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

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6

SPECIALIST STUDY

RIVER SEDIMENTATION AND MORPHOLOGY

FINAL REPORT
December 1994

SNC ♦ LAVALIN International
Northwest Hydraulic Consultants

in association with

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

Canadian International Development Agency

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

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ACRONYMS AND ABBREVIATIONS

ACE	Associate Consulting Engineers
ADB	Asian Development Bank
AEZ	Agro-ecological Zone
BIWTA	Bangladesh Inland Water Transport Authority
BIWTMAS	Bangladesh Inland Water Transport Master Plan
BM	Bench Mark
BP	Before Present
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
DA	Drainage Area
EL	Elevation
EPWAPDA	East Pakistan Water and Power Development Authority
FAO	Food and Agriculture Organization
FAP	Flood Action Plan
FCDI	Flood Control and Drainage Irrigation Project
FEC	French Engineering Consortium
GPS	Global Positioning System
GSB	Geological Survey of Bangladesh
HEC	Hydrological Engineering Centre
LAD	Least Available Draft
LLW	Local Low Water
MPO	Master Planning Organization
MRIP	Manu River Irrigation Project
NERP	Northeast Regional Water Management Project
NHC	Northwest Hydraulic Consultants
PWD	Public Works Department
SOB	Survey of Bangladesh
SRP	System Rehabilitation Project
SSFCDI	Small Scale Flood Control Drainage and Irrigation
SWMC	Surface Water Modelling Centre
UNDP	United Nations Development Programme
USGS	United States Geological Survey
WARPO	Water Resources Planning Organization
WSC	Water Survey of Canada

NERP DOCUMENTS

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

Northeast Regional Water Management Plan

- Main Report
- Appendix: Initial Environmental Evaluation

Specialist Studies

- Participatory Development and the Role of NGOs
- Population Characteristics and the State of Human Development
- Fisheries Specialist Study
- Wetland Resources Specialist Study
- Agriculture in the Northeast Region
- Ground Water Resources of the Northeast Region
- 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
- Improved Flood Warning
- Baulai River Improvement Project

TABLE OF CONTENTS

Acronyms and Abbreviations i
NERP Documents ii
Table of Contents iii

Executive Summary xi

1. INTRODUCTION 1
   - 1.1 Purpose and Scope
   - 1.2 Overview of the Region
   - 1.3 Sediment Issues and Problems
     - 1.3.1 Flood Control and Drainage Projects
     - 1.3.2 Transportation and Navigation
     - 1.3.3 Wetlands and Fisheries Habitat
     - 1.3.4 Summary
   - 1.4 Method of Approach
   - 1.5 Report Outline

2. AVAILABLE DATA 9
   - 2.1 Water Levels
   - 2.2 Discharge
   - 2.3 Suspended Sediment Concentration
   - 2.4 River Surveys
   - 2.5 Mapping and Satellite Imagery
   - 2.6 Bed Material
   - 2.7 Geology and Stratigraphy
   - 2.8 Historic Data

3. THE REGION 15
   - 3.1 Geological Setting
   - 3.2 Topography
   - 3.3 Physiography and Landforms
     - 3.3.1 Uplands
     - 3.3.2 Terraces
     - 3.3.3 Alluvial Fans
     - 3.3.4 Piedmont Floodplains
     - 3.3.5 Floodplains
     - 3.3.6 Basins
   - 3.4 Governing Processes
     - 3.4.1 Sedimentation
     - 3.4.2 Subsidence
     - 3.4.3 Tectonic Activity
     - 3.4.4 Past Channel Changes

4. RUNOFF 29
   - 4.1 Rainfall

4.2 Runoff
4.2.1 Barak River
4.2.2 Meghalaya Foothills
4.2.3 Susang Hills
4.2.4 Tripura Hills
4.3 River Systems
4.4 Base Level and Downstream Control

5. **SEDIMENT TRANSPORT** 35
5.1 Terminology
5.2 Review of Sampling Methods
5.3 Review of Data
5.4 Station Analysis
5.5 Sediment Budget
5.5.1 Tripura Hills
5.5.2 Meghalaya Hills
5.5.3 Susang Hills
5.5.4 Barak River Inflows
5.5.5 Results
5.6 Future Work

6. **ALLUVIAL FANS** 47
6.1 Introduction
6.2 Someswari River
6.2.1 Morphology
6.2.2 Hydrology
6.2.3 Flow/Sediment Interactions
6.2.4 Future Trends
6.3 Comparison with other Fans
6.4 Summary

7. **PIEDMONT RIVERS** 57
7.1 Introduction
7.2 Manu River
7.2.1 Channel Characteristics
7.2.2 Flood Control Projects
7.2.3 Hydrology
7.2.4 Channel Stability
7.2.5 Sedimentation
7.3 Khowai River
7.3.1 Channel Characteristic
7.3.2 Flood Control
7.3.3 Hydrology
7.3.4 River Hydraulics
7.3.5 Impact of Embankments on Channel Stability
7.3.6 Summary

8. **LOWLAND RIVER SYSTEMS** 69
8.1 Introduction
8.2 Surma/Baulai River System
8.2.1 River Classification
8.2.2 Evolution
8.2.3 Flood Control Infrastructure Development
8.2.4 Hydrology
8.2.5 Channel Morphology
8.2.6 Hydraulics
8.2.7 Channel Stability
8.2.8 Sediment Transport
8.2.9 Summary of Findings
8.3 Kushiyara/Kalni River System
8.3.1 River Classification
8.3.2 Evolution of River System
8.3.3 Flood Control Infrastructure
8.3.4 Hydrology
8.3.5 Channel Morphology
8.3.6 Hydraulics
8.3.7 Channel Stability
8.3.8 Sediment Transport Model of Kushiyara/Kalni River

9. **IMPACTS OF SEDIMENTATION ON RIVER DEVELOPMENT** 87
9.1 Purpose
9.2 Impacts of Full Flood Control Embankments
9.2.1 General considerations
9.2.2 Planform Changes
9.2.3 Vertical Channel Changes
9.2.4 Embankments on Alluvial Fans
9.3 Submersible (Partial Flood Control) Embankments
9.3.1 Hydraulic Effects
9.3.2 Effects on the Channels
9.3.3 Effects Inside Embanked Areas
9.4 Impacts of Loop Cuts

10. **CONCLUSIONS** 97
10.1 Nature of Sediment Problems and Issues
10.2 Impacts of FCD Projects
10.3 Future Threats

11. **REFERENCES** 99

ANNEX A: TABLES

LIST OF TABLES

Table 1.1 Rivers in the region
Table 1.2 Inventory of sediment problems in the region

Table 2.1 History of water level measurements
Table 2.2 History of discharge measurements
Table 2.3 Navigation charts used in studies

Table 3.1 Description of geologic units
Table 3.2 Land Unit Areas
Table 3.3 Reported subsidence
Table 3.4 Major earthquakes affecting the Region

Table 4.1 Physical characteristics of watersheds
Table 4.2 Water inflows to the Region

Table 5.1 Suspended sediment data
Table 5.2 Published suspended sediment data
Table 5.3 Summary of discharges at sediment stations
Table 5.4 Summary of observed sediment concentrations
Table 5.5 Summary of observed sediment loads
Table 5.6 Summary of observed sediment concentrations (inactive stations)
Table 5.7 Summary of observed sediment loads (inactive stations)
Table 5.8 Sediment rating curve coefficents, Kushiyara River at Sheola
Table 5.9 Sediment rating curve coefficents, Kushiyara River at Sherpur
Table 5.10 Sediment rating curve coefficents, Surma River at Sylhet
Table 5.11 Sediment rating curve coefficents, Khowai River at Shaistaganj
Table 5.12 Sediment rating curve coefficents, Manu River at railway
Table 5.13 Summary of estimated annual suspended sediment loads
Table 5.14 Sediment yields from Assam Rivers

Table 6.1 Comparison of sediment transport rates on Someswari River
Table 6.2 Morphologic characteristics of alluvial fans

Table 7.1 Channel Changes on Manu River
Table 7.2 Effect of Loop Cuts on River Length
Table 7.3 Channel Changes on Khowai River

Table 8.1 Morphologic Characteristics of Surma/Baulai River
Table 8.2 Discharges along Surma/Baulai River
Table 8.3 Channel Changes - Surma River between Amalshid and Sylhet
Table 8.4 Channel Changes - Surma River between Sylhet and Chhatak
Table 8.5 Hydraulic and Sediment Transport Parameters - Surma R. at Kanaighat
Table 8.6 Hydraulic and Sediment Transport Parameters - Surma R. at Sylhet
Table 8.7 Annual Bed Material Loads on Surma River
Table 8.8 Morphologic Characteristics of Kushiyara/Kalni River

Table 8.9 Discharges on Kushiyara/Kalni River
Table 8.10 Channel Changes on Kushiyara River, Amalshid to Fenchuganj
Table 8.11 Channel Changes on Kushiyara River, Fenchuganj to Manumukh
Table 8.12 Hydraulic and Sediment Transport Parameters - Sheola
Table 8.13 Hydraulic and Sediment Transport Parameters - Sherpur
Table 8.14 Bed Material Loads along Kushiyara/Kalni River
Table 8.15 Budget of Annual Bed Material Loads

Table 9.1 Channel Widening due to Embankments
Table 9.2 Average Suspended Sediment Loads in Two Time Periods

ANNEX B: FIGURES

LIST OF FIGURES

Figure 1 The Northeast Region
Figure 2 Extent of inundation in 1988 flood
Figure 3 Existing projects in the Northeast Region
Figure 4 Sediment problems in Northeast Region projects
Figure 5 Hydrometric stations and cross sections
Figure 6 NERP study sites
Figure 7 Rennell's map of NE Bangladesh, 1768-1771
Figure 8 Geological Evolution of Bangladesh
Figure 9 Tectonic map of Bangladesh
Figure 10 Quaternary sedimentation in Bangladesh
Figure 11 Evolution of river systems
Figure 12 Generalized topographic map of Bangladesh
Figure 13 Topography in NE Region
Figure 14 Physiography of NE Region
Figure 15 Agro-ecological zones
Figure 16 Jhalukhali River alluvial fan
Figure 17 Someswari River alluvial fan
Figure 18 Landforms on Lowland Floodplains
Figure 19 Meghalaya basins in dry season
Figure 20 Channel pattern on lowlands
Figure 21 Anastomosing channel patterns
Figure 22 Stratigraphy at Karchar Haor
Figure 23 Distribution of Rainfall over the Region
Figure 24 Catchments Draining into NE Region
Figure 25 Longitudinal Profile of Barak River, India
Figure 26 Discharges on Barak River at Amalshid
Figure 27 Discharge hydrographs on Meghalaya streams
Figure 28 Schematic representation of Flow Distribution in NE rivers
Figure 29 Summary hydrographs on representative rivers in NE region
Figure 30 Seasonal water levels on Meghna River
Figure 31 Sediment transport terminology
Figure 32 Suspended sediment sampling techniques
Figure 33 Location of sediment sampling stations

Figure 34 Suspended sediment rating curves
Figure 35 High sediment yields from upper Dhalai River
Figure 36 Tentative sediment budget for the Region
Figure 37 Location plan of Someswari River
Figure 38 Channel changes on Someswari River
Figure 39 Specific gauge at Durgapur
Figure 40 Flow split at Someswari River
Figure 41 Predicted bed material loads on Someswari River
Figure 42 Channel Changes on Jadukata River
Figure 43 Channel Changes on Chela River
Figure 44 Channel Changes on Dauki-Piyain River
Figure 45 Manu River Channel Changes
Figure 46 Annual Discharges on Manu River
Figure 47 Historic Water Levels on Manu River
Figure 48 Longitudinal Profile of Manu River
Figure 49 Cross Sections of Manu River at Phulpur
Figure 50 Cross Sections of Manu River at Moulvibazar
Figure 51 Map of Khowai River
Figure 52 Historic Water Levels on Khowai River
Figure 53 Channel Cross Sections - Khowai River
Figure 54 Channel Changes along Khowai River
Figure 55 Longitudinal Profile of Khowai River
Figure 56 Impacts of Berm Sedimentation on Water Levels
Figure 57 Surma / Kushiyara River System
Figure 58 Longitudinal Profile of Surma River
Figure 59 Division of Flow at Amalshid
Figure 60 Surma River Near Amalshid
Figure 61 Annual Water Levels - Upper Surma River
Figure 62 Annual Water Levels - Surma River
Figure 63 Annual Discharges - Surma River
Figure 64 Annual Water Levels - Baulai River
Figure 65 Channel Geometry of Surma/Baulai River
Figure 66 Water Level and Slope - Surma River 1988
Figure 67 Water Level and Slope - Baulai River 1988
Figure 68 Surma River Channel Changes - Amalshid to Kakura
Figure 69 Surma River Channel Changes - Sylhet to Chhatak
Figure 70 Surma River Channel Changes - Chhatak to Sunamganj
Figure 71 Surma River Channel Changes - Sunamganj to Kaliajuri
Figure 72 Baulai River Channel Changes - Kaliajuri to Dhanu River
Figure 73 Upper Meghna River / Ghorautra River Channel Changes
Figure 74 Longitudinal Profiles of Baulai River
Figure 75 Bed Level Changes on Baulai River
Figure 76 Annual Discharges on Kushiyara River
Figure 77 Annual Water Levels on Kushiyara River
Figure 78 Water Level Difference between Sunamganj and Markuli
Figure 79 Satellite Photo of Kushiyara River near Sherpur
Figure 80 Satellite Photo of Kalni River near Markuli
Figure 81 Longitudinal Profile of Kushiyara/Kalni River

Figure 82 Variation in Hydraulic Geometry along Kushiyara River
Figure 83 Map Showing Channel Changes on Upper Kushiyara River
Figure 84 Map Showing Channel Changes on Lower Kushiyara River
Figure 85 Map Showing Channel Changes on Meghna-Kalni River
Figure 86 Kushiyara River Cross Section Comparisons
Figure 87 Longitudinal Profile of Kalni River in 1963 and 1988
Figure 88 Bed Level Changes on Kushiyara/Kalni River
Figure 89 Sediment Routing along Kalni River
Figure 90 Impacts of Embankments on Channel Morphology
Figure 91 Impacts of Embankments under Backwater
Figure 92 Impacts of Loop Cuts
Figure 93 Impacts of Loop Cuts under Backwater
Figure 94 Angurali Haor Project
Figure 95 Shanir Haor Section Lines
Figure 96 Longitudinal Profiles of Shanir Haor

ANNEX C RIVER CATALOGUE

LIST OF FIGURES

Figure C-1 Bhogai-Kangsha River at Nakuagaon, River Characteristic
Figure C-2 Bhogai-Kangsha River at Nakuagaon, Hydrometric Data
Figure C-3 Bhogai-Kangsha River at Nakuagaon, Channel Properties
Figure C-4 Bhogai-Kangsha River at Nakuagaon, Hydraulic Geometry
Figure C-5 Kangsha River at Jaria Jhanjail, River Characteristic
Figure C-6 Kangsha River at Jaria Jhanjail, Hydrometric Data
Figure C-7 Kangsha River at Jaria Jhanjail, Channel Properties
Figure C-8 Kangsha River at Jaria Jhanjail, Hydraulic Geometry
Figure C-9 Khowai River at Shaistaganj, River Characteristic
Figure C-10 Khowai River at Shaistaganj, Hydrometric Data
Figure C-11 Khowai River at Shaistaganj, Channel Properties
Figure C-12 Khowai River at Shaistaganj, Hydraulic Geometry
Figure C-13 Kushiyara River at Sheola, River Characteristic
Figure C-14 Kushiyara River at Sheola, Hydrometric Data
Figure C-15 Kushiyara River at Sheola, Channel Properties
Figure C-16 Kushiyara River at Sheola, Hydraulic Geometry
Figure C-17 Kushiyara River at Sherpur, River Characteristic
Figure C-18 Kushiyara River at Sherpur, Hydrometric Data
Figure C-19 Kushiyara River at Sherpur, Channel Properties
Figure C-20 Kushiyara River at Sherpur, Hydraulic Geometry
Figure C-21 Manu River at Rail Crossing, River Characteristic
Figure C-22 Manu River at Rail Crossing, Hydrometric Data
Figure C-23 Manu River at Rail Crossing, Channel Properties
Figure C-24 Manu River at Rail Crossing, Hydraulic Geometry
Figure C-25 Someswari River at Durgapur, River Characteristic
Figure C-26 Someswari River at Durgapur, Hydrometric Data
Figure C-27 Someswari River at Durgapur, Channel Properties
Figure C-28 Shibganj Dhala River at Durgapur, Hydraulic Geometry
Figure C-29 Surma River at Kanairghat, River Characteristic

Figure C-30 Surma River at Kanairghat, Hydrometric Data
Figure C-31 Surma River at Kanairghat, Channel Properties
Figure C-32 Surma River at Kanairghat, Hydraulic Geometry
Figure C-33 Surma River at Sylhet, River Characteristic
Figure C-34 Surma River at Sylhet, Hydrometric Data
Figure C-35 Surma River at Sylhet, Channel Properties
Figure C-36 Surma River at Sylhet, Hydraulic Geometry
Figure C-37 Surma River at Chhatak, River Characteristic
Figure C-38 Surma River at Chhatak, Hydrometric Data
Figure C-39 Surma River at Chhatak, Channel Properties
Figure C-40 Surma River at Chhatak, Hydraulic Geometry
Figure C-41 Meghna River at Bhairab Bazar, River Characteristics
Figure C-42 Meghna River at Bhairab Bazar, Hydrometric Data
Figure C-43 Meghna River at Bhairab Bazar, Channel Properties
Figure C-44 Meghna River at Bhairab Bazar, Hydraulic Geometry

EXECUTIVE SUMMARY

The Northeast Region consists of a 24,000 km² triangular shaped lowland that is bounded by the Shillong Plateau on the north, the Tripura Hills on the south, the Barak River Plain on the east, and the floodplain of the Brahmaputra River on the west. The Region has formed as a result of deltaic and alluvial sedimentation into a slowly subsiding basin. Ongoing tectonic processes are expressed by recurring earthquakes and continuing slow subsidence. Preliminary estimates of contemporary subsidence rates were made from comparison of geodetic surveys and from radio-carbon dating of buried organic materials. These results suggested subsidence rates in the Northeast Region are in the order of 1-2 mm/year. Although regional subsidence is an important long-term geological process, it is of secondary importance in terms of directly affecting water resource projects and planning over the next 20 years.

A series of alluvial fans have developed along the northern side of the Region. The fans extend from the base of the Shillong Plateau and blend into the low lying floodplain of the Surma/Baulai River. The fans are characterized by periodic channel shifting and avulsions due to ongoing channel aggradation and sand deposition.

Piedmont rivers flow into the Region from the southern Tripura Hills and from the Susang Hills in its north-west corner. These streams have developed meandering sand-bed channels with prominent natural levees that extend up to 3m above the adjacent flood basins. BWDB suspended sediment measurements indicated sediment yields from Piedmont streams are high, reaching up to 2,000 tonnes/km² on the Manu River. Most of the sediment is composed of silt and approximately 30% consists of fine sand. Piedmont streams experience periodic bank breaching and over bank spills during major floods, which produces substantial flow losses in the main channels. Consequently, channel dimensions such as top width and depth decrease in a downstream direction, particularly when they flow onto the low lying floodplains of the mainstream rivers.

The Surma-Baulai and Kushiyara-Kalni Rivers are the two major lowland rivers in the Region. These rivers originate at the bifurcation of the Barak River near Amalshid on the Indian border and rejoin to form the Upper Meghna River upstream of Bhairab Bazar. The Upper Kushiyara and Upper Surma Rivers are morphologically stable channels that are subject to progressive channel shifting and meander migration. The lower Kushiyara-Kalni River and lower Surma-Baulai River traverse the Central Basin, a topographically distinctive depression that extends over 6,600 km² and is criss-crossed by a maze of former channels, khals and meander scars. This part of the Region contains a number of saucer-shaped depressions, termed haors, which have permanently inundated beels in their lowest areas. During the monsoon season, much of this land is inundated to depths of 2-3 m and as much as 75% of the monsoon flood discharge are conveyed overbank on the floodplain and flood basins. The main rivers in this sub-region experience sedimentation during the monsoon and incision and sediment re-distribution during the pre-monsoon and post-monsoon when river gradients and channel velocities are highest. A tentative sediment budget for the region indicated approximately 40% of the incoming suspended sediment is deposited in the Central Basin. River channels through the central Basin form an "anastomosed" pattern, which consists of highly meandering channels that form branching distributaries. Channel instability occurs by bank breaches and avulsion, which are initiated when spills from a main channel enlarge a minor khal or formerly abandoned channel.

The 66 major flood control and drainage projects that have been constructed in the Region during the last 10-20 years have affected the frequency and magnitude of the flood discharge and initiated morphologic changes on many of the rivers. Construction of full flood control embankments and channel closures on rivers such as the Upper Kushiyara, Upper Surma, Khowai and Manu Rivers has reduced spills to the floodplain and has contributed to increased flood discharges in the last decade. The response of the rivers has included channel widening and enlargement, sedimentation on the berms (between the embankments and river bank), and increased overbank deposition of suspended sediment downstream of the embanked reach.

Loop cuts and channel re-locations have been constructed on many rivers, particularly the Khowai River, Kushiyara-Kalni River and Surma-Baulai River. It has been common to divert the rivers into a narrow pilot channel and then let the new channel enlarge by eroding its banks and bed. In the short-term, these works have constricted the flow, which has led to increased flood levels upstream of the project.

1. INTRODUCTION

1.1 Purpose and Scope

The Northeast Regional Water Management Plan was prepared under the auspices of the Flood Action Plan to assist the Government of Bangladesh in planning and guiding the development of the region, with particular emphasis on water management. Results of the investigations have been summarized in various documents, including the Water Management Plan itself, specialist studies (including reports on Agriculture, Fisheries, Water Resources and Groundwater) and other publications.

This report summarizes results of an investigation of channel sedimentation and morphology in the Northeast Region. The purpose of these investigations were to ensure that the effects of sedimentation are properly considered during the formulation of the North East Regional Project's water management plan. Issues that are discussed in this report include:

- historical evolution of the main river channels and their current behaviour with respect to their morphology, migration, erosion and deposition;

- the role of sedimentation in contributing to flooding, channel erosion and floodplain deposition in the region;

- the type, magnitude and extent of morphological impacts that have been produced as a result of past engineering and non-engineering developments. Developments include construction of flood control, irrigation and drainage projects as well as external changes outside the region. Where possible, forecasts have been provided to indicate future trends in river behaviour.

- possible measures and strategies that would be appropriate for managing future sedimentation problems in the region.

- the kinds of long-term data collection programs and efforts that will be required to provide reliable assessments about future project impacts.

There are several reasons why it is important to consider sedimentation and morphologic change when planning future water resource developments. First, the region's rivers make up a very dynamic network that is changing and evolving. Periodic human interference from past FCD projects can initiate major adjustments to the river system. Failure to recognize these ongoing changes may lead to implementation of inappropriate projects that operate poorly in the future.

Furthermore, river dynamics and channel changes can impose a degree of uncertainty in planning future developments. In some instances it will not be realistic to assume that future hydraulic conditions will be similar to those that have been experienced in the past. This introduces additional complexity when attempting to assess project design parameters such as anticipated water levels and discharges.

New water control developments will also initiate other physical impacts and changes to the river systems. In some instances, interference with the river's natural regime may produce the opposite effect to what was initially planned. For example, sediment aggradation resulting from water control projects may potentially lead to increased flood levels, reduced drainage and impaired navigation. Such impacts may also degrade valuable habitat and lead to other environmental problems. Project screening and impact assessment can ensure that potential undesirable sedimentation effects are identified. Measures to eliminate or mitigate sedimentation effects may also be implemented if the nature of the problems are understood.

1.2 Overview of the Region

Bangladesh is the site of the world's largest delta, formed by the Ganges, Brahmaputra, Padma and Meghna Rivers. The NE Region is a triangular shaped wedge, roughly 250 km east to west and 120 km north-south (Figure 1). The study area encompasses 24,000 km^2 of land and is bounded by the Old Brahmaputra River on the west, by the Meghalaya Foothills and Shillong Plateau on the north, and by the Tripura Hills on the south east. The 30 largest rivers are listed in Table 1.1. The total length of these channels amounts to over 2,200 km. The two main river systems described in this report are the Surma/Baulai River and the Kushiyara/Kalni River. These rivers are a continuation of the Barak River which bifurcates at the Bangladesh border near Amalshid at the extreme eastern end of the study area. The region is drained by the Meghna River which flows into the Padma River just downstream of Narayanganj.

Between May to October the entire central portion of the region becomes deeply flooded in most years. During these times this basin can be considered to behave as a shallow lake and the rivers deposit their sediment in inland deltas and by lacustrine processes. Figure 2 shows the extent of inundation in October 1988, more than a month after the peak flood. About 16,000 km^2 or 67 per cent of the region was under water.

The Northeast region has an estimated population of 17.66 million, which is 17 per cent of the total population of Bangladesh. The economy is based almost entirely on agriculture and fisheries. The western part is utilized intensively for rice production. Most of these floodplain lands are used for single and double cropped rice and other crops. The central part of the region is mostly deeply flooded in the monsoon season and is used for single crop boro and for fisheries. Fisheries is a major economic sector. However, overall fish catch as well as biodiversity has been declining over the last century. Reasons for the decline that have been identified include, FCD/I projects which obstruct fish migration, industrial pollution, degradation of floodplain habitat by sedimentation and other factors.

Water resource development includes full flood control projects, partial flood control projects, and major surface irrigation projects. A total of 66 projects covering an area of 395,000 hectares, have been constructed or are nearing completion. The location of these structures are shown on Figure 3. Navigation routes are maintained by the Bangladesh Inland Water Transportation Authority (BIWTA), who have jurisdiction over about 1,400 km of classified rivers. The main navigation routes are along the Meghna/Kalni/Kushiyara River system into India and the Meghna/Baulai/Surma River system as far upstream as Chhatak.

1.3 Sediment Issues and Problems

This section provides an overview of the kinds of sediment problems that have been reported in the region in recent years. Much of this information was compiled from the draft report entitled "Regional Water Resources Development Status", NERP, 1992. Additional views and comments were obtained during field investigations to gather sediment data. The views tend to reflect people's perception of sediment impacts in the region which do not always agree with the technical findings that are presented later on in this study. Nevertheless, the results provide an overall appreciation of the extent and kinds of sediment issues that affect infrastructure, water transportation and the environment.

1.3.1 Flood Control and Drainage Projects

Existing Situation
Flood control and drainage projects are categorized as full flood control, partial flood control and drainage improvement. The objective of most full flood control projects has been to increase agricultural production by providing protection to crops throughout the monsoon season. There are 27 full flood control projects in the region covering an area of roughly 96,000 hectares. Infrastructure includes more than 600 km of embankment, 290 km of re-excavated drainage channels and 160 structures. Most full flood control projects were constructed since 1975.

The objective of partial flood control projects is to increase agricultural production by protecting the *boro* crop against early or pre-monsoon flooding (before May 15). Submersible embankments are constructed around the area to be protected and regulators are placed at strategic locations in the embankment. The regulators are intended to allow post-monsoon drainage and to allow water to enter the protected area immediately after the *boro* is harvested. Projects of this type are often constructed in areas subjected to flash floods between April and mid-May. During the monsoon season (after the *boro* is harvested), the projects may be overtopped by in excess of one metre.

Most of these projects are located in the deeply flooded central part of the Region. There are 21 completed partial flood control projects and infrastructure includes more than 900 km of submersible embankments and about 90 major structures. Although a few partial flood control projects were constructed in the Sylhet Basin early this century, there was little development prior to 1975. There has been a marked increase in development after 1975 and into the 1990's.

The objective of drainage projects are to improve land drainage so that boro crops can be planted earlier on low lands so that pre-monsoon flood damages can be reduced. There are five drainage projects in the region, of which four are re-excavation of channels only. The fifth project (Dewankhali) includes both re-excavation and construction of a sluice gate. Drainage improvement projects were largely ignored until about 1980 because it was felt that they do not have a significant impact on the hydraulic capacities of the channel systems.

Sediment Problems
Figure 4 shows the location of FCD/I projects which have been affected adversely by sedimentation and morphologic changes. Table 1.2 provides an inventory on the nature of the sediment problems at each identified project and describes the probable cause of the problem. The data have been tabulated by physiographic region to illustrate the common kinds of sediment

impacts that occur in each sub-region. These results show that the main problems are concentrated in three main areas:

- along the north side of the Region at the boundary between a series of alluvial fans and the lowlands.
- in the central part of the region along the Kalni and Baulai Rivers;
- on piedmont streams such as the Khowai River and Chillikhali River.

Virtually all submersible embankment projects constructed north of the Surma River are affected by sedimentation and channel instability from the alluvial fans that fringe the north side of the region. The most commonly reported impacts were channel erosion causing embankment breaching and sand deposition on agricultural fields. Most submersible embankments are not protected with stone and can not sustain high channel velocities, bank erosion and scour from the flash floods generated in the Meghalaya hills. The most serious problems have been experienced at Kalner Haor, Karchar Haor and Angurali Haor. For example, at Karchar Haor a 500 m breach has occurred regularly as a result of high velocities and erosion and more than 700 hectares (11% of the cultivable area) is covered with sand. It was reported that about seven years is required to reclaim the land once it has been covered by the coarse sand deposits. At Angurali Haor, sediment deposition has caused a branch of the Jadukata River to be deflected against the unprotected embankment. This causes annual breaching and ongoing sand deposition within the project area.

In the central part of the Region, submersible embankment projects have been reported to experience drainage congestion and increasing water level pre-monsoon flood levels over time. These impacts were thought to be related to overall changes in flow regime and by channel aggradation in the mainstem rivers such as the Kalni River and Baulai River. At Gurmar Haor Project, Dhankunia Khal Project, and Chandra Sonathal Project, problems of drainage congestion caused by local sedimentation were reported.

Piedmont river with flood control embankments include Khowai River and Manu River in south and Chillikhali River in the northwest corner of the region. Channel aggradation with in the embankments has been reported on both the Chillikhali River and the Khowai River and the Chillakhali River. The Chillakhali embankments were constructed in 1981/82 to control flash floods, reduce sediment deposition on arable land and to provide winter season irrigation facilities. Channel aggradation has occurred in the lower end of the embanked reach, in response to the reduction in channel gradient as the river approaches the lowland floodplains. The aggradation is so great that the river bed is higher than the surrounding floodplain outside the embankments. This could result in the river breaching the embankments, abandoning its present course and developing a new course. It was concluded that the project did not serve its intended purpose and failed to address the need to accommodate large volumes of sediment carried by the river.

Concerns about sedimentation at the Khowai River project are similar to those on the Chillikhali River - namely that aggradation will reduce the discharge capacity of the embankments and lead to greater risk of breaching and spilling out of the channel.

1.3.2 Transportation and Navigation

Existing Conditions

The Inland Water Transport Authority (IWTA) administers navigation and water transport. There are 1400 km of classified navigation routes in the region. These routes are used by larger commercial boats carrying passengers or freight. The basis of the route classification is the "Least Available Draft" or LAD:

- Class 1 routes have a LAD of 3.60 m - 3.90 m all year round;
- Class 2 routes have a LAD of 2.10 m - 2.40 m all year round and are intended to link important ports such as Bhairab Bazar with the main Class I routes;
- Class 3 routes have a LAD of 1.50 m - 1.80 m during the dry season;
- Class 4 routes are basically seasonal routes where it is not possible to maintain an LAD of 1.5 m in the dry season.

The Meghna/Kushiyara River system is an international transit route that is used to connect Calcutta with Assam via Zakiganj, with annual traffic volumes of 18000 ton/year (BIWTMAS, 1988). The other major commercial route follows the Meghna/Baulai/Surma River system, which extends up to Sunamganj and Chhattak. This route is used for transporting aggregates and stone materials from the alluvial fan rivers (Jadukata R., Dhalai Gang R. and Dauki/Piyain R.) to other parts of the country. In addition, water transport is vital to many people in the Region since so much of the land is flooded during the monsoon and post-monsoon seasons. At these times, roads will be impassable and water transport may be the only reliable means of connecting villages and towns.

Problems

The Kalni/Kushiyara River route has declined to a Class 3 channel during most of the year in response to channel sedimentation and shoaling over the last 25 years. For example, there were 15 million m^3 of shoals that restricted drafts to less than 3.6 m on the lower Kushiyara/Kalni River system in 1988. Most of these shoals were found in the 50 km reach between Madna and Markuli. Inhabitants of river ports such as Ajmiriganj have reported rapid sedimentation and declining river depths over the years. Consequently, water transport has been restricted during much of the year.

Shoaling has also been reported on the Baulai River system. For example, there is approximately 2 million m^3 of shoals that can obstruct navigation, mostly in the reach between Kaliajuri and Itna. Sedimentation has also prevented boats from gaining access to gravel quarrying sites on the upper Rakti/Jadukata River and upper Dhalai Gang River near Companiganj.

1.3.3 Wetlands and Fisheries Habitat

Most fisheries managers have reported that sedimentation has contributed to the recent declines in fisheries in the Region. Two main impacts have been described. First, some species utilize the deepest portions of the channel (*duars*) for rearing. It is reported that the number and depth of these *duars* have declined over time due to channel infilling and overall aggradation. Second, flood basins (*haors*) and permanently inundated land (*beels*) on the floodplain are an important habitat for the floodplain fisheries and other species. Environmental managers perceive that the extent of these *haors* and *beels* has also declined over time as a result of sediment deposition.

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1.3.4 Summary

The perceived problems have a common theme, namely that sedimentation has increasingly affected the beneficial uses of the resources in the region over the last few decades. The remainder of this report tries to answer relevant questions, such as :

- what are the actual patterns of sedimentation in the region?
- what are the main factors governing morphologic changes in the region?
- how do rivers adjust their channels and floodplains in response to embanking and other FCDI works? How far downstream do these impacts extend? How long do they persist?
- how do FCDI works affect sediment deposition rates on the floodplain and in haor areas?

1.4 Method of Approach

The main physical processes that "drive" the morphology and sedimentation patterns of the rivers in the region include:

- the climate and runoff patterns;
- the quantity and nature of the sediment supplied from the region's catchments;
- the pattern of water levels in the Padma River which imposes a downstream boundary condition to the region.
- regional tectonics.

Reliable predictions of future morphologic changes requires a good understanding of these driving forces. Unfortunately, the uncertainties involved in predicting future river evolution and sedimentation patterns on complex river systems can be very large. For example, even measuring a basic parameter such as the daily sediment load on a river involves much greater uncertainty than with other hydrometric data such as rainfall, water stage or discharge. Furthermore, uncertainties associated with other processes such as the hydrology and river hydraulics will affect the reliability of predicting sediment transport rates and future erosion/deposition processes.

These limitations can often be overcome by using a river geomorphology approach in addition to standard river engineering and modelling methods. This involves assessing the long-term patterns of river behaviour, defining the driving forces that govern these patterns, assessing how future driving forces will differ from the past and then projecting these new trends into the future. This geomorphic approach was adopted in conjunction with a program of field measurements and project monitoring and numerical analysis.

A substantial effort was made to compile existing historical data on channel morphology, sediment transport and river hydraulics. A reconnaissance-level morphologic survey program was carried out to collect hydraulic, geomorphologic and sediment data at selected river sites. The field work included:

- conducting site inspections to observe the characteristics of the rivers,

- surveying river cross sections and longitudinal profiles of river reaches to assess river processes and to provide comparisons with earlier surveys;
- collecting sediment samples to assess sediment transport rates;
- collecting samples of floodplain sediments from drilling in order to assess geological processes in haor areas.

The field program was considered an essential component of the sediment investigations. The morphologic data were used to develop a series of case histories to illustrate the kinds of impacts that have occurred from past engineering projects. The data also provide an overall picture of the recent evolution of the river systems and allowed assessments to be made about the key processes that govern the behaviour of the rivers.

It was considered that this combination of historical river geomorphology analysis, field surveys and project monitoring investigations and morphologic modelling provided a suitable strategy for conducting planning and pre-feasibility level assessments. However, systematic, long-term monitoring will be necessary along some rivers to adequately understand the processes that are occurring.

1.5 Report Outline

Chapter 2 summarizes the available data that has been used in this study. Wherever possible, efforts have been made to assess the reliability of the data. Measures for improving data collection techniques have also been suggested. Chapter 3 characterizes the Northeast Region in terms of its geomorphology, topography and physiography. Chapters 4 describes the hydrological characteristics and runoff patterns of the main rivers. Chapter 5 summarizes an analysis of sediment transport and sediment yields. A tentative regional sediment budget is also presented.

The remaining sections of the report provide a description of the channel regime and channel changes that have occurred in historic times on the main river systems. Chapter 6 describes the alluvial fans that fringe the region's northern border. Chapter 7 describes the piedmont rivers that enter the region from the southern hills in Tripura or from the north-western Susang hills. Chapter 8 describes the lowland rivers, including the Surma/Baulai, Kalni/Kushiyara and Meghna Rivers.

Finally, Chapter 9 provides an overall assessment of the morphologic impacts from various FCD developments and Chapter 10 provides a set of conclusions and outstanding issues. Tables and figures are contained in Annex A and Annex B respectively. A river catalogue, summarizing the hydraulic and geomorphic characteristics of various rivers is provided in Annex C.

2. AVAILABLE DATA

2.1 Water Levels

Water levels have been measured at 27 sites (24 sites in 1993) in the region (Figure 5). The history of measurement are summarized in Table 2.1. Water levels are typically measured manually by a BWDB gauge reader at a staff gauge. The gauge heights are recorded six times over the day: 06:00 hr, 09:00, 12:00, 15:00 and 18:00 hrs. The staff may have to be shifted over the course of the year so that the "gauge zero" value may be adjusted from time to time. At a few sites (Khowai River at Shaistaganj, Kushiyara River at Sherpur) automatic water levels have been installed. Daily values are published for most stations. However, at tidally affected sites (such as Meghna River at Bhairab Bazar and those on the Baulai River), maximum and minimum daily levels are published. In 1993, a Second Order Levelling Program was carried out throughout the NE Region which has allowed BWDB gauge bench marks to be adjusted. In most cases, the adjustments are in the order of 0.1 m. In a few cases, (such as Khowai River at Shaistaganj, and Baulai River at Kaliajuri) the gauge datum errors are in the order of 0.5 m. It is difficult to use this information to adjust historic data since it is not clear whether these errors were consistent over time.

2.2 Discharge

Discharges have been measured at 16 sites (13 active in 1993) in the region (Figure 5). The history of measurements are summarized in Table 2.2. Typically, discharges are measured 10-15 times in the year using a current meter from a boat (usually on a regular weekly or bi-weekly time interval). Discharge stations are always situated at sites where water levels are recorded. A stage-discharge rating curve is established from the observed discharges and water levels. Daily discharges are then estimated for the dates when discharge measurements are not carried out by using the daily water levels and stage-discharge rating curves. It is not clear how often the rating curves are revised or what criteria are used to make these revisions. The actual observed discharge data, as well as the published daily discharge data were provided to NERP. Observed data included date, water level, discharge and usually channel top width and cross sectional area. These observed data have been used to assess some key hydraulic characteristics of the rivers (Annex C).

It has been difficult for BWDB to measure discharges during flood conditions, particularly on piedmont rivers and alluvial fans due to difficulties in access, flashy nature of the rivers and occurrence of overbank spills. Consequently, on these rivers, the stage-discharge rating curves have been extrapolated to provide discharge estimates. In some cases, these extrapolations are very large. For example, in 1988 the published maximum discharge on the Khowai River at Shaistaganj was reported to be 1050 m^3/s, which is the flood of record for this site. However, the maximum measured discharge was only 360 m^3/s. Subsequent hydraulic computations suggested the actual 1988 flood peak at Shaistaganj was probably only 750 m^3/s. Unfortunately, it may never be possible to come to an accurate estimate of this event, given the uncertainties in the historic data. On the Bhogai River at Nakuagon, even the average annual flood is substantially greater than the highest measured discharge, and the published maximum discharge is over three times the magnitude of the highest measured discharge. In these instances, the accuracy of the published flood discharge estimates will be extremely low. These uncertainties

2B

in the flood records will diminish the reliability of flood frequency analyses and hydraulic computations. Careful attention must be given to the reliability of any discharge data during the monsoon season and particularly during flood conditions.

It would be desirable to clearly indicate in the published records when these types of extreme extrapolations have been carried out. Furthermore, efforts should be made to improving the reliability of peak discharge measurements, since this information is critical for design and planning of most water resource projects. Consideration should be given to installing cableways on some piedmont rivers (such as the Bhogai River) for carrying out discharge measurements. This would allow measurements to be made under conditions that are not suitable for small boats. Cableways are commonly used outside of Bangladesh on small and intermediate size rivers (Environment Canada, 1987; US Geological Survey, 1965).

2.3 Suspended Sediment Concentration

BWDB have measured suspended sediment concentration intermittently at 19 sites in the region since the 1960's. In 1993 measurements were made at 6 active hydrometric stations. In addition, miscellaneous suspended sediment samples were collected in 1992 at six gauging sites by SWMC. A detailed review of these data is summarized in Section 5.

2.4 River Surveys

Most of the river cross section information used in this investigation was provided in digital form by the modelling section of NERP. These sections which were surveyed by SWMC and BWDB in 1991 and 1992, totalled approximately 160 in number and are shown in Figure 5.

Additional, older cross sections were provided by BWDB, Morphology Directorate or the Design Circle, BWDB on the Surma River, Kushiyara River, Kalni River, Manu River and Khowai River. Historic BIWTA sounding charts on the Surma/Baulai River, Kushiyara/Kalni River and Meghna River were also used to assess changes in channel conditions. The sounding charts that were used are summarized in Table 2.3. The sounding charts show spot depths (referenced to a standard low water datum) and the approximate low water channel alignment on charts with scales ranging between 1:10,000 and 1:25,000. Bed elevations (EL referenced to PWD datum) were estimated from the charts local low water (LLW) and spot depth (D):

$$EL = LLW - D$$

Although these data are probably less accurate than the cross sections, they still proved very useful for gaining a general appreciation of the river bed topography and for changes that have occurred. On some rivers, the profile data provide the only means for assessing historic channel changes. In total, approximately 2,200 km of profiles (about 25,000 depth readings) along the Kushiyara, Kalni, Baulai, Surma and Meghna Rivers were digitized and analyzed.

In addition, NERP carried out river surveys on several rivers in order to provide additional information on river processes and sediment transport. The underwater portions of the rivers were surveyed using a Lowrance X-15 recording depth sounder. Horizontal positions were determined using a "Chainman" distance meter. All cross section hubs were located using a

Magellan NavPro 1000 Global Positioning System. The location of these special surveys are shown on Figure 6.

Amalshid Bend Erosion: Surveys were made in September 1992, October 1992, June 1993 and December 1993 to document channel scour and erosion at the Barak River bifurcation. The surveys were made to interpret channel instability, scour and effectiveness of stone protection works on the Upper Surma and Upper Kushiyara River. Results of the investigations were published in the report "Observations of Bank Protection Works along Surma & Kushiyara Rivers", December 1992, NERP.

Surma River Bank Protection Surveys: River cross sections were surveyed at Tooker Bazar and near Sunamganj to monitor channel topography and bank protection works at bends on the Surma River.

Zakiganj Bend Erosion and Scour Surveys: Surveys were made in October 1992 and October 1993 to document scour and erosion processes at bank protection works on the Upper Kushiyara River between Zakiganj and Bhuiyamura. Results of the investigation were published in the report "Monitoring Erosion & Channel Scour, Upper Kushiyara River", June 1994, NERP.

Kushiyara River Dune Surveys: Longitudinal profiles were surveyed on the Kushiyara River between Sherpur and Manumukh (12 km) in September 1992 to document the rivers profile and to monitor the state of the bed in terms of dune formation and bed forms.

Old Surma River Longitudinal Profile: River soundings were made in October 1992 along the Old Surma River and Darain River over a distance of 100 km to document channel topography and bed levels.

Kushiyara River Channel Surveys: Cross sections were surveyed on the Kushiyara River between Manamukh and Fenchuganj (10 km) to assess channel geometry and changes that have occurred since construction of embankments. These cross sections were compared with earlier sections surveyed by the Morphology Directorate , BWDB.

Kalni River Channel Monitoring: Cross sections pillars were established at nine locations between Markuli and Madna in May 1993. Repeat surveys were made in June 1993, August 1993, September 1993 and December 1993. Four more cross sections were established in March 1994 and the repeat surveys were continued in May 1994, June 1994 and August 1994. These surveys are being used to monitor seasonal patterns of channel aggradation and scour in the lower Kalni River.

Shanir Haor/Halir Haor Surveys: Cross sections were surveyed on the Baulai River and Rakti Rivers in November 1992, June 1993 and August 1993. Surveys of the submerged portions of Shanir Haor and Halir Haor were made in June 1993 and September 1993 using the depth sounder and a Global Positioning System. The purpose of these surveys was to assess rates of sedimentation in two different haors - Shanir Haor, which has been embanked for many decades and Halir Haor which is essentially unembanked.

Manu River Surveys: Repeat cross section surveys and longitudinal profiles were carried out on October 1992, May 1993, June 1993 and August 1993 to monitor channel changes and bed form properties at various times of the year. These surveys were carried out at nine locations over a distance of 35 km. Later on, an additional six cross sections were added in order to assess changes in channel geometry caused by flood control embankments.

Khowai River Surveys: Cross sections were surveyed at Chunarghat and 12 locations downstream of Shaistaganj. These cross sections were used for hydraulic and sediment modelling for assessing the impacts of flood control embankments and other works on the river's regime.

2.5 Mapping and Satellite Imagery

The most recent mapping of the region is the 1:50,000 scale colour imagery prepared by SPOT Image Corporation which were taken in 1990-1991. LANDSAT images from 1972 and 1990 were also used in some parts of the region.

The Survey of Bangladesh's 1:15,480 scale, 0.3 m contour interval topographic maps were used in this investigation. These maps were surveyed in the early 1960's. In addition, 1:40,000 scale planimetric maps, based on air photos flown in 1952 were used for establishing channel changes and shifting. Topography of the Indian watersheds draining into the region was derived from 1:500,000 scale Tactical Pilotage Charts (1984 edition) prepared by the Defense Mapping Agency, Aerospace Centre, St. Louis Missouri, USA.

2.6 Bed Material

Samples of river bed material were collected at 112 sites by SWMC in 1991 and 1992. These samples were generally collected at surveyed cross sections, usually at three locations in the channel (left bank, mid-channel and right bank). In addition, NERP collected an additional 29 samples in 1992 and 1993, A mechanical grab sampler was used by both groups. The samples, which were usually fine sand or silty sand, were approximately 1-2 kg in weight. The particle size distribution of the sediments was determined, using sieve analysis for the sand fraction and hydrometer analysis for the finer silt and clay fraction.

2.7 Geology and Stratigraphy

Generalized surficial geology and landform mapping has been undertaken by Geological Survey of Bangladesh (1990) and Rashid (1988). Soils and landscape evolution is also summarized in a number of general reports such as MPO (1986).

Information on soil stratigraphy was obtained by examining soil boring that were carried out under the Systems Rehabilitation Project, BWDB. Borehole logs are summarized in the document "Report on Geotechnical Investigation Work". These borings were made by Soil Explorers, Engineers and Designers, Dhaka. NERP accompanied the drillers at Shanir Haor and then spent time reviewing the cores and soil samples that were brought back to Dhaka. Samples of organic materials from the borings were retained and sent to Beta Analytic, USA for radio-carbon dating.

2.8 Historic Data

The earliest maps of the region that were used are the Rennell's survey of 1758 - 1768. These maps provided locations of physical features such as rivers and haors as well as cities and towns. All maps were referenced to Latitude and Longitude (referenced to Calcutta). The maps were digitized, adjusted to modern geographic coordinates and then compared with contemporary maps. Figure 7 provides a reproduction of the original maps.

An indication of its accuracy was made by comparing the locations of some of the older towns and villages which have known to have been settled permanently over the last 200 years. It was concluded that the maps were generally quite reliable, and that they could be used to provide qualitative information about channel evolution and shifting. Additional information was provided from the comments and annotations on the maps, particularly those concerning river navigability, physical descriptions of the region and habitation.

Other historic information was derived from accounts in the Sylhet District Gazetteer, Rangpur District Gazetteer and Mymensingh District Gazetteer. These publications summarize a wide range of historic events, such as the shift in the Brahmaputra River as well as major earthquakes.

3. THE REGION

3.1 Geological Setting

The Indian sub-continent, including Bangladesh, has evolved since Cretaceous times as a result of a collision between the northward moving Indian Plate and the stationary Eurasian Plate (Figure 8). During Oligocene times (38-26 million years ago) a portion of the northeast Indian Plate fractured and sank below sea-level. This portion was eventually filled with sediment to form the Bengal Basin. Since this time the land has developed by a process of deltaic sedimentation into a slowly subsiding tectonic basin.

Figure 9 shows a generalized tectonic map of the area surrounding the study region. This map, and the interpretation of the region's tectonic history are based primarily on the work of Johnson and Alam (1991). Table 3.1 summarizes the stratigraphy and lithology of the main geologic units that have been adopted by the Geological Survey of Bangladesh.

The onshore part of the Bengal Basin has been sub-divided into (1) a broad shallow platform or "shelf" on the west, (2) a slope or "hinge" (3) a deeper buried facies or basin. The Bengal Basin is gradually being encroached on by the Indo-Burman Range, an active 230 km long orogenic belt associated with eastern subduction of the Indian Plate below Myanmar. The northern most extension of the Indo-Burman Ranges merge with the west trending Himalayas in a complex zone termed the Assam Syntaxis.

The Sylhet Trough, which underlies most of the region, is a sub-basin of the Bengal Basin and consists of 13 - 20 km thickness of alluvial and deltaic sediments underlain by much older gneiss and granitic rocks. The basin is bounded by the Shillong Plateau on the north, by the Indian-Burman ranges on the east and by the Indian Shield to the west. Rapid subsidence has occurred in the basin since Miocene times (22 million years BP) as a result of encroachment of the Indo-Burman Ranges to the east and overthrusting by the Shillong Plateau along the Dauki Fault to the north (Johnson and Alam, 1991). Since Pliocene times, subsidence rates have accelerated, probably as a result of south-directed overthrusting of the Shillong Plateau along the Dauki Fault. As this Plateau was uplifted, the sedimentary cover rocks were eroded. Uplift of the Shillong Plateau also led to a major reorganization of rivers draining the Himalayas. The Brahmaputra River, which probably formed a southwards flowing delta into the region in Miocene times, was deflected about 300 km to the west into its present course.

Today, the Shillong Plateau extends 300 km east-west and 150 km north-south, reaching to El. 2500 m at its highest point. It is bounded on the south by the Dauki Fault, which forms a 5 km wide zone of extensively fractured and steep dipping Pliocene and Pleistocene strata. Most of the Plateau consists of Pre-Cambrian gneiss and granite which became exposed when pre-Pliocene sedimentary rocks were eroded during uplift. Mudstone, siltstone and very fine grained sandstone from the Surma Group (Miocene age) are found draped along the plateau's south-western face in the watershed of the upper Someswari River. Sedimentary rocks (sandstone, siltstone, mudstone and conglomerate) from the Baril Group (Oligocene age) are exposed near Jantiapur along the Dauki River and extends eastward into Assam.

East of the Region in India, the Naga Hills are composed of Disang Shales (Eocene age). Towards the interior, in the hills separating India from Mynamar, the shales become harder and slatey, and also contain quartz veins and serpentine.

The southern and eastern portions of the Sylhet Trough are characterized by a series of north trending folds which have formed as a result of deformation from the Indo-Burman Ranges. The anticlines constitute the Tripura Hills along the southern border of the Region. These anticlines are steeply folded, or box shaped, while the synclines are broad and more symmetrical. Each of the synclines is occupied by a major northwards flowing Piedmont river (Juri, Manu Dhalai, Khowai River). The anticlines, consist primarily of Pliocene and Pleistocene age sedimentary rocks (Tipam formation and Dupi Tila formation), which consist primarily of sandstone.

Pleistocene times (the last 2 million years) were characterized by several major fluctuations in sea level in response to the growth and retreat of continental glaciers in northern Asia, Europe and parts of North America. When sea level fell, the Brahmaputra-Ganges River system and its tributaries would have incised into the floodplain and deltaic deposits and eroded much of these earlier sediments. When sea level rose again, the locus of deposition would have shifted upstream again, and the deltaic sedimentation would continue. Consequently, much of the Pleistocene age deposits have been eroded. The Madhupur Tract (an uplifted block on the western boundary of the region), and the Comilla Terrace are remnants of Pleistocene sediments deposited by an early Brahmaputra-Ganges River delta.

Climate studies have indicated that most of the Tropics, including India and Bangladesh were much drier than the present at the time of world-wide glacial maximums, around 18,000 years Before Present (BP). More humid conditions prevailed from about 12,000 to about 5000 years BP in the Pluvial Epoch (Kutzbach, 1987). The change in the monsoon during this time is believed to have been very large. For example, Kutzbach suggested the annual rainfall was double the present-day amount in some parts of India. This would have led to very large runoff volumes and rapid expansion of the Brahmaputra-Ganges River delta. Most of the sediments in the region are derived from fluvial, lacustrine and deltaic sedimentation during Holocene times, less than 10,000 years Before Present (BP). Figure 10 illustrates various stages of deltaic sedimentation from the Brahmaputra and Ganges River. The earliest deltaic features in Holocene times termed the "Early Ganges" and "Early Brahmaputra" deltas. The age of these features are believed to be Early to Mid-Holocene, or between 8000 - 4000 years BP (Before Present). It can be seen that the Early Brahmaputra delta extended about mid-way into the NE Region, about to Sunamganj. Most landforms have been created by infilling of an embayment from the Brahmaputra River on the west and the Barak River on the east. This has produced a characteristic "bowl-shaped" basin, with a central sink and higher floodplain lands surrounding it.

The periods of major sediment infilling in the region have occurred when the Brahmaputra River has occupied the eastern side of its fan. Much of the NE Region is crossed by a maze of channel scars and paleo-channels which represent ancient river systems that have been abandoned by channel shifting. However, the time scales for most of these shifts are largely unknown. The last major shift in the Brahmaputra River took place shortly after Rennell's survey of 1771 and was largely completed by 1808 (Figure 11). There is still considerable debate on the cause for the abandonment of the old Brahmaputra channel. Rashid (1991) concluded the shift was accelerated by regional tilting and tectonic processes which caused a gradual modification to the river's long profile. With the completion of this avulsion, the inflow of water and sediment into the Region would have decreased.

3.2 Topography

Figure 12 shows a generalized topographic map of Bangladesh and Figure 13 shows details of the NE Region. These maps illustrate how the NE Region forms such a prominent low-lying basin in comparison to other parts of the country. Land below El. 5 m PWD extends virtually as far as the Meghalaya Foothills, over 200 km from the Bay of Bengal. Outside of the region, floodplain lands situated 200 km from the sea are typically found at El. 10 to 20 m PWD. Approximately 25 per cent of the area in the region lies below El. 5 m and 50 per cent lies below El. 8 m.

3.3 Physiography and Landforms

Figure 14 shows a classification of the region according to dominant landform type. These boundaries have been synthesized from terrain maps published by Geological Survey of Bangladesh (1990) and physiographic classifications by Rashid (1991). Table 3.2 summarizes the extent of each unit. The main landform types include:

- Uplands
- Terraces
- Alluvial Fans
- Piedmont Floodplains
- Lowland Floodplains
- Depressions (Flood Basins)

Figure 15 shows the NE region sub-divided into 10 principal Agro-ecological land units. This classification, which was developed by UNDP/FAO (1984), is based primarily on soils and physiography. The two classifications share many similarities, since landforms, topography, soils and physiography are all closely inter-related. The following discussion describes the various landforms, their origin, geographical extent and the predominant soils and topography associated with these.

3.3.1 Uplands

Uplands total about 1,970 km^2 of land in the Region or about 8 per cent of the total area. They occur in the northern margin of Jamalpur and Sherpur districts, southern part of Moulvibazar and Habiganj districts, and some areas in Sylhet district. In the southern part of the region, the uplands consist of a series of northward plunging anticlines. They consist of Dihing and Dupi Tila Formation rock of Pleistocene and Pliocene age and are composed of weathered, poorly consolidated sandstone, siltstone and conglomerate (GSB, 1990). In the northern part, the Uplands are found in isolated hills and raised tilas. Upland areas are designated as AEZ 29 on Figure 15.

