Local fishermen, particularly the poorer ones, cannot afford to bid on a lease, and are forbidden to fish in leased beels or khals. In some cases, they work as fishing labourers for the Jalmohal lease-holders who pay a very modest wage.

Tension and conflict are common as a result of the methods used by Jalmohal lease-holders to fish their beels and khals. They construct small dams at the beel outlets in order to maintain an adequate depth of water on the beels long into the dry season and so maximize fish growth before the catch in February; as a result, land needed for Boro cultivation remains flooded for a month or more after transplantation time. When, in February, they are ready for the catch the leaseholder destroys the dam, so rapidly de-watering the beel and enabling virtually the entire fish population of the beel to be caught in a single day. After such catches there are no fish left for

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the local fishermen, and the fish resources of the beel are seriously depleted for a prolonged period. This process, which completely drains the beels, deprives farmers of the water they need to irrigate their boro crops.

3.5.2 Species present in the area

There are 155 known species of fish in the Northeast Region, but only 53 of these (34%) presently inhabit the project area in significant numbers; among these 13(25%) are Baramach (large fishes), and 40 (75%) are Chotomach (small fishes). Table A.19 lists the species present in the project area.

Among the Baramach, Catla and Mrigel are now rare in the project area, and several species known to have been present formerly, including Angrot, Berkul, Nanid and Pungas, are now almost extinct.

3.5.3 Duar Fishery

Duars, which are an indispensable part of a typical floodplain fishery, act as a refuge for the large brood fish during the winter season. These fish mature, then migrate to a suitable spawning ground for breeding as water levels begin to rise early in the monsoon. There are 15 duars in the Kushiyara River Fenchuganj and Manumukh (Table A.20).

3.5.4 Hakaluki Haor

The Hakaluki Haor is the largest haor in Bangladesh with a surface area of 181 km^2 and has been identified as a "mother fishery" because of its favourable natural spawning ecology. Within the haor, relatively clear water (which allows sunlight to penetrate) flowing from the adjacent hills mixes with the more turbid water of the Kushiyara River creating an excellent environment for fish breeding. This limnological characteristic is excellent for producing phytoplankton and zooplankton — excellent food for spawn, fish fry, and fish. The brood fish overwinter in the duars of the Kushiyara River and then migrate into the beels of the Hakaluki Haor to spawn; mainly early in the monsoon season. Field work carried out by FAP 17 confirmed that the haor was a spawning ground for carp. Given that this is a spawning ground, this haor has a regional impact on fish production.

The Hakaluki Haor contains more than 60 permanent beels (3835 ha). The largest and most important of these beels are the Dulla Beel, Pinglarkona Beel, Pioula Beel, Niral Beel, Lamba Beel, Maiam Beel, Balijuri Beel, and Chinaura Beel.

3.5.5 Sources of Fish and Breeding

It is generally understood that early rain, thunder, flooding, temperature, grassy or rocky land influence the spawning of fresh water fish. If conditions are favourable, during the pre-monsoon and early monsoon period, fish migrate into shallow areas, usually from beels to adjacent grassy areas, to the rivers, and vice-versa. At this time, migration is usually contranatant.

Spawning migration of this type is reportedly associated with the following beels in the area: Majarband Beel, Ruikka Beel, Shalkatua Beel, Kata Singra Beel in Kawadighi Haor (these were carp spawning grounds prior to construction of the embankments) and Keola Beel, Daldala Beel and Pratapir Beel in the vicinity of the Dhalai River.

The spawning migration of the following species is more localized: *Boal, Pabda, Fali, Koi, Puti, Sarputi, Tengra, Magur, Singi*. Some species also make a nest within the beels for spawning: Taki, Shoal, Gazar, Cheng. In general, breeding starts from the late April and continued up to June.

The Kushiyara River was a major source of *baramaach* (major carp) in the area. Their over wintering grounds were in the duars of the Kushiyara River and they migrated through Machuakhali and Koradair River into the beels of Kawadighi Haor to spawn. Their access to Kawadighi Haor has been blocked by the embankments constructed as part of the Manu River Irrigation Project and as a result, major carp are now very scarce in Kawadighi Haor.

3.5.6 Fishing Practice

Ponds are the major source of fish in the Manu River Irrigation Project followed by floodplains, beels and river channels (ponds 67%, floodplains 28%, beels 3%, river channels 2%).

Subsistence fishing on the floodplains occurs during the flooding period (mainly June to September) and beel fishing occurs from December to February. In most cases beel fishing is done on an annual basis. Piles are not maintained as a part of the biological management of the fisheries resource, but for annual fishing the installation of *katha* is common. *Jam*, *koroch*, *hizal* and *jarul* tree branches along with bamboo stakes are widely used for *katha*. *Katha* are installed in the months of August and September when flood water starts to recede from the floodplains. For floodplain fishing *current jal, kona jal, thela jal, jhaki jal, borshi* and *chai* fishing gears are widely used. *Chouhanda jal, ber jal, ural jal, veshal jal, rek jal* and *polo* are the major gears used in beel fishing.

The Government fish seed multiplication farm (FSMF) and some other private farms in Moulvibazar, Rajnagar and Srimangal are the main sources of carp fry/fingerlings for pond culture in the Manu River Irrigation Project. Most pond owners release an uncounted number of fingerlings into their ponds without undertaking other basic management activities such as eradication of predatory and weed fish, eradication of aquatic weed, ensuring sufficient sunlight penetration, applications of lime, fertilizer and feed. Due to lack of a proper extension service, farmers mainly follow the suggestions made by fry vendors for pond preparation and management. Monitoring of growth and health of the fish is also not done on a regular basis and results in a poor harvest of fish. The fish are usually harvested during the dry season using *ber jal* and *jhaki jals* for fishing. It should be noted that many ponds adjoining homesteads provide domestic water supply for a wide variety of activities (bathing, washing clothes and dishes, occasionally watering homestead vegetable plots and so on). Recently some absentee landowners have started pond construction and fish culture in the Moulvi Bazar, Kamalganj and Rajnagar areas.

3.5.7 Production and Trends

Table 3.9: Present Floodplain Fish Production

Regime	Area (ha)	Production Rate (kg/ha)	Total Production (mt)
Flood Plain	16220	27	437.94
Beel	1220	28	34.16
Channel	1040	28	29.12
Total	18,480		501.22

At present, total flood plain fish production within the Project Area is estimated at 501 tonnes per year (see Table 3.9). This does not include production from Hakaluki Haor which is not part of the Project Area — the impacts on fish production in Hakaluki Haor as a result of proposed interventions are dealt with under the evaluation of the proposed project. According to NERP studies, fish abundance is directly related to flood duration and water depth, and to access to flooded lands. Fish production in the Project Area has apparently declined by 85-95% since the Manu River Irrigation Project was constructed, and by 30-40% in the vicinity of the Dhalai River over the last 10 years. The identified causes of these declines are outlined below:

- Siltation of beels and channels. The area of beels and channels in the Manu River Irrigation Project has been reduced by about 30-35% since the it was constructed; both depths of water and water hectare-months are gradually declining. Where formerly, the relatively clear water from the Bhatera Hills mixed with the sediment laden water of the Kushiyara to form a unique fisheries habitat, the current system is devoid of the Kushiyara inflows.

- After construction of the Manu River Irrigation Project the migration of fish into the beels, channels and floodplains was seriously affected. Project construction destroyed carp spawning grounds, facilitated algal bloom, and polluted the water (due to water stagnancy and eutrophication). As a result fish production has declined both within and outside the area.

- Reduction of reproductive stock due to indiscriminate use of certain kinds of fishing gear in the beels and floodplains (*current jal* and *kapri jal*).

- Increased fish mortality due to fish diseases caused by water pollution in the beels, particularly during the winter season.

- Over-fishing resulting from the short term leasing of the beels (jalmohal system).

- Rapid deforestation, expansion of paddy land, and the use of water for irrigation.

- Existing ponds are not specifically designed for fish culture and have multiple uses (washing, bathing, fishing, irrigation etc). Moreover, multiple ownership makes the ponds difficult for investment. About 15% of the ponds are seasonal and about 30% are flood prone.

- There is no proper extension service for pond owners to develop culture-based fish farming in the existing ponds.

3.6 Wetland Resources Utilization and Management

Kawadighi and Daldala Haor

Thatching material is the most useful natural wetland products of the area. People in the vicinity use this material in various ways: for example as roofing or wall panel material for their houses and for making mats. The thatching is done using Clinogyne locally known as *sital pati*, (murta). The land on which murta is grown is very productive and the Murta has a good price and a large market. The production rate of murta is 60,000 murta stems per hectare annually. This translates into at least Tk 15,000 per ha per year. The estimated gross value for this commodity could be as high as Tk 0.75 million from the project area. The labour involved in harvesting, this product is about 7 pd ha^{-1} which translates into about 350 pd. The post harvest processes, however, is labour intensive and utilizes an estimated 4200 pd ha^{-1} (is this per hectare or total?) to produce the finished mats.

The second most important use is for fodder. People who are living in and around the beels are fully dependant on these lands to provide fodder for their cattle — particularly during the monsoon. Almost all the aquatic plants are used for this purpose, but mainly the grass Echinichloa colonum is used. Other prominent species which are used are Nymphaea (*shapla*) and Nymphoides (*panchulli*). Quantification of their real economic value is difficult; partly because people collect their own requirement as needed so there is no formal market system which handles these products. Their value was estimated on the basis of the replacement value. This product is mainly produced on F3 lands which remain fallow in the summer (8000 ha). The estimated gross value of the product could be as high as Tk 0.32 million per year based on a yield of Tk 40 ha^{-1}. The estimated employment in gathering for this is about 0.008 million pd $year^{-1}$ based on 1 pd ha^{-1}.

The next most important use of the wetlands products are for bio-fertilizer or green manure. All the small herbs and grasses which grow in the wetlands are used for this purpose. Farmers living around the wetlands use these materials instead of chemical fertilizer. The soft aquatic plants are gathered immediately after the monsoon and placed in piles in their fields such that they decompose. They are then incorporated into the soil as fertilizer. The production, area, economic value, and employment in gathering for this purpose is estimated to be more or less the same as for fodder.

Other uses of the wetlands products are:

- Food. Mostly from Nymphaea (*shapla*), Ottelia (*penicillia*) and Aponogeton (*ghechu*). The gross estimated total worth for food could reach as high as Tk 0.2 million and the employment it generates is estimated at 0.004 million person days.

- Medicinal Plants. Mostly from Limnophila (*karpur*), Polygonum (*kukra*) and Nymphaea (*shapla*).

- Duck feed. Molluses are used for this purpose

- Fuel material. Mostly from various grasses

These common property resources are of considerable importance to the poor, who are the most likely to engage in wetland gathering, who will eat food products from the wetlands in times of scarcity, and who depend on income from wetland products. Fodder and building materials tend to be collected by men, and food and medicinal materials tend to be collected by women. Information on how the resources are managed at the micro-level is not presently available.

Hakaluki Haor

The utilization of wetland produce in Hakaluki Haor is now less intensive than that of Kawadighi Haor mainly because the vegetation of Hakaluki Haor is less dense. This is the result of over exploitation of the reeds and shrubby formations to the point that they are almost wiped out. As a result, the amount of usable wetland product remaining is comparatively small which is creating problems for local inhabitants.

Within Hakaluki Haor, the most important use of the wetland is for fodder. Most of the aquatic plants are used for this purpose. Prominent species are Nymphaea (*shapla*) and Nymphoides (*panchulli*). Quantification of the economic value of these materials is based on the replacement value. The productive area is mostly F3 lands which remain fallow in the summer. which is estimated at 12,000 ha. The estimated gross total value of the product harvested could reach as high as Tk 0.48 million year^{-1} (Tk 40 ha^{-1}). The estimated employment in gathering the fodder is about 0.012 million pd year^{-1}, (1 pd ha^{-1}).

Another important use of the resources from this wetland is for fuel wood. Due to the scarcity of fuel wood around their homesteads, people are becoming increasingly dependant on this source of fuel. Swamp forest trees (except for Hizal) are the most popular fuel wood in these areas. However, all the other woody shrubs including grasses are also used in this purpose. The naturally regenerating saplings in the swamp forests are being harvested at a non-sustainable rate because of the need for fuel. The estimated total value of the material harvested for fuel is Tk 0.3 million year^{-1}. The estimated required employment to harvest the fuel is 0.01 million pd year^{-1}

Other common uses of the products from Hakaluki Haor are as described in the previous section for Kawadighi and Daldala Haors.

3.7 Navigation

The District used to be served by "steamer" along the Kushiyara River between Dhaka and Silchar in the Indian State of Assam, but this service has long been discontinued due to siltation of the Kushiyara River downstream of the project area near Markuli. Now only local ferries ply the Kushiyara and lower Manu Rivers, and effectively link Moulvi Bazar to towns and villages along the Kushiyara River between Markuli and the Indian border at Zakiganj.

The Manu and Dhalai Rivers are not very important in terms of navigation even though the Manu River has water throughout the year. Country boats, carrying local passengers, produce and light freight, ply these rivers and penetrate into the haors where they are not isolated by embankments. The Manu River barrage is considered an impediment to navigation along the river. Country boats operate within the Manu River Irrigation Project though they are isolated by the embankments.

4. PREVIOUS STUDIES

4.1 Introduction

Several concepts have been put forward in recent years for solving the flooding problems along the Manu River system. These concepts and their shortcomings are as follows.

4.2 Dhalai River Project

During its review of the Dhalai River Project Proposal, SMEC[1] suggested relieving the flooding by installing a regulator in the Manu River Irrigation Project embankment near Kazir Bazar so as to enable excess flood water to be discharged into Kawadighi Haor. This proposal would have solved the flooding problems of the Dhalai River Project and of Moulvi Bazar town but at the expense of the Manu River Irrigation Project. NERP calculations made in 1992 showed that the pumping station in the Manu River Irrigation Project is just adequate, with continual pumping, to dispose of local runoff generated within the Manu River Irrigation Project (including the Bhatera Hills) and the irrigation return flows, and thus it would not be adequate to dispose of excess Manu flood water let in through the proposed regulator. That this is so was emphasized by the flooding of the Manu River Irrigation Project in June 1993 when, in addition to the greatest local runoff ever experienced, Manu flood water entered the area through numerous (19) public cuts in the embankment. On this occasion the pumping station was overwhelmed, not only in terms of its pumping capacity, but by being flooded internally to a level above the main floor level, despite efforts by the pumping station staff to brick up the windows and doorways as the flood levels rose. It seems apparent, therefore, that the SMEC proposal would lead to regular and substantial overloading of the pumping station. It is difficult to estimate how much additional pumping capacity would be required if this proposal was taken up, but it would probably have to be increased by a factor of about five.

4.3 Manu River Irrigation Project Interceptor Drain

In view of the perceived inadequacy of the Manu River Irrigation Project pumping station, Halcrow (1991) examined the possibility of constructing an interceptor drain (open channel) along the foot of the Bhatera Hills so as to intercept the runoff from these hills and deliver it into the Kushiyara at Kamalpur.

The study concluded that Kushiyara water levels would control water levels in the interceptor drain with the result that drainage would not be effectively achieved by this system. In addition to the drainage congestion which was expected to occur, siltation within the interceptor drain was considered a potential problem. As such, the proposal was discarded.

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[1] Snowy Mountain Engineering Corporation

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4.4 Sukalia Chara-Hail Haor Floodway Proposal

Another suggestion considered as part of the Northeast Rivers Pre-feasibility Study[1], envisaged diverting excess Manu flood water from the head pond of the Manu Barrage into the Sukalia Chara which would then deliver it to Hail Haor where ample storage capacity is available to absorb the flood water. From Hail Haor the water would drain naturally and slowly into the Lungla-Bijna river system. There is an ample difference in river water levels between the Manu Barrage and Hail Haor to enable this scheme to work. It would be very attractive except that:

- The substantial floodway, probably of 260 m top width, would have to pass through Moulvi Bazar. It is considered that the disturbance to the town which would be involved in implementing this scheme would be entirely unacceptable.

- In the event of the floodway being overtopped by a rare flood it would be the presently flood-free part of the town which would be flooded.

- The canal alignment necessarily passes close to the end of the Bilisari Hills and with a probable depth of 5.5 m it would almost certainly encounter hard bedrock. Thus excavation costs could become quite unreasonable.

In addition to the above, feasibility studies were carried out under the auspices of BWDB with regard to the projects summarized in Table 4.1. In general, these studies attempted to deal with the water management and flooding problems in the Manu River system in a very localized manner; an approach which in these circumstances usually results in adverse impacts on some other part of the system.

Table 4.1: Proposed and Studied Projects

Project Name	Year of Study	Project Components Identified from Study
Rehabilitation of Manu River Irrigation Project	1992	Re-sectioning of about 36 km of embankment Improvement of about 27 km of drainage channels Rehabilitation of 83 km of irrigation canal Construction of 2 new syphons Rehabilitation of 96 structures
Extension of Manu River FCD Schemes	1991	Construction of 23.km of embankment Construction of three drainage structures

[1] A Study commissioned by BWDB in 1986 and undertaken by Northwest Hydraulic Consultants Ltd in Association with SARM Associates.

5. WITHOUT-PROJECT TRENDS (Null Option)

Certain trends are occurring in the project area. These trends provide some indication of what the future in the project area will be if no intervention is undertaken.

Net population growth
Net population growth is forecast to be about 1.9% per year during 1991-2000 and 1.8% per year during 2000-2015. This is below the national average and below the past 10 years' growth rate which was 2.1% per year. This will result in the Project Area population growing from 278,000 in 1991 to 336,000 by the year 2000 and to 438,000 by 2015.

Food grain production growth
Food grain production is forecast to grow by about one percent per year. The cropping patterns in the future without project will be very similar to those currently being practiced. The crop damage by flooding will be the major constraints to increase the cropped area and production. Major rice cropped area in the basin will be used for the cultivation of local varieties.

There will be a small increase in the rabi cropped area resulting in a slight increase in cropping intensity. The increase in rabi crops is expected to be a result of increased urban demand as Moulvi Bazar continues to grow. The future crop patterns without project are presented in Table 5.1.

A slight increase in rice production in the Dhalai River basin is expected as a result of increases in the area cropped to hyv rice in both kharif seasons. Within the Manu River Irrigation Project, however, the rice production may well decline since a shift from high yielding to local varieties may occur during the kharif seasons as the latter are better able to withstand flooding. The future crop production without project is presented in Table 5.2.

Openwater Fisheries Production
To assess project fish impacts (FW production minus FWO production), some assumption must be made about FWO trends. Observations of past fish production indicate that it is declining by 1-3% per year overall. Conversely, estimates of future production taking into account interventions to improve biological fisheries management suggest that great increases in fish production are possible. If the FWO trend is assumed to be negative, project negative impacts on fish production will be of significantly smaller magnitude than if the FWO trend is assumed to be positive. Lacking any way to decide between these two scenarios, it is assumed that FWO production will be equal to present production.

River Course Changes
The Manu and Dhalai Rivers appear to be quite stable. The rivers' erosion and shoal formation will continue as a part of natural process. Any major intervention in the Kushiyara River may affect Manu River in its downstream reaches.

Loss of Arable Land to Settlement
Due to increases in population, homestead areas will increase but in comparison to the total basin area, the loss will not be highly significant.

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Table 5.1: Future Without Crop Patterns in Project Area

Crop Pattern	F0		F1		F2		F3		Total Area (ha)
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
b aman-fallow					780	15.3	1960	29.8	2,740.0
fallow-l boro					650	12.8	4225	64.3	4,875.0
fallow-hyv boro	504	2.1	120	2.6	182	3.6	388	5.9	1,194.0
b aus-potato			80	1.8					80.0
b aus-lt aman	3434	13.9	623	13.6	870	17.1			4,927.0
b aus-lt aman-rabi			256	5.6	373	7.3			629.0
b aus-hyv aman	4717	19.2	128	2.8					4,845.0
b aus-hyv aman-potato			256	5.6					256.0
jute-lt aman					26	0.5			26.0
hyv aus			360	8					360.0
hyv aus-potato			154	3.4					154.0
hyv aus-rabi	420	1.7	102	2.2	249	4.9			771.0
hyv aus-lt aman	5221	21.2	1612	35.3	373	7.3			7,206.0
hyv aus-hyv aman	841	3.4							841.0
lt aman-fallow	2429	9.9			780	15.3			3,209.0
lt aman-hyv boro	838	3.4	740	16.2	698	13.7			2,276.0
hyv aman-fallow	3232	13.1	128	2.8					3,360.0
hyv aman-rabi	843	3.4							843.0
hyv aman-hyv boro	2102	8.5							2,102.0
b aman-hyv boro					105	2			105.0
TOTAL	24580		4560		5085		6575		40,800.0

Source: NERP estimates

Table 5.2: Future Without Crop Production in the Project Area

Crop	Damage Free Area			Damaged Area			Total Production (t)
	Area (ha)	Yield (t/ha)	Total (t)	Area (ha)	Yield (t/ha)	Total (t)	
b aus	4744	1.5	7,116.00	5995	1.1	6,594.5	13,710.50
hyv aus	4465	4	17,860.00	4867	3.2	15,574.4	33,434.40
b aman	684	1.8	1,231.20	2161	1.3	2,809.3	4,040.50
lt aman	14297	2.15	30,738.55	3719	1.8	6,694.2	37,432.75
hyv aman	9555	4	38,220.00	2948	3.4	10,023.2	48,243.20
l boro	4629	2.25	10,415.25	246	2.1	516.6	10,931.85
hyv boro	4688	4.55	21,330.40	988	4.2	4,149.6	25,480.00
Total Rice	43,062.0		126,911.40	20,924.0		46,361.8	173,273.20
potato	363	12	4,356.00				4,356.00
pulses	337	0.85	286.45				286.45
oilseeds	1122	0.75	841.50				841.50
spices	112	2.25	252.00				252.00
vegetables	673	8	5,384.00				5,384.00
jute	26	1.65	42.90				42.90

6. DEVELOPMENT OPTIONS

6.1 Problems

Despite construction of five water resources development projects in the Manu River Basin the area's flood problems have not been solved rather aggravated in recent years. At least five problems persist in the area:

- Public cutting of Manu River Project Embankment;
- Safety of Manu Barrage
- Safety of Moulvi Bazar Town
- Manu River flooding in the upper area;
- Dhalai River flooding in its basin.

Public Cutting of Manu River Project Embankment.
The Manu River Irrigation Project embankments along the Manu River were set back a substantial distance from the river. This served to reduce compensation for the homesteads which are mostly located on the river bank and increased embankment safety against river scour.

Prior to construction of the embankments, peak Manu River flows bypassed the Manumukh outlet as follows:

- the Phanai River drained to Kushiyara River via Hakaluki Haor;
- the Kawadighi Haor (within the Manu River Irrigation Project) drained to the Kushiyara River;
- *the Manu River spilled into Hail Haor over its the left bank below Moulvi Bazar town.*

Following construction of the embankments the entire discharge is confined to the Manu Rivers' channel. In addition, there is evidence that both Manu and Dhalai River discharges have increased significantly during the past two decades (Figure 11). This is primarily due to increased rainfall and land use changes in the catchment, as well as construction of river works. This has resulted, among other things, in homesteads located between the embankment and the river bank being submerged to depths ranging from two to three metres. In response, these people cut the embankment in 1984, 1987, 1988, 1991 and 1993 which flooded the Manu River Irrigation Project resulting in damage to crops, destruction of project infrastructure, damage to homesteads and property.

It is reasonably certain that the practice of cutting the embankments will continue until adequate measures are taken to protect the homesteads and crops of people living within the floodway.

Safety of Manu Barrage
The structural integrity of the Manu Barrage has also become a matter of concern as a result of higher floods which apparently exceed its spillway design capacity. Preliminary analysis by NERP indicates that river water levels at the lower apron of the barrage will rise to 15.5 m PWD for a discharge of 1,500 m^3/s (which is the estimated 1 in 100 year discharge of the Manu River

at Moulvi Bazar if the upper reaches are confined). There will be an afflux of 0.45 m raising the upstream water level to 15.96 m PWD. The top of barrage gate opening is at 15.06 m PWD.

Safety of Moulvi Bazar Town
The average ground level of Moulvi Bazar Town is around 11.0 m PWD. The 100-year discharge of the Manu River corresponds to an elevation of 15.51 m PWD which is about 4.0 m above the ground level of the town. The existing flood protection infrastructure along the town is not considered adequate.

Manu River flooding in the Upper Area
BWDB has constructed an embankment along both banks of the Manu River from the international border to the highway bridge at Kotarkona. Downstream of the Kotarkona Bridge, the River is embanked on both banks by local bodies who at their own initiative connected the upstream BWDB embankments with those of the Manu River Irrigation Project and the Hamhami Chara Project. However, these locally constructed embankments have an inadequate section and setback. As a result, they are subjected to erosion and breaches occur when the Manu River water level rises. The May 1993 flood breached the right bank at four places and the left bank at three places downstream of Kotarkona Bridge. These flood waters inundated large tracts of land in Kulaura and Kamalganj Thanas.

Dhalai River Flooding
Flooding in the Dhalai River basin (27,500 ha gross) results from overbank spill from both the Dhalai and Manu Rivers. The feasibility study report prepared for the Dhalai River Project concludes that flooding annually damages 20% of the local transplanted aus, 16% of the hyv transplanted aus and 9% of the hyv boro.

6.2 Water Resources Development Options

Various solutions to solve the problems described above have been proposed. The proposals arising from the field reconnaissance work and from a seminar held in Moulvi Bazar town are described in Section 3.1.9 of this document. These were combined with ideas from NERP analysts and were synthesized into a number of options which were considered to have some practicability and were analyzed further. These options are described as follows.

6.2.1 River Dredging

Kushiyara River Dredging
There is a widely-held belief that dredging the Kushiyara River from Markuli to Madna will reduce flood peak water levels in the Kushiyara River at Manumukh, and that such a reduction will in turn reduce water levels in the Manu River and thus prevent public cutting of the Manu River Irrigation Project embankment.

Model studies (NERP,1992) have shown that dredging between Markuli and Madna will result in very little change in water levels of the Kushiyara River at Manumukh because the present backwater effect from Markuli barely extends up to Manumukh. The project area will not, therefore, benefit from this dredging.

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Manu River Dredging
According to this proposal the Manu River needs to be deepened and/or widened to increase its conveyance, and so reduce river water levels during floods.

Available cross-sections of the river show that the side slope of the right bank is steep. This bank is unstable — the existing dyke is often breached as a result of toe erosion. Deepening the channel would render this slope more unstable, leading to more frequent breaching of the dyke. Widening the channel would require a 25 m retirement of the dyke, and this in turn would require relocation of 75% of the houses behind the dyke. The Moulvi Bazar - Sherpur - Sylhet Highway embankment could also be rendered vulnerable to breaching by any deepening or widening of the river channel. Furthermore, no matter what style of deepening or widening was adopted, it is not apparent where the considerable volume of agriculturally worthless spoil could be disposed of. For these reasons this proposal cannot be recommended.

Dhalai River Dredging
Under this proposal the flow capacity of the Dhalai would be increased so as to reduce water levels in this river.

Since water levels in the lower reach of the Dhalai River are controlled by water levels in the Manu River they could not be reduced by dredging in this reach. Dredging, which would increase the cross-sectional area of the channel, would also correspondingly reduce water velocities and reduce the capacity of the Dhalai River to convey sediment. The Dhalai River carries a large amount of sediment.

Conclusion
Based on the above considerations it is concluded that dredging will not solve the problems of flooding in the project area. Dredging is, in any case, only a temporary measure which, if is to produce long-term benefits, needs to be repeated frequently, and this implies a vast expenditure over time. It also must be recognized that dredging produces huge quantities of worthless spoil which has to be disposed of, and for which no suitable receiving areas are available in this project area. In view of all these considerations dredging cannot be recommended.

6.2.2 Manu Floodplain Landfilling

It has been proposed that if the lower Manu River was dredged the dredgings could be used to raise ground levels of the Manu floodway, between the secondary dyke (on the Manu Rivers' right bank) and the Manu River Irrigation Project embankment, to such elevations that the homesteads in this area would no longer be flooded.

As indicated in the previous section, dredging of the lower Manu River is not recommended for technical reasons, so dredgings will not be available to form the landfill.

A further consideration is that raising the ground levels on the floodway will increase water levels in the Manu River itself. This would exacerbate the flooding problem for Moulvi Bazar town, the Dhaka-Sylhet road, and the Manu barrage, and would likely cause drainage congestion in the upstream areas.

The volume of fill required to raise ground levels sufficiently to prevent flooding is estimated at 52 million m^3. It is doubtful if such a volume of dredgings could be produced from the Manu River bed, and it is not apparent from where else such a volume of soil, suitable for agriculture, could be obtained. It is estimated that the cost of producing this volume of landfill would be Tk 130 million.

Even if suitable landfill material was available, and its high cost was acceptable, the new ground levels would be significantly higher than existing house floor levels, and so it would be necessary to demolish and re-build all housing in the area. It is estimated that some 5,000 homes would be involved in this operation, the cost of which (Tk. 1300 million) would be additional to that of the landfilling. It is also thought that the disturbance of such a large community (30,000 residents) would not be acceptable.

For all these reasons this landfill option cannot be recommended.

6.2.3 Raising and/or Re-Locating the Manu Dyke

Yet another suggestion put forward for solving the Manu floodplain flooding problem involves either raising and strengthening the existing dyke, or re-locating it some 90 m back from the Manu River bank.

Raising the dyke would be easy, but pointless unless the dyke was strengthened to resist toe erosion. Furthermore, the confinement effect produced by the strengthened and raised dyke would generate toe erosion at the left bank embankment of the Manu River which carries the Moulvi Bazar - Sherpur - Sylhet Highway and protects the lands west of the lower Manu River from flooding by the Manu River. It is estimated that a total of about 50 km of embankment (both banks) would require strengthening by some form of revetment work, and that the total cost of this option would be about Tk 1840 million.

Other undesirable effects of this option would arise from the confinement effect of the raised and strengthened dyke and left embankment. As a result of this effect flood water levels would be higher than at present downstream of Moulvi Bazar, at the Manu barrage, and in the backwater reach of the Manu barrage. Such induced additional flooding would not be acceptable to the residents of any of these affected areas.

This option alternative cannot be recommended because of its high cost, and the social unacceptability of the induced flooding upstream.

The alternative of re-locating the dyke 90 m back from the river is also considered to be socially unacceptable as about 80% of homesteads on the Manu floodplain are located within the 90 m strip between the dyke's present and proposed locations. Thus, under this option, almost all homesteads would either be left exposed to flooding, or would have to re-located behind the new dyke. Also, the new dyke and new housing would occupy a significant proportion of the agricultural land on the floodplain. The cost of these new works would be Tk 1350 million.

This option alternative also cannot be recommended because of its high cost, and the social unacceptability of the disturbance involved in re-locating the residents, and of their agricultural land losses.

6.2.4 Re-Location of Manu Floodplain Residents

It has been suggested that, as an alternative to the preceding options, it would be simpler to re-locate the Manu floodplain residents elsewhere. This would involve abandoning some 5000 pucca and semi-pucca houses, and building an equal number of houses of equivalent or better standard elsewhere. It has been estimated that the cost of this option would be at least Tk 1300 million.

Given the high population densities in the surrounding areas, and the significant number of landless people in these areas, it is not apparent where else the floodplain residents could be re-located, or whether their re-location would be acceptable to surrounding area residents. Furthermore, the floodplain residents themselves are unprepared to relocate. This re-location option cannot, therefore, be recommended in view of its high cost, and social unacceptability.

6.2.5 Removal of the Manu River Irrigation Project Embankment

It has also been suggested that if the Manu River Irrigation Project embankment, Manu section, was removed, flood water would not be trapped between it and the dyke, and so the Manu floodplain flooding could be reduced, if not eliminated. This implies that the flood water would drain naturally into Kawadighi Haor as it did before the Manu River Irrigation Project was constructed.

It has to be recognized that removal of the embankment would only reduce, not eliminate, flooding on the Manu floodplain, and the Manu River Irrigation Project pumping station could never cope, on a timely basis, with the huge volumes of flood water which would then enter the area and be trapped in Kawadighi Haor behind the Kushiyara section of the Manu River Irrigation Project embankment. In short, this is a proposal to abandon the Manu River Irrigation Project.

For these reasons this option also cannot be recommended.

6.2.6 Reduction of Manu River Discharges

Since all of the preceding options are unacceptable for one reason or another no alternative remains except to reduce flood peak discharges through the lower Manu River. In principle, this could be done either by building a flood control dam on the Manu River somewhere upstream of Moulvi Bazar, or by diverting Manu River flows in excess of the bankfull discharge out of the Manu River basin somewhere upstream of Moulvi Bazar and conveying them to the Kushiyara River by some route other than through the lower Manu River.

Available mapping suggests there is only one possible dam site in the Manu River basin, and this is in Tripura meaning that India's cooperation would be required to construct it. A dam at this site would control 860 km^2, or 38%, of the Manu River basin, and it is estimated that the flood peak reduction made possible would be $(1-(3390\ km^2-860\ km^2))=25\%$; this reduction compares unfavourably with the 50% reduction required. Thus, this option also cannot be recommended.

Available mapping suggests there are several routes by which flood peak discharges could be diverted from the upper Manu River, or from the Dhalai River. These are examined below considering that maximum diversion flows will exceed 700 m^3/s (see section 7.3).

Variant A
This variant envisages diverting excess flood water from the Dhalai River near Katabil through a floodway running through the Bilisari Hills and discharging into the Bilas Chara, a small river draining into Hail Haor near Srimangal, and diverting excess flood water from the upper Manu River near Kotarkona through a floodway leading to Sakura Beel in Hakaluki Haor via the Phanai River, a tributary of Hakaluki Haor. The diverted flood waters would be temporarily stored in these two very large haors, but eventually this stored water would drain out into the Kushiyara River. The flood water stored in Hail Haor would drain out via the Bijna and Barak Rivers into the Kushiyara River near Madna, and that stored in Hakaluki Haor would drain out via the lower Juri River into the Kushiyara River near Fenchuganj.

The advantages of this variant are:

1) The total diversion would be more or less equally divided between Hail Haor and Hakaluki Haor; this would mean that the impacts (enlargement of the naturally flooded areas and increased sediment deposition in these haors) would be minimised.

2) The needs to embank the Dhalai River would be reduced or eliminated with a substantial saving in cost.

The disadvantages of this variant are that:

1) The floodway route through the Bilisari Hills involves a very deep cut involving some 7 million m^3 of excavation in rock (Units QTdd and Tt). This rock consists mainly of sandstones, siltstones, conglomerate and shale so excavation would require the use of heavy equipment. The cost of making this cut has been estimated at Tk 150 million. A tunnel would, of course, be much more compact but the size is impractical.

It is concluded that the disadvantage of this variant far outweigh its advantages, and so is not recommended.

Variant B
This variant envisages diverting excess flood water from the Dhalai River near Katabil through a floodway running across the Dhalai River Project Area to a second diversion site on the upper Manu near Kotarkona, and the diversion of the excess flood waters of both rivers from there through a floodway to Hakaluki Haor via the Phanai River. All diverted flood water would then be stored temporarily in Hakaluki Haor prior to its draining out into the Kushiyara River via the lower Juri River.

The advantage of this variant is that:

1) The need to embank the Dhalai River would be reduced.

The disadvantages of this variant are:

1) All of the flood water would arrive in Hakaluki Haor causing a greater enlargement of the naturally flooded area of the haor, and greater sediment deposition in the haor, than would occur with Variant A.

2) The floodway route from Katabil to Kotarkona (roughly parallel to the railway) involves crossing the deeper parts of the Dhalai River Project Area. Thus, while sufficient hydraulic head is available along this route, the bed level profile of the floodway is incompatible with the ground level profile along the floodway route; this means that either a deep drop structure and deeper set floodway profile are needed to achieve compatibility with the ground level profile, or a substantial length of the floodway will have to be located on raised ground or carried in aqueduct.

It is concluded that the disadvantages of this variant also far outweigh it advantages, and so it is not recommended.

Variant C

This variant envisages diverting excess flood water from the upper Manu River only, near Kotarkona, through a floodway from there to Hakaluki Haor via the Phanai River. All the diverted water would be stored temporarily in Hakaluki Haor prior to its draining out into the Kushiyara River via the lower Juri River.

The advantage of this variant is that:

1) The total diversion acquired could be achieved at a single site, and with a considerable reduction in the total length of floodway required relative to Variants A and B; construction costs would therefore be less than for Variants A and B.

The disadvantages of this variant are:

1) All of the flood water would arrive in Hakaluki Haor; this would not involve any greater enlargement of the naturally flooded area than for Variant B, but the sediment deposition in the haor might be greater because of the greater diversion from the upper Manu River.

2) There is not full political support for this variant[1].

Despite the disadvantages, it is considered that this variant represents the best available option and that it should be analyzed more carefully.

Variant D

In view of the many reservations expressed concerning envisaged impacts of Variant C on agriculture, fisheries and the ecology of Hakaluki Haor, consideration was given to two other variants, Variants D and E, which involve diversion from the Manu River only but through floodways following routes other than that through Hakaluki Haor.

Variant D envisages diverting excess flood water from the upper Manu River at Kazir Chalk through a floodway running along the western edge of the Bhatera Hills to the Kushiyara River at Kamalpur.

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1 The Honourable Member of Parliament from Barlekha Thana (which contains a portion of Hakaluki Haor) supports the concept of diverting Manu River flood discharges in principle but is opposed to the use of Hakaluki Haor as the flood reservoir.

This route has previously been considered by Systems Rehabilitation Project consultants for a drain to intercept flood flows from the Bhatera Hills and so reduce overloading of the Manu River Irrigation Project pumping station.

The advantages of this variant are:

1) the total diversion required could be achieved at a single site, and with a further reduction in the total length of floodway required relative to Variant C

2) there would be no impacts on Hakaluki Haor since this is not involved in this variant.

The disadvantages of this variant are:

1) High embankments would be required along both banks of the upper Manu River from Kotarkona to Kazir Chalk because of the high backwater produced by the diversion structure at Kazir Chalk

2) The floodway, 100 m wide and 5 m deep, would encounter bedrock if sited close enough to the Bhatera Hills to avoid it intersecting with the Rajnagar irrigation canal of the Manu River Irrigation Project and the new Moulvi Bazar - Sylhet Highway which runs along virtually the same route as needed for the floodway over much of its length

3) The floodway, if sited far enough to the west to avoid the highway and bedrock problems, would intersect the Rajnagar canal and many of its distributary canals, and would involve the loss of a considerable area of prime (F0) agricultural land.

4) The floodway, if it also functioned as an interceptor drain for the Bhatera Hill drainage, would be exposed to heavy sediment deposition wherever it intersected one of the Bhatera Hill streams; this deposition could obstruct it causing overtopping of its left embankment, and possibly its breaching with disastrous results in the Manu River Irrigation Project.

5) The floodway, if it did not function as an interceptor drain for the Bhatera Hill drainage, would have to feature a number of overchute structures to carry this drainage across the floodway; this would add considerably to costs and disturbance.

6) The diversion has the potential to create water levels on the Kushiyara which would submerge Balaganj and Fenchuganj towns — both of which are located near the diversion channels' outfall.

It is concluded that the disadvantages of this variant far outweigh its advantages, and that it cannot be recommended.

Variant E

Variant E envisages diverting excess flood water from the head of the lower Manu River at the existing Manu River Irrigation Project barrage through a floodway following the route of Sukalia Chara, a small stream running through the Moulvi Bazar urban area and discharging into one of the several streams running westwards from the Bilisari Hills to Hail Haor.

The advantages of this variant are:

1) The existing barrage could be used to effect the diversion; a new diversion structure would not then be required and a substantial saving in cost would result from this; it would, however, be necessary to change and upgrade the operational procedure for the barrage.

2) The floodway route is shorter than for any of the other variants, and this also represents a considerable cost saving.

As discussed in Section 4.4, the disadvantage of this variant is that the floodway route runs right through the centre of the Moulvi Bazar urban area; although it follows the route of Sukalia Chara the floodway channel top width exceeds that of the stream by a factor of about 10; thus, there would very considerable problems of land and property acquisition and of property demolition, and numerous bridges would need to be constructed along the floodway to carry the town streets over it.

It is concluded that this disadvantage far outweighs the advantages of this variant, and that it cannot therefore be recommended.

6.3 Conclusion

The solution to the water management problems in the Manu River Basin which appears to best warrant further study is, therefore, the diversion of Manu River peak discharges into the Hakaluki Haor combined with embankments along the Dhalai River to reduce overbank spill. The most appropriate diversion route is considered to be via a floodway from Kotarkona to Hakaluki Haor which follows the Phanai River. This option is described in more detail as the Manu River Improvement Project in the following Chapter.

7. PROPOSED PROJECT
MANU RIVER IMPROVEMENT PROJECT

7.1 Project Rationale

In recent years, flooding in those parts of Moulvi Bazar district near the Manu River has increased in both frequency and extent despite the existence of a protective dyke on the right bank of the river (this increase appears to be correlated with increases in local rainfall and confinement effects from embankments). It has resulted in increased erosion of the river bank adjacent to Moulvi Bazar town, damage to property and infrastructure within Moulvi Bazar town, severing of the Dhaka-Sylhet road (part of the Dhaka-Sylhet corridor), damage to the Manu River Irrigation Project infrastructure, and damage to crops throughout the basin. A solution to flooding along the Manu River is thus considered the paramount water management issue in this area.

7.2 Objective

The objectives of the project are:

- to provide flood relief to 30,000 people living within Manu River floodway;
- to reduce risk of flooding in Moulvi Bazar Town;
- to reduce damage to Manu River Irrigation Project infrastructure and agriculture;
- to eliminate danger to the safety of Manu Barrage;
- to reduce flooding in the Dhalai River basin; and
- to provide security to Dhaka-Sylhet road and railway line.

7.3 Description

The Manu River Improvement Project involves construction of a 32 km diversion channel from Kotarkona (near Manu Railway bridge) to Hakaluki Haor. The associated infrastructure includes: a major diversion structure, 50 m wide embanked diversion channel (3 m high), and reconstruction of two road bridges and one railway bridge. The diversion would operate to 21 days during extreme flood years such as 1988 or 1991 and only 2 to 3 days during low flood years.

To eliminate overbank spills in the lower Dhalai River, a 3.0 m high embankment would be constructed for a length of 27 km on the right bank of the Dhalai upstream from near its confluence with the Manu River.

7.3.1 Project Design Parameters for Manu Diversion

Allowable Manu River Discharge at Moulvi Bazar

The bankfull discharge of the Manu River at Moulvi Bazar is estimated to be 650 m^3/s (see Appendix B). Given that the homesteads between the Manu River and the Manu River Irrigation Project embankments are raised about 1.5 m above the river bank level and that negative impacts of the diversion can be somewhat mitigated by minimizing the volume of water diverted, the allowable discharge in the Manu River has been set at 800 m^3/s. At this discharge, water levels would rise an estimated 1 m above bankful at Moulvi Bazar (Appendix B).

Design Flood Discharge

Since the scheme is intended to provide protection to Moulvi Bazar town, other infrastructure, as well as agriculture, the diversion would be designed to accommodate flood discharges having a frequency of occurrence of once in 100 years or less. Flood discharges on the Manu River have been synthesized and analyzed as described in Appendix B, where it is concluded that the frequency distribution of the flood discharges is well represented by an EV3 distribution yielding the 100-year flood discharge as 1576 m^3/s.

Given that the conservative process of discharge synthesis adopted may have led to a slight over-estimation of the flood discharges used in the frequency analysis, the design discharge for the Manu River Improvement Project is taken as 1500 m^3/s.

Floodway Diversion Capacity

If the design flood discharge is to be reduced to the allowable discharge, then the difference must be diverted around the floodplain. The required floodway capacity is thus 700 m^3/s.

7.3.2 Manu River Improvement Project Floodway

A large floodway channel is required to convey at least 700 m^3/s from the Manu River Improvement Project diversion structure to Sakua Beel in Hakaluki Haor. The length of this channel is 32 km, and its slope 25 cm/km. A trial section is shown in Figure 12, and suggests that the right of way required for an unlined channel with 25 m berms and embankments both sides will be in the order of 200 m. The alignment is presently proposed to follow the course of the Phanai River as far as possible, since this will result in a 40% saving in excavation. On this basis the total cost of the floodway excavation is estimated to be Tk 168.4 million. Land acquisition costs for the floodway are estimated to be Tk 36.7 million. The total cost of the floodway component of the Manu River Improvement Project is therefore Tk 205.1 million. Appendix B presents further information on the design and costing of this structure.

In view of the large right of way requirement for an unlined channel, and the probable high cost of maintaining its section, consideration should be given in the feasibility study to lining the floodway channel. Since bricks are readily available locally at reasonable cost, a brick lining is suggested. For this pre-feasibility study it was thought, but not checked, that the cost of a brick lining would not be balanced by savings on excavation and land acquisition costs. A typical brick-lined section is shown in Figure 13 which relates to Variant B, and is sufficient to show that the right of way requirement would be substantially less than for an unlined channel. A brick-lined section would also be resistant to erosion by high flows in the floodway though bricks could be pilfered.