The unit has complex relief. Hills have been dissected to different degrees over different rock types. Slopes are mainly very steep but the relief varies from very steeply dissected to gently rolling.

The major hill soils are yellow-brown to strong brown, permeable, friable, loamy, very strongly acidic and low in moisture-holding capacity. However, soil patterns generally are complex due to local differences in sand, silt and clay content of the underlying sedimentary rocks, and in the amount of erosion that has occurred. Deep soils (more than 120 cm) predominate. Shallow soils (less than 60 cm) occur mainly over hard sandstones and shales on very steep slopes in parts of AEZ 29a. The soils occupy relatively small parts of AEZ 29b and AEZ 29c over hard rock and ironpan (laterite), and on some very steep eroded slopes over soft shales.

3.3.2 Terraces

Uplifted Pleistocene age deposits (Madhupur Tract) occur along the south western edge of the study region and confine portions of the Old Brahmaputra River. It occupies the northern part of Gazipur district, extreme northern and south-western parts of Narsingdi district, and western part of Kishoreganj district. This terrace, which occupies an area of 494 km^2, has been raised by uplifting and faulting so that it is no longer subject to inundation by normal flooding activity. Recent faulting is continuing to control the alignment of the Old Brahmaputra and Lakhya River channels in this area. The Madhupur Tract is labelled as AEZ 28 on Figure 15.

AEZ 28a and AEZ 28d are comprised of level upland areas. There are, however, a few valleys in AEZ 28d. Closely dissected upland areas and deep broad valleys occur in AEZ 28b. AEZ 28c is characterized by closely dissected areas and shallow valleys. Broad valleys occur in AEZ 28e.

AEZ 28 has complex relief and soils, developed over the Madhupur clay. Level upland areas include deep red and brown soils in AEZ 28a. AEZ 28b has deep red soils on level upland sites. Brown soils occur on gently undulating uplands and shallow valleys in AEZ 28c. Level upland areas in AEZ 28d are comprised of deep and shallow silty soils. In AEZ 28e, broad valleys have mainly dark grey heavy clays. Some floodplain lands included in this AEZ have grey loamy soils on ridge and silty clay basins.

3.3.3 Alluvial Fans

Alluvial fans are found along the northern border of the Meghalaya Foothills. The fans are produced when steep mountainous streams exit from their canyons and spread over the flat, unconfined land of the lowland floodplains and Sylhet Depression. The decrease in channel gradient and reduction in velocity as the streams below their canyons causes deposition of sand and gravel sediments in the form of a "fan-shaped", conical delta. Alluvial fans are characterized by sudden, irregular channel shifts (avulsions) which results in the periodic abandonment of some channel and the development of new channels across the fan surface. Figure 16 and 17 illustrate typical alluvial fan features below the Meghalaya Foothills north of Sunamganj.

The Meghalaya fans appear to be transporting high sand loads. Gravel and cobble-sized sediments are restricted to within a few kilometres of the canyon mouths or are absent from some streams (such as Someswari Fan). Another unusual feature is the low gradient of the fans. As a result, the land surfaces on the fans have generally not been built up above the surrounding low-lying floodplains, and may be deeply flooded during the monsoon season.

Principal streams which have developed alluvial fans include the Someswari River, Jadukata River, Chela River, Jhalukhali River and Dauki/Piyain River. A review of existing water control projects in the NE Region indicated most sediment problems have occurred at sites affected by alluvial fans (NERP, 1992). The northern portions of AEZ 22 are alluvial fans.

3.3.4 Piedmont Floodplains

Piedmont floodplains have formed along the southern and northern margins of the region by relatively small, steep tributary streams. Streams in Tripura piedmont include the Khowai, Manu, Sutang, Dhalai and Juri Rivers which flow northwards from the Tripura Hills in India and join into the Kushiyara River. The total area occupied by these floodplains amounts to 960 km^2. Piedmont floodplains have also developed at the base of the Garo Hills in the extreme north west corner of the region along the Malijhee River, Chillikhali River and Bhogai River.

Surface gradients on piedmont floodplains are much steeper (typically 3 m/km) than on the low lying mainstem floodplains, with elevations typically ranging between 8 - 16 m PWD. Piedmont floodplains correspond to the southern and north-western portions of AEZ 22C. The unit has complex soil patterns due to the irregular deposition of sediments of different textures during successive flash floods. The sub-zones have complex relief and soil patterns, especially in areas close to the hills. Deposits range from sands to clays, though AEZ 22a has, in addition, some older soils (Grey Terrace Soils) with a grey silty topsoil over a grey and red mottled clay loam subsoil. The Piedmont Plains in AEZ 22a grade into moderately deeply to deeply flooded basins with predominantly clay soils.

3.3.5 Floodplains

Floodplains are landforms that have been created as a result of fluvial deposition and erosion. Floodplains from the Surma/Kushiyara River, Meghna River, Old Brahmaputra River and Jamuna River account for 55% of the land area in the region, totalling 13,260 km^2. Old Brahmaputra floodplain lands consist of sediments that were laid down prior to the river's avulsion in the 18th Century. Jamuna floodplain consists of lands that are currently being modified by the modern Jamuna/Brahmaputra River. Floodplain lands include AEZ 7, AEZ 8, AEZ 9, AEZ 16, and AEZ 20.

Floodplains include channel deposits such as point bars and fills, over bank deposits such as natural levees and crevasse splays and fine grained flood basin and back channel deposits. Levees are wedge shaped ridges of sediment bordering stream channels and are most highly developed on the convex (outer) side of meanders. Levees often are the highest points of land on the floodplain and project 3 - 5 m above the adjacent lower lying back basins. Natural levees are formed by deposition of sediment when flood waters of a stream overtops its banks. During overtopping, the velocities are reduced causing deposition of sediment with the rate of deposition decreasing sharply away from the channel. On most streams, floodwaters spill through distinct channels that cut across the levees, rather than by sheet overflow. These cut channels, called crevasses develop their own pattern and drainage system and extend across the levee systems into the flood basins. Sand and finer sediments may be deposited as crevasse splays at the outlets of these channels. Occasionally, the main river may shift through the crevasse causing a river avulsion to occur. Figure 18 illustrates these landforms on a typical lowland river floodplain. Land elevations typically range between 16 m to 9 m on the Surma/Kushiyara floodplain, 22 m to 9 m on the Old Brahmaputra floodplain and less than 7 m on the Meghna floodplain.

The main lowland floodplains are described below.

Active Brahmaputra-Jamuna Floodplain (AEZ 7)
AEZ 7 occurs in the north-western part of the Northeast Region comprising part of Kurigram district. It comprises a belt of unstable floodplain land along the Brahmaputra River which is constantly being formed and eroded by shifting river channels. The land consists of irregular, broad and narrow ridges and depressions, and interrupted by cut-off channels and active channels. Both the outline and relief of *char* formations are liable to change each flood season due to bank erosion by shifting channels and to depressions of irregular thickness of new alluvium. Local differences in elevation are mainly 2-5 m. Virtually the whole area is subject to seasonal flooding: shallow on higher parts, deep in the lower parts.

This AEZ has complex mixtures of sandy and silty alluvium, rich in weatherable minerals and slightly alkaline. The proportions of sandy and silty alluvium vary from place to place and year to year. Silty deposits are more extensive than sandy deposits. However, large areas of sand may be deposited in high flood years. Organic matter content ranges from 1.0-2.0 percent in the cultivated layer.

Young Brahmaputra and Jamuna Floodplain (AEZ 8)
AEZ 8 occurs on the western side of the Northeast Region, extending from Rajibpur thana of Kurigram district to Kapasia thana of Gazipur district through the western part of Jamalpur and Sherpur districts and south-west of Mymensingh, Netrokona and Kishoreganj districts, including the southern part of Bandar thana in Narayanganj district.

AEZ 8 consists of floodplain land and is occupied by a complex relief of broad and narrow ridges, inter-ridges, depressions, partially infilled cut-off channels, and basins. The difference in elevation between the tops of ridges and adjoining basins varies from 2-5 m, being least in AEZ 8b and greatest in AEZ 8d.

The highest floodplain ridge soils lie above the normal flood plain. The middle and lower parts of ridges are subject to shallow flooding. Basins are mainly shallowly flooded, but basin centres and old channels are generally moderately deeply flooded. Basin centres are subject to early and rapid flooding by run-off from adjoining higher land when there is heavy pre-monsoon or early rainfall, and generally stay wet for part or all of the dry season.

The region is comprised of Brahmaputra River sediments. The soils range from shallow, permeable, sandy loams and silty loams on ridge crests to impervious heavy clays in some basin centres. Silt loams and silty clay loams occupy the greater part of the area.

Old Brahmaputra Floodplain (AEZ 9)
AEZ 9 occurs in the western part of the Northeast region. It occupies the north-eastern part of Jamalpur district, central part of Sherpur district, western part of Mymensingh district, western and southern part of Netrokona district, northern and central parts of Kishoreganj district, eastern

part of Gazipur district, most of Narsingdi district, and the northern part of Narayanganj district.

AEZ 9 is comprised of mainly broad ridges and basins. AEZ 9a has some inter-ridge depressions. Relief is locally irregular, especially near old and present river channels. The basins are relatively more extensive in AEZ 9d and AEZ 9e. Usually, the differences in elevation between ridge tops and basin centres is 2-5 m. It exceeds five metres in AEZ 9d and AEZ 9e, especially in areas adjoining Sylhet Basin (AEZ 21).

Ridge soils are generally wet or shallowly flooded at the peak of the annual floods. Basin centres are subject to early and rapid flooding by run-off from adjoining higher land when heavy pre-monsoon or early monsoon rainfall occurs locally or in adjacent AEZs. At other times, flood-levels are controlled by water levels in the Old Brahmaputra River and the Sylhet Basin. The highest ridges in AEZ 9a are moderately well drained. Broad ridges and inter-ridge depressions in this sub-zone lie above normal flood-level. Depressions are mainly shallowly flooded. In AEZ 9b, the highest ridge soils stand above normal flood-levels. Lower ridge and basin margin soils are shallowly flooded seasonally. Small areas in basin centres are moderately deeply flooded, and stay wet for most or all of the dry season. Depressions and haors are moderately deeply flooded in AEZ 9d, and deeply flooded in AEZ 9e.

The AEZ has a large area of Brahmaputra sediments. Ridge soils are mainly silt loams and silty clay loams. Clays predominate in haors. Silt loams and silty clay loams predominate in AEZ 9a and AEZ 9b, especially in the highest ridge sites. Clays predominate in AEZ 9d and AEZ 9e.

Middle Meghna River Floodplain (AEZ 16)

AEZ 16 occurs along Meghna River bank occupying the south-eastern part of Kishoreganj district, eastern part of Narsingdi district, and north-eastern part of Narayanganj district. The AEZ is comprised of various kinds of relief: low-lying basins with surrounding low ridges along Meghna River banks; areas with low ridges, inter ridge depressions and old channels; and highest sandy ridges.

The AEZ occupies an abandoned channel of the Brahmaputra River. Three main kinds of soils occur: (1) Grey loams and clays on ridge and basin sites in areas of Meghna alluvium; (2) Grey loamy ridge soils and dark grey basin soils in included areas of Old Brahmaputra alluvium; and (3) Grey sands to loamy sands with a compact silty topsoil in areas of Old Brahmaputra char land.

Old Meghna Estuarine Floodplain (AEZ 19)

AEZ 19 occurs in the southern part of the Northeast region. It occupies the eastern part of Kishoreganj district, western part of Habiganj district and southern part of Araihazar thana in Narayanganj district. AEZ 19 comprised of smooth, almost level, floodplain ridges and shallow basins. Soils are relatively uniform. Silty soils predominate. There are significant proportions of silty clay or clay basin soils in sub-zone AEZ 19f. This AEZ has a significant proportion of basin clays. Most soils have dark grey to black topsoil. In depression soils, the upper part or all of the subsoil is dark coloured. In higher soils, the subsoil is grey-brown to yellow-brown with dark grey coatings on the faces of subsoil cracks.

Eastern Surma-Kushiyara Floodplain (AEZ 20)

This AEZ occurs in the eastern part of the region and is comprised of parts of Sunamganj, Habiganj, Sylhet and Moulvibazar districts. AEZ 20 is comprised of mainly smooth, broad ridges and basins, with 3-6 m local differences in elevation. Along the lower Kushiyara River, there is a broad belt of irregular relief, with narrow, linear, ridges and inter-ridge depressions. Minor areas of small, low, hillocks occur locally in the east. This AEZ includes perennial wetlands where several haor complexes exist.

Ridges are shallowly flooded within field bunds and when high floods occur. Haors are deeply flooded. The whole area is subject to early floods and a rapid rise in water levels following heavy rainfall locally and in adjoining hills.

AEZ 20 occupies the relatively higher parts of the Surma-Kushiyara Floodplain formed by river sediments draining into the Meghna catchment area from the hills. Grey, heavy, silty clay loams predominate on the ridges; clay in the basins. Small areas of loamy soils occur alongside rivers, together with mixed sandy and silty alluvium. Peats occupy some wet basin centres.

3.3.6 Basins

The major flood basins form a low lying, bowl-shaped depression in the middle of the region and occupy an area of 6,000 km^2. Virtually all of the land lies below El. 8 m PWD and is deeply flooded during the monsoon season. This sub-region is characterized by large saucer-shaped depressions, termed *haors* and permanently inundated water bodies termed *beels*. This features are an expression of long-term subsidence and isolation from major sediment sources. The Flood Basin lands corresponds to AEZ 21 on Figure 15.

Geological Survey of Bangladesh identified three main basins in the region. The Meghalaya Basin, is bordered by the Meghalaya Foothills on the north and by the Surma/Baulai River on the south and by the Old Brahmaputra River floodplain on the west. The main haors in this unit include Kalner Haor, Karchar Haor, Shanir Haor, Matian Haor, Gurmar Haor and Tangua Haor. Figure 19 shows a satellite image of Matian Haor and Tangua Haor which lie at the base of the foothills west of Jadukata River. Morgan and McIntire (1959) and Coleman (1969) suggested that some haors such as Gurmar and Halir haor occupy ancient paleo-channels of the Brahmaputra River. The haors are typically poorly drained, flat, featureless areas that are adjacent to active or abandoned stream channels. Natural levees from these channels prevents rapid drainage from the haors after the monsoon season so that permanently flooded beels occupy the lowest point of the haor. A survey through Shanir Haor showed the lowest point in the haor was about El. -2 m PWD, which was comparable to the thalweg in the adjacent channel of the Baulai River.

GSB mapped most of the sediments in the Meghalaya Basin as marsh clay and peat, consisting of grey or bluish grey clay, black herbaceous peat and yellowish-grey silt. Alternating beds of peat and peaty clay are common in beels and haors. Sediment cores collected from Shanir Haor showed a widespread layer of peat at about El. -1 m, or 3 m below the surrounding land.

The Central Basin occupies 3,200 km^2 of land that is bounded by the Surma River on the north, the Surma/Kushiyara floodplain on the east and the Old Brahmaputra River on the west. Land elevations typically range between El. 3 - 7 m PWD. The area is occupied primarily by back swamp and flood basins. Much of the land is traversed by distributary spill channels and other old partially infilled channels which at one time connected the Surma River system to the Kushiyara River. (Figure 20). The main haors in the Central basin include Deker Haor, Shanghair Haor, Pagner Haor, Baram Haor, Chaptir Haor and Naluar Haor. The basin is isolated from active sediment sources. GSB mapped the area as primarily medium - dark grey silt to clay and some organic rich clay, which suggests most of the sediments have been laid down in a near-lacustrine environment when the region is deeply inundated.

The Sylhet Lowland is a discontinuous area of haor and flood basin land located east of the Central Basin. This unit includes Hail Haor, south of Moulvibazar, Damrir Haor and Maijail Haor near Fenchuganj and Pakohadir Haor north of Sylhet. These features are generally surrounded by higher floodplain land and the boundary between floodplain and haor is gradational. The total area occupied by the Sylhet Lowland amounts to 600 km^2.

Two main kinds of soils occur in the AEZ. They are: (1) Grey silty clay loams and clays with developed profiles on the relatively higher land which dries out seasonally; and (2) Grey (often bluish grey or greenish grey) clays with alluvium at a shallow depth which occupy basins and stay wet throughout the year. There are minor inclusions of dark grey loamy and clay soils of the adjoining Old Brahmaputra Floodplain (AEZ 9) in the west and Old Meghna Estuarine Floodplain (AEZ 19) in the south, grey loams and clays of the piedmont belt to the north, and peat in some haors.

3.4 Governing Processes

The previous sections have provided a general description of the geological setting, topography and landforms found in the region. The remaining part of this chapter tries to summarize the main processes that have governed the physical development of the region's rivers and landforms. The main factors that are considered include:

- alluvial sedimentation
- subsidence
- earthquake activity
- past

3.4.1 Sedimentation

Fluvial and deltaic sedimentation are the principal processes that are responsible for the landforms in the NE Region. Several "styles" of sedimentation can be recognized.

Avulsions and Alluvial Fan Deposition:
Development of conical-shaped fans below the canyons of steep mountain rivers that spill onto low-lying floodplains and flood basins. The streams are characterized by periodic channel avulsions and shifting from one side of the fan to the other, in response to sand deposition and aggradation. The sands are deposited on lowland floodplains as shallow sheets and splays and as sand bars in the main river channels. Boulders and gravel-sized sediment are virtually absent, except at the canyon mouths.

Levees and Floodplain Deposition:
The major floodplains all have prominent natural levees that are formed by spills of water and sediment when bankfull conditions are exceeded or when bank breaching occurs. The sediments are deposited in close proximity to the main channels as soon as the velocities decrease. Consequently, in much of the NE Region, the highest ground is located near the main rivers, and

the channels tend to be elevated above the adjacent floodplain. Under these conditions, overbank spills may be diverted outside the river system into other rivers or basins.

Anastomosing Channels and Flood Basin Deposition:
The maze of distributary channels and relic channels, oxbows, haors and beels of the Central Basin reflects a combination of shallow deltaic and alluvial deposition. The stream channels develop a characteristic anastomosed channel pattern as soon as they enter the low-lying deeply flooded basins (Figure 21). Since most of the discharge is conveyed on the floodplain in the monsoon season, the channels also decrease in size in a downstream direction. The deepest portions of the basin are located away from nearby sediment sources. Active channels prograde through the basin, somewhat like a shallow "Birds Foot" delta advancing into a shallow lake (SEPM, 1989). During flash floods, bank breaching can cause flows to be diverted into other abandoned distributaries or minor khals, which will then be temporarily re-activated and become the dominant flow channels during the low-water season. Since these basins are deeply flooded during the monsoon, deposition of fine suspended sediment (silt and clay) will occur on the floodplains adjacent to the active channels. Sand deposition is generally restricted to the active channels and margins, since overbank velocities are generally very low.

3.4.2 Subsidence

The NE Region is described as experiencing some of the greatest subsidence rates in Bangladesh. Evidence for rapid subsidence was reportedly (1) gravity anomalies (as low as -86 mGal Bouger Anomaly) (2) seismic (reflector of Pliocene-Pleistocene sediments down thrown 5 km below the surface and (3) geomorphic (presence of a vast topographic depression with peat). However, estimates of contemporary subsidence rates appear rather tenuous given the lack of data available. Morgan and McIntire (1959) compared elevations from ancient channel levees found in the NE Region (near Shanir Haor) with elevations of modern levees on the Brahmaputra River and concluded that "the Sylhet Basin had subsided 30 - 40 feet (10-12 m) within the last several hundred years". Evidence of subsidence in the surrounding areas (Calcutta and vicinity, Khulna and Sundarbans) were also provided (reproduced in Table 3.3). No estimates of subsidence rates were given, since the time scales of these vertical changes was unknown. Over the years, other writers have made various assumptions about these time scales and have then gone on to estimate subsidence rates from this data. With time, the original basis of these assumptions have either been lost or no longer reported, so that these estimates have been adopted as scientific fact.

For example, a subsidence rate of 21 mm/year in the Surma Basin was reported in MPO (1985) and FEC (1989). This value appears to have been arrived at by using Morgan & McIntire's estimate of 10 m subsidence in 500 years (their "several hundred years") Uncertainties of this estimate include (1) the age of the paleo-channels could be much older than "several hundred years"; (2) the stratigraphy and morphology of these paleo-channels appears quite different from the present-day Brahmaputra River, so they may have formed under very different conditions. Consequently, the comparison of elevations may not be very meaningful; (3) the Brahmaputra delta front has advanced over time, so if it was situated near Shanir Haor in Holocene times it is expected that the floodplain levels would be lower.

Estimates of subsidence rates in other parts of Bangladesh have ranged 1.5-2.5 mm/year in the Northern Hinge Zone (near Mymensingh) and 0.8-1.4 mm/year in the Sundarbans. For the case of the Sundarbans, it was assumed that swamp type vegetation including mangroves, thrived in the deltaic plains 5000 years ago (MPO, 1985).

If subsidence rates approached 20 mm/year (2 m/century), then this process would significantly affect flood control and drainage developments and planning, since these projects are designed to operate over several decades. However, the uncertainty of these rates appears so large that it does not seem valid to use them for quantitative predictions. Two kinds of analysis could improve the estimates.

First, long-term monitoring of permanent vertical control bench marks that are tied together through a survey network might be able to detect differential displacements across a region. In order to measure absolute vertical changes, the network would have to be tied in to some other external reference level such as mean sea level (based on tide gauges or some other means). The recently completed Second Order Levelling Programme in the NE Region, carried out by the Survey of Bangladesh, may be able to provide this information. This survey involved 2283 km of levelling and established elevations at 374 monuments. The survey was based on bench marks from high precision levelling in 1911-1912, 1953-1955 and 1973-1975. Check levelling was carried out between the old BMs before the main work commenced. Benchmarks which were found intact and correct were accepted as starting and closing BMs for the second order levelling work.

A comprehensive survey adjustment analysis, including a review of closures and tie-ins with BMs outside the region has been proposed but has not been completed at this time. However, the fact that the surveys could be completed within Second Order tolerance, using benchmarks dating back to 1911 suggests that subsidence has been rather low (smaller than Second Order Tolerance). For example, according to SOB, the discrepancy (in mm) between two sets of readings obtained from two directions of traverse has not exceeded $8.4\sqrt{k}$, where k is the distance in km. If the maximum two-way traverse length in the NE Region is 400 km, the maximum discrepancy would be less than 168 mm. If the period from the time of BM establishment and the 1992 re-survey is 40 years (taking 1953 as the first date), subsidence rates would have to be less than 4 mm/year. If the time period extended back to the first surveys in 1911, subsidence rates would be less than 2 mm/year. Since the surveys did in fact achieve or exceed Second Order tolerance, these figures provide an upper bound on the potential subsidence rate in the region.

A second approach for estimating subsidence is to use geomorphic evidence. If buried organic materials (such as peat, tree stumps, organic remains) are found in borings or surface exposures, it may be possible to estimate the date these materials were buried by using radio-carbon methods. If some idea about initial base levels and sedimentation rates can also be inferred, the subsidence rate can also be estimated. If the rates of floodplain accretion and subsidence are in equilibrium, then the magnitude of the subsidence will equal the depth of the material below the present land surface. If the accretion rate exceeds the subsidence rate, then the actual subsidence will be less than the depth of burial.

So far, no radio-carbon dates have been reported from sediment samples in the NE Region. However, in 1993 NERP was able to initiate this analysis using samples collected during soil borings in Shanir Haor and Karchar Haor as part of engineering studies conducted by the Systems Rehabilitation Project. The soil borings were conducted by Soil Explorers, Engineers & Designers of Dhaka, who used a manually operated percussion drill with 3.05 m long, 5 cm diameter pipe sections. A chopping bit was attached to the lower end of the drill rod and high pressure water was circulated through the drilling rod. The driller chopped up and down and rotated the drilling pipe to disintegrate the soil. The loose soil was forced out of the bore hole with the circulating water and the drilling was advanced to the desired level. Soil samples were collected at 1.5 m intervals using a split spoon sampler. The samples were preserved in polythene bags and returned to the laboratory.

NERP team members accompanied the drillers during their program, reviewed the borehole logs and identified samples which contained organic materials that would be appropriate for dating. The stratigraphy at Borehole 1, Karchar Haor at Sonapur is shown in Figure 22. Fragments of wood in a black organic-rich silt were found 5.5 m below the ground surface (El. -0.7 m PWD). This was overlain by dark grey peat with wood fragments and topped with fine sand. Beta-Analytic Inc. of Miami Florida established the age of the wood fragments as 4580 years BP + 70 years. or roughly 4644 years old. If the overall subsidence rate and floodplain deposition rate have remained approximately in equilibrium over this time, the subsidence rate would correspond to 1.2 mm/year, which is comparable to the estimated rate reported for the Sundarbans.

There is a clear need for further research on this topic by geomorphologists and other earth scientists. In terms of the kind of planning studies and pre-feasibility level investigations carried out under NERP, two conclusions can be made from the available information (1) subsidence over geological time scales has greatly affected the physical setting and topography of the NE Region; (2) over relatively short planning time frames (10 - 20 years), subsidence is of minor significance in comparison to other fluvial processes and impacts related to engineering projects.

3.4.3 Tectonic Activity

Rahman (1990) lists more than 20 large earthquakes that been recorded in and around Bangladesh over the last 130 years. These earthquakes have been centred in the Shillong Plateau in Assam, in the Arakon Yoma Ranges and in the Indo-Burman Ranges in Myanmar. Virtually all of the region is classified as "Seismic Zone 1" which represents the most active seismic zone in the country. The largest documented events are summarized in Table 3.4. The 1897 earthquake in the Shillong Plateau measured 8.7 in magnitude and was described by Sharma (1989) as *"possibly the greatest ever recorded anywhere in the world"*. It caused extensive fissures and landslides and took a toll of 1542 lives. There was a 10 m vertical displacement over a length of 20 km along the Chedrang fault. Preliminary estimates of return periods for some earthquakes were reported in BETS(1989). That report suggested the event of 1897 probably had a return period of between 300 to 1000 years, while earthquakes in 1918 and 1923 probably had a return period of 30 to 50 years. It should be noted that over a 25 year planning time frame, the chance of experiencing at least one event similar or greater than the 1918 event is between 40 to 60 per cent.

There are well documented descriptions of ground liquefaction, landsliding, rapid subsidence, collapse of river banks and changes to river courses in the region during past earthquakes (District Gazetteer, 1917). Descriptions of effects of earthquakes along the Brahmaputra River by Oldham (1899) were reproduced in FEC (1989). These comments suggested the strong ground shaking triggered liquefaction of the river cross section, followed in later years by increased channel shifting and channel abandonment. Earthquakes have also induced landsliding and slope failures in headwater catchments, which can greatly increase the amount of sediment supplied to the region for many years. Joglekar (1971) described impacts of major earthquakes on the upper Brahmaputra River in Assam India. After the earthquakes of 1947 and 1950, the bed level near Dibrugarh rose substantially, with low water levels rising by as much as three to four metres between 1947 - 1951. Therefore, river processes and sedimentation patterns in the NE Region may be subject to major disruptions following a severe seismic event.

3.4.4 Past Channel Changes

Humans observe rivers and landforms over fairly short time scales, so it is common to assume that conditions have remained fairly static over time. However, often the present-day channel pattern and morphology are determined by past conditions, not the present situation. This is particularly true in the NE Region where the overall drainage pattern has been substantially re-arranged during the last 200 years. Consequently, there are many situations where the present-day channel pattern and morphology are determined by events that happened in the past not by the current runoff and sediment transport regime. Therefore, to understand the present regime it is necessary to understand the past situation.

In order to document this, the earliest maps of the Region were reviewed to determine channel patterns and alignments. The earliest maps of the NE Region were prepared by J. Rennell between 1764 and 1767. Reproductions of these maps were obtained and digitized in order to make comparisons with modern maps. Rennell's journals were also obtained in order to provide early descriptions of the Region (La Touche, 1910). Figure 7 shows the main river systems, including the Brahmaputra River flowing through its Arial Khan course, before its last major shift. The westward shift of the Brahmaputra River has been described by Coleman (1967) and Rashid (1991). It appears this avulsion was largely completed by 1808. With this avulsion, the flow of water and sediment into the western end of the NE Region decreased. Consequently, most of the Meghna River (from the Lakya channel to Satnal) is flowing along a course that once carried in the order of five times the flow of the present river system. It appears the shift in the Brahmaputra River was accompanied by major changes in flow distribution through the NE Region as well.

It was found that the Surma River has followed its current alignment from its bifurcation at Amalshid to near Sunamganj over the last 200 years. However, the entire flow then turned southwards until it joined the "Little Meghna River" (Rennell's name given to the present-day Kalni-Dhaleswari River) near the town of Ajmiriganj. Part of the Jadukata River flows turned east along the route of the Nawa channel (opposite to its current route) into the Surma River. Under present conditions, this course (called the "Old Surma River") is a minor distributary of the Surma River and most of the flow heads west down the Nawa River and into the Baulai River. Consequently, the Old Surma River channel is a remnant feature that was formed under much higher discharges than the present. Furthermore, major changes in discharge regime have occurred on the channels downstream of Ajmiriganj. Previously, all of the Barak River inflows from India and virtually all of the Meghalaya tributary inflows passed through the "Little Meghna River" at Ajmiriganj, so that the present channel is carrying approximately one third of the discharge than in the past. The most noticeable feature reflecting this past discharge regime, is that the river widens and the meander wavelength increases noticeably downstream of Ajmiriganj.

The Kushiyara River started as a small distributary of the Barak River at Amalshid (described by Rennell as "navigable during the wet season", and flowed along the course of the Sari Bardhal River channel until joining its present course near Fenchuganj. It then split near Sherpur, with part of the flow heading south-west down the ShakaBarak channel, joining the Khowai River near Habiganj and entering the "Little Meghna River" near the present site of Madna. The Shaka Barak drainage channel is the remnant of this former major channel. Another branch of the

Kushiyara headed westwards along the Bibyana course and then through to Ajmiriganj. This remnant, called the "Old Kushiyara River", carries very little discharge under present conditions and is gradually filling-in with sediment.

The Kangsha River was shown flowing 10-15 km north of its present alignment in its upper reaches, then re-joined its present channel just upstream of Jaria Janjail. It is not clear whether this channel alignment was accurate or reflects mapping errors. However, recent maps show a infilled paleo-channel occupies the course identified on Rennell's map. The Kharia River, a distributary of the Brahmaputra River, flowed eastwards from near Mymensingh, then along the present course of the Kangsha River from Sarchapur to Jaria and into the Baulai River. The Kharia is now virtually dead since spills from the Brahmaputra River have declined. The Mogra River branched off from the Kangsha River and turned southwards along its present course. A minor khal and spill channel is the only remnant of this branch of the Mogra River. Therefore, the channel of the lower Mogra River is probably still adjusting to the decreased discharges.

4. RUNOFF

Sediment yield and river morphology are closely related to climate and runoff from a watershed (Schumm, 1967). In particular, morphologic changes will often be associated with changes in runoff and flood hydrology. The following brief descriptions are intended primarily to assist in interpreting historical changes in river behaviour in the region. More detailed descriptions of the regions water resources can be found in other related studies (NERP 1993).

It should also be noted that most of the runoff and sediment are generated outside of Bangladesh in the states of Assam and Tripura, India. Unfortunately, the study team was not allowed by Indian authorities to visit these areas. Therefore, conditions in these external watersheds have been assessed only from office studies using available data, maps and, in some cases, LANDSAT imagery.

4.1 Rainfall

Rainfall patterns are governed by the onset and withdrawal of the annual monsoon. The water year is normally sub-divided into four distinct seasons:

Pre-monsoon (April-May), which is characterized by increasing rainfall, short-duration, intense rainstorms and flash flooding.

Monsoon (June through September), when the bulk of the annual rainfall occurs.

Post-monsoon (October and November), which is characterized by decreasing rainfall and draining of inundated lands and flood basins.

Dry Season (December to March), when there is little or no rainfall and river stages decline to their lowest levels.

The seasonal distribution of rainfall is typically 23.8% - 17.8% in the pre-monsoon season, 64.3 % - 73.8% in the monsoon, 5.8% - 7.8 % in the post-monsoon and 2.6% - 4% in the dry season.

Figure 23 shows the spatial distribution of rainfall over the region and Indian watersheds (from NERP, 1993). The isohyetals were estimated by using data from 51 rain gauges in India and Bangladesh. The map illustrates the great spatial variability in rainfall, with annual amounts reaching up to 10,000 mm/year over the Shillong Plateau due to orographic effects as the warm moist air is forced up over the southern slopes of the mountains. Rainfall volumes decrease to less than 3000 mm/year over the southern Tripura Hills and in the extreme eastern parts of the Barak River in India.

The temporal variation in annual rainfall has been investigated by many people over the years. For example, in 1910 Walker used rain gauge records starting in 1840 to describe the variability of annual rainfall in India. These studies were prompted by the severe drought of 1905 and by concerns about long-term changes to the monsoon. One notable feature of investigations of monsoon variability is that both drought years and flood years often occur in runs, rather than randomly through the period of record (Kutzbach, 1987).

Shukla (1987) investigated variations of monsoon rainfall based on 81 years of data for 31 districts in India, including North Assam, which constitutes the main catchment area to the NE Region. The normalized rainfall anomaly (P') was defined as:

$$P' = \frac{(P - P_{avg})}{\sigma}$$

where P is the percentage departure from the normal period (taken as 1901-1950)
P_{avg} is the mean for the 81 year record 1901-1980
σ is the standard deviation of the departures for the 81 years of data

Low rainfall years were considered to have occurred when P' < -1, while high rainfall years were defined as P' > 1. Based on these criteria, drought years in north eastern Assam were found to occur in 1901, 1903, 1908, 1912, 1914, 1925, 1940, 1951, 1954, 1957, 1958, 1959, 1966, 1967, 1972, 1975 and 1979. High rainfall years were identified in 1905, 1918, 1922, 1942, 1971 and 1974.

A time series plot of the cumulative departures from the mean, defined as:

$$\Sigma(P' - P_{avg})$$

showed the record could be sub-divided into four periods:

1901-1916:	lower than the long-term average
1917-1935:	near or slightly above the long-term average
1936-1961:	lower than the long-term average
1961-1981:	higher than the long-term average

Therefore, Shukla's findings about the cyclical patterns and clustering of high and low years are in general agreement with earlier studies described previously.

Sediment yields usually increase when rainfall increases. Furthermore, river instability is usually related to discharge intensity and times when bankfull discharge conditions are exceeded. Therefore, patterns of high sedimentation and channel instability would be expected to follow the trends noted above (assuming other factors remain constant).

4.2 Runoff

The watershed draining into the NE Region can be sub-divided into four main sub-regions on the basis of climate, physiography and sediment delivery:

- Barak River watershed
- Meghalaya Foothills watersheds
- Susang Hills watersheds

- Tripura Hills watersheds

Table 4.1 lists the main physical characteristics of the watersheds. Figure 24 shows the watershed boundaries. The total area draining into the region amounts to 31,000 km^2.

4.2.1 Barak River

The Barak River drains 25,260 km^2 of land in the states of Assam, Manipur and Mizoram in India. The basin has a relief of over 3,000 m and much of the land is extremely mountainous. Most of the region is composed of sedimentary rocks of Tertiary age. The highest peaks occur in the Barail Range and coincide closely to the Disang Thrust fault. The alignment of the main valleys and rivers in the basin are structurally controlled, following the synclines and are generally oriented NNE-SSW. Figure 25 shows a longitudinal profile of the river. The stream gradient flattens out appreciably about 300 km from the Bangladesh border. The lower 60 km has a broad valley floor and the river channel appears to have developed a tortuously meandering channel. Most of the vegetation in the basin is described as "Wet Evergreen Forest" and "Moist Semi-evergreen Forest" (Robinson, 1989).

NERP's modelling section synthesized daily discharge records for the Barak River at the Indian border for the period 1964-1991 using historic water level records and stage-discharge relations. Figure 26 summarizes historic inflows into Bangladesh. The long-term mean flow was estimated to be 1111 m^3/s, and the seasonal distribution of flow was estimated as follows:

Pre-monsoon season (April-May): 730 m^3/s, or 15% of the total annual runoff volume;
Monsoon season (June-Sept): 2600 m^3/s or 67% of the total annual runoff volume;
Post-monsoon season (Oct.-Nov): 750 m^3/s or 12% of the total annual runoff volume;
Dry season (December-March): 120 m^3/s or 6% of the total annual runoff volume.

Low runoff years occurred in 1965, 1967, 1972 and 1979 while unusually high runoff years occurred in 1966, 1983 and 1991. The average flow in the period 1964-1975 and 1976-1991 were virtually identical (1099 m^3/s and 1123 m^3/s respectively).

The mean annual maximum daily discharge was estimated to be 4662 m^3/s, with the highest flood reaching up to 5519 m^3/s in 1974 and other high flows occurring in 1989 and 1991. The average flood in the period 1964-1975 was slightly lower than the average between 1976-1991 (4594 m^3/s and 4720 m^3/s).

These patterns suggest the flow regime has remained approximately stationary between 1964-1991. Since the annual sediment loads from a watershed are usually closely related to the flow regime, it is likely that the incoming sediment loads have also remained approximately stationary during this period.

4.2.2 Meghalaya Foothills

Streams draining the Meghalaya Foothills include Lubha River, Hari River, Dauki River, Dhalai gang, Chela River, Jhalukhali River, Jadukata River, Lengura River and Someswari River. The watersheds are all located in the Shillong Plateau.

89

The total Meghalaya catchment area amounts to 13,466 km^2 which represents 20.4% of the regions external catchment area. The two largest basins are the Jadukata River basin (2,500 km^2) and Someswari River (2,480 km^2). The Dauki, Jhalukhali and Jadukata basins are the most mountainous, with 65 - 75 per cent of the land area above El. 900 m (Table 4.1). The Meghalaya catchments have an overall length of 30 - 70 km and reach up to an elevation of 2,000 m. Valley gradients are very steep, typically between 0.03 and 0.06 (30 m/km - 60 m/km).

The average annual rainfall increases rapidly with elevation, reaching up to 12,000 mm/year near the headwaters of the Chela River. Runoff generated from the Meghalaya hills is extremely flashy and of extremely high intensity. Some examples of published peak daily discharges include:

- 2800 m^3/s on the Dhalai Gang in 1988 and 1991, which corresponds to a unit discharge of 8.2 m^3/s per km^2 ;
- 3150 m^3/s on the Someswari River in 1988, which corresponds to a unit discharge of 1.5 m^3/s per km^2 ;
- 5000 m^3/s on the Jadukata River in 1991, which corresponds to a unit discharge of 2.07 m^3/s per km^2 .

Figure 27 shows hydrographs on the Dhalai Gang and Jadukata River in 1991. The high flood intensities, rapid fluctuations in discharges and high velocities in the channel make it difficult to measure peak discharges reliably, so the accuracy of these estimates is probably low.

Based on an analysis of rainfall and runoff data, NERP (1993) estimated that the long-term average flow from the Meghalaya watersheds was 1993 m^3/s. This inflow is 1.8 times the value from the Barak River, which has a catchment area twice the size of the Meghalaya hills.

4.2.3 Susang Hills

The Susang Hills in Bangladesh and Tura Range in India are drained by the Bughai River, Chillikhali River and Malijhee River, which drain into the extreme north-west corner of the region. (Figure 24). These basins range in size from 453 km^2 (Bhogai River) to 118 km^2 (Chillikhali River). The Chillikhali and Malijhee catchments are of low relief, reaching a maximum elevation of 150 m and have a relatively low gradient (0.6%). The Bhogai River watershed is more mountainous, reaching up to El. 1412 m and steeper (6%). Rainfall volumes range between 2,700 - 3,500 mm/year, generally decreasing to the west.

Runoff intensities are generally lower than from streams draining the Meghalaya hills. However, the streams are very flashy and subject to high flood discharges. For example, NERP stream surveyors observed the Bhogai River at Nakuagaon rose 1.8 m in 3 hours during a flash flood in July 1994. The published maximum daily discharge on the Bhogai River is reported to be 1240 m^3/s, which corresponds to a unit discharge of 2.74 m^3/s per km^2.

4.2.4 Tripura Hills

Streams draining the Tripura Hills include the Juri River, Manu River, Dhalai River, Karangi River, Khowai River and Sutang River (Table 4.1). The total catchment area amounts to 6845

km^2, or about 24 % of the total draining into the region. The catchment areas are defined by five prominent north-south trending ridges that project from India into the region (Figure 1). These long linear ridges are plunging anticlines composed primarily of sandstone, siltstone and shale. The intervening basins are long and narrow and have wide, flat valley floors. Relief is relatively low, typically under 1,000 m. Rainfall averages around 2,300 mm/year in the headwaters.

Runoff intensities are lower in the Tripura hills than either the Sutang Hills or Meghalaya. For example, the published flood of record on the Khowai River is 1050 m^3/s, which corresponds to a unit discharge of 0.94 m^3/s per km^2. This is less than one half of the runoff intensity from recent floods on the Jadukata River. Furthermore, runoff intensities appear to decrease from west to east due to decreased precipitation. However, most of these Piedmont rivers are subject to large flow spills when bankfull conditions are exceeded, with the losses from the main channel increasing in a downstream direction. Since most hydrometric stations are located in the middle or lower reaches of these river systems, the discharge records are truncated and do not actually represent the total flood inflows generated by the catchments.

The mean daily discharge from the Tripura Hills watershed was estimated to be 321 m^3/s, or about 30% of the Barak inflows and 15% of the Meghalaya streams.

Flood peaks on most streams draining the Tripura Hills have increased noticeably over the period 1964-1991. These trends are shown on the summary hydrographs for the Manu River, Dhalai River and Khowai River in Annex C.

4.3 River Systems

Table 4.2 shows the distribution of annual inflows in the region. This shows that about 60% of the runoff is generated outside the region and 40% is generated locally. Figure 28 provides a schematized flow network for the NE Region and is intended to illustrate the variations in mean annual discharge along the main river systems. These mean annual discharges were estimated using a regional water balance (NERP, 1993). Major river systems inside the region include:

- Surma-Baulai-Ghorautra River system which starts as the northern branch of the Barak River at Amalshid and collects inflows from the Meghalaya hills and Kangsha system;
- Kushiyara-Kalni-Dhaleswari River system, which starts as the southern branch of the Barak River at Amalshid and collects inflows from the Tripura Hills, local runoff, and spills from the Surma River;
- Kangsha River system, which includes inflows from the Susang Hills and locally generated runoff from the northwest corner of the region;
- Old Brahmaputra River, which now only carries spills from the Brahmaputra River and local runoff;

- Upper Meghna River, which commences 5 km upstream of Bhairab Bazar at the junction of the Ghorautra and Dhaleswari River systems, to form the outlet of the NE Region.

Representative hydrographs on these rivers are shown in Figure 29.

The division of flow (long-term mean) at the Barak River bifurcation is estimated to be 65% down the Kushiyara River and 35% down the Surma River. However, inflows from the Meghalaya catchments and the Susang Hills increases the discharge on the Surma River system from 363 m^3/s at Amalshid to 3247 m^3/s below Itna, where it flows into the Upper Meghna River system. By comparison, the inflows from Tripura and local runoff increases discharges on the Kushiyara River system from 675 m^3/s at Amalshid to 1560 m^3 /s on the Dhaleswari River where it joins the Upper Meghna River. The estimated mean annual flow from the Upper Meghna River is estimated to be 5540 m^3/s, which includes the contribution from the Old Brahmaputra River.

4.4 Base Level and Downstream Control

The water level in the lower Padma River provides a downstream boundary condition that affects water levels, water surface slopes and inundation depths throughout much of the region. Figure 30 shows a summary of water levels recorded at the Meghna River at Satnal near its junction with the Padma River. This plot shows that average water level remains between El. 1.1 m and 2.2 m throughout the dry season months (November - May), rises at the start of the monsoon in June and July, peaks in August and September, then recedes near the end of the monsoon in October. The river is tidally affected during the low flow season and river discharges reverse on the flood tidal cycle during the dry season (reverse flows of up to 2,500 m^3/s have been measured at Bhairab Bazar).

The average annual maximum daily water level at Satnal is 5.22 m and the highest recorded daily water level reached El. 6.04 m PWD in 1988. There is only about 0.8 m difference between the highest flood peak and the average annual peak water level. About one quarter of the Northeast Region is lower than 5 m and about one third is lower than 6.0 m (Figure 13). This means virtually all of the haors and lowlands in the Central Basin could potentially be inundated solely as a result of backwater by the Padma River. During the monsoon season the runoff from the Barak/Meghalaya and Tripura catchments produces an additional 1.0 - 1.5 m of head between the Central Basin and the Padma/Meghna River confluence. Therefore, the actual extent of inundation would be somewhat greater than the amount described above.

The effect of this backwater condition is to impound water in the haors and flood basins for several months of the year, so that much of the region can be effectively considered as a shallow lake that becomes temporarily dry in the low flow months (November to April). This also means that lake and deltaic sedimentation processes will dominate in the flood basins and haors. This means that silts and fine sands will be deposited during the monsoon season in deeply flooded basins where velocities are sufficiently low to promote settling.

5. SEDIMENT TRANSPORT

5.1 Terminology

In this investigation, the following definitions are used to specify sediment sizes:

- "sand" is sediment in the range of 0.063 mm - 2.0 mm
- "silt" is sediment in the range of 0.063 mm - 0.004 mm
- "clay" is sediment finer than 0.004 mm

Figure 31 illustrates various ways that are used to classify sediment transport, including its source (wash load or bed material load), mode of movement (in suspension, saltation or by traction) and its methods of measurement. "Wash load" consists of fine sediment (usually silt and clay) that is generated from mass wasting and erosion processes in the watershed. Its transport rate depends solely on the rate of supply from the watershed, not on the streams transport capacity (which is usually much greater). Consequently, wash load materials are not found in the channel bed material. These finer sediments are flushed through the channel system but can be deposited in overbank areas on the floodplain where velocities are low. The "bed material load" consists of river bed sediments (usually sand) that move by traction and saltation (the "bed load") and in suspension (the suspended bed material load).

The distinction between bed material load and wash load is usually determined by an examination of bed material particle size distribution curves. According to Einstein (1950), the D_{10} bed material size can be used for estimating the division between wash load and bed material load. On most lowland and Piedmont rivers in the NE Region, the D_{10} size is typically around 0.06 mm -0.1 mm (fine sand). Therefore, on these rivers, the sand load (fraction coarser than 0.063 mm) can be taken to represent the bed material load, while the silt and clay load can be considered as wash load. On steep gravel-bed rivers draining the Meghalaya/Shillong Plateau, all of the suspended sediment can be considered as wash load.

5.2 Review of Sampling Methods

Only measurements of suspended sediment transport have been made in the NE Region. It is far more difficult to measure bed load. Furthermore, on most low gradient sand bed rivers the bed load usually represents only a small fraction of the total load (Schumm, 1976).

Table 5.1 lists the available suspended sediment concentration record for the NE Region. Suspended sediment concentration measurements are typically carried out 24 - 12 times per year by BWDB at selected hydrometric stations. Measurements on the Meghna River at Bhairab Bazar are made using a Binkley sampler (Figure 32), which is an instantaneous sampler that retains a water sample at one point in the river vertical. The sampler was originally developed for oceanographic studies and water quality investigation. The sampler is operated from a river survey launch, using a reel and sampling is repeated at two or more depths. An estimate of the depth-averaged sediment concentration in the vertical can be made when sampling depths and point velocities are provided with the data. Problems with this approach include (1) the sample is not time-integrated (2) sampling is not iso-kinetic, so the concentrations values will be biased (WSC, 1989). However, FAO (1969) compared measurements with the Binkley sampler and a5

with a USGS P-61 sampler and concluded *"the results were sufficiently in accord that the continued use of the Binkley was justified."*

At the remaining sampling sites in the region, simple surface grab samples are collected, usually at one or occasionally at two locations in the river cross section (Figure 32). Standard procedures observed on the Khowai River and Kushiyara River in 1994 involved filling a plastic petrol bottle that is immersed approximately 0.6 m below the water surface. Samples obtained in this manner should underestimate the suspended load, since the concentrations near the surface are usually substantially lower than concentrations near the bed. The magnitude of this bias will depend on the shear stresses in the river and the fall velocity of the sediment in suspension. If the suspended sediment consists primarily of fine silt and clay, then the bias may not be too great, particularly during high flow conditions when turbulence is high. If the suspended load is mainly sand and river velocities are low, then the bias could be very large. A second problem with this sampling method is that the precision of the measurements will be low, since they are not time integrated.

The BWDB samples are sent for laboratory analysis to the River Research Institute in Faripur (the laboratory was visited by NERP personnel in 1992). Suspended sediment concentrations are determined by filtration. No information on the particle size of the suspended load are routinely provided. The data are published annually under the title "Annual Report on General Suspended Sediment Studies". An example of these published results are shown in Table 5.2.

Additional miscellaneous suspended sediment samples were collected in 1991 and 1992 at six sites by SWMC using a pump sampling technique. This involved pumping a 1 litre volume sample at anywhere from two to five depths in the vertical of a river cross section. The measurements were typically made at three verticals - left, centre and right side of the channel. Velocity profiles were measured at each vertical so that a discharge-weighted average concentration could be estimated. Separate large volume samples were collected for measuring the size distribution of the suspended load by means of a settling tube.

The BWDB and SWMC programmes overlap to some extent, which allows some comparisons to be made. In general, it appears the concentrations determined by SWMC are lower than BWDB. For example, suspended sediment concentrations on September 24, 1992 at Sheola on the Kushiyara River were reported to be 758 mg/l by BWDB, while the SWMC concentrations varied between 3 and 8 mg/l. This difference is the opposite of what was expected, since the BWDB samples were surface grabs, while the SWMC samples were collected over a range of depths. A review of the hydrograph showed the water levels and discharge were not fluctuating rapidly around this date, so that the difference is unlikely to be caused by rapid changes in hydrological conditions during the day. In fact, correlations between sediment concentration and discharge using SWMC and BWDB data show concentration rating curves differed by two orders of magnitude. Similar, or even greater differences were found on the Khowai River at Shaistaganj. These differences could arise from many different causes during field sampling or in the subsequent laboratory analysis. The extremely low concentrations reported by SWMC on the Kushiyara River and Khowai River do not seem realistic given the high turbidity levels observed on these rivers. On the basis of discussions with SWMC, it was decided to rely primarily on the BWDB data for this investigation. The SWMC data was used for the Meghalaya streams (where less BWDB data is available) and for estimating the size distribution of the loads. Furthermore, in 1994, a program of measurements was started at five sites in the region using a depth-integrated suspended sediment sampler (US D-74). It is expected these field measurements will lead to improved data collection procedures in the Region. Results from these investigations will be described in forthcoming feasibility studies carried out under the Phase II component of NERP.

5.3 Review of Data

BWDB sediment stations were divided into three groups - (1) active stations with an ongoing program that has been maintained since the mid-1960's, (2) discontinued stations where an ongoing program was maintained in the 1950's and 1960's, and (3) short-term stations at which only a few miscellaneous measurements were made, usually in the 1950's and 1960's. These stations are shown on Figure 33. Efforts were focused primarily on the active stations since it was possible to verify the sampling methods and procedures for these sites. The data from the discontinued stations were compiled and reviewed. However, it was felt that there was more uncertainty with this data since it was not clear how the data were collected or what laboratory procedures were followed. No analysis was carried out with the short-term miscellaneous data.

Table 5.1 summarizes the number of sampling days for each station in each year of the program. Table 5.3 summarizes the range in river discharges at each site over the period 1964-1991. Table 5.4 and Table 5.5 summarize the observed range of suspended sediment concentrations and daily suspended sediment loads at the seven long-term gauging sites in the region. Table 5.6 and Table 5.7 summarize the same information for the discontinued stations.

5.4 Station Analysis

Past studies have shown that reasonably good estimates of long-term sediment yield can be achieved even when relatively few samples are available by using rating curve techniques (Kellerhals, Church and Ward, 1985, Kellerhals, Abrahams and von Gaza, 1974). The rating curve method involves:

- estimating average concentrations from measurements in the cross section;
- plotting the average concentration versus the observed discharge;
- developing power law-type relations using a linear regression between log-transformed sediment concentration (Ct) and discharge (Qt);

$$Ln(C_t)=a+bLn(Q_t)$$

- applying a "bias correction factor" (K) to compensate for the under-prediction introduced by the logarithmic transformation (Smillie and Koch, 1986);

$$K=\exp(\frac{\sigma}{2})^2$$

- estimating the daily suspended sediment load (g_t);

$$g_t=K*A*Q_t^{\,b}$$

- adding up the estimated daily loads to compute the annual suspended sediment load;

$$Ga = \Sigma g_i$$

The variance of the annual load was estimated using the method presented by Thompson, Joe and Church (1987). In that study, the variance of the total load (Ga) was expressed as:

$$Var(\Sigma K Q_i C_i) = Var(\Sigma A_i C_i) = \Sigma A_i^2 Var(C_i)$$

$$Var(C_i) = \exp(2(a + bLnQ_i + \sigma^2)) - \exp(2(a + bLnQ_i) + \sigma^2)$$

where **a, b** and σ are estimated from the rating curve regressions.

Various tests were carried out to see if the regressions could be improved by stratifying the data by season, by carrying out regressions for each year or by combining several years of data together. In virtually all cases, no significant improvement could be achieved. Examples of typical rating curves are summarized in Figure 34. Tables 5.4 - 5.12 summarize statistics from the various rating curve regressions. Comments are provided for selected stations below. Descriptions of river characteristics at these sites are included in Annex C.

Kushiyara River at Sheola:
This station provides a measure of the major portion of sediment inflows from the Barak River in India. The observed sediment concentrations have varied from a low of 4 mg/l in the dry season, up to 4639 mg/l during the monsoon flood and averaged 253 mg/l over the period of observations. The corresponding daily suspended sediment loads have ranged between 22 tonne/day and 427,600 tonnes/day.

A comparison of sediment rating curves using the earliest data (1958-1961) with more recent measurements showed concentrations have decreased over time, at least for discharges less than 1000 m^3/s. For example, at a discharge of 800 m^3/s, sediment concentrations ranged between 500-1000 mg/l between 1958-61 and 150-250 mg/l between 1984-85. No measurements were carried out at higher flows during the early period of measurements, so comparisons can not be made during flood conditions. It is not clear whether this apparent change reflects differences in sampling methods or actual changes in sediment yields. People's perception is that sedimentation has increased while this data suggests the opposite. For estimating annual loads, only sediment data collected after 1966 were used in the analysis.

Figure 34 and Table 5.8 summarize rating curve characteristics for this river. The average annual suspended sediment load was estimated to be 8.6 million tonnes/year and ranged between 4.2 million tonne/year - 15.8 million tonnes/year. The coefficient of variation of the annual loads typically amounted to 26%, which is an indication of the expected precision of the total load. The seasonal distribution of the load was estimated as follows:

- pre-monsoon season: 4%,
- monsoon season: 80%
- post-monsoon season: 11%
- dry season: 1%

Miscellaneous measurements by SWMC indicated the sediment in suspension typically consisted of 20 % sand, 54 % silt and 24 % clay, although wide variations were noted. Bed material samples at Sheola indicate the D_{50} size is around 0.1 mm and the D_{10} size is 0.06 mm (Annex C). Consequently, the suspended sand load should provide a reasonably close estimate of the total bed material load. Based on the particle size data reported above, the annual sand load of the Kushiyara River is probably in the order of 2 million tonnes/year.

Surma River at Sylhet:
The record of measurements on the Surma River at Sylhet commenced in 1957 and extends to 1992. Observed suspended sediment concentrations have ranged between 4 mg/l - 1947 mg/l and averaged 608 mg/l during the period of measurements. The corresponding suspended sediment loads have ranged between 3 tonnes/day and 82,000 tonnes/day. Figure 34 shows sediment rating curves at Sylhet, while Table 5.10 summarizes rating curve statistics. The estimated annual load averaged 3.7 million tonnes/year and ranged between 2.2 - 4.5 million tonnes. The seasonal distribution of the annual load average 6.6 % in the pre-monsoon season, 82% in the monsoon, 11% in the post-monsoon season and 1% in the dry season.

Tripura Hills Streams:
Long-term records are available for the Manu River at the rail crossing (gauge 201), Dhalai River at Kamalganj (67), which is a tributary to the Manu River, and Khowai River at Shaistaganj (158.1). These sites have recorded the highest suspended sediment concentrations in the region, reaching up to 9300 mg/l on the Dhalai River and up to 7665 mg/l on the Manu River. The average observed concentration is also noticeably higher than other streams, exceeding 1000 mg/l on the Dhalai River, 799 mg/l on the Manu River and 608 mg/l on the Khowai River. These patterns are consistent over the period 1964-1991.

The suspended load on the Khowai River was found to consist, on average, of 33 % sand, 49 % silt and 18 % clay. This distribution did not change appreciably with discharge or season. Bed material samples from the Khowai River and Manu River are summarized in Annex C. These data show that the channel deposits consist of fine and medium sand and the D_{10} size is around 0.06 mm. Therefore, approximately one third of the suspended load can be considered as bed material load.

Figure 34 shows rating curves for the Khowai River and Manu River. Predicted suspended sediment loads were generally consistent from year to year, and were less variable than larger streams such as the Kushiyara River. The annual suspended sediment loads were estimated as follows:

Manu River: average load = 4.9 million tonnes/year (range 1.4-10.4 million tonnes/year)
Dhalai River: average load = 1.6 million tonnes/year (range 1.6-2.5 million tonnes/year)
Khowai River: average load= 1.7 million tonnes/year (range 0.2-6.0 million tonnes/year)

The seasonal distribution of the annual sediment loads average 10 % in the pre-monsoon, 80% in the monsoon, 9% in the post-monsoon season and 1% in the dry season. However, during unusual flood years such as 1991, up to 40% of the transport occurred during the pre-monsoon season (essentially the month of May).

Annual sediment loads were noticeably lower (typically 25 % of the long-term mean) on the Khowai River during the period 1970-1980. This was due to the unusually low river discharges during this period, which may reflect errors in flow measurement or diversion of flow during embankment construction.

Samara River at Durgapur

This is the only major tributary draining the Meghalaya Hills with sufficient data to estimate annual sediment loads. The available data includes measurements by BWDB between 1960-1964 and SWMC in 1991-1992. Suspended sediment concentrations are noticeably lower than the Tripura Hills streams, with observed values averaging 116 mg/l and ranging up to 636 mg/l. The data are the only set in the region that display a seasonal hysteresis, with concentrations in the pre-monsoon season (March-May) being substantially greater than during the monsoon period. This probably reflects the greater sediment availability and supply during the early part of the hydrological season and exhaustion of the source materials at the end of the monsoon.

The suspended sediment is substantially coarser than in the other rivers in the region. The overall composite size distribution is 46% sand, 47% silt and 7% clay. However, during high flows, the sand fraction may reach up to 90% of the load. The bed material near Durgapur consists of medium sand, with a D_{50} size of 0.69 mm and a D_{10} size of 0.29 mm. Using the D_{10} size as a criteria for distinguishing wash load, it appears that most of the sand fraction of the load is suspended bed material. Furthermore, it appears that bed load (medium and coarse sand moving in bedforms and by saltation) makes up a significant fraction of the total bed material load at this site. Bed load has not been measured by either BWDB or SWMC.

In order to estimate annual sediment loads, the data were sub-divided into two seasons (January -May and June - December) and a separate rating curve was established for each period. In addition, a separate analysis was made using only the SWMC samples from 1991-92. The two results differ by approximately a factor of two:

BWDB data 1960-64 (42 sample-days):
Average load = 684,000 tonne/year
Computed range in the period 1964-1991 = 174,000 tonne/year - 1,425,000 tonne/year

SWMC data 1991 (11 sample-days)
average load = 304,000 tonne/year
computed range in the period 1964-1991 = 67,000 tonne/year - 802,000 tonne/year

Given the small number of samples, different sampling methods and the time span between the two data sets, these differences are not surprising. Additional sampling will be required to improve the estimates. NERP initiated a suspended sampling program on the Someswari River in 1994 to resolve this issue. Results of this investigation will be reported in the Upper Kangsha River Basin study that is presently underway.

Meghna River at Bhairab Bazar:

Sediment concentrations in the Meghna River are noticeably lower than other rivers in the NE Region. Observed values ranged from 2 - 1832 mg/l and average 98 mg/l. The size distribution of the load was found to be finer than all other rivers in the region, with the sand fraction accounting for only about 18% of the load (average composite). Most of the suspended load was made up of silt (58%) and clay (24%). Bed material samples from the Meghna River (Annex

C) show the river bed is composed of fine sand, with a D_{50} size of 0.12 mm and a D_{10} size of 0.06 mm. Consequently the sand fraction of the suspended load should also provide a reasonable estimate of the total bed material load.

Substantial year to year variations in concentrations were noted. For example, values in 1986 remained low throughout the monsoon season (typically 20 mg/l), less than 10% of values reported in other years. It is not known whether this difference is due to an error in analysis or is accurate. It was found that even within a year, the suspended sediment concentrations varied in a random manner, and showed no correlation with discharge. Therefore, the rating curve method was not used at this site. Instead, average monthly concentrations were computed from the observed data and used with the monthly discharge to estimate sediment loads. The monthly loads were then summed to estimate the annual load. Annual loads could only be estimated for the period 1982-1992, since earlier discharge records were not available. The average sediment load over this period was 16.9 million tonnes/year, ranging from a low of 4.2 million tonnes/year (1986) to a high of 20.4 million tonnes/year (1990). The corresponding annual bed material load should be around 3 million tonnes/year.

5.5 Sediment Budget

A sediment budget is a useful tool for assessing the long-term pattern of sediment accumulation or removal and the contributions from various components or localities in the region (Goswami, 1989). A regional scale sediment budget for the NE Region can be expressed as follows:

$$G_{Barak}+G_{Tripura}+G_{Meghalaya}+G_{Tripura}-G_{Meghna}=\frac{\Delta S}{\Delta t}$$

where G_{Barak} is the total inflow from the Barak River at Amalshid
$G_{Tripura}$ is the total inflow from the southern Tripura Hills
$G_{Meghalaya}$ is the total inflow from the Meghalaya Hills
G_{Meghna} is the outflow at Bhairab Bazar
$\Delta S/\Delta t$ is the change in sediment storage in the region

The two main components of the budget are the sediment fluxes (G) and the change in sediment storage in the region $\Delta S/\Delta t$ (accumulation or depletion rate). This latter term provides an estimate of the net deposition or net degradation in the region but doesn't say where these changes are taking place. Additional details about changes on individual rivers (bank erosion or channel aggradation) would be required to improve the resolution of the budget. However, given the low accuracy of most historic data in the region, it is doubtful that the additional calculations would be warranted. The direct morphological evidence described along selected river reaches in the remaining sections of this report provide qualitative estimates of these terms.

5.5.1 Tripura Hills:

There are direct measurements of suspended sediment load on all streams draining the Tripura Hills. These results consistently show high concentrations and high sediment yields on all of the rivers, particularly the Manu River and Dhalai River.

(49)

A review of 1990 satellite photos and topographic maps from the 1950's suggests the sediment yields from the headwaters of the Tripura watersheds has increased substantially in recent years. These changes have occurred in the Indian portion of the catchments and are most noticeable on the upper Juri River, upper Manu River and upper Dhalai River. Figure 35 shows evidence of high rates of erosion and mass wasting from hillsides and tributary valleys in these watersheds. This has transformed several headwater streams from small, stable meandering channels into much wider, braided rivers. It was not possible to visit the Indian portion of the catchments, so the cause of these watershed changes is not certain. Land clearing for agriculture and plantations is one likely factor. Regardless, it appears that the rate of sediment supply from these watersheds will continue to remain high in the near future.

Estimated sediment yields for these streams are as follows:

- Khowai River: 1.7 million tonne/year or 1527 tonnes/km^2
- Manu River: 4.9 million tonne/year or 2192 tonnes/km^2
- Dhalai River: 1.6 million tonne/year or 2532 tonnes/km^2
- Juri River: 1.0 million tonne/year or 1500 tonnes/km^2

The sediment and discharge records on the Juri River are not adequate for computing long-term sediment loads, so the value was estimated by assuming the sediment yield was similar to that of the Khowai River (1500 tonnes/km^2). This provides a total suspended sediment inflow of 9.2 million tonnes/year, of which approximately 3 million tonnes/year would be sand (the bed material load).

5.5.2 Meghalaya Hills:

The analysis of measurements on the Samara River and Jadukata River showed two principle findings (1) suspended sediment concentrations and sediment yields appear to be lower on these rivers than on most other rivers in the region (2) the suspended load is substantially coarser than on other streams (virtually all sand at high flows).

The lower sediment yield from the Meghalaya probably reflects a lower availability of readily erodible, easily mobilized sediments in these watersheds in comparison to the Tripura and Barak basin. This difference is sediment supply, in turn, is probably related mainly to differences in geology - much of the easily erodible Pliocene-Pleistocene sediments was eroded during the uplift of the Meghalaya/Shillong Plateau region, leaving relatively inerodible Pre-Cambrian gneiss and granites exposed through much of the watersheds. Consequently, in spite of the huge rainfall and runoff generated, the amount of fine suspended sediment generated is relatively small. A much greater portion of the sediment load in the Meghalaya rivers consists of gravel, cobbles and boulders which will be transported as bed load and is deposited at the base of the hills near the International border. This coarse sediment has not been included in the sediment budget.

In order to provide estimates of suspended sediment loads from the un-gauged streams in this sub-region, results from studies in Assam, India were used to develop regional sediment yield values for the Meghalaya watersheds. Goswami (1985) presented a comprehensive sediment budget of the Brahmaputra River in Assam, India, by analysing suspended sediment loads transported on the main stem and by various tributaries during the period 1971-1979. Suspended sediment inflows from several streams draining the northern flanks of the Meghalaya/Shillong Plateau were reported, including:

- Jinari River which drains the western end of the Plateau
- Krishnai River, opposite the Someswari River
- Dudhnoi River
- Digaru River, opposite the Jadukata River
- Dhansiri River, which drains a portion of the Indo-Burman ranges and Mikir Massif, east of Meghalaya

Table 5.14 summarizes the drainage basin characteristics (determined from 1:1,000,000 scale Tactical Pilotage maps) and the estimated average annual sediment loads for these six streams. Sediment yields from the Meghalaya streams range from 139 tonnes/km^2 to 229 tonnes/km^2, and up to 360 tonnes/year on the Dhansiri River. A simple relation between annual sediment load (Ga in tonnes/year) and drainage area (DA) was derived:

$$G_a = 11.7 * DA^{1.4}$$

Goswami indicated that the data was collected between 1971-79, which was characterized by low runoff and sediment transport. For example, the long-term sediment load of the Brahmaputra River at Pandau was 2.16 times greater than for the period 1971-79. A review of flow records and sediment transport estimates from rivers in the NE region confirmed that this period included several low runoff years. It was estimated that the sediment yields should be increased by approximately 25 % to determine long-term values. Using this correction factor, the regional analysis predicts an annual sediment load of 625,000 tonnes/year for the Someswari River. By comparison, estimates from direct measurements and rating curves ranged from 682,000 tonnes/year (BWDB data) and 304,000 tonnes/year (SWMC data). This comparison shows that the results of the regional analysis and BWDB sampling program agree reasonably well. The computed suspended sediment loads for the other Meghalaya streams are as follows:

- Jadukata River: 0.81 million tonnes/year
- Jhalukhali River: 0.07 million tonnes/year
- Chela River: 0.09 million tonnes/year
- Dhalai Gang River: 0.05 million tonnes/year
- Hari River: 0.16 million tonnes/year
- Lubha River: 0.14 million tonnes/year

Therefore, the total suspended load from the Meghalaya watersheds amounts to approximately 2.5 million tonnes/year, of which in the order of 80 % consists of sand.

5.5.3 Susang Hills:

No sediment data are available from the Nitai River, Bhogai River, Chillikhali River or Malijhee River. Therefore, sediment inflows from these rivers were estimated from the Meghalaya regional analysis. The total inflows were estimated to be 0.2 million tonnes/year.

5.5.4 Barak River Inflows:

The annual inflow from the Barak River at Amalshid was estimated as the sum of the loads carried by the Surma River and Kushiyara River. The measurements on the Surma River (at

Sylhet) are 100 km downstream of Amalshid and include inflows from the Lubha River as well as contributions from local bank erosion. On the other hand, it is known that major spills occur along the Surma River, which results in substantial losses from the main channel and deposition on the floodplain. A review of changes in flood flows along the river suggests the incoming annual loads at Amalshid would be around 15% greater than the estimated loads at Sylhet.

The total suspended sediment inflow was estimated as follows:

8.7 million t/year (Kushiyara) + 1.15*3.7 million t/year (Surma) = 13.0 million t/year

Approximately one third of the load is transported by the Surma River and two thirds by the Kushiyara River. This ratio is comparable to the observed flow split at Amalshid during the monsoon season. The estimated sediment yield of the Barak River amounts to around 500 tonnes/km^2. This value is close to the estimated sediment yield for the Dhansiri River, Assam (460 tonnes/km^2). This comparison also provides some independent verification that the data from the Surma and Kushiyara River are reasonably representative of actual sediment transport conditions.

5.5.5 Results

The terms of the suspended sediment budget (in million tonnes/year) are as follows:

INFLOWS - OUTFLOWS = NET ACCUMULATION

13.0 (Barak River)
9.2 (Tripura Hills)
2.5 (Meghalaya)
0.2 (Susang Hills)
24.9 (total inflow) - 16.9 (Meghna R.) = +8.0 (net accumulation)

Figure 36 shows a tentative annual budget for the suspended sand loads entering the NE region. The net suspended sedimentation rate for the region amounts to 8.0 million tonnes/year, which means the region has an overall sediment trap efficiency of approximately 40 %. This sediment trapping effect was described 200 years ago by Rennell, who noted (while describing the lower Surma River) "*the clearness of the water is due to the numerous jhils (beels) through which it flows, where the silt carried by the river is to a great extent deposited*"

If this sediment was spread evenly over the region, the average deposition would amount to approximately 0.3 mm/year. These figures do not include coarser sand and gravel-sized sediment deposited near the heads of the Meghalaya fans. Furthermore, it does not consider the internal re-distribution of sediment within the region. For example, actual sediment deposition tends to be localized in specific sedimentation zones and much of the sediment is generated from local erosion and scour in unstable reaches within the region.

The sediment budget analysis represents a first attempt to quantify the amount of sand-sized sediment that is being supplied to the region. Given the nature of the available data, the results must be considered as preliminary and should be updated when more reliable sediment data comes available.

5.6 Future Work

In the future, consideration should be given to implementing a rationale long-term sediment monitoring network for the NE Region. The aim of the programme would be to maximize the information that can be obtained, given the physical and financial constraints that are imposed. Some examples of sediment network planning are described in Day (1991) and Stichling (1973).

One of the first steps would be to define potential users of the data. For the NE Region, some of the potential uses include (1) engineering assessments of FCD/I impacts (2) environmental assessments related to environmental impact assessments of development projects, (3) water quality monitoring for water use studies (water supply, agriculture) (4) fisheries management, related to water quality, habitat management (5) research related to geomorphology, soil science and wetlands ecology. This illustrates that in the future, probably the main uses of the data will lie in the environmental management field, since it encompasses the total range of bio-physical activities in the region.

The next step would be to identify the core client groups who would be the users of the data. These users will include various departments of the Water Board, agencies such as the Department of the Environment, and Department of Fisheries, and planning groups such as WARPO, as well as academic groups such as BUET, and research institutes. Consultation and discussions would be required to establish priorities and overlapping interests (for example, some efficiency might be gained by having suspended sediment programmes executed during water quality measurements. This would also help determine which aspects of the sediment programme are most critical. For example, do people need to know the annual sediment loads, or only peak suspended sediment concentrations during floods, or the seasonal ranges in average concentrations? On the basis of these findings a sampling strategy would be developed. This might involve picking a few critical sites for long-term, permanent monitoring, throughout the year. These base stations would be used as a monitoring network for assessing long-term patterns and trends (such as changes in sediment loads due to land-use changes) as well as for assessing sampling requirements for other short-term programmes. For example, ongoing statistical analysis of the data would be needed to determine the sampling effort that is required to answer basic questions such as what is the annual sediment load, what is the range of concentrations, etc. Using these results, a revolving, short-term programme would commence throughout the region to address specific questions and issues. These short-term stations would only operate until sufficient data was collected to meet the objectives of the programmes.

Consideration should be given to using other types of samplers during data collection. Depth-integrated suspended sediment samplers such as the US DH-48 and US-D 74 would be very suitable for measuring suspended sediment concentrations on the relatively shallow streams in the NE region. These samplers have been adopted for most routine sediment measurement programmes in the United States and Canada (Vanoni, 1977; Water Survey of Canada, 1989). There are five main reasons for using these types of samplers over equipment currently in-use. (1) the samplers are designed to sample "iso-kinetically" so that the velocity of the sediment/water mixture entering the sampler is the same as the free-stream velocity in the river. This prevents sampling bias from occurring. (2) the sample is depth-integrated and discharge weighted. This means only one sample is required for each vertical and no additional velocity profile data is required to estimate the average concentration. This reduces the number of samples that need to be analyzed in the laboratory, which allows more work to be accomplished with the same resources. (3) the samples are time-integrated, which improves the precision of the measurement

(4) the samplers can be easily attached to existing BWDB current meter reels and do not require electrical power or additional cabling. (5) the samplers can be constructed locally, are simple to operate and are virtually indestructible.

6. ALLUVIAL FANS

6.1 Introduction

Alluvial fans are formed when steep mountain streams exit from their canyons and spread over flatter unconfined lowlands. The decrease in channel gradient and reduction in velocity causes deposition of sand and gravel in the form of a fan shaped conical delta. Alluvial fans are characterized by sudden, irregular channel shifts which result in periodic abandonment of some channels and the creation of new channels across the fan surface. As a result, channel shifting on alluvial fans is usually unpredictable and erratic.

The main hazards on fans are associated with periodic channel erosion during avulsions and channel shifting as well as flooding by channel spills, overland flow and inundation. After an avulsion occurs, lands adjacent to the newly formed channel will experience erosion as the new channel widens to accommodate the high velocity flows from upstream spills and overland flows. Large amounts of coarse sand will also be deposited overbank during subsequent floods over a zone of several kilometres in width as the river spills out of bank. Sand may also be deposited downstream in trunk rivers that receive flows from the newly formed channels. Consequently, sedimentation impacts may be felt a long way from the site of the initial channel shift.

As mentioned in chapter 5, virtually all of the runoff and sediment are generated outside the region in the Meghalaya Foothills/Shillong Plateau in India. This makes it impossible to control sedimentation in the source areas or to even monitor ongoing changes in the watersheds.

Someswari River provides a good case history for illustrating some of the issues involved in managing sediment problems on alluvial fans and most of the quantitative analysis completed to-date has been on this fan. Additional discussion has been presented on the other major fans in the region, namely on Jadukata River, Jhalukhali River, Chela River, Dhalai gang and Piyain/Dauki Rivers.

6.2 Someswari River

6.2.1 Morphology

The Someswari River drains 2,135 km^2 of steep, mountainous terrain from the Meghalaya Foothills. Table 4.1 listed some key features of the watershed in India. The alluvial fan of Someswari River covers an area of 138 km^2 (Figure 37). Annex C summarizes key morphologic characteristics of the Someswari River.

The overall gradient on the fan is relatively low; 0.0005 between the fan apex at Bagmara and Durgapur and 0.00015 downstream of Durgapur. As a result, the land surface has been built up only a few metres (typically less than 3 m) above the surrounding low-lying floodplain and beels. Most land on the active fan lies between El. 9 - 15 m PWD. Consequently, the lower portions of the fans may be deeply inundated during the monsoon season by backwater from the Kangsha River (backwater extends to about 2 kilometres downstream of Durgapur).

Most of the channels on the fan are composed of uniform sand, with a median size ranging between 0.25 - 0.40 mm and maximum sizes ranging between 1 - 2 mm. Unlike other fans in the region there is virtually no gravel or cobble sized materials in the river-beds.

Figure 38 shows past channel changes on the alluvial fan, based on maps from 1768 (Rennell's survey), 1952 (1:40,000 mapping) and 1989 (SPOT image). In 1768 a single channel of the Someswari River flowed southwards from its canyon mouth to the Kangsha River. East of the Someswari River Rennell's showed a large haor area (marked as "marshy lake" on Figure 38). In 1952 the Someswari River flowed in a single braided channel which turned east into the Baulai River system. This channel is called Old Someswari River in this report. The presence of channel scars and abandoned channels on the east and west side of the fan suggests the river probably shifted at least two other times in the interval between 1768 and 1952.

Local inhabitants reported a landslide occurred in the upper catchment in the early 1960's. Following this, channel deposition on the fan caused the river to shift back towards the west, excavating a new channel to the Kangsha River. This new channel, which coincides approximately to the alignment of the river mapped by Rennell's is termed "Shibganjdhala River" in this report. Based on the dimensions of this new channel, approximately 6 million m^3 of predominantly fine sand and silt sized sediment was eroded during the course of this avulsion. Much of this eroded sediment was flushed into the Kangsha River or has been deposited overbank into low lying areas on the fan such as Silti Beel.

Information about past rates of channel changes on the fan can be made by interpreting the discharge measurements that were conducted by BWDB at Durgapur. Figure 39 shows "specific gauge" plots for the Shibganjdhala channel and Old Someswari River channel. The graphs illustrate trends in water levels at specific discharges, and provide a means for assessing long-term aggradation or degradation processes. It can be seen that aggradation in the Old Someswari River took place in three stages 1959 - 1962, 1973 - 1974 and 1988 - 1989. By contrast, the water levels in the Shibganjdhala River decreased most rapidly between 1965 - 1975, probably in response to channel widening and incision following the avulsion. Since 1986, there is evidence of slight aggradation. Therefore, after the avulsion occurred, degradation and channel enlargement took place in the Shibganjdhala channel while sediment deposition occurred overbank on the adjacent floodplain or in the abandoned channel.

The present-day Shibganjdhala channel has an incised width at bankfull stage of about 100 m. However, the river spills out of bank in many locations and is depositing lobes of sediment over a 3 km wide zone. These broad sandy deposits extend as far east as the Jaria - Durgapur highway and as far west as the low lying haors near Silti Beel.

The shift from the Old Someswari River to the Shibganjdhala River has reduced sediment loads into the lower Someswari/Baulai River system and increased sediment loads in the Kangsha River. Channel aggradation has occurred over the last 25 years along the lower Kangsha River as far downstream as Mohanganj. This aggradation has virtually blocked off the original Kangsha channel and resulted in the Kangsha River shifting into a former khal (Ghulam khali channel). Impacts from the avulsion on Someswari River have extended over a distance of about 100 km.

Two new avulsion paths have opened up since 1988 on the east side of the Someswari River, upstream of Durgapur near the fan apex. Local residents reported the Atrikhali channel developed after the 1988 flood when flow spilled through a minor distributary. Since that time, the channel has widened to approximately 60 m and has developed a permanent channel which flows eastward into a former course of the Old Someswari channel. A second spill channel is evident approximately 1 km upstream of the Atrikhali channel. There is also evidence of recent sand deposition near the west side of the fan apex, which suggests the river may also have spilled towards the Nitai River system. These features indicate that the pattern of flooding and channel shifting on the fan is likely to be very dynamic in the future.

6.2.2 Hydrology

BWDB have periodically measured river discharges and water levels on the three main branches of the Someswari River (Old Someswari channel, Shibganjdhala channel, Atrikhali channel). SWMC has also measured discharges near the head of the fan at Bagmara in 1992. The reliability of the discharge data is questionable, particularly at high flows. Analysis of measured discharges and water levels at these gauge sites indicates the rating curves at the gauge sites are highly unstable. Furthermore, there are a number of unresolved inconsistencies at this time in the published daily flow records. Therefore, the magnitude of the incoming flood discharges can only be estimated very approximately.

Figure 40 illustrates the flow distribution at the three channels at various discharge conditions and time periods. During the 1960's the Old Someswari channel carried up to 65 per cent of the total gauged river flows. By 1972, the Old Someswari channel was carrying less than one half of the flow during the months of June - August. Observations in 1988 - 1990 indicate the Old Someswari channel carries negligible flow until the river stage exceeds El. 11.5 m. This elevation corresponds to the lowest bed level at the entrance to the Old Someswari channel. When river stages exceed this sill elevation, flow spills down the Old Someswari channel. During recent spills, the fraction of the total gauged flow carried by the Old Someswari channel typically ranged between 10-32 per cent, with the fraction decreasing noticeably after the 1988 flood peak. The highest measured discharge reached 694 m^3/s on July 7 1988. Uniform flow computations indicate the Old Someswari channel can carry about 550 m^3/s when the river stage reaches El. 14 m at Durgapur. This stage has been exceeded four times in the last ten years (1982-1991). Therefore, although the Old Someswari channel is dry for most of the year, it still conveys a substantial fraction of the total flows during flood conditions.

The Atrikhali channel has increased in size since 1988 to the point where it carries between 20 - 50 per cent of the flows in the dry season and 10 - 15 per cent in the monsoon season. Since the channel appears to be widening, it will probably carry more of the incoming flows in the future if no action is taken.

Analysis of hydrometric records show the Shibganjdhala channel enlarged in the 1960's and 1970's and has captured a greater portion of the total flow on the Someswari River. In recent years it has carried roughly 65 per cent of the total gauged flows during the monsoon season. The largest measured discharge reached 1,379 m^3/s on July 7 1988 (the stage was 13.60 m). The highest published daily discharge on the river was reported to be 2,050 m^3/s on June 24, 1988. The corresponding daily stage was 14.58 m, which is nearly 1 m higher than at the time of the highest flow measurement. It is believed that this event is one of the largest floods in the period of record. Other major floods of comparable magnitude occurred in 1964 and 1984.

The total incoming flood discharge at the head of the fan in 1988 can be estimated approximately from the observed measurements on the Old Someswari and Shibganjdhala channel. Based on the measured flow distributions in 1988 and the published daily discharge, the total flood flow would have been approximately 3,150 m^3/s. However, this figure is speculative since the rating curves were known to be very unstable during the course of the flood. Actual inflows may have been higher since additional flows probably spilled overbank between the fan head and the Old Someswari channel. The low reliability of the discharge estimates due to periodic channel scour and deposition, variable nature of the flow split, and presence of large ungauged spills in some years makes the flow data of dubious quality for predicting frequencies and magnitudes of total flood inflows. These features are characteristic of alluvial fans and add to the uncertainty of planning future flood control developments on them.

6.2.3 Flow/Sediment Interactions

Measurements of suspended sediment concentration on the Someswari River have been described in Chapter 5. The average annual load was estimated to be 0.68 million tonne/year. Coarse sand, which moves in direct contact with the bed (the "bed load") has not been measured.

Additional sediment transport calculations were carried out to develop a better understanding of sedimentation processes along the fan. These calculations involved estimating the daily bed material loads using the Ackers-White and Engelund-Hansen sediment transport equations, and then summing up the daily loads over the year to arrive at estimates of the annual loads. The calculations were carried out at three locations:

- at the head of the fan, near Bagmara hydrometric station;
- approximately mid-fan on the Shibganjdhala River downstream of Durgapur;
- the Kangsha River at Jaria Janjail, 2 km below the Shibganjdhala confluence.

These theoretical formulae are intended to estimate both the bed load and the suspended bed material load. The calculated loads must be considered as order of magnitude estimates given the poor quality of the hydrological and hydraulic data.

The estimates do not include the finer wash load since this component is not found in significant quantities in the bed. Analysis of bed material samples collected by NERP along the Someswari and Kangsha Rivers indicates the cutoff between "wash load" and "bed material load" is about 0.15 mm. Rating curves for the two locations on the fan are shown in Figure 41. Estimated annual loads at all three locations are summarized in Table 6.1. The calculations show that the Someswari River transports in the order of 3.6 million tonnes of sand at the head of the fan near Bagmara during a major flood such as in 1988 and 1.3 million tonnes/year at mid-fan below Durgapur, indicating more than half of the incoming sand load could be deposited in this 14 km reach.

By comparison, the Kangsha River at Jaria Janjail had the capacity to transport about 0.5 million tonnes of sand in 1988. Therefore, virtually all of the incoming sand load at Bagmara (85 %) will be deposited on the fan. However, fine sand and silt sized sediment which behaves as wash load on the fan will be flushed through the Shibganjdhala channel into the Kangsha River. It is this finer sediment that is causing aggradation in the lower Kangsha River.

6.2.4 Future Trends

Short-term

Future channel instability can be anticipated during the next five to ten years on the Someswari fan. The Shibganjdhala channel is in the process of developing a wider channel. It is expected that this will induce additional sand deposition to the west in Silti Beel and to the east adjacent to the Jaria - Durgapur road. The active channel and floodplain zone will extend over a width of about 3,000 m. This zone will be subject to high velocity over bank spills, bank erosion and sand deposition.

The Old Someswari River will continue to carry less flow at high flood stages in the near future due to ongoing aggradation at the channel entrance. However, the gradual closure of the channel will probably not lead to increased discharges in the Shibganjdhala River since more flow will be lost through the Atrikhali River. In fact, it appears that the Atrikhali River is rapidly becoming the dominant low flow channel in the system. As this process continues in the future, the loss of flow on the Shibganjdhala River will cause sediment deposition rates to increase near Durgapur since the locus of sediment deposition will shift further upstream. This will lead to increased channel instability near Durgapur but may reduce the rate of siltation on the lower end of the fan (and possibly Silti beel).

Long-term

In the long-term (10 to 20 years) there is a high probability of new flow paths and avulsions developing across the fan. At this time, the most likely course for a new avulsion path is into the Atrikhali channel upstream of Durgapur. However, there are several other potential avulsion paths that could also develop into future channels. Figure 38 indicates several potential avulsion routes.

Future channel widening and erosion on Shibganjdhala channel will also add in the order of five million m^3 of fine sand and silt to the Kangsha River over the next decade. This will produce additional sedimentation in the lower Kangsha and Dhonakhali channels and will raise water levels, particularly in the low - medium flows. This could result in the abandonment of the lower Kangsha channel, and eventual capture of the entire Kangsha River flow by the Ghulamkhali channel.

Channel widening on the Atrikhali River channel will lead to further diversion of flows from the Someswari and will threaten developments and villages on the eastern side of the fan by increasing damages due to flooding, channel erosion and sedimentation. A complete avulsion down Atrikhali channel would seriously affect roughly one quarter (38 km^2) of land on the fan. It is likely that this increased instability would persist for at least 20 to 30 years. Of course, such a shift would reduce sedimentation and erosion problems along the Shibganjdhala channel.

Increased sediment yields due to watershed disturbances in India represent a potential future threat to developments on the entire fan surface. Sediment yields could be increased as a result of forest clearing or changing agricultural practices, or as a result of natural processes such as landslides generated by high intensity storms or earthquakes.

6.3 Comparison With Other Fans

Table 6.2 compares the morphologic characteristics of the main alluvial fans in the region. Satellite photographs of some alluvial fans were described in Chapter 3 (Figures 16-17). Figures 42 - 44 illustrate recent channel changes that have occurred on the fans. During field visits it was noticed that some rivers are in the process of opening up new channels indicating that new avulsions may be underway. These sites have also been identified.

The following notes indicate the main processes that have been occurring on each fan:

Jadukata Fan:
The Jadukata River has produced the largest fan in the region, extending from the base of the Meghalaya hills near Saktiarkhola to the lowlands of Shanir Haor and Karcher Haor. The watershed generates extremely high runoff volumes and high intensity flash floods. During the two years of discharge measurements at Saktiarkhola in 1990 - 1991, flows of up to 5,000 m^3/s (double the highest flood of record on the Surma River at Sylhet) have been recorded. The river is probably transporting the highest sediment loads of all Meghalaya streams.

Gravel and cobble-sized sediments are deposited within a few kilometres of the fan apex near the Indian border. Gravel and cobble stone is quarried from the upper Jadukata River by local contractors and gravel mining operators. The stone is transported by barki boat to Sunamganj on Surma River and later shipped to Dhaka. In October 1992 it was estimated that 5,000 to 6,000 barki boats were operating on the river and 72,000 m^3 of coarse sand and 33,000 m^3 of gravel was extracted. Assuming the operations were sustained four months of the year, the total gravel removed would be 130,000 m^3. There is no evidence to suggest that the rate of extraction exceeds the incoming supply (the river is not degrading), so that the annual gravel load is probably at least 130,000 m^3/year.

Rennell's 1768 survey showed the Jadukata River splitting into two channels, a western branch that headed in a south-westerly direction along the approximate path of the Maharram channel into the Baulai River, and a second channel that headed southwards into the Rakti River and then into the Surma River. Abandoned channel scars from these routes are clearly visible on recent satellite imagery (Figure 19). The Nandia Gang channel apparently did not exist at that time and neither did Shanir Haor. Matian Haor and Tangua Haor can both be identified on Rennell's map. Until 1915, the land around Shanir Haor consisted of uncultivated marsh land and jungle. Around 1915 - 1920 embankments and a regulator were constructed. Older residents estimate the "jungle" disappeared 50 years ago.

Maps from 1952 show the Jadukata River flowed southwards in a wide braided channel until it split into the Baulai/Rakti branches at the north east corner of Shanir Haor (Figure 42). The river becomes much smaller after this point, indicating that most of the flood discharges have spilled out of the channel. The Rakti River split again into the westward flowing Nandia Gang while a southern branch continued on towards Surma River. Since the 1950's there has been one avulsion near the bifurcation of the Baulai/Rakti River. Ongoing sand deposition has virtually infilled the upper part of the Baulai River (on the north east corner of Shanir Haor) so virtually all the low flow passes down the Nandia branch. The southern flowing Rakti channel has become nearly completely infilled as a result of sediment deposition.

Jadukata River has started a new avulsion during the last few years just below the fan apex back into the Maharram River (Figure 42). This avulsion will divert most of the flow and sediment into Matian Haor, Tangua Haor and Gurmar Haor and then into the lower Baulai River. Once completed, the Rakti and Nandia Gang channels will become virtually dead channels and will have a greater tendency to infill with fine sediment. These changes will significantly alter the flow regime over an area of roughly 225 km^2. The main negative impacts will include:

- Navigation routes into settlements such as Tiapur in Shanir Haor will be more difficult. Transportation of gravel aggregate from the fan apex to Fazilpur will require increased travel times since the route will be about 10 km longer than at present;

- increased sedimentation and channel instability in Matian Haor submersible embankment project;

- increased sedimentation in Tangua Haor (one of six sites in the region identified in NERP (1993) as having outstanding national and international importance for nature conservation values;

- possible reduced drainage from the haor due to higher water levels at the outlet.

The main positive impacts from the avulsion will be reduced chance of embankment breaching and sand deposition within Shanir Haor.

Chela River:
Figure 43 shows recent changes on the Chela River. In the 1950's, the river exited from its canyon and spilled down the eastern side of its fan, eventually flowing into the Surma River near Chhatak. Maps from the mid-1970's show this alignment was approximately unchanged at that time. By 1990 two separate avulsions had occurred. The first avulsion (identified on Figure 43) took place at the fan apex, with a wide braided channel opening up in India which allowed the river to spill down the western side of the fan. At present, the new channel decreases in size down the fan and virtually disappears a few kilometres below the apex. However, future high spills should result in establishment of a more defined channel.

The second avulsion took place 5 km downstream of the apex on the eastern side of the fan. This shift caused the river to spill into the Old Piyain River channel east of Chhatak. Future instability on the fan is likely to affect the existing Pathar Churi submersible embankment project and the proposed Nainda Haor Project which are situated along the southern margin of the fan. These impacts will involve erosion of embankments and breaching during pre-monsoon flash floods and unanticipated sand deposition in the haors and on agricultural land within the project.

Dhalai River:
Figure 43 shows recent changes on Dhalai Gang fan near Bolaganj. This is the site of the largest stone quarrying operation in the region. Virtually all of the gravel and boulder sized materials are deposited within about 2 km of the Indian border. Although only a few years of discharge measurements have been carried out, some huge flood inflows have been measured near the fan apex (up to 5,000 m^3/s). The stream channels at the downstream end of the fan have the capacity to carry only a few hundred m^3/s, so most of these flood inflows will spill over the entire fan.

The active channel width decreases from about 1000 m in the gravel reach to about 80 m in the sand-bed reach downstream of Companiganj.

The downstream end of the fan merges into land belonging to "Surma River Floodplain" and "Sylhet Lowland" physiographic units. Most of the recent channel instability has been associated with sand deposition (0.06 mm - 2 mm) on the lower half of the fan where the stream gradients decline. According to local residents, up until a few years ago the river flowed directly southwards past the town of Companiganj into the Piyain River. Around 1989 the river began to spill east into an area of low-lying beels and developed a new channel (approximately 40 m x 3 m at bankfull condition) into the Piyain River. Reduced flows in the old channel downstream of the bifurcation promoted sand deposition and aggradation over a length of about 3 km near Companiganj. At present, virtually all of the low flows are now passing down the new channel, which has impaired navigation into Companiganj. The new sand deposition in Rauta Beel is also damaging fisheries habitat. Although it might have been possible to re-direct the channel down its former route a few years ago, this option appears very difficult at present since the old channel has become silted-in and major river training works would be required to close the new channel. Given the immense flood flows and sediment loads coming in through the head of the fan, the entire fan area is clearly situated in a high hazard zone. Attempts to confine the channel within narrow embankments would probably prove futile and could induce severe impacts downstream.

Daukai/Piyain Fan:
Figure 44 shows channel changes on the Dauki/Piyain Fan near Jaflong. The Dauki River splits into two channels at the Indian border, with one branch heading south into the Goyain River and the Piyain branch heading west, eventually being joined by the Dhalai gang. Gravel and cobble sized materials are deposited within 2 km of the Indian border and most of the sediment deposition on the fan consists of coarse - medium sand. The downstream limit of the fan merges gradually into "Surma Floodplain" and "Sylhet Lowland" physiographic units.

In the 1950's the Piyain River flowed westwards for a length of about 8 km along the border with the Meghalaya Plateau on the extreme northern edge of the fan and then turned south and became known as the "Old Piyain Channel". Over this reach the stream transformed from a 500 m wide shallow braided sand-bed channel into a 60 m wide meandering distributary. In the 1970's an avulsion occurred causing the Piyain River to abandon its northern channel and develop a more southerly route towards the Dhalai gang. As a result, the "New Piyain River" became the main active distributary through the low lands. In around 1990, a new avulsion started on the Piyain River (identified as "avulsion in progress" on Figure 44) which is diverting flow into the Goyain River. If this avulsion continues to grow there will be another major change to the overall flow regime and drainage pattern on the lowlands. This change will produce a range of impacts in the affected area including reduced discharges and faster drainage in the area between Dhalai Gang and Piyain River, and higher discharges and slower drainage on the Goyain River system.

6.4 Summary

The Meghalaya alluvial fans are unusual features in several respects. First, they generally have low gradients, indicating the volume of sediment stored in the fans is quite small, in spite of the huge runoff volumes generated in the watersheds. Second, the streams are dominated by sand transport, much of which appears to transported as bed load. Gravel and cobble-sized sediment is generally not transported past the mouths of the canyons at the International border. Finally, channel avulsions have occurred on all of the fans in historic times (in some cases more than once). However, the channel shifts generally required several years (or even decades) to be completed. In most cases, the avulsions took place when the river re-occupied former channels or minor khals.

7. PIEDMONT RIVERS

7.1 Introduction

Piedmont rivers drain uplands and hilly areas on the southern and north - west boundaries of the study region and eventually flow onto the main low-land floodplains and flood basins. Southern Piedmont streams flow out of the Tripura Hills in India onto the Kushiyara River floodplain (Juri River and Manu River) or flow onto the Central Basin haor area (Karangi River, Khowai River, Sutang River). Northern Piedmont streams (Bhogai River, Chillikhali River and Malijhee River) flow out of the Susang Hills onto the Old Brahmaputra River floodplain. The rivers are all characterized by several common features:

- relatively steep water surface slopes (typically 0.0002 - 0.0003)
- flashy flood hydrographs
- predominantly sandy bed and bank materials
- high suspended sediment transport rates
- presence of natural levees adjacent to the active channels

The streams also become noticeably smaller when they enter the low-lands. This feature is caused by the increased overbank spills as they enter the deeply flooded, backwater-controlled lowlands. According to "Regime Theory", this loss of flow greatly reduces the "dominant" or "channel-forming" discharge, which in turn, leads to an adjustment in channel geometry (Blench, 1959).

The following sections describe two of the principle Piedmont rivers in the NE region - the Manu River and Khowai River.

7.2 Manu River

7.2.1 Channel Characteristics

Figure 45 shows the Manu River from the International border to its confluence with the Kushiyara River. Additional supplementary morphologic information is summarized in Annex C (Figures C-21 to C-24).

The Manu River flows out of the Tripura Hills in India, deflects off Pleistocene/Pliocene uplands near Haripasha and then turns northwards and flows into the Kushiyara River near Manumukh. The total length of the river in Bangladesh is 80 km. In this investigation, the river has been sub-divided into three reaches:

- upper Manu River in India
- Manu River from Indian border to Dhali River confluence
- lower Manu River from Dhali confluence to Manumukh

The upper Manu River occupies a narrow valley between two prominent north-south trending anticlinal ridges. The lower portions of these ridges consist of poorly consolidated, often highly weathered Pleistocene and Pliocene-age sediments (Dihing and Dupi Tila formation) that are dissected and gullied by the network of headwater channels that form a dendritic drainage pattern. As discussed in Chapter 5, it appears sediment production from these slopes is very high (Figure 35). The upper Manu River flows in a confined, irregularly meandering channel and displays large sandy point bars, mid-channel bars and side bars, which are also indicative of high sediment transport rates.

Downstream of the border, the river flows in a northwesterly direction, across the strike of the anticlines, and breaks through a gap between these ridges below Hashimpur. The channel turns westwards and is confined by the Bhatera Hills on its right bank and bordered by Dakdhala Haor on its left. However, there are indications the river has followed other courses in the past:

- old channel scars and partially infilled paleo-channels lead off from the present channel just upstream of the Manu railway bridge and follow the east side of the Bhatera Hills into Hakaluki Haor;

- a second former channel leads off to the north from the present channel near Kazir Bazar, just upstream of the Dhalai River confluence. This ancient channel flowed along the west side of the Bhatera Hills, towards the Kushiyara River near Fenchuganj.

The present-day Manu River has a highly sinuous, regular meandering pattern in this reach. A comparison of 1990 SPOT satellite photos with 1:40,000 scale maps (1952 era), showed there has been localized channel shifting due to progressive meander migration and two apparently natural cutoffs (Figure 45). Bed material samples collected by NERP indicated the channel is composed of medium-fine sand (D_{50} of 0.2 mm). Typical channel dimensions are summarized in Table 7.1. The channel has an average top width of 103 m and an average cross sectional area of 410 m^2 at bankfull stage. As shown in Figure C23 (Annex C), bankfull stage corresponds closely to a mean annual flood.

The Dhalai River enters the left bank of the Manu River just downstream of Dakdhala Haor. During the June 1993 flood it was observed that inflows from the Dhalai River and other return spills induced appreciable backwater on the Manu River. This resulted in a noticeable flattening of the river gradient and overbank sediment deposition. Immediately downstream of the Dhalai River, the left (south) bank of the Manu River is confined by the Balishiri Hills and highly weathered sandstone can be seen outcropping in the left bank. The river turns abruptly northwards near Moulvibazar and flows in an irregular, low sinuosity channel until joining the Kushiyara River near Manumukh. In spite of the inflows from the Dhalai River, and other tributaries, the channel dimensions remain virtually unchanged in the reach, with the width actually decreasing in the lower 5 km. Surveys during flood conditions showed the confined channel below the barrage develops prominent dunes and sand waves on the river bed as a result of the higher velocities in the channel. These dunes averaged 60 m in wave length and 2 m in height (occasionally reaching 3 m or more) on June 14, 1993.

Figure 48 shows a longitudinal profile of the river. The water surface slope at a mean annual flood condition is relatively uniform, averaging around 0.00015 between Moulvibazar and Manumukh and 0.00018 upstream of Moulvibazar. The water levels in the lower end of the river are affected by backwater from the Kushiyara River. An analysis of slope changes was made by computing daily water surface slopes between Moulvibazar and Manumukh and comparing these with the incoming discharges from the Manu. It was found that the daily slope values followed the flood hydrograph very closely during the flood season. When flood peaks occurred, the water surface slope of the Manu River steepened and when the discharges decreased the slope declined.

7.2.2 Flood Control Projects

The Manu River Irrigation Project (MRIP), is located on the right bank of the Manu River between Haripasha and Manumukh (Figure 45). "Dwarf" embankments were first constructed here in the early 1960's. Later, low embankments were built, but these breached frequently. The MRIP, with full flood control embankments was constructed between 1976-1983. The MRIP embankments are set-back from the river about 500 m on average. In some places the embankment is over 1 km from the Manu River. The original design called for a standard set-back of 120 m (400 feet). Many residents opposed this alignment (as they were not threatened by floods at this time) so the embankment was moved back to the present location. Valuable land and property outside the main embankments was threatened by the higher water levels that occurred during the 1980's. As a result, 23.7 km of secondary embankments were built (and are still being strengthened) on the river's edge. The people living in between the two embankments cut the project embankment when their property is threatened by floods. It is known that cuts were made in 1984, 1987,1988, and 1991. SRP (1993) reported that the embankments have been cut or breached every year since the project began. Their profile of the existing Manu right embankment shows large sections of embankment missing, upstream of the barrage (Figure 48). There is no record of water ever over-topping the project embankment.

A barrage (completed in 1978) diverts water from the Manu into the MRIP for irrigation purposes and operates from December through April.

The left bank between Haripasha and the Dhali River is considered to have no embankments (though some low embankments were observed in the field). This area is included in a proposed project, "The Dhali River Project". The 1986 feasibility study, by Associated Consulting Engineers (Bangladesh) Ltd., proposed 142 km of embankment along the Dhali and the left bank of the Manu.

From the Dhali River to Moulvibazar town (2-3 km), full embankments exist on the left bank. These are part of the Hamhami Chara project which was completed in 1991. Moulvibazar town protection embankments were built in 1979/80 under a nation-wide town protection program. Increased flooding in town "caused by the MRIP embankments" has necessitated improvements. Under the FAP 9 project, construction began in 1993. The left bank embankments on the most downstream portion of the Manu River (Moulvibazar to Manumukh) was built in 1983-85. The main purpose of this project was to protect the Dhaka-Sylhet highway. This embankment was breached during the 1985 flood, causing extensive damage. The section was again upgraded in 1987-88 under the Hail Hoar project.

The upstream section of the Manu river is covered under a project entitled "Manu River FCD Sub-System". Low embankments built under local initiative existed in the area at least as early as the 1970's, possibly earlier. However, these embankments breach regularly in many places. Between 1984 and 1987 five regulators were built by BWDB. In 1989, the project was included in the SSFCDI program. The sub-system is divided in two sections. The first section, railway bridge to Indian border, is phase one of the project. The second section, railway bridge to

Haripasha, appears to be phase two. The first phase, which included re-sectioning 20 km of embankments was completed in 1992. Phase 2 is in the design stage at the present time.

Efforts were made to assess the overall impact from these embankments on the river channel morphology and sedimentation processes. An important concern is whether channel aggradation has occurred in the embanked reach and whether aggradation is causing flood levels to rise over time. This has been a perception of many local people in the area. The following analysis is intended to answer this question.

7.2.3 Hydrology

Figure 46 shows recorded peak discharges at the Manu rail bridge and the sum of daily peak discharges on the Manu River at the rail bridge and Dhalai River at Kamalganj. These latter values provide an approximation to the flows at the barrage. The average annual flood peak at the rail bridge was 609 m^3/s and the highest of record was 875 m^3/s in 1991. The average flood peak of the combined Dhalai/Manu River discharges was 803 m^3/s and the highest was 1242 m^3/s. The peak discharge time series at both sites show a trend of increasing peak discharges over time, which is consistent with trends of increasing rainfall intensity.

Figure 47 shows water level hydrographs at the rail bridge, Moulvibazar and Manumukh on the Kushiyara River confluence. There has been remarkably little variation in the annual maximum flood levels at Moulvibazar over the last 25 years.

7.2.4 Channel Stability

Assessment of channel changes and trends has been based on comparisons of historic maps and satellite images, analysis of hydrometric data and a comparison of channel cross sections and surveys. Some of the most useful information for assessing vertical changes (degradation/aggradation) are the historic stage-discharge rating curves at BWDB's hydrometric station on the Manu River (gauge 201). These rating curves were compared to produce specific gauge plots (Figure C-24, Annex C). It can be seen that there has been virtually no change over the years 1965-1991 at the lower discharges and a decrease over time at higher flows (approximately 0.6 m over 25 years). This suggests the channel section has increased over time, probably by widening rather than lowering of the river bottom.

River cross sections were surveyed along the Manu River downstream of the barrage in 1985 and 1986 by BWDB. NERP re-surveyed these cross sections in 1993 in order to determine whether significant channel changes have occurred in response to the construction of the Manu embankments. In total, cross sections were surveyed at 26 sites on the Manu River. At some sections, surveys were repeated on three occasions (August 1992, Feb/March 1993 and August 1993) to assess scour and fill processes. Figure 49 compares a set of cross sections near Palpur, about 2.5 km upstream of the Kushiyara River confluence. The exact locations of the BWDB cross sections could not always be determined in the field. Therefore, the comparisons of channel changes were made on the basis of changes in cross sectional area and top width.

Figure 50 shows a set of cross sections near Moulvibazar. Results of the comparisons are provided in Table 7.1. There has been only minor change to the overall channel geometry downstream of Moulvibazar between 1985/86 and 1993. The river's top width increased by about 10 per cent in both reaches and the available channel area increased by between 3 % and

5 %. The completion date of the Manu embankments is believed to be around 1983. It is unlikely that major channel changes could be completed between the time of embankment construction (1983) and the BWDB surveys (1985). Therefore, it appears that channel impacts from the project have been minimal to-date. Furthermore, it appears the lower portion of the Manu River (from Moulvibazar to Manumukh) is a stable transport reach, that is neither aggrading nor degrading.

7.2.5 Sedimentation

Results of suspended sediment sampling on the Manu River were described in Chapter 5. It was shown that sediment concentrations on the Manu River can exceed 5000 mg/l, and are amongst the highest recorded in the Region. Furthermore, the average annual suspended sediment load was estimated to be in the order of 4.9 million tonnes/year, which corresponds to one of the highest sediment yields in the Region (only the yield from the Dhalai River was higher).

Various local residents and environmental organizations have suggested that rapid sedimentation has been occurring along the Manu River and adjacent floodplains and haors. It is difficult to verify these perceptions since there are not sufficient survey data in the overbank areas to estimate deposition rates before and after the project. Furthermore, other factors, such as changes in discharges and flood frequency may have also affected sedimentation rates.

The survey comparisons and other morphologic data presented earlier indicate that the main channel of the Manu River has remained fairly stable over the last decade and shows no evidence of aggrading. Therefore, some explanation is required to resolve people's perception of increasing sedimentation in adjacent areas (such as Kawadighi Haor north of Moulvibazar) and the apparent stability of the Manu River channel. One explanation is that the higher incidence of flood flows in recent years has caused more frequent breaching and overbank spills which has diverted more suspended sediment from the main channel into the adjacent lowlands.

In order to test this idea, the sediment rating curve developed for the Manu River (Chapter 5) was used to estimate the total quantity of sediment transported on days when bankfull flow conditions were exceeded. The calculations were made using the available daily discharge records between 1964 and 1991. First, the threshold for initiating an overbank spill was estimated from the stage-discharge relation at the Manu hydrometric station and from the channel cross section near the gauge (Figure C-23, Annex C). It was concluded that bankfull flow near this site was around 609 m^3/s (about the mean annual flood). The total sediment load transported on days when flows exceeded this bankfull condition was then computed. It was found that prior to 1983 there were many years when flows never exceeded bankfull. However, after 1983, bankfull flows were exceeded every year, often several days or weeks/year. The sediment load transported during this time of overbank flows was very large. The total load over the nine year periods 1974-1982 and 1983-1991 are summarized below:

1974-1982 = 525,820 tonnes
1983-1991 = 12,661,448 tonnes

This shows that the suspended sediment load on the Manu River during times when overbank spills were occurring was 20 times greater after 1983 than in the preceding period. Of course, not all of the sediment transported in this period would be deposited overbank. Most of the suspended sediment would have remained in the main channel. The fraction of the load lost overbank would be approximately proportional to the fraction of the river discharge spilled from the main channel. If overbank spills amount to 10 % of the flood flows, the amount of sediment carried overbank would be in the order of 10 % of the channel load. Given the fact that embankments have breached in every year after their construction, there would be the opportunity for the spills to transport sediment laden water out of the river into the adjacent flood basins and haor areas.

Therefore, these calculations are sufficient to demonstrate that increased sedimentation in recent years on the floodplain and in adjacent haors reflects the higher incidence of overbank spills. The reason for the increasing trend in discharges may be related to changes in rainfall in the watershed or other impacts upstream of the gauge (such as confinement effects from other embankment works).

7.3 Khowai River

7.3.1 Channel Characteristics

The Khowai River flows northwards from the Tripura Hills in India and crosses into Bangladesh near the town of Ballah. Downstream of Ballah, the Khowai River flows in a meandering sand-bed channel for a distance of about 60 km to the town of Habiganj. The river turns westward when it crosses into the low-lying, deeply flooded Central Basin. Downstream of this point it becomes known as the "Barak River". The river rapidly decreases in size and flows for about 30 km before joining the Kalni River near Madna.

The river can be sub-divided into three main reaches (Figure 51):

- Indian border to Chunarghat
- Chunarghat to Below Habiganj town
- Barak River reach

The Khowai River flows in a sinuously meandering sand-bed channel throughout most of its length. At Shaistaganj, the river flows on top of a broad floodplain that is up to 3 m higher than the adjacent flood basin lands.

The channel width and mean depth at bankfull stage average around 70 m and 5 m respectively between Ballah and Habiganj. Downstream of Habiganj the channel narrows to about 20 m after it flows onto the low-lying Central Basin. The channel virtually vanishes in the broad flat lowlands which are covered by ancient channel scars, scroll bars and ox-bow lakes from an ancient river (possibly an early Meghna River) which flowed through this area.

Samples of bed material were collected by NERP at four sites along the river between Chunarghat and the Barak River. The bed and over-bank deposits consist of fine uniform sand. The median grain size decreases from about 0.18 mm near Chunarghat to 0.1 mm just downstream of Habiganj. The D_{10} size was approximately 0.06 mm in all samples. Since the D_{10} size is commonly used to distinguish wash load from bed material load, this indicates all of the sand load on the Khowai River can be considered as bed material load. Additional morphologic data on the Khowai River are summarized in Figures C-9 to C-12, Annex C.

7.3.2 Flood Control

The high embankments along the Khowai River were constructed by BWDB as part of the Khowai River Project. Phase 1 of the Project dealt with protection from Shaistaganj to Habiganj. The project was reviewed by BWDB in 1974-1975 and was submitted to ADB. After the project was turned down, BWDB went ahead without external funding. Details about the sequence of construction and completion dates are scarce. It was reported that by 1976 a cutoff had been made just upstream of Shaistaganj and high embankments were constructed on both sides of the new channel (Galay, 1976). Figure 54 shows the Khowai River channel alignment before and after the embankment work was completed. Several bends were cutoff during the project in order to straighten the river. Centre line channel distances before and after river training are summarized in Table 7.2. Most of the channel straightening has occurred in the reach between Shaistaganj and Chunarghat, where the centreline channel length was reduced by about 6.8 km. The overall length of the Khowai River from its confluence with the Barak River to Ballah near the Indian Border has been shortened by about 12 km.

The embankments were extended upstream and downstream between 1976 and 1985 until they extended continuously between Habiganj to Chunarghat. The embankments were originally designed for protection against a flood of 700 m^3/s, which was believed to have a return period of 50 years. Subsequent analysis has shown that the return period of this design condition was closer to 10 years. The embankments were breached at many points in 1984 and 1985. Surveys from 1988 and 1991 indicate the embankments have been raised by 1.5 - 3.0 m above the original design levels. For example, BWDB's 1988 surveys shows the top of the embankments typically remained 1-2 m above the highest flood levels that occurred in 1988 (Figure 55). Since additional land was not acquired for this work, raising the embankments has constricted the channel further and reduced the embankment set-back.

By 1992 the right bank embankment ended near Chunarghat, while the left bank embankment extended about 5 km further upstream to near Raja Bazar (NERP, 1992). At present, the embankments are typically between 120 m - 200 m apart, with the main channel being 60 - 70 m wide. Spills still take place in the unembanked reach between Chunarghat and Ballah or in locations where the embankment is undermined by erosion and scour. Channel maintenance is required every year and BWDB have identified 24 places where the embankments are prone to erosion.