7.3.3 Manu River Improvement Project Diversion Works

A large diversion structure is required on the upper Manu River near Kotarkona to divert flood flows at least as high as 700 m^3/s to Hakaluki Haor. It is presently envisaged that this structure would consist of a barrage with vertical lift gates, and that it would closely resemble the existing Manu River Irrigation Project barrage at Moulvi Bazar. Such a structure would be technically appropriate although less expensive structures are thought possible. The main reasons for assuming, for the purpose of this report, that the structure will consist of a vertical lift gate barrage are that:

1) The construction of this type of structure is known to be within the capability of the BWDB since it constructed the existing barrage.

2) The construction cost of this type of structure can be estimated from the known cost of the existing barrage.

It is considered, however, that in any follow on study, consideration should be given to developing a structure of the type shown in Figure 13. This alternative structure does not feature gates but would operate so as to largely achieve the required degree of flow control; it would cost substantially less to construct, require much less maintenance work and no power supply. In contrast, a vertical lift gate barrage would require the installation of a 33 KV line to site, and a sub-station at site, even though there is an existing 33 KV line passing nearby (Srimangal-Kulaura-Barlekha line).

The precise location of this structure also requires detailed study at feasibility level. Its siting should be such as to minimise floodway excavation, and interference with existing and other proposed infrastructure in its vicinity. Notable among the latter are the railway bridge and the railway line, existing dirt roads, and possibly a new road bridge and surfaced road (Moulvi Bazar-Kulaura-Barlekha, with a spur to the proposed airport at Shamsernagar); these are all located in the immediate vicinity of the proposed diversion structure.

The design and operation of the diversion structure, whatever form it takes, must ensure that in the 100-year flood event:

1) At least 700 m^3/s, can be diverted to Hakaluki Haor without causing higher water levels upstream of the structure than naturally occur in the 100-year flood event

2) That the bedload sediment carried by the 100-year flood event can be proportioned as necessary between the floodway and the Manu River.

These requirements are easily met if the structure consists of a gated barrage; they are not so easily met by the rigid structure shown in Figure 13 which is known to require modification since it relates to Variant B (described in the previous Chapter).

If, in the feasibility study, it is concluded that a gated barrage is essential, then it is recommended that a radial gate be considered; this type of gate is less costly than the vertical lift type, and less troublesome in operation; furthermore, radial gates lend themselves to hoisting assistance by built-in counter-weights or buoyancy tanks, in which case power requirements are substantially reduced.

Assuming the diversion structure will be a vertical lift gate barrage, the total cost of the barrage and floodway inlet structure is estimated to be Tk 200 million. Appendix B presents further information on the design and costing of this structure.

7.3.4 Floodway Appurtenant Structures

The floodway channel, as presently located, will require that the existing bridges over the Phanai River are replaced with larger bridges. Involved are the existing road bridges at Tilagaon and Nowagaon, and one railway bridge on the Kulaura-Fenchuganj section of the Dhaka-Sylhet railway line.

The floodway channel will also cut across a number of inter-village roads, and it is presently estimated that a minimum of five footbridges over the floodway will be required.

The total cost of all these bridge works is estimated to be Tk. 110 million. Appendix B presents further information on the design and costing of these structures.

7.3.5 Dhalai River Development

Embankments
Embankments will be required to protect the Dhalai flood plain from flooding by both in the Dhalai and Manu Rivers. An entirely new embankment will be required from the Manu-Dhalai confluence upstream as far as Kamalganj. South of Kamalganj there is an existing road embankment which it is proposed to upgrade to form the flood protection embankment from Kamalganj southwards to the Indo-Bangladesh border.

The Manu-Dhalai Confluence-Kamalganj section will be 27 km in length, and its cost is estimated to be Tk 26.75 million including turfing which is considered essential. The cost of upgrading the Kamalganj-Indo-Bangladesh Border section, which is 17 km long, is estimated to be Tk 5.05 million. The design embankment crest elevations are provided in Table 7.1. The total cost of the embankment works is therefore Tk 31.8 million. Land acquisition costs are estimated to be Tk 41.1 million, so the total cost of works to protect the Dhalai flood foodplain is Tk 72.9 million. Appendix B presents further information on the design and costing of these embankments.

Structures
Since the Dhalai River does not receive any drainage inflow along its right bank, no drainage structures are proposed.

7.3.6 System Drainage

Manu River
Drainage of the Manu River Irrigation Project would continue to be effected by the drainage pumps located at Kashimpur. With substantially reduced in-channel flows in the lower Manu River, the embankments are not expected to be

Table 7.1: Design Embankment Crest Elevation

Locations	Section (km)	Crest Level (m PWD)
Dhalai Outfall	0.0	14.61
Kamalganj Highway Bridge	27.0	22.12
International Border	44.0	26.85

cut. As a result, drainage requirements would be more in line with those for which the pumping system was designed.

Dhalai River
With completion of the Manu River Improvement Project, the drainage requirements of the Dhalai floodplain will be substantially reduced since present flood spills from the Manu and Dhalai Rivers will decrease. The area will be drained via the Khallalia Khal. The outfall of which will remain open to the Manu River. This khal does not appear to require any improvement though this would be verified at feasibility.

7.3.7 Expected Benefits

The benefits accruing from the project are various. Moulvi Bazar town and the associated communication infrastructure (roads and railways) will be afforded a much higher level of protection; Flooding of rural homesteads and agriculture will be diminished, and damage to infrastructure associated with the Manu River Irrigation Project will be reduced. The present level of investigation does not quantify the benefits associated with urban or infrastructure protection[1] — nor are these benefits incorporated into the financial and economic analysis. It is expected that this would form part of the next stage of study. Attempts were made, however, to quantify agricultural benefits and they alone appear to justify examining the Manu River Improvement Project in more detail.

Agriculture Benefits
Land types are expected to change in both pre- and monsoon seasons as shown in Tables 7.2 and 7.3. These changes are expected to be associated with the changes in area under the various cropping patterns as shown in Table 7.4.

Table 7.2: Pre-Monsoon Shifts in Cultivable Area between Land Flooding Categories

Land Flooding Category	Cultivable Area (ha)			
	Manu River Irrigation Project Area		Dhalai Flood Plain	
	Pre-Project	Post-Project[a]	Pre-Project	Post-Project[a]
F0	6115	18600	10420	20800
F1	12485	0	3690	950
F2	0	0	5800	0
F3	0	0	2290	0
Total	18600	18600	22200	21750

[a] *These figures include cultivable land acquired for infrastructure. Production impacts on these lands are documented in the evaluation section.*

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[1] According to Moulvi Bazar Municipality, the damage to infrastructure in the 1984 floods at current prices was Tk 162 million (1984 Tk). This figure does not include secondary impacts such as loss of productivity.

Table 7.3: Monsoon Season Shifts in Cultivable Area between Land Flooding Categories

Land Flooding Category	Cultivable Area (ha)			
	Manu River Irrigation Project Area		Dhalai River Floodplain	
	Pre-Project	Post-Project[a]	Pre-Project	Post- Project[a]
F0	8400	12000	16180	20290
F1	2000	2000	2560	844
F2	2600	2750	2845	416
F3	5600	1850	975	200
Total	18600	18600	22200	18750

[a] *These figures include cultivable land acquired for infrastructure. Production impacts on these lands are documented in the evaluation section.*

The flood protection will reduce damage to rice in all three seasons: kharif I, kharif II, and boro. Future with project crop production has been estimated (Table 7.5) assuming that the yields presently being obtained in the areas free of damage would be obtained through out the flood protected area.

As a result of the project, cereal production is expected to increase by about 57,944 tonnes annually from 173,273 tonnes (FWO) to 231,217 tonnes (FW). This is an increase of 33%.

Non-cereal production is expected to increase by an estimated 2776 tonnes annually from 11,159 tonnes (FWO) to 13,935 tonnes (FW). This is an increase of 25%. The expected increase in non-cereals is mainly due to an increase in area cultivated from 2633 ha to 3539 ha.

7.3.8 Mitigation Measures Incorporated

The Manu River Improvement Project has the potential to alter the sediment regime in the Manu River and in Hakaluki Haor. Mitigation measures to alleviate potential impacts (the possible impacts are described in more detail in Section 7.8.1) involve measures to facilitate careful management of the sediment. This aspect of the project remains to be studied in much more detail but entails care in designing the infrastructure and rationale operating methods (modes of operation are described in more detail in section 7.4). These measures include:

- designing the diversion structure to facilitate some control over where the sediments are routed — whether down the Manu or into Hakaluki Haor.

- designing the floodway to have the steepest gradient possible to discourage sediment deposition within it.

- avoidance of any diversions except those needed to mitigate flooding in the lower Manu River.

Table 7.4: Future With Crop Patterns in Project Area

Crop Pattern	F0		F1		F2		F3		Total Area (ha)
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
b aman-fallow					825	26.1	636	31	1,461.0
fallow-l boro					808	25.5	1230	60	2,038.0
fallow-hyv boro					273	8.6	185	9	458.0
b aus-potato			80	2.8					80.0
b aus-lt aman	2431	7.5	282	9.9	83	2.6			2,796.0
b aus-lt aman-rabi			42	1.5	83	2.6			125.0
b aus-hyv aman	2980	9.2	43	1.5					3,023.0
b aus-hyv aman-potato	203	0.6	84	2.9					287.0
b aus-hyv aman-rabi	882	2.7							882.0
jute-lt aman					27	0.8			27.0
hyv aus			338	11.9					338.0
hyv aus-potato			401	14.1					401.0
hyv aus-rabi	600	1.9							600.0
hyv aus-lt aman	5460	16.9	512	18	62	1.9			6,034.0
hyv aus-hyv aman	10446	32.4	200	7					10,646.0
lt aman-fallow	2008	6.2			690	21.8			2,698.0
lt aman-hyv boro	597	1.8	581	20.4	235	7.4			1,413.0
hyv aman-fallow	2002	6.2							2,002.0
hyv aman-rabi	1198	3.7							1,198.0
hyv aman-hyv boro	3481	10.8	280	9.8					3,761.0
b aman-hyv boro					81	2.5			81.0
TOTAL	32290		2844		3166		2050		40,350.0

Source: NERP estimates

Table 7.5: Future With Project Crop Production in the Project Area

Crop	Damage Free Area			Damaged Area			Total Production (t)
	Area (ha)	Yield (t/ha)	Total (t)	Area (ha)	Yield (t/ha)	Total (t)	
b aus	6794	1.5	10,191.00	401	1.1	441.1	10,632.10
hyv aus	17041	4.1	69,868.10	979	3.2	3,132.8	73,000.90
b aman	1432	1.8	2,577.60	109	1.3	141.7	2,719.30
lt aman	12605	2.15	27,100.75	489	1.8	880.2	27,980.95
hyv aman	20599	4	82,396.00	1201	3.4	4,083.4	86,479.40
l boro	1956	2.25	4,401.00	82	2.1	172.2	4,573.20
hyv boro	5258	4.55	23,923.90	454	4.2	1,906.8	25,830.70
Total Rice	65,685.0		220,458.35	3,715.0	17.1	10,758.2	231,216.55
potato	368	12	4,416.00				4,416.00
pulses	472	0.85	401.20				401.20
oilseeds	1572	0.75	1,179.00				1,179.00
spices	157	2.25	353.25				353.25
vegetables	943	8	7,544.00				7,544.00
jute	27	1.65	44.55				44.55

7.4 Project Operation and Maintenance

7.4.1 Diversion Operation

The way in which the project would work is explained by way of a numerical example in Table 7.6. A more detailed description follows.

Table 7.6: Numerical Example of Diversion Operation (m^3/s)

Mode	Flow Approaching Moulvi Bazar	Without Project		With Project		
		Flow through Moulvi Bazar		Floodway Flow	Flow through Moulvi Bazar	
		Total	Overbank		Total	Overbank
1	$Q_T > Q_D$	1600	950	700	900	250
2	$Q_T = Q_D$	1500	850	700	800	150
3	$Q_A < Q_T < Q_D$	1100	450	300	800	150
4	$Q_T < Q_D$	500	Zero	Zero	500	Zero

Notes: *Q_T represents a flood discharge of frequency once in T years approaching Moulvi Bazar*
Q_B represents the design flood discharge
Q_A represents the allowable discharge through Moulvi Bazar

Mode 1
In Mode 1, $Q_T > Q_D$, so if Q_T = 1600 m³/s the flow through Moulvi Bazar without the diversion in place would be 1600 m³/s of which 950 m³/s would pass through the river channel at levels above the bankfull level and so cause extensive flooding on the Manu River floodplain. With the diversion in place, 700 m³/s would be diverted via the floodway, so the flow through Moulvi Bazar would be 900 m³/s, and of this only 250 m³/s would occur at levels above the bankfull level; thus, while overbank spill onto the floodplain would occur in this rare situation, the flooding would be far less extensive than in the without project case since the overbank flow is reduced by 74% from 950 m³/s to 250 m³/s. Such reductions in the extent of flooding are a benefit additional to that resulting from the frequency reduction which is the prime objective of the project.

Mode 2
In Mode 2, $Q_T = Q_D$, so Q_T = 1500 m³/s and, without the diversion in place, this flow would pass through Moulvi Bazar with 850 m³/s occurring at overbank levels. With the diversion in place, 700 m³/s would be diverted leaving 800 m³/s passing through Moulvi Bazar; this would result in water levels of 1 m over bank which is acceptable to area residents.

Mode 3
In Mode 3, $Q_A < Q_T < Q_D$, so if Q_T = 1100 m³/s the flow through Moulvi Bazar without the diversion in place would be 1100 m³/s of which 450 m³/s would occur at overbank levels and cause flooding on the Manu River floodplain. With the diversion in place 300 m³/s would be diverted leaving only 800 m³/s passing through Moulvi Bazar. It should be noted that when this mode of operation prevails no more flow should be diverted than is necessary to ensure that the flow passing through Moulvi Bazar does not exceed 800 m³/s; this rule should be followed to minimise the inflow of water-borne sediment to the floodway.

Mode 4
In Mode 4, $Q_T < Q_A$, so if Q_T = 500 m³/s the flow through Moulvi Bazar without the diversion would be 500 m³/s. Since this is less than the allowable discharge, even with the diversion in place, there would be no need to divert any flow, and the whole 500 m³/s would be passed downriver together with its sediment load, and so encourage the onward movement of any sediment deposited downstream of the diversion point as a result of diversions made in other operating modes.

7.4.2 Embankments

Maintenance requirements of the flood embankments would be reduced after the construction of the Manu Improvement Project. The reason is that the need for public cuts in the embankments will no longer be present and this in turn will end the extensive erosion of the embankments which is associated with the cuts. The embankments will, however, require regular inspection and maintenance and this would be the mandate of the BWDB.

7.5 Organization and Management

During the early part of the feasibility study process, a client group would need to be organized to oversee project development. These client groups would be composed of representatives from the local farming community, fishing community, and would include relevant technical officers.

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The groups would ensure that the problems of the area are clearly understood and adequately reflected in the feasibility work and that the technical solutions being proposed address the problems in an acceptable manner. They would be continually briefed as the feasibility work was carried out and would need to confirm the conclusions of the exercise. They would also be informed as to details of designs being proposed by BWDB design engineers which designs, in the end, would require their concurrence. The groups would also monitor the construction program which would be carried out by BWDB.

BWDB would be responsible for undertaking technical work related to implementation of the project in accordance with current practice but would be responsive to the client group described above. The general tasks include completion of final designs, preparation of tenders, pre-qualification of contractors, contract awards and construction supervision. The general management of BWDB activities would be under the Executive Engineer stationed in Moulvi Bazar. Construction supervision would be carried out by sub-divisional field staff.

The Department of Agricultural Extension (DAE) is responsible for the provision of extension services to the farmers within the project.

In summary, the organization and management of this project has a high dependency on central government for key inputs. The extent to which project targets are realized will be determined by how effectively it serves people's needs and how actively the local community participates in all stages of project development.

Bangladesh Rural Development Board (BRDB) is responsible for assisting with command area development through farmers' training and by organizing farmers into cooperatives which will then have access to short term crop production loans. Medium term credits are available to these cooperatives from all nationalized banks.

The supply of all agricultural inputs has been deregulated and the distribution placed into the hands of the private sector.

7.6 Cost Estimates

Total project costs are estimated Tk 845 million as shown in Table 7.7. Details are provided in Annex B.

Table 7.7 Capital Cost Summary

Item	Cost ('000 Tk)
Structures	200,000
Embankments	31,800
Channels	168,400
Bridges	110,000
Buildings	-
Land Acquisition	77,800
BASE COST	588,000
Physical Contingencies (25%)	147,000
SUBTOTAL	735,000
Study Costs[1] (15% of Subtotal)	110,250
TOTAL	**845,250**
Net Area (ha)	40,800
Unit Cost (Tk/ha)	20,717

[1] *Includes preparation of EIA and Environ-mental Management Plan.*

The estimates of land requirement and physical works are based on preliminary designs and lay-out plans prepared using four inch to one mile topographic maps, and historic hydrological data.

Land costs reflect the current prices obtained from field interviews: land which was single cropped was estimated at 120,000 Tk/ha; land that could be double cropped was 300,000 Tk/ha; and, land suitable for homesteads and gardens (including high ridges along the rivers) was 500,000 Tk/ha. Earthwork costs are based on the BWDB Schedule of Rates for Sylhet Circle indexed to June 1991 prices. Structure costs are based on parametric costs developed for the Region, also indexed to June 1991 prices in accordance with the FPCO Guidelines for Project Assessment. Diversion structures' cost is estimated based on Manu Barrage cost.

7.7 Project Phasing and Disbursement Period

Five years are required to implement the project. One year (year zero) is required for completion of feasibility studies and conducting field surveys. Preparation of detail designs should start in year one and be completed in year two. Land acquisition should commence in year one, be implemented in phases preceding construction, and completed in year three. Construction activities should start in year one and be completed in year four. An itemized implementation schedule is shown in Table 7.8.

Table 7.8 Implementation Schedule

Activity	Year (% Completion)				
	0	1	2	3	4
Preconstruction Activities					
Feasibility Study	100				
Engineering Investigation	70	30			
Detail Designs		50	50		
Land Acquisition		30	40	30	
Construction Activities					
Construction of Embankments			20	40	40
Excavation of Channels			20	40	40
Construction of Structures		10	30	40	20
Construction of Bridges		10	30	50	10
Project Buildings					

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7.8 Evaluation

7.8.1 Environmental

The key areas of environmental impact for this project are described briefly below. Additional information is given in Annex C, Initial Environmental Evaluation.

Water Levels In Hakaluki Haor

The results of a preliminary hydrodynamic model run indicate that under 1991 flooding conditions (which occurred in early May and which time is the most critical for the boro crop in Hakaluki Haor), the diversion to Hakaluki Haor would cause water levels to rise from 11.30 m PWD to 11.50 m PWD. This would result in submerging about 1500 ha of additional land (Figure 14). This is about 5% of the land that was submerged in 1991. It should be noted that the 1991 flood has a recurrence interval of 100-years.

Diversions which may be necessary after May would marginally increase the surface area of the Haor but would not affect agriculture since these lands are fallow at this time.

Sedimentation in Hakaluki Haor

The periodic influx of high flood flows could have a major impact on the physical characteristics of Hakaluki Haor. Considering the period from 1981 to 1991 when the Manu River experienced almost all the high flood peaks, the sediment load that would be diverted from the Manu River averaged roughly 0.9 million tonnes/year.

The pattern of sedimentation from the diversion will probably be like a rapidly prograding "birds foot delta" — with the channel migrating through a single beel such as Sakua Beel in relatively short period (say a decade). During this time the impacts in other beels and other parts of the haor will probably be minor. In other words, only a relatively small portion of the haor will be affected during the period of diversion operations — say in the order of 200 - 400 ha. This because of the relatively shallow depths involved and the fact that most of the sediment will be deposited near the active channel. As the delta grows and channels shift, the locus of deposition will shift further downstream. The pattern of development is illustrated in Figure 15.

Therefore, assuming the diversion channel outfalls into Sakura Beel, it is likely that over a period of 10-20 years a substantial portion of Sakura Beel and Dulla Beel would be transformed to shallowly flooded lands. For example, given a sediment inflow of 0.9 million tonnes/years, Sakua and Dulla Beels could aggrade by an average of 1.2 m in 10 years. For the time being, these two beels can be considered to constitute the "high impact" zone from the project. These beels amounts to 11% of the total beel area. Sediment deposition from the diversion could also modify the pattern of growth of the Juri River delta, which might for example, cause the river to shift eastwards, back towards Chatal Beel. Over longer time periods, the delta would continue to prograde and cover a greater extent of the haor. Mitigation works, such as constructing an embankment could be used to guide the delta's evolution and to prevent it prograding into areas that are critical for fisheries or other habitat.

Land Use

Land use changes are summarized in Table 7.9. A total of 450 ha of land (about 0.86% of the project gross area) will be required for construction of embankment and diversion channel. Of this:

- 446 ha will be taken from cultivated area. Assuming average yields 2.7 tonnes/ha and that this is all under rice, this corresponds to cereal production foregone of about 1200 tonnes per year or about 1.6% of total incremental cereal production. However, economic analysis has considered this loss.

- 4 ha will be taken from homestead area. This is 0.1% of total homestead area, which implies that 200 households or about 2270 persons will be displaced. Also, homestead agricultural production from these sites will be lost. Roughly estimating homestead agricultural production at Tk 1000 per decimal or Tk 200,000 per ha, this comes to Tk 800,000 per year.

Table 7.9: Changes in Land Use

Use	Change in area (ha)
Cultivated	(-) 446[a]
Homesteads	(-) 4
Beels	-
Ponds	-
Channels	-
Hills	-
Fallow[1]	-
Infrastructure[2]	-

[1] Multi-use land, wetlands, grazing lands, village grounds.
[2] Government-owned land not appearing elsewhere.
[a] While computing agricultural benefit, production from 450 ha of land has been foregone.

Agriculture

Increased cereal production is documented in Section 7.3.7, Expected Benefits. The cereal production increase implies a per person increase in cereal availability from 871 (FWO) to 1163 (FW) gm per person per day, an increase of +33% (Table 7.10), allowing 10% for seed, feed, and waste, and 65% for conversion of paddy to rice. Current Bangladesh average consumption is 440 gm per person per day.

Non-cereal production (also documented in Section 7.3.7) is expected to increase from 11,159 tonnes (FWO) to 13,935 tonnes (FW) (+25%). This implies an increase in the availability of non-cereals from 56 to 70 grams per person per day (Table 7.10).

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Openwater fisheries production
The Northeast Region has an estimated 100,000 ha of "mother fishery" which contribute an estimated 50,000 tonnes of fish (NERP Fisheries Specialist Study, 1993) to the regional production of 100,000 tonnes. Hakaluki Haor with a spawning habitat of 5000 ha has been identified as a "Mother Fishery" contributing an estimated 2500 tonnes to the Regions fish production.

Table 7.10 Indicators of Food Availability
(grams/person/day)

Food Group	Present (1993)	FW (2000)	FW (2015)	FWO (2015)
Cereals	1293	1521	1163	871
Non-Cereals	77	92	70	56
Fish	3.78	0.49	0.37	2.52

As described earlier in this section, the diversion will introduce sediment into Hakaluki Haor. In the absence of more refined estimates, it is assumed that the spawning habitat will be destroyed and that the loss to fisheries will be 2500 tonnes per year.

In addition, within the Project area reduced flooding will reduce flood plain, beel and channel areas, which combined with some deterioration in water quality and impaired migration will result in losses to fisheries.

The total annual openwater fisheries production impact is (-) 2927 tonnes, which is 97% of the FWO annual production of 3001 tonnes. Impacts on fisheries are summarized in Table 7.11.

These changes in fish production imply a decrease in per person openwater-source fish availability attributable to the project from 2.52 (FWO) to 0.37 (FW) gm per person per day (Table 7.10). While estimating the fish availability per person, the spawning impact has not been considered since the impacted population is not known.

Table 7.11: Fish Production Indicators

Regime	FWO (2015)		FW (2015)			
	Area (ha)	Production ('000 kg)	Area (ha)	Area Equivalent	Production Impact ('000 kg)	Net Value ('000 Tk)
Flood Plain	16220	437.9	8060	2418	-373	12077
Beels	1220	34.2	1220	183	-29	1830
Channels /Rivers	1040	29.1	1040	156	-25	1467
Mother Fishery	5000	2500	5000	0	-2500	-50000
Totals		3,001.2			-2,927.0	-65374

Homestead flooding

Homestead flood damage would be significantly reduced. Due to the lack of historical data on flood damage costs, a simple model was used to estimate future costs. There are about 81,490 homesteads in the area, and the average plinth level is at about the 1:5 year flood level. About 66% of homesteads are affected by flooding of 10-20 cm in the 1:10 to 1:25 year floods. The estimated annualized economic value of reduced flood damage is Tk 33 million.

Table 7.12: Floodplain Grazing and Wetland Changes

Land Type	Winter Grazing Area			
	FWO	FW	Change	%
sc/wf F0	19874	25329	5455	
sc/wf F1	2979	1438	-1541	
sc/wf F2	2829	1687	-1142	
Fallow Highland	970	970	0	
Total	26652	29424	2772	10

Land Type	Winter Wetland			
sc/wf F3	1960	636	-1324	
F4, Beel, Channel	2490	2470	-18	
Total	4,450	3108	-1342	-30

Land Type	Summer Wetland			
wc/sf F1	120	0	-120	
wc/sf F2	832	1081	249	
wc/sf F3	4613	1415	-3198	
F4, Beel, Channel	2490	2472	-18	
Total	8055	4968	-3087	-38

FW areas shown here reflect cultivable land acquired for infrastructure (see Land Use, Section 7.8.1). 'sc' - summer cultivated. 'wc' - winter cultivated. 'sf' - summer fallow. 'wf' - winter fallow.

Wetland Habitats and Grazing Area - Kawadighi and Dadala Haor

Impacts are difficult to quantify, but a general impression is given by Table 7.12, which shows the impact on:

- "Winter grazing area." Defined as F0, F1, and F2 lands that lie fallow in the dry season (winter) plus any perenially-fallow highlands. This land would have limited residual moisture. While it is clear that animals do graze on such areas, productivity per unit area is not known.

- "Winter wetland". Defined as F3 land that lies fallow in the dry season, plus any perennially-fallow lowland (F4), beel, and channel areas. This land would likely have considerable residual moisture and could support a range of wetland plant communities.

- "Summer wetland". Defined as F1, F2, and F3 land that lies fallow in the summer, plus perennially-fallow lowland (F4 area), beel, and perennial channel areas. This land would be inundated to >0.3 m and would support submerged, free-floating, rooted floating, and sedge/meadow plant communities.

The impact of the project would be to increase winter grazing area by 10%, decrease winter wetland area by 30%, and decrease summer wetland area by 38%.

There would be no impact on swamp forest trees.

Economic and employment impacts of the project on wetland plant and animal production can only roughly estimated. Assuming an annual economic production of Tk 80 per hectare for both summer and winter wetland areas gives a total annual loss of Tk 350,000 per year. Assuming 2.0 pd $(ha\ yr)^{-1}$ for harvesting, the employment impact would be - 9,000 pd per year.

Wetland Habitat and Grazing Area - Hakaluki Haor
Diversion of peak Manu flood discharges into Hakaluki Haor are expected to have the following impacts:

- "Winter grazing area". An increase in winter grazing area is expected. This will occur for two reasons: any boro crops produced on the margins of the permanent water bodies will be at risk if flood diversion from the Manu River becomes necessary in the pre-monsoon season, and sediments brought in by the diversion would tend to raise land levels to the point where crop production without irrigation would not be possible. Relatedly, sediments would eventually infill the permanent beels in the southern area of the Haor such that water would be unavailable for crops in the area.

- "Winter wetland". The impact of the project would be to decrease winter wetland area. The area most critically affected is expected to be Sakua and Dulla Beels which, in all likelihood, would become seasonally flooded lands. This would reduce fisheries habitat, irrigation water availability, and waterfowl roosting habitat.

- "Summer wetland". The diversion might not result in a reduction of the total surface area of the summer wetland, rather it may increase. However, the depth of flooding could be reduced in some locations (due to sediment deposition) which would induce the growth of aquatic weeds. This could lead to some eutrophication. While this may in fact be favourable for some of the aquatic plant community, it may well reduce species and community diversity. The Sedge/meadow community which is associated with various grasses might dominate in the long run.

Although the swamp forest trees can tolerate and survive in much drier condition, their propagation and well established regeneration systems may be affected. If this were the case, it could impact negatively on the existing swamp forest patches and would hinder the development of new ones.

No attempts have been made to quantify the economic and employment impacts of the project on wetland plant and animal production in the Haor. A thorough assessment of the impacts on these communities in the context of a better understanding of the sediment regime would be required in the next stage of project analysis.

Transportation/navigation
The total length of existing motorable roads in the project is about 300 km of which about 120 km are inundated every year. The project would result in these 120 km being flood-free (up to the 1:100 year flood). Assuming a capital cost of Tk 190,000/km and 15% flood damage, the annual benefit to the road network is Tk 2.4 million.

Higher flood levels
Kushiyara River flood levels could increase but preliminary modelling suggests that this will not be by more than 0.20 m at Fenchuganj. This estimate will need to be refined since even this increase could have some impact on areas outside the project.

7.8.2 Social

The key areas of social impact (or lack thereof) for this project are described below. Additional information is given in Annex C, Initial Environmental Evaluation.

Employment
There will be an overall increase in employment of 0.738 million person-days per year. This is composed of:

- an increase in owner-labour employment of 0.676 million pd yr^{-1}, of which very roughly 20% is post-harvest processing activities traditionally done by women of the household.

- an net increase in employment opportunities for landless people of 0.062 million pd yr^{-1}, composed of changes in the following areas:

  - Agricultural hired labour: 0.829 million pd yr^{-1}, of which about 10% is for post-harvest processing traditionally done by women hired in (mainly by larger farmers) for the purpose.

  - Fishing labour: -0.758 million pd yr^{-1}; in addition to this, there would be a corresponding loss in support activities such as net-making and post-catch processing (mainly drying) much of which is done by women. Note that this does not include the labour lost as a result of production losses from the "mother fisheries".

  - Wetland labour (gathering wetland products): -.009 million pd yr^{-1}. Fodder and building material is gathered mainly by men. Food, fuel, and medicine is gathered mainly by women.

Displacement impacts due to land use changes
Households whose homestead land is acquired, for proper cash compensation, by the project may have difficulty relocating. This is because suitable homestead lands are so scarce that availability of replacement land for purchase is not assured.

Two mitigation options bear consideration. Embankments could be constructed with berms at strategic locations to support homesteads. Alternatively, provision could be included for the construction of raised housing platforms to facilitate relocation. The experience of BWDB in resettling landless people on embankments in the Cyclone Protection Project may be relevant to the requirements of this project area.

Conflicts
The area over which the diversion channel will flow down will receive no benefit from development of the project. Should the perception develop that a problem is being shifted onto them they may well respond by sabotaging the infrastructure.

Equity
The net equity impact would appear to be strongly *regressive*. Who benefits?

- Landowners, in proportion to landholdings, benefit directly from investment in agriculture production. This is the main quantified benefit (91% in economic terms) of the project and its distribution is quite *regressive*.

- Urban dwellers and business who constitute the wealthier segment of society and its distribution is quite *regressive*

- Travellers, a proportion of whom are able to afford ownership of their own vehicles and is *regressive*.

Who loses?

- Families dependent upon fishing labour. These families are mainly landless and tend to be poorer than average. *Regressive*.

- Families involved in gathering wetland products. These families are mainly landless and tend to be very poor. *Regressive*.

- Families displaced from their homesteads by project land acquisition. Insofar as more wealthy families can influence infrastructure siting/alignment, this is *regressive*.

Gender Equity
The net equity impact would appear to be somewhat *progressive*. Employment opportunities for women will increase in all categories <u>except</u> wetland gathering. Reduced homestead flood damage will disproportionately favour women, given that most women still spend most of their lives within the homestead. By the same token, the adverse effects of acquisition of 4 ha of homestead land (200 households or 1135 women) may fall mainly on the women in those households.

Qualitative Impact Scoring
The qualitative criteria shown in Table 7.15 are scored on an 11 level scale of -5 to +5. Scoring of those criteria that are impacts (some are not, like "responds to public concerns") is shown in Table 7.13. The scoring procedure is analogous to that used in the FAP 19 EIA case studies, but simplified to eliminate half-point scores (1.5, 2.5, 3.5, etc). Here, each score sums across five equally weighted logical (true/false) criteria, with each "true" counting for a value of one and each "false" for zero. The sign reflects whether the impact is positive or negative.

7.8.3 Economic

The project has an economic rate of return of 27%, which compares well to the required rate of 12% as prescribed by government. It is a high investment project, at Tk 845 million or Tk 20,717 per hectare, and it covers a large geographic area (52,300 ha gross). The rate of return, however, is quite sensitive to the timing of the benefits, and a delay in benefits by two years would reduce the ERR to 20%. The other sensitive variable is an increase in capital costs (a 20% increase in capital cost would reduce the rate of return to 24%). The sensitivity to a 20% increase in fish losses is low; the ERR would decrease by 4%.

Table 7.13 Qualitative Impact Scoring

Qualitative Impact	Impact Sign	True=1 False=0 Sensitive	Magnitude	Immediate	Sustainable Pos Impact/ Irreversible Neg Impact	No Mitigation Required/ Possible	Score
Ecological Character of Hakaluki Haor	-1	1	1	1	1	1	-5
Regional Biodiversity	-1	0	0	1	1	1	-3
Road Transportation	1	1	1	1	1	1	5
Navigation	-1	0	0	0	0	1	-1
Flood Levels Outside Project Area	-1	1	1	1	0	0	-3
Conflicts	-1	1	1	1	1	1	-5
Socioeconomic Equity	-1	0	0	0	1	0	-1
Gender Equity	1	0	0	0	1	1	2

The foreign costs associated with the project are low, at 9% (excluding FFW contributions). Donor funding considerations would clearly need to include funding local costs.

Almost all of the benefits of the project relate to increased rice production, mostly resulting from protection of crops from floods. Average crop yields would increase as a result of reduced flood damage, and cropping intensity would increase by 12%. Non-cereal production would increase by 25%. Floodplain fish production fall to about 97% of future-without-project production. The value of the lost fisheries output amounts to about 17% of the value of increased agricultural output. About 11% of project benefits would result from reduced homestead flooding. A small amount of disbenefits would result from loss of food, shelter, and tree products that are currently harvested from the seasonal wetlands. A summary of salient data in provided in Table 7.14. The benefits to Moulvi Bazar town and other infrastructure is not included in this analysis.

It is anticipated that the established crop marketing system will handle incremental crop production without any reduction in prevailing average price levels. Assuming the current annual growth in the demand for grain remains about 3%, the increased cereal production is unlikely to present any marketing difficulties.

A significant caution is that the economic benefits are based largely on protection against flood damage, and if this did not occur, the project would not be viable. Lessons of the past have shown that if a project's O&M is very poor, the project does not serve the intended objective.

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7.8.4 Summary Analysis

From a multi-criteria perspective (Table 7.15), the project as it is presently understood, is not particularly attractive:

- Benefits derive from protection of an urban centre (Moulvi Bazar), from protection of communications infrastructure and from increased rice production, at the expense of fisheries and wetlands.
- The net employment impact is positive, but is composed of a large gain in employment for owners at the expense of a significant number of jobs for hired labourers.
- A number of households would lose their homestead land to project land acquisition.
- The project would adversely affect regional biodiversity by changing the ecological character of Hakaluki Haor, a wetland of international importance.
- Kushiyara flood levels would increase somewhat.
- Conflict could be induced between people living in the Manu River basin (who benefit from much improved flood control) and people living in the Hakaluki Haor area (where flooding is made worse).
- The project has a high dependency on central government for implementation.

The positive aspects of the project would be:

- The rate of return is acceptable.
- There is a substantial increase in rice production.
- Economic returns to land owners increase.
- The risk of flooding of Moulvi Bazar Town, Rajnagar and Kamalganj Thana centres is reduced which in turn promotes economic development in a much larger area.
- Flood damage to homesteads and roads, and infrastructures is reduced.
- There is a substantial increment in non-cereal production.
- The gender equity of impacts is somewhat progressive.
- The Project responds to some public concerns.

Table 7.14: Summary of Salient Data

Economic Rate of Return (ERR)	27			
Capital Investment (Tk million)	845			
Maximum O+M (Tk million / yr)	27			
Capital Investment (Tk/ha)	20717			
Foreign Cost Component	9%			
Net Project Area (ha)	40800			
Land Acquisition Required (ha)	450			

AGRICULTURAL IMPACTS		Present	FWO	FW
Incremental Net Econ Output (Tk million / yr)	274.8			
Cropping Intensity		1.6	1.6	1.8
Average Yield (tonnes/ha)		2.7	2.8	3.4
Average Gross Margins (Tk/ha)		14845	14857	17848
Owner Labour (md/ha)		122	122	121
Hired Labour (md/ha)		32	33	41
Irrigation (ha)		15111	15791	17494
Incremental Cereal Prod'n (' 000 tonnes / yr)	58			
Incremental Non-Cereal (' 000 tonnes / yr)	3			
Incremental Owner Labour (' 000 pd / yr)	676			
Incremental Hired Labour (' 000 pd / yr)	829			

FISHERIES IMPACTS		Spawning	Flood plain	Beels	Channels
Incremental Net Econ Output (Tk million / yr)	-46	-35	-8	-1	-1
Impacted Area (ha)			16220	1220	1040
Average Gross Margins (Tk/ha)			945	1960	1960
Remaining Production %		0	15	1960	15%
Incremental Fish Production (tonnes / year)		-2500	-373	-29	-25
Incremental Labour ('000 pd / yr)	758		746	4	8

FLOOD DAMAGE BENEFITS				
Households Affected	53783			
Reduced Econ Damage Households (Tk M / yr)	33			
Embankments/Roads Affected (km)	120			
Reduced Econ Damage Roads (Tk M / yr)	2.4			

OTHER IMPACTS				
Wetland Incr Net Econ Output (Tk M/ yr)	-0.35			
Wetland Incremental Labour ('000 pd / yr)	-9.0			
Acquired Cult & Homestead Lands, Incr Net Econ output (Tk M/ yr)	6.86			
Persons Displaced by Homestead Acquisition	2270			

Table 7.15: Multi-Criteria Analysis

Economic		
Indicator	**Units**	**Value**
Economic Internal Rate of Return (EIRR)	per cent	27
EIRR, Increase Capital Costs by 20%	per cent	24
EIRR, decrease in net value agr./fish by 20%	per cent	24
EIRR, Delay Benefits by Two Years	per cent	20
Net Present Value	'000 Tk	694.25

Quantitative Impacts			
Indicator	**Units**	**Value**	**Percent[1]**
Incremental Cereal Production[2]	tonnes	58000	33
Incremental Non-Cereal Production	tonnes	3000	25
Incremental Fish Production	tonnes	-2927	97
Change in Floodplain Wetland/Fisheries Habitat	ha	8160	50
Homesteads Displaced Due to Project Land Acquisition	homesteads	200	0.1
Homesteads Protected From Floods	homesteads	53783	66
Roads Protected From Floods	km	120	40
Kushiyara Flood Levels/increase	m	0.20	–
Owner Employment	million pd/yr	0.67	8
Hired Employment (Agri+Fishing+Wetland)	million pd/yr	0.06	2

Qualitative Impacts (ranked from -5 ...0... +5)	
Impact	**Rank**
Ecological Character of Key Wetland Site (Hakaluki Haor)	-5
Regional Biodiversity	-3
Road Transportation	5
Navigation	-1
Flood Levels Outside Project Area	-3
Conflicts	-5
Socioeconomic Equity	-1
Gender Equity	2
Decentralized Organization and Management	-3
Responds to Public Concerns	3
Conformity to Regional Strategy	4

[1] Percent changes are calculated relative to future-without-project values of: total production of cereal, non-cereal, and fisheries; total floodplain area; total number of homesteads (for displacement due to land acquisition); flood-affected homesteads; flood-affected roads; Kushiyara water level; and total employment for owners and hired labourers.

[2] Includes incremental production foregone due to acquisition of cultivated land.

8. OUTSTANDING ISSUES

There is room for debate regarding the controlled Manu River discharge for which the project is to be designed. On one hand, decreasing this discharge will reduce the amount of flooding along the Manu and its floodplain and will reduce the risk of infrastructure failure. On the other hand, adopting a larger flow will increase the impacts on Hakaluki Haor to which the diversion will discharge.

In the present study a design value of 800 m^3/s has been adopted for the Manu discharge, which is 150 m^3/s greater than the bankfull capacity at Moulvi Bazar. It is recognized that this value will result in some amount of flooding on the floodplain between the River and the Manu embankments, to a depth of approximately 1 m, but the residents living there have said that their homestead platforms are raised above this level and that they will tolerate flooding for a short period of time.

It is recognized, however that:

- the existing models and analyses allow for only a preliminary assessment of the potential damages to Hakaluki Haor,
- the scope of the project ($20 million) is sufficiently large that failure to provide adequate flood protection would not be acceptable.

It is also recognized that there is a suggestion that flood discharges have increased lately and may further increase due to watershed changes and increased rainfall. Therefore a more conservative approach may be possible and indeed adviseable in the final analysis, and the matter of the controlled Manu discharge and conversely, the diversion rate, need to be subjected to more detailed analysis and review in the feasibility study stage. Important considerations are those which are outlined above as well as feedback from the benefitting groups, the impacted groups, and the funding agencies as to what costs and levels of risk are acceptable.