In the winter of 1992, a one kilometre long loop cut channel with high embankments on both sides was constructed downstream of Habiganj near Chandpur village. Only a narrow pilot channel was constructed in the loop cut (sufficient to construct the embankments). In 1993/94 these efforts to confine the lower end of the river were continued when another channel re-location was carried out and the embankments were extended by approximately 1.5 km.

The berms between the river channel and the embankments is utilized for growing sugar cane. These crops, which are up to 2.5 m in height, are virtually continuous between Chunarghat and Shaistaganj and provide a very dense cover over the floodway. The fields appear to be very effective at trapping suspended sediment and also contribute to high flow resistance. The crops are less prevalent downstream of Shaistaganj.

7.3.3 Hydrology

The drainage area at the Indian border is 1113 km^2. Prior to embankment construction in the 1980's, local tributary inflows increased the drainage area by approximately 200 km^2 between Ballah and Shaistaganj. After the flood embankments were constructed, most of this local drainage would have been cutoff from the main channel.

Daily discharge data is available from the hydrometric station "Khowai River near Shaistaganj" (gauge 158.1) and Karangi River near Sofiabad (gauge 138). Both of these stations have operated since the mid-1950's. Water levels have also been recorded along the Khowai River at Ballah (gauge 157) near the border, at Chunarghat (gauge 158), at Shaistaganj (158.1) and at Habiganj (159). The average daily discharge at Shaistaganj during the period 1964 - 1991 was 36.4 m^3/s and the mean monthly flow in June is 66.4 m^3/s. The minimum flows in the year have typically ranged between 4 - 8 m^3/s during the last 25 years and show no obvious pattern over time.

The Khowai River has a flashy flood regime and several flood peaks typically occur between May and October each year. For example, in 1988 record peaks occurred on May 30, June 26 and August 15. Figure C-10 (Annex C) shows annual maximum daily discharges at Shaistaganj. Large floods took place between 1984 - 1989, particularly in 1982, 1984, 1985, 1986, 1988 and 1989. It is interesting to note that the annual maximum daily discharges in these six years exceeded all flows in the 16 year period between 1966 and 1981. Only the flood in June 1964 is comparable in magnitude to the high flows that occurred during the 1980's.

However, the maximum daily discharge in 1988 (1050 m^3/s) is nearly double the magnitude of the 1964 event. A similar pattern occurred on the Karangi River at Sofiabad, which is located east of the Khowai River. At this station, the maximum daily discharge on May 30, 1988 reached 500 m^3/s which is about four times greater than the magnitude of floods that occurred in the period between 1965 and 1980. It has been reported that a major spill occurred on the Khowai River upstream of Chunarghat into the Karangi River and the Sutang River during the 1988 flood. The flood record on the Karangi River shows unusually high floods also occurred in 1985 and 1980. Based on the available hydrometric records, the magnitude of the spills from the Khowai River into the Karangi River seems to have increased since the embankments were constructed downstream of Chunarghat.

There are some large and probably unresolvable inconsistencies in the flood records on the Khowai River. One of the most serious problems with the data is that no discharge measurements have been made at high flows. Consequently, all flood discharges have been estimated by extrapolating stage-discharge rating curves. This situation is illustrated in Figure C-11 (Annex C). For the case of the flood of record, the estimated flood discharge is nearly three times the magnitude of the highest observed discharge. NHC (1986) concluded "the available discharge data series is truncated (due to spills and overbank flows) and non-homogeneous and can not be analyzed for frequencies of total flood runoff". The unreliability of the discharge records also makes it difficult to interpret impacts from embankments and morphologic changes on the water levels along the river. Use of a metering cableway, instead of measurements from country boats, would provide a better means for measuring high discharges.

Figure 52 shows daily water levels recorded at Ballah, Chunarghat, Shaistaganj, and Habiganj. Water levels at Madna on the Kalni River have also been shown as these levels provide a downstream boundary condition to the Khowai River. There are several interesting features in these plots:

- at Ballah, low water stages rose by about 1 m after 1976 and have remained approximately constant since then. Flood stages show no obvious trend, though it should be noted that the 1988 flood stage at Ballah was much lower than in some previous floods. Further downstream, at Shaistaganj, the 1988 flood was the largest in the period of record.

- at Chunarghat, the flood levels do not display obvious trends, though the low water stages appear to rise by about 0.3 m after 1976;

- at Shaistaganj, both high flood stages and low water stages increased noticeably after about 1976. Flood stages in 1989 and 1990 were about 2 m higher than flood stages in 1965 and 1966, even though the discharges were similar. Low water levels rose at Shaistaganj about 0.7 m between 1976 and 1990.

- at Habiganj, the time series jumps abruptly around 1977, with the low water levels rising by 1.5 m. The peak levels rise progressively during the 1980's and consistently exceed the flood peaks by about 3 m.

- at Madna on the Kalni River, both low water and high water levels show no obvious trends or jumps over the last 25 years.

The remarkable increases in flood levels at Habiganj and Shaistaganj, in conjunction with the apparently stationary flood levels at Chunarghat and Ballah, illustrate the impact of extending flood control embankments upstream from Shaistaganj. It appears that as the embankments were extended, overbank spills and floodplain flows were confined to the main channel. As a result, flood discharges at Shaistaganj have increased over time since more of the flood flows are confined to the channel, instead of spilling into the Karangi River system to the east. These effects would not have any direct impact on low water levels. However, channel aggradation would produce such effects.

7.3.4 River Hydraulics

Figure 55 shows a longitudinal profile of the mean annual flood levels for the period between 1977-1991. Also shown are the approximate bankfull elevation of the cross section at each gauge site. Under present conditions during a mean annual flood, water levels are about 0.3 m below bankfull stage at Ballah and Chunarghat, about 0.3 m above bankfull stage at Shaistaganj and approximately at bankfull stage at Habiganj.

The water surface slope is approximately uniform between Ballah and Habiganj and averages about 0.00028. The mean annual flood water level difference between Ballah and Habiganj was noticeably greater in the period between 1965-1976:

- 15.62 m (1965-1976)
- 14.27 m (1977-1991)

Normally, this would indicate the river has flattened out. However, due to the loop cuts, the distance between Ballah and Habiganj has shortened, so the water surface slope has actually steepened from 0.00024 to 0.00028. Downstream of Habiganj the water surface slope varies seasonally, depending on the backwater conditions in the Kalni River. When flash floods occur in May and June, the water level in the Kalni River is typically around 5.0 m while in the August the level may reach 7.0 m. Since 1977, the water surface slope below Habiganj has become steeper during flood conditions. This will change the river's sediment transport regime, allowing more sediment to be transported below Habiganj than in the past.

7.3.5 Impacts of Embankments on Channel Stability

Efforts were made to assess channel changes in response to embankment construction although the analysis was hampered by the lack of reliable pre-project data. Several different types of data were utilized. First, river cross sections from 1969 and 1988 were compared. The nine 1969 cross sections were surveyed by EPWPDA in the reach between Shaistaganj and Chunarghat. The Habiganj Division of BWDB surveyed 121 cross sections between Ballah and Habiganj in 1988 (approximately one section every 0.5 km). The position of these sections did not coincide exactly with the locations of the earlier surveys. Nevertheless, they provide a good representation of the present-day average channel characteristics. However, the reliability of the data is suspect, since recent surveys during the Second Order Levelling Program have indicated errors in BWDB gauge datums of up to 0.48 m.

Longitudinal profiles of the top of bank and river thalweg upstream of Chunarghat were presented in ACE (1969). The longitudinal profiles from 1969 were compared with the 1988 cross section data to estimate changes in thalweg levels upstream of the embankments. These surveys will also suffer from the same datum uncertainties as the cross sections. Geomorphic studies were conducted between Shaistaganj and Habiganj to estimate deposition on the berms adjacent to the embankments. This involved measuring the amount of sedimentation by dating cultural artifacts buried on the floodplain. The main advantage of this approach is that it did not have to rely on early surveys and datum adjustments. Finally, stage-discharge rating curves at Shaistaganj provided another independent check of apparent channel changes.

Ballah to Chunarghat:
The only early survey data in this reach was the longitudinal profile published in ACE (1969). This profiles is compared with the 1988 BWDB data in Figure 55. The comparison suggests bed levels have risen by approximately 1 m, indicating the channel has aggraded. Dry season water levels at Ballah have also risen by about 1 m since 1980, which tends to verify that some channel aggradation has taken place along the upper Khowai River.

Chunarghat to Shaistaganj:
Comparison of the ACE (1969) longitudinal profile with the BWDB profile showed thalweg levels in the embanked reach upstream of Shaistaganj have lowered by around 1 m, indicating the bed has degraded. Seven cross sections were surveyed in this reach in 1969 and 30 in 1988.

Table 7.3 compares bankfull channel geometry at each surveyed cross section in the reach between Chunarghat and Shaistaganj. Each cross section appears to have enlarged over time, with the reach - averaged cross sectional area increasing from 190 m^2 in 1969 to 270 m^2 in 1988. The net erosion in this 16 km reach was estimated to be about 1.3 million m^3 (in the order of 150,00 m^3/year).

Figure C-12 (Annex C) shows the specific gauge record for the Shaistaganj hydrometric station. The plot shows an abrupt shift of over 1 m took place between 1967 and 1970. Between 1975 and 1991, water levels at discharges of 100 m^3/s and 150 m^3/s have lowered by about 0.5 m, with abrupt fluctuations of up to 1 m between 1984 and 1987. At 50 m^3/s, water levels have risen steadily by 0.5 m between 1975 and 1991. The trends at low flows are consistent with the changes in low water levels shown in Figure 52 and provides further evidence of aggradation at this site. The very complex changes at higher discharges are difficult to interpret, but probably reflect impacts of downstream channel re-locations, as well as possible changes in gauge datums and other shifts.

Shaistaganj to Habiganj

Pre-project cross sections are available in this reach. However, a careful review of this data showed there were major errors in datums that made it unsuitable for analysis. However, a short distance downstream of Habiganj, longitudinal surveys from 1969 suggested bed levels have risen by 1 m - 3 m, indicating the bed had aggraded.

Siltation rates on the berms were estimated at two sites by using a geomorphic approach. This involved finding cultural artifacts buried under the deposited sediment and dating the age of these features. The first site was located just downstream of Habiganj, on the right bank of the river at Vairab Tala. During cross section surveys, portions of a brick boundary wall and floor were found exposed in an eroding river bank. This structure had been constructed around a banyan tree, known in the area by local Hindus as "Vairab Dibta". The present top of bank is about 1 m above the floor level of this brick and mortar structure. The NERP Social Anthropology team visited this area, and interviewed Mr. Mahadev Roy, the builder of the temple. It was established that the structure was constructed in 1965. The Khowai embankment was constructed in this area around 1984. It was reported that no noticeable deposition occurred prior to the embankment being constructed. Since 1984, sand and silt were deposited on the berms between the embankment and the channel, eventually burying the temple floor until it was re-exposed in 1993 as a result of bank erosion. The total amount of deposition on the berms amounts to 1 m over ten years.

The second site was located on the right berm, approximately 0.5 km upstream of Shaistaganj near the village of Ganga Nagar. Two Hindu shrines were found on the floodplain, inside the embankments near the right bank of the Khowai River. The two shrines were constructed in 1984 in memory of Shatish Chandra Dev and his wife Kushum Kamini Dev. The level of the shrine's floor was originally built about 0.3 m below the ground level. By 1983, the floor was buried up to a depth of 2.3 m, leaving only the top of the shrine poking out of the ground. The embankment was constructed around 1984. Therefore, the overall deposition rate on the berm has amounted to 2.3 m over the last 10 years. The mechanism for this deposition appears to be related to the spilling of highly sediment laden water from the main channel onto the floodplain. Before embanking, these spills would continue into adjacent channel systems such as the Karangi and Sutang Rivers. With embanking, the sediment deposition zone extends along the strip of land forming the berms. In some years this land has been cultivated with sugar cane, which has promoted overbank deposition by trapping the fine grained sediments.

The effect of deposition on the river berms on flood levels was illustrated by carrying out a series of simplified uniform flow hydraulic computations. This involved estimating water levels for three conditions:

- the natural channel, without embankments and before berm sedimentation takes place;
- after embankments are constructed, with the berms at the initial floodplain level;
- with the embankments in-place and with berms raised by 1.5 m

The assumed geometry of the channel and embankments are representative of conditions between Shaistaganj and Habiganj (Figure 56). The calculations illustrate that deposition on the berms could raise water levels by in the order of 0.3 - 0.5 m when discharges exceed 500 m^3/s. However, it is also clear that the greatest impacts to water levels are from the confinement effects from the embankments. Sedimentation on the berms, simply increases the confinement effect.

Downstream of Habiganj

The recently completed loop cut and embankment extension 6 km downstream of Habiganj (near Chandpur village) provides an example of another type of morphologic impact from FCD works (Figure 54). As described in Section 7.3.2, this project involved constructing a pilot loop cut through a meander bend and then confining the new channel with full flood control embankments. The pilot channel was expected to widen and enlarge during subsequent floods. The floods of June and July 1993 (estimated peak discharge 655 m^3/s at Shaistaganj) were the first floods experienced by the project. The highest water levels in July at Habiganj exceeded the 1988 flood of record by 0.3 m, inspite of the discharge being nearly half the magnitude of the 1988 flood. Water levels were not unusually high further upstream at Chunarghat or Ballah. Inspection of the pilot cut after the flood showed much of the channel was very shallow, although considerable bank erosion and widening had taken place. Near the lower end of the confined reach, a very deep scour hole had been created, at least 10 m lower than the adjacent bed levels (Figure C-11, Annex C). This scour hole appears to have been formed due to the draw down effect and very high velocities that would have developed at the downstream end of the embanked reach. A series of backwater computations using the HEC-2 steady flow gradually varied flow program suggested that the confinement effect through the pilot channel could have been sufficient to raise water levels at Habiganj by about 1 m. It may take several years and several flood events for the pilot channel to develop a "regime" channel cross section, particularly if much of the bed and bank materials are cohesive in nature. Consequently, the confinement effect from the channel constriction may persist for some time before diminishing. However, downstream extension of full flood control embankments will lead to higher water levels at upstream locations such as Habiganj.

7.3.6 Summary

Flood control embankments have substantially altered the magnitude of flood discharges on the river by confining flood spills that formerly diverted water into other systems (Karangi River and Sutang River). The Khowai River has apparently experienced aggradation in the upstream embanked reach near Ballah and channel enlargement (mainly by widening) within the embanked reach between Chunarghat and Shaistaganj. Deposition of up to 2 m on the berms (the land between the embankments and the channel) has also taken place between Shaistaganj and Habiganj. Further developments, such as downstream extension of the embankments will continue to induce impacts, contributing to higher water levels at Habiganj.

8. LOWLAND RIVER SYSTEMS

8.1 Introduction

The purpose of the chapter is to characterize the processes that are governing sedimentation and channel instability on the main rivers in the region. Identification of these processes will define the internal driving forces that are controlling morphologic change. This chapter discusses the main lowland rivers, namely the Surma, Kushiyara, Kangsha and Meghna Rivers.

8.2 Surma/Baulai River System

8.2.1 River Classification

For the purposes of this investigation, the Surma/Baulai River system has been sub-divided into six reaches:

- Upper Surma River (Amalshid to Chhatak)
- Lower Surma River (Chhatak to Old Surma River offtake)
- Baulai River (from Baulai River junction to Kaliajuri)
- Lower Baulai River (Kaliajuri to start of Ghorautra River)
- Ghorautra River to junction with upper Meghna River

Table 8.1 summarizes the main geomorphic features in each reach, while Table 8.2 provides information on river discharges. Figure 57 shows a general map of the Surma/Kushiyara River system. Figure 58 shows a longitudinal profile of the river from Amalshid to its junction with the upper Meghna River.

8.2.2 Evolution

The Barak River bifurcates into the Surma River and Kushiyara River at the Bangladesh border near Amalshid. The Surma and Kushiyara re-join 300 km downstream where they flow into the upper Meghna River (Figure 57).

A review of satellite images and historic maps shows that the Surma River has adopted several different courses in the past. A prominent ancient channel can be seen west of Kanairghat heading towards the Meghalaya Foothills and then swinging southwards towards the river's present course near Chhatak. The upper part of this channel is presently an important spill channel, while the lower part of this paleo-channel is occupied by the Sari-Gowain River.

The Rennell's survey of 1768 shows the Surma River was the direct continuation of the Barak River (Figure 7). The Surma River was shown to be very close to its present alignment between Amalshid and Sunamganj. Near Sunamganj, the river turned abruptly south until it joined the Kalni/Kushiyara River near the town of Ajmiriganj. This course between Sunamganj and Ajmiriganj is called the "Old Surma River". Rennells also showed several distributary channels branching from the Surma River in the vicinity of Sylhet/Chhatak which flowed southwards to join the Kalni/Kushiyara River system.

Maps prepared from 1952 air photos show the Surma River split into two main branches downstream of Sunamganj:

- the Old Surma River channel;
- the Nawa/Baulai River which flowed westwards and then south until joining the Meghna River near the town of Dilapur.

By 1952 the Nawa/Baulai River was the main branch of the river and the Old Surma channel was a smaller distributary. A memo by BWDB dated May 8, 1963 reported:

> "*low flow of Surma does not join Meghna at Markuli but flows to Baulai River. The channel from near Sunamganj (Old Surma) to Markuli probably does not carry much of the flood flows of Surma.*"

By 1992, the entrance to the Old Surma River was only about 40 m wide and 2 m deep in the dry season. The main flow route now is through the Nawa River and into the southward flowing Baulai River. The Baulai River is joined by other streams from the western side of the region including the Someswari River, Kangsha River, Mogra River and Dhanu River. The lower 30 km of the Baulai River is called the Ghorautra River. The Ghorautra River flows into the upper Meghna River near the town of Dilapur.

8.2.3 Flood Control Infrastructure Development

Figure 57 indicates the approximate extent of major existing flood control projects along the Surma/Baulai River. Construction of high embankments along the left bank of the Surma River between Amalshid and Sylhet has been ongoing for decades. However, recent site inspections indicated there were many breaches and public cuts — 32 reported in NERP (1992). Therefore, the hydraulic impacts of the embankment may not be too appreciable. Probably more significant impacts have been caused by closure of spill channels (khals) which connect the main channel to the major flood basin lying between the Surma/Kushiyara Rivers. Nine spill channels have been closed and two others have been provided with regulators between Kanairghat and Sylhet.

Submersible embankments have been constructed in the 1980's on both sides of the Surma/Baulai River downstream of Chhatak (Figure 57). Submersible embankment projects include Kalner Haor and Karchar Haor on the north bank, Sonamoral Haor Project, Dhankunia Haor Project, Chandra Sonarthal Haor Project, Nawtana Khal Project on the right bank and Pagner Haor on the left bank. These projects are all intended to protect against pre-monsoon flooding.

Two major loop cuts were constructed downstream of Sylhet in the 1960's and 1970's to control bank erosion, which was threatening the rail line. A loop cut was also constructed about 16 km downstream of Chhatak in the early 1950's. Nine loop cuts were constructed in the early 1980's on the Baulai River in the reach between Kaliajuri and Itna. It is believed this work was carried out mainly to improve navigation during the dry season. The river straightening has shortened the river's length by 23 km in this reach.

8.2.4 Hydrology

Comments have been made that the Surma River is gradually "dying" and that the channel is carrying much less flow than in the past (ACE, 1973). This reduction in discharge has been attributed to changes in the flow split at the Barak River bifurcation near Amalshid. A review of discharge measurements on the Surma and Kushiyara River shows that at most stages the flow split has remained remarkably stable over the last 20 years (Figure 59). However, the distribution of flow changes seasonally, with the Surma River carrying about 40 per cent of the Barak River flow during flood stages in June and July and less than 10 per cent of the flow in the dry season. At low flows, virtually all of the Barak River passes down the Kushiyara River and the discharge in the Surma River is virtually zero at Amalshid. This unequal distribution during the dry season occurs as a result of bar accretion which has produced a "sill" across the channel. One of these bars is illustrated in Figure 60 which shows the channel topography immediately below the bifurcation in October 1992. These surveys show that local erosion and deposition processes have produced a deep scour hole on the concave bank of the Surma channel and formed a broad diagonal bar immediately downstream from it. The crest of the bar varies between El. 6 m to El. 8 m, so that as river stages approach this level virtually all flow is forced into the Kushiyara River. Removal of these shoals could presumably allow more flow to pass down the Surma during the dry season.

Figures 61 - 62 show annual maximum, minimum and pre-monsoon flood levels at stations on the Surma River. The annual maximum water levels are very consistent from year to year, typically ranging between 17 - 18 m at Amalshid, 14-15 m at Kanairghat, 11-12 m at Sylhet, and 7 - 8 m at Kaliajuri. Maximum levels in the pre-monsoon season (March 1 - May 15) are much more variable. At most stations there have been occasions when the maximum annual flood stage has occurred in the pre-monsoon season. However, typically the highest level in the pre-monsoon season is between 2 m - 4 m lower than the annual maximum.

Figure 63 shows annual maximum and pre-monsoon discharges recorded at Kanairghat and Sylhet. These flows do not represent the actual maximum discharges since substantial spills are known to occur on both the right and left banks. Actual total flood discharges along the Surma River are not known. However, published miscellaneous discharge measurements on Sada Khal in the Surma/Kushiyara flood basin, indicated flows reached up to 2,000 m^3/s (these figures include spills from both the Surma and Kushiyara Rivers). Suggestions have been made that the unusually low flows at Kanairghat and Sylhet in the mid-1970's was due to opening up of spill channels such as Kakura Khal. The in-channel discharges measured at Kanairghat and Sylhet are probably very sensitive to the status of the spill channels and distributaries that branch from the main river. Closure of some of these spill channels during the 1980's may also partially account for the sequence of high flows that have been recorded recently.

The Sari-Gowain River, Piyain River, Dhalai River and Chela River drain the steep, mountainous catchments of the Meghalaya and flow into the Surma River near Chhatak. Unfortunately, discharges have only been measured intermittently at Chhatak. These results show that during the monsoon season, peak flows can be anywhere between 1.3 and 2.2 times the flow measured at Sylhet. The highest discharge reported between 1967 - 1973 was 4814 m^3/s (in 1970).

The junction with the Old Surma River is situated about 12 km downstream of Sunamganj. Measurements by SWMC in 1991 indicated flows down the Old Surma River channel reached about 250 m^3/s in the monsoon season, or less than 10 per cent of the total Surma discharge.

Historic discharge data is not available for the lower Surma/Baulai River. Table 8.2 shows estimates of annual and monthly discharges. These values were computed by means of a water balance of the contributing catchments (NERP, 1992). The results of this analysis demonstrate the huge flow contribution from the Meghalaya Foothills catchments. For example, the estimated mean annual discharge above the Mogra/Dhanu River junction is about five times the magnitude of the flow measured at Sylhet.

Figure 64 shows a time series of annual maximum, maximum pre-monsoon and minimum water levels at Kaliajuri and Dilapur. One notable feature of the plot is that the lowest annual water level has risen by about 0.6 m on average during the period between 1964 - 1990. Peak pre-monsoon water levels have fluctuated over a 3 m range during the period of record while the range in annual maximums is about 2 m. Since the late 1970's, the peak pre-monsoon level is between 1 - 2.5 m lower than the annual maximum level.

8.2.5 Channel Morphology

The Upper Surma River flows through Surma Floodplain deposits until a point downstream of Chhatak where it enters the haor areas of the Central Basin. The Upper Surma floodplain is cut by distributary channels which connect the main river to the adjacent low lying flood basins. West of Sylhet, the Bahia Gang, Kazanchi Khal and Bhata Khal were at one time major southward flowing distributaries which eventually joined the Kalni/Kushiyara River system. It appears that the entrance to the Bahia Gang and Kazanchi Khal has been blocked so that the flow carried by these channels has been reduced substantially. The flood basin within the Central Basin consists of low-lying areas dissected by minor distributaries, beels and ox-bow lakes which represent former meander bends.

Between Amalshid and Chhatak, the Surma River flows in a single, irregularly meandering sand-bed channel that frequently deflects off bedrock and other inerodible deposits. The channel has an average top width of 172 m and a mean depth of 8.6 m at bankfull stage. The river becomes noticeably wider downstream of Chhatak, with an average top width of 250 m and a mean depth of 10.2 m (Figure 65). During most water level conditions there are no bars exposed and no islands. The river narrows again in the Nawa Reach, downstream of the Old Surma River offtake. This channel has been relatively recently formed and may still be adjusting to the higher flows that have been occurring with the gradual closure of the Old Surma channel. There is no morphologic evidence to indicate that the river is receiving sand from Meghalaya streams such as Jadukata River and Jhalukhali River even though these tributaries are obviously carrying huge sediment loads. It appears most of the sand from the Meghalaya is being deposited on the fan surfaces and in the haor areas north of the river. If significant amounts of sand were added to the Nawa channel, there would be an obvious change in morphology, with the river becoming wider, shallower and having more sand bars and shoals exposed at low water.

The Baulai reach, like the Nawa reach appears to be still adjusting to the westward shift of the main Surma River. The river becomes progressively smaller in this reach, having a top width of 149 m and a mean depth of 7.1 m at bankfull stage. The bed profile also flattens out appreciably and the river contains frequent mid-channel shoals and bars. These bars are mainly found in the straight "cross-overs" or "riffles" that occur between bends. Shoals also occur in split channels where loop cuts have been carried out since the flow is now divided between two channels.

Prior to recent loop cutting, the Baulai River flowed in a single irregularly meandering channel. After completion of loop cuts in the 1980's, the river had a straight, anastomosed channel pattern with flow often splitting around large mid-channel islands. This pattern appears to be unstable and the river is just beginning to adjust to its altered regime. The top of the river banks are typically 3 - 4 m below the level of a typical monsoon flood, so the channel is deeply flooded and not confined by natural levees.

The channel enlarges substantially in the Ghorautra reach and displays a single tortuously meandering sand-bed channel. The river has huge point bars that are exposed at low water. The increase in channel size is not due to the additional flow from the Mogra/Dhanu River, as this contribution is quite minor (Table 8.2). It is more likely that the river is flowing through a paleo-channel, which was formed in the past by much greater flows, either from the Brahmaputra River or the combined Surma/Kalni River.

The bed material in the Surma/Baulai River consists of fine to medium sand, with median sizes ranging from 0.25 mm to 0.085 mm. There is a noticeable decline in the grain size along the river, with the sediments in the Baulai River having a median size of only about 0.1 mm. There are virtually no sediments finer than 0.063 mm in the channel bed, which indicates that finer silt sizes are transported through the channel as "wash load".

8.2.6 Hydraulics

Figures 66 and 67 show seasonal variations in water surface slope on the Surma and Baulai Rivers. Daily variations in slope can be very large, with the slopes tending to be highest on the rising limb of the flood waves and decreasing on the falling limb. During the dry season water surface slopes in some reaches (such as between Chhatak and Sunamganj) are virtually zero or even negative. During the dry season the river is tidally affected as far upstream as Sunamganj with daily tidal fluctuations of up to $\pm$ 0.3 m. These tidal fluctuations may account for some instances of negative slopes on the lower Surma River. Errors in gauge datums and measurement inconsistencies are also likely to be an important factor.

Figure 58 shows a longitudinal profile of the Surma/Baulai River, including the thalweg level, left and right bank levels and the mean annual flood at the available hydrometric stations. Both the water surface profile and the bed profile show a characteristic concave shape, indicating their slope decreases in a downstream direction. For example, the river gradient averages about 0.00005 between Amalshid and Chhatak, 0.000026 between Chhatak and Sunamganj and 0.00001 below Kaliajuri during the monsoon season (Table 8.1). The longitudinal profile also indicates that the top of bank coincides very closely to the mean annual flood level over the reach from Amalshid to the Old Surma River offtake. The corresponding bankfull discharge was estimated to be around 2,100 m^3/s at Sylhet and 3,350 m^3/s near Chhatak.

Downstream of the Old Surma River offtake, the top of bank becomes progressively lower so that by Kaliajuri it is nearly 5 m below the mean annual flood level during the monsoon. In the Baulai Reach, the cross sectional area at bankfull stage averages only 1,058 m^2, which is about 40% of the value in the reach near Chhatak. The bankfull capacity was estimated to be approximately 1,000 m^3/s using uniform flow calculations. This is less than the river's long-term mean discharge. Furthermore, even when water levels are 3 m above bankfull stage, the channel's discharge capacity was still less than 2000 m^3/s which is in the order of one third to one half of the typical monthly discharges in this reach during the monsoon season. These results illustrate that during the monsoon season, the channel conveyance becomes less important than the floodplain conveyance, with the in-channel flows being "drowned out" by the huge inundated lake of the Central Basin. This feature is clearly evident in the satellite photo of the 1988 flood (Figure 2).

8.2.7 Channel Stability

Figures 68 to 73 indicate changes in channel alignment along the river since the early 1950's (based on 1:40,000 scale maps and 1990 SPOT imagery). Additional information on long-term channel changes was made by digitizing the original Rennell's maps from the 1760's. More recent changes were derived from 1983 1:50,0000 scale air photographs. All of this information was used for reconnaissance level interpretation of channel changes (such as loop cuts and avulsions). The resolution of the data is not adequate for detailed assessments of bank erosion rates, since most of these changes are smaller than the precision of the mapping.

The Upper Surma River between Amalshid to the Old Surma River offtake has remained remarkably stable over the last 200 years. Comparisons between banklines in 1952 and 1990 show erosion is occurring slowly along the concave (outer) sides of most free meanders. This erosion is due to progressive downstream migration of the meander pattern.

The Baulai River reach was laterally stable during the period between 1952-1983. The reach appears to have become more active since loop cuts were constructed in the 1980's. For example, much of the channel is now flowing in a split channel and is subject to local channel switching. If the channel pattern remains split, sediment deposition and shoal formation will be promoted, which is the opposite to what was intended by the work. Further monitoring and analysis is being carried out to assess future channel impacts in this reach.

Channel cross sections have been surveyed along the Surma River between Amalshid and the Old Surma River offtake by the Morphology Directorate, BWDB and by BWDB as part of feasibility investigations for the Upper Kushiyara Project (ACE, 1973). This data includes 15 cross sections in the mid-1960's and 30 cross sections in 1970, 1972 and 1974. In addition, 29 cross sections were re-surveyed in this same reach by the SWMC in 1989/1990. The cross sectional area and top width at bankfull stage were computed for each cross section in order to compare channel changes. Tables 8.3 and 8.4 summarize the final results of this comparison. Though considerable local variation may have occurred along the river, the average cross sectional area and top width at bankfull stage have not changed appreciably over the last 25 years. The greatest change occurred in the reach between Sylhet and the Old Surma River offtake where the average cross sectional area has increased by about 12 per cent. This indicates the channel has enlarged slightly by degradation.

An independent check on the river's stability was made by comparing the stage-discharge rating curves that have been established by BWDB at Kanairghat and Sylhet hydrometric stations. Figures C-32 and C-36 (Annex C) shows "specific gauge plots" at the two stations. The graphs show that stage -discharge relations at the two sites have remained very stable over the last 25 years, with water levels lowering slightly over the last 20 years at Kanairghat and rising slightly at Sylhet.

These results indicate the Surma River has been morphologically stable between Amalshid and the Old Surma River offtake during the last 25 years or more. The reach appears to be near equilibrium, with the river behaving as a "transport reach" so that virtually all the incoming sediment load is conveyed through it.

Although recent cross sections have been surveyed along the Baulai River, NERP could not find any older cross sections to provide comparisons. Therefore, BIWTA's historic sounding charts from 1963, 1977, 1983 and 1992 were the only source of information to estimate bed level changes. Figure 74 shows longitudinal profiles of the Baulai River in 1963 and 1992. These plots indicate the Baulai River degraded substantially (up to 5 m) between 1963 and 1983, particularly in the reach between Kaliajuri and the Nawa River. However, since 1983 this trend has reversed with aggradation, or general raising of the river bed occurring in the reach downstream of Kaliajuri and in the Ghorautra River. Figure 75 shows plots of bed level changes, averaged over 1 km intervals. A crude estimate of volumetric change was made using the relation:

$$\Delta V = W * X * \Delta z$$

where X is the reach length, W is the average bed width and z is the bed level.

Aggradation has amounted to roughly 5 million m^3 since 1983 which corresponds to roughly 500,000 m^3 per year. Most aggradation is occurring in relatively deep sections of the river, but in the order of 1 million m^3 has been deposited as low water shoals. Field inspections indicate additional finer sediments are being deposited overbank in the beels and haor areas outside the main channel. However, there is no data available to estimate the rate of siltation in these areas.

The net change for the period between 1963 and 1992 has been overall aggradation in the reach between Kaliajuri and Itna and net degradation in the upper Baulai and Nawa River reaches. The degradation in the 1960's is probably a response to the increased discharges resulting from diversion of flow from the Old Surma River channel. The reason for recent aggradation in the lower reaches and its relation to the loop cutting that has occurred on the Baulai River has not been clearly established at this time. There is a strong need to establish a monitoring program on the Baulai River by conducting cross sectional surveys and morphologic observations. These surveys should be repeated every one or two years in order to provide more reliable information on ongoing morphologic change. The surveys should be designed to investigate impacts of the recent loop cutting and to determine future trends in aggradation on the lower river.

8.2.8 Sediment Transport

Tables 8.5 and 8.6 show hydraulic properties at various flow conditions at Kanairghat and Sylhet. These results were derived from BWDB's observed discharge and water level measurements at the two hydrometric stations. The calculations suggest that the river bed will be inactive during the low flow season between November and April. Using van Rijn's criteria, river dunes will start to develop on the channel bed at flows of 400 m^3/s to 700 m^3/s and will grow in wave length and height during the flood season (Van Rijn, 1986). Bed shear stresses remain relatively low and will not be high enough to wash out the bed forms even at high flood stages.

Table 8.7 lists computed annual bed material loads at the two gauge stations using the Ackers-White sediment transport equation. These loads correspond to sand coarser than about 0.12 mm, moving as bed load and in suspension. In 1988 and 1989 the annual loads were noticeably higher at Kanairghat than at Sylhet, indicating local aggradation would have occurred in the reach during these years. The lower transport capacity at Sylhet is partly due to the reduction in flood flows along the reach caused by overbank spills. For example, in 1989, the peak river flows decreased from 2,570 m^3/s at Kanairghat to only 1,890 m^3/s at Sylhet. It is interesting to note that the total sand load (sediment coarser than 0.06 mm) at Kanairghat estimated from BWDB's suspended sediment samples is around 4 million tonnes/year. This indicates that most of the fine sand fraction on the Upper Surma River can be considered as "wash load".

There is insufficient hydrologic and hydraulic information to assess annual bed material loads along the Baulai River at this time. Additional work will be carried out to assess whether results from the MIKE 11 hydrodynamic model can be used to generate reliable hydraulic information. Based on the present analysis it is clear that the reduction in water surface slope and the deep submergence of the channel during the monsoon will cause a reduction in sediment transport carrying capacity in this reach. As a result, the lower reach of the Baulai River will behave as a sedimentation zone and will experience sediment deposition in the same fashion as a shallow lake delta. It is not clear whether the sediment accumulated during the monsoon period can be flushed out of the channel by pre-monsoon floods which are generally contained within the channel and are characterized by steeper water surface slopes and higher velocities than the monsoon flood. The evidence of recent aggradation in the lower Baulai/Ghorautra River indicates that overall net sediment deposition has been occurring over the last decade.

8.2.9 Summary of Findings

The Surma River flows in a stable "transport reach" between Amalshid and Chhatak. The river has established a stable sand-bed channel that can accommodate a mean annual flood without spilling its banks. There has been some enlargement of the channel over the last 20 years, probably in response to higher discharges that have been experienced recently. The river does not have a particularly high sediment transport capacity and is transporting in the order of 1.2 million tonnes/year of bed material and roughly 4 million tonnes/year of sand.

Downstream of the Old Surma River offtake, the river flows through the Central Basin lowlands and experiences backwater from the Meghna River throughout the monsoon season. As a result, flow spills out of bank and the channel becomes deeply submerged in the vast lake of the flood basin. During these conditions the channel carries only a small fraction (in the order of one third to one half) of the total river discharge and the channel's capacity to transport sediment becomes substantially reduced. Therefore, this lower reach becomes a natural sedimentation zone during the monsoon.

The Nawa and Baulai River reaches have been adjusting to the higher discharges caused by the diversion of flow from the Old Surma River channel. After this shift occurred, the Nawa and Baulai Rivers appear to have degraded and enlarged their channels to accommodate the increased discharges. Since the early 1980's this trend appears to have reversed and channel aggradation has occurred, particularly between Kaliajuri and Itna. The amount of aggradation can only be roughly estimated, but is believed to be in the order of 500,000 m^3/year. The lower end of the river is behaving as an inland delta. Eventually, aggradation will propagate back upstream which could promote future instability and channel switching. However, the time scale for this is probably beyond the period of this planning investigation.

Recent loop cuts have shortened and straightened the lower Baulai River by about 23 km. This has caused the river to develop a more laterally unstable split channel pattern. The loop cuts do not appear to have had much effect in terms of reversing the aggradation on the lower Baulai River.

8.3 Kushiyara/Kalni River System

8.3.1 River Classification

The Kushiyara/Kalni River system has been sub-divided into six sub-reaches which have similar hydraulic and morphologic characteristics. These reaches are as follows:

- Kushiyara River, Amalshid to Fenchuganj
- Kushiyara River, Fenchuganj to Manumukh
- Kushiyara River, Manumukh to start of Suriya River (downstream of Sherpur)
- Suriya River
- Kalni River from Markuli to start of Dhaleswari River
- Dhaleswari River to Meghna River confluence

Figure 57 shows their extent and Table 8.8 summarizes morphologic and hydraulic characteristics.

8.3.2 Evolution of River System

The Rennells survey of 1768 showed the upper Kushiyara River was a minor distributary of the Barak River and was much smaller than the Surma River. Rennells noted the upper Kushiyara River was "navigable only by small boats during the flood season". Furthermore, the map showed the river flowed down Sonai Bardhal channel, meeting its present-day course near Fenchuganj. The Kalni River originated as a southward flowing distributary that connected the Surma River to the Kushiyara system at Markuli. The Surma River flowed into the Kalni/Kushiyara River at Ajmiriganj. The combined flow formed the Dhaleswari River and joined the Brahmaputra River.

1952 maps show the Kushiyara River flowing in its present course between Amalshid and Sherpur. Downstream of Sherpur the river flowed through the Bibyana River channel until Markuli, where it was joined by the Kalni River, a major southward flowing distributary that drained the low flood basin lying between the Surma/Kushiyara Rivers. Downstream of Markuli, the Kushiyara River was referred to as the "Kalni River" even though by that time most flows in this reach were derived from the Upper Kushiyara River. Previously, most flows would have come from the north through the Surma River system. The Old Surma River channel entered the Kalni River near the town of Ajmiriganj. At that time the Old Surma River was still an important branch of the Surma River.

During the 1960's the Kushiyara River shifted northwards out of the Bibyana River channel and developed a new route between Sherpur and Markuli, called the Suriya River. This alignment has remained approximately unchanged over the last 20 years.

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8.3.3 Flood Control Infrastructure

Flood embankments and spill channel closures have been constructed along the Kushiyara/Kalni River system since the 1950's. EPWPDA (1966) provides some documentation on the closure of the Sonai Bardhal channel near Zakiganj:

> "Originally the Langai River joined the Kushiyara near Zakiganj. The Sonai spill channel was an offtake from the Kushiyara just downstream of the Langai. The Indian Government however, has closed the connection of these channels with the Kushiyara and diverted the Langai into the Sonai. The Indian Government has also constructed a flood embankment along the left bank and closed all other spill channels".

This indicates that by 1966 the left bank of the Kushiyara River was embanked continuously along the Indian border downstream of Amalshid (Figure 57). High ridges with homesteads and roads extend along the left side from Sheola to Bairgair Bazar and submersible embankments were constructed from Bairgair Bazar to Bagla. There are no embankments between Bagla and Fenchuganj. High embankments exist along the left bank from Fenchunganj to Manumukh as part of the Manu River Irrigation Project which was constructed in the early 1980's.

The right bank of the river is embanked from Amalshid to Sheola and downstream of Balaganj (opposite Manu Irrigation Project). These structures were originally designed as submersible embankments, but have been gradually raised so that they are rarely overtopped even during the monsoon. Dates of construction of most of this work is sketchy.

Between 1952 and 1963 a major loop cut was made near Sherpur (Figure 84). The shift from the Bibyana Channel to the Suriya Channel occurred immediately downstream of this loop cut during this same period. It is not clear whether the channel shift was planned or occurred naturally in response to the cutoff. Four additional loop cuts were constructed between 1977 and 1983 on the Kalni River, to improve navigation in the reach. The combination of loop cuts and the diversion into the Suriya Channel has shortened the river by about 29 km in the reach between Ajmiriganj and Sherpur (at present, the channel length between these two towns is about 68 km).

There has also been ongoing work to isolate the lower Kushiyara/Kalni River system from the Surma system through closure of connecting distributaries. About 1978, the Kalni River was closed at Markuli and flows were diverted westwards through the small Darain River. Part of this water would have entered the river near Ajmiriganj with the remainder eventually flowing into the Baulai River system. In 1993 a second closure was constructed near Ajmiriganj.

8.3.4 Hydrology

Water levels have been recorded at Sheola, Fenchuganj, Manumukh, and Sherpur on the Kushiyara River and at Markuli, Ajmiriganj, and Madna on the Kalni River. Long-term discharge records available at Sheola, and measurements have been made at Sherpur since 1982.

Section 8.2.3 presented information that the flow split between the Surma and Kushiyara Rivers at Amalshid has remained reasonably stable over the last 20 years at least at medium and high discharges.

Figure 76 shows the pattern of annual maximum daily discharges and maximum pre-monsoon discharges that have been recorded at Sheola. The pre-monsoon time period was defined as the interval between March 1 and May 15. The time series of the annual maximums is very unusual, showing an overall rising trend between 1965 and 1991. There appear to be two sudden jumps in the record, the first occurring around 1967-1968 and the second occurring around 1982. Pre-monsoon peak discharges have not followed this trend and have varied more randomly from year to year. The overall pattern is similar to the time series observed on the Surma River at Kanairghat. There are at least two possible explanations for the trend. First, the pattern could reflect changes in flood inflows from the Barak River in India. Data from the Barak River would be required to confirm this. The second and probably more likely explanation is that past closure of spill channels and construction of embankments on both sides of the Kushiyara River have reduced overbank spills onto the floodplain. Over time, this confinement has resulted in a greater fraction of the total flood flow being carried in the main channel.

Figure 77 shows time series plots of water levels at Sheola, Manumukh/Sherpur, and Markuli over the period 1950 to 1991. The annual maximum water levels at Sheola have risen gradually by about 1 m over the last 40 years. Comparison of Figures 76 and 77 leads to the question of why should there be such wide variations in annual flood discharges but relatively minor variations in flood stage? One explanation is that a large fraction of the total flood inflow is continuing to spill overbank during major floods so that the water level is insensitive to the in-channel discharge. In addition, morphologic changes (such as degradation) may occur in the channel to compensate for the higher peak discharges that are being experienced.

The maximum levels at Manumukh show a sudden rise of 1.0 m - 1.5 m around 1959 and then remarkably constant levels since that time. The date of this sudden shift coincides with the loop cutting and channel re-location work downstream of Sherpur and the shift from the Bibyana River to the Suriya River channel. It appears these actions resulted in a permanent increase in flood levels of at least 1 m on the Kushiyara River. By contrast, the annual maximum levels on the Kalni River at Markuli have decreased over the period 1951 - 1991 by approximately 1 m. This decrease is probably due to the reduction in discharges in the Kalni River caused by the shift in the Surma River towards the Baulai River and the gradual abandonment of the Old Surma River channel.

The pattern of pre-monsoon flooding at Sheola, Manumukh/Sherpur and Markuli is fairly consistent. There have been several periods (1957-58, 1964, 1973, 1977, 1980, 1983 and 1990-91) when the maximum pre-monsoon level has approached the annual maximum level. Maximum pre-monsoon levels have risen by an average of about 2 m at Markuli and by about 1 m at Sherpur since 1965.

Figure 77 shows that minimum water levels have remained more or less constant from year to year at Sheola and Manumukh/Sherpur but have risen progressively by about 1.5 m since the mid-1960's. One explanation for this rise in levels is that channel aggradation has occurred in the lower reach of the river.

Table 8.9 shows estimates of average runoff on the Kushiyara and Kalni River systems. These estimates were made by means of an overall water balance of the region (NERP, 1992). The main tributaries from Tripura include the Juri River which enters near Fenchuganj and the Manu River which enters at Manumukh. Historically, substantial inflows occurred from distributary channels that connected the Surma River system to the Kalni. Very little is known about the magnitude of the inflows and spills through these distributary channels at Markuli and Ajmiriganj. The direction of flow through the channels probably changed seasonally - during the monsoon water flowed from the Surma to the Kushiyara, while in the pre-monsoon, flows probably spilled out of the Kushiyara. Figure 78 shows the water level difference between Sunamganj and Markuli between 1964 and 1990. The plot shows that until 1978, the water level at Sunamganj was always higher than at Markuli, varying from near zero in February and March and between 1.5 - 2.5 m in July and August. After the Kalni closure at Markuli in 1978, the water levels on the Kushiyara River rose by about 1.5 m during the months between January and April. As a result, after 1978 the water levels in the Kushiyara River have remained higher than in the Surma River at Sunamganj during most of the early pre-monsoon season. The increased water levels in March and April may contribute to higher water levels during a pre-monsoon flood, since the river will be running at a higher stage during the onset of the flood event. However, other factors such as increased inflowing discharges and channel aggradation have also contributed to the water level changes in the reach. These issues will be discussed further under the topic "Channel Stability" in Section 8.3.7.

8.3.5 Channel Morphology

Some key information on the morphology of the Kushiyara river is summarized in Annex C.

The Kushiyara River flows mainly through the "Kushiyara/Surma Flood-plain" physiographic unit, except for a short reach between Fenchuganj and Manumukh which is part of the "Sylhet Lowland" (Figure 14). The Upper Kushiyara River flows between natural alluvial levees that are between 3 - 4 m higher than the adjacent low lying flood basin land. The levees are cut by khals or spill channels which used to connect the main channel with Sada Khal, a large drain that flows along the lowest point in the flood basin.

Downstream of Sherpur, the river enters the deeply flooded "Central Basin". This low-lying land is scarred with abandoned channels, ox-bow lakes and beels and is drained by an intricate maze of spill channels and distributaries.

The Kushiyara River flows in a single, irregularly meandering sand-bed channel. There are few exposed point bars and no major islands (Figure 79). Downstream of Markuli, the river sinuosity is reduced and the river flows in long straight reaches because of the recently constructed loop cuts (Figure 80). The Dhaleswari River is a transitional reach that links the Kalni River with the upper Meghna River. In this backwater controlled reach, the river splits around large permanent islands and displays large bars and sand shoals.

The bed material in the Kushiyara and Kalni reaches is typically fine to medium sand (median size between 0.30 and 0.16 mm). Banks are typically stiff clay or silty clay.

The channel has an average top width of 150 m between Amalshid and Fenchuganj, 225 m between Fenchuganj and Manumukh and 240 m between Manumukh and the Suriya Channel (Table 8.8). The average depth at bankfull stage averages between 8 m - 9 m in these reaches. However, deep scour holes have developed along the concave (outer) banks at most meander bends along the river. Surveys by NERP indicated maximum depths typically reached 28 m - 30 m during bankfull conditions at most sharp bends. The soundings indicated the side slopes in some bends are very steep and subject to slumping, which suggests the river has scoured down into cohesive sediments in some locations.

Figure 81 shows a longitudinal profile of the Kushiyara/Kalni River. Figure 82 shows the variation in hydraulic geometry along the river. The channel widens and shoals to an average depth of only 4 m downstream of Markuli. The channel geometry becomes highly irregular downstream of Markuli, with narrow, deep sections occurring in sections near recent loop cuts and wide, shallow sections immediately downstream from the cuts. The channel is virtually flat throughout this reach, with bars and shoals typically reaching to El. 0 m PWD (Figure 87). These shoals obstruct navigation and reduce available navigation drafts to below 4 m at most times of the year.

8.3.6 Hydraulics

Water surface slopes vary seasonally and spatially. During the monsoon season, the slope decreases from upstream to downstream, averaging between 0.00006 near Amalshid, 0.000004 between Fenchuganj and Sherpur, 0.00003 in the Suriya River reach and only 0.000008 downstream of Markuli. However, during the pre-monsoon season, the water surface slope steepens appreciably along the Kalni River downstream of Markuli, reaching 0.00008 during pre-monsoon flood conditions (ten times the slope during the monsoon period).

Bankfull stage coincides closely to a mean annual flood condition between Amalshid and Sherpur (Figure 87). The channel's natural bankfull discharge capacity is around 2,100 m^3/s between Amalshid and Manumukh and 2,600 m^3/s at Sherpur. The river enters the Central Basin lowlands just downstream of Sherpur. Downstream from that point the bankfull level becomes lower and flood level flattens out appreciably so that the channel banks become submerged to a depth of 2 - 3 m during the monsoon season. Based on uniform flow calculations, the actual bankfull discharge capacity downstream of Markuli is approximately 1,400 m^3/s. This value is typical of pre-monsoon flood peaks and is less than half of some recent flood discharges. These calculations also indicate that during the height of the monsoon, when water levels are highest and water slopes are lowest, only about 40 per cent of the total discharge will be carried by the main channel, with most flow conveyed overbank on the floodplain or carried by adjacent spill channels.

8.3.7 Channel Stability

Lateral Stability: The Kushiyara River must have undergone considerable channel widening and enlargement during the last 200 years, since it has transformed from a minor distributary into the main low flow course of the Barak River. However, most of this widening appears to have been completed before 1952 since maps from that time show the river having approximately similar characteristics as to-day.

Figures 83 to 85 show the banklines of the Kushiyara/Kalni River in 1952, 1963 and 1990. These maps show that over most of its length, the Kushiyara River is shifting as a result of progressive meander migration. This shifting is driven by the secondary currents that scour sediment from the concave (outer) sides of the bends and deposit the material on point bars that form on the convex (inner) sides of the meanders. At most bends between Amalshid and Sheola, the maximum rate of bank retreat is expected to be less than 8 m per year. Assuming the bank heights average about 8 m and the length of the eroded concave banks averages about between 1 km per bend, the quantity of sediment eroded from each bend averages about 50,000 m^3 - 100,000 m^3/year (70,000 - 140,000 tonnes/year). Most of this eroded material will be deposited on the adjacent point bar downstream from the eroding bend. By comparison, the total annual

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sand load transported through the reach averages about 4 million tonnes/year. These figures illustrate that recent bank erosion has contributed less than 3 per cent of the river's actual sediment load in the Upper Kushiyara reach.

The major avulsion that occurred between 1952 and 1963 on the Bibyana River reach downstream of Sherpur is an example of the kind of periodic channel switching that occurs as a result of channel aggradation. This type of event occurs relatively infrequently, but produces far greater impacts than the results of the local bank erosion experienced in individual meander bends. The amount of sediment eroded from the 30 km reach below Sherpur during this shift was estimated to be approximately 60 million m^3. This volume of sediment represents about 15 times the annual sand load at Sheola. It would be valuable to obtain better documentation about the shift, particularly about its relation to the channel re-location and loop cutting that took place immediately upstream.

The Kalni River appears to be widening and undergoing considerable channel instability downstream of Ajmiriganj. Most of these changes are related to local channel adjustments following construction of the loop cuts in the reach. However, given the high fraction of the discharge flowing overbank, it is also possible that new channels could develop which would pass water into the Baulai River system.

Vertical Stability: The Morphology Directorate, BWDB surveyed 15 cross sections on the Kushiyara River between Manumukh and Sheola in 1969, 1970 and 1978. SWMC surveyed five cross sections on the Upper Kushiyara River between Amalshid and Sheola and nine cross sections between Sheola and Manumukh in 1990. NERP surveyed four cross sections near Zakiganj and four cross sections near Manumukh in 1992/93. Each of these cross sections was digitized and plotted to a common scale in order to facilitate comparisons between surveys. The bankfull hydraulic geometry was also computed.

Table 8.10 compares the average channel dimensions between Sheola and Fenchuganj in 1969, 1978 and 1990. There has been virtually no change in the average channel cross section between 1969 and 1990 (the channel has enlarged slightly). Figure C-16, Annex C shows a specific gauge plot using observed discharge measurements at Sheola. This plot indicates that at most discharge conditions, there has been a trend of decreasing water levels over time. This suggests either the channel is enlarging or is becoming more hydraulically efficient. The specific gauge analysis confirms the results of the cross section comparisons.

Figure 86 and Table 8.11 compare four cross sections between Fenchuganj and Manumukh that were surveyed in 1969, 1972, 1973, 1978 by BWDB and re-surveyed by NERP in 1993. Although there has been considerable local erosion and deposition within each cross section, the net changes have been small. For example, three cross sections showed net enlargement of the channel between 1969 and 1993, while one cross section showed net aggradation. The 3 m rise in the bed at Section 3 seems to be related to formation of a shoal in the meander bend.

Full flood control embankments were constructed in the early 1980's along the left bank of the river in this reach as part of the Manu Irrigation Project. Several groups have suggested that the Kushiyara River experienced rapid aggradation in the last few years as a result of the Manu Project embankments. These surveys show that aggradation has not occurred in the main channel. However, evidence of recent siltation has been reported in the beels and haors north of the river. This low-lying depression may be infilling with fine sediments as a result of the exceptionally high discharges that have been experienced in recent years (Figure 76). It is unlikely that the Manu Project has had much impact on the siltation rate in this area.

Figure 87 shows bed levels along the Kalni River and Suriya River in 1963 and 1988 between Madna and Sherpur. The profiles were digitized from BIWTA sounding charts. Figure 88 shows 1 km average bed level changes between 1975-1988 and 1963-1988.

The sounding data indicates there has been considerable degradation or lowering of the channel (up to 5 m) along the Suriya River between Sherpur and Markuli. This degradation occurred as a result of the shift from the Bibyana channel into the Suriya channel. The channel responded to this avulsion by first cutting a deep, narrow channel, then gradually widening. Most degradation occurred between 1963 and 1975 when the Suriya channel was still relatively narrow. Most of this widening took place between 1977 and 1988. Degradation has also occurred immediately below Markuli, in the loop cuts that were constructed between 1977-1983. Most of these cuts have remained narrower than the natural channel, which has promoted scour in the constricted channel and deposition immediately downstream in the wider natural channel.

Substantial aggradation or raising of the channel bed has occurred between 1963 and 1988 in the reach downstream of Ajmiriganj. Most of this aggradation has developed since 1975. Figure 88 shows bed levels have risen by up to 5 m near Ajmiriganj. Independent estimates of channel siltation were obtained from residents of Ajmiriganj. Their estimates of channel infilling ranged from 15 - 20 feet (4.5 m - 6 m) over the last 15 to 20 years, which are consistent with the values obtained from the BIWTA sounding charts. Aggradation rates decline downstream from Ajmiriganj and bed levels have remained virtually unchanged over the last 30 years at Madna. Therefore, the aggradation has developed in the form of a 50 km long "wedge" between Ajmiriganj and Madna.

An estimate of the sediment deposition volume was made from the BIWTA soundings. In the order of 25,000,000 m^3 of sediment has been deposited below Ajmiriganj in the period between 1963 and 1988. The rate of deposition between 1963 and 1988 amounts to roughly 1,000,000 m^3/year. Analysis of bed material samples collected from the main channel indicate the sediments are composed mainly of fine sand (median grain size 0.15 mm). During a site inspection by the NERP team it was observed that additional sediment deposition has also occurred outside of the main navigation channel on the floodplain and in adjacent back channels. For example, surveys by NERP indicated 0.1 m - 0.4 m of predominantly silty sediment had been deposited on the floodplain at two sites over a three year period. Additional surveys are being carried out to provide more information on overbank siltation.

It appears at least two factors have contributed to the aggradation below Ajmiriganj:

First, loop cutting and channel re-location near Sherpur and the avulsion from the Bibyana River into the Suriya River have greatly increased sediment inflows to the reach below Markuli by steepening the channel gradient and increasing velocities. The net degradation in the 30 km reach downstream of Sherpur amounted to about 60 million m^3 of sediment. A substantial portion of this sediment is probably composed of silty materials that are either flushed through the river system or deposited over bank. The remaining coarser sand has been transported downstream into the Kalni River. The eroded volume is comparable to the total aggradation that has occurred below Ajmiriganj.