ANNEX A

TABLES

Table A.1

BWDB Rain Gauges Relevant to the MRIP Area, 1961-90

Rain Gauge	Location Relative to Project Area
Srimangal	Peripheral, to the southwest
Kamalganj	Inside, in the south
Moulvi Bazar	Inside, on the west
Langla	Peripheral, to the east
Monumukh	Peripheral, to the northwest
Chandbagh	Peripheral, to the northeast

Table A.2

Average Rainfall Over the MRIP Area, 1961-90
(mm)

Period	Srimangal	Kamalganj	Moulvi Bazar	Langla	Manumukh	Chandbagh
	(SW)	(S)	(W)	(E)	(NW)	(NE)
Jan	10	9	9	10	11	9
Feb	27	33	29	29	24	25
Mar	96	68	87	98	88	85
Apr	263	254	263	286	256	312
May	434	437	426	455	482	506
Jun	471	499	535	563	640	638
Jul	361	370	433	420	497	515
Aug	338	351	394	415	416	442
Sep	248	256	289	294	317	359
Oct	149	154	150	170	159	177
Nov	41	37	27	34	23	43
Dec	12	11	8	12	10	11
Year	2447 (100%)	2512 (103%)	2687 (110%)	2808 (115%)	2898 (118%)	3168 (129%)

Source: BWDB

X7

Table A.3

Climatological Averages
Srimangal, 1948-91

Month	Sunshine hrs	Temperature Mean Max C	Mean Min C	Mean C	Humidity %
Jan	7.8	25.6	9.3	17.6	83
Feb	8.1	27.9	11.7	19.8	77
Mar	7.3	31.9	16.8	24.5	73
Apr	7.1	33.2	21.1	27.2	75
May	6.7	32.4	22.9	27.7	81
Jun	5.0	31.7	24.7	28.3	86
Jul	4.2	31.9	25.1	28.5	87
Aug	4.8	32.2	25.1	28.7	88
Sep	4.4	32.0	24.5	28.3	88
Oct	6.4	31.1	21.8	26.7	87
Nov	8.1	28.9	15.9	22.4	85
Dec	8.0	26.4	10.9	19.1	78
Year	6.2	33.2	9.3	24.9	81

Month	Wind Speed km/hr	Wind Direction	Rain mm	PET mm	Surplus/Deficit mm
Jan	5.7	SSE	7	146	-139
Feb	7.6	SSW	39	160	-121
Mar	9.0	S	84	214	-130
Apr	7.8	SSE	237	243	-6
May	7.5	SSE	404	198	206
Jun	7.3	SSE	483	159	324
Jul	7.3	SSE	319	158	161
Aug	7.1	SSE	345	133	212
Sep	7.1	SE	265	141	124
Oct	7.1	SE	159	177	-18
Nov	5.7	SE	50	171	-121
Dec	9.9	SE	6	143	-137
Year	7.3	SSE	2431	1460.0	971

Station: Location 24°18'N, 91°44'E
Elevation 22.0 m

Source: BMD
BARC (for PET)

Table A.4

Climatological Extremes
Srimangal, 1948-1992

Month	Daily Temperature		Monthly Rainfall		Maximum Daily	
	Max	Min	Max	Min	Rainfall	Wind Speed
	C	C	mm	mm	mm	km/hr
Jan	31.1	3.4	71	0	42	20
Feb	34.4	2.8	129	0	86	33
Mar	38.4	6.7	376	0	91	67
Apr	43.4	10.6	695	0	213	130
May	40.0	14.8	651	12	177	80
Jun	39.8	20.3	1285	283	225	39
Jul	37.8	16.2	655	119	131	167
Aug	37.3	21.2	544	181	260	65
Sep	37.0	19.1	602	22	514	30
Oct	35.3	14.3	398	36	155	65
Nov	33.9	6.5	211	0	96	28
Dec	31.2	4.4	66	0	60	22
Year	43.4	2.8	1285	0	514	167

Source: BMD

Table A.5

Relevant Catchment Areas in the Manu/Dhalai River Basin

River	Flowpoint or Intermediate Catchment	Area (km^2)
Manu (Upper)	Upstream Indo-Bangladesh Border	2210
	Intermediate Catchment A	45
	Upstream Manu Railway Bridge (Gauging Stn.201)	2255
	Intermediate Catchment B	35
	Upstream Manu/Kalkalia Confluence	2290
Kalkalia	Upstream Manu/Kalkalia Confluence	230
Dhalai	Upstream Indo-Bangladesh Border	595
	Intermediate Catchment C	185
	Upstream Kamalganj Railway Bridge (Gauging Stn.67)	780
	Intermediate Catchment D	60
	Upstream Manu/Dhalai Confluence	840
Manu (Lower)	Upstream Manu/Dhalai Confluence	3360
	Intermediate Catchment E	20
	Upstream MRIP Barrage	3380
	Upstream Catchment F	10
	Upstream Chandnighat Bridge (Gauging Stn.202)	3390

Table A.6

MEAN MONTHLY DISCHARGE
Gauge 201 MANU R. at MANU RLY. BRIDGE

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	229	160	189	200	150	117	130	37	21	15	17	13
1965	13	24	179	152	160	119	69	35	15	12	9	8
1966	12	86	226	199	185	169	123	28	36	21	13	22
1967	72	70	82	134	132	110	103	23	18	10	11	9
1968	29	59	229	282	191	127	46	22	14	12	9	10
1969	60	25	140	96	165	86	69	17	12	9	9	7
1970	9	14	90	205	181	75	95		15	10	9	6
1971												
1972	41	62	103	79	134	51	19	9	7	7	5	7
1973	27	239	288	239	211	151	91	140	51	18	12	12
1974	51	122	284	252	172	197	93	32	21	13	10	6
1975	39	42	133	115	127	159	78	61	17	11	10	10
1976	25	83	355	273	183	204	43	23	16	12	12	8
1977	206	241	316	133	211	118	98	60	20	13	10	7
1978	15	209	306	204	191	125	49	20	14	10	8	10
1979	10	9	42	181	102	137	34	13	18	8	8	17
1980	27	133	223	82	63	247	80	21	14	11	11	13
1981	69	122	149	198	178	82	24	13	10	8	10	7
1982			105	146	208	103	49	17	12	9	9	77
1983	89	248	164	190	264	136	111	31	21	16	11	7
1984	7	231	102	131	176	236	121	30	18	13	14	21
1985	56	139	318	85	152	158	60	21	14	12	10	8
1986	55	69	33	77	138	123	230	87	21	16	9	15
1987	44	39	150	65	182	103				10	11	17
1988	25	253	163	300	295	165	101	32	29	15	14	8
1989	16	41	105	132	248	197	202	33	18	12	12	65
1990	145	141	255	103	226	184	170	63	22	18	23	10
1991	86	551	233	94	117	148	137	79	40	23	22	17
Number	26	26	27	27	27	27	26	25	26	27	27	27
Minimum	7	9	33	65	63	51	19	9	7	7	5	6
Mean	56	131	184	161	176	142	93	38	20	13	11	15
Maximum	229	551	355	300	295	247	230	140	51	23	23	77

Table A.7

MEAN MONTHLY DISCHARGE
Gauge 67 DHALAI R. at KAMALGANJ

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	73	62	59	77	58	32	46	19	8	5	5	3
1965	3								5	4	2	3
1966	11	46	101	98	78	50	50	12	14	10		13
1967	40	34	44	53	40	34	55	8	6	4	3	3
1968	16	31	97	100	76	62	18	8	6	4	3	4
1969	28	8	78	27	61	26	24	6	4	3	3	2
1970	4	9	31	49	52	25	33	8	5	3	4	
1971												
1972	3	7	31	25	50	13	8	4	3	3	2	2
1973							29	43	20	8	4	5
1974	27	54	90	81	54	61	31	10	7	5	3	2
1975	10	15	41	30	43	37	19	10	4	3	2	2
1976	4	38	108	105	69	56	17	8	6	5	4	3
1977	49	74	121	41	62	33	24	25	9	6	4	3
1978	4	73	95	67	61	33	14	8	6	5	4	4
1979	3	2	10	39	40	47	10	5	6	3	2	4
1980	5	88	86	61	37	92	25	10	7			
1981												
1982	11	25	35	59	54	40	12	5	4	3	3	29
1983	28	90	55	42	81	63	39	10	7	6	4	2
1984	2	71	37	39	40	75	31	10	7	5	6	8
1985	20			31	43	49	16	11	6	4	3	2
1986	22	28	9	16	36	52	85	36	8	7		
1987	14	10	40	35	83	50	30	9	6	3	3	4
1988	4	73	63	71	88	46	46	12	11	6	5	4
1989	5	23	73	59	49	40	51	10	7	5		
1990		72	99	28	65	67	39	21	11	6	8	4
1991	46	218	135	26	28	53	60	30	18	10	10	5

Number	24	23	23	24	24	24	25	25	26	25	22	22
Minimum	2	2	9	16	28	13	8	4	3	3	2	2
Mean	18	50	67	52	56	47	32	14	8	5	4	5
Maximum	73	218	135	105	88	92	85	43	20	10	10	29

Table A.8

MEAN MONTHLY WATER LEVEL
Gauge 201 MANU R. at MANU R. BRIDGE

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	15.83	15.29	15.53	15.73	15.26	15.00	15.07	13.73	13.27	13.03	13.07	12.89
1965	12.98	13.23	15.55	15.37	15.52	14.96	14.29	13.62	13.12	12.97	12.82	12.79
1966	12.96	14.23	16.13	15.98	15.66	15.54	14.94	13.46	13.54	13.22	12.94	13.22
1967	14.10	14.55	14.45	15.64	15.55	14.90	14.93	13.30	13.02	12.85	12.80	12.75
1968	13.27	13.91	15.71	16.06	15.84	15.10	13.76	13.25	13.03	12.96	12.85	12.85
1969	13.73	13.28	15.08	14.57	15.52	14.42	14.08	13.14	12.90	12.82	12.81	12.75
1970	12.75	12.91	14.49	15.50	15.36	14.33	14.40	13.48	13.00	12.84	12.78	12.63
1971	14.01	14.40	14.76				13.92	13.54		12.82	12.77	12.69
1972	13.41	13.87	14.39	14.26	15.01	13.87	13.17	12.86	12.78	12.77	12.70	12.76
1973	13.13	15.56	16.22	15.82	15.61	15.02	14.32	14.88	13.69	13.11	12.93	12.90
1974	13.78	14.71	16.26	15.97	15.36	15.59	14.49	13.51	13.25	13.02	12.92	12.79
1975	13.47	13.61	14.94	14.55	14.91	15.28	14.25	13.95	13.15	12.97	12.90	12.90
1976	13.16	14.11	16.86	16.31	15.43	15.51	13.68	13.21	13.02	12.88	12.86	12.73
1977	15.52	15.70	16.27	14.80	15.43	14.65	14.39	13.83	13.16	12.99	12.88	12.77
1978	13.00	15.50	16.70	15.99	15.73	15.06	13.88	13.18	13.00	12.88	12.80	12.84
1979	12.83	12.87	13.47	15.23	14.62	14.77	13.55	13.05	13.15	12.86	12.80	13.06
1980	13.17	14.96	16.03	14.47	14.08	16.22	14.39	13.35	13.07	12.99	12.93	12.98
1981	13.99	14.53	14.98	15.70	15.40	14.29	13.34	13.04	12.94	12.84	12.87	12.76
1982	13.80	14.01	14.64	15.15	15.88	14.81	13.85	13.14	13.00	12.94	12.86	13.90
1983	14.09	16.17	15.32	15.71	16.57	15.01	14.75	13.44	13.21	13.07	12.92	12.78
1984	12.76	15.51	14.50	14.69	15.24	15.85	14.70	13.49	13.17	13.02	13.01	13.04
1985	13.72	14.54	16.57	14.33	14.85	14.97	13.84	13.15	12.99	12.91	12.81	12.71
1986	13.59	13.88	13.33	14.11	14.47	14.68	15.50	14.13	13.22	13.03	12.89	12.98
1987	13.45	13.55	14.79	13.95	15.32	14.41	13.82	13.23	12.96	12.83	12.83	12.94
1988	13.03	15.41	15.02	16.17	16.06	14.96	14.49	13.27	13.19	12.88	12.88	12.68
1989	12.72	13.32	14.24	14.52	15.46	15.00	15.17	13.39	13.05	12.90	12.85	13.48
1990	14.61	14.65	15.71	14.45	15.29	15.03	14.98	13.82	13.29	13.17	13.27	12.94
1991	14.06	17.19	15.96	14.57	14.77	14.98	14.94	14.26	13.62	13.27	13.22	13.09

Number	28	28	28	27	27	27	28	28	27	28	28	28
Minimum	12.72	12.87	13.33	13.95	14.08	13.87	13.17	12.86	12.78	12.77	12.70	12.63
Mean	13.60	14.48	15.28	15.17	15.34	14.97	14.32	13.49	13.14	12.96	12.89	12.91
Maximum	15.83	17.19	16.86	16.31	16.57	16.22	15.50	14.88	13.69	13.27	13.27	13.90

Table A.9

MEAN MONTHLY WATER LEVEL
Gauge 67 DHALAI R. at KAMALGANJ

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	18.68	18.51	18.41	18.80	18.48	17.92	18.19	17.57	17.25	17.12	17.11	17.01
1965	17.06	17.20	18.41	18.96	18.40	17.99	17.52	17.36	17.07	17.03	16.92	16.98
1966	17.07	17.94	18.97	18.94	18.64	18.32	18.19	17.42	17.33	17.31	17.06	17.35
1967	17.90	17.95	18.14	18.34	18.13	17.94	18.32	17.25	17.15	17.03	16.98	16.98
1968	17.34	17.69	18.92	18.87	18.65	18.47	17.61	17.28	17.16	17.06	16.99	17.00
1969	17.56	17.22	18.64	17.81	18.36	17.76	17.66	17.21	17.08	17.05	17.20	16.99
1970	17.02	17.19	17.94	18.32	18.36	17.81	17.97	17.26	17.10	17.02	17.07	
1971					17.88	17.76					17.09	16.94
1972	16.96	17.17	17.91	17.75	18.39	17.46	17.23	17.00	16.95	16.92	16.87	16.88
1973	17.00	18.97	18.93	18.81	18.74		17.65	17.89	17.48	17.12	16.96	16.96
1974	17.72	18.22	18.85	18.74	18.31	18.37	17.86	17.34	17.22	17.11	17.03	16.93
1975	17.23	17.44	18.10	17.76	18.17	18.07	17.60	17.37	17.11	17.00	16.95	16.91
1976	16.94	17.80	18.92	18.95	18.40	18.16	17.49	17.24	17.13	17.04	16.99	16.90
1977	18.11	18.43	19.06	18.04	18.29	17.88	17.66	17.61	17.25	17.15	17.05	16.96
1978	17.06	18.70	19.21	18.74	18.65	18.11	17.58	17.32	17.20	17.13	17.06	17.07
1979	17.10	17.03	17.39	18.17	18.20	18.29	17.43	17.20	17.25	17.08	17.03	17.13
1980	17.15	18.77	18.81	18.54	18.19	19.02	17.80	17.28	17.13	17.07	17.04	17.10
1981	17.89	18.21	17.98	18.26	17.91	17.66	17.31	17.02	16.94	16.89	16.88	16.81
1982	17.26	17.63	17.88	18.53	18.44	18.13	17.29	17.02	16.94	16.86	16.85	17.62
1983	17.66	18.81	18.20	18.22	18.98	18.57	18.11	17.34	17.20	17.11	17.02	16.92
1984	16.88	18.70	18.05	18.03	18.14	18.77	17.89	17.31	17.13	17.05	17.08	17.06
1985	17.49	18.03	19.07	18.05	18.09	18.19	17.54	17.19	17.07	17.02	16.93	16.85
1986	17.60	17.69	17.14	17.39	17.87	18.17	18.49	17.72	17.09	16.97	16.86	16.91
1987	17.16	17.13	17.80	17.64	18.50	17.97	17.70	17.25	17.07	16.95	16.94	17.04
1988	16.98	18.41	18.25	18.83	18.71	18.33	18.08	17.34	17.28	17.03	16.95	16.86
1989	16.87	17.52	18.31	18.14	18.22	17.95	18.12	17.14	16.97	16.88	16.85	17.19
1990	17.77	18.07	18.56	17.66	18.17	18.31	18.06	17.33	17.10	17.04	17.12	16.91
1991	17.79	19.68	18.89	17.69	17.73	18.15	18.27	17.65	17.32	17.08	17.08	16.86

Number	27	27	27	27	28	27	27	27	27	27	28	27
Minimum	16.87	17.03	17.14	17.39	17.73	17.46	17.23	17.00	16.94	16.86	16.85	16.81
Mean	17.38	18.00	18.40	18.30	18.32	18.13	17.80	17.33	17.15	17.04	17.00	17.00
Maximum	18.68	19.68	19.21	18.96	18.98	19.02	18.49	17.89	17.48	17.31	17.20	17.62

Table A.10

MEAN MONTHLY WATER LEVEL
Gauge 202 MANU R. at MOULVIBAZAR

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	9.35	9.20	9.68	9.87	9.69	9.17	9.09	7.85	7.09	6.79	6.79	6.52
1965	6.63	7.01	9.36	9.44	9.76	9.07	8.32	7.74	7.19	6.88	6.49	6.51
1966	6.67	7.68	10.26	10.44	9.80	9.84	8.93	7.07	6.85	6.37	6.11	6.33
1967	7.40	7.88	8.32	9.73	9.47	8.64	8.96	6.60	6.29	6.09	5.99	5.97
1968	6.53	7.32	9.78	10.43	10.10	9.40	7.71	6.78	6.48	6.38	6.26	6.27
1969	7.27	6.65	8.91	9.04	9.90	8.69	7.60	6.40	6.12	5.99	5.94	5.86
1970	5.97	6.38	8.51	9.80	9.77	8.55	8.71	6.99	6.28	6.05	5.97	5.79
1971	6.95		8.45	8.34	8.78	9.31	8.16	7.07		6.12	6.14	5.97
1972	6.67	7.56	8.57	9.03	9.43	8.02	6.70	6.17	6.02	5.91	5.83	5.94
1973	6.57	9.55	10.24	9.72	9.75	9.11	8.05	8.12	7.27	6.56	6.33	6.30
1974	7.58	8.62	10.15	10.35	9.73	9.69	8.64	7.38	6.94	6.66	6.54	6.33
1975	7.09	7.59	8.79	8.69	9.55	9.44	8.43	7.86	6.93	6.66	6.57	6.53
1976	6.76	8.06	10.89	10.75	9.67	9.53	7.77	6.99	6.74	6.57	6.52	6.42
1977	9.45	10.03	10.72	9.31	9.58	8.58	8.15	7.53	6.70	6.46	6.29	6.13
1978	6.46	9.30	10.91	10.01	9.75	8.98	7.87	6.95	6.66	6.49	6.38	6.41
1979	6.41	6.51	7.53	9.55	8.84	9.35	7.71	6.70	6.71	6.32	6.21	6.61
1980	6.70	9.21	10.11	9.05	8.70	10.09	8.54	7.15	6.63	6.50	6.41	6.43
1981	7.97	8.42	9.07	9.74	9.65	8.90	7.20	6.57	6.39	6.26	6.31	6.16
1982	7.17	7.81	8.61	9.68	10.12	8.85	7.57	6.64	6.40	6.30	6.20	7.53
1983	7.76	10.49	9.35	9.87	11.03	9.58	8.82	7.09	6.56	6.42	6.21	5.90
1984	5.99	9.77	9.04	9.04	9.19	10.15	8.55	7.00	6.51	6.38	6.33	6.45
1985	7.48	8.26	11.24	8.92	8.91	9.08	7.74	6.59	6.15	5.78	5.78	5.72
1986	7.23	7.40	6.76	8.08	8.62	8.85	9.92	7.96	6.55	6.00	5.85	6.10
1987	6.94	7.16	9.12	8.56	10.05	8.94	8.25	6.76	6.16	5.74	5.92	6.28
1988	6.29	9.24	9.53	10.63	10.17	9.61	8.71	6.99	6.79	5.85	6.00	5.82
1989	6.10	7.45	8.60	9.07	10.29	9.34	9.45	7.19	6.32	5.89	5.95	6.70
1990	8.36	8.65	10.17	8.87	9.54	9.24	9.29	7.52	6.68	6.39	6.81	6.11
1991												

Number	27	26	27	27	27	27	27	27	26	27	27	27
Minimum	5.97	6.38	6.76	8.08	8.62	8.02	6.70	6.17	6.02	5.74	5.78	5.72
Mean	7.10	8.20	9.36	9.48	9.62	9.18	8.33	7.10	6.59	6.29	6.23	6.26
Maximum	9.45	10.49	11.24	10.75	11.03	10.15	9.92	8.12	7.27	6.88	6.81	7.53

Table A.11

MEAN MONTHLY DISCHARGE
Gauge 173 KUSHIYARA R. at SHEOLA

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	525	720	1249	1383	1112	1146	755	297	152	92	146	58
1965	111	277	915	1147	1202	951	789	346	148	100	69	58
1966	69	312	1161	1198	1138	1155	902	299	234	134	91	99
1967	165	440	806	1552	1012	745	818	186	104	69	52	69
1968	139	306	1048	1731	1685	1079	499	207	109	73	61	56
1969	223	166	1187	1624	1754	785	356	156	89	65	61	83
1970	224	419	982	1633	1517	1145	1104	337	133	80	68	
1971												
1972	188	544	978	1303	1165	708	330	128	83	59	45	55
1973	162	747	1524	1456	1939	1129	652	721	249	137	89	98
1974	321	476	1498	2004	1540	1560	941	286	183	111	92	70
1975	166	392	813	1554	1342	1397	1041	652	175	112	97	197
1976	318	352	1751	2021	1611	1196	445	172	140	95	87	82
1977	804	961	1780	1818	1561	811	457	309	131	96	67	49
1978	70	493	1267	1561	1618	1227	535	165	100	65	51	64
1979	89	272	419	1319	905	1438	610	163	137	75	64	138
1980	263	721	1537	1546	1275	1221	915	284	132	108	95	162
1981	363	498	956	1536	1322	1415	328	112	71	46	51	37
1982	423	401	1137	2029	1247	679	475	152	96	84	62	445
1983	870	1204	1192	1992	2188	1903	915	265	134	126	70	40
1984	108	1039	952	1601	974	1559	646	217	136	99	102	208
1985	545	578	2135	1722	1554	1678	663	210	125	102	84	67
1986	299	291	465	1251	1257	1229	1487	376	167	119	87	123
1987	290	268	1255	1512	1678	1858	747	393	149	108	84	138
1988	174	978	1147	1946	2146	1688	1139	213	201	109	109	84
1989	376	808	951	1800	2170	1753	1706	346	167	132	115	183
1990	857	833	2126	2141	2268	1404	1436	367	198	135	154	121
1991	441	2265	2252	1398	1603	1691	1205	508			162	205

	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Number	27	27	27	27	27	27	27	27	26	26	27	26
Minimum	69	166	419	1147	905	679	328	112	71	46	45	37
Mean	318	621	1240	1621	1510	1280	811	291	144	97	86	115
Maximum	870	2265	2252	2141	2268	1903	1706	721	249	137	162	445

Table A.12

MEAN MONTHLY DISCHARGE
Gauge 175.5 KUSHIYARA R. at SHERPUR

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964												
1965												
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982	812	1177	931	1804	1823	1241	891	248	133	89	71	579
1983	1202	2124	1773	2384	2594	2512	1628	558	198	158	103	62
1984	139	1545	1846	1779	1386	1676	1209	453	204	131	124	276
1985	991				1759	1902	1050	331	167	136	110	82
1986	479	627	573	1387	1600	1643	2180	1143	280	184	106	200
1987	584	654	1620	1775	2129	2176	1498	432	204	142	118	179
1988	291	1682	1845	2449	2463	2409	1668	583	402	168	139	88
1989	465	1452	1693	1952	2431	2183	2210	1044	269	166	122	245
1990	1340	1549	2557	2525	2465	1917	2386	1047	331	230	255	154
1991	1001	3240	3227	2080	1715	2017	1799	998	426	326	210	246

Number	10	9	9	9	10	10	10	10	10	10	10	10
Minimum	139	627	573	1387	1386	1241	891	248	133	89	71	62
Mean	730	1561	1785	2015	2036	1968	1652	684	261	173	136	211
Maximum	1340	3240	3227	2525	2594	2512	2386	1143	426	326	255	579

Table A.13

MEAN MONTHLY WATER LEVEL
Gauge 173 KUSHIYARA R. at SHEOLA

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	9.43	10.76	12.44	12.95	12.24	12.37	11.16	7.79	6.05	5.22	5.91	4.66
1965	5.38	7.25	11.36	12.49	12.65	11.74	10.91	7.89	5.84	5.25	4.83	4.66
1966	5.02	7.44	13.08	13.29	12.98	13.07	11.67	7.66	7.19	5.98	5.39	5.47
1967	6.48	9.15	10.60	13.07	11.96	11.09	10.91	6.78	5.62	5.17	4.92	5.17
1968	6.13	7.76	11.95	13.27	13.26	12.24	9.55	7.06	5.75	5.18	4.92	4.85
1969	6.66	6.33	11.53	13.06	13.31	11.19	9.13	6.59	5.55	5.17	5.10	5.46
1970	7.26	9.02	11.41	12.98	12.77	12.04	11.62	8.48	6.14	5.30	5.09	4.48
1971	6.85		11.64	12.89	12.94	12.41		8.82	5.85	4.79	5.04	4.73
1972	6.57	9.65	10.90	12.46	12.12	10.36	8.24	5.78	5.06	4.65	4.39	4.57
1973	6.08	10.22	12.62	12.44	13.51	11.73	10.06	10.28	7.41	5.61	4.91	5.07
1974	7.93	9.10	12.47	13.66	12.75	12.82	11.09	7.71	6.42	5.24	4.91	4.47
1975	5.84	8.41	10.66	12.71	12.30	12.45	11.35	9.78	6.25	5.20	4.94	6.25
1976	7.36	8.16	13.09	13.83	13.01	11.89	8.76	6.36	5.76	4.88	4.69	4.60
1977	10.51	11.40	13.19	13.24	12.81	10.86	9.31	7.94	5.76	5.16	4.58	4.23
1978	4.68	8.41	11.88	12.52	12.60	11.83	9.47	6.41	5.24	4.60	4.34	4.56
1979	4.86	7.41	8.61	12.32	11.18	12.47	9.74	6.12	5.69	4.59	4.41	5.67
1980	6.42	10.75	12.90	12.76	12.28	12.01	11.28	7.66	5.64	5.22	4.80	5.41
1981	7.81	8.46	11.44	12.64	12.38	12.48	8.42	5.88	5.02	4.52	4.65	4.30
1982	9.28	9.23	10.19	13.16	12.27	10.39	9.02	5.83	4.83	4.45	4.20	7.49
1983	10.61	12.09	11.90	13.50	13.63	13.25	11.38	7.53	5.92	5.50	4.73	4.17
1984	5.12	10.59	11.64	12.96	11.39	12.38	9.89	6.65	5.45	4.96	4.97	6.02
1985	9.11	8.20	13.70	12.97	12.43	12.33	9.43	6.37	5.43	5.03	4.69	4.41
1986	7.01	7.17	7.79	11.66	11.53	11.60	12.08	8.97	6.02	5.31	4.81	5.24
1987	7.96	7.49	11.54	12.39	12.91	12.90	10.35	7.24	5.66	5.03	4.67	5.46
1988	5.56	10.47	11.40	13.30	13.42	12.89	11.40	6.90	6.48	5.33	5.23	4.79
1989	7.13	9.96	11.07	13.13	13.73	13.02	12.66	8.16	6.16	5.48	5.21	5.98
1990	10.18	10.53	13.35	13.24	13.51	12.14	11.89	8.21	6.50	5.96	5.95	5.35
1991	8.42	13.42	13.58	12.35	12.85	12.88	11.73	8.84	6.80	6.20	5.69	6.03

Number	28	27	28	28	28	28	27	28	28	28	28	28
Minimum	4.68	6.33	7.79	11.66	11.18	10.36	8.24	5.78	4.83	4.45	4.20	4.17
Mean	7.20	9.22	11.71	12.90	12.67	12.10	10.46	7.49	5.91	5.18	4.93	5.13
Maximum	10.61	13.42	13.70	13.83	13.73	13.25	12.66	10.28	7.41	6.20	5.95	7.49

Table A.14

MEAN MONTHLY WATER LEVEL
Gauge 175.5 KUSHIYARA R. at SHERPUR

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964												
1965												
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982	5.44	6.26	6.47	8.56	8.47	7.46	6.31	3.57	2.56	2.18	1.97	4.19
1983	6.30	7.99	7.55	8.55	8.83	8.77	7.80	5.33	3.45	3.08	2.39	1.99
1984	2.74	6.84	7.88	8.27	7.88	8.28	7.24	4.72	3.16	2.59	2.51	3.25
1985	5.90	5.38	8.70	8.37	8.03	7.82	6.77	4.43	3.34	2.95	2.62	2.40
1986	4.35	5.10	4.67	7.31	7.65	7.77	8.16	6.65	3.93	3.02	2.59	2.94
1987	5.05	5.12	7.49	8.06	8.65	8.26	7.57	4.97	3.43	2.78	2.45	3.18
1988	3.41	6.82	8.11	8.88	8.67	8.70	7.73	4.91	4.37	3.03	2.86	2.48
1989	3.89	6.76	7.57	8.38	8.97	8.50	8.31	6.19	4.27	3.50	3.22	3.96
1990	6.65	7.37	8.53	8.36	8.55	8.01	8.14	6.10	4.92	4.52	4.39	3.66
1991	6.24	8.73	8.89	8.36	8.11	8.27	7.91	6.36	5.00	4.47	3.79	4.00

Number	10	10	10	10	10	10	10	10	10	10	10	10
Minimum	2.74	5.10	4.67	7.31	7.65	7.46	6.31	3.57	2.56	2.18	1.97	1.99
Mean	5.00	6.64	7.59	8.31	8.38	8.18	7.59	5.32	3.84	3.21	2.88	3.21
Maximum	6.65	8.73	8.89	8.88	8.97	8.77	8.31	6.65	5.00	4.52	4.39	4.19

Table A.15

MEAN MONTHLY WATER LEVEL
Gauge 174 KUSHIYARA R. at FENCHUGANJ

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	7.52	9.01	9.76	10.20	10.03	9.77	8.86	6.63	4.04	3.09	3.67	2.61
1965	3.45	5.41	8.61	9.71	10.11	9.43	8.68	6.42	3.71	3.14	2.70	2.60
1966	3.07	5.31	10.00	10.45	10.00	10.03	9.16	5.90	4.40	3.52	2.90	3.05
1967	4.52	7.56	8.20	10.06	9.60	8.86	8.77	5.12	3.47	2.96	2.66	2.84
1968	4.06	5.48	9.41	10.43	10.37	9.84	7.99	5.10	3.34	2.75	2.55	2.73
1969	4.78	4.66	8.36	10.07	10.24	9.40	7.41	4.59	3.18	2.74	2.64	3.02
1970	4.97	6.58	8.80	10.01	10.22	9.36	9.39	6.81	3.96	2.99	2.72	2.27
1971	4.93	6.25	8.22	9.40	9.79	10.08	8.93	6.79	4.07	3.18	3.16	2.68
1972	4.42	7.60	8.76	9.98	9.75	8.73	6.75	3.92	2.89	2.50	2.28	2.55
1973	4.14	8.42	9.68	9.90	10.23	9.44	7.92	7.78	5.83	3.87	3.17	3.18
1974	6.41	7.82	9.31	10.46	10.10	9.93	8.85	6.45	4.37	3.25	2.99	2.69
1975	3.89	6.34	8.40	9.16	9.94	9.68	8.91	7.56	4.57	3.35	3.06	4.59
1976	5.32	6.44	9.91	10.71	10.07	9.50	7.31	4.86	3.94	3.00	2.66	2.86
1977	8.34	9.21	10.23	10.17	9.67	8.86	7.58	6.09	4.29	3.51	2.97	2.71
1978	3.09	6.68	9.57	9.83	9.83	9.14	7.76	5.20	3.83	3.19	2.93	3.09
1979	3.39	5.28	6.67	9.48	9.02	9.73	8.28	4.85	3.96	3.02	2.77	3.65
1980	4.37	8.74	9.82	9.93	9.69	9.33	9.07	6.58	4.19	3.58	3.36	3.62
1981	5.90	6.55	9.01	9.53	9.86	9.88	7.04	4.18	3.36	2.93	2.98	2.79
1982	6.82	7.68	7.78	10.29	10.03	8.59	7.23	4.14	3.16	2.83	2.65	5.12
1983	7.88	9.75	9.22	10.37	10.55	10.46	9.17	5.96	4.05	3.69	2.99	2.55
1984	3.29	8.11	9.48	9.77	9.14	9.72	8.38	5.38	3.78	3.27	3.14	4.00
1985	7.14	6.29	10.54	10.15	9.52	9.34	7.91	4.81	3.72	3.31	2.97	2.69
1986	5.03	5.80	5.46	8.62	9.00	9.21	9.69	7.61	4.50	3.52	3.12	3.59
1987	6.01	6.09	9.13	9.69	10.25	9.89	8.94	5.88	3.93	3.26	2.93	3.72
1988	4.04	7.93	9.52	10.47	10.32	10.33	9.12	5.45	4.94	3.55	3.38	3.02
1989	4.72	7.99	9.07	10.14	10.83	10.34	10.03	6.93	4.55	3.74	3.44	4.24
1990	7.60	8.57	10.31	10.14	10.34	9.54	9.76	6.80	5.18	4.69	4.64	3.93
1991	6.74	10.44	10.80	10.02	9.69	9.73	9.34	7.19	5.37	4.78	4.08	4.34

Number	28	28	28	28	28	28	28	28	28	28	28	28
Minimum	3.07	4.66	5.46	8.62	9.00	8.59	6.75	3.92	2.89	2.50	2.28	2.27
Mean	5.21	7.21	9.07	9.97	9.94	9.58	8.51	5.89	4.09	3.33	3.05	3.24
Maximum	8.34	10.44	10.80	10.71	10.83	10.46	10.03	7.78	5.83	4.78	4.64	5.12

Table A.16

MEAN MONTHLY WATER LEVEL
Gauge 175 KUSHIYARA R. at MANUMUKH

Year	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1964	6.54	7.78	8.31	8.64	8.61	8.34	7.64	5.99	3.44	2.58	3.09	2.30
1965	2.89	4.75	7.38	8.26	8.66	8.08	7.58	5.70	3.10	2.59	2.28	2.13
1966	2.56	4.52	8.55	9.02	8.39	8.44	7.68	5.08	3.71	2.87	2.27	2.46
1967	3.71	6.42	7.12	8.68	8.26	7.65	7.60	4.56	2.89	2.39	2.17	2.28
1968	3.37	4.60	8.09	9.05	8.94	8.49	7.03	4.56	2.89	2.24	2.04	2.08
1969	4.04	4.13	7.18	8.59	8.75	8.22	6.55	4.08	2.28	1.62	2.22	2.49
1970	4.08	5.61	7.71	8.65	8.90	8.14	8.11	6.04	3.42	2.40	2.17	1.85
1971	4.15	4.96	6.91		8.37	7.81	7.77	6.10			2.66	2.25
1972	3.70	6.40	7.52	8.56	8.40	7.57	5.95	3.42	2.42	2.08	1.94	2.13
1973	3.47	7.23	8.31	8.61	8.88	8.25	7.06	6.66	5.08	3.40	2.76	2.65
1974	5.42	6.83	8.01	9.12	8.87	8.59	7.67	5.72	3.74	2.76	2.52	2.25
1975	3.35	5.52	7.34	7.88	8.64	8.42	7.83	6.46	4.05	2.86	2.59	3.75
1976	4.37	5.51	8.61	9.34	8.61	8.15	6.45	4.44	3.52	2.59	2.28	2.55
1977	7.12	7.90	8.74	8.68	8.37	7.81	6.80	5.61	4.07	3.30	2.82	2.59
1978	2.88	5.93	8.38	8.53	8.51	7.97	6.91	4.90	3.49	2.82	2.59	2.39
1979												
1980												
1981												
1982	5.63	6.49	6.37	8.86								
1983												
1984												
1985												
1986												
1987												
1988												
1989												
1990												
1991												

Number	16	16	16	15	15	15	15	15	14	14	15	15
Minimum	2.56	4.13	6.37	7.88	8.26	7.57	5.95	3.42	2.28	1.62	1.94	1.85
Mean	4.20	5.91	7.78	8.70	8.61	8.13	7.24	5.29	3.43	2.61	2.43	2.41
Maximum	7.12	7.90	8.74	9.34	8.94	8.59	8.11	6.66	5.08	3.40	3.09	3.75

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Table A.17

Water Bodies in Manu River Basin

Thana	Open Water Bodies (Dry Season) Area[1] (ha)	Closed Water Bodies			
		No. of Ponds	Pond Area[2] (ha)	Average Pond Size (ha)	Pond Conc (nos/km2)
Moulvi Bazar	56	760	55	0.07	9
Rajnagar	1034	4030	300	0.08	12
Kamalganj	94	5580	420	0.08	14
Kulaura	36	735	45	0.06	10
Total	1220	11,105	820	0.07	

Source:[1] CIDA (1989); [2] BFRSS, 1986

Table A.18

Major Jalmohals in the MRIP Area

Kawadighi Haor		Daldala Haor
Beels	**Rivers**	**Beels**
Balita	Koradair	Daldala
Bhabanaga	Machuakhali	Keola
Bodirkhara	Burijuri Beel	Pratapir
Boldabolchira		
Erali Pukuria		
Goali		
Hawa		
Hawagulaya		
Jibinia		
Majarband		
Matikura		
Melagor		
Mukkanchandi		
Peala		
Shalkatua		
Singua		

Table A.19

Major Fish Species Present in the Manu River Basin

Baramach		Chotomach			
Air	Rita	Bacha	Chapila	Gutum	Napit
Boal	Rui	Cailla	Chela	Icha	Pabda
Catla	Shoal	Baim	Cheng	Kaikka	Potka
Chital		Bajari	Darkina	Kajali	Puti
Gazar		Bata	Dhela	Kanpona	Sarputi
Ghagot		Batashi	Dilon Chuki	Kechki	Singi
Ghonia		Bheda	Fali	Khoilsa	Taki
Ilish		Boicha	Faring	Koi	Tara Baim
Kalibaus		Chaitya	Garua	Magur	Tengra
Mrigel		Chanda	Gulsha	Mola	Titputi

Table A.20

Duars in the Kushiyara River between Fenchuganj and Manumukh

Name of Duar**	Dry Season Water Depth (m)	Baramach encountered	Chotomach encountered
Dekapurar	10-11	LC, MC, C	B, Ch, Ca, L
Sonapurar	13-14	LC, MC, C	B, Ch, Ca, L
Sadapurar	10-11	LC, MC, C	B, Ch, Ca, L
Azampurar	10-11	LC, MC, C	B, Ch, Ca, L
Sheikhpurar	10-11	LC, MC, C	B, Ch, Ca, L
Islampurar	11-12	LC, MC, C	B, Ch, Ca, L
Berkurir	19*	LC, MC	B, Ch, Ca, L
Shahpurar	15*	LC, MC	B, Ch, Ca, L
Korchar	17*	LC, MC	B, Ch, Ca, L
Chorkir	21*	LC, MC, C	B, Ch, Ca, L
Jalalpurar	18*	LC, MC	B, Ch, Ca, L
Jamirkonar	17*	LC, MC	B, Ch, Ca, L
Poradair	12*	LC, MC	B, Ch, Ca, L
Poradair	17*	LC, MC	B, Ch, Ca, L
Monumukh	14*	LC, MC	B, Ch, Ca, L

Baramach:
MC-Major Carp; LC-Large Catfish; C-Chital

Chotomach:
B-Bacha; Ca-Chapila; Ch-Chela; L-Saso

* Echo sounding data (all other depths from interviews with fishermen)
** These duars are all proposed as fish sanctuaries

Source: NERP, 1992

ANNEX B

ENGINEERING ANALYSES

ANNEX B: ENGINEERING ANALYSES

B1 Rainfall and Flood Discharges Trend Analyses

Trend analyses have been carried out to identify the effects on river flood discharges and water levels of the increasing rainfall observed in recent years and of the confinement effect of the MRP embankment.

B1.1 Annual Flood Discharges and Causative Rainfall

The annual maximum mean daily discharges of the Manu at Manu Railway Bridge (Gauging Station No. 201), and of the Dhalai at Kamalganj (Gauging Station No. 67), are listed in Table B2.1 and plotted chronologically in Figure 16.

From the dates of occurrence given in Table B2.1 it is apparent that the annual floods at the two gauging stations occurred (see asterisks in Table B2.1):

- 3 times on the same day of the year (1972, 1989, 1991)
- 4 times on consecutive days (1967, 1904, 1985, 1987)
- 3 times within two days (1969, 1970, 1974)

In the other 17 years of this 27 year record the annual floods of the two rivers occurred weeks, even months, apart. This indicates that most floods are caused by isolated thunderstorms which are not large enough in area to cover both catchments completely and simultaneously, but that in 37% of years larger area storms occur causing both rivers to flood simultaneously. It is noteworthy that the annual floods of both rivers in 1991 occurred on 6 May, one week after the hurricane of 29 April 1991 devastated coastal areas of Bangladesh; it is possible that these floods were caused by the remnant of that hurricane. Thus, it is apparent that the smaller annual floods are caused by cumulonimbus clouds which generate intense rainfall for an hour or two over areas of 100 to 200 km^2, but the larger annual floods are caused by nimbostratus clouds which generate much rainfall of moderate intensity for several days over much larger areas. Cumulonimbus clouds are associated with thunderstorms, and nimbostratus with deep depressions including degenerate hurricanes which have moved inland; in severe storms it is quite possible for cumulonimbus to occur in the midst of nimbostratus. Among the 10 larger flood events listed in Table B2.1 it is noteworthy that 7 occurred in July/August, and 3 in May; the former were therefore probably caused by normal depressions of the monsoon season, and the latter by degenerate hurricanes of the pre-monsoon season. Since hurricanes affecting Bangladesh normally follow a northeasterly course, it is to be expected that they will penetrate into the Northeast Region before in-filling completely. Also to be noted in Table B2.1 is the lull in large storm occurrence during 1975/1983 which may correspond with a trough in normal climatic activity; before 1975 there were five large storms, and the other five occurred after 1983.

There is no doubt, however, that this cyclic activity has been over-ridden by either the arrival of the peak of some longer-term climatic cycle, or of a permanent (monoclinal) change in climate or in some other aspect of the environment. As can be seen in Figure 16 the floods have increased relentlessly throughout the 27-year period, and show no evidence of having reached a peak; the floods of 1993, when relevant discharge data are available, will no doubt reinforce the upward trends evident in this figure. The least-squares trend lines shown in Figure 16 enable average rates of increase in flood discharges to be established with the following results:

Station	Trend Line Discharge (m^3/s) 1964	1991	Ratio 1991/1964
Dhalai/Kamalganj	183	311	1.70
Manu/Manu RB	457	759	1.66
Manu/Moulvi Bazar	668	1159	1.74
3-Station Average			1.70

Thus, flood discharges have increased in magnitude by a factor of about 1.70 over the last 27 years. The question then is: What has caused this increase in discharge?

The fact that the increase is evident at Kamalganj, upstream of where there is no water resource project to influence flows, and at Manu Railway Bridge upstream of where there are only two relatively minor water resource projects, immediately suggests that an increase in rainfall is the cause. In developing 30-year mean rainfall maps for the Northeast Region and its surroundings NERP found that regional annual rainfall increased 7% in the period 1964-90. Figures 17 and 18 show the trends apparent in annual rainfall at the local rain gauges in the Manu-Dhalai river basin, and the results of least-squares trend analyses are as follows:

Station	Trend Line Annual Rainfall (mm) 1964	1989	Ratio 1989/1964
Chandbagh	2957	3422	1.16
Langla	2456	3146	1.28
Kamalganj	2473	2567	1.04
Moulvi Bazar	2633	2787	1.06
Manumukh	3106	2765	0.89
Srimangal	2339	2596	1.11
5-Station Average*			1.13

*Manumukh Excluded

The gauge at Manumukh has been operated sporadically and some reservation must attach to the use of its data. Discounting the Manumukh result, it is apparent that local annual rainfall increased 13% on average during 1964-89. This increase is not as great as that observed in the case of floods in the river basin (70%) due to the fact that floods are caused by the rainfall of individual storms lasting for one to several days rather than by the annual rainfall. More meaningful results can therefore be obtained by carrying out the trend analyses on annual maximum 1-day and 2-day rainfalls as shown in Figures 19 through 22 for Langla, Kamalganj and Moulvi Bazar. As can be seen in these figures there has also been a relentless increase in storm rainfall throughout the last 27 years; the events of recent years do, however, dominate this increase. The results of the least-squares trend analyses pertaining to these figures are:

Station	Trend Line Annual Maximum Rainfall (mm) 1964	1989	Ratio 1989/1964
For 1 Day Rainfalls:			
Langla	102	210	2.06
Kamalganj	122	171	1.40
Moulvi Bazar	113	185	1.64
3-Station Average			1.70
For 2 Day Rainfalls:			
Langla	122	325	2.66
Kamalganj	174	224	1.29
Moulvi Bazar	140	262	1.87
3-Station Average			1.94

Thus it is apparent that 1-day maximum rainfalls have increased on average by a factor of 1.70, and 2-day rainfalls by a factor of 1.94. The increase in 1-day rainfall (by a factor of 1.70) is sufficient to explain the observed increase (by a factor of 1.70) in flood discharges.

Another significant effect evidenced by these results is that the rainfall increases have been larger for the downstream portion of the river basin, as represented by Langla and Moulvi Bazar, than for the upstream portion as represented by Kamalganj. The reason for this is not readily apparent, especially as the higher hill elevations are in the south; near Langla the Bhattera Hills rise to a peak elevation of 80m (262 ft), southwest of Kamalganj the Balisira Hills reach a peak of 145 m (476 ft), and the head of the Manu catchment in Tripura is at 938 m (3077 ft); thus, the rainfall pattern is the opposite of that which topographic elevations would suggest. Depending on storm tracks, however, it is possible that moist air is inducted into the basin from the northwest in which case the Bhattera Hills in particular might act as a topographic trap funnelling the air southwards into the river basin and lifting it most rapidly over its northern portion; a study in synoptic climatology is required to confirm this but is beyond the scope of this study. Referring to the 30-year mean annual rainfall map for 1961-90 (Figure 23) it is seen that the Manu/Dhalai river basin lies in Rainfall Zone 2 which is characterized by a northward increase in rainfall toward the Shillong Plateau; this suggests that rainfall over the river basin is influenced more by the regional topography than by the local topography. Whatever the reason, however, it is the fact which is important, and the solution to the flooding problem suggested later in this paper should recognize that the more severe rainfall conditions occur over that portion of the river basin lying downstream of practical diversion structure sites.

The trend analysis just described dealt with the data available since 1964 as a whole. Inspection of the data points in Figures 16 through 22 reveals that there are two distinct trends within the period of data, and that the upward trends in both flood discharge and rainfall have been greater since about 1980 than they were earlier. Dividing the data into two groups, one containing data prior to 1980/81, the other containing data subsequent to 1980/81, and establishing least squares trend lines for each period leads to the following results for flood discharges (Figure 24):

Station	Trend Line Discharges (m^3/s)			Ratio	
	1964	1980	1991	1980/1964	1991/1964
Dhalai/Kamalganj	212	227	387	1.07	1.83
Manu/Manu RB	484	598	819	1.24	1.69
Manu/Moulvi Bazar	740	856	1337	1.16	1.81
3-Station Average				1.16	1.78

A parallel re-analysis of the rainfall data yields the following results (Figures 25 to 28):

Station	Trend Line Rainfall (mm)			Ratio	
	1964	1980	1991	1980/1964	1991/1964
For 1-Day Rainfalls:					
Kamalganj	126	144	161	1.14	1.28
Langla	124	144	261	1.16	2.10
Moulvi Bazar	118	156	213	1.32	1.81
3-Station Average				1.21	1.73
For 2-Day Rainfalls:					
Kamalganj	182	193	228	1.06	1.25
Langla	158	209	409	1.32	1.59
Moulvi Bazar	137	226	278	1.65	2.02
3-Station Average				1.34	1.95

When the 3-station averages for floods and rainfalls are rounded and compared it is seen that there is fairly close agreement between the discharge and rainfall ratios:

Data Type	3-Station Average Ratio	
	1980/1964	1991/1964
Floods	1.2	1.8
1-Day Rainfall	1.2	1.8
2-Day Rainfall	1.3	2.1

The agreement between the flood ratios and 1-day rainfall ratios indicates that:

- the excess rainfall which causes floods occurs on 1 day
- the increases in 1-day rainfall are alone sufficient to explain the observed increases in flood discharges, including the time pattern of the increases.

B1.2 Confinement Effect of Embankments

Although it has just been shown that the increased rainfall in recent years can account for the increased flood discharges, and it is obvious that if discharges have increased then river water levels must also have increased, it cannot be argued that the increased discharges must account for <u>all</u> of the increase in river water levels at Moulvi Bazar. This is because the water levels at Moulvi Bazar can be influenced by other factors besides the discharge entering the river reach from Kazir Chalk to Moulvi Bazar, at Kazir Chalk. In the pre-Manu River Project situation overbank spill from this reach of the river used to occur into Kawadighi Haor, as well as into the lower Dhalai basin, so reducing the river discharge at Moulvi Bazar to a value significantly less than that entering the reach at Kazir Chalk. It is impossible to assess the magnitude of this reduction without resort to mathematical modelling, but the presence of several distributary channels running from this reach to Kawadighi Haor, and of beels in the lower Dhalai basin, suggests the reduction was substantial. Construction of the Manu River Project embankment has obviously put a stop to the overbank spill into Kawadighi Haor so that now whatever discharge enters the reach at Kazir Chalk must now largely (there may be some increased outflow into the Dhalai basin) pass out of the reach at Moulvi Bazar. Consequently, river water levels experienced at Moulvi Bazar for a given inflow at Kazir Chalk will be higher than in the pre-project situation. This is the well-known "confinement effect", and it is the basis for the argument that the Manu River Project embankments are responsible for the flooding in Moulvi Bazar. Those who support this argument tend to assume too readily that the confinement effect is <u>solely</u> responsible for increased river water levels at Moulvi Bazar. This argument is partly countered by the fact, established in the previous section of this paper, that discharges entering the reach have increased in recent years in response to increased rainfall, and those who would argue against the confinement effect can certainly point to two other factors in the situation which tend to offset this effect:

- higher water levels in the reach will promote larger back flows into the Dhalai basin through the outfalls of both the Dhalai and Kalkalia rivers; it is well-known, and clearly visible on SPOT satellite imagery, that ponding of flood water occurs in the lower Dhalai/Kalkalia basin; thus it can be argued that the overbank spill which used to pass into Kawadighi Haor is now occurring into this basin so tending to maintain the discharge reduction which used to occur

- higher discharges through the reach will tend to scour the mobile river bed; thus it can be argued that the flow area required to pass the increased discharge is provided by a drop in river bed level, and so river water levels are maintained at, or near, their pre-project values.

There is little doubt that increased inflows, confinement, spillage into the Dhalai basin, and perhaps river bed scour, are all influencing river water levels at Moulvi Bazar. The problem then is to determine their net effect, and the significance of each factor upon it.

The annual maximum water levels at the three rivers gauges are listed in Table B2.2, and plotted chronologically in Figure 29. Least-squares trend lines have been established, in the same way as for discharges and rainfall, and are shown in the figure. The results of the trend analysis are:

Station	Trend Line Water Level (m PWD) 1964	1991	Increase (m)
Dhalai/Kamalganj	20.41	20.80	0.39
Manu/Manu RB	18.21	18.73	0.52
Manu/Moulvi Bazar	11.45	12.57	1.12

The conclusions which may, tentatively, be drawn from these results are:

- Since no infrastructure has been constructed near Kamalganj in the period 1964-91 (the road and rail embankments were constructed prior to 1964) the increase of 0.39 m is solely attributable to the increased discharges of the river in recent years.

- The increase of 0.52 m at Manu Railway Bridge is attributable mainly to increased discharges of the river since the Manu FCD Sub-Project was not constructed until 1989 (the data points in Figure 30 show water levels have been <u>less</u> since then!).

- Since the river channel is of about the same width at Moulvi Bazar as at Manu Railway Bridge a similar increase could be expected at both places in the absence of the Manu River Project embankments; in fact, the increase at Moulvi Bazar (1.12 m) is more than twice that at the Railway Bridge (0.52 m), and this suggests that the confinement effect, net of the off-setting effects of spillage into the Dhalai basin and river bed scour, <u>is</u> affecting water levels.

Breaking the sample data into two groups, as for discharges and rainfall, yields the following results (Figure 30):

Station	**Trend Line Water Levels (mPWD)**				**Increases (m)**	
	1964	**1980**	**1981**	**1991**	**1964/80**	**1981/90**
Dhalai/Kamalganj	20.43	20.60	20.62	20.82	0.17	0.20
Manu/Manu RB	18.20	18.47	18.74	18.57	0.27	-0.17
Manu/Moulvi Bazar	11.68	11.69	12.45	12.49	0.01	0.04

From these results it is apparent that:

- Water levels at Kamalganj increased steadily throughout 1964/91 the increases for 1964/80 (0.17 m) and 1981/90 (0.20 m) being practically the same; again, this points to a steady increase in discharges taking place in the absence of any new infrastructure.

- At Manu Railway Bridge the increase in water levels during 1964/80 (0.27 m) appears to have been reversed (-0.17 m) upon completion of Manu FCD Sub-Project!

- At Moulvi Bazar the increases over time were negligible in both periods; however, the absolute water levels still increased by 1.12 m over the whole period and, by inspection of Figure 30, it can be seen that this occurred rapidly about 1980/81; this is about the time when the Manu River Project embankments were completed.

Examination of the "steps" in Figure 30 shows:

Station	Trend Line Water Level (m PWD)		Increase (m)
	1980	1981	1980/81
Dhalai/Kamalganj	20.60	20.62	0.02
Manu/Manu RB	18.47	18.74	0.27
Manu/Moulvi Bazar	11.69	12.45	0.76

These results suggest:

- There was virtually no step increase (only 0.02 m) at Kamalganj; this is in line with the knowledge that there was no change in the infrastructure there
- There is a step increase (0.27 m) at Manu Railway Bridge but, obviously, it does not correspond with construction of the Manu FCD Sub-Project; rather it appears due to construction of the original embankments by local people
- There is a very marked step increase (0.76 m) at Moulvi Bazar in 1980/81 when it is known that the Manu River Project embankment was in the later stage of its construction.

Based on the total increases found for 1964-1991, and the step increases found for 1980/81, it is possible to assess how much of the total increase was due to the confinement effect and how much was due to increased flood discharges. This assessment assumes, reasonably, that the step increases are attributable to the confinement effect, and yields the following results:

Station	Total Increase in Water Level (m)	Step Increase, or Confinement Portion (m)	Difference, or Discharge Portion (m)
Dhalai/Kamalganj	0.39		0.39
Manu/Manu RB	0.52	0.27	0.25
Manu/Moulvi Bazar	1.12	0.76	0.36

In the case of Dhalai/Kamalganj, where there is no known infrastructure change during 1964-1991, the step increase (0.02 m) is considered negligible, and the whole of the total increase is attributed to increased discharges in the river. In the case of Manu/Manu Railway Bridge, where water levels appear to have been influenced by the dykes built by local people in the 1970's, the step increase (0.27 m) is attributed to the confinement effect of these dykes, and (0.52-0.27)=0.25 m is attributed to increased discharges. The fact that the indicated increase due to increased discharges is less for Manu/Manu Railway Bridge (0.25 m) than for Dhalai/Kamalganj (0.39 m) is a reflection of the larger flow section available at the former site. In the case of the Manu at Moulvi Bazar, where the water levels must be influenced by the Manu River Project embankment, the step increase (0.76 m) is attributed to its confinement effect, and (1.12-0.76)=0.36 m is attributed to increased discharges. This assessment is rather crude, and needs to be refined by means of mathematical modelling, but it is thought to be basically correct.

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Thus, regardless of what off-setting effects due to overbank spill into the Dhalai basin and river bed scour may be present, the net effect of the Manu River Project embankment (0.76 m) cannot be denied.

B1.3 Conclusions

The overall conclusion from this study is that everyone is right, to some extent, as to the cause of the worsening flood situation in Moulvi Bazar, i.e:

- There has been a definite and substantial increase in the flood discharges entering the middle reach of the Manu (70%), and this has contributed significantly to higher water levels at Moulvi Bazar (0.36 m)

- There is a confinement effect due to the Manu River Project embankments, and this has also contributed significantly to higher water levels at Moulvi Bazar (0.76 m)

- There is backflow from the Manu into the Dhalai basin but this is obviously not sufficient to offset the confinement effect; if this backflow did not occur the confinement effect would be greater than 0.76 m.

- There is probably no significant river bed scour occurring in the reach through Moulvi Bazar due to the probable presence of bedrock in the river bed, and so the confinement effect is probably not offset by riverbed scour

On the basis of these conclusions it can be seen that a solution to the problem of flooding in Moulvi Bazar must recognize the following:

- Dredging the river bed throughout the Moulvi Bazar reach of the Manu is probably impossible due to the presence of bedrock in,or very close to, the river bed

- Encouraging back flow from the middle Manu into the Dhalai basin would transfer the flooding problem from Moulvi Bazar to the farmlands of the Dhalai basin, and would add to the problems now frustrating implementation of the Dhalai River Project

- Abandoning the Manu River Project and removing its embankments would eliminate the confinement effect but would transfer the flooding problem back to the farmlands of Kawadighi Haor, and frustrate forever the achievement of the intended benefits of the Manu River Project. It is extremely unlikely, in view of the cost of the Manu River Project infrastructure and its potential agricultural benefits, that government would agree to this solution, and it certainly should not.

- Reducing discharges into the middle Manu is seen as the only satisfactory solution to the flooding problem in Moulvi Bazar. This recognizes the facts that river discharges have increased and are likely to remain high for at least another decade, or even to stay high longer into the future, and that the confinement effect of the Manu River Project embankments exists and cannot reasonably be eliminated.

Accepting this view of the situation it is obvious that the only acceptable solution to the flooding problem in Moulvi Bazar is to divert river flows in excess of the bank full discharge at Moulvi Bazar at points well upstream of the town, and convey them out of the Manu/Dhalai basin to points where they can conveniently and safely be disposed of. Such a solution will obviously require the construction of appropriate diversion structures at appropriate locations on the Manu and Dhalai rivers, and floodway canals to convey the excess flood waters from the diversion structures to acceptable disposal points.

B2 Flood Frequency Analyses

Frequency analyses have been carried out to identify design discharges, bankfull discharges and design water levels for the Project.

B2.1 Annual Discharge Series for the Manu River at Moulvi Bazar

Since the flow of the Manu River at Moulvi Bazar has not been measured, annual peak discharges there have been synthesized as the sum of peak discharges observed at the Manu Railway Bridge and Kamalganj gauging stations plus an allowance for the contribution of the catchment area intervening between these gauging stations and Moulvi Bazar based on the prevailing runoff rate in the Dhalai river basin. The synthesis and the resulting series of synthetic annual flood peak discharges at Moulvi Bazar are recorded in Table B2.1.

B2.2 Method of Analysis

The annual series of river discharges and water levels have been analysed by the method of L-moments assuming the data are distributed according to the GEV probability distribution. The annual series for the three stations given in Tables B2.1 and B2.2 in Manu-Dhalai River basin, and the resulting frequency distributions for all stations of interest are given in Tables B2.3 through B2.6.

It has been seen from examination of the frequency curves that the annual series are all, apparently, well fit by EV distributions. However, the L-kurtosis/L-skewness diagram (Figure 31) shows the fits are not as satisfactory as they appear to be from the frequency curves (Figures 33, 36, and 38); this is not surprising in view of the trends established in Section B1, and sample testing indicates the samples are dependent, non-stationary and heterogeneous. Most of the points plotted on the L-kurtosis/L-skewness diagram lie above the theoretical (test) curve for the GEV distribution, and this clearly indicates that the samples are mixed samples and will not be better fit by any of the other commonly used distributions such as the log-normal, etc. the test curves of which all lie below that of the GEV distribution.

The frequency curves established are considered acceptable for the purposes of this pre-feasibility report, but for the following feasibility report they should be re-examined on the basis of separating the sample data into two groups.

B3 Design Discharges

Flood relief channel works are commonly designed to provide protection against the 100-year flood, Q_{100}. As given in Table B2.5, the 100-yr flood discharges for Manu River at Manu Rly.Bridge and Moulvi Bazar and Dhalai River at Kamalganj are 873 m^3/sec, 1576 m^3/sec and 506 m^3/sec respectively, say 870 m^3/sec, 1500 m^3/sec and 506 m^3/sec.

B3.1 Bankfull Discharges

B3.1.1 Methods of Estimation

For flood relief channel works a critically important factor in design is the bank full discharge of the river Q_B at the site to be protected against overbank flooding. The works must be capable of ensuring that Q_B is not exceeded on average more than once in 100 years.

Four techniques are available for estimating Q_B:

Rating Curve Technique

A rating curve for the section to be protected, when plotted on log-log paper, will show a break in slope at the bank full flow condition; the point where this break occurs identifies the bank full river water level L_B and discharge Q_B. For stable river channels this point on the rating curve is easily and reliably identifiable, but for unstable river channels in which the river bed aggrades and degrades frequently, the point where the slope breaks is not uniquely defined and may not be even approximately identifiable.

Flood Frequency Technique

Geomorphologists have studied correlations between Q_B and flood frequency. On the basis of their findings Q_B may be identified from the site flood discharge frequency curve as the discharge corresponding to a certain return period T where T=1.5 years for gravel-bed rivers and 1.1 years for sand-bed rivers (Richards, 1982, Rivers, Pages 138 and 139). These return periods correspond, however, to most probable (modal) values of bank full discharge, and the scatter of values about these these return periods is rather large.

Slope-Area Technique

If the slope, or hydraulic gradient, of the river water surface is measured during a number of flood events at the site, and the roughness of the river channel is known, then Q_B can be calculated using the cross-sectional properties of the site flow section, by a uniform flow equation such as Manning's:

$$Q_B = A_B R^{2/3}{}_B S^{1/2}/n$$

where:

A_B = the area of the section below the bank full water level L_B (m^2)

R_B = hydraulic radius of the section (m)

S = hydraulic gradient, or slope of the water surface (dimensionless)

n = roughness coefficient of the river channel (dimensionless)

For wide rivers the hydraulic radius, which is defined as the flow section area divided the wetted perimeter of the section, can be adequately computed as:

$$R_B = A_B/W_B$$

where W_B is the top width of the flow section. The main problem with this technique relates to appropriate estimation of the roughness coefficient n. Tables and photos are available to assist in the selection of a suitable value (Ven Te Chow, 1983, Pages 108 to 123) but they are no substitute for a directly determined value based on a discharge measurement at, or near, the section; in fact, these aids are often quite misleading. Since most river channels have values in the range 0.025 to 0.035 a good rule of thumb is: If in doubt, use n = 0.030. It is also worth noting that n is normally at a minimum when the water level is at the level of the bank.

Hydraulic Modelling

Where sufficient data are available hydraulic models such as HEC-2 can be used to simulate river water level profiles. Comparison of these profiles with that of the natural river bank enables the bankfull discharge to be identified.

While all the techniques should be applied, it is too much to expect they will yield closely consistent results; consistency within ± 10% is probably the best that can be expected. Such a level of consistency is, however, usually sufficient to enable the designer to decide on values to be adopted for Q_B in design.

B3.1.2 Manu at Manu Railway Bridge

Rating Curve Technique

The rating curve prepared by SWMC is shown in Figure 32, and represented by the equation:

$$Q = 10.202(H-11.80)^{2.274} \qquad (2)$$

The data points do not evidence any break is slope of the rating so the technique is inapplicable in this case. The lack of a break in slope is significant in showing that flow measurements and water levels at this station are unaffected by overbank spill upstream.

Flood Frequency Technique

The flood discharge frequency curve prepared by NERP for 1964-91 is shown in Figure 33. Entering this with a return period of 1.1 years gives a value of Q_B = 430 m^3/s.

Slope Area Technique

The hydraulic gradient in the reach downstream of the gauging station can be estimated from TWL's observed at the gauging station and at the NERP/PMP staff gauge at Kazir Chalk for the flood of 14 June 1993:

Manu Railway Bridge TWL	:	17.95 m PWD
Kazir Chalk TWL	:	15.72 m PWD
Fall		2.23
Slope		0.000149

The slope is based on the distance between these points which is 15 km. For the same flood corresponding data for the reach from Kazir Chalk to Moulvi Bazar, which are 22 km apart, are:

Manu Railway Bridge TWL	:	15.72 m PWD
Kazir Chalk TWL	:	12.44 m PWD
Fall		3.28
Slope		0.000149

Thus, this slope (0.000149) is valid throughout the reach from Manu Railway Bridge to Moulvi Bazar. Entering the TWL at Manu Railway Bridge (17.95 m) in equation (2) gives the flow on 14 June 1993 as 635 m^3/s. NERP has surveyed a section at Kazir Bazar, about one kilometre downstream of Kazir Chalk, which has the following section properties:

For the June 1993 Flood (TWL = 15.72 m PWD):

Flow Area	:	427 m^2
Top Width	:	81.2 m
Hydraulic Mean Depth	:	5.26 m

For Bank Full Flow (TWL = 15.11 m PWD):

Flow Area	:	378 m^2
Top Width	:	75.9 m
Hydraulic Mean Depth	:	4.98 m

For the June 1993 flood therefore:

$$n = (427\ m^2)(5.26\ m)^{2/3}(0.000149)^{1/2}/635\ m^3/s = 0.025$$

Using this value of n for the bank full condition gives:

$$Q_B = (378\ m^2)(4.98\ m)^{2/3}(0.000149)^{1/2}/0.025 = 538\ m^3/s$$

The value of n found is, perhaps, too low; if so, the reason would be that the SWMC rating yielded too high a discharge for the flood of June 1993. The curve was derived before this flood occurred, and high data points in Figure 32 suggest the discharge corresponding to a TWL = 17.95 m PWD might be as low as 535 m^3/s; in this case n would be 0.030 and Q_B = 449 m^3/s.

Hydraulic Modelling

Figure 34 shows the results of hydraulic modelling for the reach of the Manu River from Manumukh to Manu-Dhalai confluence and to Manu Rly.Bridge. This shows there will be some overbank spill even when the flow is as low as 450 m^3/s in the reach between Manu-Dhalai confluence and Manu Rly.Bridge, so the bankfull discharge for this reach is probably about 430 m^3/s.

B3.1.3 Dhalai at Kamalganj

Rating Curve Technique

The rating curve prepared by the SWMC is shown in Figure 35, and represented by the equation:

$$Q = 7.67(H-16.10)^{2.441} \quad (1)$$

A trend line drawn through these points suggests the bank full discharge is 160 m^3/s.

Flood Frequency Technique

The flood discharge frequency curve prepared by NERP for 1964-91 is shown in Figure 36. Entering this with a return period of 1.1 years (sand-bed river) gives a value of 160 m^3/s.

Slope-Area Technique

The consultant ACE made a slope-area estimate of design discharge for the Dhalai River Project based on a section 11.5 km upstream of the gauging station at Kamalganj. Details of this section are shown in Figure 37 for the flood of May 1984. The following information can be derived from this figure for the main channel:

For the May 1984 Flood (TWL = 24.43 m SOB):

Flow Area	:	214 m^2
Top Width	:	42.7 m
Hydraulic Mean Depth	:	5.01 m

For Bank Full Flow (TWL = 23.02 m SOB):

Flow Area	:	154 m^2
Top Width	:	42.4 m
Hydraulic Mean Depth	:	3.62 m

For the May 1984 flood SMEC (1990) give the TWL at Kamalganj as 21.24 m PWD, and the flow "measured" as 260 m^3/s. Converting the TWL at the ACE section to PWD datum gives (24.43 + 0.46) = 24.89 m PWD for this flood. Hence the hydraulic gradient is

$$S = (24.89 - 21.24)/11500 = 3.65/11500 = 0.000317$$

This is practically the same value as ACE give in Figure 37 (0.000316). For no stated reason, however, SMEC later modified the slope to 0.000272; the most likely reason for this change would appear to be an error in the river distance which ACE may have under-estimated at 11.5 km; based on these slope values the true river distance would appear to be 11.5 (316/272)=13.4 km.

As a check on the correctness of the slope consider the TWL's observed at Kamalganj and Moulvi Bazar, which are 35 km apart, in 1992:

Kamalganj TWL	21.13 mPWD
Moulvi Bazar TWL	10.83 mPWD
Fall	10.30 m
Slope	0.000 294

This result indicates that SMEC's slope of 0.000272 is the correct value for the reach upstream of Kamalganj; it is therefore accepted here.

ACE used, and SMEC retained, a roughness coefficient of 0.045, apparently for the section as a whole; this is probably too high for the main channel. The discharge of 260 m^3/s quoted by SMEC was apparently not available to ACE, but it can be used to check the value of the roughness coefficient for the main channel assuming, reasonably, that it carried all of the flow measured at Kamalganj; this gives:

$$n = (214\ m^2)(5.01\ m)^{2/3}(0.000272)^{1/2}/260\ m^3/s = 0.040$$

Accepting this value of n, and SMEC's slope, the bankfull discharge is then:

$$Q_B = (154\ m^2)(3.62\ m)^{2/3}(0.000272)^{1/2}/0.040 = 150\ m^3/s$$

It is to be noted that it would only require n = 0.037 to raise Q_B to 160 m^3/s as indicated by the other two techniques.

Hydraulic Modelling

Data are insufficient at the present time to enable the Dhalai River reach to be modelled.

B3.1.4 Manu at Moulvi Bazar

Rating Curve Technique

Since there are no discharge data for this station a rating can only be estimated by adding together the discharges for Manu Railway Bridge and Kamalganj. This has been done by NERP with results typified in Figure 38 for 1988; the scatter of the data points is considerable but there is no doubt a break in slope of the curve occurs at a discharge of about 600 m^3/s; for higher discharges the water level never exceeded 12 m. This pattern is repeated in other years as shown for 1988 in Figure 39 wherein the water level never exceeded 13 m for discharges in excess of 600 m^3/s.

Flood Frequency Technique

In a separate study (see Table 2 of this report) NERP established on annual series of flood discharges for Moulvi Bazar. A frequency analysis of these artificial data is shown in Figure 39. Entering this with a return period of 1.1 years gives Q_B = 650 m^3/s.

Slope Area Technique

A slope area study of the reach through Moulvi Bazar awaits further work by NERP. A study has, however, recently been made of the sensitivity of water levels along the Lower Manu to water levels in the Kushiyara when flow into the Lower Manu is 750 m^3/s. The resultant profiles are compared to the right bank profile of the Lower Manu in Figure 40 wherein it can be seen that all the water profiles are above the bank profile in the vicinity of Moulvi Bazar by the least 0.8 m. From this it is clear that the bank full discharge in this reach is considerably less than 750 m^3/s.

The results of the slope-area calculations for the Manu at Kazir Chalk can, in combination with the result of this sensitivity study, be used to adjust the latter and so obtain an estimate of the bank full discharge. Velocities at Kazir Bazar were:

For the June 1993 Flood ($Q = 535\ m^3/s$, $n = 0.030$):

$$v = (5.62)^{2/3}(0.000149)^{1/2}/0.030 = 1.23\ m/s$$

For the Bank Full Flow ($Q = 449\ m^3/s$, $n = 0.030$):

$$v = (4.98)^{2/3}(0.000149)^{1/2}/0.030 = 1.19\ m/s$$

The top width of the river at both Kazir Bazar and the Manu Barrage is 75 m, and this is probably appropriate throughout the town area. Hence the depths of flow can be estimated as:

For a flow of 750 m^3/s:

$$D = (750\ m^3/s)/(75\ m)(1.23\ m/s) = 8.13\ m$$

For bank full flow:

$$D_B = 8.13\ m - 0.8\ m = 7.33\ m$$

$$Q_B = (75\ m)(7.33\ m)(1.19\ m/s) = 654\ m^3/s$$

Hydraulic Modelling

Figure 34 shown the results of hydraulic modelling for the reach of the Manu River from the Manu-Dhalai confluence to Manumukh. The figure shows there will be some overbank spill when the flow is 650 m^3/sec. However, this discharge has been judged to be the bankful discharge for the reach.

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B3.1.5 Conclusions

The various results obtained above can be summarised as follows:

Technique	Bank Full Discharge Estimates (m^3/s)		
	Dhalai	Upper Manu	Lower Manu
Rating Curve	160	NA	600
Flood Frequency	160	430	640
Slope-Area	150	449	654

Considering the reliability of these results leads to the conclusions that:

- the rating curve results are the least reliable, and should probably be discounted altogether
- the flood frequency results are probably slightly low; they were obtained as $Q_{1.1}$ for sand-bed rivers but to the extent that some gravel may be present in these river beds a higher return period may apply; for a pure gravel bed $Q_B = Q_{1.5}$ according to Hey (1975) but this is considered too high for the Manu-Dhalai case.
- the slope area results reflect difficulties in choosing appropriate roughness values; that for the Dhalai (0.040) is probably still too high, even though it is lower than that adopted by ACE and SMEC (0.045); that for the upper Manu is judged to be about right at 0.030 but it could be as low as 0.025; that for the Lower Manu is difficult to judge - the sensitivity analysis assumed $n = 0.025$, the velocities used in the adjustment were derived assuming $n = 0.030$.

In view of these conclusions it is considered that, pending more elaborate and sophisticated studies, the bank full discharges of these rivers are probably:

Dhalai	:	160 m^3/s
Upper Manu	:	450 m^3/s
Lower Manu	:	650 m^3/s

Comparing the sum of the results for Dhalai and Upper Manu (610 m^3/s) to the result for the Lower Manu (650 m^3/s), the ratio is found to be 650/610 = 1.07. In contrast, the ratio of the catchments involved is, from Table 1, 3520 km^2/(2270 km^2 + 840 km^2) = 1.13. It could be argued on this basis that the estimated bank full discharge for the Lower Manu (650 m^3/s) is too low, and ought to be (160 + 450)(1.13)=690 m^3/s. A counter argument is that much of the intermediate catchment area between the gauging stations and Moulvi Bazar, i.e the catchment area of Kalkalia Khal (275 km^2), does not contribute to the flood peak in Moulvi Bazar; this is because the outfall of Kalkalia Khal is blocked by backwater from the Manu when it is in flood, a fact evidenced by the existence of swampy beels in the extreme downstream part of the Kalkalia Khal catchment. This counter argument is accepted here, and the bank full discharges given at the beginning of this paragraph are viewed as mutually consistent.

The accuracy of these bank full discharges can be assessed by considering the probable error in the roughness coefficients adopted; this is considered to be ± 0.002 in which case the upper and lower limits of the bank full discharge would be:

River	Adopted Roughness	Bank Full Discharges			Variation (%)
		Adopted Value	Upper Limit	Lower Limit	
Dhalai	0.038*	160	169	152	± 6
Upper Manu	0.030	450	482	422	± 7
Lower Manu	0.029**	650	698	608	± 7

* 0.040(150/160)
** 0.025(750/650)

This assessment assumes, of course, the best judgement has been applied in selecting roughness values, but it suggests the adopted values of bank full discharge are probably within ± 10% of their true values.

B3.2 Allowable Manu River Discharge at Moulvi Bazar

In the reach between Manu-Dhalai confluence and Manumukh, Manu River is capable of discharging about 650 m^3/sec of flow at bankful and 800 m^3/sec with inundation of one metre over the bank. This has been computed by using HEC-2 model (computer version of Standard Step Method) for the given conditions of outfall water level of 9.40 m,PWD (1 in 5 year Kushiyara water level at Manumukh), Manning's roughness co-efficient of 0.029 (calibrated) and measured cross sections. The water levels and bank level profiles is shown in Figure 34. The water levels at Manu-Dhalai confluence are 13.04 m,PWD and 13.70 m,PWD respectively.

It is considered that one metre inundation over the river banks down the confluence will be safe for the people of Moulvi Bazar area. This is also safe for Manu Barrage (Barrage design discharge of 906 $m^3/sec > 800\ m^3/sec$) and Manu River Irrigation Project (Embankment is much higher than one metre). So, the flow of 800 m^3/sec through this reach is considered safe discharge for the area.

B3.3 Design Water Level in Upper Reaches

Upper Manu (Manu Rly. Bridge - Manu/Dhalai Confluence). Under the scheme's operational conditions, this reach will receive 470 m^3/sec of discharge at the maximum (Figure 41). The water level profile for this reach for the discharge of 470 m^3/sec is given in Figure 34. Bankful discharge as shown in the same figure is about 450 m^3/sec for Manning's roughness co-efficient of 0.03. The water level for 470 m^3/sec at the proposed diversion point is 17.58 m,PWD.

Upper Dhalai (Kamalganj-Manu/Dhalai Confluence). As Dhalai water level remains unaltered at Kamalganj by the diversion, the 100-yr flood level at Kamalganj has been computed by frequency analysis using GEV-III distribution. The value is 21.21 m,PWD.

B4 Quantity and Cost Estimate

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The following structural components are required for this scheme. The locations are shown in Figure 42 along Manu Rly.Bridge-Hakaluki Haor Diversion Route and Dhalai River.

- **Diversion Barrage across Manu River.** The structure is very preliminarily designed as a broadcrested weir to approximate its size.

Design discharge	:	470 m^3/sec
Upstream water level	:	18.95 m,PWD (100-yr flood level at MRB)
Downstream water level	:	17.58 m,PWD (computed for 470 m^3/sec discharge)
Barrage sill level	:	12.50 m,PWD (Manu bed level)
Head over the weir (H)	:	6.45 m
Head difference across the structure	:	1.37 m > 0.2 H

The weir will act as a semi module structure

$$Q = CLH^{3/2} = 1.71xLx6.45^{3/2} = 470$$

$$L = 16.78 \text{ m}$$

Provide 4 bays with clear opening of 5.0 m.

Abutment to abutment width = 4x5.0 m+3x2.0m+2x3.0m = 32.0 m

Cost of the structure = Tk. 100.00 million (estimated based on Manu Barrage cost)

- **Intake Structure at Diversion Channel Offtake**

Design discharge	:	700 m^3/sec
Upstream level	:	18.95 m,PWD (100-yr flood level at MRB)
Downstream water level	:	17.57 m,PWD (Computed diversion channel water level)
Barrage sill level	:	12.50 m,PWD (Manu bed level)
Head over the weir (H)	:	6.45 m
Head difference across	:	1.38 m > 0.2 H

The weir will act as a semi-module structure

$$Q = CLH^{3/2} = 1.71xLx6.45^{3/2} = 700$$
$$L \approx 25.0 \text{ m}$$

Provide 5 bays with clear opening of 5.0 m

Abutment to abutment width = 5x5.0m+4x2.0m+2x3.0m = 39.0 m

Cost of the structure = Tk. 100.00 million (estimated based on Manu Barrage)

- **Diversion Channel**

The 32.0 km diversion channel is designed for an outfall water level of 9.48 m,PWD (1:10-yr pre-monsoon water level of Kushiyara River at Fenchuganj), bed width of 60.0 m and 25.0 m berm width, bed slope 25 cm/km and Mannings roughness co-efficient of 0.03. The long and cross-section are shown in Figure 12.

The net excavation quantity is 4.18 Mm^3 assuming 40% earthwork to be saved from existing Phanai River. Excavation cost per cubic metre including spreading and forming embankment as per drawing is Tk. 40.30. The total cost is Tk. 168.40 million.

- **Rehabilitation of two road and one rly. bridges**

The diversion channel will dislocate the existing bridges at Tilagaon and Nowagaon and one rly. bridge in the Kulaura-Fenchuganj Rly. section. Assuming 7.00 m as an average depth of the canal section, the top width comes to be 88.0 m.

Cost of road bridge = Tk. 443.000x88.00 = Tk. 39.0 million each.

Cost of rly. bridge = Tk. 27.0 million (lump sum)

- **Foot Bridge**

The diversion channel will dislocate many village roads. Provision for five foot bridges has been kept in the cost estimate.

Cost : Tk. 5.00 million (lump sum).

- **Embankment along right bank of Dhalai River**

a. Manu-Dhalai confluence - Kamalganj Reach
Length : 27.00 km;
Average height : 3.00 m;
Crest width : 4.27 m
Side slope : 2:1 (c/s) and 3:1 (r/s)

Quantity

Earthwork : 1048680 m^3
Turfing : 558900 m^2

Cost

Earthwork : Tk. 24.27x1048680 = Tk. 25,451,464

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Turfing : Tk. 2.27x558900 = Tk. 26,720,167

b. Kamalganj - International Border

There exists a 17 km road on the right bank from Kamalganj to international border. To minimize land acquisition and construction cost, it is proposed to upgrade this road to be used as flood embankment. It is assumed that road upgrading costs about 30% of the new embankment.

Cost of the work = 0.30x26720167x17/27 = Tk. 5047143

Total cost of embankment = Tk. 31.8 million

- **Land acquisition**

Land acquisition for embankment : 5.07x27=137 ha

Cost : Tk. 300,000x137 = Tk. 41.1 million

Land acquisition for diversion channel : 0.6x160x32000/10000=306 ha assuming 40% available from the existing channel

Cost : Tk. 120,000x306 = Tk. 36.7 million

Total : Tk. 77.8 million

Table B2.1
Annual Maximum Discharges in the Manu-Dhalai River Basin

Year	Date	Manu MRB	Manu Kamalganj	Dhalai Kamalganj	Dhalai MRB	Manu + Dhalai	Incremental Area	Manu Moulvi	Annual Series of Manu at Moulvi Bazar	
		(m³/s)	(m³/s)	(m³/s)	(m³/s)	(m³/s)	(m³/s)	(m³/s)	(m³/s)	Order
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	15 Jun	532	175			707	80	787	787	19
1964	31 Jul			195	481	676	89	765		
	13 Jun	473	11			484	5	489		
1965	19 Jun			269	243	512	122	634	634	25
	19 Jun	463	215			678	98	776	776	20
1966	18 Aug			219	403	622	100	722		
	9 Jul	305	159			464	72	536		
1967**	8 Jul			211	298	509	96	605	605	27
	11 Jul	756	227			983	103	1086	1086	7
1968	17 Aug			269	577	846	122	968		
	20 Aug	408	185			593	84	677		
1969***	18 Aug			225	393	618	102	720	720	22
	16 Aug	659	156			815	71	886	886	12
1970***	18 Aug			162	512	674	74	748		
		NA								
1971				NA						
	23 Aug	436	159			595	72	667	667	24
1972*	23 Aug			159	436	595	72	667		
	7 Jun	628	87			715	40	755	755	21
1973	11 May			190	475	665	86	751		
	6 Jul	555	160			715	73	788		
1974***	4 Jul			206	490	696	94	790	790	18
	28 Jul	509	135			644	61	705	705	23
1975	9 Jul			190	231	421	86	507		
	10 Jun	591	210			801	96	897	897	11
1976	2 Jul			215	526	741	98	839		
	1 May	611	225			836	102	938		
1977	30 May			331	560	891	151	1042	1042	9
	24 May	560	166			726	76	802		
1978	26 Jun			209	501	710	95	805	805	17
	3 Jul	644	151			815	69	884	884	13
1979	12 Sep			191	604	795	87	882		
	13 Sep	506	71			577	32	609		
1980	29 May			269	228	497	122	619	619	26
	7 Aug	589	18			607	8	615		
1981	3 Jul			214	507	721	97	818	818	16
	4 Aug	591	177			768	81	849	849	15
1982	12 May			200	NA	NA	91	NA		
	2 May	618	169			787	77	864	864	14
1983	20 Jun			216	471	687	98	785		
	15 May	756	201			957	91	1048	1048	8
1984**	14 May			253	434	687	115	802		
	27 May	681	188			869	86	955	955	10
1985**	26 May			236	538	774	107	881		
	10 Oct	766	271			1037	123	1160	1160	5
1986	10 Nov			297	626	923	135	1058		
	1 Aug	668	289			957	132	1089	1089	6
1987**	31 Jul			321	491	812	146	958		
	15 Aug	751	297			1048	135	1183	1183	4
1988	30 May			303	727	1030	138	1168		
	30 Jul	757	303			1060	138	1198	1198	3
1989*	30 Jul			303	757	1060	138	1198		
	2 Jun	741	271			1012	123	1135		
1990	16 May			448	638	1086	204	1290	1290	2
	6 May	875	367			1242	167	1409	1409	1
1991*	6 May			367	875	1242	167	1409		

Table B2.2
Annual Maximum Water Levels: 1964-91

Year	Kamalganj WL (m,PWD)	Manu RB WL (m,PWD)	Moulvi Bazar WL (m,PWD)
1964	20.62	18.14	11.67
1965	20.44	18.16	11.10
1966	20.27	18.22	12.02
1967	20.70	18.20	11.55
1968	20.47	18.41	11.99
1969	20.62	18.63	12.19
1970	20.25	18.38	11.68
1971	NA	NA	NA
1972	20.34	17.95	11.33
1973	20.54	18.56	11.68
1974	20.52	18.18	11.60
1975	20.32	17.91	11.31
1976	20.40	18.46	12.10
1977	20.68	18.85	11.84
1978	20.73	18.69	11.93
1979	20.86	18.28	11.59
1980	20.52	18.36	11.42
1981	20.68	18.46	11.79
1982	20.51	18.74	12.20
1983	20.40	18.72	12.74
1984	21.18	18.82	13.10
1985	20.54	18.60	12.95
1986	20.86	18.92	12.46
1987	20.55	18.73	12.11
1988	20.84	18.90	12.95
1989	20.86	18.49	12.41
1990	20.91	18.44	11.97
1991	20.66	18.41	NA

Table B2.3: Pre-Monsoon Flood Discharges of Manu, Dhalai and Kushiyara Rivers for Different Return Period

River	Station Name	Period Record	Discharge (m^3/sec)			
			2-yr	5-yr	10-yr	20-yr
Manu	201 Manu Rly. Bridge	1964-91	329	483	567	638
Dhalai	67 Kamalganj	1964-91	148	201	222	237
Kushiyara	173 Sheola	1964-91	800	1310	1720	2180
	175.5 Sherpur	1982-91	1690	2400	2990	3560

Table B2.4: Pre-Monsoon Flood Levels of Different Rivers at Different Locations for Different Return Period

River	Station Name	Period Record	Water Level m,PWD			
			2-yr	5-yr	10-yr	20-yr
Manu	201 Manu Rly. Bridge	1964-91	16.98	18.08	18.53	18.84
	202 Moulvi Bazar	1964-90	10.11	11.23	11.75	12.13
Dhalai	67 Kamalganj	1964-91	19.63	20.39	20.71	20.92
Kushiyara	173 Sheola	1964-91	11.20	12.60	13.35	13.90
	174 Fenchuganj	1964-91	8.04	9.03	9.48	9.80
	175.5 Sherpur	1982-91	7.40	8.24	8.78	9.30

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Table B2.5: Monsoon Flood Discharges of Manu, Dhalai and Kushiyara Rivers for Different Return Period

River	Station Name	Period Record	Discharge (m³/sec)					
			2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
Manu	201 Manu Rly. Bridge	1964-91	615	720	775	815	850	873
	202 Moulvi Bazar	1964-91	890	1080	1200	1330	1430	1576
Dhalai	67 Kamalganj	1964-91	230	290	330	380	440	506
Kushiyara	173 Sheola	1964-91	2200	2550	2730	2850	2980	3040
	175.5 Sherpur	1982-91	2600	3020	3380	3740	4270	4700

Table B2.6: Monsoon Flood Levels of Different Rivers at Different Locations for Different Return Period

River	Station Name	Period Record	Water Level (m,PWD)					
			2-yr	5-yr	10-yr	20-yr	50-yr	100-yr
Manu	201 Manu Rly. Bridge	1964-91	18.45	18.67	18.77	18.84	18.90	18.95
	202 Moulvi Bazar	1964-90	11.92	12.40	12.70	12.92	13.50	13.47
Dhalai	67 Kamalganj	1964-91	20.58	20.78	20.90	21.00	21.11	21.21
Kushiyara	173 Sheola	1964-91	13.90	14.10	14.18	14.20	14.25	14.30
	174 Fenchuganj	1964-91	10.58	10.79	10.90	11.00	11.12	11.19
	175.5 Sherpur	1982-91	9.00	9.20	9.32	9.40	9.50	9.56

Table B2.7: Bill of Quantities

Item	Description of Item	Unit	Quantity	Rate (Tk/Unit)	Amount (MTK)
Structure	1. Construction of diversion barrage as per design and specifications	1	one	L.S	100.00
	2. Construction of intake structure at off-take of diversion channel as per design and specification	1	one	L.S	100.00
Sub-Total					**200.00**
Embank-ment	1. Construction of 27.00 km of new embankment as per design and specification	m^3	1048680	24.27	25.47
	2. Turfing	m^2	55890	2.27	1.28
	3. Upgrading of 17 km of road to be used as embankment	m	17000	296.89	5.05
Sub-total					**31.8**
Channel	1. Excavation/re-excavation of 32 km of diversion channel including spreading and forming of embankment by spoil as per design and specification	m^3	4,180,000	40.30	168.40
Sub-total					**168.40**
Bridge	1. Rehabilitation of two road bridges; total span = 176.0 m	m	176	443,000	78.0
	2. Rehabilitation of one Rly. bridge	no	1	L.S	27.0
	3. Construction of foot bridge	no	5	L.S	5.0
Sub-total					**110.0**
Land acquisition	1. Land for embankment	ha	137	300,000	41.1
	2. Land for diversion channel	ha	306	120,000	3 6.7
Sub-total					77.8
TOTAL					588

ANNEX C

INITIAL ENVIRONMENTAL EXAMINATION

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ANNEX C: INITIAL ENVIRONMENTAL EXAMINATION

C.1 Introduction

This Initial Environmental Examination (IEE) (pre-feasibility level Environmental Impact Assessment or EIA) follows the steps specified in the *Bangladesh Flood Action Plan Guidelines for Environmental Impact Assessment* (ISPAN, 1992). These steps are illustrated in Figure 2 of ISPAN (1992).

Much of the information required for the IEE/EIA appears in the main body of the study. The section and chapter references given below cite this information.

C.2 Alternative 1: Proposed FCD Project

C.2.1 Project Design and Description (Step 1)

As in Section 7.3, Project Description.

C.2.2 Environmental Baseline Description (Step 2)

As in Chapter 2, Biophysical Description, and Chapter 3, Settlement, Development, and Resource Management.

C.2.3 Scoping (Step 3)

Technical:

Literature review: Presented in Chapter 4, Previous Studies.

Local community: As described in Section 3.1.9, People's Perception.

C.2.4 Bounding (Step 4)

Physical:

Gross area: 52,300 ha.
Impacted (net) area: 40,800 ha.
Impacted area outside project:32,000 ha. gross (Hakaluki Haor)

Temporal:

Preconstruction: year 0 through year 3
Construction: year 1 through year 4
Operation: embankment and channel maintenance will be required; diversion structure will require to be operated; Hakaluki Haor environment will require to be managed
Abandonment: after year 50.

Cumulative impacts:

With other floodplain infrastructure: none
With pre-existing no-project trends. Described in Chapter 5.

C.2.5 Field Investigations (Step 5)

Field investigations were limited to seven to ten days of informal reconnaissance by a multi-disciplinary team.

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C.2.6 Impact Assessment (Step 6)

At this level of detail, a screening matrix (Table C.1) was filled out by the project team. Impacts are designated by:

+	positive impact
-	negative impact
•	neutral impact (such as conversion from one productive land use to another)
?	insufficient information to designate

Impacts are discussed in Section 7.8.

C.2.7 Quantify and Value Impacts (Step 7)

Quantification and evaluation of impacts is documented in Section 7.8 and Tables 7.9 through 7.15. Fisheries impacts were assessed using the model described in this section :

Fisheries Model. The openwater fishery ecosystem is extremely complex. Impacts on production are assessed here using a highly simplified model. The limitations of the model mirror the limitations in our current understanding of and information about the system.

The major system processes about which we have some insight are:

- Migration access and timing. It seems to be accepted that:
  - a multiplicity of access points is desirable (i.e. that closing any or some channels is still deleterious),
  - the most important channels are those at the downstream end (that with flood onset, fish mainly migrate upstream and onto the floodplain, and downstream out of the beels into the river), and
  - delay of flooding, as in partial flood control schemes, is highly disruptive

- Overwintering (dry season) habitat extent.

- Wet season habitat (floodplain grazing extent and duration). [It is suspected that production also varies as a function of land type (F1, F2, F3) — probably such that shallower (F1, F2) land is more productive than deeper (F3) land — but as data to show this is lacking it has been neglected in the model.]