Aggradation on the Kalni River has contributed to the rising water levels at Markuli that have been described previously. Low water and pre-monsoon flood levels at Ajmiriganj and Markuli have been rising steadily since the 1960's so that pre-monsoon flood stages have approached or exceeded the bankfull level in virtually every year since 1980. At Madna, low water levels and pre-monsoon flood levels have not risen over time.

Peak water levels during the monsoon have not been affected by deposition, since the channel is overtopped by at least 2 m and the water surface elevation is governed by backwater from the Meghna River. Other factors, such as changes in the flow regime of the Kushiyara River and the closure of the Kalni River distributary at Markuli have also affected the pattern of discharges and water levels in this reach. Results from hydrodynamic model simulations should eventually improve our understanding of the impacts from these changes.

8.3.8 Sediment Transport Model of Kushiyara/Kalni River

Sediment routing computations were made to develop a conceptual model of aggradation and degradation along the river. This involved computing annual bed material transport rates at Sheola, Sherpur, Ajmiriganj and Madna using the Ackers-White sediment transport equation. Hydraulic information at Sheola and Sherpur were based on actual discharge measurements made by BWDB at the hydrometric stations. Hydraulic parameters from these stations are summarized in Tables 8.12 and 8.13. Hydraulic data at Ajmiriganj and Madna were derived from standard step backwater computations using the US Army Corps of Engineers HEC-2 computer program. The sediment transport computations were repeated for several years and then used to develop an overall sediment budget for each river reach:

$$\frac{\Delta M}{\Delta t} = G_i - G_{out}$$

where "M" is the mass of sediment stored in the reach, "t" is the time interval and G_i is the sediment inflow to the reach and G_{out} is the sediment outflow. The computations were carried out on a daily, monthly and annual basis. Table 8.14 summarizes the annual bed material loads and Table 8.15 shows the corresponding net aggradation/degradation within each reach. It should be stressed that sediment transport rates can only be estimated very approximately and that the estimates are very sensitive to some of the input parameters such as bed material size and mean velocity. Actual loads might fall within two times to one half of the estimated values. However, since a consistent set of procedures was adopted, the relative variation in load along the river is probably represented fairly well.

The results indicate the sediment inflows are less than the outflows between Sheola and Sherpur, which suggests that the reach will degrade in some years. It should be noted that the cross section comparison and specific gauge records at Sheola provided some historic evidence of degradation in this reach. However, additional sediment is being supplied from the Manu River, which may compensate for this apparent sediment deficit. Additional computations will be made to verify this.

The sediment budget indicates net aggradation in the two reaches between Sherpur and Madna, since the annual sediment inflows exceeded the outflows in all four years. The total aggradation ranged between 1.2 million and 4.8 million tonnes/year, which corresponds to 0.9 million to 3.4 million m^3/year. These values are comparable to the historical sedimentation rates that were estimated from BIWTA's sounding surveys.

Figure 89 illustrates the daily variation in discharge, stage water surface slope and sediment transport rate at Sherpur and Ajmiriganj during a single year. The plots show that the pattern of sediment movement is very different at the two locations. At Sherpur, the sediment transport rate increases with discharge during the monsoon season between June and August. However, at Ajmiriganj, the water surface slope rises steeply in the pre-monsoon season and then drops to near zero during the monsoon as the backwater from the Meghna River drowns out the channel cross section. As a result, the sediment transport rates in the Kalni River rise very steeply during the pre-monsoon flood and fall to near zero during the peak of the monsoon. Therefore, sediment is flushed out of the reach during pre-monsoon floods when the slope is highest and channel velocities are highest. Sediment is deposited in the reach during the monsoon when velocities and slopes are still high at Sherpur but low near Ajmiriganj. This means that the overall sedimentation pattern in the Kalni River is very sensitive to the runoff conditions during the pre-monsoon period. If pre-monsoon flows are reduced in the Kalni River, then sedimentation rates will accelerate. If pre-monsoon flows are increased while monsoon flows remain the same, the river will flush out more of the sediment into the Meghna River.

9. IMPACTS OF SEDIMENTATION ON RIVER DEVELOPMENT

9.1 Purpose

This chapter attempts to draw together some of the findings from the various detailed investigations described previously. These findings are used to summarize the main kinds of impacts that have developed from FCD works in the Region. Additional analysis was carried out to generalize and extend these findings. This included conducting various test calculations using the HEC-6 mobile bed math model to predict morphologic impacts from the developments. This model, developed by the Hydrological Engineering Centre (HEC, 1977) was selected because of its general success over a wide range of applications. The program is designed to analyze scour and deposition by modelling the interaction between the water-sediment mixture, bed material sediments and the hydraulics of the flow. The main limitations of the program are that it applies to one dimensional, steady flow. No provision is provided for simulating meander migration.

The types of projects that are considered include:

- full flood control embankments;
- changes in discharge regime due to channel closures or other natural causes
- submersible embankments
- loop cutting and channel re-locations.

9.2 Impacts of Full Flood Control Embankments

9.2.1 General Considerations

River discharges are generally confined to the main channel until flows approach or exceed "bankfull" conditions. In most naturally formed river systems, the bankfull discharge usually corresponds to a relatively frequently occurring annual flood, typically with a return period of between 1.5 and 5 years. Most of the rivers in the NE Region follow this pattern, and the mean annual flood (2.3 year return period) is usually very close to bankfull conditions. However, in the deeply flooded Central Basin, which is affected by backwater from the Meghna River, bankfull conditions are usually exceeded by over 1 m at a mean annual flood discharge during the monsoon season.

Once bankfull conditions are approached or exceeded, water and sediment will spill onto the floodplain by several mechanisms, including direct overtopping of banks, through breaching of banks, or as spills through distributaries or *khals* that connect the main channel with the lower-lying flood basins. A portion of the fine sediment load will be deposited overbank in flood basins where velocities are low, while some of the sand load is deposited as natural levees or crevasse splays near the main channel.

Floodplains are important hydrologically because they provide overbank conveyance and storage which can reduce peak flows and attenuate flood hydrographs. The magnitude of these floodplain flows can be substantial. Discharge measurements were made in the Kushiyara floodplain in

1993 at three locations where the floodplain discharges are reasonably confined; at Sheola, Fenchuganj, and Sherpur (Figure 5). These measurements demonstrate that the floodplain discharge in a major flood can be as large as that in the main river channel (at Fenchuganj), or, stated another way, that the floodplain can carry as much as one-half of the total discharge. Floodplain flows in the Central Basin are more difficult to measure, but hydrodynamic model results indicate that as much as three-quarters of the total flow is carried on the floodplain during the monsoon season.

Cutting off floodplain spills by means of embankments and *khal* closures will increase main channel discharges due both to direct flow confinement and to reduction of floodplain storage. Examples of such project impacts can be provided from several past developments in the region.

For example, full embankments and *khal* closures have been constructed along the Kushiyara and the Surma left bank since the 1960's. One effect has been to reduce floodplain discharge. This change was observed on the Kushiyara River in the 1970's when discharges were measured at both Sheola (the main channel) and at Sada Khal, a major spill route in the Surma-Kushiyara Inter-basin (Figure 57). Embankments and khal closures resulted in decreased floodplain discharges and corresponding increases in flood discharges on the Kushiyara River (Figure 76). Impacts on water levels were described previously (Section 8.2). Peak water levels at Sheola have risen by approximately 0.5 m, mostly before 1978 around the time when embankment works were being constructed along the river.

Other examples of embankment impacts were documented in Chapter 7 for the Manu River Project and the Khowai River Project near Habiganj. In both cases, confinement of spills and over bank discharges has substantially increased flood magnitudes further downstream.

Once embankments are in place, the river's channel geometry, longitudinal profile, and morphology will respond to the changed hydrologic regime. Two main types of river response have been considered, (1) lateral channel adjustments (width changes and channel pattern) (2) channel changes, including changes to the main channel and the berms.

9.2.2 Planform Changes

When full flood control embankments increase the peak discharges in the confined reach, the "dominant discharge" is effectively raised. Consequently, if the banks are not protected, the channel will tend to widen over time as a result of bank erosion. The magnitude of this impact can be estimated approximately by using simple empirical regime equations. Observations on many rivers throughout the world show the average top width (W) of an alluvial channel is related to the dominant discharge, Q, by:

$$W \propto Q^{1/2}$$

Table 9.1 shows the expected change in width after the channel forming discharges are increased. The case studies presented in Chapters 6 through 8 generally found most rivers enlarged their section after embankments were constructed. Observed changes in channel widths along the Upper Surma, Upper Kushiyara, Manu, and Khowai Rivers generally agree with estimates derived from simple regime-type equations. This enlargement may partially offset the confinement effects from the embankments, particularly at moderate flow conditions. This would explain the general finding that virtually all stage-discharge rating curves at hydrometric stations in the Region have been lowering over the last 20 years. This feature can be verified by reviewing the specific gauge plots in Annex C.

Other long-term responses due to confinement effects can be considerably more complex, particularly when local geomorphic controls are present. It is usually considered that the meander wave length is proportional to the channel top width. Therefore, any increase in channel width should be accompanied by a similar change in meander properties. Furthermore, it would be expected that the rate of meander migration and bank erosion should also increase if the main channel discharges are increased. However, these effects could not be detected on any of the rivers in the Region. Under extreme conditions, increases in flood discharge and sediment inflow can cause a change in channel type, not just size: for example, a previously meandering channel can change into a predominantly split or braided one. A transformation of this kind produces major changes to channel geometry, channel migration pattern, and sedimentation patterns. So far, transformations of this nature have not yet occurred in the Region.

9.2.3 Vertical Channel Changes

Main Channel

Figure 90 illustrates an idealized case of river responses following construction of embankments along a uniform river reach. The example is for a piedmont river having a top width of 67 m and a channel slope of 0.0003 and actually represents a schematized version of the upper Khowai River. At the test discharge condition of 737 m^3/s (roughly a 10 year flood), approximately 25 per cent of the total flow was carried by the floodplain in the pre-project condition. Initial hydraulic changes include:

- Increased main channel velocities and depths during large floods. Water surface slopes increased through the embanked reach, producing an afflux, with the greatest water level rise occurring at the embankments' upstream end;

- An "M-1" type backwater profile upstream of the embankments due to higher water levels in the embanked reach. Levels gradually converged to pre-project levels upstream of the embankment;

- Increased sediment loads during high floods through the embanked reach due to higher velocities, depths, and slopes. The implications of this for river erosion can be considerable, since sediment transport in fine sand-bed channels is quite sensitive to small changes in velocity or stream power. As a result, the channel will tend to degrade through the embanked reach, since its transport capacity will exceed the sediment supply from upstream.

At the start of the simulation, the computed sediment loads were about double the incoming load to the reach. As a result, the bed degraded through the embanked reach during successive time steps. Local aggradation occurred near the upstream end of the embankment in the region of the M-1 backwater profile. During successive time steps the afflux began to decrease slightly due to degradation in the embanked reach. Eventually, as the sediment transport rates decreased in the embanked reach, a new equilibrium was established and the bed profile stabilized. No net change occurred in the reach downstream of the embankments. Therefore, the main impact from the project was degradation in the embanked reach and local aggradation immediately upstream until a final equilibrium profile was achieved.

208

These trends are consistent with the channel changes that were observed on several of the rivers that were embanked or affected by spill channel closures in the Region. These changes included:

- Upper Surma River - minor channel degradation
- Upper Kushiyara River - minor channel degradation
- Manu River below barrage - minor change, slight degradation
- Khowai River, Shaistaganj to Chunarghat degradation, aggradation upstream of embankments.

Several rivers undergo a decrease in water surface slope when they flow on to the Central Basin lowlands. Alluvial fans are an example of streams that show this rapid decline in gradient. The lower reaches of piedmont streams such as the Khowai River, Chillikhali and Bhogai River also display this feature. Figure 91 illustrates predicted channel impacts when embankments are constructed upstream of these transitional reaches. This simulation was intended to provide an idealized representation of the lower Khowai River and the effect of backwater from the Kalni/Meghna River. Other conditions for the test calculations were similar to the case described previously.

The main difference between this result and the earlier example is that substantial aggradation was predicted in the backwater zone downstream from the embankments. This is because sediment was flushed out of the embanked reach and deposited immediately downstream in the deeply flooded low velocity reach. Increased bed levels in the lower reach eventually caused water levels to rise near the downstream end of the embankments. This induced aggradation which gradually propagated further upstream over time. As a result, water levels gradually rose further upstream in the embanked reach.

Other processes that were not considered in this simplified model will substantially modify this idealized deposition pattern. For example, once bed levels start to rise downstream of the embankments, the sediment will spill over the floodplain and will be spread over a wide area. Consequently, the overall rate of aggradation may be relatively low. This type of process has been observed on the lower Khowai River and the Chillikhali River at the lower end of its embankments.

The Berms
The preceding comments describe the response of the river bed in the main channel. Additional changes may occur to the berms, the overbank section of the river between the embankment and the top of the channel bank. It is commonly perceived that berms aggrade rapidly after embankments are constructed. However, it is difficult to verify this claim with the available historic survey data. The most reliable information is from the Khowai River, where the berms were found to have aggraded by 1 - 2 m over a ten year period in the reach between Shaistaganj and Habiganj. As shown in Section 7.2, this aggradation has contributed to the confinement of flood flows and increased flood levels in the embanked reach. It should be noted that conventional one dimensional morphologic models can not simulate overbank sedimentation separately from the degradation/aggradation in the main channel. This reduces the overall usefulness of the model for assessing morphologic impacts from actual project developments.

9.2.4 Embankments on Alluvial Fans

A special class of embankment problems concerns attempts to confine streams carrying high sediment loads on alluvial fans. To-date, there are no existing projects of this type, although proposals have been made to confine the Someswari River between full flood control embankments. The following comments describe the kinds of sediment impacts that could be expected from such an attempt:

- increased channel instability, bank erosion and development of a wider channel. The embankments may be subjected to high velocity spills and erosion.

- initially, channel incision will occur along most of the channel. The embankments will shift sediment deposition further downstream on the fan, near the lower end of the embanked reach. Due to the rapid decrease in slope, it will not be possible to flush the coarse sand through the system. Channel aggradation would progress as a wedge both upstream and downstream leading to channel shifting and flow impingement against the unprotected embankments.

- downstream sedimentation. Finer sands would be flushed through the embanked reach and would be deposited near the confluence with the flatter, lowland rivers. Under natural conditions most of this sediment is deposited on the fan surface and does not reach the main river systems. Potential impacts would include obstruction to navigation, drainage congestion during post-monsoon conditions and channel aggradation in the main rivers.

These processes will make it extremely difficult to confine the Meghalaya fans within narrow embankments. Extensive, ongoing channel maintenance requirements, including sediment removal would probably be required to make this type of project sustainable.

9.3 Submersible (Partial Flood Control) Embankments

9.3.1 Hydraulic Effects

Submersible embankments reduce floodplain discharges and increase in-channel discharges during the pre-monsoon season. They tend to concentrate floodplain discharges and overbank spills into fewer locations and more specific spill points, often at locations where embankments are eroded and channel erosion/deposition problems are occurring. Further, while water level and discharge effects may be negligible for individual submersible embankment projects, several such projects occurring together within a drainage system can produce significant cumulative effects on water levels and flows.

In the past in the Northeast Region, this potential for cumulative impacts was not appreciated and numerous submersible embankment projects were built throughout the Central Basin without planning for systemic drainage and other requirements. As it has turned out, their potential for cumulative impact has not been fully realized as a result of frequent embankment breeches, wave damage, public cuts, and incomplete structures and embankments. It is expected that if these projects became fully operational (as could happen if in the future they were rehabilitated), they would have significant impacts on pre-monsoon and in some cases monsoon water levels and flows.

The assumption that monsoon conditions are less affected by submersible embankments than by full flood embankments holds good where monsoon water levels are distinctly higher than pre-monsoon water levels. For example, the difference between a 1:10 year pre-monsoon flood and an average monsoon flood varies between one to three metres in the region. In locations with only one metre difference, submersible embankments having normal freeboard allowances will begin to encroach on the lower-magnitude monsoon flood flows. In these cases, the kinds of impacts associated with full flood control embankments will begin to be experienced.

9.3.2 Effects on the Channels

Outside the Central Basin, morphologic impacts from submersible embankments are expected to be minor in comparison to full flood control embankments since the structures are designed to be overtopped during the period of highest flows. Berm deposition could be accentuated since the submersible embankments will tend to trap fine sediments carried overbank during the monsoon season.

Impacts on rivers flowing through the deeply flooded Central Basin may be more appreciable. In this area, channel velocities and water surface slopes are highest during the pre-monsoon season (April and early May). Later, during the monsoon season, backwater from the Meghna River drowns the rivers and reduces their slopes, channel velocities, and sediment transport capacity. Thus, confinement effects during the morphologically active pre-monsoon period could conceivably induce channel responses similar to those described above for full flood embankments i.e. initial degradation and channel enlargement in the embanked reach.

9.3.3 Effects Inside Embanked Areas

Submersible embankments are often constructed around low-lying *haors* to enclose areas subject to pre-monsoon flooding (for example, Shanir Haor shown in Figures 19 and 42). These embanked enclosures are sometimes referred to as "polders". Questions have arisen on the effect of the embankments on sediment deposition inside the enclosed areas. For example, many residents have complained that haors have been silting-in rapidly in recent years and that this is related to construction of embankments. Some of the effects of these structures during various seasons are described below:

Pre-monsoon season: Sediment loads transported during this season average 8% of the annual load on many rivers in the Region (Chapter 5). However, this fraction reached up to 40 % on some Tripura streams during flash floods. The fraction carried during the pre-monsoon season on Meghalaya streams is apt to be lower, since huge runoff volumes are generated in the monsoon season. Flash floods and sediment inflows to the haor areas will be eliminated, if the project operates satisfactorily. If the embankments breach, then sediment laden spills will enter the haor area and be deposited over a wide area, with coarse sand materials deposited near the inlet and the silt load deposited over the flood basins. Therefore, the embankments should either reduce sedimentation (when the project works) or have little or no impact (when it doesn't work).

Monsoon season: Sediment loads during the monsoon typically average 80 % of the annual load on most rivers in the Region. At this time, the embankments could be overtopped by 1 m or more for several weeks duration. Flood depths inside and outside the haor could typically be 3 m - 5 m. The embankments may still provide a significant obstruction to river flows and may therefore, reduce direct sediment inflows. For example, it is unlikely that any of the sand load could be carried into the haors, unless the embankments are breached. However, embankments would also reduce the mixing and exchange of water between the haor and the river system. Therefore, the sediment that does enter the haor will have a greater tenancy to settle out. The overall net effect is likely to depend on a number of site specific factors including the height of the embankments, water levels and flow velocities in the adjacent river channels, etc.

Post-monsoon season: Sediment loads during the post-monsoon season typically account for around 10-12 % of the annual load. During this time, regulators in the project embankments will be draining water from the haors back into the external rivers. Virtually all of the sediment that entered the haors during the monsoon will have settled out. Therefore, during this period, the projects should have virtually no impact on sedimentation rates inside the haors.

None of the haors in the Region has been monitored systematically to assess historical rates of infilling before and after embankment construction. Even if such data were available, it would be difficult to interpret, since other factors such as changing runoff and sediment inflow quantities could affect the rate of deposition. This problem is especially critical since it is known that flood flows have changed significantly in recent years. Therefore, another approach was adopted. This involved comparing sedimentation rates in adjacent haors, one with a long history of embankments, the other only recently embanked. This approach, which is analogous to a "paired basin study" was thought to provide a relatively simple means for assessing the effect of embankments on siltation rates inside haor areas.

The two adjacent sites were Shanir Haor, located south of the Jadukata alluvial fan and Angaruli Haor, immediately to the east, situated between Jadukata River and Jhalukhali River (Figure 42). Landforms in this area are shown in Figures 16, 19 and 42. Maps of the haors are shown in Figures 94-95.

Embankments at Shanir Haor date back to the 1920's when 19 km of submersible embankments were constructed. In 1976, BWDB took over the project and between 1976/77 and 1979/80 additional embankments were constructed. Angaruli Haor project was completed between 1982 and 1987. Recurring breaches at Michikhali and Gondamara have occurred each year since the project's construction (Figure 94). Therefore, it is expected that impacts on sedimentation rates should be more pronounced on Shanir Haor than on Angurali Haor.

Topographic changes in the haors were assessed by comparing ground levels surveyed in 1964 (published in the form of 1:15,840 scale mapping) and ground levels surveyed by NERP in 1993. It was felt that the 30 year time interval between surveys would be sufficient to resolve overall sedimentation patterns. The NERP surveys were made when the haors were submerged, using a portable depth sounder and GPS survey system. Sounding lines were surveyed back and forth across the haors until sufficient data was collected to adequately represent the topography. The surveys were all conducted during a single week long field trip.

Figure 96 shows apparent ground level changes on a survey line through Shanir Haor. It was found that deposition has occurred in both haors. In Shanir Haor, the thickness of the deposits typically varied between 0 - 1.5 m. It was found that most sedimentation occurred near the north eastern corner of the project, closest to the junction of the Jadukata River. Sedimentation was virtually zero in the lower south west corner of the project, which is located further away from active sediment inflows. The average depth of sedimentation over the 7761 ha project area was 0.55 m. The volume of deposition inside the project was estimated to average 1.45 million m^3/year. This corresponds to an average sedimentation rate of 18 mm/year over the last 30 years.

Deposition in Angaruli Haor typically ranged between 0.5 m and 2 m. The overall average depth of deposition over the 2592 ha area was 0.72 m. Although this comparison, is not definitive, it provides evidence that overall sedimentation rates were lower in Shanir haor, which had the longest history of embankments and flood control works. However, the difference between the two values is not very large, indicating that the overall impact from the embankments has probably been quite small. The overall effect of constructing these polders appears to be a slight reduction in the rate of sedimentation in the haors.

This finding does not explain why so many people have perceived that the rate of sediment infilling in many haors has increased in recent years. One explanation is simply that the annual sediment loads have increased appreciably over the last 20 years, in response to the high sequence of flood flows that have been experienced over the last decade. If sediment inflows have increased substantially in response to increased flooding frequency and magnitude, then it is reasonable to assume that the rate of siltation in the haors and floodbasins should also increase. This effect was demonstrated for the case of the Manu River (Section 7.1) by estimating the sediment load transported each year during the time when bankfull flow conditions were exceeded. It was found that the total sediment load during this flow condition was 20 times greater in the period 1983-1991 than in the period 1973-1982. A review of estimated annual sediment loads on other rivers such as the Kushiyara River at Sheola and Surma River at Sylhet showed that the annual suspended sediment loads have been much higher since the mid-1980's (Table 9.2). For example, the annual sediment load on the Kushiyara River at Sheola and Surma River at Sylhet were 70 % and 50 % higher in the period 1983-1991 than in the period 1974-1982. Since these loads were estimated with a single rating curve, the increase in the loads must be due to the increased occurrence of higher flows. Consequently, this implies that the incidence of unusually high flood flows over the last decade could contribute to the increasing rate of siltation in these haor areas. More detailed field studies in these haors, using geological methods such as Cesium dating and sediment coring could probably provide more definitive answers to this question.

9.4 Impacts of Loop Cuts

Loop cuts are commonly used to improve navigation conditions on rivers by eliminating bends and producing a straighter channel alignment. For example, about 26 km of loop cuts have been made on the Baulai River. Loop cuts have also been made on rivers such as the Khowai to reduce the length of embankment that was required.

Loop cuts reduce the effective length of the river, particularly during low-to-medium flows, thereby increasing river slopes and lowering upstream water levels. Hydrologic impacts of individual loop cuts depend on the initial river slope and the channel length reduction relative to original channel length. Impacts tend to be relatively small in the Northeast Region where river slopes are relatively low.

Impacts of loop cuts are reduced during high flood stages when a large portion of the flow passes onto the floodplain and is therefore not affected by the channel changes. These changes become more significant when the loop cuts are combined with adjacent embankments which modify the overbank flows.

The main morphologic impacts from loop cuts arise from the change in slope through the shortened reach. These impacts are illustrated in Figure 92, which shows a simplified model of channel changes from a series of loop cuts on a piedmont river. In the artificially straightened reach, the slope will be increased, water levels will be lowered and the water surface will develop an M-2 type drawdown profile. As a result, the velocity and sediment transport capacity will increase through the straightened reach. This will initiate channel degradation, leading to further reductions in water levels. This secondary degradation will initiate further slope adjustments upstream, leading to a transient degradation wave progressing along the river.

If the natural channel slope flattens out downstream of the straightened reach, there can be appreciable aggradation immediately downstream of the loop cut (Figure 93). This aggradation occurs because the lower reach's sediment transport capacity will be substantially less than the transport rate in the straightened reach.

Loop cut impacts can be very unpredictable. If the excavated pilot channel runs near inerodible plugs or through highly variable bed and bank materials, the pilot cut will not enlarge uniformly and a channel of highly irregular width and depth may develop. If the bed and banks contain cohesive materials, the channel will not enlarge to a full cross-section, which will produce a local high-velocity constriction. Consequently, water levels may be raised, rather than lowered as intended. This situation has occurred at loop cuts on the Kalni River (documented in Section 8.3.7) and on the lower Khowai River (documented in Section 7.3.5).

Loop cuts may also impact lateral channel processes by modifying the channel pattern and sinuosity and by initiating new bank erosion.

10. CONCLUSIONS

10.1 Nature of Sediment Problems and Issues

1. Areas that are at a high risk from channel instability, erosion and sedimentation are localized to a small percentage of the Region (mainly the fan areas, some piedmont streams and parts of the lower Kushiyara/Kalni River and Baulai River flowing through the Central Basin). Most of the Region, particularly the floodplains of the Surma, Kushiyara, Kangsha, Meghna and Old Brahmaputra River is morphologically stable.

2. Most of the sediment supplied to the region is generated outside of Bangladesh in the Meghalaya Foothills, Tripura Hills or Barak basin in India. There is no chance to control sediment problems at their source or to even monitor changes that are occurring there. For example, a major avulsion on Someswari River was reportedly triggered after landsliding in the headwaters of the basin.

3. People live in very close proximity to the active river channels and are exposed to high risks from even minor erosion or channel changes. This situation produces the perception that most rivers are highly unstable and are eroding vast areas of land. However, bank migration rates are actually low in comparison to other regions and the erosion is usually the result of progressive meander migration. Often, hazards to erosion are high, not because the rivers are extremely active, but because of the nature of the settlement patterns. Furthermore, it is difficult to alter these conditions, for example, by providing embankment set-backs to allow for future anticipated river erosion. This is because if substantial set-back distances are provided, people will occupy the land between the river and embankments and will cut the embankments during high floods to reduce water levels.

4. The rivers in the Region exhibit several characteristic styles of channel instability and bank erosion. For example, the alluvial fans are characterized by slowly developing avulsions which cause one channel to be abandoned and new channels to be developed. As sand deposition continues to occur, the new channel begins to aggrade and eventually a new route across the fan will be developed. Rivers crossing the Central Basin lowlands (such as the Baulai and Kalni) have an "anastomosing" channel pattern, with frequent channel splits and branching distributary channels. On these rivers, the characteristic mode of instability involves sudden, abrupt shifts with the river re-occupying former channels and khals and breaching banks.

5. Impacts from past channel changes and past developments can carry on for a long time and can extend over great distances. For example, problems that have been experienced in recent years on the Kalni River originated from actions that occurred during the 1960's. Impacts from an avulsion on the Someswari River have propagated over a distance of 100 km and affected flow and sedimentation patterns in two other major river systems - the lower Kangsha River and Baulai River system. Planning remedial measures and future developments requires looking at the overall situation in the Region, rather than studying a number of related problems in isolation.

226

10.2 Impacts from FCD Projects

1. Construction of full flood control embankments and khal channel closures on rivers such as the Upper Kushiyara River, Khowai River and Manu River have reduced spills and overbank flows onto the floodplain. This has contributed to the marked increase in the magnitude and frequency of flood discharges on reaches downstream from these works. The main morphologic impacts have occurred at the downstream end of these projects and include greater frequency of overbank flows and breaches, and greater spills of suspended sediment onto floodplain areas and berms. In the embanked reaches, the channel has normally responded by widening and enlarging its channel.

2. Loop cuts and channel re-locations have been carried out on many rivers to improve navigation and for flood control purposes. Usually only very small pilot excavations are made and the river is allowed to develop a full cross section by erosion and scouring. In some cases, high magnitude floods have occurred shortly after the project was completed and before the section had enlarged. This has constricted the flows and resulted in increased flood levels upstream from the work, which has produced the opposite effect than was intended.

10.3 Future Threats

1. Land-use changes in the Indian catchments, climatic changes or other singular events (such as an earthquake) could lead to greater sediment supply to the region in the future. This would produce greater channel instability on the Meghalaya fans and on the piedmont streams. Increasing sediment yields from the Tripura Hills is probably already occurring, although its downstream effects have not been clearly established at this time.

2. Attempts to channelize the steeper piedmont rivers and alluvial fans which carry high sediment loads could produce substantial downstream impacts. For example, channelizing these streams would flush sediment that was normally deposited onto the fans or piedmont floodplains into the mainstem rivers which would lead to rapid channel aggradation.

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ANNEX A

TABLES

Table 1.1: Major Rivers in the Region

River	Length (km)
Meghna	110
Kushiyara / Kalni	235
Surma / Baulai	385
Dhaleswari	37
Juri	62
Manu	80
Dhalai	59
Lungla / Ratna	116
Karangi	49
Khowai / Barak	87
Sutang	77
Lubha	11
Sari-Gowain	83
Daukai	11
Piyain	51
Dhalai gang	15
Active Chela	11
Jhalukhali	12
Jadukata / Baulai	63
Patnai gang	34
Lengura	43
Someswari	82
Mogra / Dhanu	170
Chillikhali	22
Malijhee	47
Nitai	36
Shibganj Dhala / Upper Someswari	23
Bhogai / Kangsha	227
Total Length of Channels	2239

Table 1.2: Inventory of Reported Sediment Problems at Major FCID Projects

Project	Proj. Type	Land Unit	Sediment Problem 1	2	3	4	5	6	Cause of Problem
Angurali Haor	PFC	Fan/Meghalaya Basin		X		X	X		Avulsion on Jadukata R.
Kalner Haor	PFC	Fan/Meghalaya Basin		X		X			Avulsion from Jhalukhali R.
Karchar Haor	PFC	Fan/Meghalaya Basin		X	X	X	X		Shifting on Jhalukhali R. fan
Shanir Haor	PFC	Fan/Meghalaya Basin	X	X	X	X		X	Sedimentation on Jadukata fan
Matian Haor	PFC	Fan/Meghalaya Basin	X			X	X		Shifting on Jhalukhali R. fan
Joal Bhanga Haor	PFC	Fan/Meghalaya Basin					X	X	Shifting on Jadukata R. fan
Mohalia Haor	PFC	Fan/Meghalaya Basin				X			Shifting on Jadukata R. fan
Halir Haor	PFC	Fan/Meghalaya Basin					X		Shifting on Jadukata R. fan
Chillikhali R.	FC	Piedmont	X	X			X	X	Embankments in deposition zone
Khowai R.	FC	Piedmont	X			X			Deposition in Kalni/Meghna backwater
Pagner Haor	PFC	Central Basin		X		X			Spills from Baulai R.
Baram Haor	PFC	Central Basin	X		X		X		Regime changes on Kalni R.
Bhanda Beel	PFC	Central Basin	X		X		X		Regime changes on Kalni R.
Chandra Sonathal	PFC	Central Basin			X			X	Avulsion on Someswari R.
Chaptir Haor	PFC	Central Basin	X				X		Regime changes on Kalni R.
Damrir Haor	D	Central Basin			X			X	Spill from Kushiyara R.
Dhankunia Khal	PFC	Central Basin			X			X	Avulsion on Someswari R.
Gurmar Haor	PFC	Central Basin			X				Avulsion on Someswari R.
Haijda Embankment	PFC	Central Basin			X				Avulsion on Someswari R.

PFC: Partial Flood Control
FC: Full Flood Control
D: Drainage Improvement

Sediment Problem Legend:
1: Aggradation in embanked channels causing increased flood levels
2: Overbank sand deposition on agricultural land, fish habitat & wetlands
3: Local siltation causing drainage congestion
4: Channel avulsion and shifting; erosion and embankment breaching
5: Region-wide impacts to water levels and flow patterns
6: Siltation causing navigation obstruction

Table 2.1: Daily Water Level Measurements

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																											
				DEG	MIN	DEG	MIN				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
3	T	Anderson khal	Brahamabaria R.R. bridge	23	57.0000	91	7.0000		1957	1981	H	H	H	H	H	H	H	H	H	H	H																	
3A	TQ	Anderson khal	Brahamabaria	23	57.3845	91	7.3746	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	
6	Q	Bahia	Surma Offtake	24	54.0000	91	49.0000		1959		H	H	H	H	H	H	H	H	H	H	H	H	H															
9.5	T	Banar-Lakhya	Trimohini	24	15.5000	90	33.5000		1962		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H				C	C	C	C	C	C	C
33	Q	Bhatakhal	Gobindaganga	24	56.2000	91	41.5000		1958		H	H	H	H	H	H	H		H	H	H	H	H	H	H	H	H	H										
34	Q	Bhogai-kangsha	Nakuagaon	25	11.3807	90	13.1257	GPS	1957		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
35		Bhogai-kangsha	Nalitabari	25	5.0569	90	11.9557	GPS	1957		H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
35.5	Q	Bhogai-kangsha	Sarchapur	24	59.7503	90	21.6908	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
36	Q	Bhogai-kangsha	Jaria Jhanjail	25	0.5591	90	39.3106	GPS	1949		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
36.1	Q	Bhogai-kangsha	Mohanganj	24	52.3357	90	58.5817	GPS	1963		H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C
45.5		Brahmaputra	Chilmari	25	32.5000	89	43.5000		1957			C	C	C	C	C	C	C	C	C	C	C	C	C	H	C	H	C	C	C	C	C	C	C	C	C	C	C
46		Brahmaputra	Kamarjani	25	23.2000	89	38.6000		1957		C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C
46.7 L		Brahmaputra	Kholabarichar	25	13.8000	89	42.0000		1963		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
46.9 L	Q	Brahmaputra	Bahadurabad	25	8.5000	89	41.0000		1963		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
53	Q	Chilla Khali	Bathkuchi	25	11.6235	90	10.7062	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
67	Q	Dhalai	Kamalganj	24	21.3579	91	51.0793	GPS	1957		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C
71	T	Dhaleswari	Kalagachia	23	34.7684	90	32.5516	GPS	1945			H	H	H	H	H	H	H	H	H	H	H	H	C	C		C			C	C	C	C	C	C	C	C	
71 A	T	Dhaleswari	Rekabi Bazar	23	34.1856	90	30.2902	GPS	1965			H	H	H	H	H	H	H	H	H	H			H			H			C	C	C	C	C	C	C	C	
72	T	Baulai	Kaliajuri	24	41.3052	91	7.3302	GPS	1945		H	H	H	H	H	H	H	H	H	H	H		H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
72 B	Q	Baulai	Sukdevpur	24	52.7637	91	9.9385	GPS																					C	C	C	C	C	C	C	C	C	C
73	T	Baulai	Itna	24	31.8347	91	5.6318	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
74	T	Ghorautra-Baulai	Dilalpur	24	11.2258	90	58.5953	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
115	T	Gumti	Daudkandi	23	32.3719	90	43.0712	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H			H		C	C	C	C	C	C	C	C	
123	Q	Hawrah	Gangasagar RR Brdg	23	49.9887	91	12.0678	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
131	Q	Jadukata	Saktiarkhola	25	11.4795	91	15.2472	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C
131.5	Q	Jadukata	Lourerghar						1991																													C
135	Q	Juri	Juri	24	36.4800	92	8.2200	GPS	1957		C	C	C	H	H	H	H	H	H	H	H	H	C	H											H			
135A	Q	Juri - Continala Branch	Juri(continala)	24	35.5983	92	6.7331	GPS	1967					H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C
138	Q	Korangi	Sofiabad	24	17.5477	91	32.9787	GPS			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C
155.5		Khajanchi Khal	Khajanchigaon	24	52.5000	91	45.5000	NHCL			H																											
157		Khowai	Ballah	24	5.0070	91	36.0154	GPS	1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
158		Khowai	Chunarghat	24	12.1010	91	31.8220	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
158.1	Q	Khowai	Shaistaganj	24	18.3825	91	28.5790	GPS	1964		C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
159		Khowai/Barak	Habiganj	24	22.1080	91	25.6750	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
172	Q	Kushiyara	Amalshid	24	52.1300	92	28.5400	GPS	1951		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
173	Q	Kushiyara	Sheola	24	53.3950	92	11.4460	GPS	1949		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
173A	Q	Sada Khal	Sheola	24	53.8055	92	10.7268	GPS	1947		H		H	H	H	H	H	H	H	H	H	H	H	H														
174	Q	Kushiyara	Fenchuganj	24	42.1250	91	56.4800	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
175	Q	Kushiyara	Monumukh	24	35.7000	91	43.5000	NERP	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	H				C									
175.5	Q	Kushiyara	Sherpur	24	37.6564	91	40.9657	GPS																					C	C	C	C	C	C	C	C	C	C
177	T	Lakhya	Lakhpur	24	3.9359	90	38.4169	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C			C	C	C	C	C	C	C		
178	T	Lakhya	Ghorasal	23	56.8300	90	37.5000		1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H			H											
179	TQ	Lakhya	Demra	23	43.6029	90	30.5306	GPS	1952		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	H	C	C	C	C	C	C	C		C	C	
180	T	Lakhya	Narayanganj	23	37.8185	90	31.0363	GPS	1947			H	H	H	H	H	H	H	H	H	H	H	H	H	H		H	H	H									
192	Q	Langla	Motiganj	24	18.2950	91	40.8870	GPS	1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
199	Q	Mahasingh	Mahasingh Ferryghat	24	55.5000	91	28.5000		1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H													
201	Q	Monu	Monu R.R. bridge	24	25.7133	91	56.5840	GPS	1958		H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
202		Monu	Moulavi bazar	24	29.6476	91	46.4358	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	
220.5		Nitai	Ghosgaon	25	7.1000	90	34.5000	NHCL			H																											
223		Old Brahmaputra	Goal Khanda	25	19.5000	89	49.3000		1944		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
224		Old Brahmaputra	Bangshi offtake	25	0.0000	89	53.3000	NHCL	1958		H	H																										
225		Old Brahmaputra	Jamalpur	24	55.3728	89	57.9079	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	H	C
226		Old Brahmaputra	Sirkhali offtake	24	52.5000	90	12.0000		1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C							
227	Q	Old Brahmaputra	Sutia Offtake	24	47.8486	90	19.2707	GPS	1958		H	H	H	H		H	H		H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C
228		Old Brahmaputra	Mymensingh	24	45.0000	90	25.5000		1944		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H		C	C	C	C						
228.5	Q	Old Brahmaputra	Mymenshing	24	43.5058	90	26.6017	GPS	1964				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
229	T	Old Brahmaputra	Toke	24	15.5000	90	39.0000		1948		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	
230	T	Old Brahmaputra	Motkhola	24	14.0000	90	41.0000		1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H			H								
230.1	TQ	Old Brahmaputra	Bhairab Bazar R.R. bridge	24	2.2875	90	57.8883	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H	C	C	C	C	C	C	C	C	C	C	
233	Q	Piyan	Ratner bhanga	25	9.7168	91	58.2311	GPS	1956		H	H										H	H	H	H	H	H		C	C	C	C	C	C	C	C	C	C
233A	Q	Piyan/Dauki	Jaflong	25	9.3000	92	1.3880	GPS	1991												H	H																
234	Q	Piyan	Companyganj	25	5.4598	91	45.7364	GPS	1950		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	H	C	C	C	C	C	C	C			
251	Q	Sari-gowain	Sharighat	25	5.7650	92	6.7760	GPS	1950		H	H	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C
252	Q	Sari-gowain	Gowainghat	25	5.4936	91	59.1089	GPS	1950		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	
252.1	Q	Sari-gowain	Salutikar	24	59.4890	91	51.1250	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
262	Q	Someswari	Bagmara/Bijoypur	25	10.2212	90	39.7547	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
263	Q	Someswari	Durgapur	25	6.5765	90	40.2972	GPS	1958		C	C	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C
263.1	Q	Someswari	Kalmakanda	25	4.5654	90	53.8631	GPS	1963		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C
263.2		Someswari	Madhyanagar	25	2.7294	90	59.6071	GPS																						C								
263A	Q	Someswari	Durgapur	25	6.5765	90	40.2972	GPS																														

Table 2.1 : Daily Water Level Measurements

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																											
				DEG	MIN	DEG	MIN				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
263B	Q	Someswari	Durgapur	25	6.8124	90	40.5226	GPS																														
264		Sonai	Madhabpur	24	5.3000	91	17.6000		1958		H	H	H	H		H	H	H	H	H	H	H																
265	Q	Sonai-Bardal	Jaldhup	24	46.4370	92	10.3620	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C		C	C	C
266	Q	Surma	Kanairghat	25	0.0000	92	15.5520	GPS	1951		H	H	H	H	H	C	C	H	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C
267	Q	Surma	Sylhet	24	53.2413	91	52.2655	GPS	1938		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C
268	Q	Surma	Chatak	25	2.1561	91	39.9331	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	C	C	C	C	C	C	C	C	C	C
269	Q	Surma-Meghna	Sunamganj	25	4.5307	91	24.8461	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C
270	T	Kusiyara	Markuli	24	41.6220	91	22.8710	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C		C		C
271	T	Kalni-Kushiyara	Ajmiriganj	24	33.2220	91	13.7290	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
272	T	Kalni-Kushiyara	Madna	24	20.1410	91	14.2620	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H		C	C	C	H		C	C	C	C	C	C	C	C		
272.1	T	Dhaleswari-Kushiyara	Austagram	24	16.3000	91	6.0000		1962			H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C		C	
273	TQ	Meghna	Bhairab bazar	24	2.6911	90	59.6681	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C
274	T	Meghna	Narsingdi	23	55.0915	90	43.7660	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	C	C	C	C	C	C	C	C	C	C
275	T	Meghna	Badyar Bazar	23	38.8833	90	37.5825	GPS	1958			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C	C		C	C	C
275.5	T	Meghna	Meghna Ferry Ghat	23	36.0757	90	37.3871	GPS	1965			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C	C			C	C
276	T	Meghna	Satnal	23	28.6911	90	35.7416	GPS	1951			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C
280	Q	Sutang	Sutang rly.br.	24	16.9890	91	24.1560	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	H	H	C	C	C	C	C	C	C	C	C	C
295	T	Titas	Ajabpur	24	7.2362	91	3.5001	GPS	1959		H	H	H	H	H	H	H	H	H	H	H	H		C		H	H	H	C	C	C	C	C	C	C	C	C	
296	T	Titas	Akhaura	23	52.7330	91	12.2282	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	H	H	C	C	C	C	C	C	C	C	C	
297	T	Titas	Gokarnaghat	23	57.2592	91	5.2856	GPS	1959			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C	C	C	C	C	
298	T	Titas	Nabinagar	23	54.2545	90	58.5626	GPS	1947			H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
308	Q	Khajanchi Nadi	Khajanchigaon RR Brdg.	24	52.5000	91	45.5000		1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H														
310	Q	Mogra	Netrokona	24	52.8989	90	43.6416	GPS																H	H	H			C	C	C	C	C	C	C	C	C	C
311		Mogra	Atpara	24	48.5167	90	52.1404	GPS																					C	C		C	C	C	C	C	C	C
314	Q	Nitai	Ghosegaon	25	8.5000	90	30.5000		1964			C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C
315	Q	Madhabpur khal	Chhatak	25	0.5000	91	39.8000		1965				H	H		H	H	H	H	H	H																	
326	Q	Lubachara	Luba Outfall	25	2.2000	92	18.1000																						C	C	C	C	C	C	C	C		
327			Boalmari	25	19.6000	89	46.7000																						C	C	C	C	C	C	C	C	C	C
332	Q	Dhalagang	Islampur	25	7.9680	91	45.2750	GPS																														
333	Q	Jhalukati	Muslimpur	25	6.6640	91	23.4850	GPS																														
337	Q	Nawagang	Ururgaon	25	7.2500	91	35.6400	GPS																														
341	Q	Umium	Chelasonapur	25	7.6900	91	40.3200	GPS																														
BWDB	Q	Juri	Silghat (Auto)	24	35.3326	92	7.3977	GPS																														
BWDB		Rukti	Durlabpur	24	59.8068	91	15.8226	GPS																														
BWDB		Monu river	Manu Pumping Station	24	36.3735	91	45.4563	GPS																														
BWDB		Monu river	Manu Barrage	24	29.5406	91	48.1379	GPS																														
NERP	Q	Khowai	Remabagan	24	6.5414	91	35.9903	GPS																														
NERP		Baulai	Marala	25	3.0941	91	8.2061	GPS																														
NERP		Kushiyara	Kamalpur	24	38.9874	91	54.1919	GPS																														
NERP		Monu	Kazir Chaik	24	29.1289	91	54.3300	GPS																														
NERP		Monu	Dhamai Chara	24	36.6997	91	54.3282	GPS																														
NERP		Baulai	Tahirpur	25	5.9747	91	10.7484	GPS																														
SWMC	Q	Surma	Nilpur	24	59.7166	91	23.2457	GPS																														
SWMC	Q	Dhona Khali	Thakurakona	24	54.5052	90	49.8149	GPS																														
SWMC	Q	Dahuka/Bhatta	Rampur	24	55.6101	91	41.4065	GPS																														
SWMC		Bijna River	Terapasha	24	33.1202	91	36.5193	GPS																														
SWMC		Mahasingh	Akther Bazar	24	53.5895	91	28.7161	GPS																														
SWMC		Saiduli	Gogbazar	24	41.2783	90	51.9817	GPS																														
SWMC		Dhanu	Chamraghat	24	27.5470	90	57.7330	GPS																														
SWMC		Old Kushiyara	Khagapasha (Najibpur)	24	33.0590	91	26.2750	GPS																														
SWMC	Q	Jhalukhali	Dulura (u/s of Muslimpur)	25	9.7510	91	23.5200	GPS																														
SWMC		Surma	Baraigram	24	54.4700	92	8.6450	GPS																														
SWMC		Itakhola	Biswanath (Kaliganj)	24	47.4290	91	44.3240	GPS																														
SWMC	Q	Gowain	Lallakhal (u/s of Sarighat)	25	6.9900	92	10.9400	GPS																														
SWMC	Q	Lubha	Lubhachara	25	2.7440	92	20.0770	GPS	1992																													
SWMC		Zurdia Regulator	Joysree (Rainy season)	24	57.4618	91	5.5192	GPS																														
SWMC		Zurdia Regulator	Joysree (Dry season)	24	57.7746	91	6.5605	GPS																														
SWMC	Q	Active Piyan	Ambari	25	3.1000	91	41.4300	GPS																														
SWMC		Naluar	Jaganathpur																																			
SWMC	Q	Surma	Amalshid																																			
SWMC	Q	Jaflong	Jaflong	25	9.3	92	1.388	GPS																														
SWMC	Q	Telekhal	Telekhal																																			
SWMC		Dhanu	Daksin Hasanpur	24	35	90	58.6	GPS																														
SWMC		Matian Haor	Barakhal																																			

Table 2.2 : MEAN DAILY DISCHARGE

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N) DEG	LATITUDE (N) MIN	LONGITUDE (E) DEG	LONGITUDE (E) MIN	CONFIRM	DATE INSTALLED	DATE REMOVED
3A	Q	Anderson Khal	Brahmanbaria RR Bridge	23	57.3845	91	7.3746	GPS	1957	
6	Q	Bahia	Surma Offtake	24	54.0000	91	49.0000		1959	1977
33	Q	Bhattakhal	Gobindaganj	24	56.2000	91	41.5000		1958	1977
34	Q	Bhugai-kangsha	Nakuagaon	25	11.3807	90	13.1257	GPS	1957	
35.5	Q	Bhugai-kangsha	Sarchapur	24	59.7503	90	21.6908	GPS	1991	
36	Q	Kangsha	Jariajanjail	25	0.5591	90	39.3106	GPS	1949	
36.1	Q	Kangsha	Mohanganj	24	52.3357	90	58.5817	GPS	1991	
46.9 L	Q	Brahmaputra	Bahadurabad	25	9.3000	89	40.5000		1953	
53	Q	Chilla Khali	Bathkuchi	25	11.6235	90	10.7062	GPS	1957	
67	Q	Dhalai	Kamalganj	24	21.3579	91	51.0793	GPS	1957	
72 B	Q	Baulai	Sukdebpur	24	52.7637	91	9.9385	GPS	1990	
123	Q	Hawrah	Gangasagar RR Bridge	23	49.9887	91	12.0678	GPS	1957	
131	Q	Jadukata	Saktiarkhola	25	11.4795	91	15.2472	GPS	1957	
131.5	Q	Jadukata	Lourerghar						1991	
135	Q	Juri	Continala	24	36.4800	92	8.2200	GPS	1957	1977
135A	Q	Continala	Continala	24	35.5983	92	6.7331	GPS	1964	1980
138	Q	Karangi	Sofiabad	24	17.5477	91	32.9787	GPS	1958	
158.1	Q	Khowai	Shaistaganj	24	16.3825	91	28.5790	GPS	1964	
172	Q	Kushiyara	Amalshid	24	52.1300	92	28.5400	GPS	1951	
173	Q	Kushiyara	Sheola	24	53.3950	92	11.4460	GPS	1949	
173A	Q	Sada Khal	Sheola	24	53.8055	92	10.7268	GPS	1947	1977
174	Q	Kushiyara	Fenchuganj	24	42.1250	91	56.4800	GPS	1947	
175	Q	Kushiyara	Monumukh	24	35.7000	91	43.5000	NERP	1949	
175.5	Q	Kushiyara	Sherpur	24	37.6564	91	40.9657	GPS	1982	
179	Q	Lakhya	Demra	23	43.6029	90	30.5306	GPS	1952	
192	Q	Lungla	Motiganj	24	18.2950	91	40.8870	GPS	1958	1980
199	Q	Mahasingh	Mahasingh Ferryghat	24	55.5000	91	26.5000		1958	
201	Q	Monu	Monu rly. br.	24	25.7133	91	56.5640	GPS	1958	
227	Q	Old Bramahputra	Sutia Offtake	24	47.8486	90	19.2707	GPS	1958	
228.5	Q	Old Bramahputra	Mymensingh	24	43.5058	90	26.6017	GPS	1964	
230.1	Q	Old Bramahputra	Bhairab Bazar	24	2.2875	90	57.8883	GPS	1964	
233	Q	Piyagang	Ratnerbhanga	25	9.7168	91	58.2311	GPS	1956	1980
233A	Q	Piyan/Dauki	Jaflong	25	9.3000	92	1.3880	GPS	1965	1977
234	Q	Piyan	Companyganj	25	5.4598	91	45.7364	GPS	1950	
251	Q	Sarigowain	Sarighat	25	5.7650	92	6.7760	GPS	1950	
252	Q	Sarigowain	Gowainghat	25	5.4936	91	59.1089	GPS	1950	
252.1	Q	Sarigowain	Salutikar	24	59.4890	91	51.1250	GPS	1964	1977
262	Q	Someswari	Bijoypur/Bagmara	25	10.2212	90	39.7547	GPS	1945	
263	Q	Someswari Com.	Durgapur							
263A	Q	Someswari Main	Durgapur	25	6.5765	90	40.2972	GPS	1958	
263B	Q	Someswari Spill Ch	Durgapur	25	6.8124	90	40.5226	GPS	1958	
263.1	Q	Someswari	Kalmakanda	25	4.5854	90	53.8631	GPS	1988	
265	Q	Sonai bardal	Jaldhup	24	46.4370	92	10.3620	GPS	1957	
266	Q	Surma	Kanairghat	25	0.0000	92	15.5520	GPS	1951	
267	Q	Surma	Sylhet	24	53.2413	91	52.2655	GPS	1938	
268	Q	Surma	Chhatak	25	2.1561	91	39.9331	GPS	1949	1977
269	Q	Surma	Sunamganj	25	4.5307	91	24.8461	GPS	1949	
273	Q	Meghna	Bhairab bazar	24	2.6911	90	59.6681	GPS	1949	
280	Q	Sutang	Sutang rly.b	24	16.9890	91	24.1560	GPS	1957	
308	Q	Khajanchi Nadi	Khajanchigaon RR Bridge	24	52.5000	91	45.5000		1964	1977
310	Q	Mogra	Netrokona	24	52.8989	90	43.6416	GPS	1991	
314	Q	Nitai	Ghosegaon	25	8.5000	90	30.5000		1964	
315	Q	Madhabpur Khal	Chhatak	25	0.5000	91	39.8000		1965	1977
326	Q	Lubachara	Luba Outfall	25	2.2000	92	18.1000			1980
332	Q	Dhaligang	Islampur	25	7.9680	91	45.2750	GPS	1990	
333	Q	Jhalukhali	Muslimpur	25	6.6640	91	23.4850	GPS	1988	
337	Q	Jawagang	Ururgaon	25	7.2500	91	35.6400	GPS	1988	
341	Q	Umium	Chelasonapur	25	7.6900	91	40.3200	GPS	1988	
SWMC	Q	Surma	Nilpur	24	59.7166	91	23.2457	GPS	1991	
SWMC	Q	Dhonai khali	Thakurakona	24	54.5052	90	49.8149	GPS	1991	
SWMC	Q	Dahuka/bhatta	Rampur	24	55.8101	91	41.4085	GPS	1991	
SWMC	Q	Gowain	Lallakhal (u/s of Sarighat)	25	6.9900	92	10.9400	GPS		
SWMC	Q	Lubha	Lubachara	25	2.7440	92	20.0770	GPS		
SWMC	Q	Jalukhali	Dulura (u/s of Muslimpur)	25	9.7510	91	23.5200	GPS		
SWMC	Q	Active Piyan	Ambari	25	3.1000	91	41.4300	GPS		
SWMC	Q	Surma	Amalshid							
SWMC	Q	Jaflong	Jaflong	25	9.3	92	1.388	GPS		
SWMC	Q	Telekhal	Telekhal							
BWDB	Q	Juri	Silghat (Auto)	24	35.3326	92	7.3977	GPS		
NERP	Q	Khowai	Remabagan	24	6.5414	91	35.9903	GPS		

WATER YEAR

STATION NO.	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
3A	H		H							H	H	H	H																	
6	C	C	C	C	C	C	C		C	C	C	C	C	C																
33	C	C	C	C	C	C	C		C	C	C	C	C	C																
34	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C	C		
35.5																														
36	C	C	C	C	C		C		C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C		
36.1																														
46.9 L	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C		
53																									C	C	C			
67	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C		
72 B																														
123		C										C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
131																									C			C		
131.5																												C		
135	C	C					C		C	C		C	C	C																
135A	C									C	C	C	C	C	C	C	C													
138	C	C	C			C	C		C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			
158.1	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
172																														
173	C	C	C	C	C	H	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
173A	H	H				H	H		H	H	H	H	H																	
174																														
175																														
175.5																			C	C	C	C	C	C	C	C	C	C		
179		C	C	C	C							C	C	C		C	C	C	C	C	C	C	C	C	C	C				
192	C						C			C	C	C	C	C	C	C	C								C	C	C	C		
199																														
201	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
227	H	H	H			H	H					H	H	H	H	H	H	H	H											
228.5	C	C	C	C	C	C	C				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
230.1						H	H		C	C	C	C		C	C	C	C		C					C	C	C	C	C		
233	H																								C	C	C	C		
233A																														
234																														
251	H	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C			
252																														
252.1	H	H	H			H	H		H	H	H	H	H	H																
262																														
263																														
263A																											C	C		
263B																														
263.1																														
265	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C				C	C	C	C	C	C	C	C		
266						C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
267	C	C	C			C	C		C	C	C	C	C	C				C	C	C	C	C	C	C	C	C	C	C		
268		H	H	H		H	H			H																				
269																														
273	C	C	C	C	C	C	C		C	C	C	C	C					C	C	C	C	C	C	C	C	C	C	C		
280	C	C								C	C	C	C	C		C									C	C	C			
308		H	H			H	H		H		H																			
310																														
314	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C	C		
315		H	H			H	H		H	H	H																			
326																														
332																									C	C	C	C		
333																									C			C		
337																														
341																														