- Habitat quality. Habitat quality would include water quality, vegetation, and other conditions (presence of preferred types of substrate e.g. sand, rocks, brush). Water quality would appear to be most relevant during low volume/flow periods, and during the times of flood onset and recession when contaminants can disperse or accumulate.

- Spawning. Production <u>outside the project area</u> can also be impacted if habitats suitable for spawning within the project are adversely affected. It is believed that most of the region's fish production stems from spawning occurring in: mother fishery areas, which are those exhibiting extensive, well-interconnected, and varied habitats with good water quality; key beels; and river <u>duars</u>. <u>Duars</u> are somewhat a separate problem as they are located in rivers and larger channels, not on the floodplain.

The foregoing is represented quantitatively here as:

FWO production =

$$(R_0 * P_{RO}) + (B_0 * P_{BO}) + (W_0 * P_{WO}) + (A_M/A_T) * 50{,}000$$

FW production =

$$[M * Q * (R_1 * P_{RO})] + [M * Q * (B_1 * P_{BO})] + [M * (W_1 * P_{WO})]$$

$$+ [D * (A_M/A_T) * 50{,}000]$$

Thus,

Impact = FW - FWO production =

$$\{ [(M * Q * R_1) - R_0] * P_{RO} \} +$$

$$\{ [(M * Q * B_1) - B_0] * P_{BO} \} +$$

$$\{ [(M * W_1) - W_0] * P_{WO} \} +$$

$$[(D - 1) * (A_M/A_T) * 50{,}000]$$

where

sub-0 and sub-1 refer to FWO and FW respectively

R, B, and W are river/channel, beel, and floodplain (F1+F2+F3) areas, in ha

P is the unit FWO production in kg/ha for the respective habitats. Estimated regional average values are 175, 410, and 44 respectively.

M is the FW quality-weighted migration access remaining, relative to FWO conditions (range 0 to 1 for negative impacts, >1 for positive impacts)

Q is the FW acceptability of habitat/water quality relative to FWO conditions (range 0 to 1 for negative impacts; >1 for positive impacts).

A_M is the area of mother fishery and key beels.

D is a factor (range 0 to 1 for negative impacts, >1 for positive impacts) reflecting the degree of degradation/enhancement of the mother fishery.

T is the estimated annual regional fish production attributable to spawning exported from mother fisheries/key beels (a constant of 50,000 tonnes, which is 50% of the total regional fish production of 100,000 tonnes)

A_T is the estimated regional mother fishery/key beel area (a constant of 100,000 ha).

Estimated values for this project are shown in Table C.1. Where standard values, established for the region or for a particular project type, are used, this is noted. Comments on project-specific values are also shown

C.2.8 Environmental Management Plan (Step 8)

At a pre-feasibility level, this section focuses on "identification of broad management options and major constraints" (p. 28, ISPAN, 1992).

Table C.1 : Estimated Values of Fisheries Parameters

Var	*Value*	*Stnd value?*	*Comments*
M	0.30	0.30	*Severe impact on migration due to blocking of all khals by embankment/structures*
Q	0.50	0.50	*Impact on water quality due to restricted circulation and flushing and agrochemical contamination*
D	0.0	0-1.0	*Assumed 100% fisheries habitat destroyed*
R_0	1040		*Pre-project channel area within the project*
R_1	1040		*No changes in channel area after project construction*
B_0	1220		*Pre-project beel area*
B_1	1220		*No change in beel area after Project development*
W_0	16220		*Pre-project floodplain area (F1+F2+F3)*
W_1	8060		*Reduced floodplain due to reduced flood depth resulting from Project development*
P_{R0}	28	175	*NERP field survey*
P_{B0}	28	410	*NERP field survey*
P_{W0}	27	44	*NERP field survey*
A_M	5000		*NERP field survey*

Mitigation and enhancement. Negative impacts are expected to be substantial on fisheries and wetlands in Hakaluki Haor. Mitigation works have been outlined in Section 7.3.8.

Compensation. Land acquisition will be required for construction of embankment and diversion channel. Market value compensation is required to be paid and independent monitoring is required to ensure that proper compensation does occur.

Monitoring. There is a need to define monitoring needs and methodologies at regional, institutional (BWDB), and project levels. This exercise should reflect (i) the need for greater people's participation in all project activities, which would include monitoring project function and opportunities for discussion with BWDB and (ii) the need for greater emphasis on operation and maintenance, of which monitoring can play an important role.

People's participation. There is a need at regional, institutional, and project levels to maintain enthusiasm for people's participation, and to develop effective and efficient public participation modalities.

Disaster management (contingency planning). The project will improve the flooding conditions in the Manu River below the diversion point and reduce the homestead flooding. The risk associated with this is the probable increase of water level above diversion point and breaching of embankment and possible flooding in the upper Manu right and left bank areas.

EMP institutionalization. Arrangements for sharing EMP responsibility between BWDB and local people would need to be worked out. Project implementation should be contingent upon agreement on this matter between BWDB and local people.

Residual impact description. This should be generated as part of the feasibility-level EIA.

Reporting and accountability framework. At a national or regional scale, there is a need to develop satisfactory reporting/accountability arrangements involving BWDB, DOF and DOE, probably through an Environmental Cell within BWDB linked to DOE and DOF. At the project level, the client committee and local BWDB staff should develop reporting/accountability arrangements satisfactory to themselves. Project implementation should be contingent upon development of satisfactory arrangements at the local level, at a minimum.

Budget estimates. These should be generated as part of the feasibility study.

Environmental Screening Matrix

Screening matrix PHASE	Normal/ Abnormal	Activity / Important Environmental Component	Land Use	Agri-culture	Fisheries	Water Quality	Water Quantity	Human Health	Social Issues	Wild Plants & Animals	Hazards	Other
Preconstruction	Normal	Surveys & instrumentation: landmark, topographic, benchmark, hydrologic, climatic, socio-economic, land use, natural resource										
		Land acquisition		—					—			
		People's participation activities		+	+							
	Abnormal											
Construction	Normal	Site preparation: vegetation removal, infrastructure removal/relocation, resettlement, levelling, temporary structure installation (access roads, godowns, accommodations, garages and parking sites, cooking and eating facilities, waste disposal sites, water supply, drainage, sanitary facilities)										
		Canal excavation: labor and materials mobilization, crossdam construction, spoil transport, spoil disposal							+			
		Embankment construction: labor and materials mobilization, topsoil removal, soil taking and transport, compaction, turfing, paving							+			
		Structure (sluice gate, culvert, pump house, and so on) construction: labor and material mobilization, de-watering, excavation, pile driving, foundation works, structure construction, earthwork filling, turfing, paving										
		Tube well installation: boring, distribution facilities, electrification N/A										
	Abnormal	Suspension of construction before completion, construction delays		—	+	+				+		
		Incorrect construction practices or techniques										

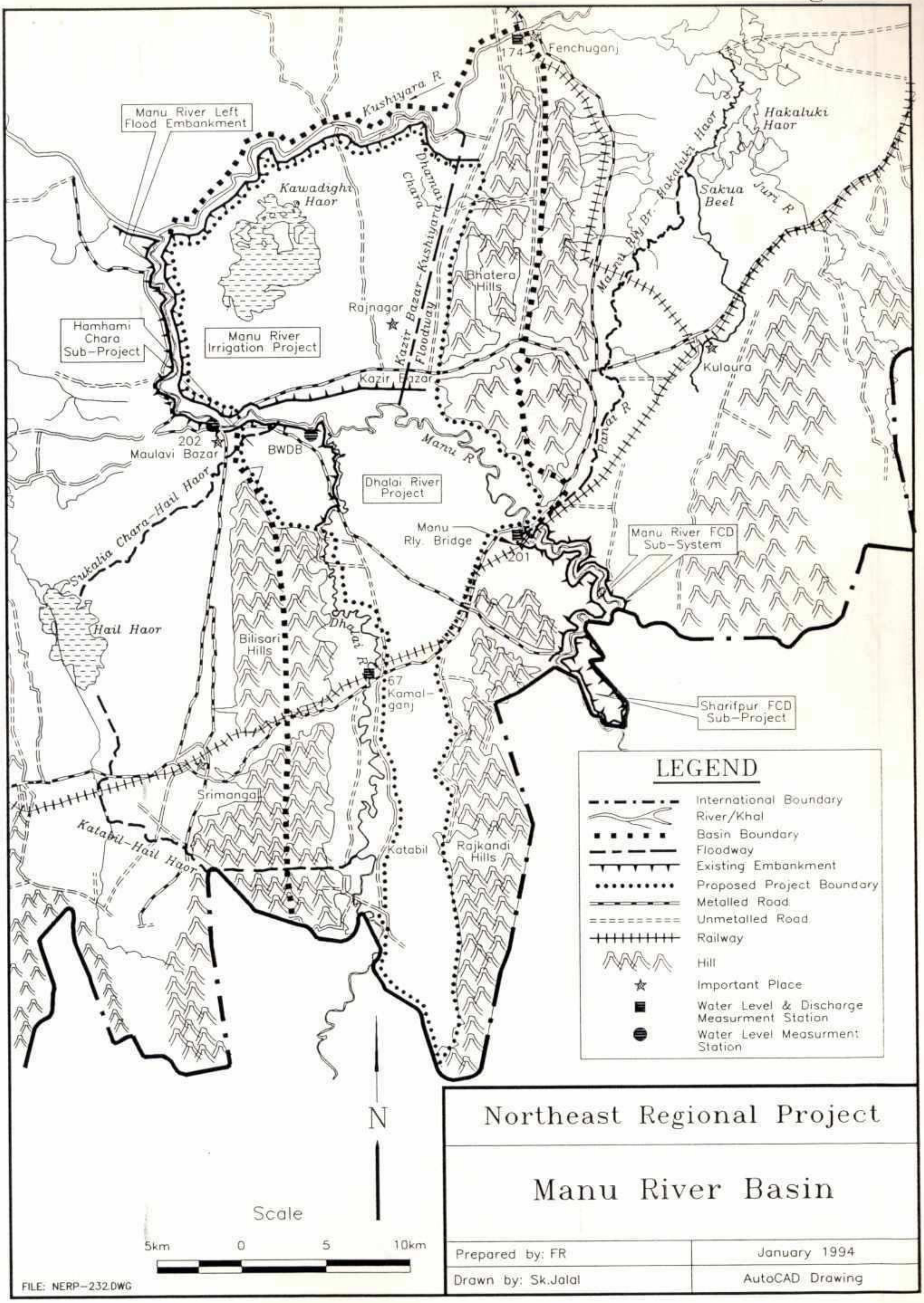
Environmental Screening Matrix

Screening matrix PHASE	Normal/ Abnormal	Activity / Important Environmental Component	Land Use	Agri-culture	Fisheries	Water Quality	Water Quantity	Human Health	Social Issues	Wild Plants & Animals	Hazards	Other
Construction (continued)	Abnormal (cont'd)											
Operation	Normal	Pre-monsoon flood protection		+	–	–						
		Monsoon flood protection		+	–	–						
		Surface water irrigation		+	–							
		Ground water irrigation N/A										
		Drainage										
		Agriculture: operation of institutions, extension, credit, seed distribution, fertilizer and pesticide storage and use, farmer groups		+		–						
		Water management: activities of BWDB, subproject implementation committee, local water user groups, structure committees and guards		+								
	Abnormal (relative to FWO, not FW normal)	Pre-monsoon flooding (due to extreme event, infrastructure failure)		–	+	+					–	
		Monsoon flooding (due to extreme event, infrastructure failure)		–	+	+					–	
		Embankment overtopping		–	+	+					–	
		Under- and over-drainage										
		Improper operation (public cuts, mistiming of scheduled O&M events etc)		–								
		Riverbed aggradation/degradation		–	+							
Abandonment	Normal	Re-occupation of infrastructure sites										
		Reclamation of materials										
	Abnormal											

ANNEX D

FIGURES

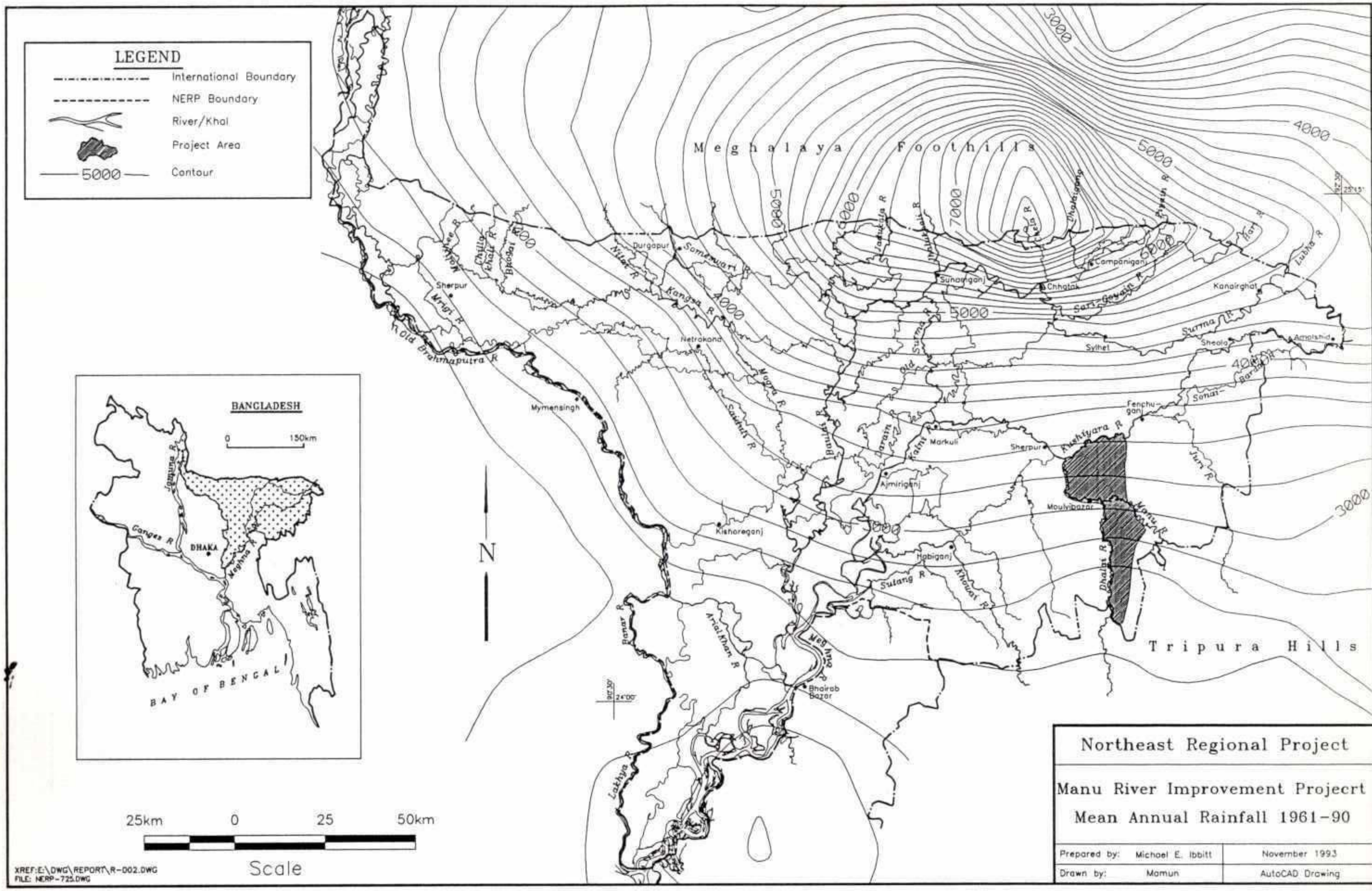
Figure 1



Northeast Regional Project

Manu River Basin

Prepared by: FR	January 1994
Drawn by: Sk.Jalal	AutoCAD Drawing



Northeast Regional Project

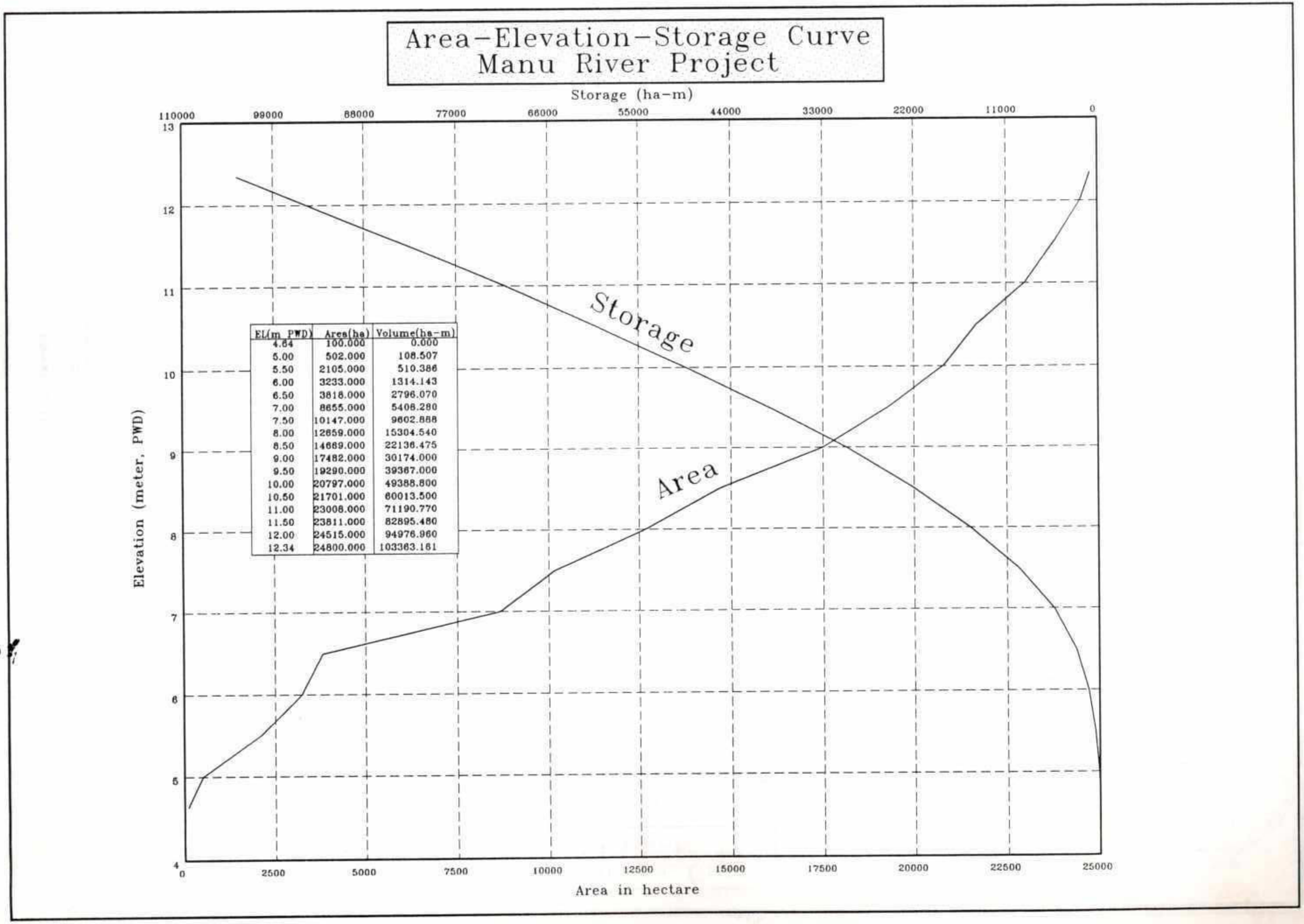
Manu River Improvement Projecrt

Mean Annual Rainfall 1961-90

Prepared by:	Michael E. Ibbitt	November 1993	
Drawn by:	Mamun	AutoCAD Drawing	

Figure 2

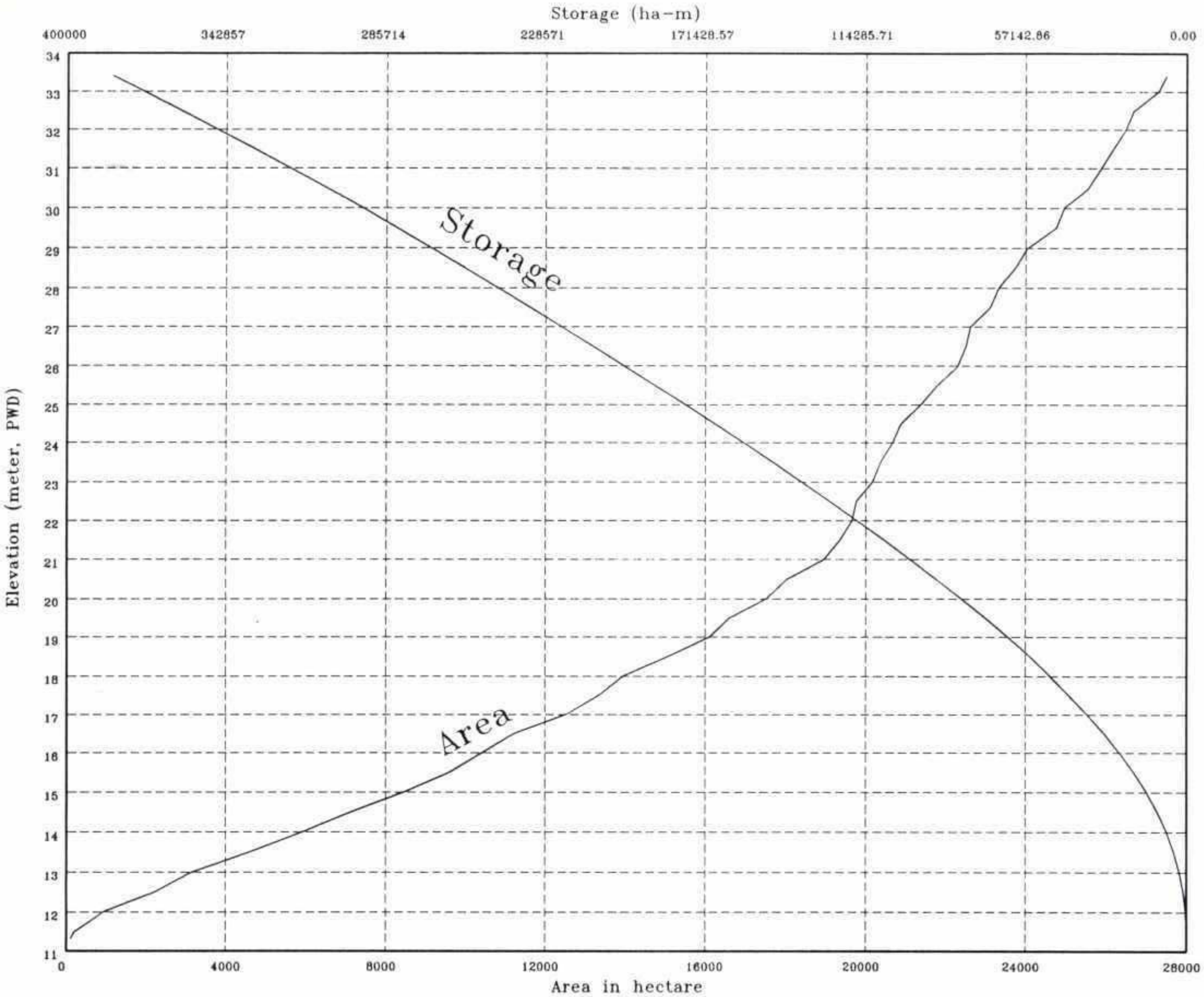
Figure 3



EL(m PWD)	Area(ha)	Volume(ha-m)
4.64	100.000	0.000
5.00	502.000	108.507
5.50	2105.000	510.386
6.00	3233.000	1314.143
6.50	3818.000	2796.070
7.00	8655.000	5408.280
7.50	10147.000	9602.888
8.00	12659.000	15304.540
8.50	14669.000	22136.475
9.00	17482.000	30174.000
9.50	19290.000	39367.000
10.00	20797.000	49388.800
10.50	21701.000	60013.500
11.00	23008.000	71190.770
11.50	23811.000	82895.480
12.00	24515.000	94976.960
12.34	24800.000	103363.161

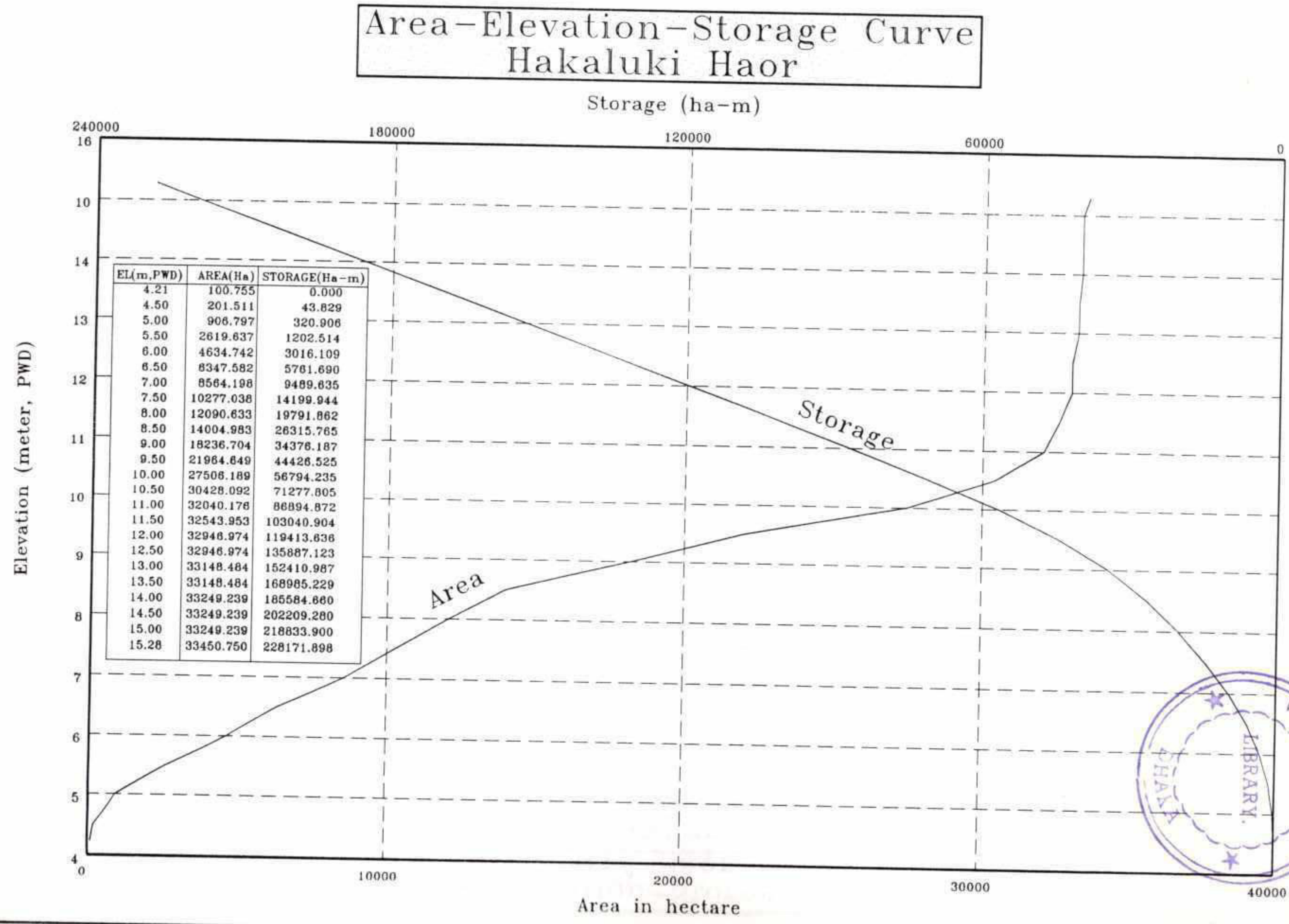
Figure 4

Area-Elevation-Storage Curve
Dhalai River Project



EL(m PWD)	Area(ha)	Volume(ha-m)
11.33	102.000	0.000
11.50	204.000	25.970
12.00	917.000	306.070
12.50	2241.000	1095.420
13.00	3157.000	2444.950
13.50	4563.000	4380.140
14.00	5907.000	7002.820
14.50	7130.000	10262.080
15.00	8454.000	14157.920
15.50	9574.000	18664.860
16.00	10389.000	23655.600
16.50	11204.000	29053.750
17.00	12528.000	34986.620
17.50	13343.000	41454.210
18.00	13954.000	48278.290
18.50	15074.000	55535.230
19.00	16093.000	63326.900
19.50	16602.000	71500.510
20.00	17519.000	80030.600
20.50	18028.000	88917.180
21.00	18944.000	98160.230
21.50	19352.000	107734.310
22.00	19657.000	117486.620
22.50	19759.000	127340.790
23.00	20167.000	137322.270
23.50	20370.000	147456.530
24.00	20676.000	157718.100
24.50	20880.000	168106.990
25.00	21389.000	178674.120
25.50	21796.000	189470.420
26.00	22306.000	200495.880
26.50	22509.000	211699.580
27.00	22611.000	222979.680
27.50	23120.000	234412.550
28.00	23324.000	246023.660
28.50	23731.000	257787.550
29.00	24037.000	269729.680
29.50	24750.000	281926.440
30.00	24954.000	294352.360
30.50	25565.000	306981.990
31.00	25870.000	319840.790
31.50	26176.000	332852.360
32.00	26481.000	346016.710
32.50	26685.000	359308.380
33.00	27296.000	372803.750
33.40	27500.000	383763.010

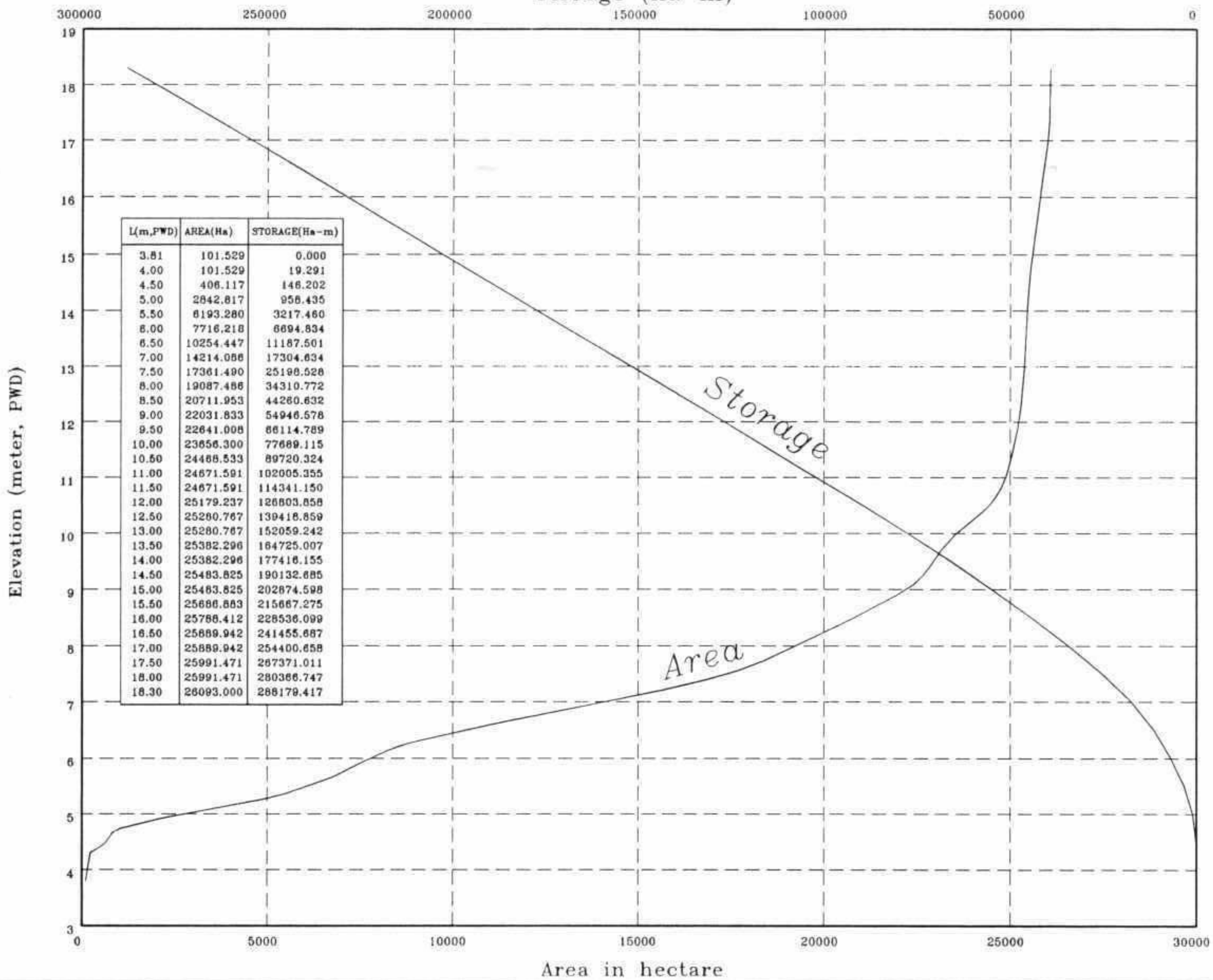
Figure 5



EL(m,PWD)	AREA(Ha)	STORAGE(Ha-m)
4.21	100.755	0.000
4.50	201.511	43.829
5.00	906.797	320.906
5.50	2619.637	1202.514
6.00	4634.742	3016.109
6.50	6347.582	5761.690
7.00	8564.198	9489.635
7.50	10277.038	14199.944
8.00	12090.633	19791.862
8.50	14004.983	26315.765
9.00	18236.704	34376.187
9.50	21964.649	44426.525
10.00	27506.189	56794.235
10.50	30428.092	71277.805
11.00	32040.176	86894.872
11.50	32543.953	103040.904
12.00	32946.974	119413.636
12.50	32946.974	135887.123
13.00	33148.484	152410.987
13.50	33148.484	168985.229
14.00	33249.239	185584.660
14.50	33249.239	202209.280
15.00	33249.239	218833.900
15.28	33450.750	228171.898

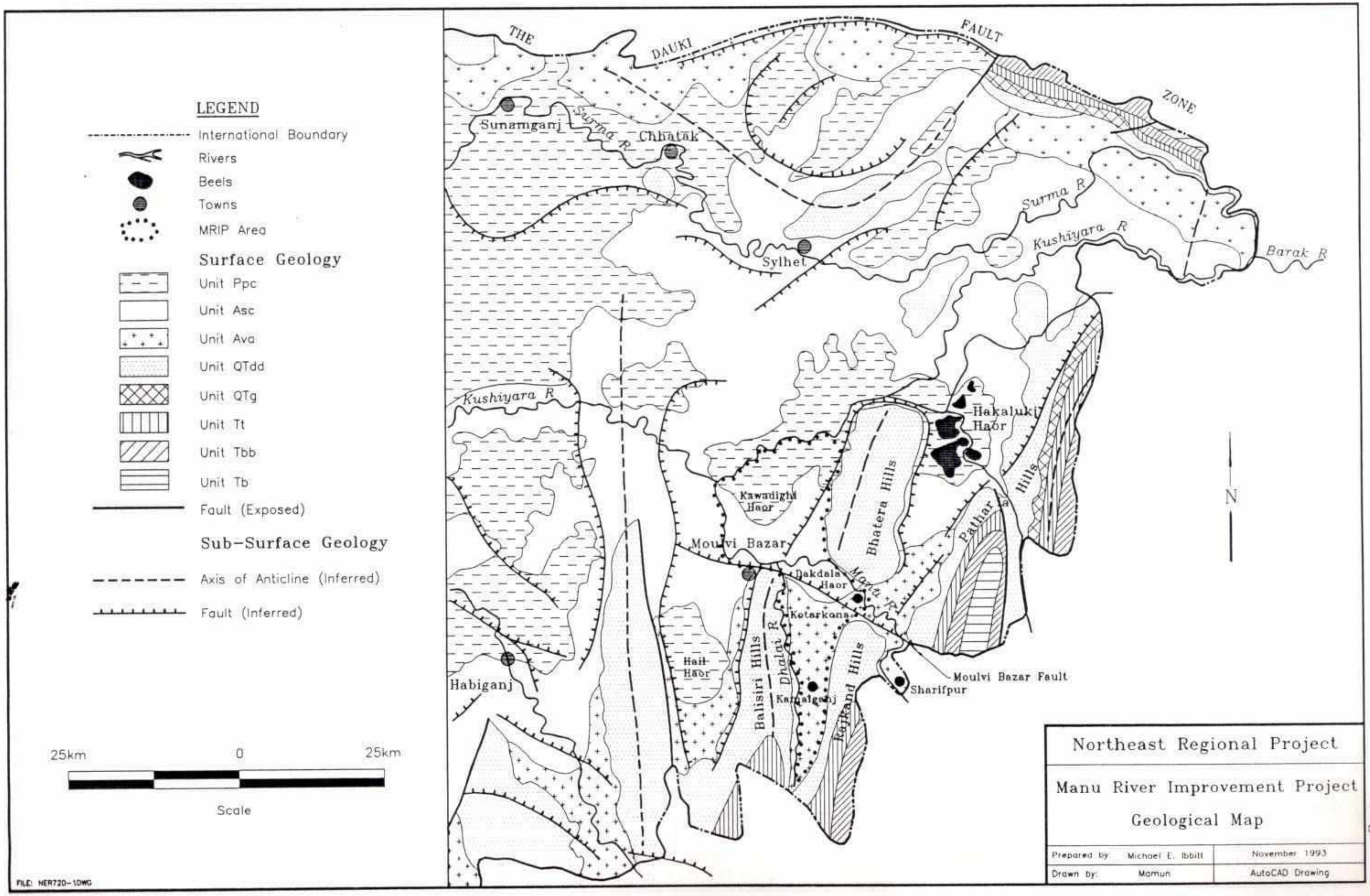
Figure 6

Area-Elevation-Storage Curve
Hail Haor



L(m,PWD)	AREA(Ha)	STORAGE(Ha-m)
3.81	101.529	0.000
4.00	101.529	19.291
4.50	406.117	146.202
5.00	2842.817	956.435
5.50	6193.280	3217.460
6.00	7716.218	6694.834
6.50	10254.447	11187.501
7.00	14214.086	17304.634
7.50	17361.490	25198.528
8.00	19087.486	34310.772
8.50	20711.953	44260.632
9.00	22031.833	54946.578
9.50	22641.008	66114.789
10.00	23656.300	77689.115
10.50	24468.533	89720.324
11.00	24671.591	102005.355
11.50	24671.591	114341.150
12.00	25179.237	126803.858
12.50	25280.767	139418.859
13.00	25280.767	152059.242
13.50	25382.296	164725.007
14.00	25382.296	177416.155
14.50	25483.825	190132.685
15.00	25483.825	202874.598
15.50	25686.883	215667.275
16.00	25788.412	228536.099
16.50	25889.942	241455.687
17.00	25889.942	254400.658
17.50	25991.471	267371.011
18.00	25991.471	280366.747
18.30	26093.000	288179.417

Figure 7


LEGEND
International Boundary
Rivers
Beels
Towns
MRIP Area
Surface Geology
Unit Ppc
Unit Asc
Unit Ava
Unit QTdd
Unit QTg
Unit Tt
Unit Tbb
Unit Tb
Fault (Exposed)
Sub-Surface Geology
Axis of Anticline (Inferred)
Fault (Inferred)
25km
0
25km
Scale
FILE: NER720-1DWG
THE DAUKI FAULT ZONE
Sunamganj
Surma R
Chhatak
Sylhet
Surma R
Kushiyara R
Barak R
Kushiyara R
Hakaluki Haor
Hills
Pathar
Bhatera Hills
Kawadighi Haor
Moulvi Bazar
Dakdala Haor
Manu R
Kotarkona
Hail Haor
Balisiri Hills
Dhalai R
Kamalganj
Rajkand Hills
Moulvi Bazar Fault
Sharifpur
Habiganj
N
Northeast Regional Project
Manu River Improvement Project
Geological Map
Prepared by: Michael E. Ibbitt
November 1993
Drawn by: Mamun
AutoCAD Drawing

286

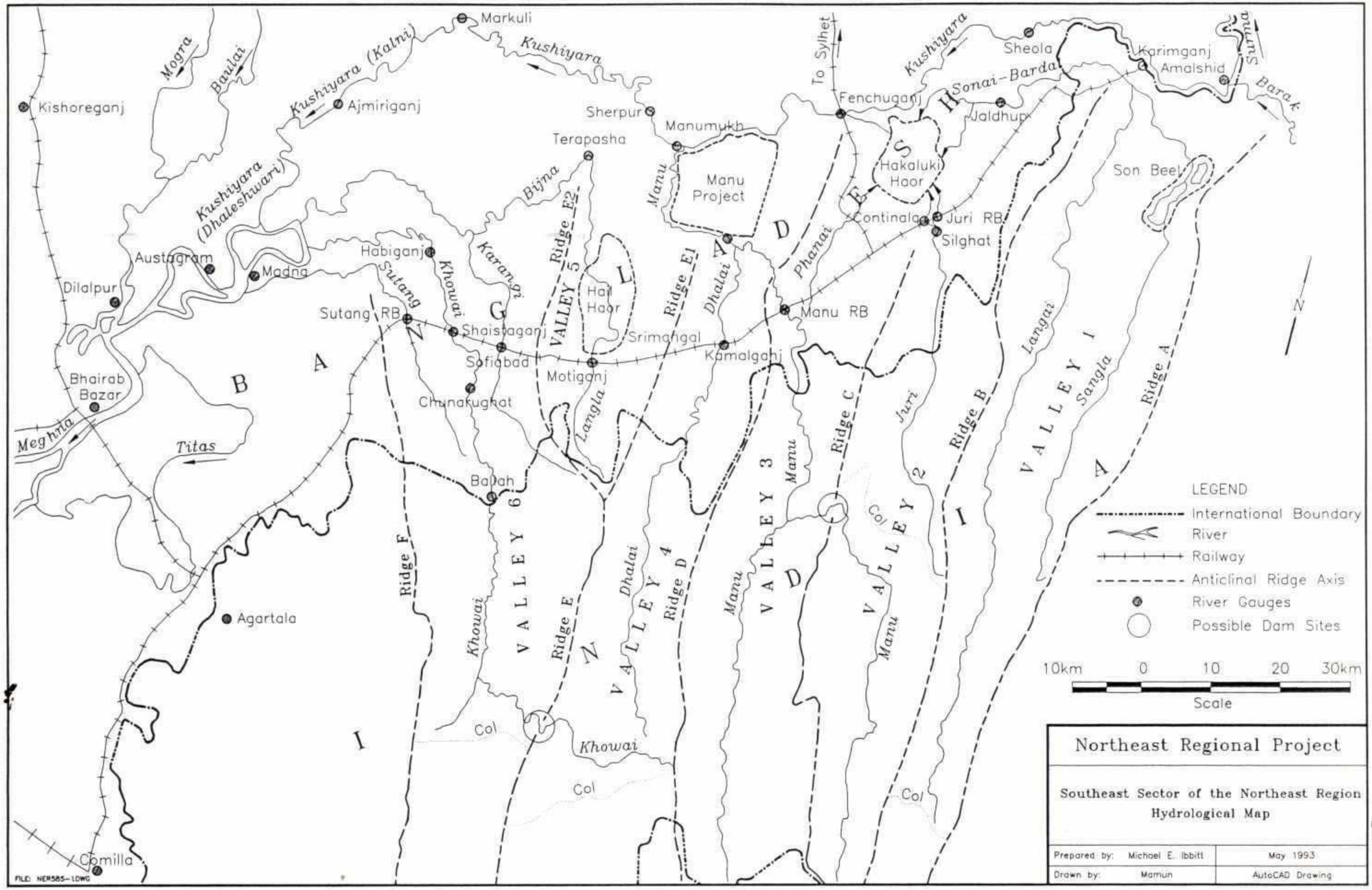
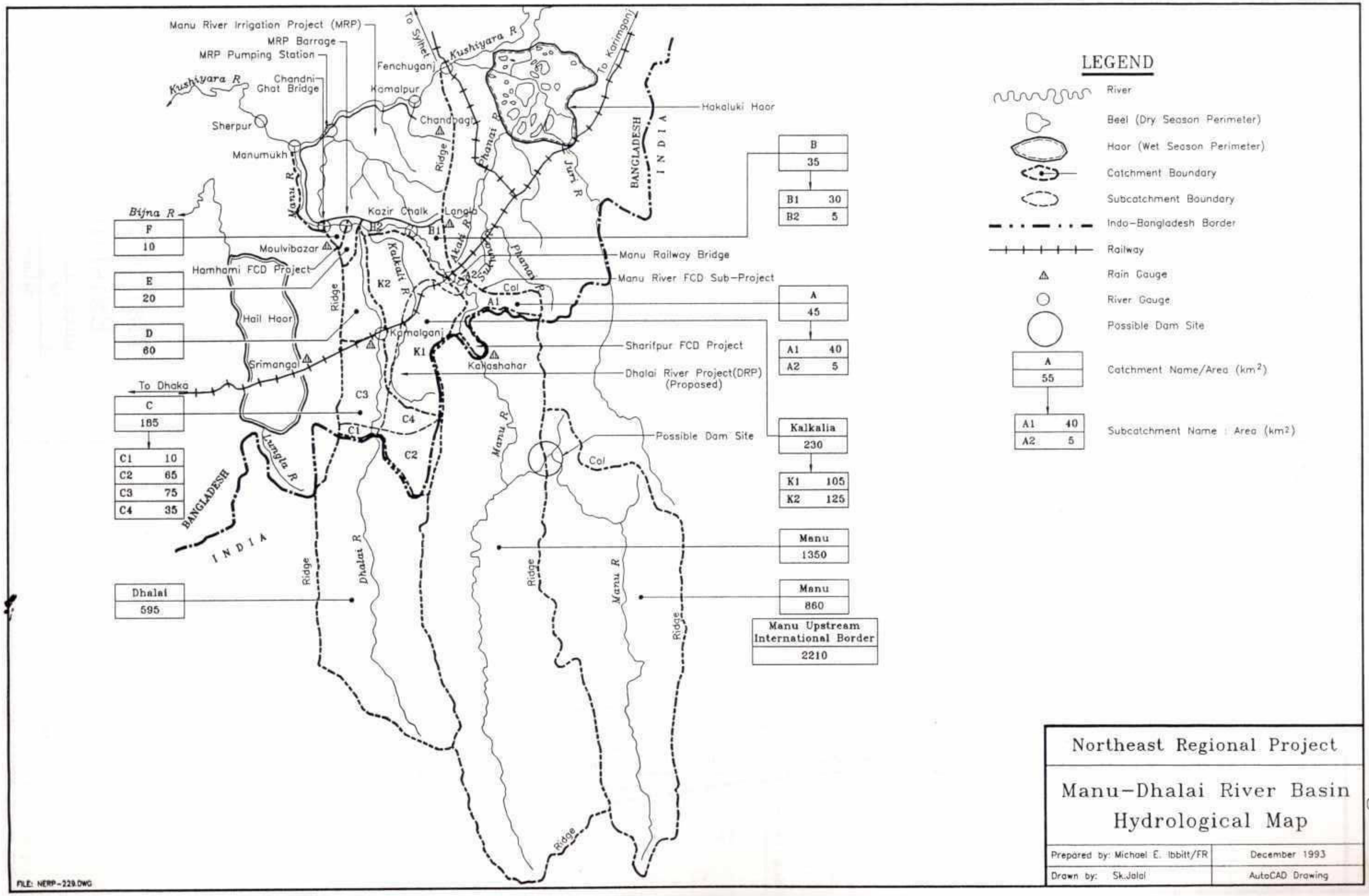
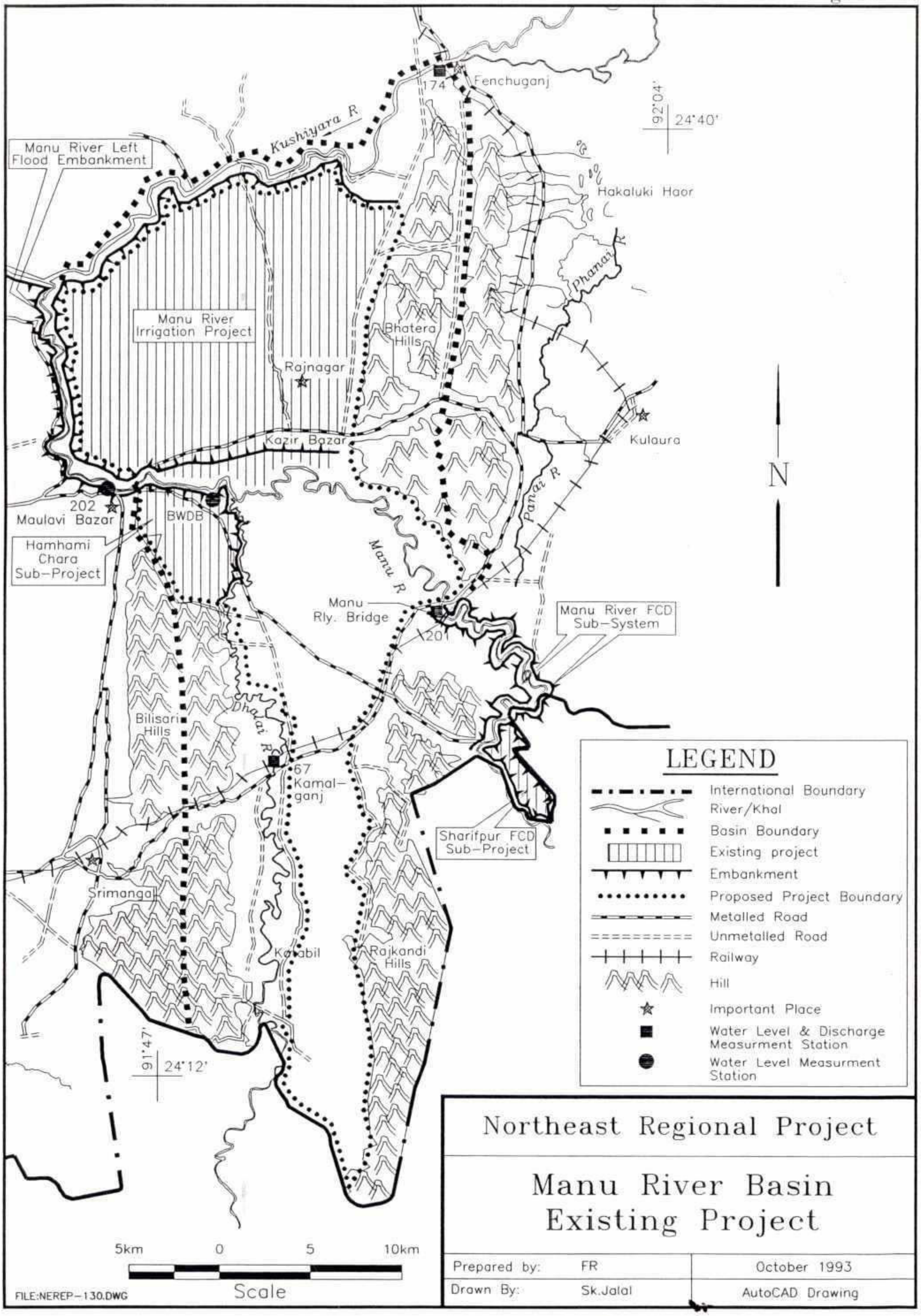

Northeast Regional Project
Southeast Sector of the Northeast Region
Hydrological Map
Prepared by: Michael E. Ibbitt
May 1993
Drawn by: Mamun
AutoCAD Drawing
LEGEND
International Boundary
River
Railway
Anticlinal Ridge Axis
River Gauges
Possible Dam Sites
10km 0 10 20 30km
Scale
N
B A N G L A D E S H
I N D I A
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
Kishoreganj
Markuli
Ajmiriganj
Kushiyara (Kalni)
Kushiyara
Kushiyara (Dhaleshwari)
Mogra
Baulai
Austagram
Madna
Dilalpur
Bhairab Bazar
Meghna
Titas
Agartala
Comilla
Habiganj
Sutang
Sutang RB
Khowai
Karangi
Bijna
Terapasha
Sherpur
Manumukh
Manu
Manu Project
Hail Haor
Shaistaganj
Sofiabad
Chunarughat
Motiganj
Srimangal
Kamalganj
Langla
Dhalai
Balla
Manu RB
Phanai
To Sylhet
Fenchuganj
Hakaluki Haor
Continala
Juri RB
Silghat
Juri
Jaldhup
Sonai-Barda
Sheola
Karimganj
Amalshid
Surma
Barak
Son Beel
Langai
Sangla
Col
FILE: NER585-1.DWG

Figure 8

Figure 9


Manu River Irrigation Project (MRP)
MRP Barrage
MRP Pumping Station
Chandni-Ghat Bridge
Kushiyara R
Sherpur
Manumukh
Fenchuganj
Komalpur
To Sylhet
Kushiyara R
To Karimganj
Chandbagh
Hakaluki Haor
BANGLADESH
INDIA
Juri R
Phanai R
Ridge
Bijna R
Kazir Chalk
Langla
B1
B2
Moulvibazar
Hamhami FCD Project
Manu R
Kalkali R
Akali R
Sukhnai
Phanai R
Col
A1
A2
K2
K1
Hail Haor
Kamalganj
Kamalashahar
Srimangal
To Dhaka
C3
C4
C1
C2
Langla R
BANGLADESH
INDIA
Dhalai R
Manu R
Manu R
Ridge
Possible Dam Site
Manu Railway Bridge
Manu River FCD Sub-Project
Sharifpur FCD Project
Dhalai River Project(DRP) (Proposed)
F 10
E 20
D 60
C 185
C1 10
C2 65
C3 75
C4 35
Dhalai 595
B 35
B1 30
B2 5
A 45
A1 40
A2 5
Kalkalia 230
K1 105
K2 125
Manu 1350
Manu 860
Manu Upstream International Border 2210
LEGEND
River
Beel (Dry Season Perimeter)
Haor (Wet Season Perimeter)
Catchment Boundary
Subcatchment Boundary
Indo-Bangladesh Border
Railway
Rain Gauge
River Gauge
Possible Dam Site
A 55
Catchment Name/Area (km²)
A1 40
A2 5
Subcatchment Name : Area (km²)
Northeast Regional Project
Manu-Dhalai River Basin Hydrological Map
Prepared by: Michael E. Ibbitt/FR
December 1993
Drawn by: Sk.Jalal
AutoCAD Drawing
FILE: NERP-229.DWG

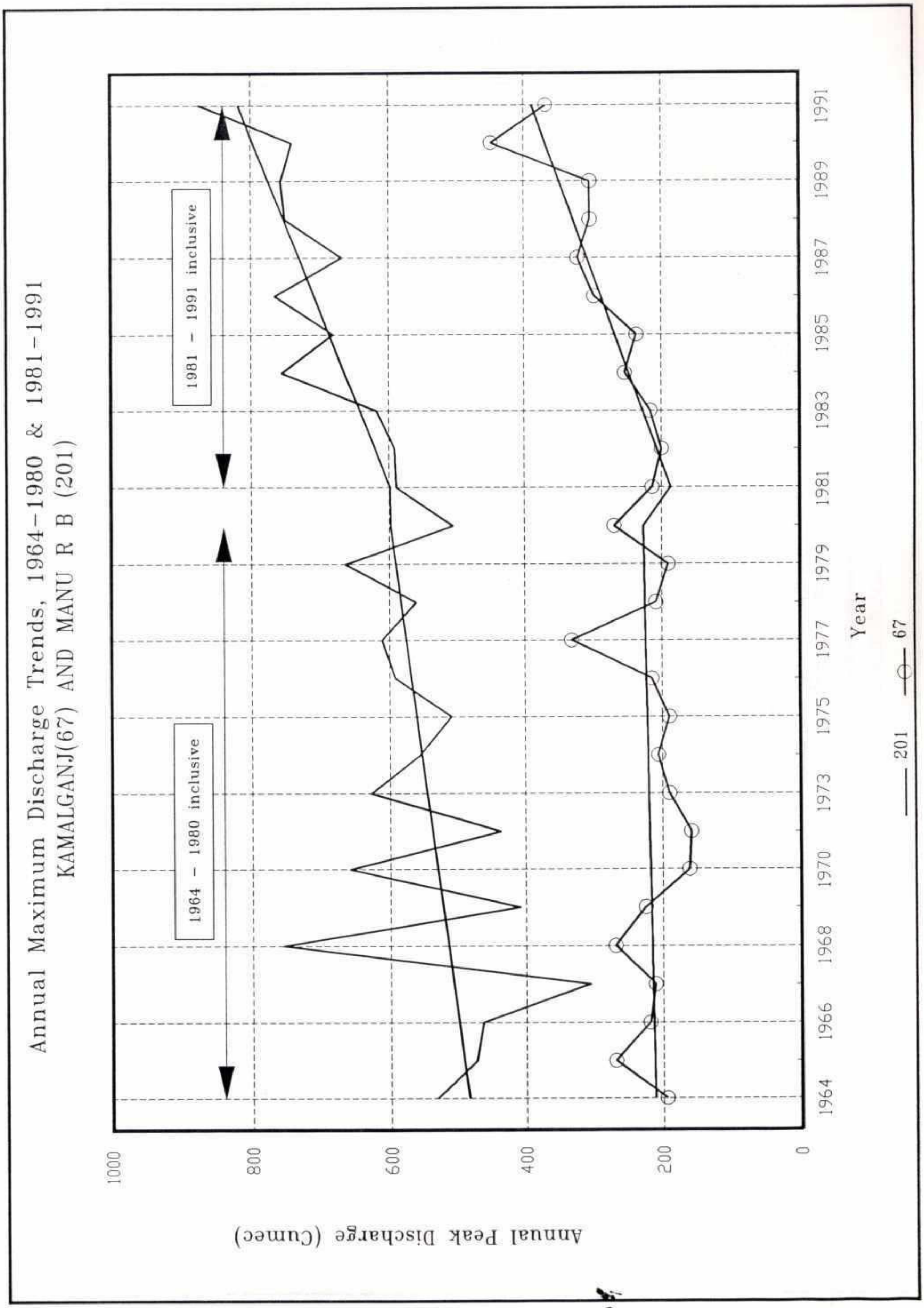


Northeast Regional Project

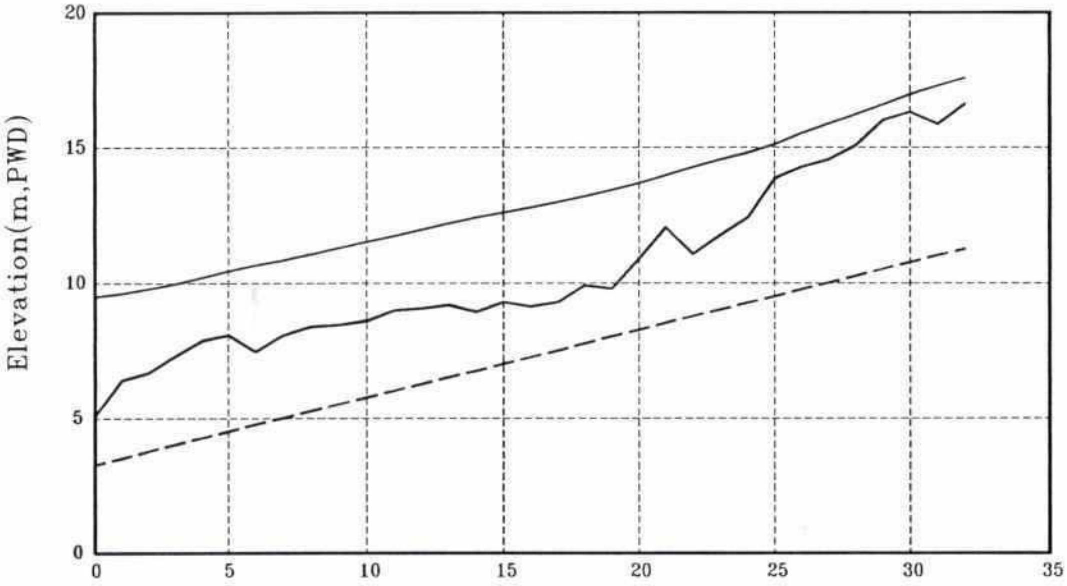
Manu River Basin Existing Project

Prepared by:	FR	October 1993
Drawn By:	Sk.Jalal	AutoCAD Drawing

Figure 11


Annual Maximum Discharge Trends, 1964-1980 & 1981-1991
KAMALGANJ(67) AND MANU R B (201)
1964 - 1980 inclusive
1981 - 1991 inclusive
Annual Peak Discharge (Cumec)
1000
800
600
400
200
0
1964
1966
1968
1970
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
Year
201
67

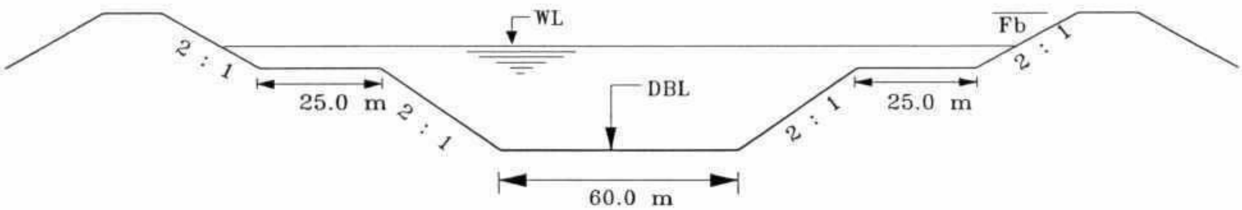
LONG PROFILES OF DIVERSION CHANNEL



LEGEND :

WL ———— DBL - - - - - - - - GL

Free board = 0.91 m
Manning's n = 0.03
Design bed slope = 25 cm/km
Design bed width = 60 m

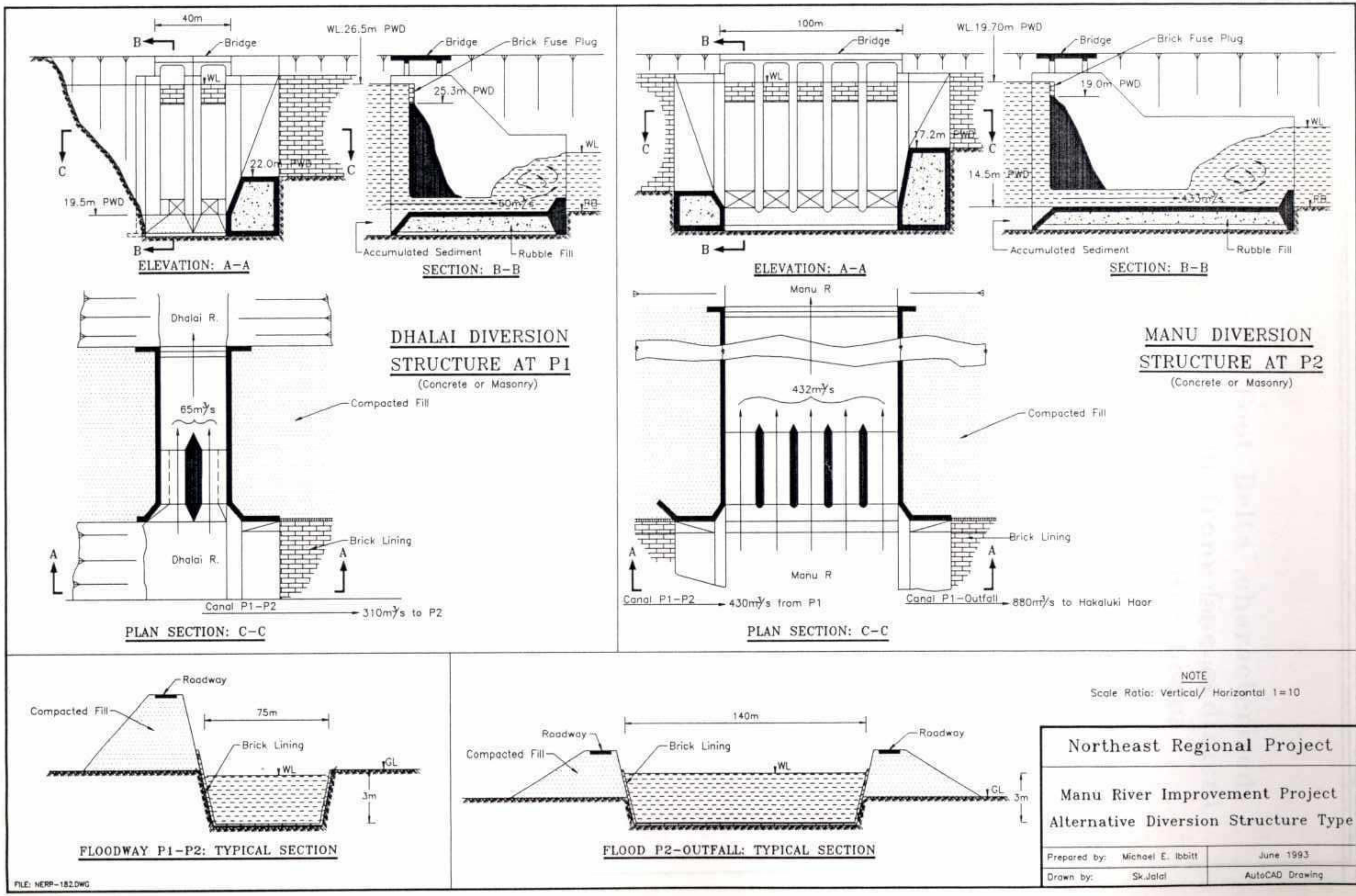


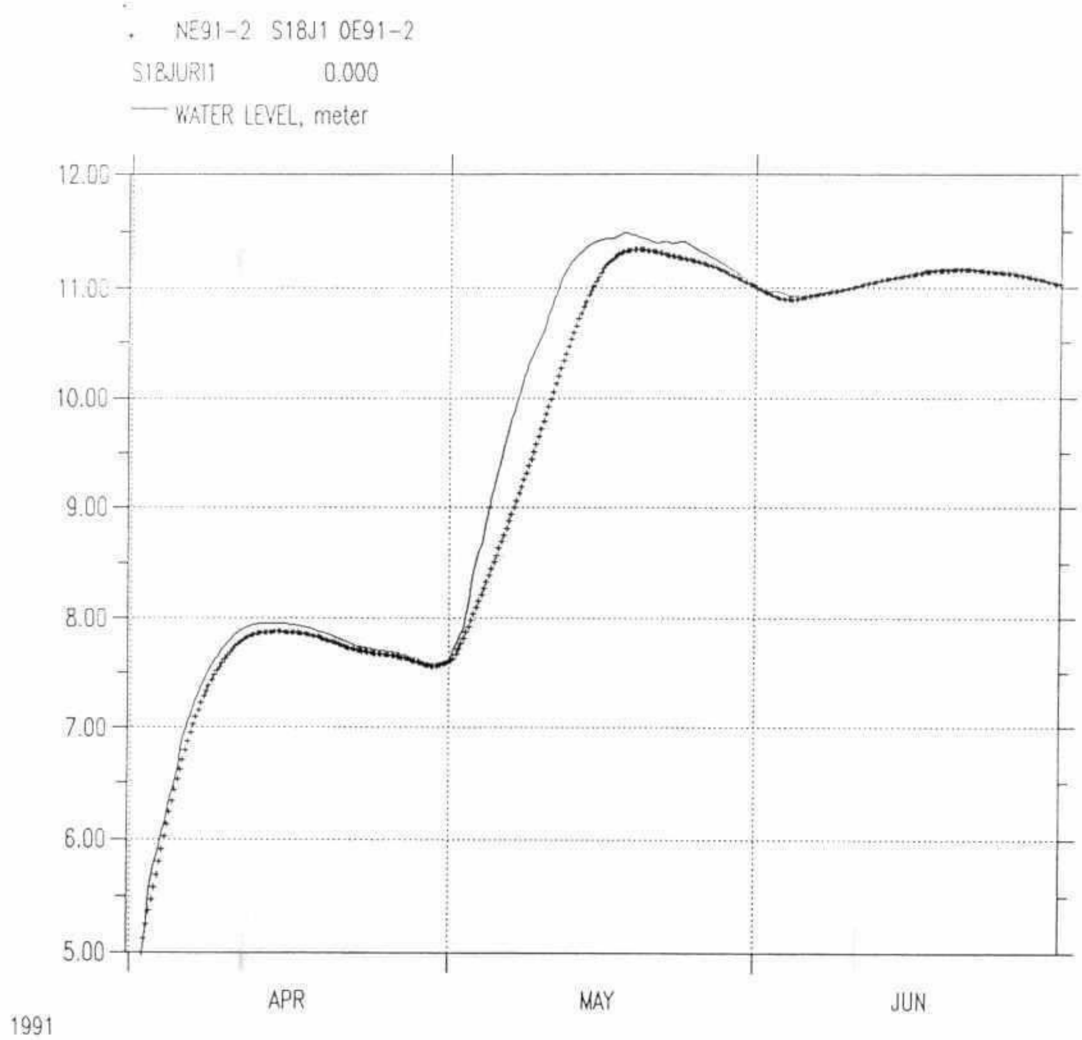
Typical Design X-Section

Data :

Distance(km)	0.00	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00	32.00
Gl(m,PWD)	5.09	6.68	7.87	7.47	8.39	8.60	9.06	8.93	9.12	9.91	10.91	11.04	12.41	14.30	15.09	16.31	16.61
DBL(m,PWD)	3.26	3.76	4.26	4.76	5.26	5.76	6.26	6.76	7.26	7.76	8.26	8.76	9.26	9.76	10.26	10.76	11.26
CWL(m,PWD)	9.48	9.78	10.19	10.65	11.06	11.51	11.96	12.41	12.80	13.19	13.69	14.28	14.80	15.51	16.22	16.97	17.57

Figure 13


DHALAI DIVERSION STRUCTURE AT P1
(Concrete or Masonry)
ELEVATION: A-A
40m
Bridge
WL
22.0m PWD
19.5m PWD
WL.26.5m PWD
SECTION: B-B
Bridge
Brick Fuse Plug
25.3m PWD
WL
RB
Accumulated Sediment
Rubble Fill
PLAN SECTION: C-C
Dhalai R.
65m³/s
Compacted Fill
Brick Lining
Canal P1-P2
310m³/s to P2
MANU DIVERSION STRUCTURE AT P2
(Concrete or Masonry)
ELEVATION: A-A
100m
Bridge
WL
17.2m PWD
14.5m PWD
WL.19.70m PWD
SECTION: B-B
Bridge
Brick Fuse Plug
19.0m PWD
433m³/s
RB
Accumulated Sediment
Rubble Fill
PLAN SECTION: C-C
Manu R
432m³/s
Compacted Fill
Brick Lining
Canal P1-P2
430m³/s from P1
Canal P1-Outfall
880m³/s to Hakaluki Haor
FLOODWAY P1-P2: TYPICAL SECTION
Roadway
Compacted Fill
75m
Brick Lining
WL
GL
3m
FLOOD P2-OUTFALL: TYPICAL SECTION
140m
Roadway
Compacted Fill
Brick Lining
WL
GL
3m
NOTE
Scale Ratio: Vertical/ Horizontal 1=10
Northeast Regional Project
Manu River Improvement Project
Alternative Diversion Structure Type
Prepared by: Michael E. Ibbitt
June 1993
Drawn by: Sk.Jalal
AutoCAD Drawing
FILE: NERP-182.DWG



Plus Line(++):Prediversion ; Solid Line: Post-diversion
Outflow Point (Diversion) at Manu River Rly. Bridge
Inflow Point at Hakaluki Haor (S18JURI1 0.00 Km.)

Growth of a "Bird's Foot Delta",characterized by natural levee formation from fine sediment deposition in a shallow water body.

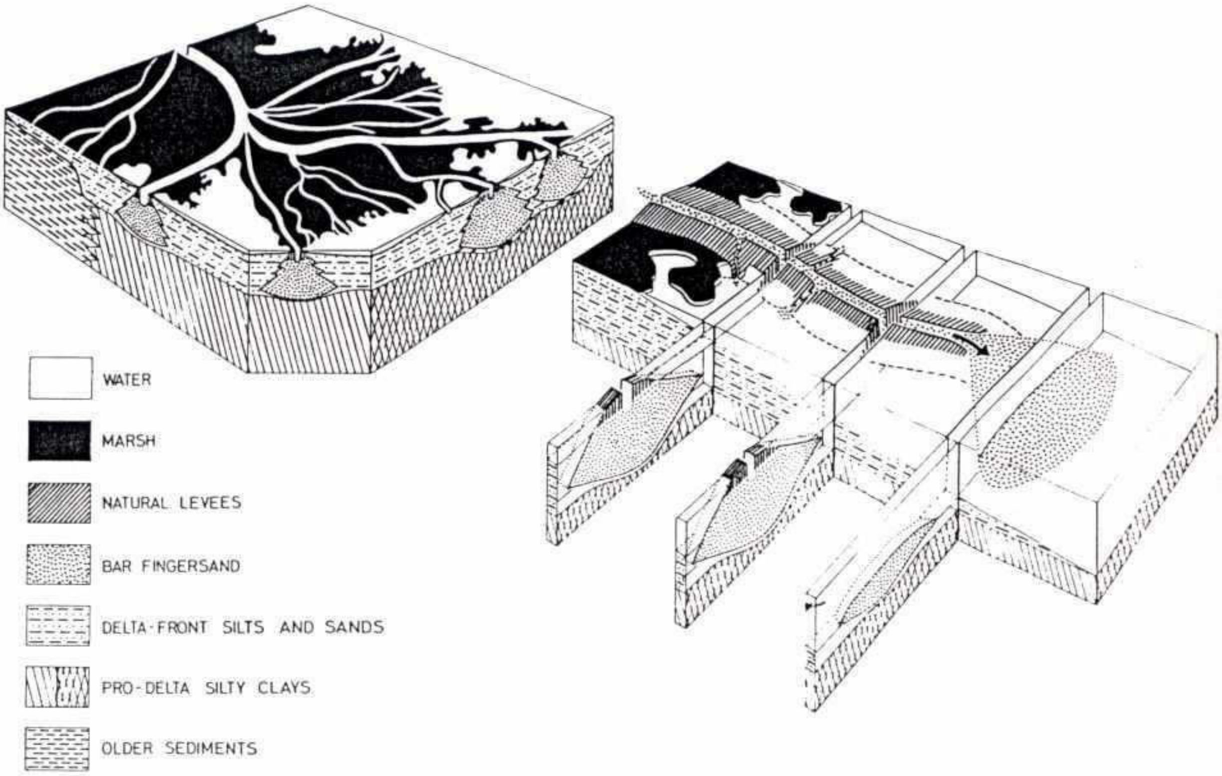


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Figure 17

ANNUAL RAINFALL TREND 1964 TO 1989

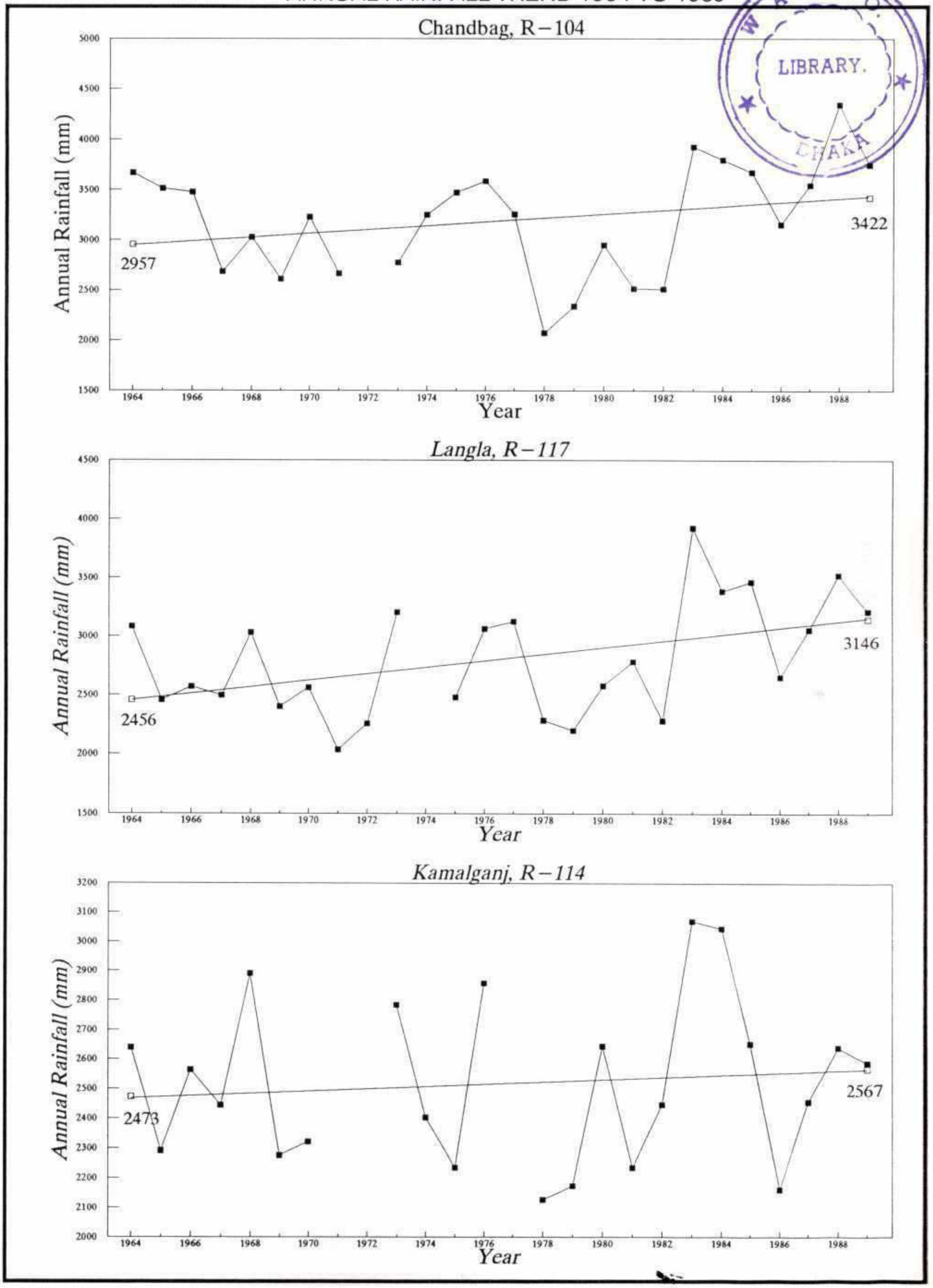


Figure 18

ANNUAL RAINFALL TREND 1964 TO 1989

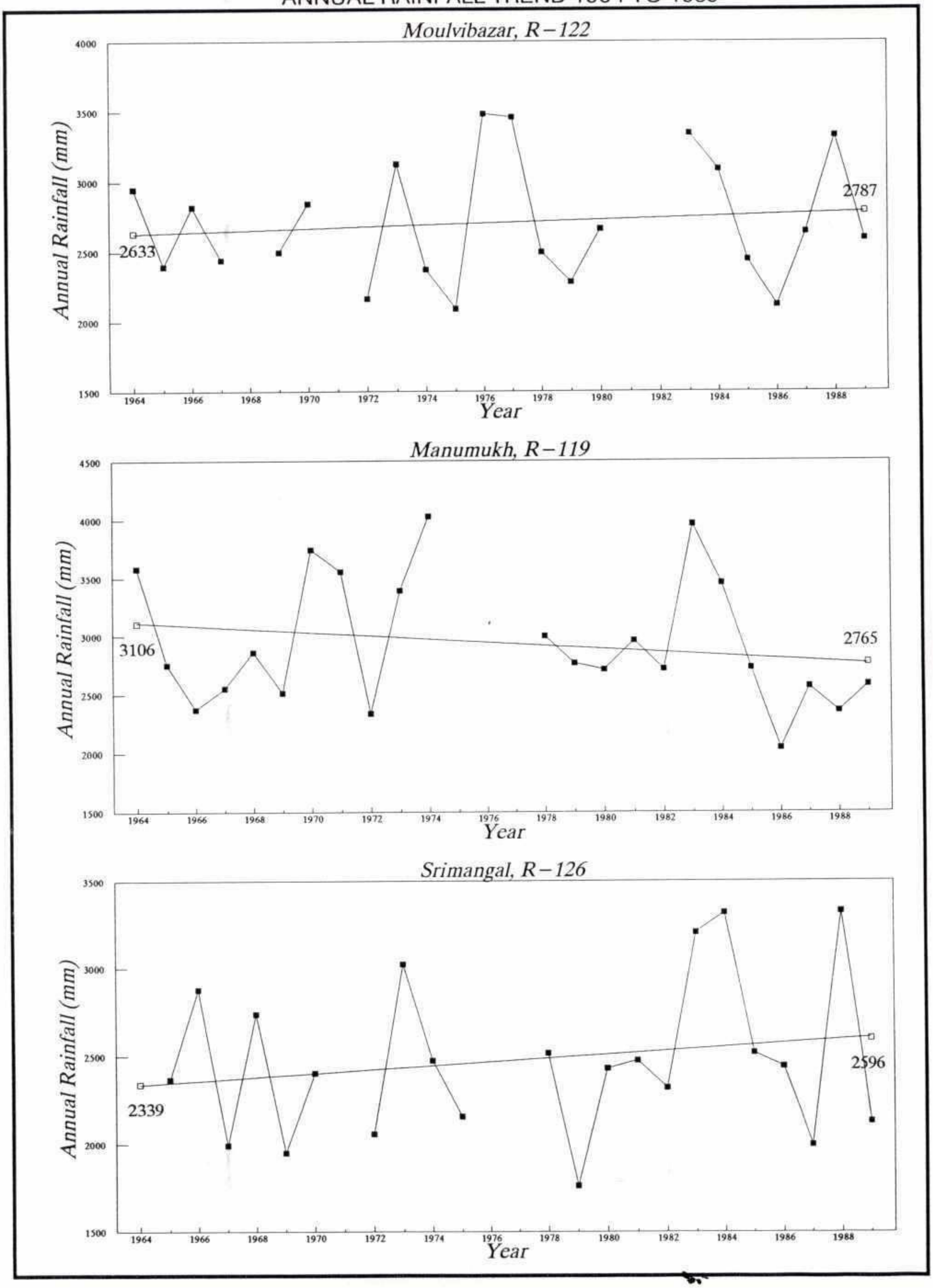
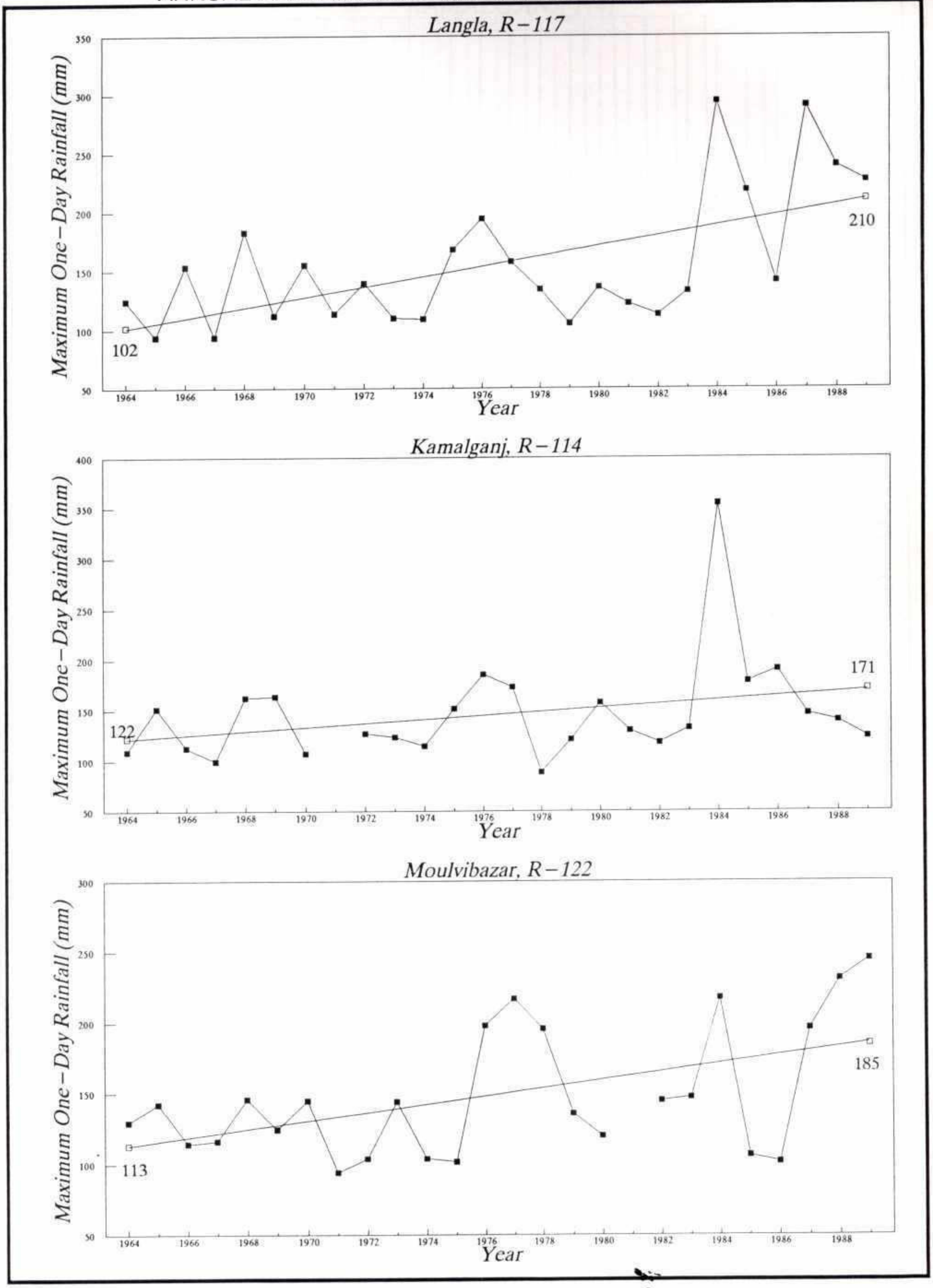