308 Q Khajanchi Nadi Khajanchigaon RR Bridge = ABANDONED STATION

= DATA IN HAND

= DATA NOT AVAILABLE

222

Table 2.3: BIWTA navigation charts used in studies

River	Year	Charts
Meghna	1967	105/67 A-D
	1968	S118/68 A-D
	1978	S196/78 A-D
	1988	349/88 A-F
Surma/Baulai	1963	S57 A-H
	1977	S186 A-H
	1978	S193 A-K
	1983	S238 B-O
	1992	S444 A-K
Kalni/Kushiyara	1963	S58 D-K
	1977	S179 A-S1
	1988	S349 D-F
	1988	S349 D-F

Table 3.1: Description of Geological Units in NE Region

Age	Group	Formation	Description
Pleistocene		Madhupur	Silty to sandy clay
Pleistocene/Pliocene	Dupi-Tila	Dihing	poorly consolidated sandstone
		Dupi Tila	sandstone, siltstone, conglomerate
Neogene	Tipam	Tipam	sandstone, siltstone & shale
Neogene	Surma	Boka Bil	shale, siltstone, sandstone
Miocene		Bhuba	sandstone, siltstone & claystone
Oligocene		Baril	sandtone, siltstone & shale
Eocene	Jantia	Sylhet	limestone

From: Geological Survey of Bangladesh (1990)

Table 3.2: Summary of Land Unit Areas

Landform Unit	Physiographic Unit	Area (km^2)	% of Region	% by Landform Unit
Uplands	Susang Hills	120	0.5	7.8
	Sylhet Hills	1750	7.3	
Terrace	Madhupur Tract	494	2.1	2.1
Alluvial Fan	Meghalaya Fans	1486	6.2	6.2
Piedmont Floodplain	Tripura Piedmont	960	4.0	4.0
	Susang Piedmont			
Lowland Floodplain	Surma/Kushiyara	4636	19.3	55.2
	Old Brahmaputra	7220	30.1	
	Meghna	727	3.0	
	Jamuna	678	2.8	
Flood Basin/Haor	Central Basin	5605	23.3	24.7
	Meghalaya Basin			
	Sylhet Lowland	335	1.4	

Table 3.3: Evidence of Subsidence in the Recent Deltaic Plan

Location of Data and Type Informaiton			Evidence	Subsidence Indicated (In feet)	Source of Information
Calcutta and Vicinity	Near Hoogly River	Water-well boring	Rotten wood	32-55	East, 1818, 544-16
	Chowrhinghee Road	Tank excavation	Decayed wood	35	East, 1818, p.547
	Sialdah	Tank excavation	*Sundri trees in situ*	30	
	King George dock	Excavation	Wood (*Ceriops* sp.)	40	
	Fort Williams	Water-well boring	Peat and *Sundari* trees	30-50	
	Port Canning on Matla River	Tank excavation		10	
Khulna and Vicinity	At Khulna, about 12 mi.N.Sundarbans	Tank excavation	Large *Sundri* trees in place and layer of vegetable mould	18	Hunter, 1975, p.291
	Khulna shipyard docks	Foundation Borings: No. 4	Decayed Wood	86.5-99	R. Toriana, personal communication
		No. 6	Decayed wood	4-18	
		No. 6	Decayed vegetation	23-48	
		No. 6	Decayed wood	97-99	
Sundarbans (Coastal Region)	Near Kobadak Forest Station	Shallow hand auger boring	Wood (*Sundri*)	12-14	Borings made by writers December-March, 1956
	Talpatti Khal	Shallow hand auger boring	Peat layer	14	Borings made by writers December-March, 1956
	Near mouth of Raimangal River	Shallow hand auger boring	Intermittent organic down to 20 feet	20	Borings made by writers December-March, 1956
	Dhaki Khal boring	Shallow hand auger boring	Peat layer	13-16	Borings made by writers December-March, 1956
			Wood (*Sundri*)	18	
			Peat layer	21-22	
	Dhaki khal ¼ mile from boring	Tank excavation	Wood (*Sundri*)	18	Field observation
	Dhaki Khal 200 yards from boring	Tank excavation	Human artifact (Mill-ing or grinding stone)	13	Field observation
	Dubla Island	Shallow hand auger boring	Intermittent organic down to 20 feet	20	Borings made by writers December-March, 1956
	Shukretak Ruins near Sibsa River	Shallow hank auger boring	Peat	6	Borings made by writers December-March, 1956
			Wood	16	
			Wood	20-23	
			Organic	23-34.5	

Table 3.4: Major Earthquakes Affecting the Region

Date	Epicentre	Magnitude
April 2, 1762	Arakon Yoma	8.4
July 14, 1885	Bengal	7.0
June 12, 1897	Shillong	8.7
July 8, 1918	Srimangal, Sylhet	7.6
August 15, 1950	Assam	8.5

Table 4.1: Physical Characteristics of Watersheds

Basin	Area Km^2	Relief m	Length km	Slope	% Above El. 900 m
Barak	25260	3,015	470	0.0064	
Malijhee	125	150	25	0.0060	0
Chillikhali	118	150	22	0.0068	0
Bugai	453	1412	30	0.0470	0
Nitai	381	626	25	0.0250	0
Someswari	2134	1412	55	0.0260	10
Jadukata	2513	1925	70	0.0270	60
Jhalukhali	448	1885	31	0.0610	65
Chela	518	1964	52	0.0380	75
Dhali	342	1892	32	0.0590	50
Dauki	810	1964	68	0.0290	70
Hari	802	1405	35	0.040	65
Lubha	724	1627	35	0.046	15
Juri	629	457	47	0.010	-
Manu	2235	938	80	0.012	1
Dhalai	632	509	44	0.012	-
Khowai	1113	481	58	0.008	-

322

Table 4.2: Runoff from Catchments

Catchment	Volume km³/yr	Runoff m³/s
Inflow from Tripura	10.2	323
Inflow from Meghalaya	62.9	1993
Inflow from Barak R.	31.8	1008
Total Inflow from India	104.9	3324
Rainfall on NE/Meghna	68.4	2167

Table 5.1: Suspended Sediment Data

River	Station	No.	First Year	Number of Sample days/Year																											
				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
Dhalai	Kamalganj	67	1957	23	11	18	15	10	10			3		29	15	9	12	10	10	7				17							1
Juri	Continala		1957	24	5	16	12	10	8			3	1	7	9	6			5	4											1
Karangi	Sofiabad	138	1958	17	17	16	18	19	29				1	6	4	9	21	17	21		7	12	5								
Khowai	Shaistaganj	158.1	1964	15		13	15	20	28				2		7	19	23	29	24	26	7	22	14	26	38	39	26	26	26	26	25
Khowai	Habiganj	158	1957	8																											
Kushiyara	Sheola	173	1958	17	14	7	21	28	33	33		22		33	33	33	24	20	16	13	11	11	6	18	17	27	27	26	18	19	
Kushiyara	Sherpur	175.5	1968					4					3	13	15	10	15	6	12	5	4		5	16	17	26	28		15	19	
Lungla	Motiganj	192	1958	21	15	15	24	25	25																						2
Manu	Rail bridge	201	1963	13	5	14	18	10	9			3	2	26	23	20	21	5	11	6	4		3	17							
Manu	Moulvibazar	202	1958																												2
Somesawari	Durgapur	263	1958	6																											
Surma	Sylhet	267	1957	30	31	13	23	25	31	10	7		3	36	29	36	27	13	17	11	12	9	6	19	18	27	26	25	17	22	3
Meghna	Bhairab	273	1960	1	22		17	10	12						7									9	6	16	24	25	23	27	21
Sutang	Rail bridge	280	1959		22		17	10	12				1	3	1		8	7	6												1

Table 5.2: Example of Published Sediment Data

River: Kushiyara

Station: Sheola

Sampling Date	WL in meter PWD Datum	Sampling		Velocity in meter/sec.	Discharge in cumecs	Sediment concentration in PPM by wt.	Average sediment concentration in PPM by Wt	Remarks
		Position meter	Depth meter					
1	2	3	4	5	6	7	8	9
06.02.92	6.078	100 REW	0.61	0.546 (Surface)	196.071	57		
09.04.92	6.42	102 REW	0.61	0.640 "	259.721	40		
10.05.92	3.535	114 REW	0.61	0.694 "	476.808	99		
21.05.92	12.38	114 REW	0.61	1.127 "	1454.153	320		
19.06.92	9.075	112 REW	0.61	0.491 "	457.973	57		
02.07.92	12.21	115 REW	0.61	0.843 "	1246.914	263		
16.07.92	12.56	115 REW	0.61	1.005 "	1320.596	288		
30.07.92	10.975	116 REW	0.61	0.748 "	782.78	296		
13.08.92	12.68	116 REW	0.61	1.235 "	1518.56	272		
27.03.92	11.93	116 REW	0.61	1.10 "	1197.81	706		
10.09.92	24.57	126 REW	0.61	1.235 "	1954.24	84		
24.08.92	10.99	111 REW	0.61	0.613 "	623.88	75		

Table 5.3: Summary of Discharges at Sediment Stations

Gauge	Station	Discharge (m³/s)				
		MIN	MEAN	MAX	APF	MAF
67	Dhalai R. at Kamalganj	0.57	29.8	498	152	234
138	Karangi R. at Sofiabad	0.03	8.1	500		
158	Khowai R. at Shaistaganj	0.82	36.4	1050	130	303
173	Kushiyara R. at Sheola	27.7	682	2960	966	2198
175.5	Kushiyara R. at Sherpur	45.6	1101	3950	1884	2708
192	Lungla R at Mohanganj		8.7	333		87.5
201	Manu R. at rail crossing	2.9	86.8	875	350	609
263	Someswari R. at Durgapur				147	1446
267	Surma R. at Sylhet	2.6	563	2480	1360	2120
273	Meghna R. at Bhairab	2.0	4725	19800	3002	13883
280	Sutang R. at rail bridge		9.6	253		87

Note: APF = average pre-monsoon flood
MAF = mean annual flood

268

Table 5.4: Summary of Observed Sediment Concentrations

Gauge	Station	Period	Suspended Sediment Concentration (mg/l)		
			Min.	Max.	Avg.
67	Dhalai R at Kamalganj	1966-86	26	9300	1040
158.1	Khowai R at Shaistaganj	1963-92	12	5099	401
173	Kushiyara R at Sheola	1966-92	4	4639	253
175.5	Kushiyara R at Sherpur	1966-92	13	658	144
201	Manu R. at rail crossing	1964-92	15	7665	799
267	Surma R at Sylhet	1966-92	4	1947	608
273	Meghna R at Bhairab Bazar	1966-92	2	1832	98

Table 5.5 Summary of observed suspended sediment loads

Gauge	Station	Period	Suspended Sediment Load (tonne/day)		
			Min.	Max.	Avg.
67	Dhalai R at Kamalganj	1966-86	5	90,800	9300
158.1	Khowai R at Shaistaganj	1963-92	11	159,300	2775
173	Kushiyara R at Sheola	1966-92	22	427,600	33,400
175.5	Kushiyara R at Sherpur	1966-92	95	155,300	18,400
201	Manu R. at rail crossing	1964-92	13	324,400	16,300
267	Surma R at Sylhet	1966-92	3	82,000	10,750
273	Meghna R at Bhairab Bazar	1966-92	570	3,048,000	96,200

262

Table 5.6: Summary of Observed Sediment Concentrations (inactive stations)

Gauge	Station	Period	Suspended Sediment Concentration (mg/l)		
			Min.	Max.	Avg.
131.5	Jadukata R. at Saktiarkhola	1958-62	0	81	28
138	Karangi R. at Sofiabad	1979-83	6	540	164
159	Khowai R at Habiganj	1958-64	18	4523	464
192	Lungla R at Mohanganj	1966-80	38	844	237
202	Manu R. at Moulvibazar	1957-63	6	2705	392
234	Piyain R. at Companyganj	1957-63	3	195	39
263	Someswari R. at Durgapur	1958-64	2	636	116
280	Sutang R. at reil crossing	1965-79	35	1260	230
252	Gowain R. at Gowainghat	1957-62	3	747	45

Table 5.7: Summary of Observed Sediment Loads (inactive stations)

Gauge	Station	Period	Suspended Sediment load (t/d)		
			Min.	Max.	Avg.
131.5	Jadukata R. at Saktiarkhola	1958-62	0	6250	573
138	Karangi R. at Sofiabad	1979-83	0.3	1480	204
159	Khowai R at Habiganj	1958-64	14	34800	2760
192	Lungla R at Mohanganj	1966-80	1.1	81,000	2690
202	Manu R. at Moulvibazar	1957-63	9	10,300	8200
234	Piyain R. at Companyganj	1957-63	0.6	2325	218
263	Someswari R. at Durgapur	1958-64	6	12,000	1760
280	Sutang R. at reil crossing	1965-79	2.2	2110	277
252	Gowain R. at Gowainghat	1957-62	4	5830	700

Table 5.8: Sediment Rating Curve Coefficents, Kushiyara River at Sheola

Year	a	b	r^2	SEE	K
1986-92	-0.4013	0.908	0.64	0.36	1.41
1992	-0.2597	0.841	0.50	0.29	1.25
1990	0.6679	0.652	0.55	0.38	1.47
1988	-0.7098	0.995	0.85	0.23	1.16

where a & b are coefficents from the regression equation: $\log(C) = a+b*\log(Q)$
r^2 is the coefficent of determination
SEE is the standard error of estimate of the regression
K is the bias correction factor

Table 5.9: Sediment Rating Curve Coefficents, Kushiyara River at Sherpur

Year	a	b	r^2	SEE	K
1986-92	0.551	0.500	0.35	0.33	1.33
1992	1.001	0.354	0.11	0.36	1.41
1989	0.114	0.6788	0.66	0.27	1.21
1986	-0.1395	0.694	0.60	0.28	1.23

where a & b are coefficents from the regression equation: $\log(C) = a+b*\log(Q)$
r2 is the coefficent of determination
SEE is the standard error of estimate of the regression
K is the bias correction factor

269

Table 5.10: Sediment Rating Curve Coefficents, Surma River at Sylhet

Year	a	b	r^2	SEE	K
1986-90	1.167	0.311	0.37	0.36	1.41
1990	1.742	0.1848	0.22	0.34	1.36
1989	0.976	0.4456	0.69	0.30	1.27
1988	1.0274	0.346	0.47	0.34	1.36

where a & b are coefficents from the regression equation: $\log(C) = a+b*\log(Q)$
r^2 is the coefficent of determination
SEE is the standard error of estimate of the regression
K is the bias correction factor

Table 5.11: Sediment Rating Curve Coefficents, Khowai River at Shaistaganj

Year	a	b	r^2	SEE	K
1986-92	1.0585	0.9181	0.46	0.39	1.49
1992	0.9490	1.017	0.43	0.273	1.22
1990	1.2936	0.837	0.61	0.26	1.20
1987	0.495	1.292	0.74	0.20	1.11

where a & b are coefficents from the regression equation: $\log(C) = a+b*\log(Q)$
r2 is the coefficent of determination
SEE is the standard error of estimate of the regression
K is the bias correction factor

Table 5.12: Sediment Rating Curve Coefficents,
Manu River at Rail Crossing

Year	a	b	r^2	SEE	K
1963-84	1.029	0.89	0.66	0.38	1.47
1984	0.796	1.01	0.83	0.18	1.09
1977	0.859	1.00	0.88	0.31	1.29
1976	1.124	0.82	0.82	0.10	1.03

where a & b are coefficents from the regression equation: log(C) = a+b*log(Q)
r2 is the coefficent of determination
SEE is the standard error of estimate of the regression
K is the bias correction factor

Table 5.13: Summary of Estimated Annual Suspended Sediment Loads

Gauge	Station	Period	Suspended Sediment Load (tonne/year)		
			Avg.	Min.	Max.
67	Dhalai R at Kamalganj	1966-86	1.6	0.4 (1972)	2.5 (1966)
158.1	Khowai R at Shaistaganj	1963-92	1.7	0.2 (1972)	6.0 (1988)
173	Kushiyara R at Sheola	1966-92	8.6	4.2 (1965)	15.8 (1990)
175.5	Kushiyara R at Sherpur	1966-92	6.7	4.2 (1985)	10.0 (1991)
201	Manu R. at rail crossing	1964-92	4.9	1.4 (1972)	10.4 (1991)
267	Surma R at Sylhet	1966-92	3.7	2.2 (1972)	4.5 (1991)
273	Meghna R at Bhairab Bazar	1966-92	16.9	4.2 (1986)	20.4 (1990)

Table 5.14: Sediment Yields from Assam Rivers

River	Drainage Area (km^2)	Suspended Sediment Load (tonne/year)	Sediment Yield ($tonnes/km^2$)
Jinari	443	62,000	139
Krishnai	986	218,000	221
Dudhnor	489	62,000	126
Digaru	1517	237,000	156
Dhansiri	9369	4,306,000	460

Note: sediment loads from Goswami (1985)

Table 6.1: Comparison of Sediment Transport Rates on Someswari River

Year	Fan Apex	Mid-Fan	Kangsha River
1987	2,600,000	680,000	390,000
1988	3,600,000	1,300,000	510,000
1989	2,210,000	380,000	390,000

Table 6.2: Morphologic Characteristics of Alluvial Fans

River	Drainage Area km2	Basin Relief (m)	Sand Inflow (t/year)	Active Fan Area (km2)	Avulsions since 1960
Someswari	2134	1412	2.5	138	1 + 1 in progress
Jadukata	2513	1925	4.0	200	1 + 1 in progress
Jhalukhali	448	1885	1.8	100	none
Chela	518	1964	1.5	80	2
Dhalai	342	1892	1.3	80	1
Dauki/Piyain	810	1964	1.3	150	2

282

Table 7.1: Manu River Channel Geometry

Reach	1985/86 Survey		1993 Survey	
	Area (m^2)	Width (m)	Area (m^2)	Width (m)
2.65-2.9	396	79	416	88
17.-19.8	527	103	545	114

Table 7.2: Effect of Loop Cuts on River Length

Reach	Channel Length (km)		Changes (km)	
	1967	1989	By Reach	Total
Barak -Habiganj	15.8	14	1.8	1.8
Habiganj - Shaistaganj	16.5	14	2.5	4.3
Shaistaganj - Chunarghat	22.8	16	6.8	11.1
Chunarghat - Ballah	22.9	22	0.9	12.0

Table 7.3: Channel Changes on Khowai River

Section	1969 Survey		1987 Survey	
	Area (m^2)	Width (m)	Area (m^2)	Width (m)
12	184	54	273	61
1	224	59	290	61
2	178	69	261	68
3	197	77	305	76
4	187	74	248	78
5	180	66	317	78
6	180	67	197	60

Table 8.1: Morphologic Characteristics of Surma/Baulai River

Extent of River Reach	Physio-graphic Unit	Channel Pattern	Channel Confinement	Bars	Islands	Vertical Stability	Lateral Stability	Bed Material D_{65} (mm) D_{50} (mm) D_{35} (mm)	Bank Material	Sinuosity (Lc/Lv)	Slope(m/km) Average Pre-monsoon Monsoon	Bankfull Dimensions Top Width Mean Depth Area
Amalshid - Chhatak km 0 - km 164	Surma/ Kushiyara Floodplain	Single; Irregular meanders	Often deflects off uplands & inerodible materials	Point Bars	Absent	Stable	Minor erosion due to progres-sive meander migration	0.23 0.20 0.16	Silt Clay	1.51	0.040 0.040 0.050	172 8.4 1448
Chhatak - Old Surma River km 164 - km 220	Central Basin	Single; Sinuous meanders	Unconfined	Absent	Absent	Degrading	minor widening	0.18 0.16 0.13	Silt Clay	1.58	0.005 0.005 0.026	251 10.3 2583
Old Surma River - Baulai River km 220 - km 248	Meghalaya Basin	Single ; Irregular/ Sinuous	Unconfined	Absent	Few	Degrading	Minor widening,	0.10 0.095 0.08	Clay, Silt and Peat	1.24	0.008 0.030 0.014	177 11.3 1996
Baulai Junction - Kaliajuri River km 248 - km 288	Central Basin	Split Channel; Irregular/ Straight	Unconfined	Absent	Occasi onal	Aggrading	Cutoffs, irregular shifts	0.11 0.10 0.086	Clay Silt and Peat	1.27	0.008 0.028 0.014	172 6.0 1036
Kaliajuri - Ghorautra km 288 - km 350	Central Basin	Split Channel; Irregular Meanders	Unconfined	Absent	Occasi onal	Aggrading	Cutoffs, irregular shifts	0.11 0.10 0.086	Silt Clay Peat	1.64	0.008 0.010 0.006	236 6.8 1591
Ghorautra River - Meghna River km 350 - km 384	Central Basin	Single Channel; Irregular Meanders	Unconfined	Point bars	Occasi onal	??	Cutoffs, irregular shifts	0.11 0.10 0.086	Silty Clay, Peat	1.47	0.008 0.010 0.006	356 7.4 2627

Note:
1. River classification criteria based on Neill and Galay (1967).
2. Extent of river reaches are shown on Figure 5-7.
3. Definition of Physiographic Units shown on Figure 14.
4. Channel Sinuosity = Channel Length/Valley Length

Table 8.2: Discharges Along Surma-Baulai River

Location	Mean Annual Flow m^3/s	May Q m^3/s	July Q m^3/s	Mean Annual Flood m^3/s
Surma River at Kanairghat	549	552	1,426	2,140
Surma at Sylhet	563	543	1,459	2,040
Surma above junction with Baulai	1,646	1,600 e	4,300 e	?
Baulai above Dhanu/Mogra junction	2,879	2,450 e	7,500 e	?
Ghorautra	3,267	2,780 e	8,500 e	?

Note: Monthly flows and mean annual floods estimated for period 1964-1989.

Table 8.3: Channel Changes on Surma River Amalshid to Sylhet

Year	Cross section Area (m^2)	Top Width (m)	Mean Depth (m)
1965	1420	164	8.7
1970	1482	182	8.3
1972	1366	193	7.1
1974	1388	188	7.4
1990	1436	176	8.2

288

Table 8.4: Channel Changes on Surma River Sylhet to Old Surma River Offtake

Year	Cross section Area (m2)	Top Width (m)	Mean Depth (m)
1970	1282	163	7.9
1972	1316	166	7.9
1974	1205	164	7.3
1990	1455	165	8.8

284

Table 8.5: Hydraulic and Sediment Transport Parameters Surma River at Kanairghat

Q (m^3/s)	Hydraulic Geometry W (m)	d (m)	V (m/s)	Froude Number Fr	Water Slope	Bed Shear (N/m^2)	Z	Shields Number
550	161	4.61	0.73	0.108	0.00005	1.36	1.82	0.42
950	183	6.19	0.85	0.109	0.000045	3.04	1.22	0.94
1425	201	7.69	0.96	0.110	0.00005	3.77	1.09	1.17
2140	219	9.32	1.06	0.111	0.00004	3.66	1.11	1.13
2730	231	10.52	1.13	0.111	0.00004	4.13	1.04	1.28

Note: Hydraulic properties have been calculated for the following five discharge conditions for the period 1965 - 1989:

1. Long term mean discharge
2. Average annual maximum pre-monsoon discharge
3. Average discharge in the month of July
4. Average annual maximum daily discharge
5. Maximum daily discharge in period of record

Definition of Terms:

W = Channel Top Width (m)
d = Mean depth (m)
V = Mean channel velocity (m/s)
Fr = Froude Number

$$Fr = V/\sqrt{(gd)}$$

Z = Rouse Number

$$Z = \frac{w}{kV_*}$$

where w = sediment fall velocity, V_* = shear velocity and k = Von Karman Coefficient

Shields Number

$$\psi = \frac{\gamma dS}{(\gamma_s - \gamma) D_{50}}$$

where D_{50} = median size of bed material

Table 8.6: Hydraulic and Sediment Transport Parameters

Surma River at Sylhet

Q (m^3/s)	Hydraulic Geometry W (m)	d (m)	V (m/s)	Froude Number Fr	Water Slope	Bed Shear (N/m^2)	Z	Shields Number
562	180	5.02	0.61	0.087	0.00003	1.48	1.74	0.46
757	183	5.60	0.71	0.095	0.000035	2.00	1.54	0.60
1458	191	7.49	1.02	0.119	0.00004	2.94	1.24	0.91
2040	195	8.59	1.22	0.133	0.00004	3.37	1.16	1.04
2480	200	9.32	1.37	0.143	0.00004	3.66	1.11	1.13

Note: Hydraulic properties have been calculated for the following five discharge conditions for the period 1964-1989:

1. Long term mean discharge
2. Average annual maximum pre-monsoon discharge
3. Average discharge in the month of July
4. Average annual maximum daily discharge
5. Maximum daily discharge in period of record

Definition of Terms:

W = Channel Top Width (m)
d = Mean depth (m)
V = Mean channel velocity (m/s)
Fr = Froude Number

$$Fr = V/\sqrt{(gd)}$$

Z = Rouse Number

$$Z = \frac{w}{kV_*}$$

where w = sediment fall velocity, V_* = shear velocity and k = Von Karman Coefficient

Shields Number

$$\psi = \frac{\gamma dS}{(\gamma_s - \gamma) D_{50}}$$

where D_{50} = median size of bed material

Table 8.7: Estimated Annual Bed Material Loads

Year	Bed Material Load (tonne/yr)	
	Kanairghat	Sylhet
1986	690,000	593,000
1987	950,000	852,000
1988	1,540,000	1,221,000
1989	1,530,000	995,000

Table 8.8: Morphologic Characteristics of Kushiyara/Kalni River

Extent of Reach	Physiographic Unit	Channel Pattern	Channel Confinement	Bars	Islands	Vertical Stability	Lateral Stability	Bed Material D_{65} (mm) D_{50} (mm) D_{35} (mm)	Bank Material	Sinuosity (Lc/Lv)	Slope(m/km) Average Pre-monsoon Monsoon	Bankfull Dimensions Top Width Mean Depth Area
Amalshid - Fenchuganj Km 0 - Km 95	Kushiyara Floodplain	Single channel; Irregular meanders	Often deflects off uplands & inerodible materials	Point Bars	Absent	Stable, minor degradation	progressive meander migration channel widening	0.23 0.20 0.16	Silt Clay	1.42	0.040 0.070 0.060	166 9.76 1410
Fenchuganj - Manumukh Km 95 - Km 130	Kushiyara Floodplain	Single channel; Irregular meanders	Partly confined by embankments	Absent	Absent	Stable	progressive meander migration channel widening	0.18 0.16 0.13	Silt Clay	1.28	0.030 0.040 0.040	225 8.06 1810
Manumukh - Suriya River Km 130 - Km 152	Kushiyara Floodplain	Single channel; Irregular/sinuous	Partly confined by embankments	Absent	Absent	Degrading	channel switching due to loop cutting, channel widening	0.10 0.095 0.08	Clay, organic clay and silt	1.25	0.020 0.040 0.040	240 9.1 2177
Suriya River - Markuli Km 152 - Km 180	Kushiyara Floodplain	Single channel; Irregular/straight due to loop cutting	Unconfined	Absent	Absent	Degrading	major avulsion in 1960's ongoing widening and shifting due to loop cutting	0.11 0.10 0.086	Clay organic clay and silt	1.36	0.010 0.030 0.030	251 6.82 1711
Markuli Dhaleswari River Km 180 - Km 235	Central Basin	Single channel; Irregular meanders	Unconfined	Absent	Few	Aggrading rapidly	Channel widening and irregular shifting due to loop cutting	0.11 0.10 0.086	Silty Clay	1.12	0.022 0.080 0.008	335 4.1 1365
Dhalewari River Km 235 - Km 271	Central Basin	Split channel; Irregular sinuous	Unconfined	Point bars	Common	Aggrading slowly	Irregular shifts and avulsion of distributary channels	0.11 0.10 0.086	Silty Clay,	1.76	0.015 0.060 0.006	na

Note:

1. River classification criteria based on Neill and Galay (1967).
2. Extent of river reaches are shown on Figures 57
3. Definition of Physiographic Units shown on Figure 14
4. Channel Sinuosity = Channel Length/Valley Length

282

Table 8.9: Discharges Along Kushiyara - Kalni River

Location	Mean Annual Flow m^3/s	May Q m^3/s	July Q m^3/s	Mean Annual Flood m^3/s
Kushiyara at Sheola	682	621	1,621	2,160
Kushiyara at Sherpur	1,100	1,123	1,883	2,550
Kalni at junction with Meghna	1,830	1,870e	4,300e	?

Note: 1. Mean annual discharges provided by Hydrology group, NERP

2. Monthly flows and mean annual floods estimated for period 1964-1989. These values are approximate.

Table 8.10: Channel Changes on Kushiyara River
Amalshid to Fenchuganj

Year	Cross section Area(m2)	Top Width (m)	Mean Depth (m)
1969	1377	166	8.3
1978	1365	164	8.3
1990	1410	156	9.0

Table 8.11: Channel Changes Between Fenchuganj and Manumukh

Cross Section	Area (m^2)	Top Width (m)	Mean Depth (m)	Thalweg Level (m PWD)
1-1969	1420	170	8.35	-5.93
1-1972	1336	214	6.23	-7.3
1-1973	1348	164	8.22	-8.63
1-1978	1649	262	6.29	-5.83
1-1993	1429	212	6.73	-5.92
2-1969	1569	207	7.58	-8.25
2-1972	1507	155	9.7	-8.5
2-1973	1523	183	8.33	-9.87
2-1978	1541	172	8.98	-5.43
2-1993	1644	178	9.24	-6.81
3-1969	1714	177	9.66	-5.16
3-1972	1738	198	8.77	-5.96
3-1973	1668	249	6.7	-9.11
3-1978	1792	189	9.5	-5.34
3-1993	1660	191	8.7	-2.0
4-1969	1022	110	9.28	-4.36
4-1972	1226	135	9.06	-6.8
4-1973	1274	146	8.76	-8.23
4-1978	1342	125	10.72	-7.32
4-1993	1370	147	9.32	-6.52

Table 8.12: Hydraulic and Sediment Transport Parameters

Kushiyara River at Sheola

Q (m^3/s)	Hydraulic Geometry			Froude Number Fr	Water Slope	Bed Shear (N/m^2)	Z	Shields Number
	W (m)	d (m)	V (m/s)					
682	134	6.38	0.78	0.099	0.00004	2.50	1.50	0.70
884	138	7.12	0.88	0.106	0.00004	2.79	1.42	0.78
1610	150	9.26	1.19	0.125	0.00005	4.54	1.12	1.27
2160	156	10.3	1.34	0.134	0.00005	5.06	1.06	1.42
2820	161	11.5	1.52	0.143	0.00005	5.65	1.01	1.59

Note: Hydraulic properties have been calculated for the following five discharge conditions for the period 1965 - 1989:

1. Long term mean discharge
2. Average annual maximum pre-monsoon discharge
3. Average discharge in the month of July
4. Average annual maximum daily discharge
5. Maximum daily discharge in period of record

Definition of Terms:

W = Channel Top Width (m)
d = Mean depth (m)
V = Mean channel velocity (m/s)

Fr = Froude Number

$$Fr = V/\sqrt{(gd)}$$

Z = Rouse Number

$$Z = \frac{w}{kV_*}$$

where w = sediment fall velocity, V_* = shear velocity and k = Von Karman Coefficient

Shields Number

$$\psi = \frac{\gamma dS}{(\gamma_s - \gamma) D_{50}}$$

where D_{50} = median size of bed material

Table 8.13: Hydraulic and Sediment Transport Parameters

Kushiyara River at Sherpur

Q (m^3/s)	Hydraulic Geometry W (m)	d (m)	V (m/s)	Froude Number Fr	Water Slope	Bed Shear (N/m^2)	Z	Shields Number
1100	223	7.27	0.68	0.081	0.00004	2.85	0.93	1.10
1587	232	7.82	0.85	0.097	0.00004	3.07	0.90	1.19
2015	238	8.27	1.01	0.112	0.00004	3.25	0.87	1.25
2545	245	8.72	1.20	0.134	0.00004	3.57	0.83	1.37
3950	260	9.6	1.62	0.160	0.00004	3.77	0.80	1.45

Note: Hydraulic properties have been calculated for the following five discharge conditions for the period 1982-1991:

1. Long term mean discharge
2. Average annual maximum pre-monsoon discharge
3. Average discharge in the month of July
4. Average annual maximum daily discharge
5. Maximum daily discharge in period of record

Definition of Terms:

W = Channel Top Width (m)

d = Mean depth (m)

V = Mean channel velocity (m/s)

Fr = Froude Number

$$Fr = V/\sqrt{(gd)}$$

Z = Rouse Number

$$Z = \frac{w}{kV_*}$$

where w = sediment fall velocity, V_* = shear velocity and k = Von Karman Coefficient

Shields Number

$$\psi = \frac{\gamma d S}{(\gamma_s - \gamma) D_{50}}$$

where D_{50} = median size of bed material

Table 8.14: Bed Material Loads along Kushiyara/Kalni River

Year	Annual Bed Material Transport Rates (tonnes)			
	Sheola	Sherpur	Ajmiriganj	Madna
1982	1600000	1650000	947000	413000
1986	1647000	1535000	846000	260000
1987	2808000	3305000	659000	274000
1989	2642000	5236000	1281000	456000

Table 8.15: Budget of Annual Bed Material Load

Year	Net Inflow/Outflow from Reach (tonnes)		
	Sheola - Sherpur	Sherpur - Ajmiriganj	Ajmiriganj -Madna
1982	-50000	703000	534000
1986	112000	689000	586000
1987	-497000	2646000	385000
1989	-2595000	3955000	826000

Table 9.1: Channel Widening due to Embankments

% Change in Dominant Discharge	% Change in Channel Top Width
10	5
20	10
30	14
50	22

Table 9.2: Average Suspended Sediment
Loads in Two Time Periods

Site	Sediment Load (million t/yr)		
	1974-82	1983-91	% Increase
Kushiyara River at Sheola	5.6	8.51	52
Surma River at Sylhet	1.5	2.5	70
Khowai River at Shaistaganj	0.5	1.2	125
Manu River at Railway	4.7	6.1	30

[illegible]

ANNEX B

FIGURES

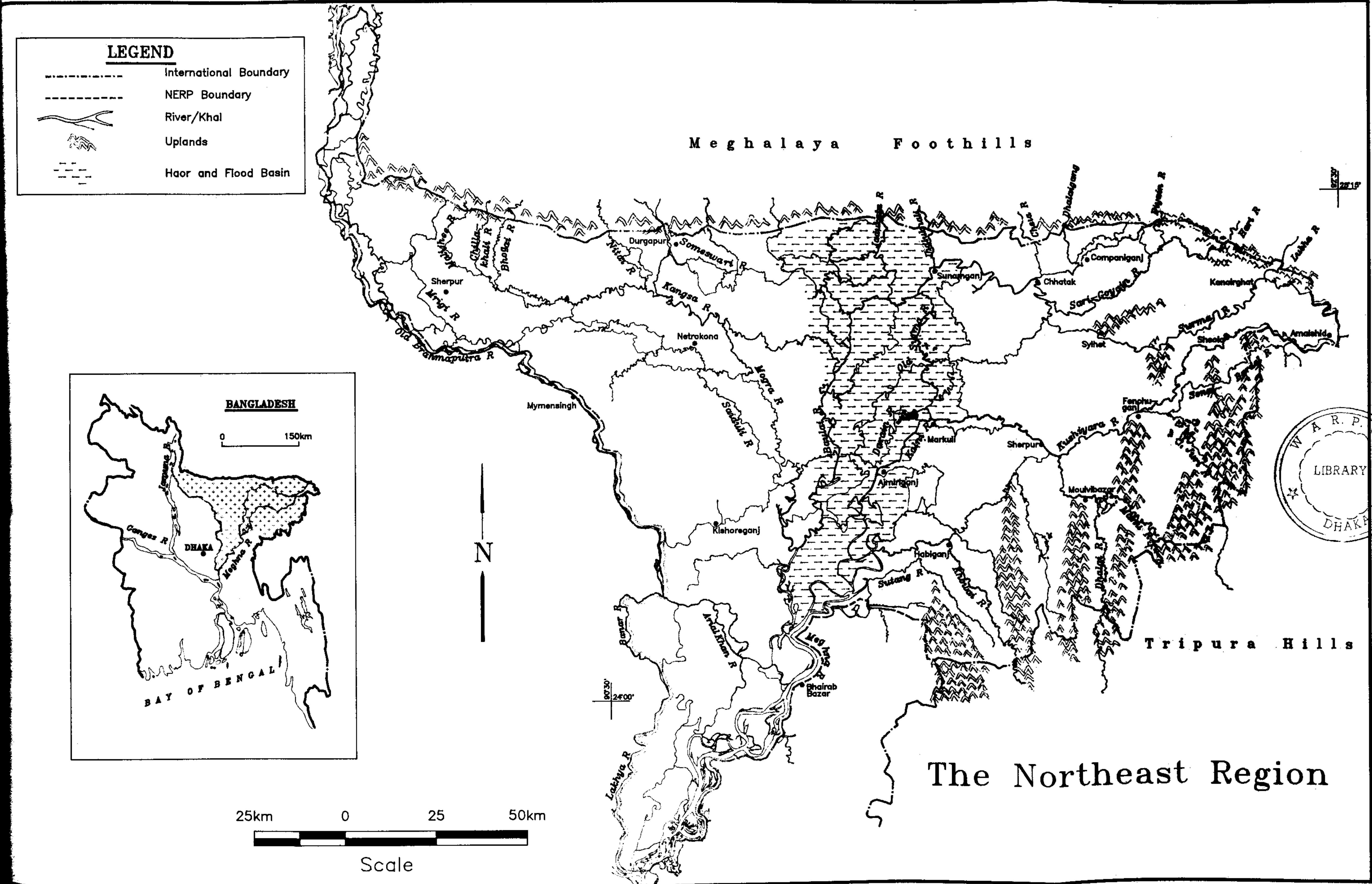
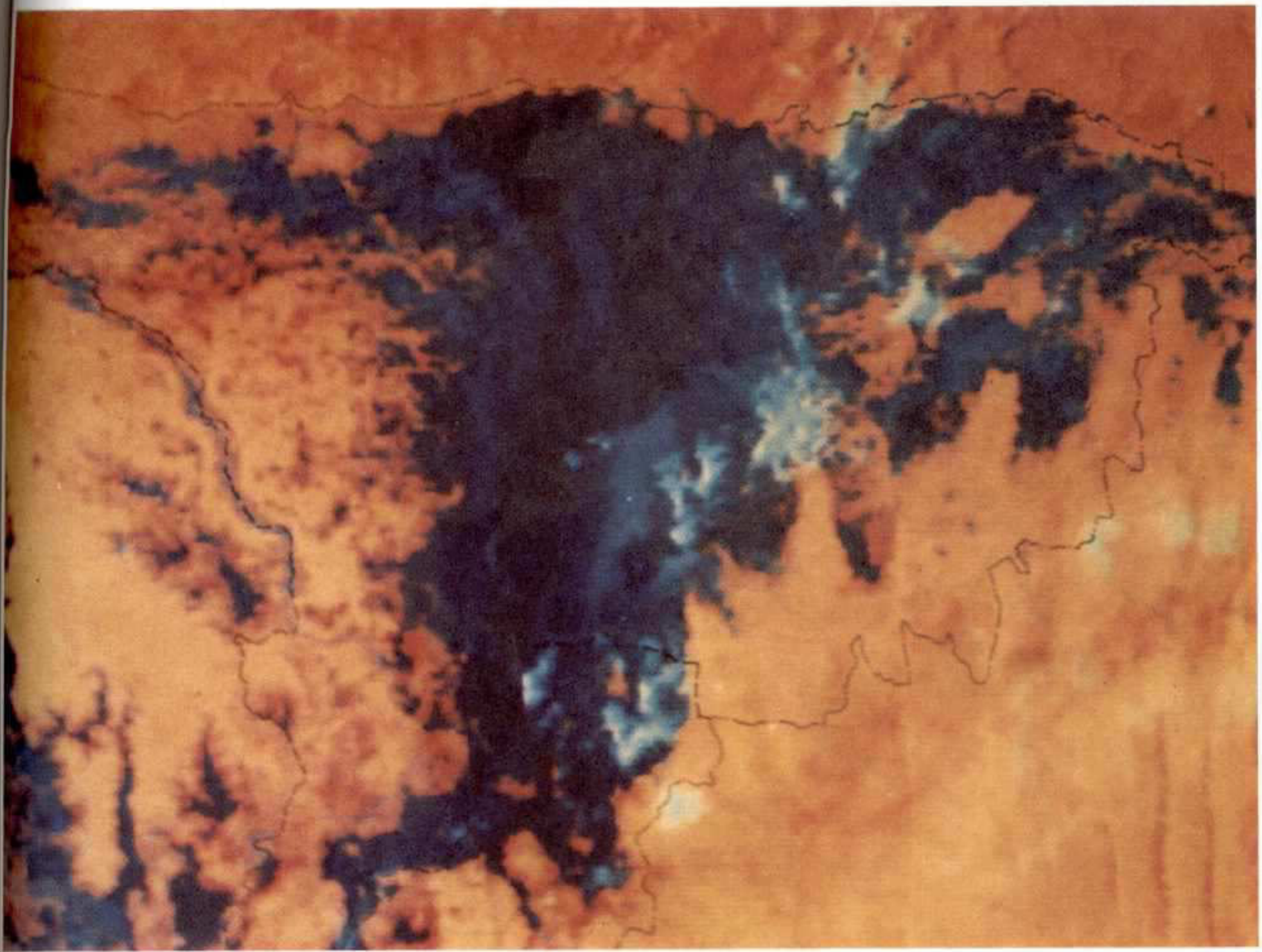
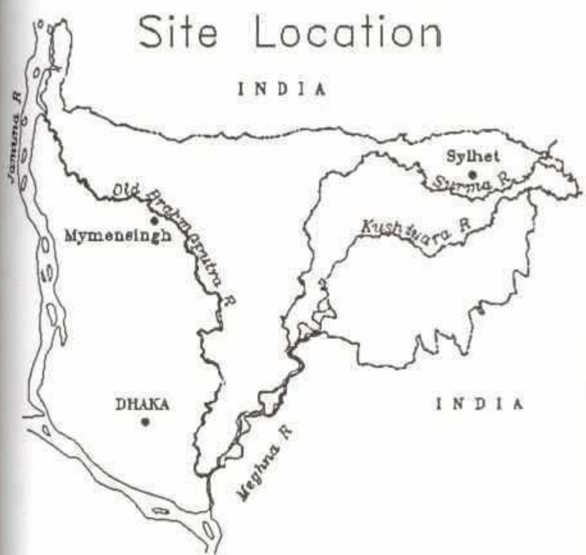

LEGEND
International Boundary
NERP Boundary
River/Khal
Uplands
Haor and Flood Basin
Meghalaya Foothills
Tripura Hills
BANGLADESH
0
150km
DHAKA
BAY OF BENGAL
Durgapur
Sherpur
Netrokona
Mymensingh
Kishoreganj
Sunamganj
Chhatak
Companiganj
Kanaighat
Sylhet
Sheola
Amalshid
Fenchuganj
Sherpur
Markuli
Ajmiriganj
Moulvibazar
Habiganj
Bhairab Bazar
Someswari R
Kangsa R
Mogra R
Old Brahmaputra R
Kushiyara R
Sari-Goyain R
Surma R
Lubha R
Sutang R
Khowai R
Dhalai R
Arial Khan R
Banar R
Lakhya R
Meghna R
N
25km
0
25
50km
Scale
The Northeast Region

Figure 2



Site Location



Scale

20km 0 20 40 km

1:1,500,000 (approx)

N

Photo Courtesy of SPARRSO

Northeast Regional Project	
Extent of Inundation in October 1988	
Prepared by: DMc	May 1993

FILE: dm187.DWG

Figure 3

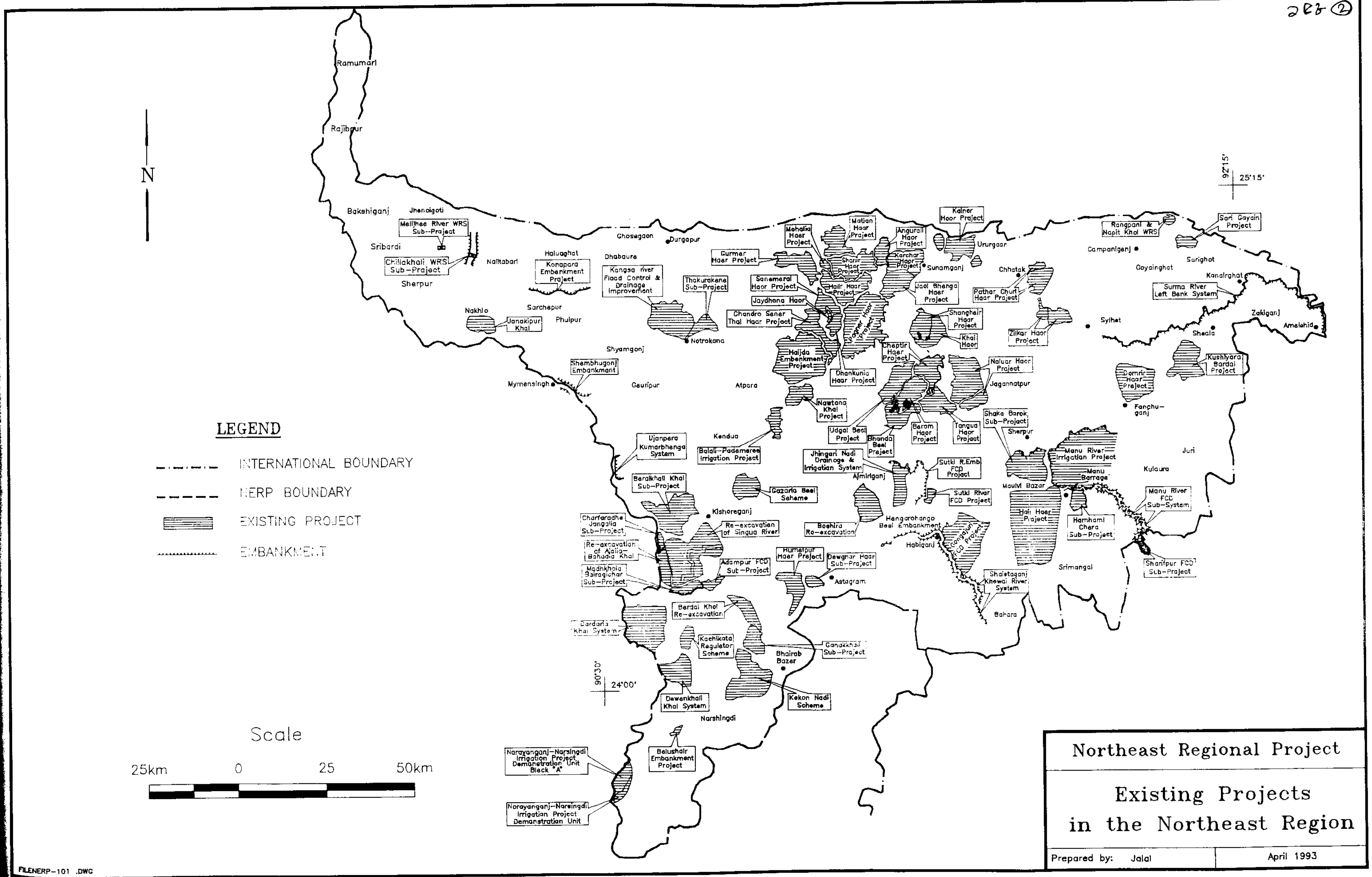
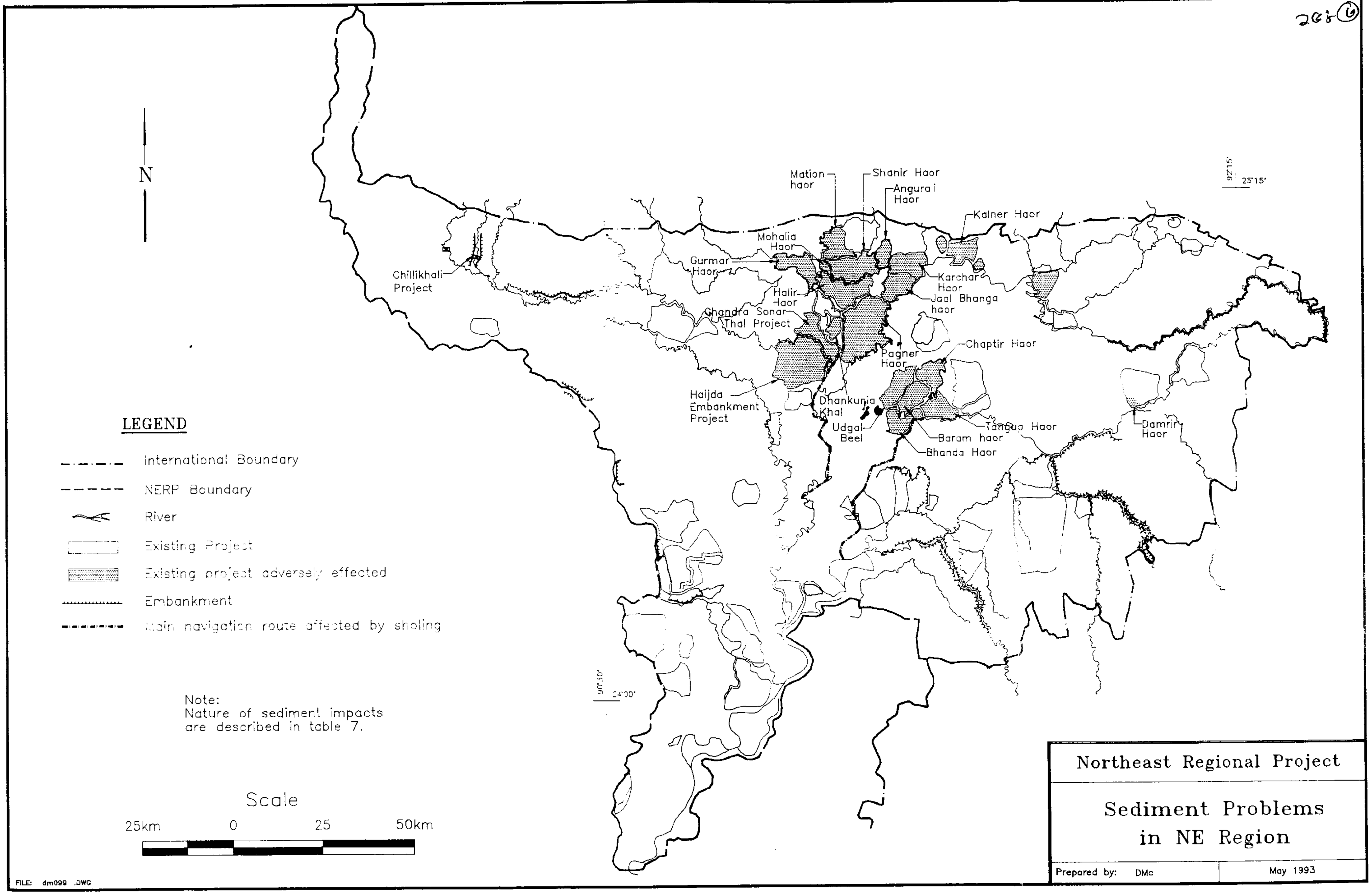

Northeast Regional Project
Existing Projects in the Northeast Region
Prepared by: Jalal
April 1993
LEGEND
INTERNATIONAL BOUNDARY
NERP BOUNDARY
EXISTING PROJECT
EMBANKMENT
Scale
25km 0 25 50km
N
25°15'
92°15'
24°00'
90°30'
Ramumari
Rajibpur
Bakshiganj
Jhenaigati
Sribardi
Sherpur
Nalitabari
Haluaghat
Dhabaura
Ghosegaon
Durgapur
Nakhla
Sarchapur
Phulpur
Netrokona
Shyamganj
Mymensingh
Gauripur
Atpara
Kendua
Kishoreganj
Hangarohango Beel Embankment
Habiganj
Astagram
Bhairab Bazar
Narshingdi
Sunamganj
Ururgaon
Chhatak
Companiganj
Goyainghat
Sarighat
Kanairghat
Zakiganj
Sylhet
Amalshid
Sheala
Jagannatpur
Fanchu-ganj
Sherpur
Juri
Kulaura
Maulvi Bazar
Srimangal
Bahara
Ajmiriganj
Meilihae River WRS Sub-Project
Chillakhali WRS Sub-Project
Konapara Embankment Project
Kangsa river Flood Control & Drainage Improvement
Thakurakona Sub-Project
Janakipur Khal
Shambhuganj Embankment
Gurmar Haor Project
Mohalia Haor Project
Matian Haor Project
Angurali Haor Project
Kalner Haor Project
Rangpani & Napit Khal WRS
Sari Gayain Project
Sanameral Haor Project
Jaydhona Haor
Chandro Sonar Thal Haor Project
Shanir Haor Project
Karchar Haor Project
Hail Haor Project
Jaoi Bhanga Haor Project
Pathar Churi Haor Project
Surma River Left Bank System
Shanghair Haor Project
Khai Haor
Zilkar Haor Project
Haijda Embankment Project
Dhankunia Haor Project
Chaptir Haor Project
Naluar Haor Project
Kushiyara Bardal Project
Damrir Haor Project
Nawtana Khal Project
Udgal Beel Project
Bhanda Beel Project
Barom Haor Project
Tangua Haor Project
Shaka Barok Sub-Project
Balali-Padamoree Irrigation Project
Jhingari Nadi Drainage & Irrigation System
Sutki R.Emb FCD Project
Sutki River FCD Project
Manu River Irrigation Project
Manu Barrage
Ujanpara Kumarbhanga System
Baraikhali Khal Sub-Project
Gazaria Beel Scheme
Charfaradhe Jangalia Sub-Project
Re-excavation of Singua River
Re-excavation of Adiia-Bahadia Khal
Baghira Re-excavation
Kongsa FCD Project
Hail Haor Project
Hamhami Chera Sub-Project
Manu River FCD Sub-System
Madhkhola Bairagichar Sub-Project
Adampur FCD Sub-Project
Humaipur Haor Project
Dewghar Haor Sub-Project
Shaistaganj Khowai River System
Shaitpur FCD Sub-Project
Bardal Khal Re-excavation
Dardaria Khal System
Kachikata Regulator Scheme
Ganakkhali Sub-Project
Dewankhali Khal System
Kekon Nadi Scheme
Narayanganj-Narsingdi Irrigation Project Demonstration Unit Block "A"
Belushair Embankment Project
Narayanganj-Narsingdi Irrigation Project Demonstration Unit
FILENERP-101 .DWG

Figure 4

261(6)