Figure 19

ANNUAL MAXIMUM ONE-DAY RAINFALL TREND 1964-1989



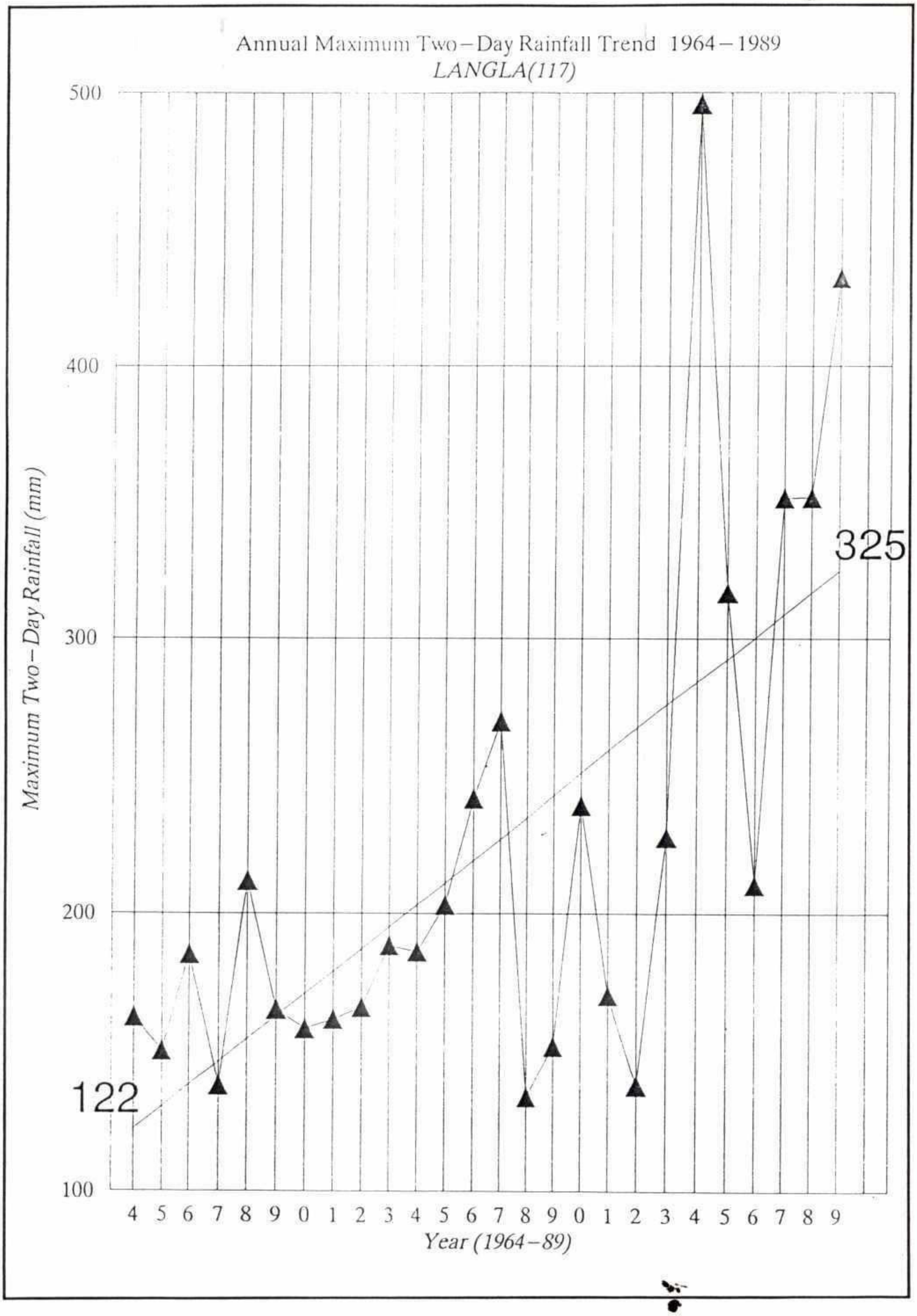
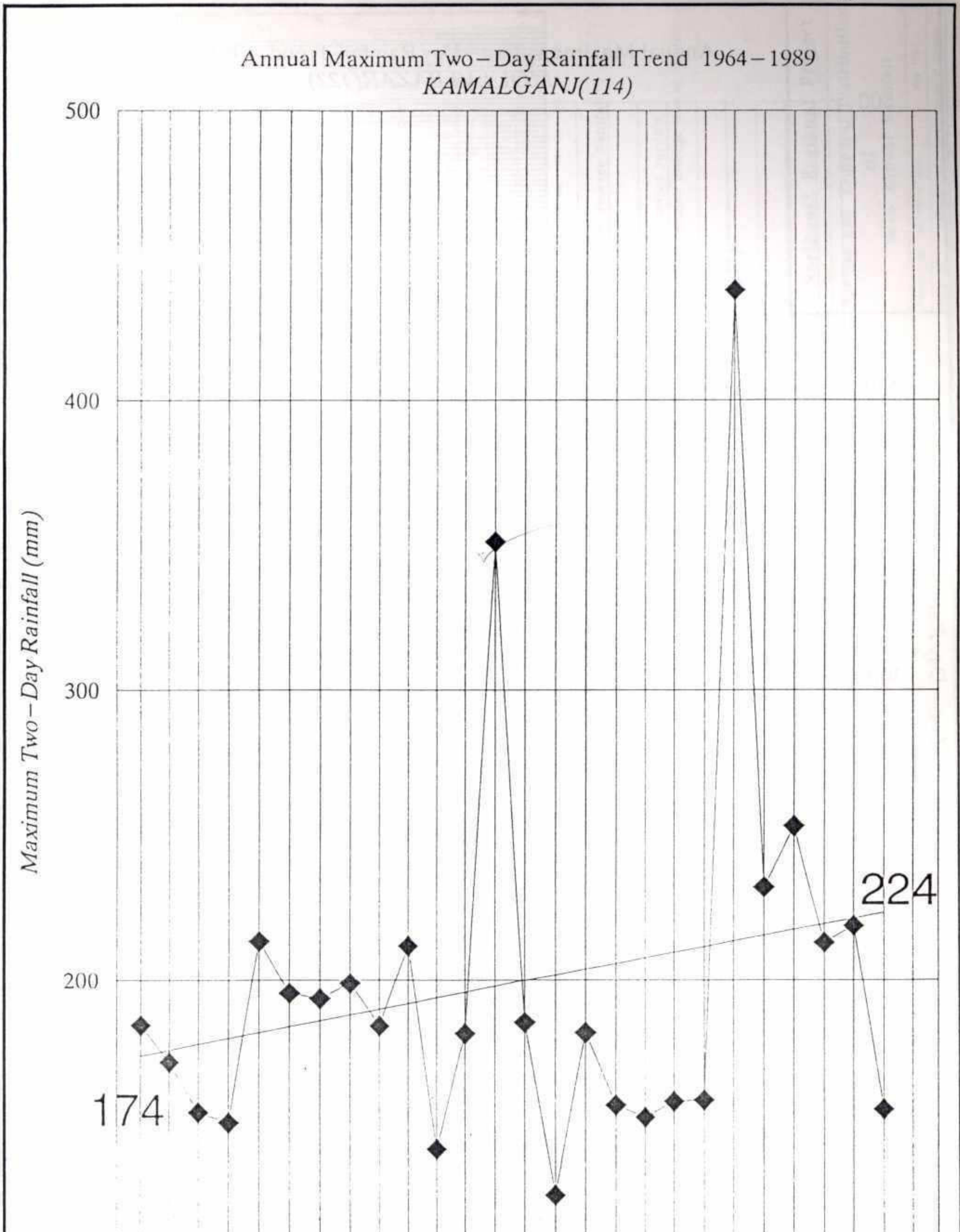

Annual Maximum Two – Day Rainfall Trend 1964 – 1989
LANGLA(117)
500
400
300
200
100
Maximum Two – Day Rainfall (mm)
325
122
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964 – 89)

Figure 21



Annual Maximum Two-Day Rainfall Trend 1964-1989
KAMALGANJ(114)
500
400
300
200
100
Maximum Two-Day Rainfall (mm)
224
174
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964-89)

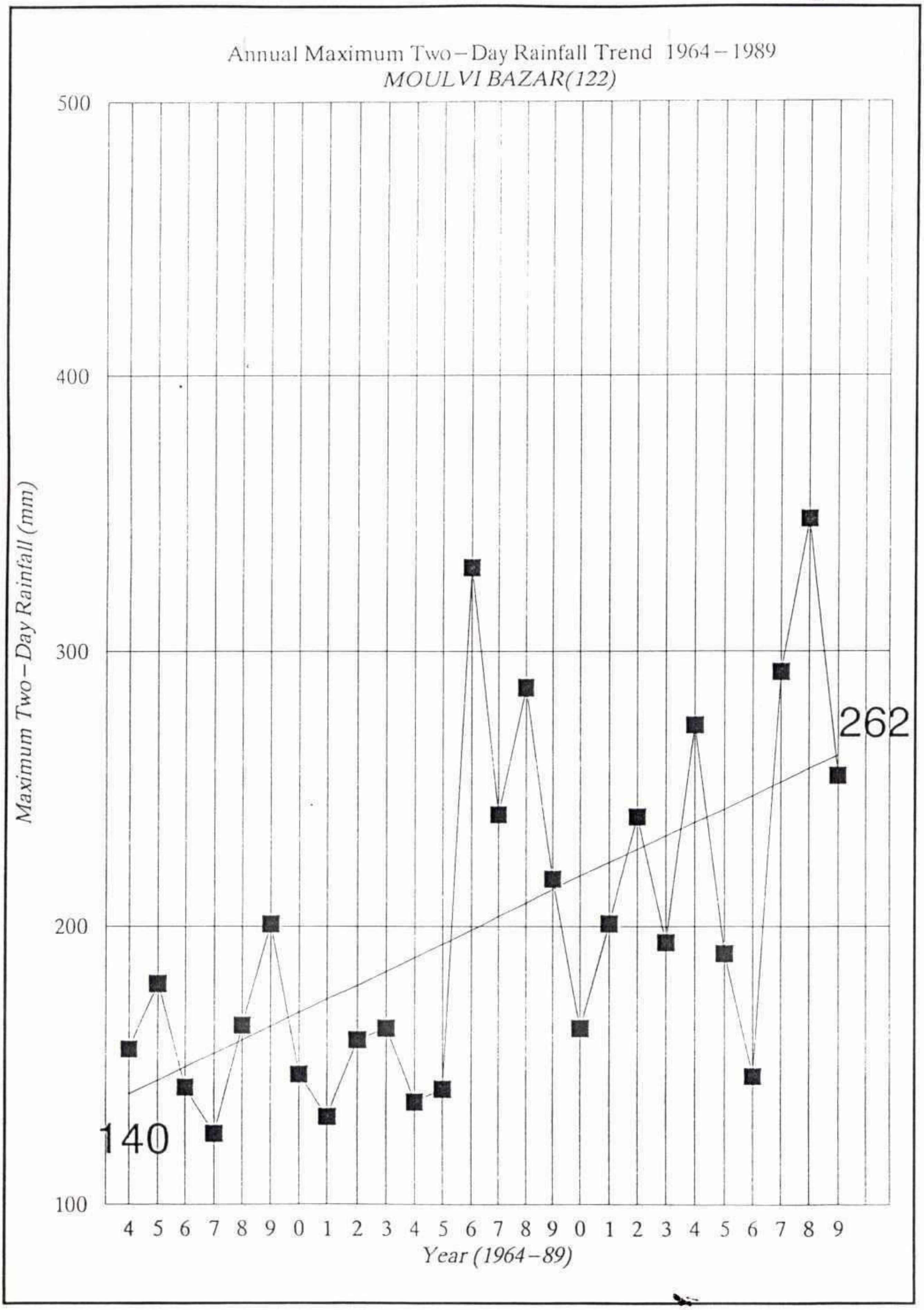
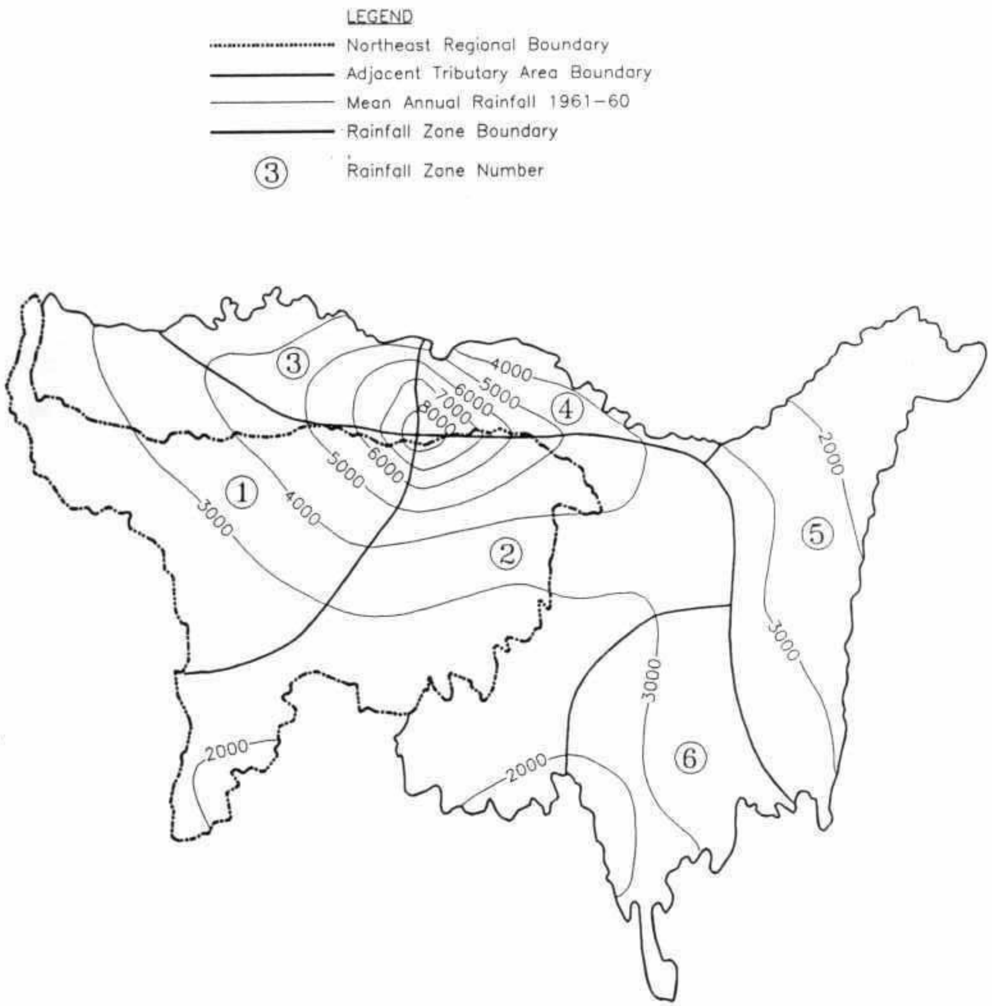
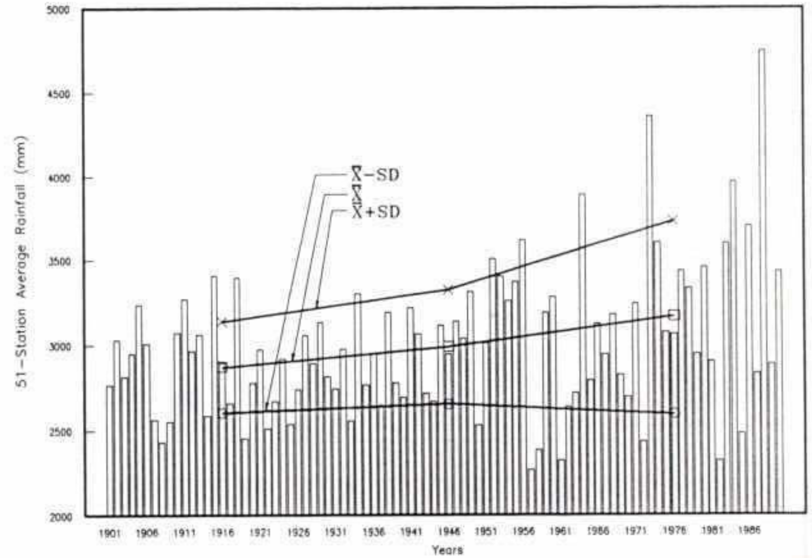

Annual Maximum Two-Day Rainfall Trend 1964-1989
MOULVI BAZAR(122)
Maximum Two-Day Rainfall (mm)
500
400
300
200
100
262
140
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964-89)

Figure 23



Rainfall Zones of the Northeast Region
and Adjacent Tributary Areas

(A)



Time Variation of the 51-Station Average Rainfall

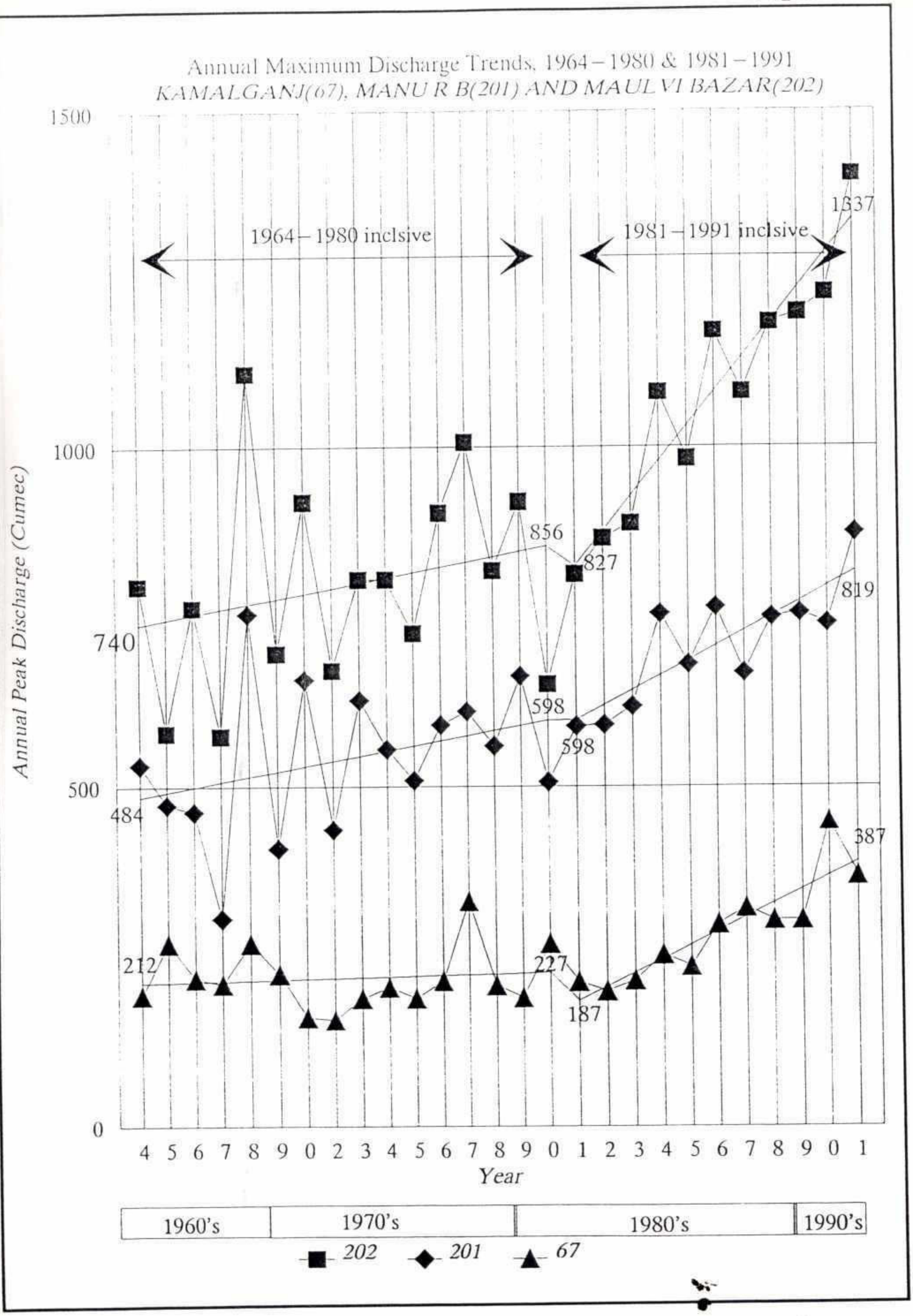
NOTE
X= mean of 30 years of 51-station average annual rainfalls
SD= standard deviation of 30 years of 51-station average annual rainfalls

(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-754.DWG

Figure 24



Annual Maximum Discharge Trends, 1964 – 1980 & 1981 – 1991
KAMALGANJ(67), MANU R B(201) AND MAULVI BAZAR(202)
1500
1000
500
0
Annual Peak Discharge (Cumec)
1964 – 1980 inclsive
1981 – 1991 inclsive
1337
856
827
740
819
598
598
484
387
212
227
187
4 5 6 7 8 9 0 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Year
1960's
1970's
1980's
1990's
202
201
67

Figure 25

ANNUAL MAXIMUM ONE-DAY RAINFALL TREND 1964-1980 & 1981-1989

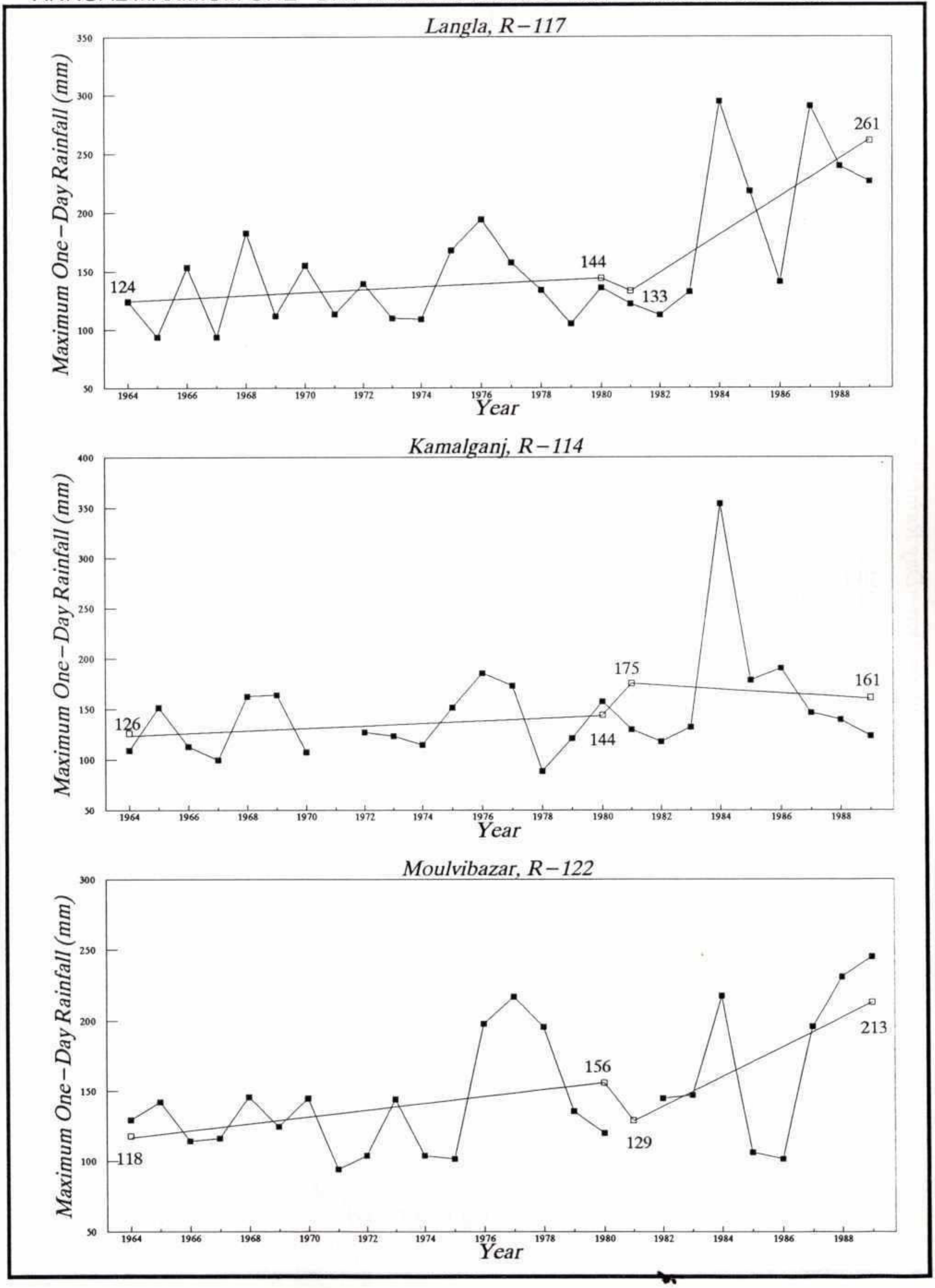
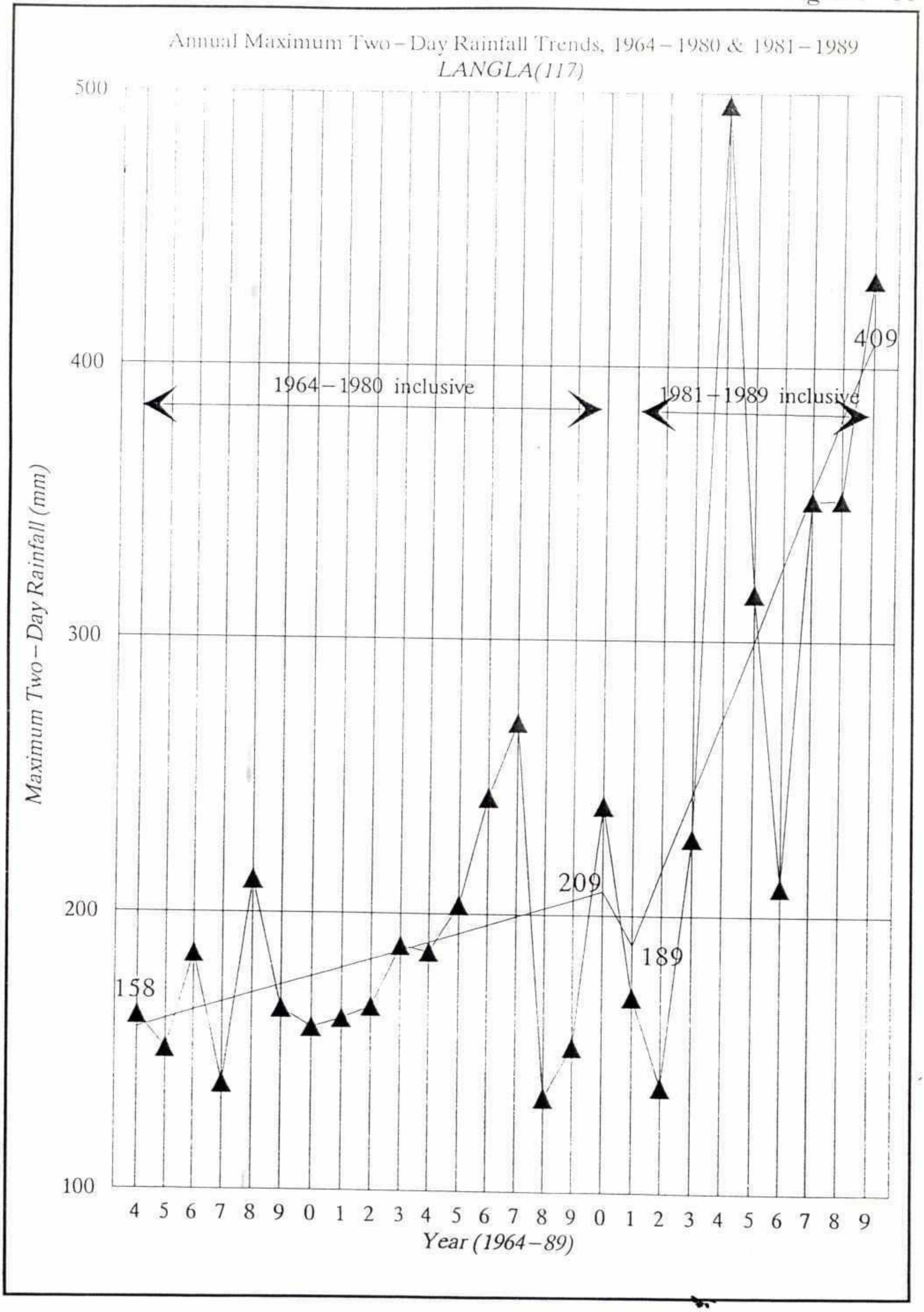
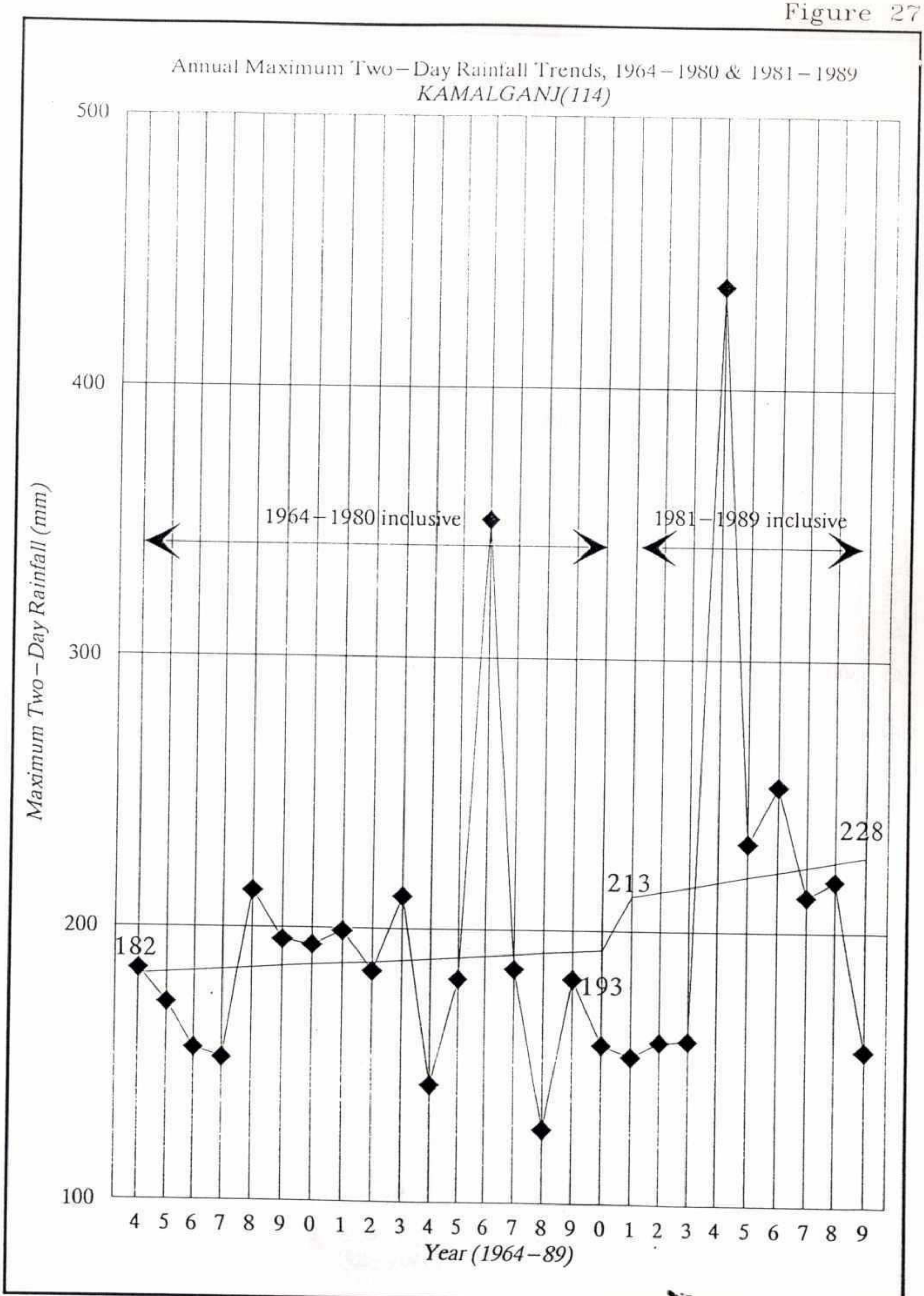


Figure 26



Annual Maximum Two-Day Rainfall Trends, 1964-1980 & 1981-1989
LANGLA(117)
1964-1980 inclusive
1981-1989 inclusive
158
209
189
409
500
400
300
200
100
Maximum Two-Day Rainfall (mm)
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964-89)

Figure 27



Annual Maximum Two – Day Rainfall Trends, 1964 – 1980 & 1981 – 1989
KAMALGANJ(114)
Maximum Two – Day Rainfall (mm)
500
400
300
200
100
1964 – 1980 inclusive
1981 – 1989 inclusive
182
193
213
228
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964 – 89)

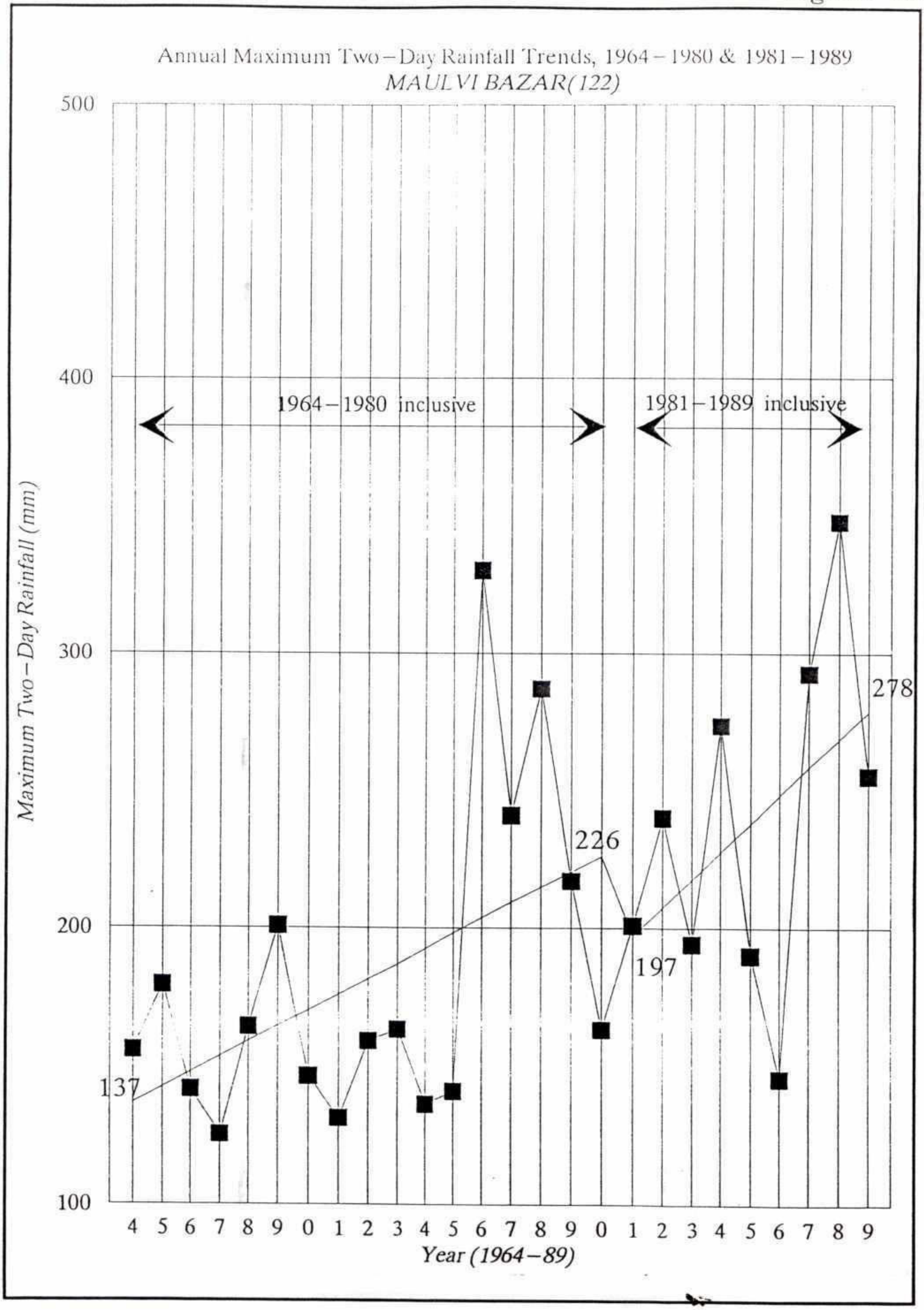
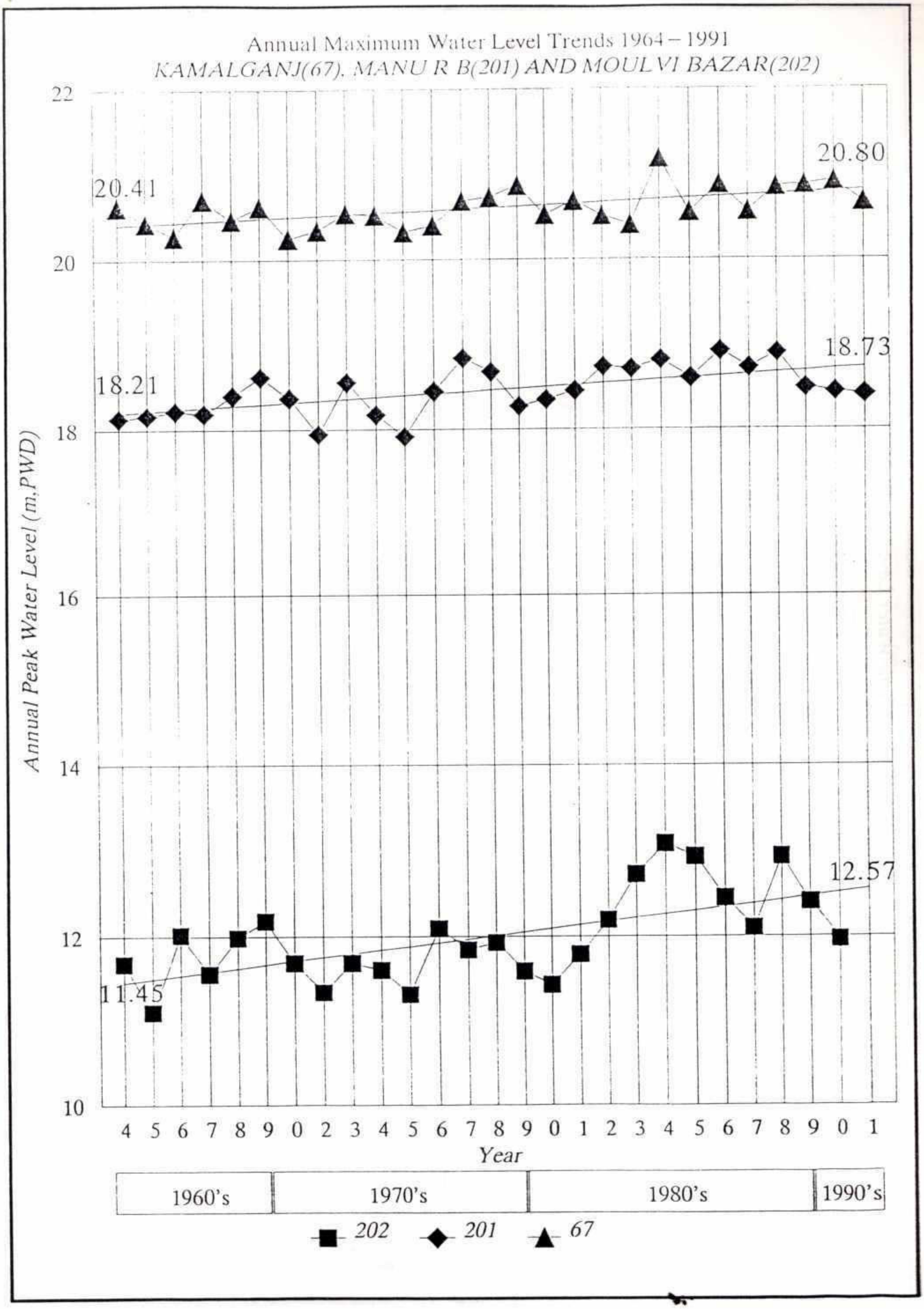
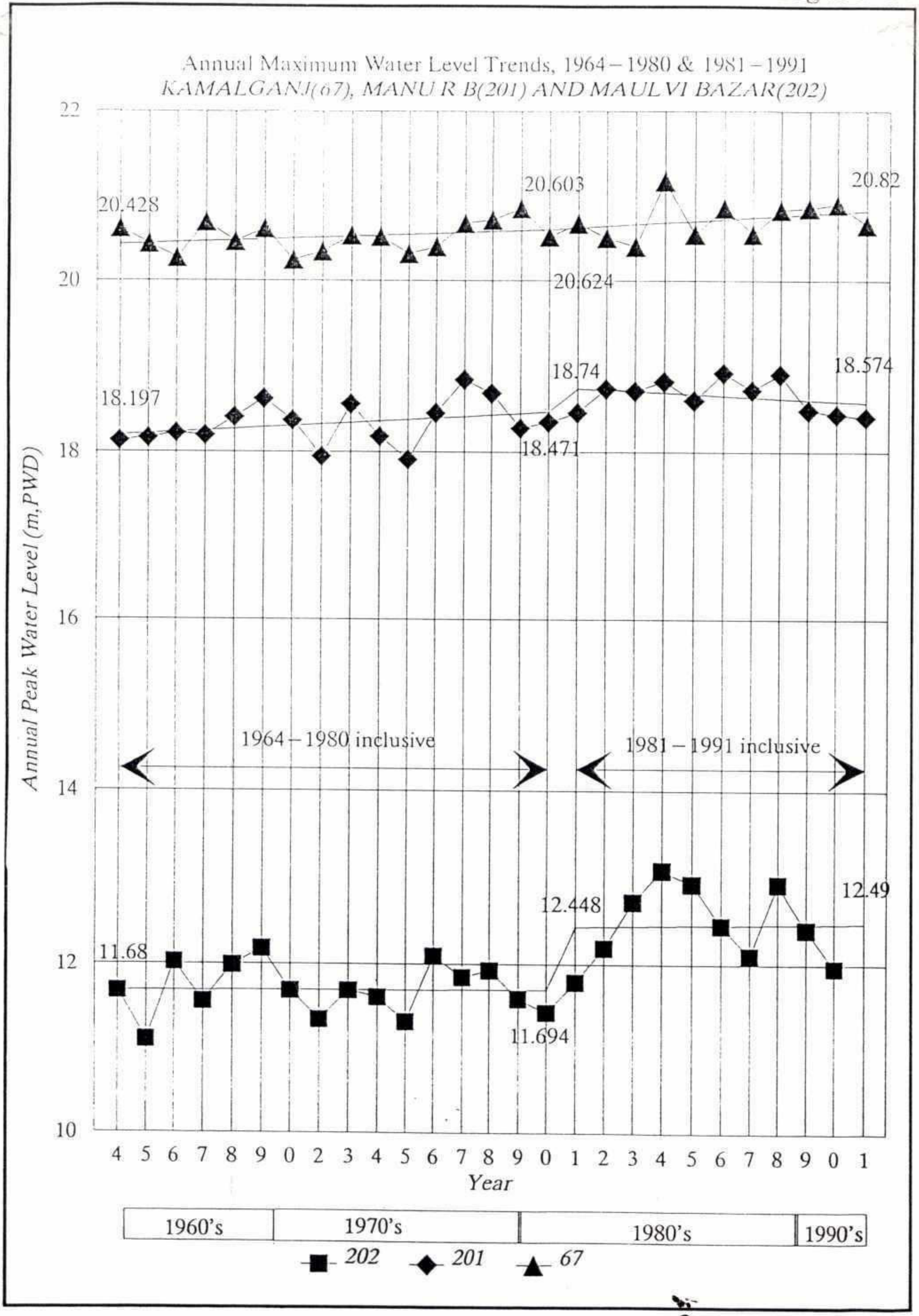

Annual Maximum Two–Day Rainfall Trends, 1964–1980 & 1981–1989
MAULVI BAZAR(122)
500
400
300
200
100
Maximum Two–Day Rainfall (mm)
1964–1980 inclusive
1981–1989 inclusive
137
226
197
278
4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
Year (1964–89)

Figure 29



Annual Maximum Water Level Trends 1964 – 1991
KAMALGANJ(67), MANU R B(201) AND MOULVI BAZAR(202)
Annual Peak Water Level (m,PWD)
22
20
18
16
14
12
10
20.41
20.80
18.21
18.73
11.45
12.57
4 5 6 7 8 9 0 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Year
1960's
1970's
1980's
1990's
202
201
67

Figure 30



Annual Maximum Water Level Trends, 1964 – 1980 & 1981 – 1991
KAMALGANJ(67), MANU R B(201) AND MAULVI BAZAR(202)
22
20
18
16
14
12
10
Annual Peak Water Level (m,PWD)
20.428
20.603
20.82
20.624
18.197
18.74
18.574
18.471
1964 – 1980 inclusive
1981 – 1991 inclusive
12.448
12.49
11.68
11.694
4 5 6 7 8 9 0 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Year
1960's
1970's
1980's
1990's
202
201
67

Figure 31

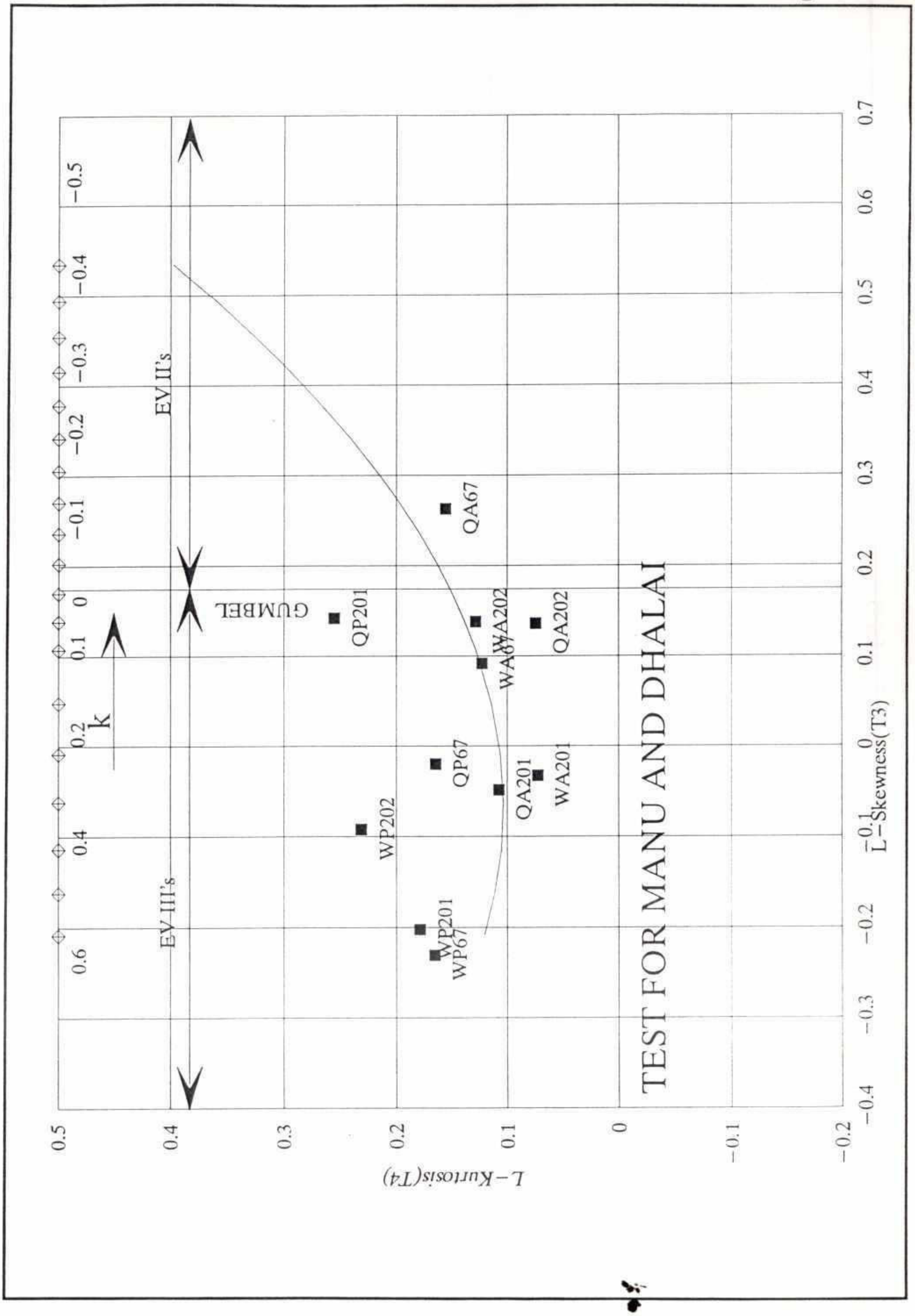
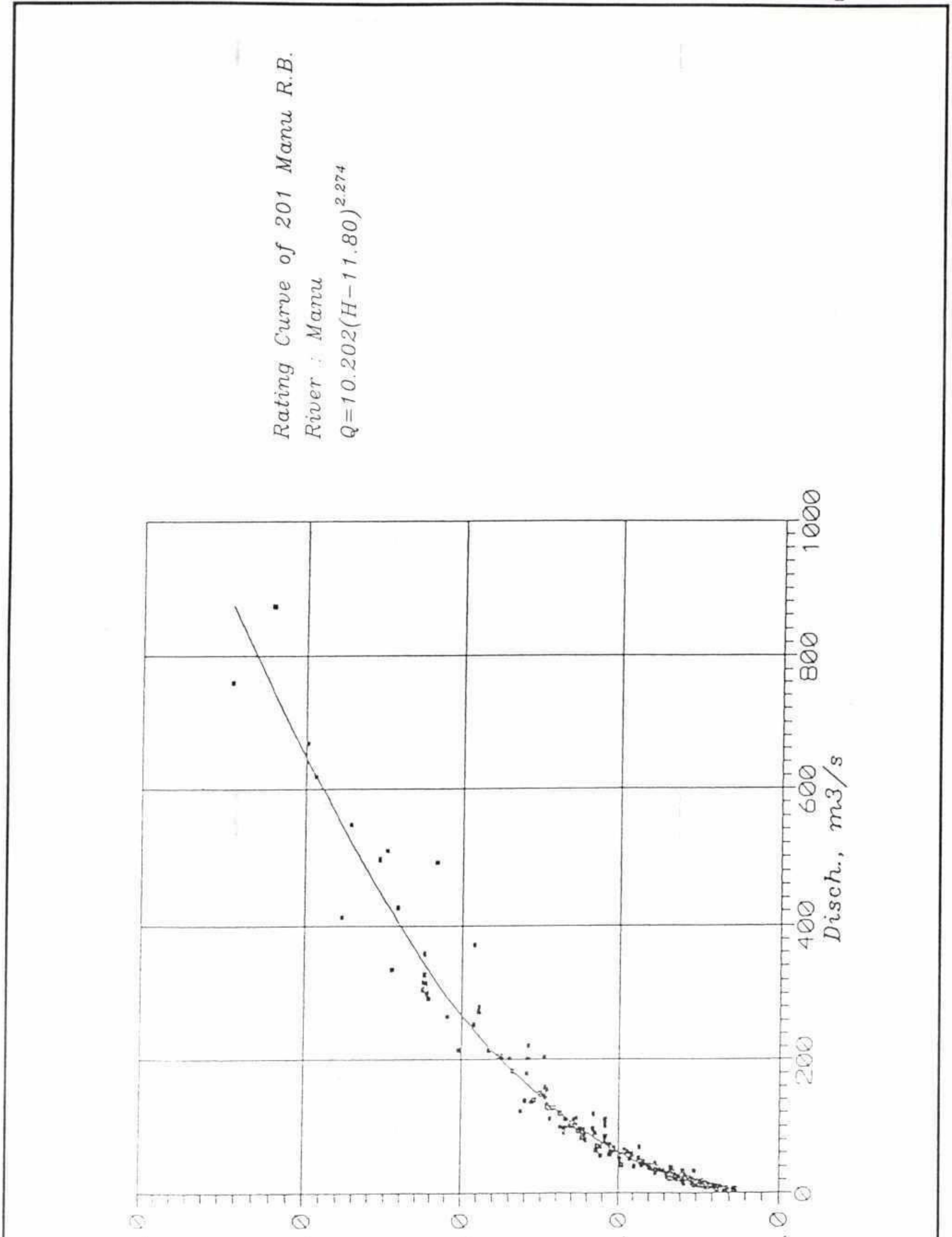
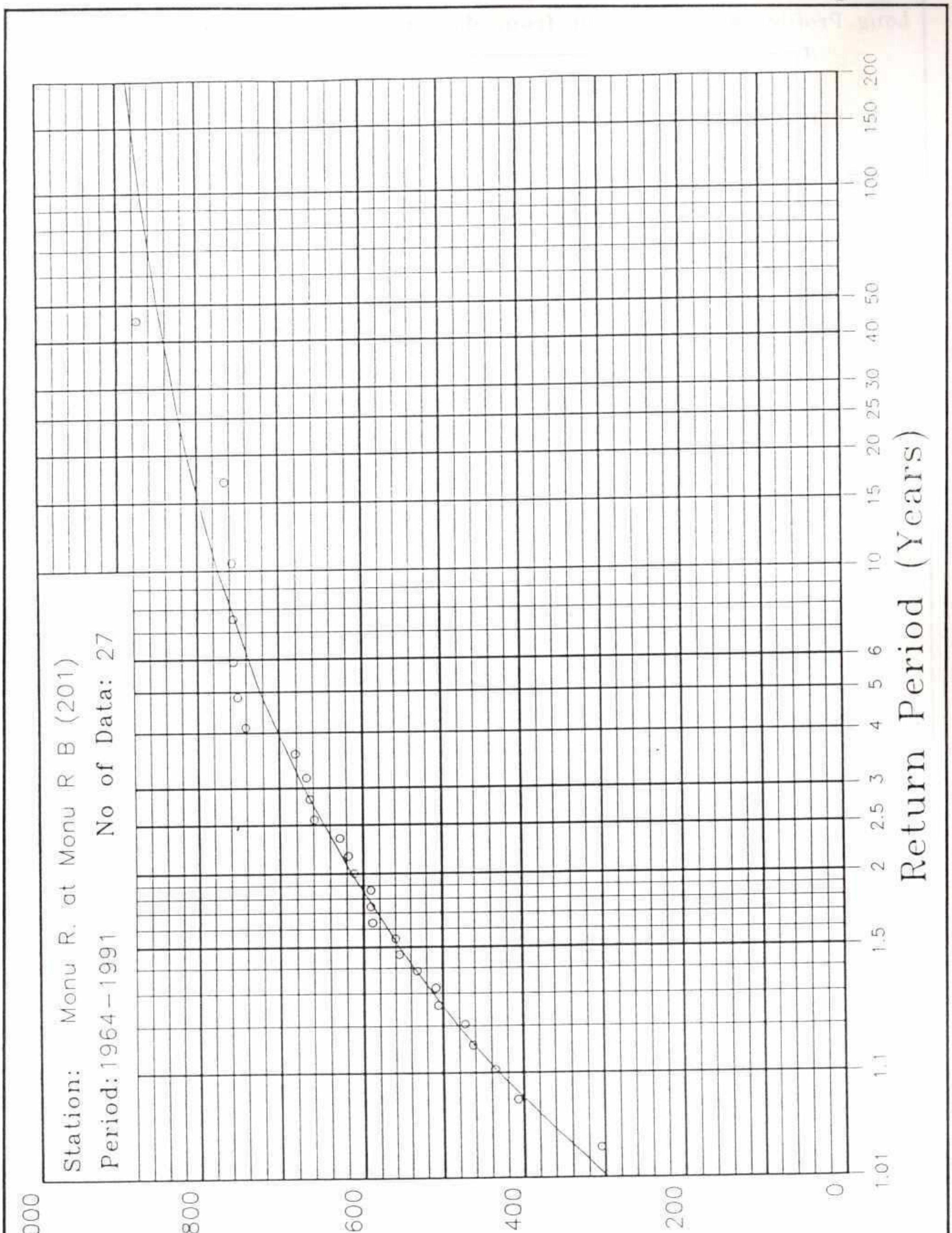

TEST FOR MANU AND DHALAI
L−Skewness(T3)
L−Kurtosis(T4)
EV II's
EV III's
GUMBEL
k
QA67
QP201
WA202
WA67
QA202
QP67
QA201
WA201
WP202
WP201
WP67

Figure 32

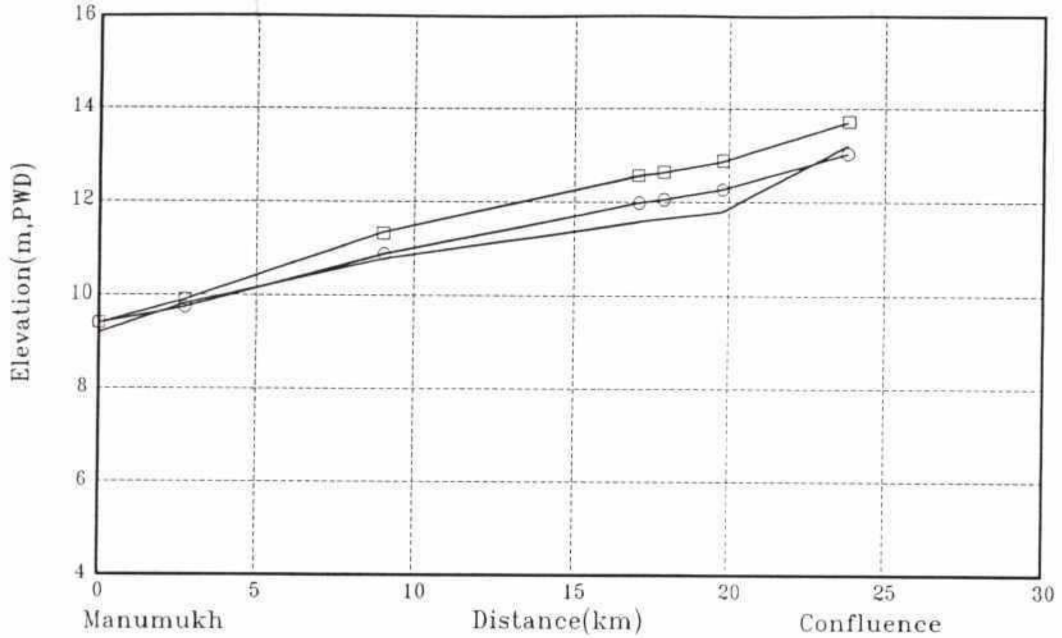


Rating Curve of 201 Manu R.B.
River : Manu
Q=10.202(H-11.80)^2.274
WL, m(PWD)
20.0
18.0
16.0
14.0
12.0
0
200
400
600
800
1000
Disch., m3/s

Figure 33


Station: Monu R. at Monu R B (201)
Period: 1964-1991
No of Data: 27
Discharge (m3/s)
0
200
400
600
800
1000
Return Period (Years)
1.01
1.1
1.5
2
2.5
3
4
5
6
10
15
20
25
30
40
50
100
150
200

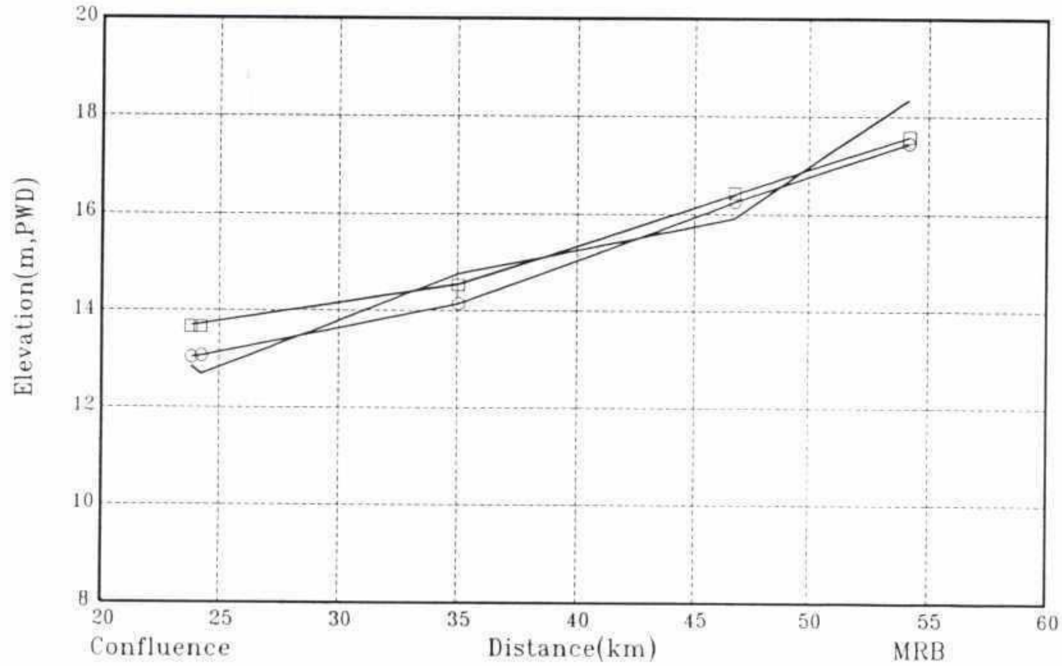
Long Profiles of Manu River from Manumukh to Manu-Dhalai Confluence



Computed water level : —— Right Bank
—□— Q = 800 m3/s
—○— Q = 650 m3/s

Outfall Water level = 9.40 m,PWD(1 in 5 year monson wl at Manumukh)
Manning's n = 0.029

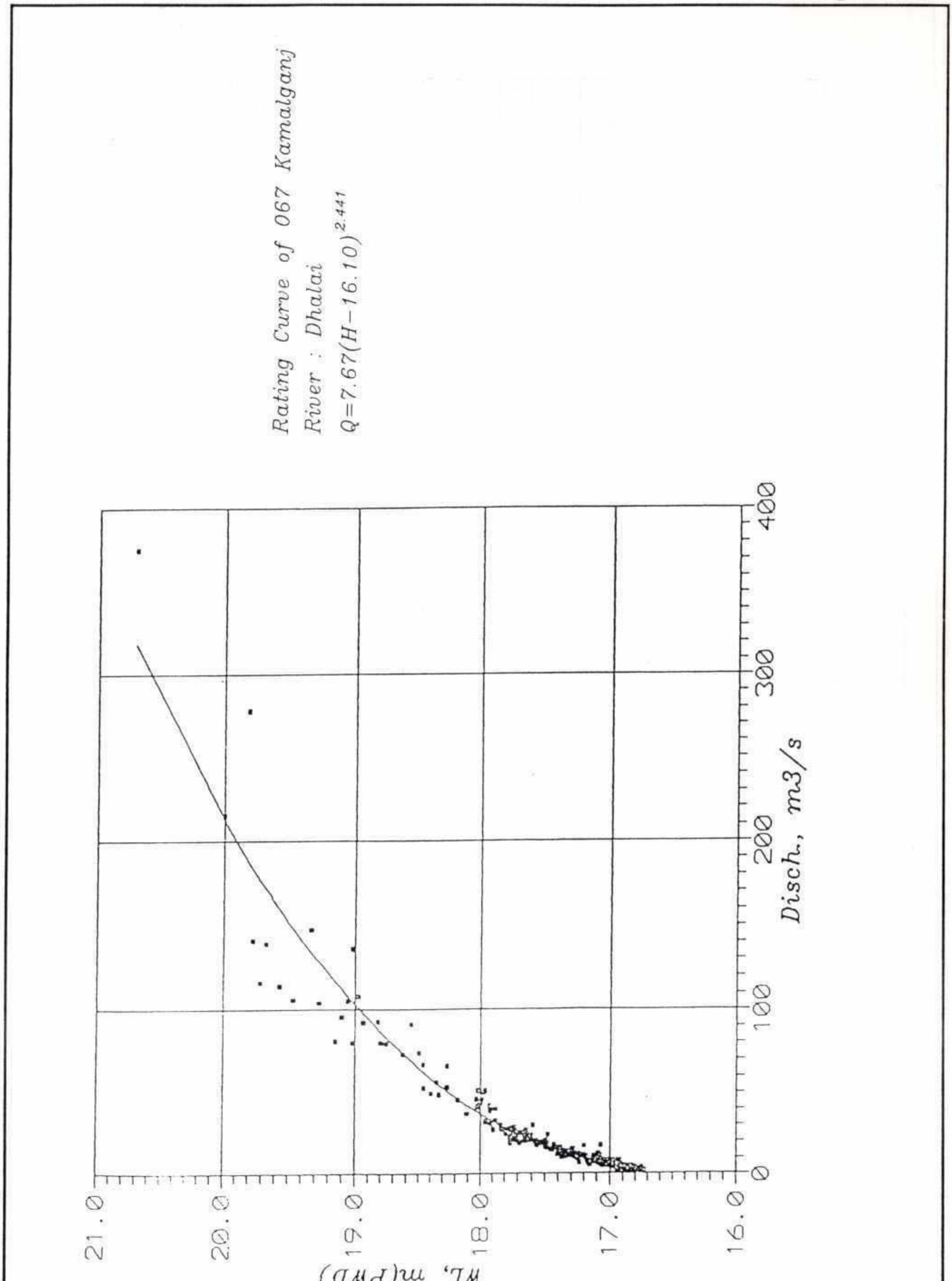
Long Profiles of Manu River from Manu-Dhalai Confluence to Manu Rly.Br



Computed water level : —— Left Bank
—□— Q = 470 m3/s
—○— Q = 450 m3/s

Manning's n = 0.03

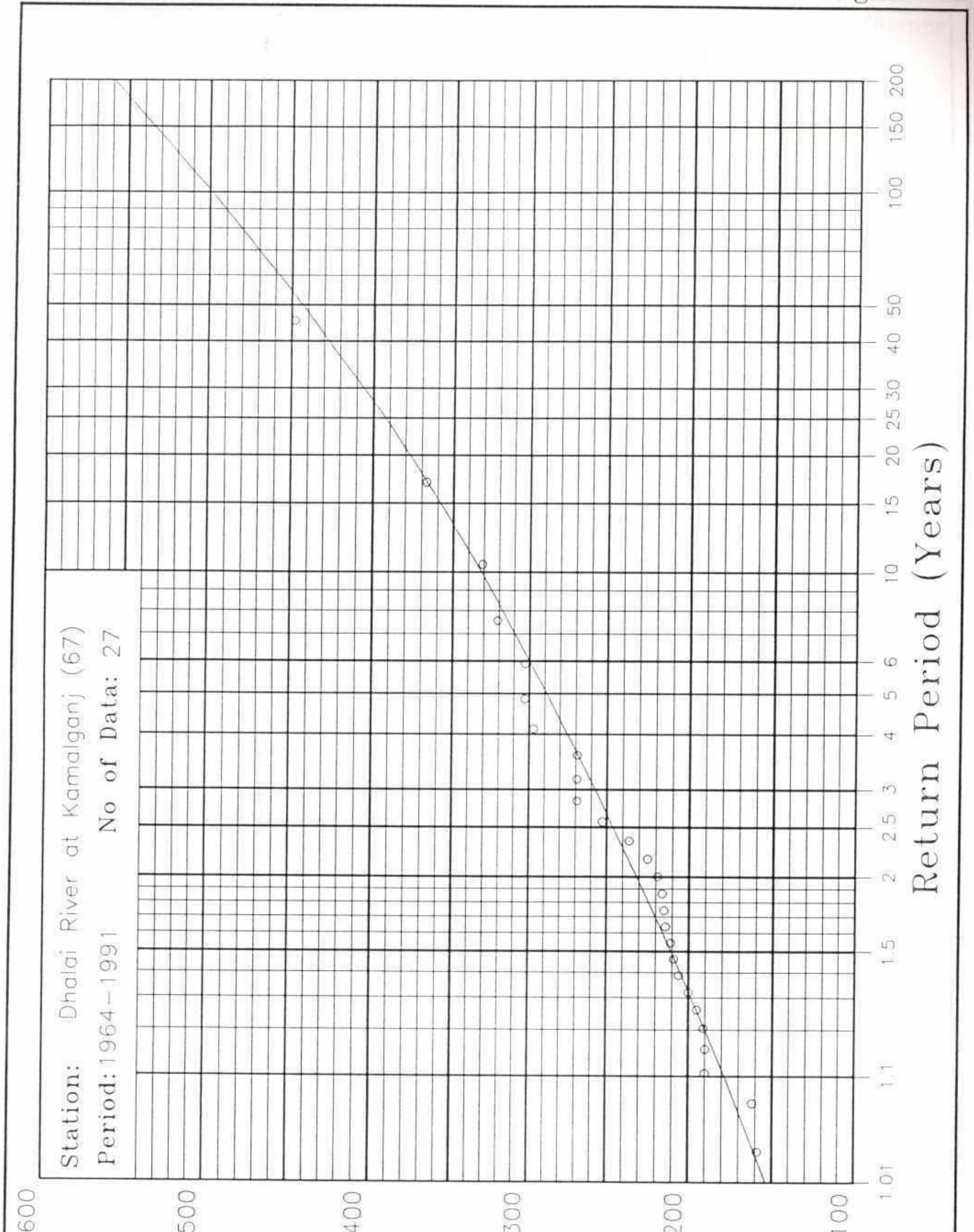
Figure 35



Rating Curve of 067 Kamalganj
River : Dhalai
Q=7.67(H-16.10)^2.441
WL, m(PWD)
21.0
20.0
19.0
18.0
17.0
16.0
0
100
200
300
400
Disch., m3/s

292

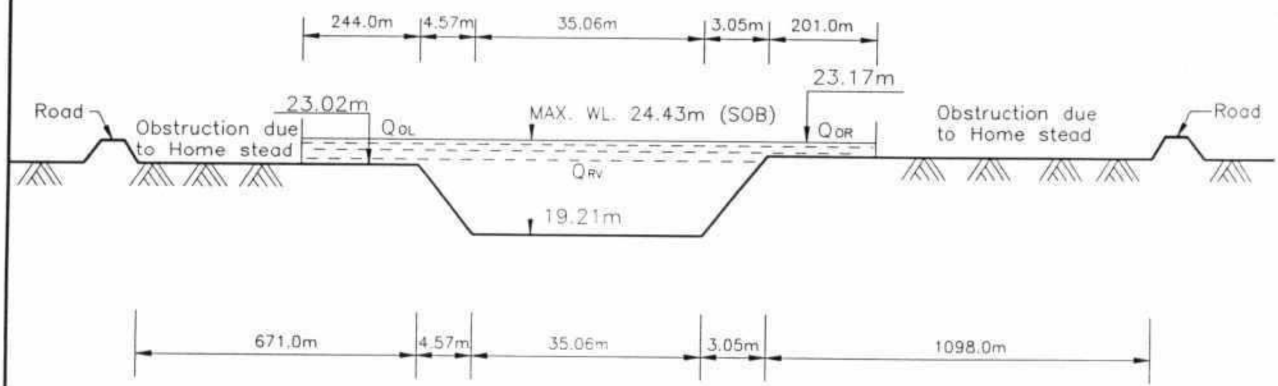
Figure 36



FLOW SECTION OF DHALAI RIVER
FLOOD OF 1984

DESIGN CRITERIA:

1. MANNING'S FORMULA
2. ROUGHNESS CO-EFFICIENT n
   - a. MAJOR STREAMS IRREGULAR AND ROUGH SECTION = 0.045
   - b. FLOOD PLAINS MATURE FIELD CROPS = 0.050
3. VALLEY PROFILE AT A DISTANCE OF 11.5 km UP-STREAM OF KAMALGANJ
4. S = 0.000316
5. MAX. OBSERVED WATER LEVEL = 24.43m (SOB)



LEFT BANK OVERLAND FLOW	Q_{OL}	= 154	CUMECS
RIVER DISCHARGE	Q_{RV}	= 225	CUMECS
ROGHT BANK OVERLAND FLOW	Q_{OR}	= 105	CUMECS

$$Q_{MAX} = Q_{OL} + Q_{RV} + Q_{OR}$$
$$= 154 + 225 + 105$$
$$Q_{MAX} = 484 \text{ CUMECS}$$

Source: SMEC, 1989 Dhalai River Project, Feasibility Report.

Figure 38

RATING CURVE – MOULVIBAZAR
1988

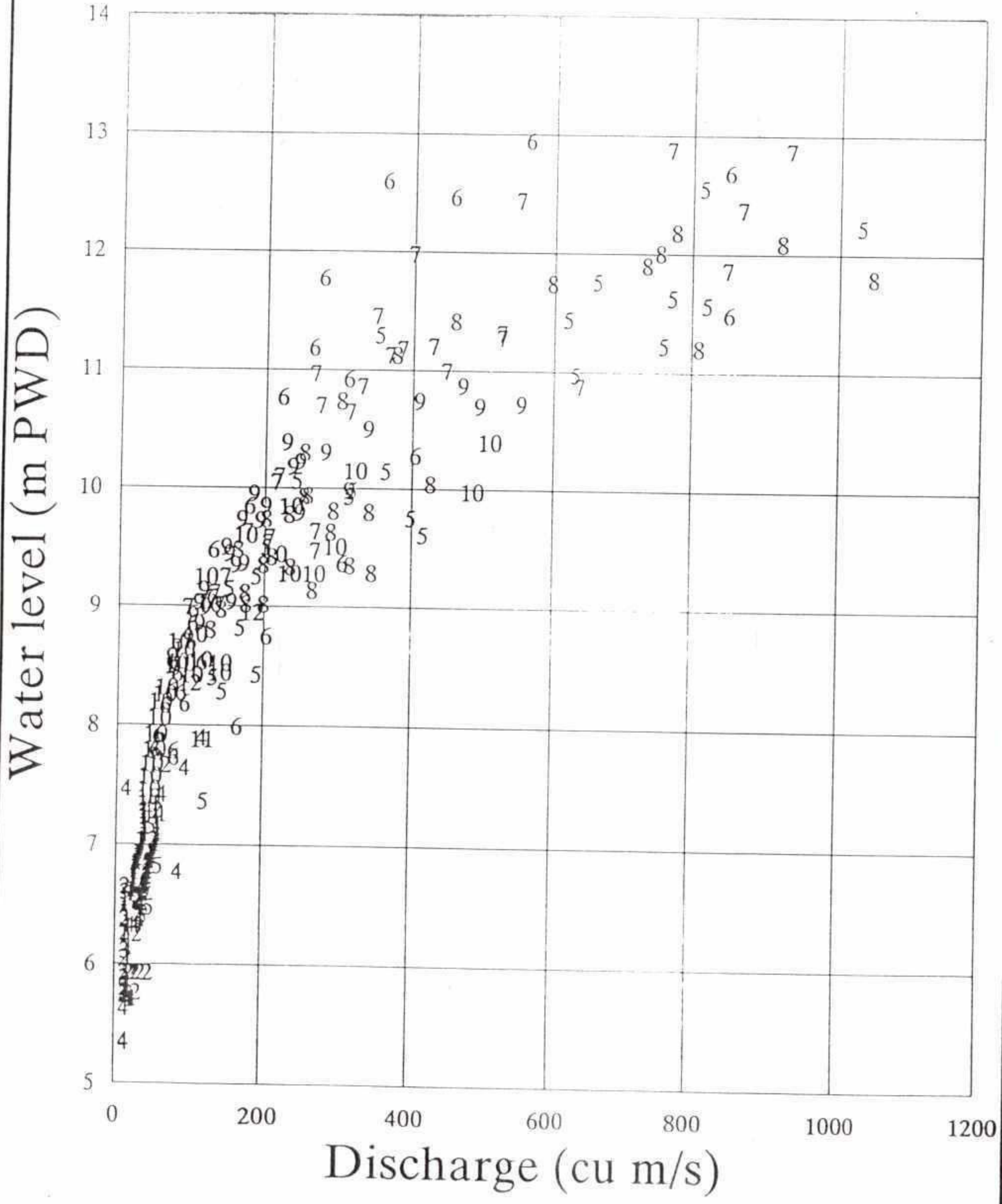
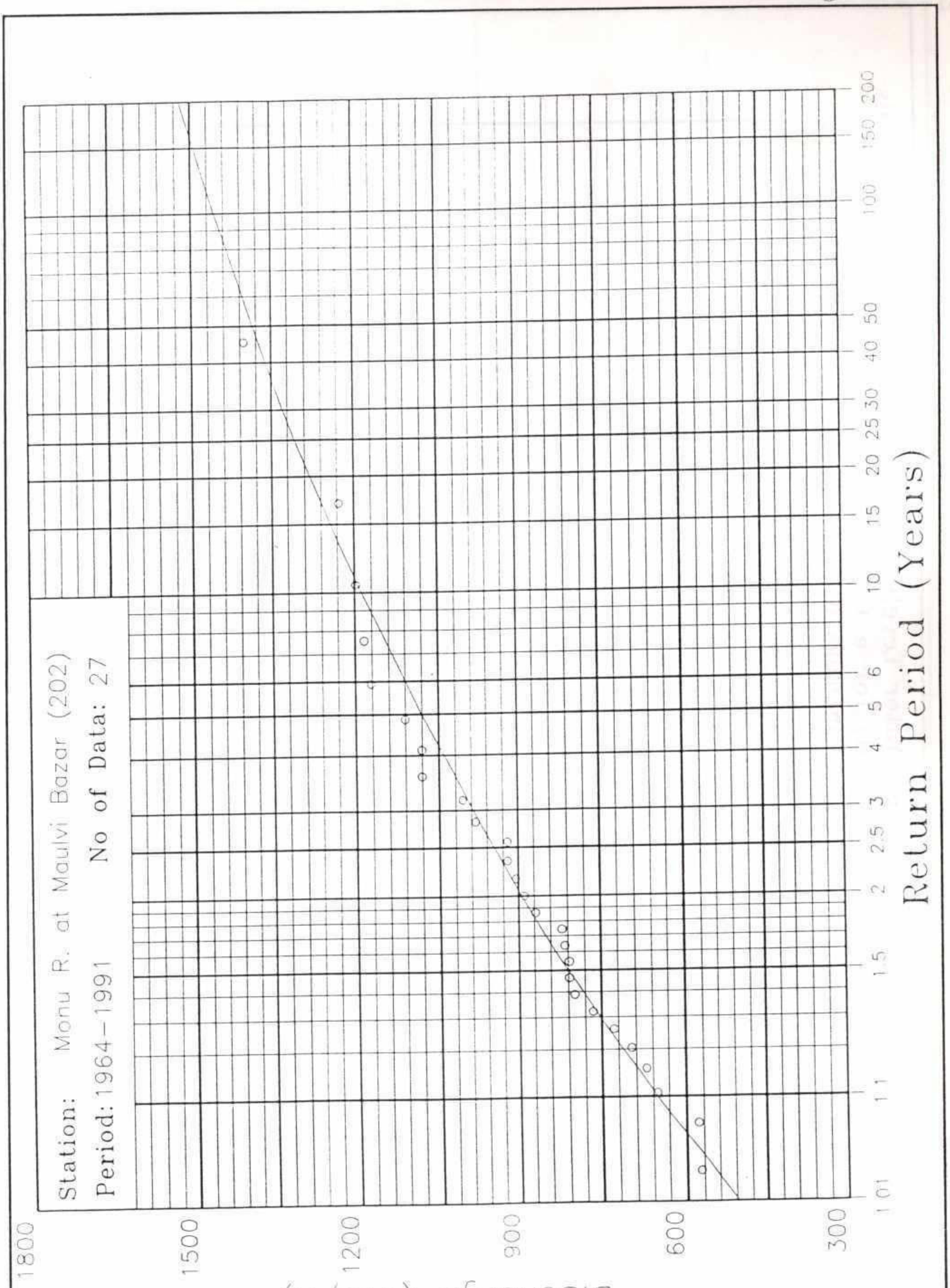
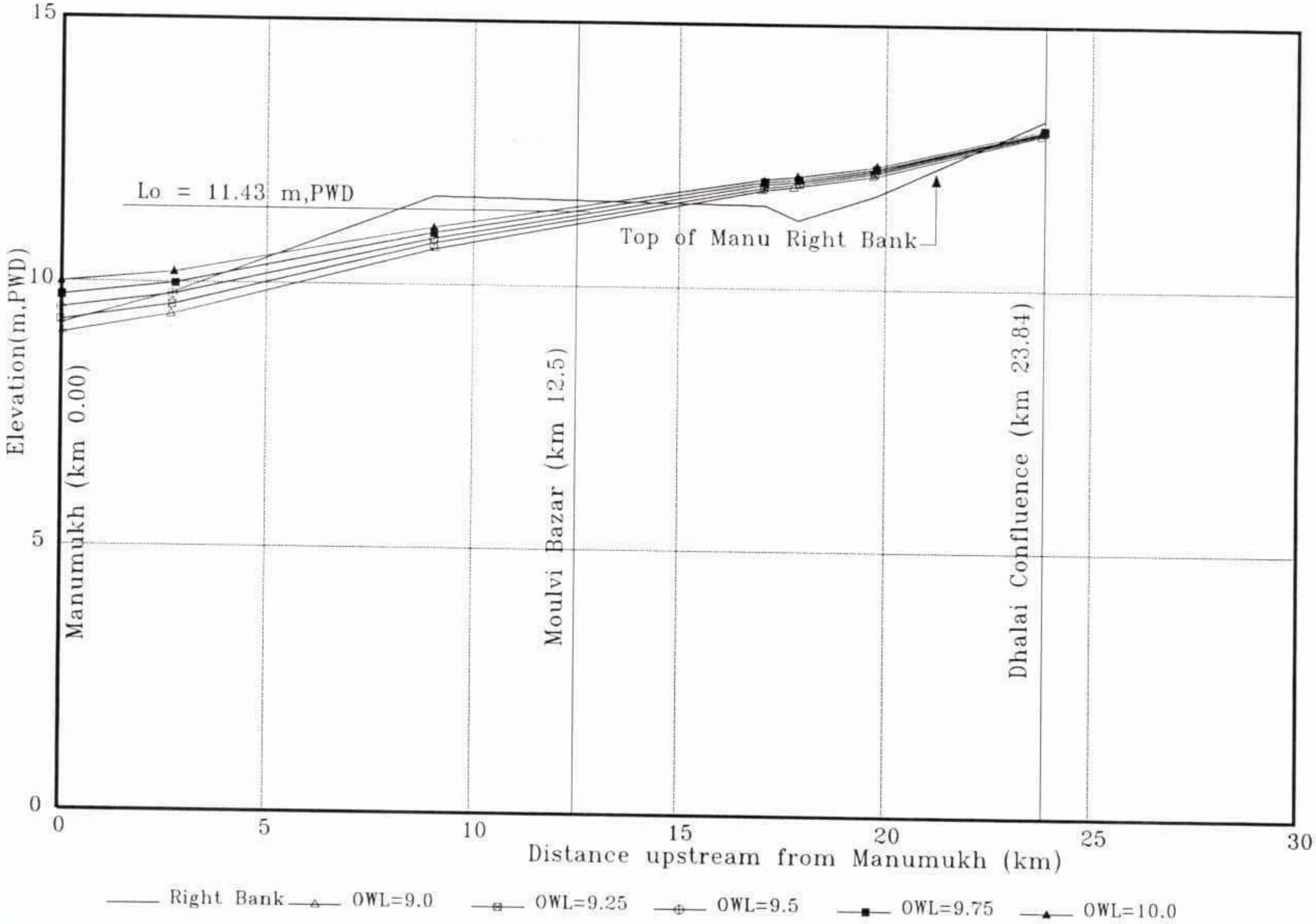
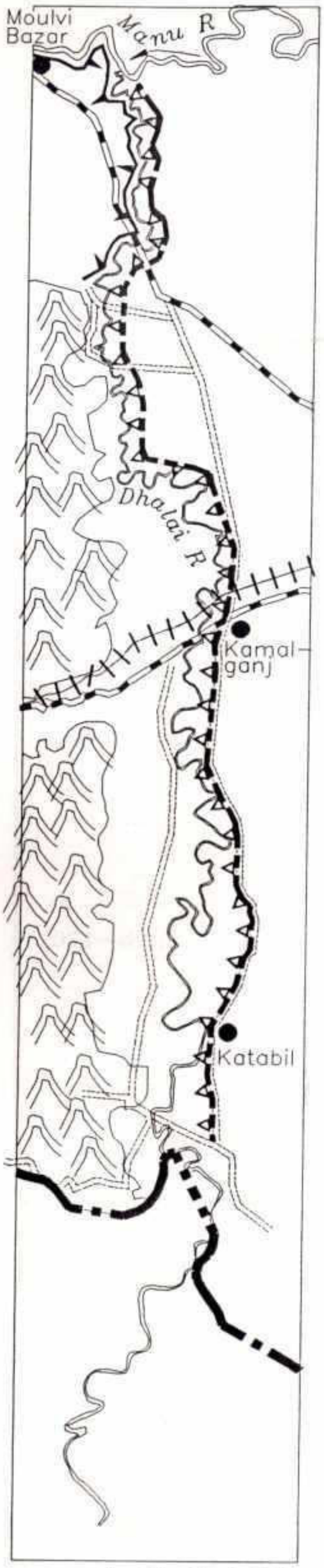


Figure 39

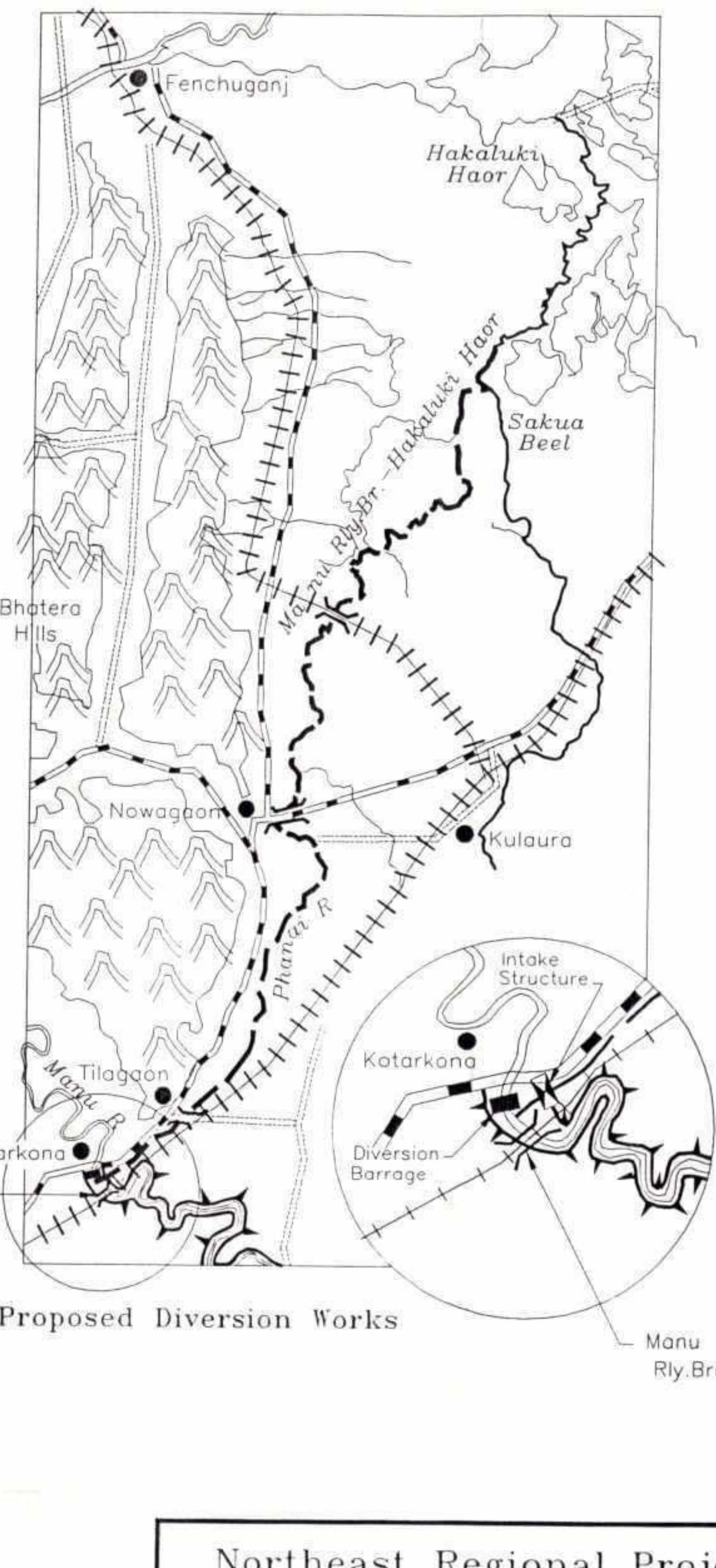

Station: Monu R. at Maulvi Bazar (202)
Period: 1964-1991
No of Data: 27
Return Period (Years)
Discharge (m3/s)
1.01
1.1
1.5
2
2.5
3
4
5
6
10
15
20
25
30
40
50
100
150
200
300
600
900
1200
1500
1800

Sensitivity of Lower Manu River Water Levels to Kushiyara River Water Levels at Manumukh (Manu Outfall) for a Constant Inflow of 750 m3/s
(Manu River - Manumukh to Dhalai Confluence)





Proposed Dhalai River Embankment
(Right Bank)



Proposed Diversion Works

Northeast Regional Project

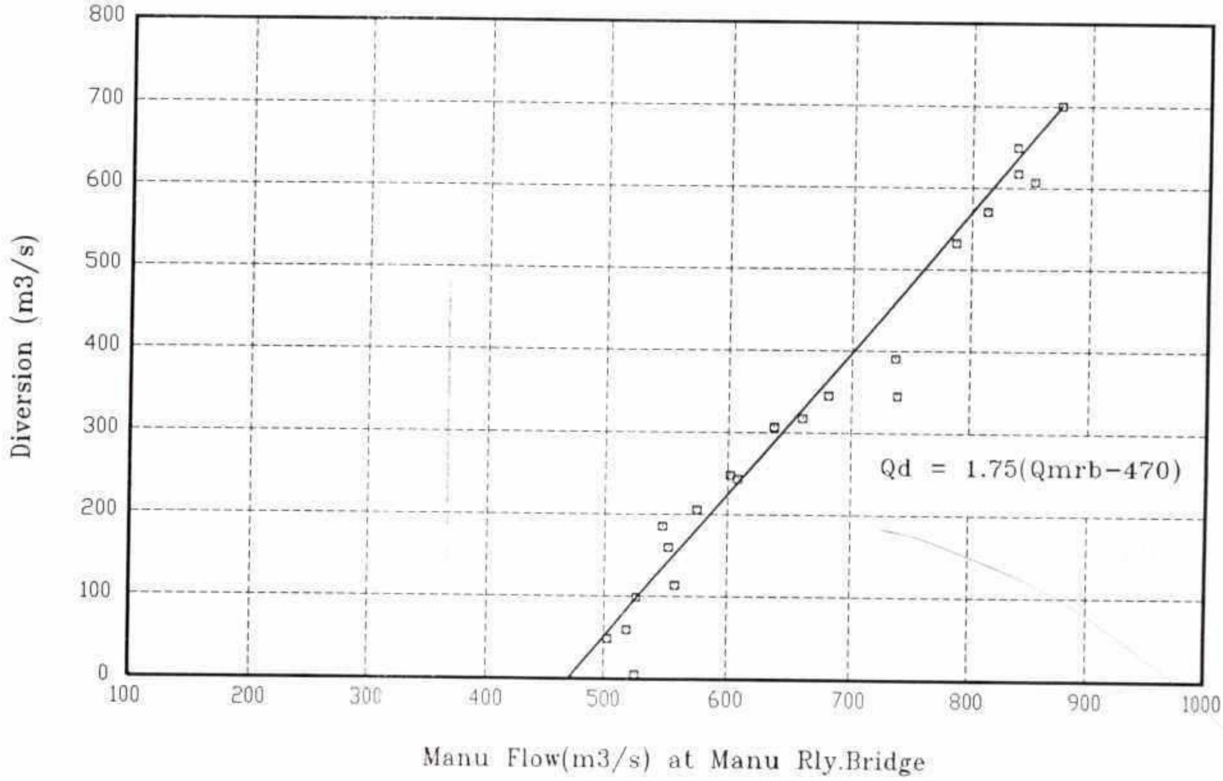
Manu River Improvement Project
Project Structure

Prepared by: FR	January 1994
Drawn by: Sk.Jalal	AutoCAD Drawing

FILE: NERP-234.DWG

Figure 41

Rule Curve
(Based on 1991 Manu Flow at MRB)



Data :

Manu Flow(m³/s)	256	602	429	839	637	875	838	813	853	736	681	787	717	526	503	558	519	553	660	527	469	406	608	548	575	398	334	253	204	168	197
Diversion(m3/s)	0	248	0	618	306	700	649	571	607	391	345	532	349	6	49	114	60	160	317	99	0	0	244	186	206	0	0	0	0	0	0