Northeast Regional Project

Sediment Problems in NE Region

Prepared by: DMc | May 1993

Figure 5

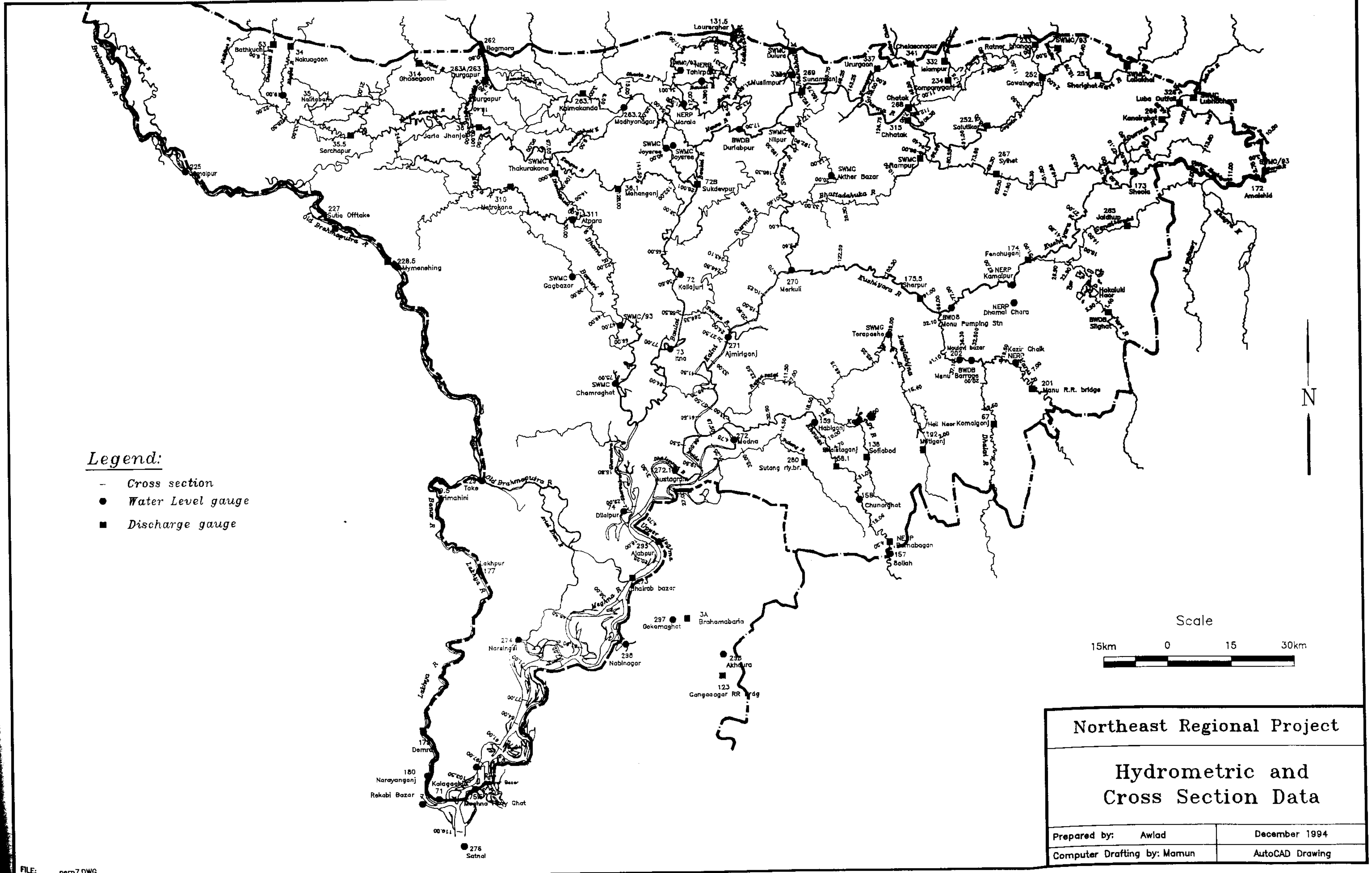
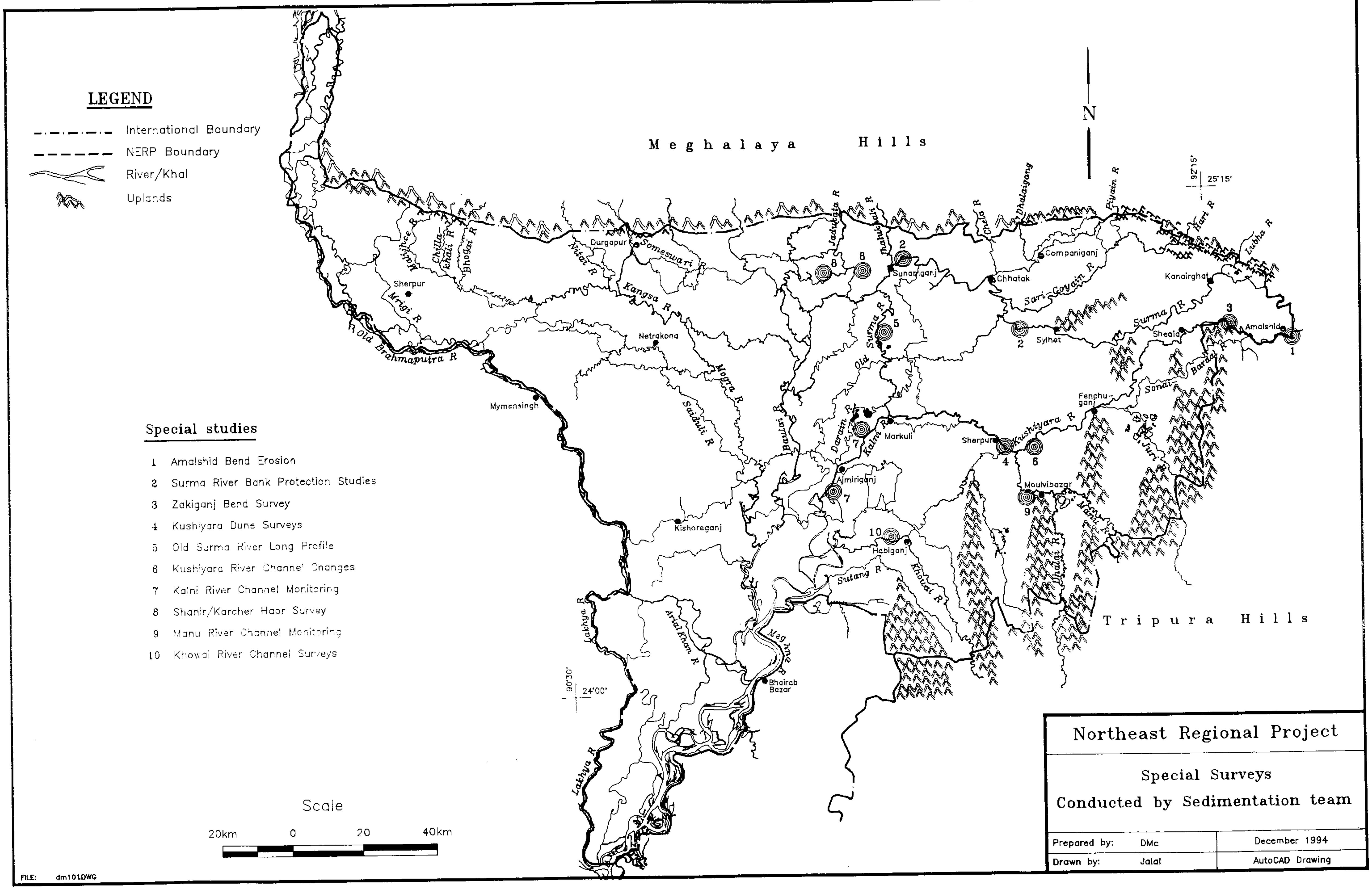
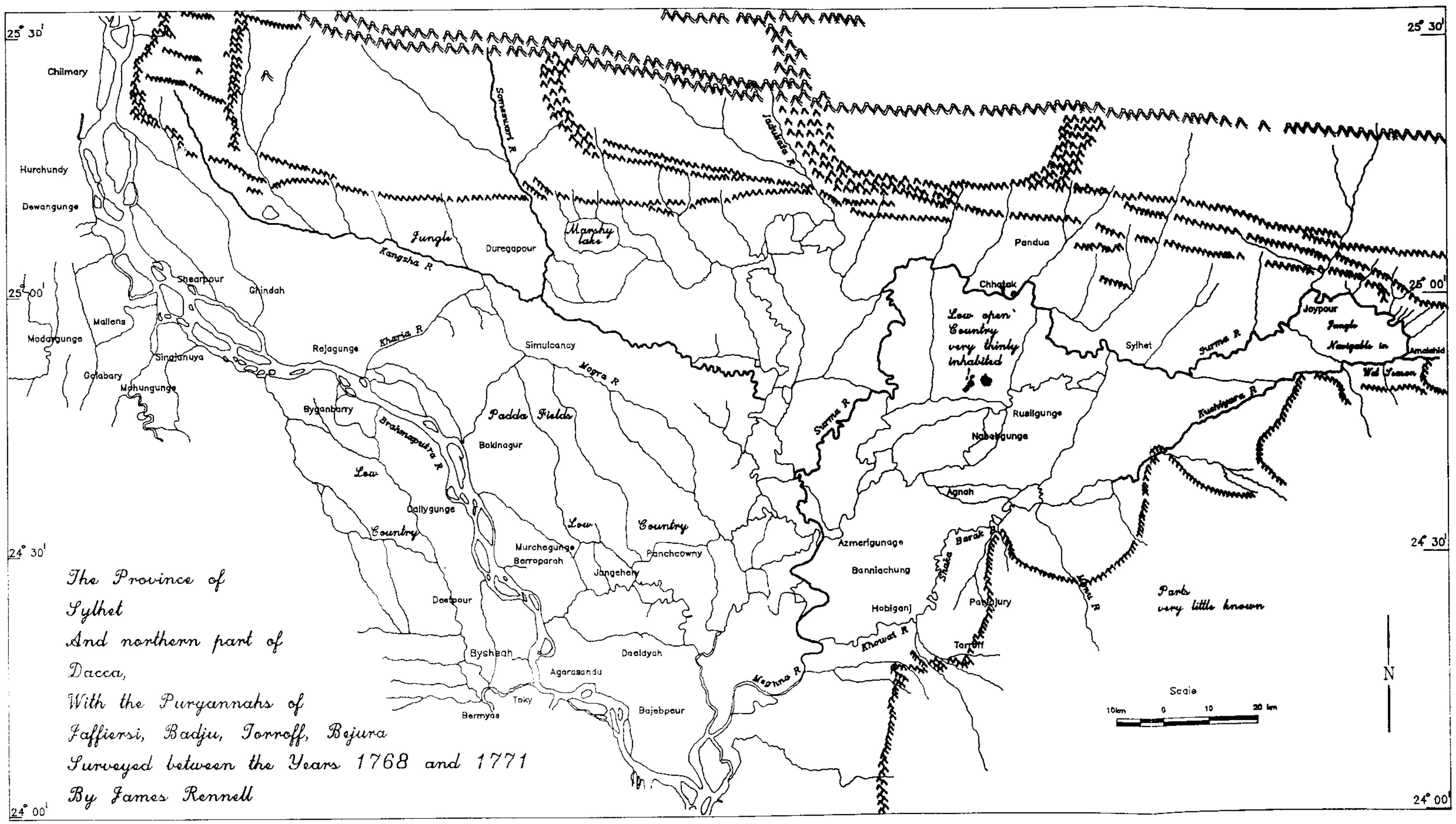

Legend:
Cross section
Water Level gauge
Discharge gauge
Scale
15km 0 15 30km
N
Northeast Regional Project
Hydrometric and Cross Section Data
Prepared by: Awlad
December 1994
Computer Drafting by: Mamun
AutoCAD Drawing
FILE: narp7.DWG

Figure 6

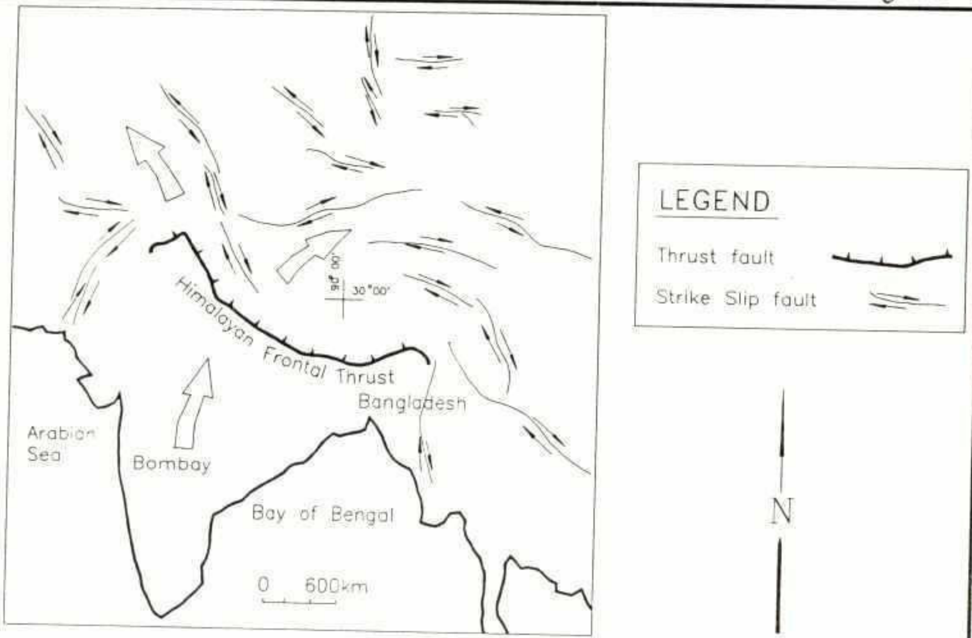


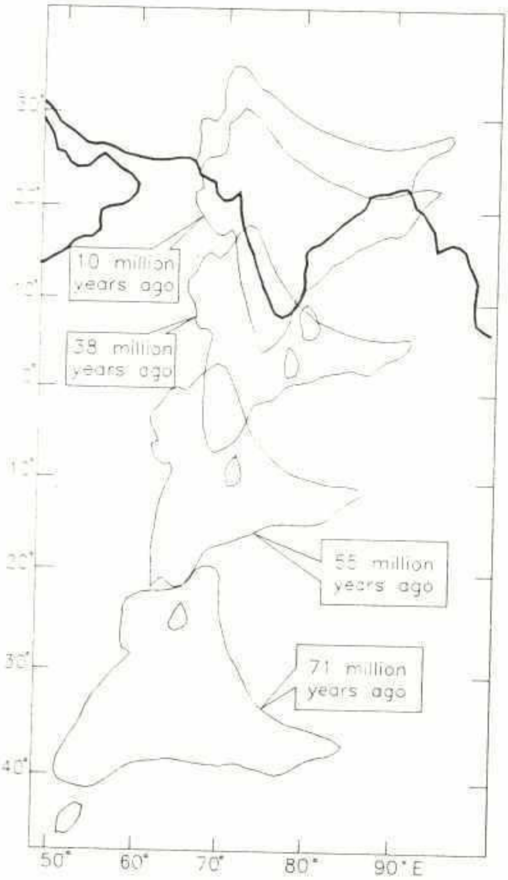
LEGEND
International Boundary
NERP Boundary
River/Khal
Uplands
Special studies
1 Amalshid Bend Erosion
2 Surma River Bank Protection Studies
3 Zakiganj Bend Survey
4 Kushiyara Dune Surveys
5 Old Surma River Long Profile
6 Kushiyara River Channel Changes
7 Kalni River Channel Monitoring
8 Shanir/Karcher Haor Survey
9 Manu River Channel Monitoring
10 Khowai River Channel Surveys
Scale
20km 0 20 40km
Meghalaya Hills
Tripura Hills
N
Sherpur
Durgapur
Netrakona
Mymensingh
Kishoreganj
Bhairab Bazar
Sunamganj
Chhatak
Companiganj
Kanairghat
Sylhet
Sheala
Amalshid
Fenchuganj
Markuli
Sherpur
Ajmiriganj
Moulvibazar
Habiganj
Old Brahmaputra R
Someswari R
Kangsa R
Mogra R
Saidhuli R
Baulai R
Darain R
Kalni R
Old Surma R
Kushiyara R
Sari-Goyain R
Surma R
Sonai R
Barak R
Manu R
Dhalai R
Khowai R
Sutang R
Meghna R
Arial Khan R
Lakhya R
Jadukata R
Jhalukhali R
Chela R
Dhalaigang
Piyain R
Hari R
Lubha R
Malijhee R
Chillakhali R
Bhogai R
Mrigi R
Nitai R
Juri R
90°30'
24°00'
92°15'
25°15'
Northeast Regional Project
Special Surveys
Conducted by Sedimentation team
Prepared by: DMc
December 1994
Drawn by: Jalal
AutoCAD Drawing
FILE: dm101.DWG

Figure 7



The Province of
Sylhet
And northern part of
Dacca,
With the Purgannahs of
Jaffiersi, Badju, Torroff, Bejura
Surveyed between the Years 1768 and 1771
By James Rennell
25° 30'
25° 00'
24° 30'
24° 00'
Chilmary
Hurchundy
Dewangunge
Shearpour
Ghindah
Mallens
Modagunge
Singjanuya
Golabary
Mohungunge
Rajagunge
Kharia R
Byganbarry
Brahmaputra R
Low
Country
Dallygunge
Deepour
Byshkah
Bermyas
Toky
Agarasandu
Jungle
Kangsha R
Duregapour
Somesworj R
Marshy lake
Simulcanoy
Mogra R
Padda Fields
Bokinagur
Murchagunge
Barraparah
Jangehary
Low
Country
Panchcowny
Daaldyah
Bajabpour
Meghna R
Jadukata R
Surma R
Azmerigunage
Banniachung
Hobiganj
Khowai R
Shaka Barak
Pandua
Chhatak
Low open Country very thinly inhabited
Rusligunge
Nabobgunge
Agnah
Panjury
Tarruff
Sylhet
Surma R
Kushiyara R
Joypour
Jungle
Navigable in
Wet Season
Amalshid
Parts very little known
Scale
10km 0 10 20 km
N
NERP-906.DWG





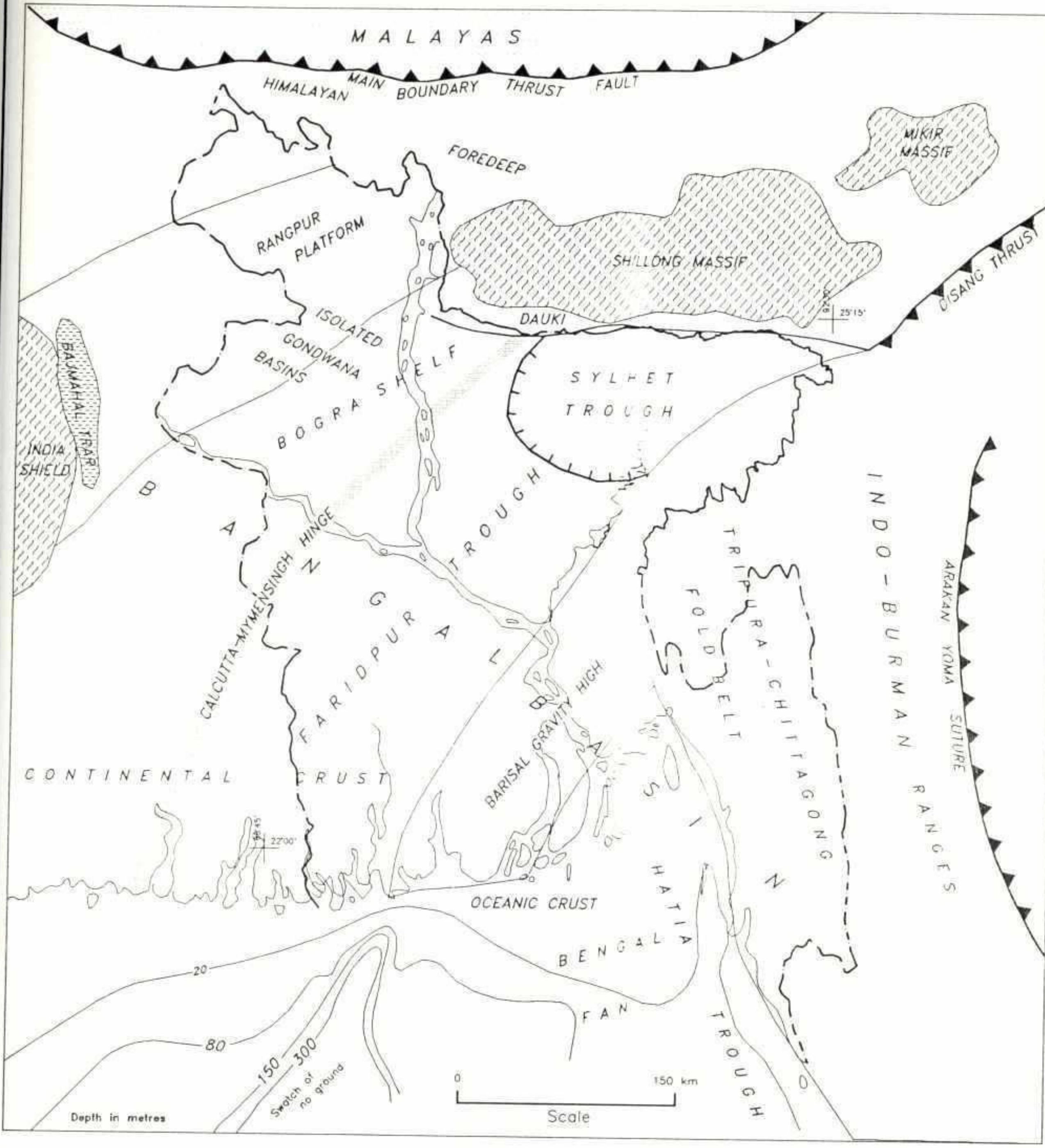
Northeast Regional Project

Geological Evolution of Bangladesh

FILE: NERP-021DWG

Prepared by: DAVE/SJ April 1992

Figure 9



Note:-
Reproduced from Geological Survey of Bangladesh (1990)

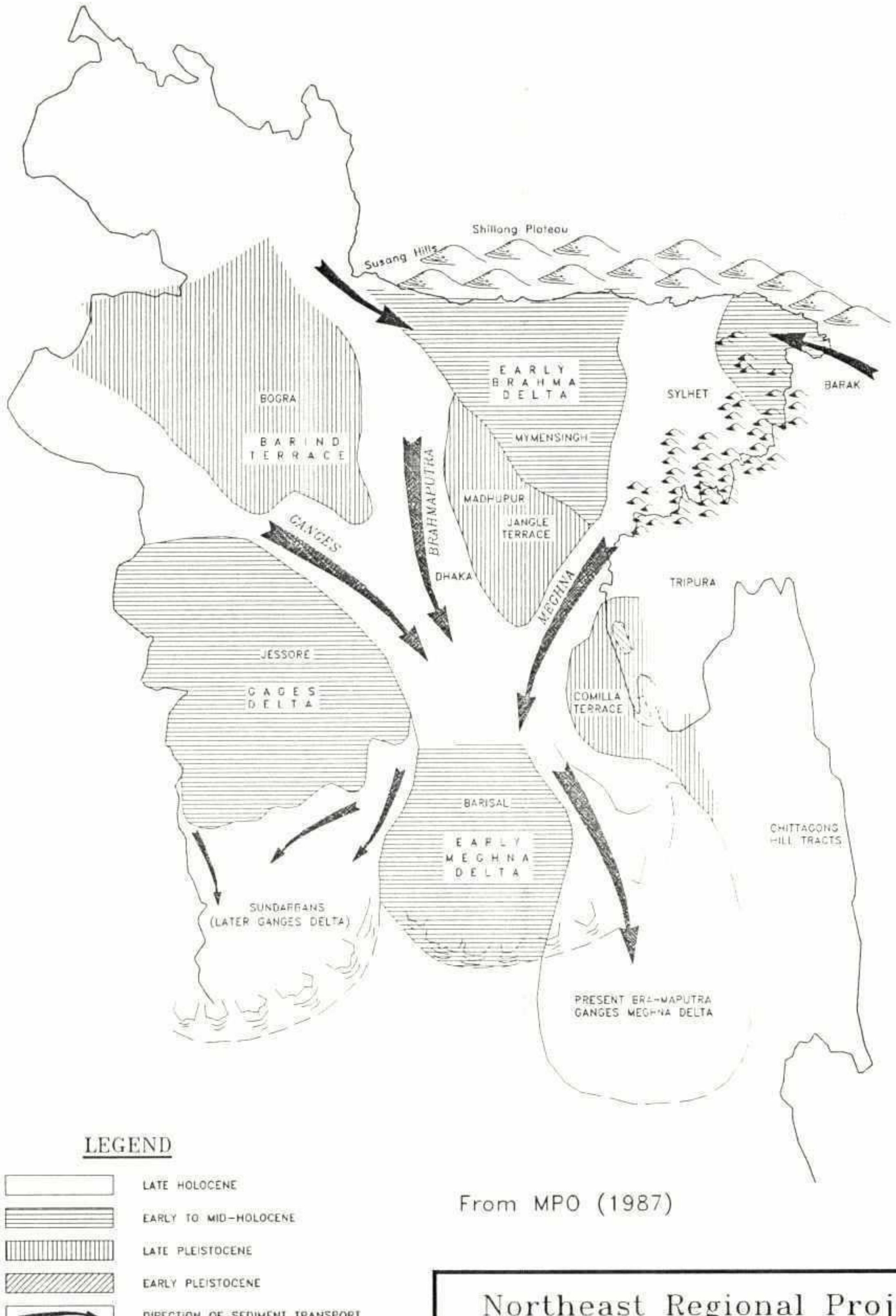
Northeast Regional Project

Tectonic Map of Bangladesh

Prepared by: DMc/Jalal May 1993

FILE: DM-160.DWG

Figure 10



From MPO (1987)

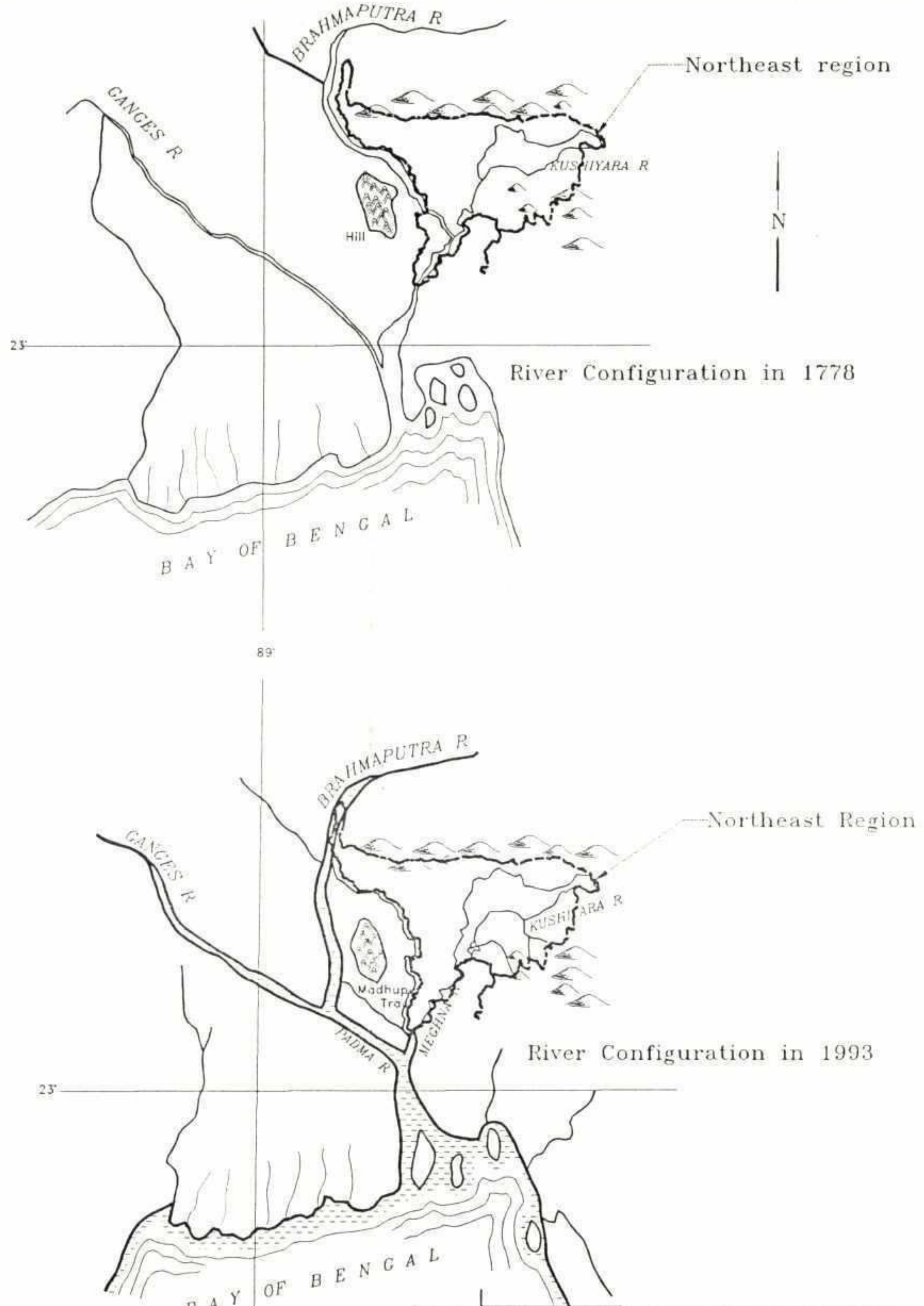
Northeast Regional Project

Quaternary Sedimentation in Bangladesh

Prepared by: DMc	May 1993

FILE: dm199.DWG

Figure 11



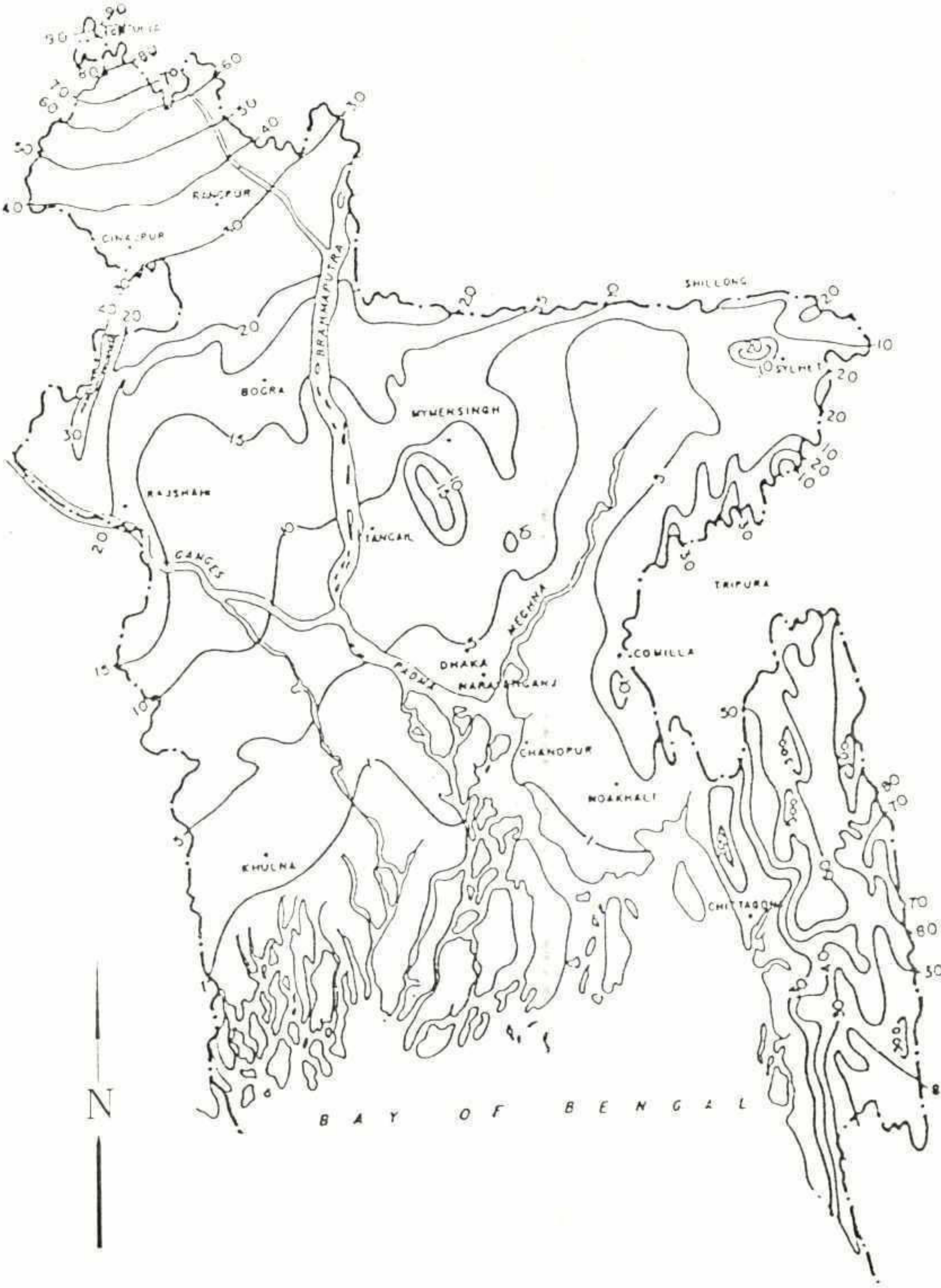
Northeast Regional Project

Evolution of River Systems

Prepared by: DMc/Jalal	April 1993

FILE: DM195.DWG

Figure 12



Notes:

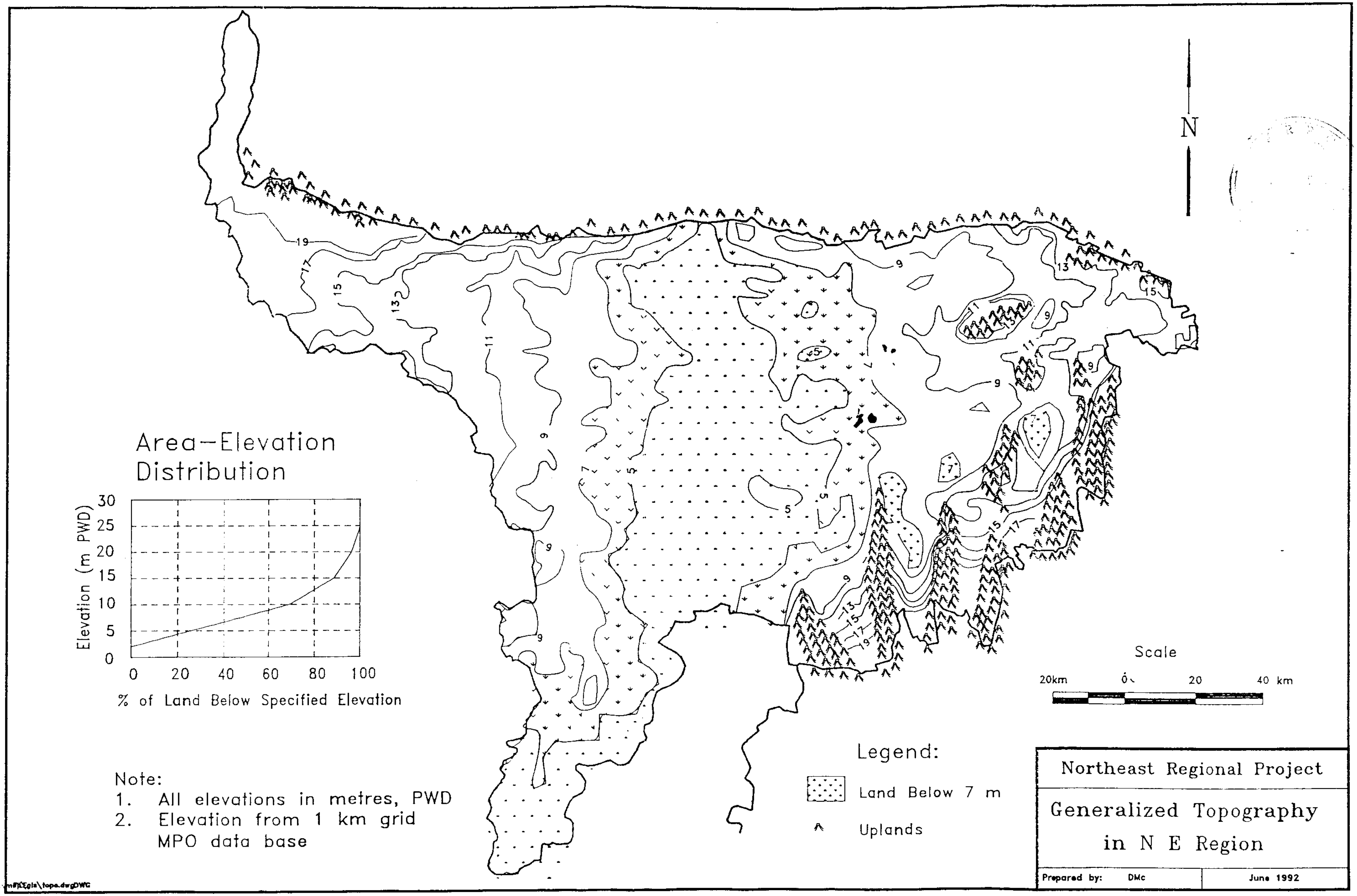
1. Map reproduced from MPO, 1986.
2. Contours in metres

Northeast Regional Project

Generalized Topography of Bangladesh

Prepared by: DMc Dec 1992

FILE: DM157.DWG

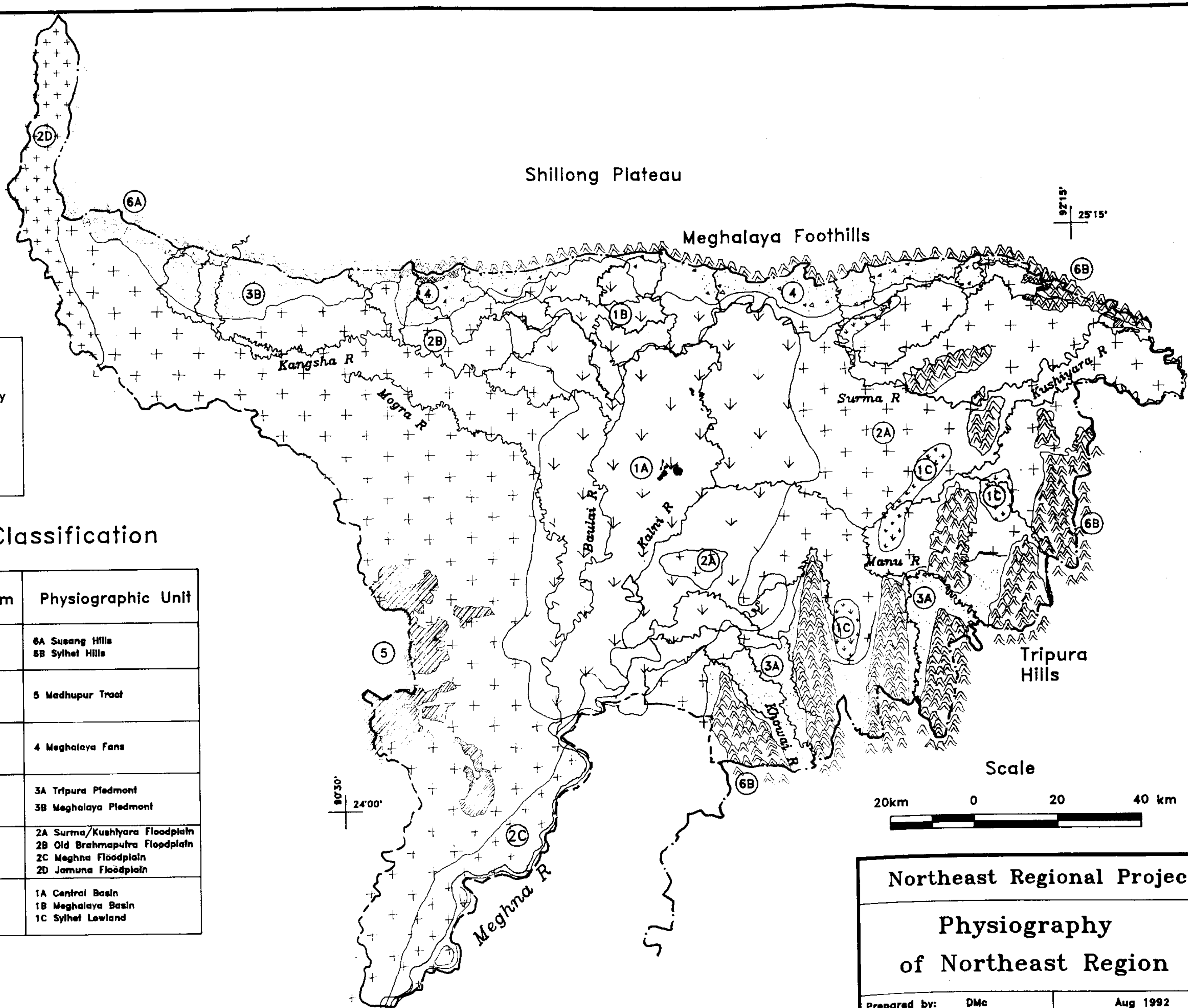


Northeast Regional Project

Generalized Topography in N E Region

Prepared by: DMc June 1992

Figure 14



Legend

- River Channel
- Physiographic Boundary
- International Boundary
- NERP Boundary

Physiographic Classification

Legend	Dominant Landform	Physiographic Unit
	Uplands	6A Susang Hills 6B Sylhet Hills
	Terrace	5 Madhupur Tract
	Alluvial Fan	4 Meghalaya Fans
	Piedmont Floodplain	3A Tripura Piedmont 3B Meghalaya Piedmont
	Lowland Floodplain	2A Surma/Kushiyara Floodplain 2B Old Brahmaputra Floodplain 2C Meghna Floodplain 2D Jamuna Floodplain
	Haor & Flood Basin	1A Central Basin 1B Meghalaya Basin 1C Sylhet Lowland

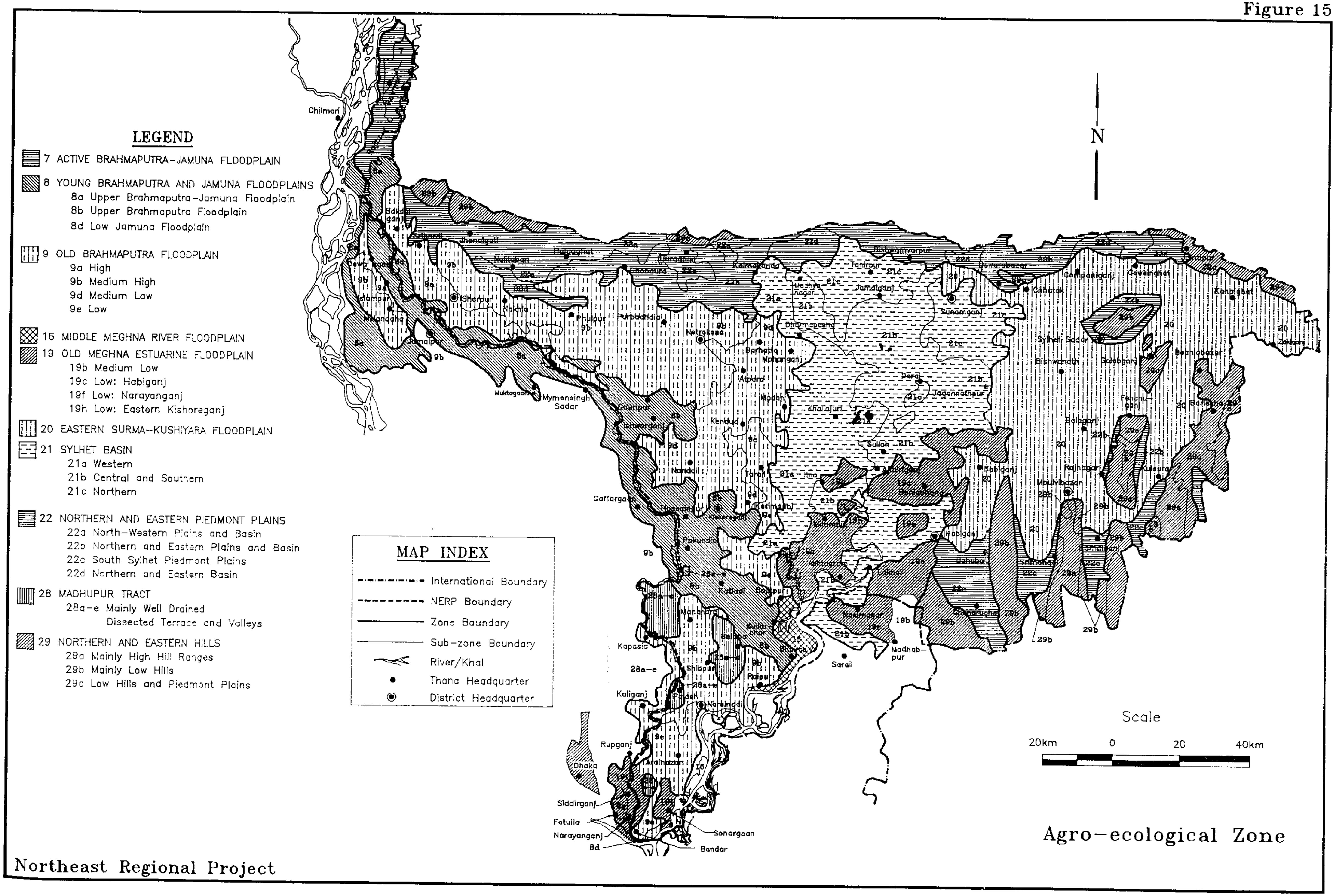
Northeast Regional Project

Physiography of Northeast Region

Prepared by:	DMc	Aug 1992

FILE: DM-109.DWG

Figure 15



Agro-ecological Zone

Northeast Regional Project

Figure 16

Jadukata River   Jhalukhali River

Surma River

Scale

2 0 2 4 km

Approx.

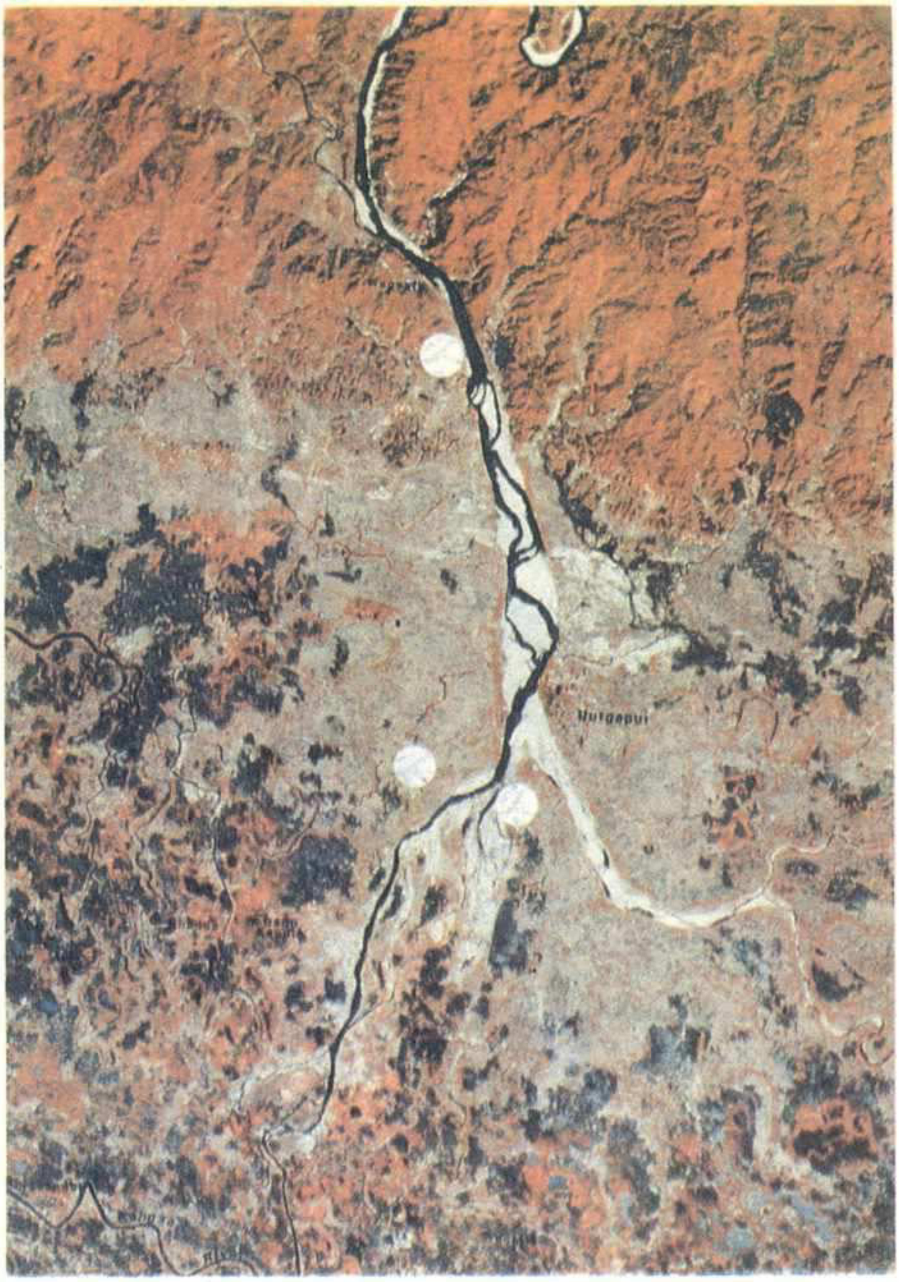
N

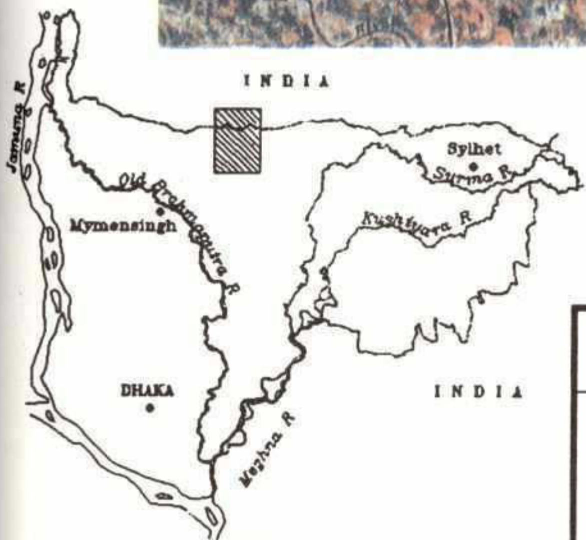
Site Location

Northeast Regional Project	
Jhalukhali River Alluvial Fan	
Prepared by: DMc	May 1993

FILE: Fig. 13.DWG

Figure 17





Site Location

Scale

2 0 2 4 km

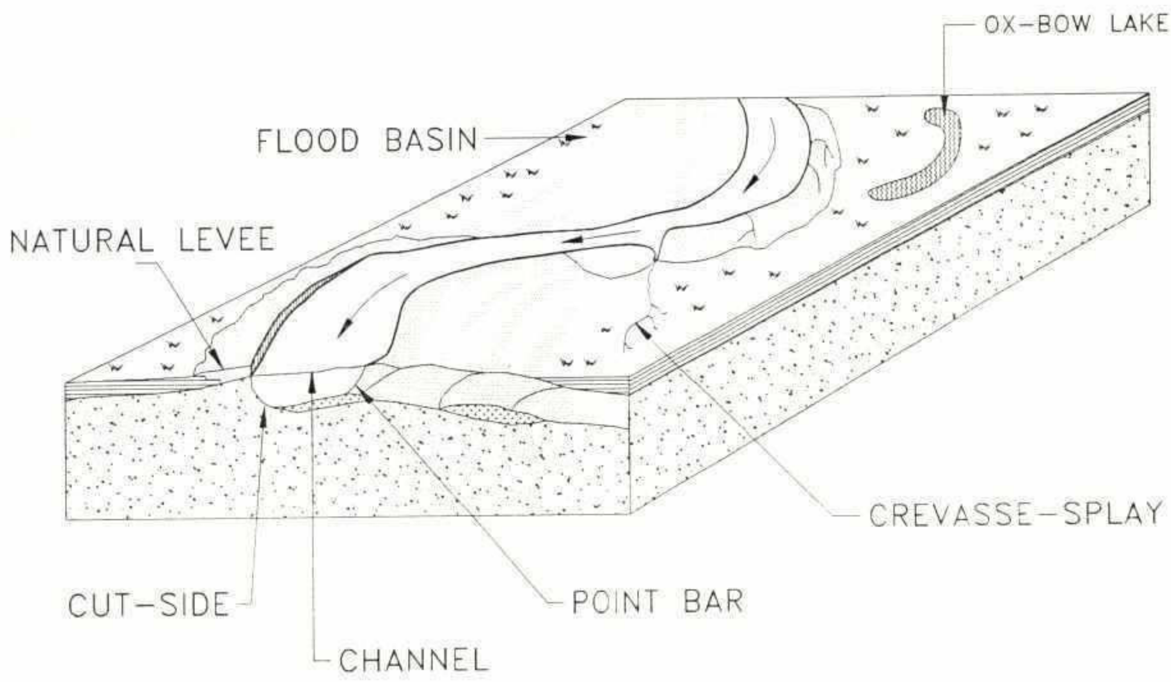
Approx.

Northeast Regional Project

Someswari River Alluvial Fan

File: Fig. 17.DWG

Prepared by: DMc May 1993



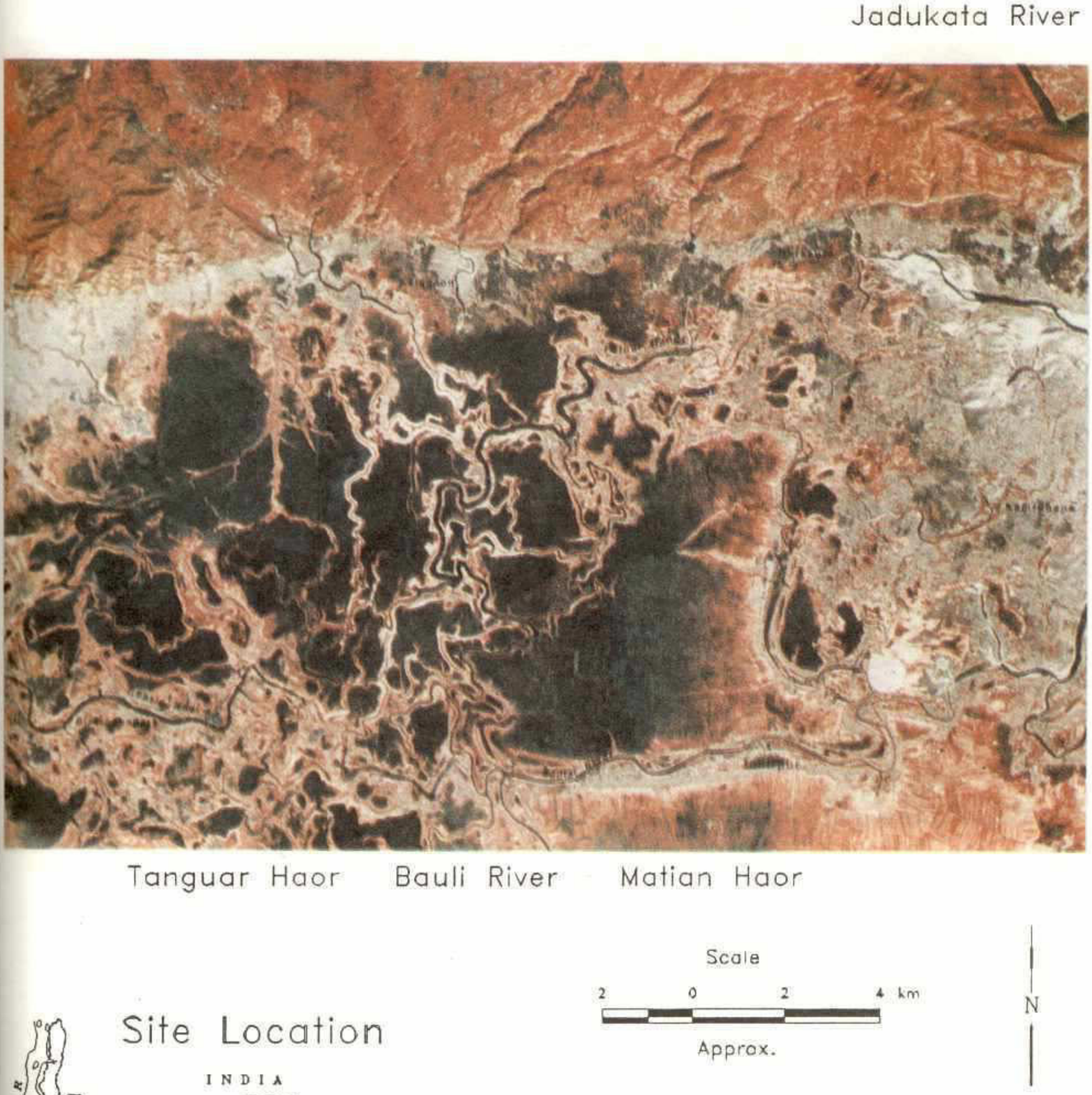
Northeast Regional Project

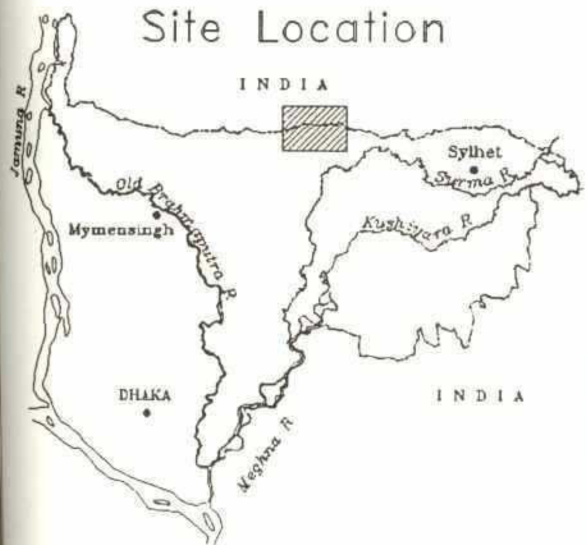
Landforms on Lowland Floodplains

Prepared by: Jalal | May 1993

FILE: dm196.DWG

Figure 19



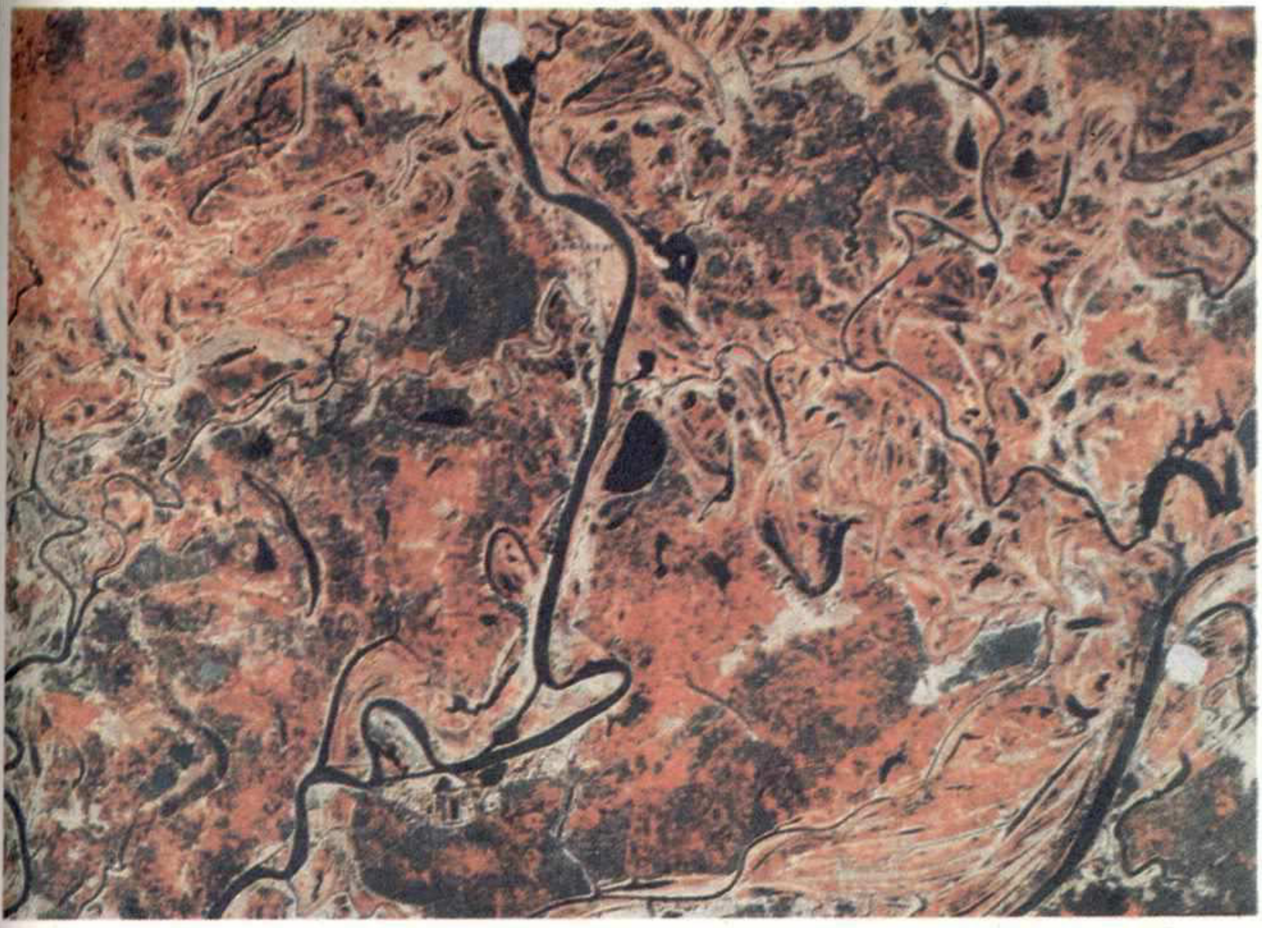


Northeast Regional Project

Meghalaya Basin Haors in Dry Season

Prepared by: DMc	May 1993

FILE: fig. 12.DWG



Baulai River

Kalni River

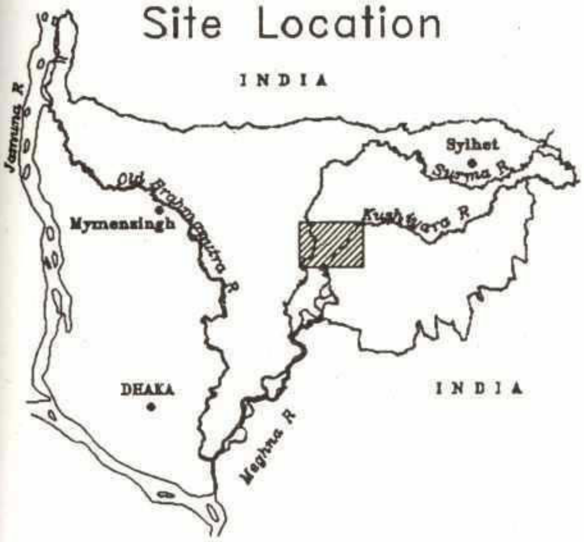
Scale

2 0 2 4 km

Approx.

N

Site Location



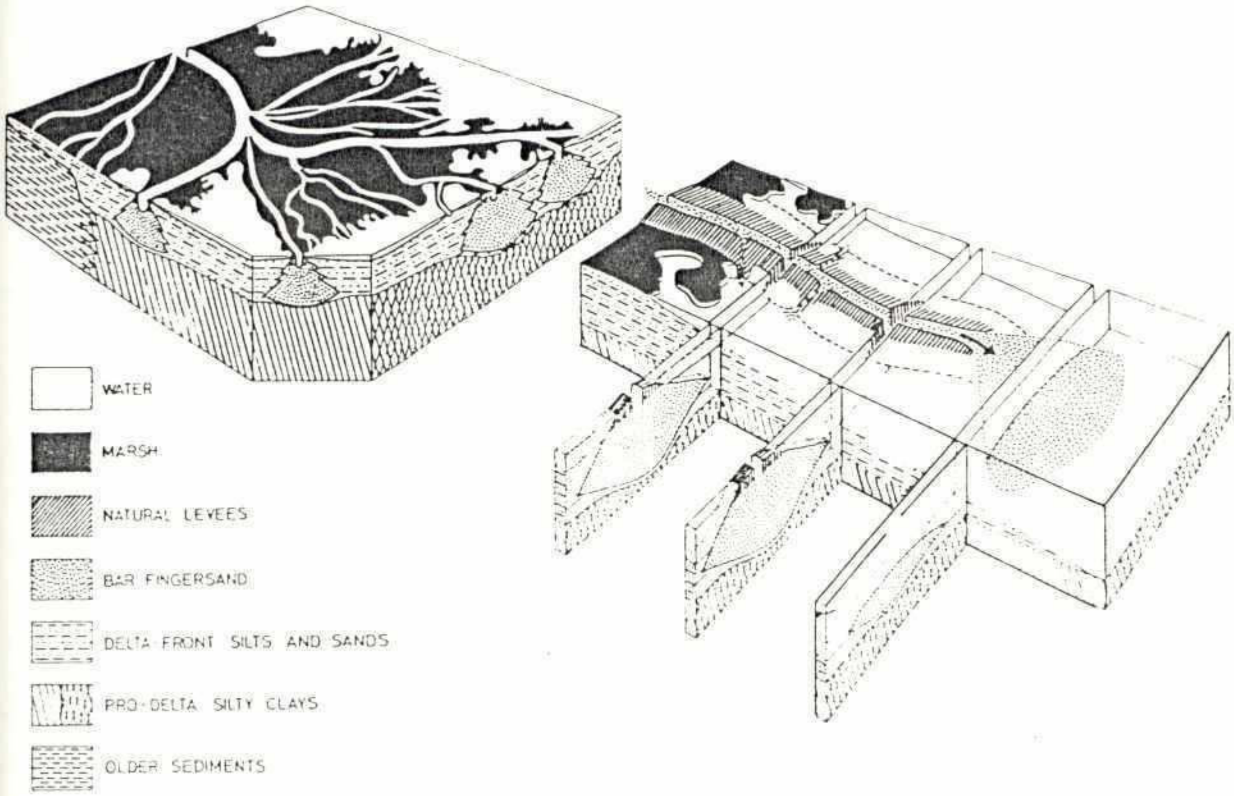
Northeast Regional Project

Channel Pattern on Flood Basin Lowlands

Prepared by: DMc	May 1993

FILE: dm188.DWG

Figure 21

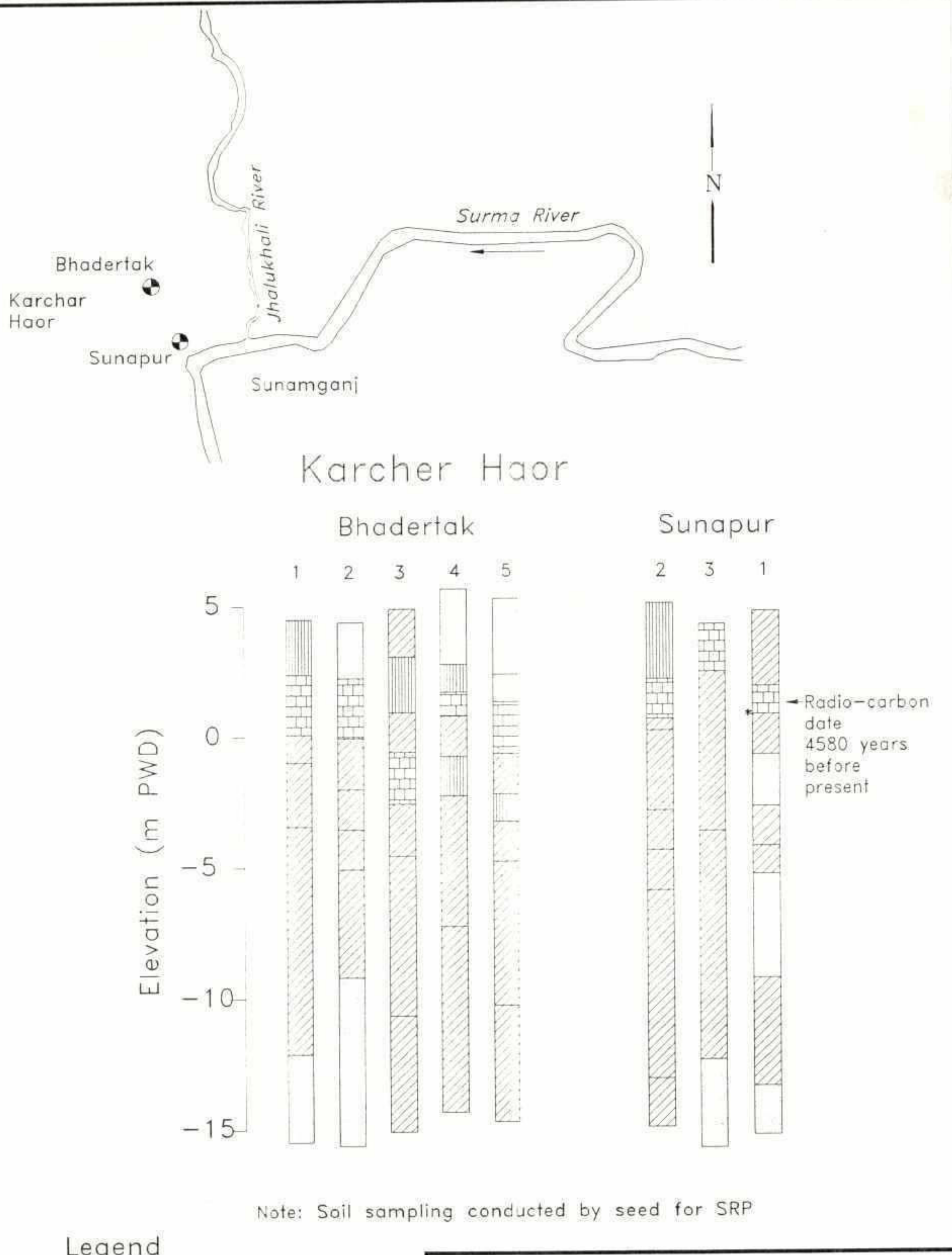


Growth of a "Bird's Foot Delta", characterized by natural levee formation from fine sediment deposition in a shallow water body.
The lowgradient, high sinuosity branching distributary channels have a characteristic "anastomosing" channel pattern.

Northeast Regional Project	
Anastomosing Channel Pattern on Lowland Rivers int the Central Basin	
Prepared by: Dmc	December 1994
Drawn by: Jalal	AutoCAD Drawing

FILE: dm103.DWG

Figure 22



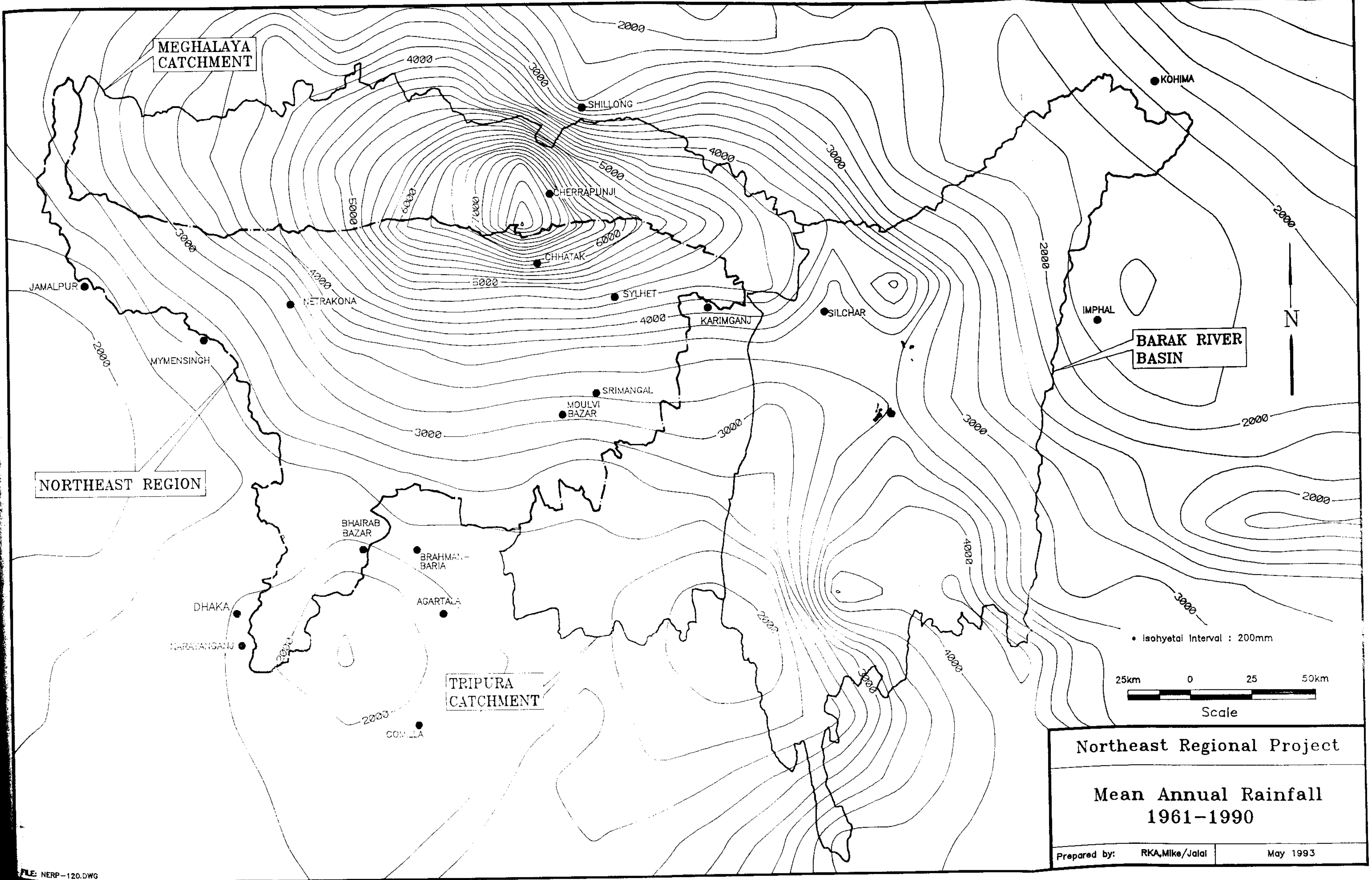
FILE: karchar.DWG

Northeast Regional Project

Floodplain Stratigraphy At Karchar Haor

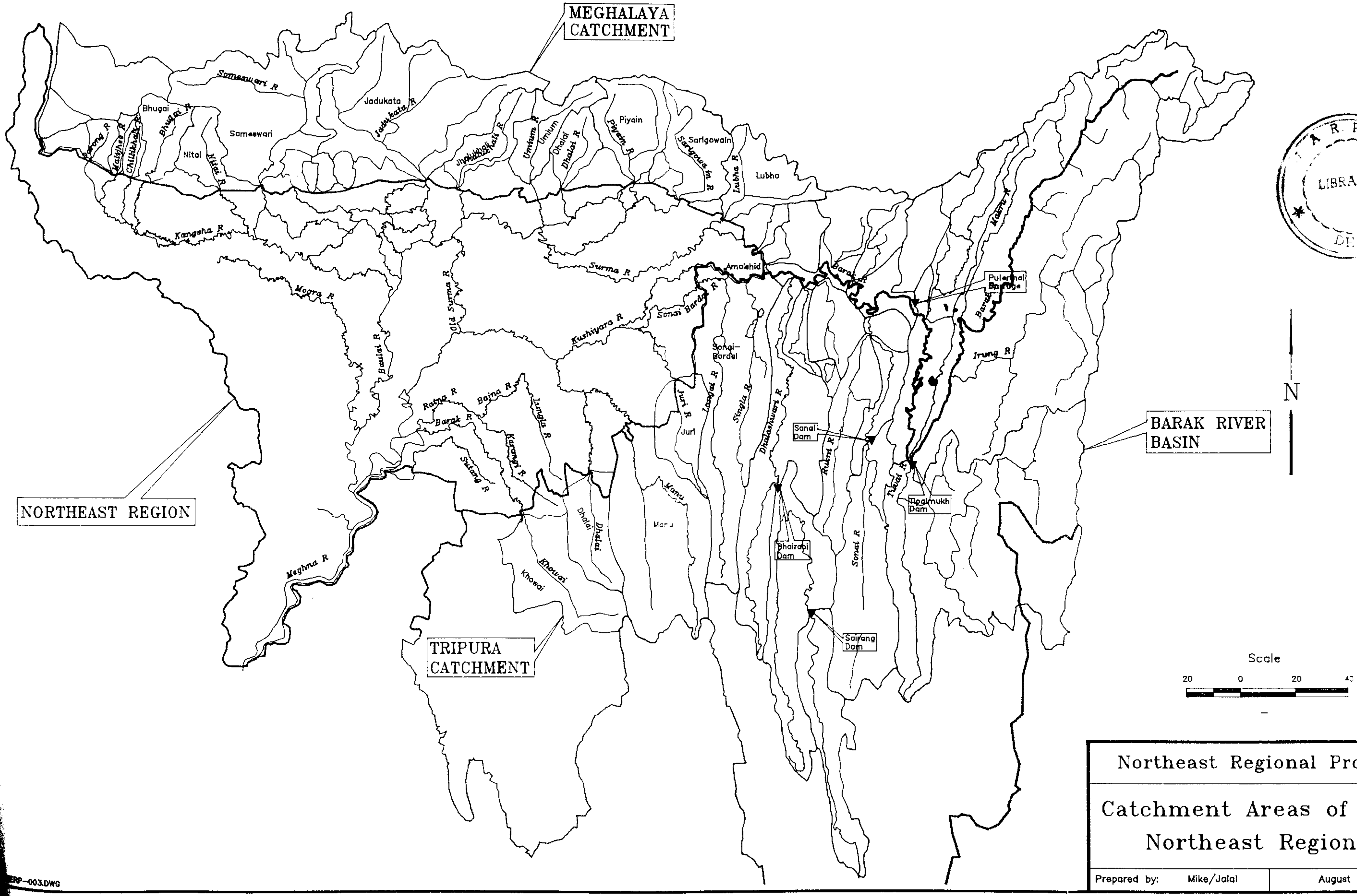
Prepared by: DMc | June 1993

Figure 23



Northeast Regional Project	
Mean Annual Rainfall 1961-1990	
Prepared by: RKA,Mike/Jalal	May 1993

Figure 24



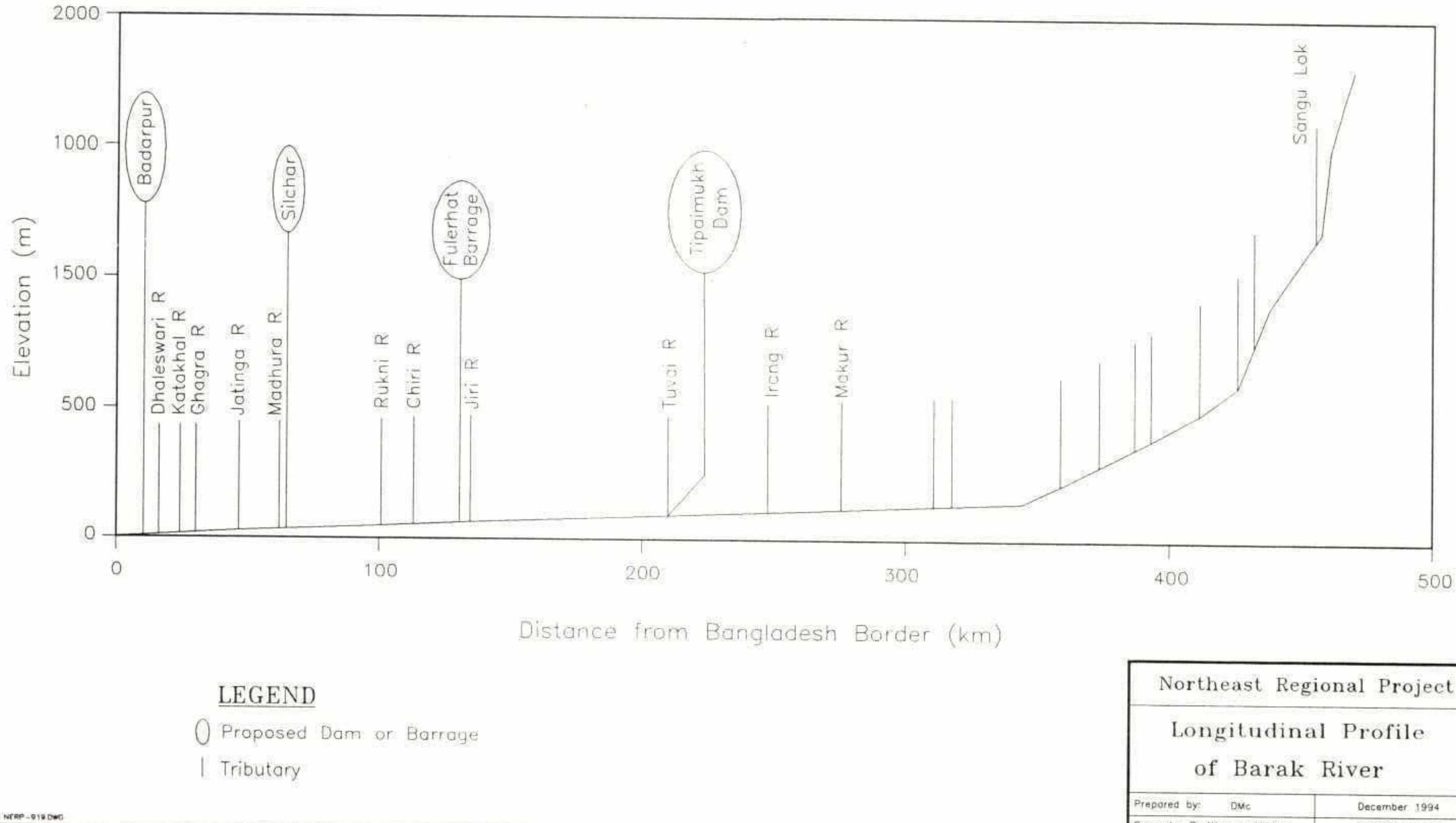
Northeast Regional Project

Catchment Areas of the Northeast Region

Prepared by: Mike/Jalal | August 1992

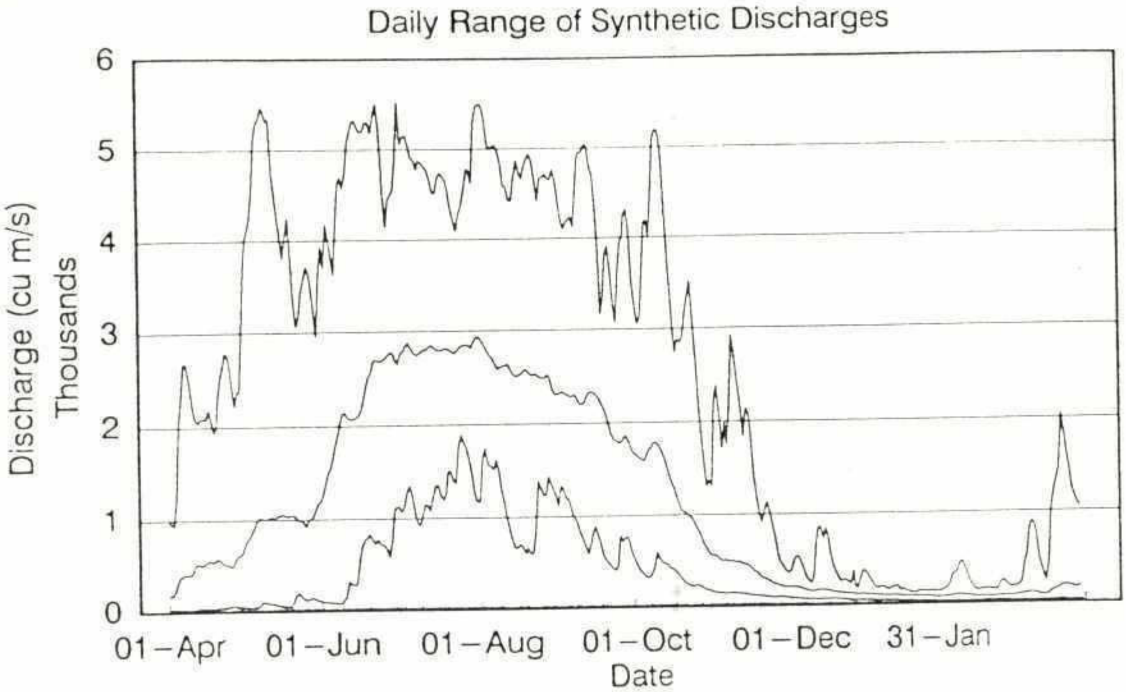
NERP-003.DWG

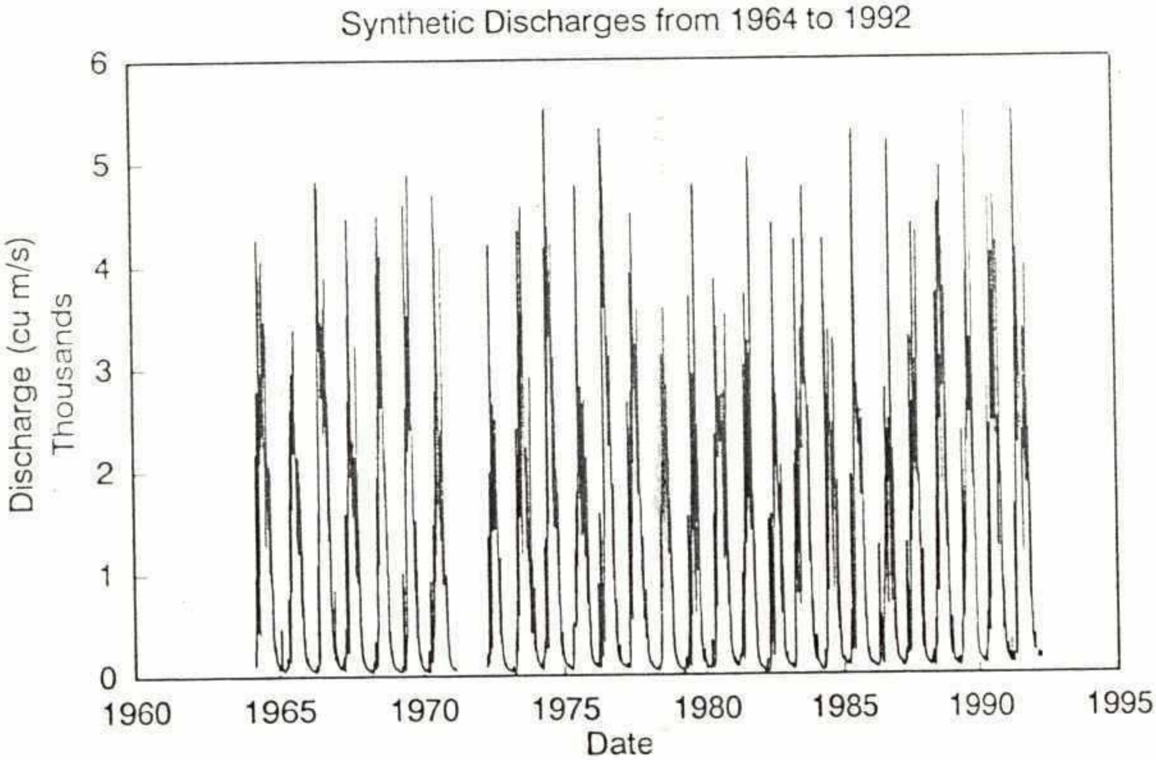
Figure 25



Northeast Regional Project	
Longitudinal Profile of Barak River	
Prepared by: DMc	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

Figure 26





Note:
discharged synthesized from daily water level records by NERP modelling section.

Northeast Regional Project	
Estimated Discharges Barak River at Amalshid	
Prepared by: DMc	December 1994
Drawn by: Jalal	AutoCAD Drawing

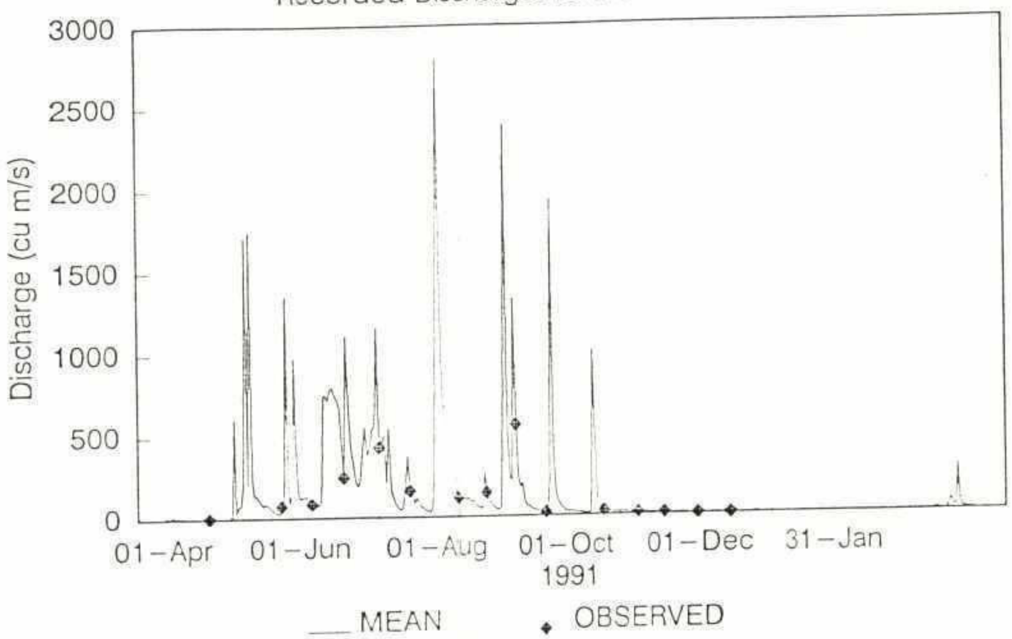
FILE: dm100.DWG

DF.

Figure 27

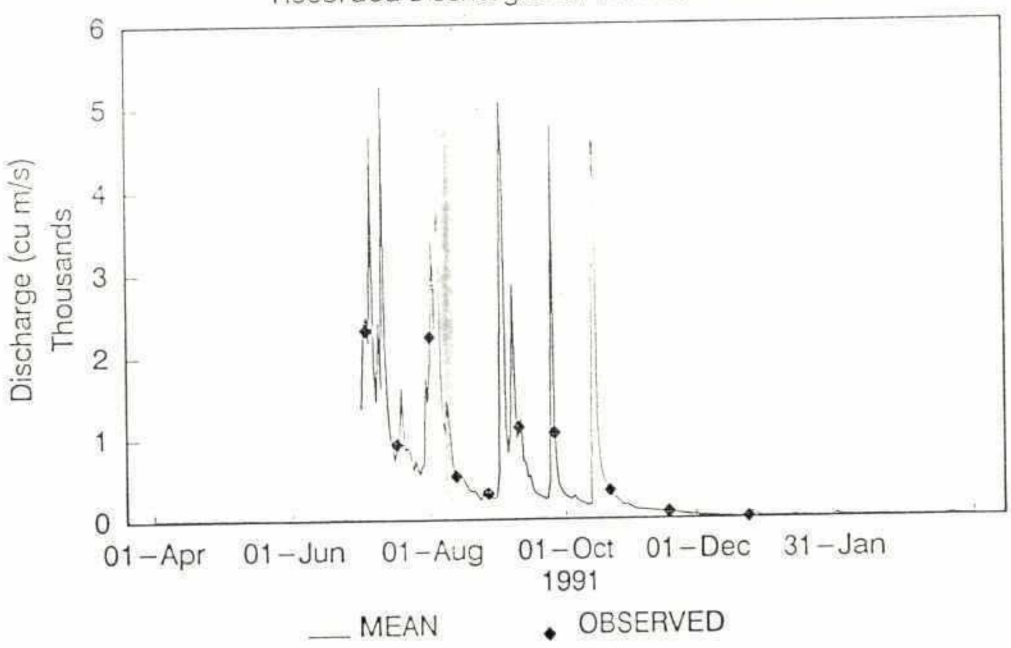
Gauge 332 DHALIGANG R. at ISLAMPUR

Recorded Discharges for the Water Year 1991



Gauge 131.5 JADUKATA R. at SAKTIARKHOLA

Recorded Discharges for the Water Year 1991



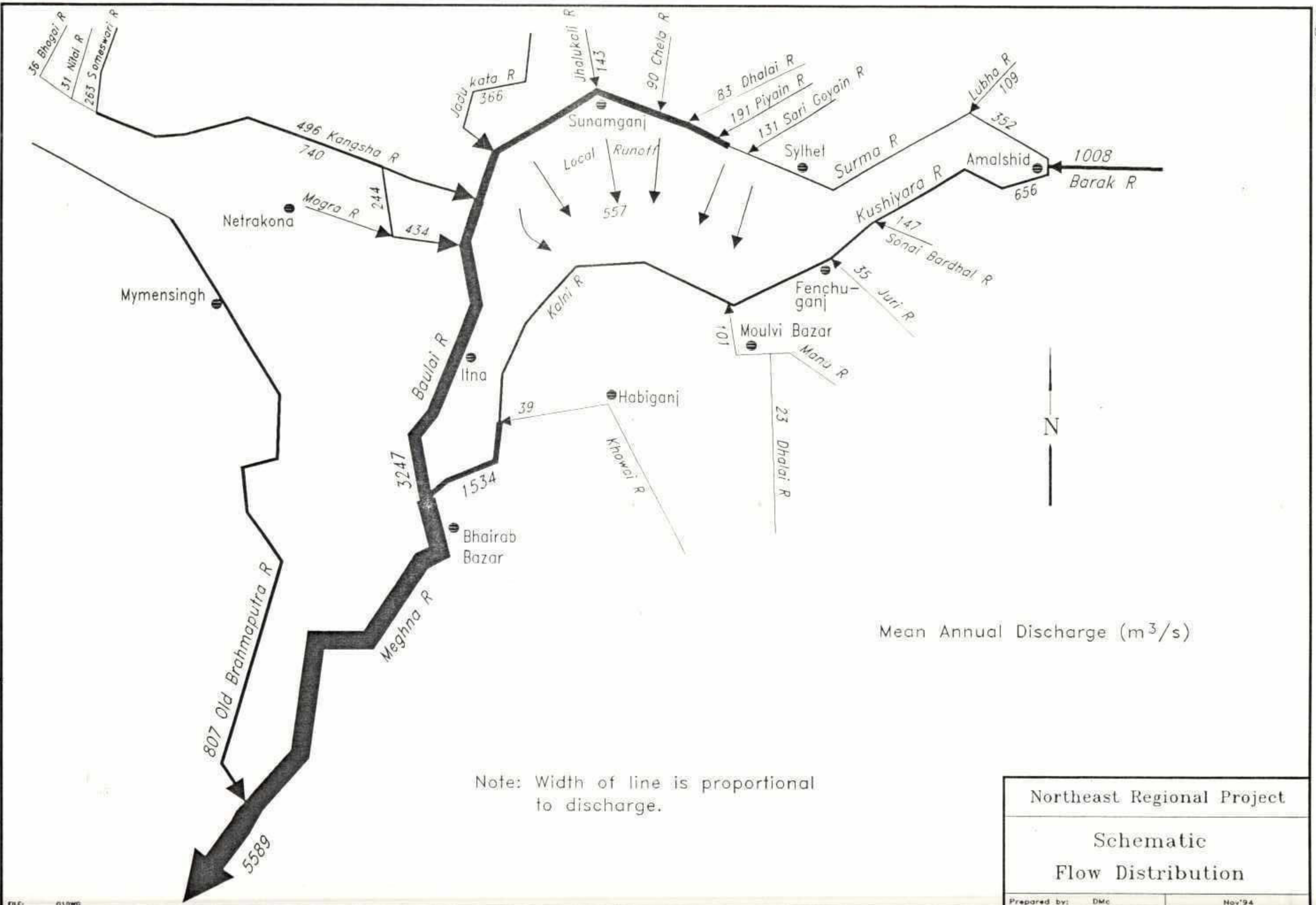
Northeast Regional Project

Discharge Hydrographs on Meghalaya Streams

Prepared by: DM | May 1993

FILE: dm20LDWG

Figure 28

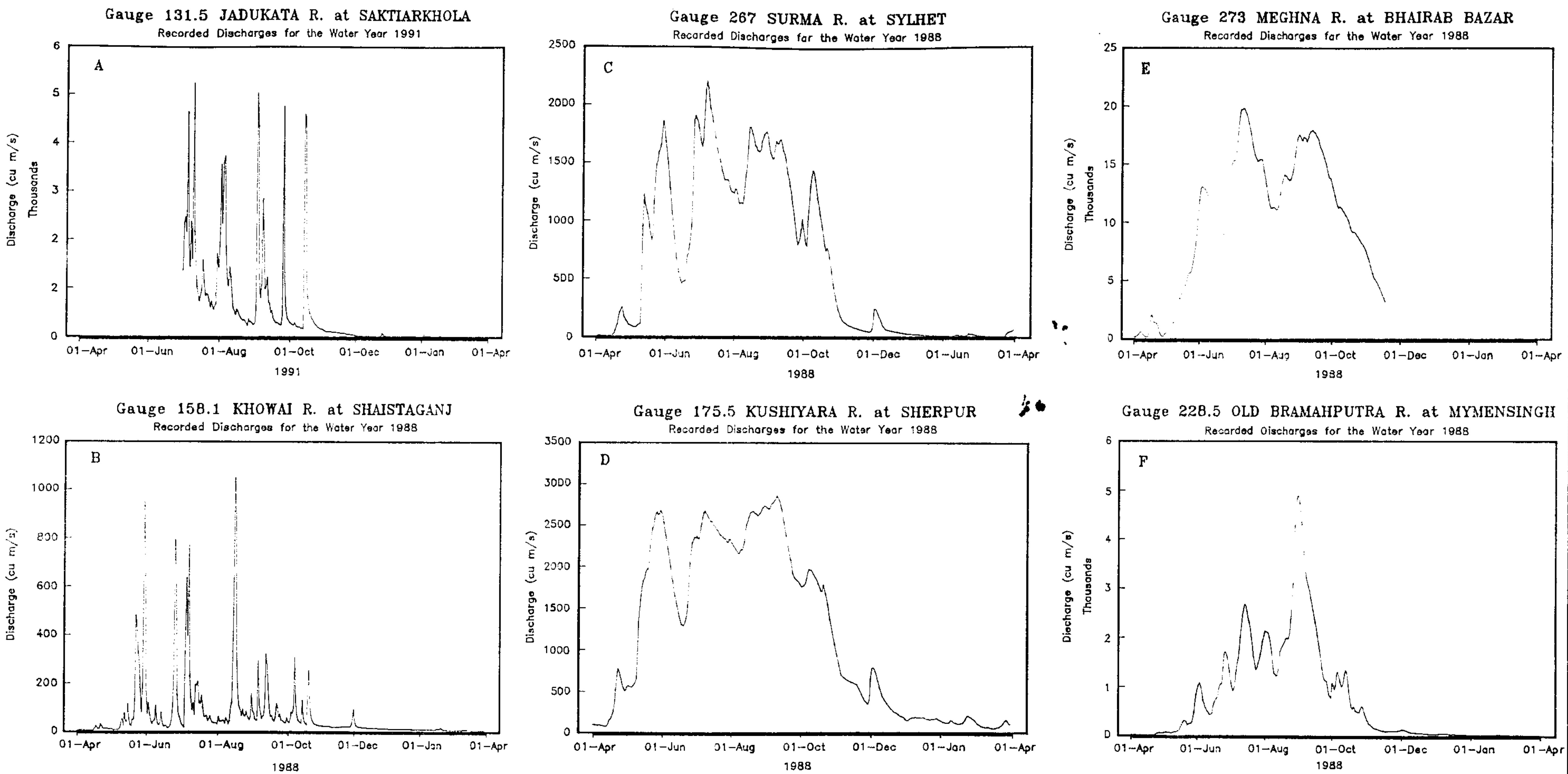


Northeast Regional Project

Schematic Flow Distribution

Prepared by: DMc Nov'94

FILE: GLOWG

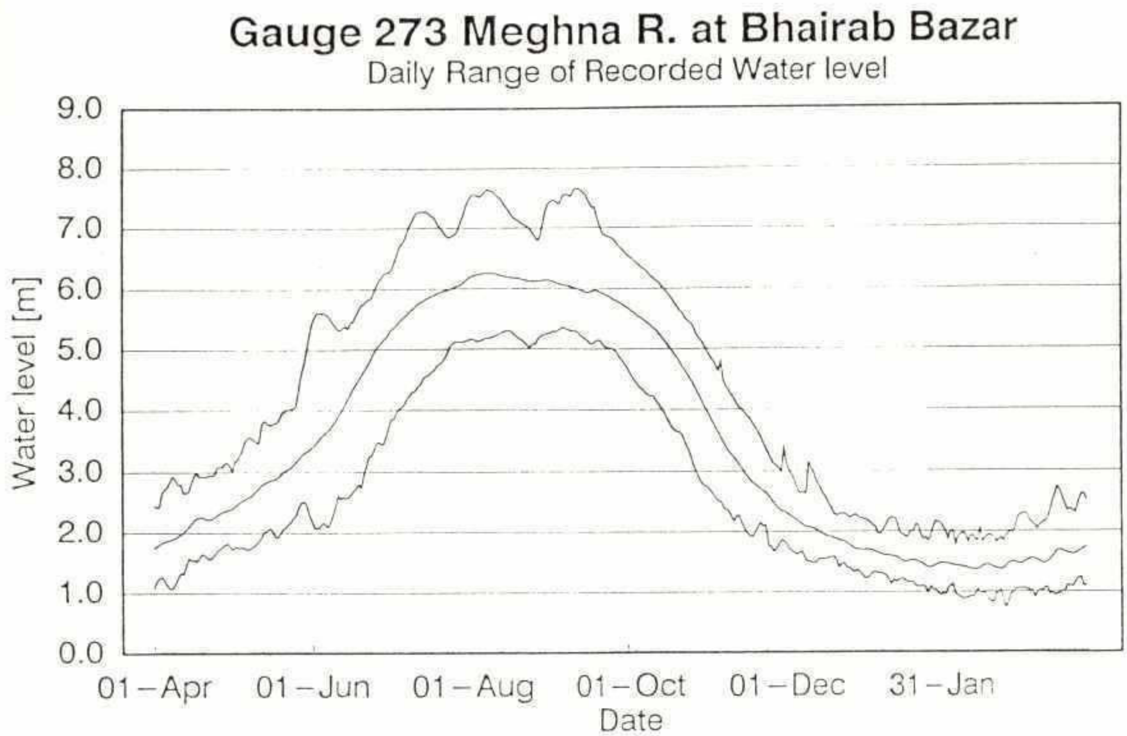


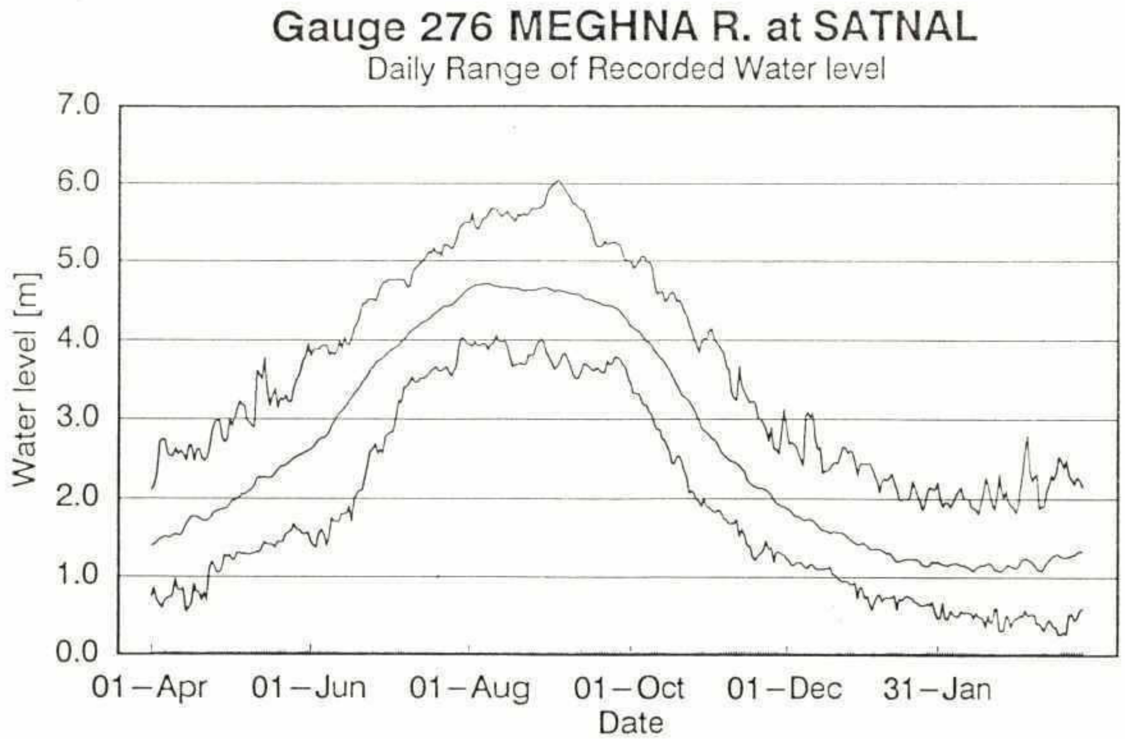
Northeast Regional Project

Representative Hydrographs of Regional Rivers

Prepared by: Mike/Mamun | May 1993

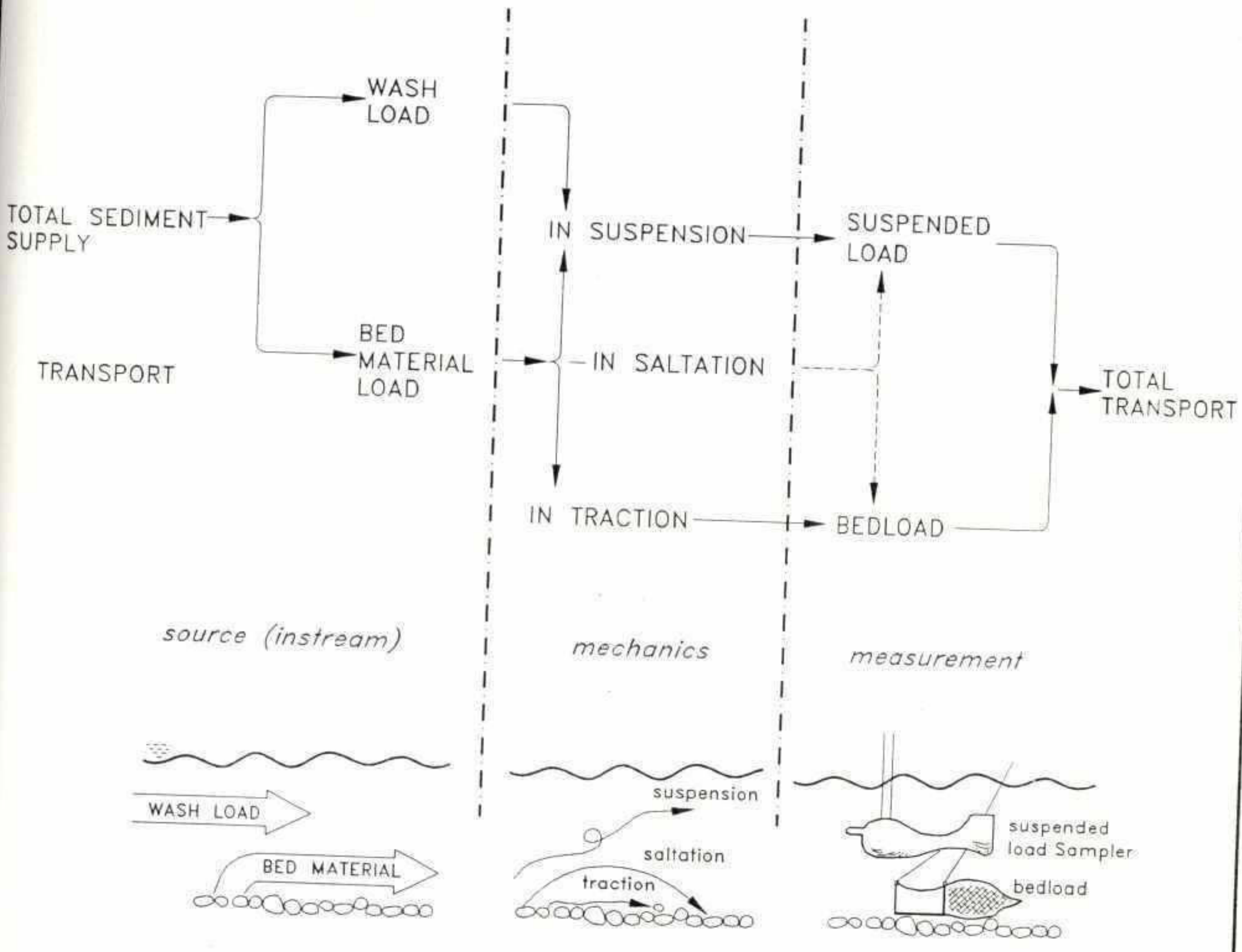
FILE: NERP-594DWG





Northeast Regional Project	
Historic Water Levels Meghna River	
Prepared by: CHW	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: BORD4.DWG



From: Church (1986)

Northeast Regional Project

Classification of Sediment Transport in Rivers

Prepared by: DMc/Jalal | April 1993

FILE: DM198.DWG

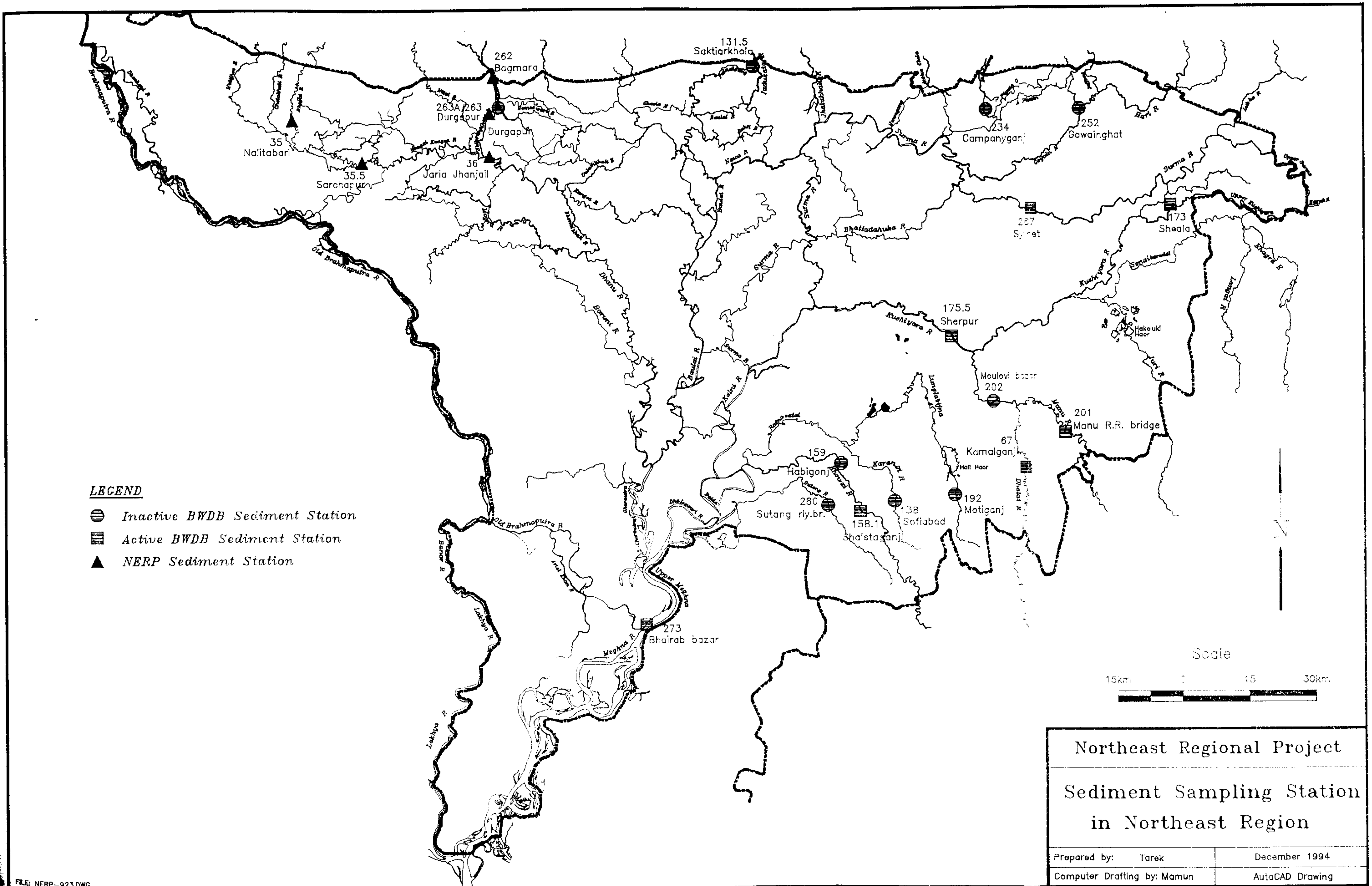
Figure 32

Binkley Sampler used on Meghna River

Discharge measurement and dip sample on Khowai River

Suspended sediment sampling techniques

Figure 33

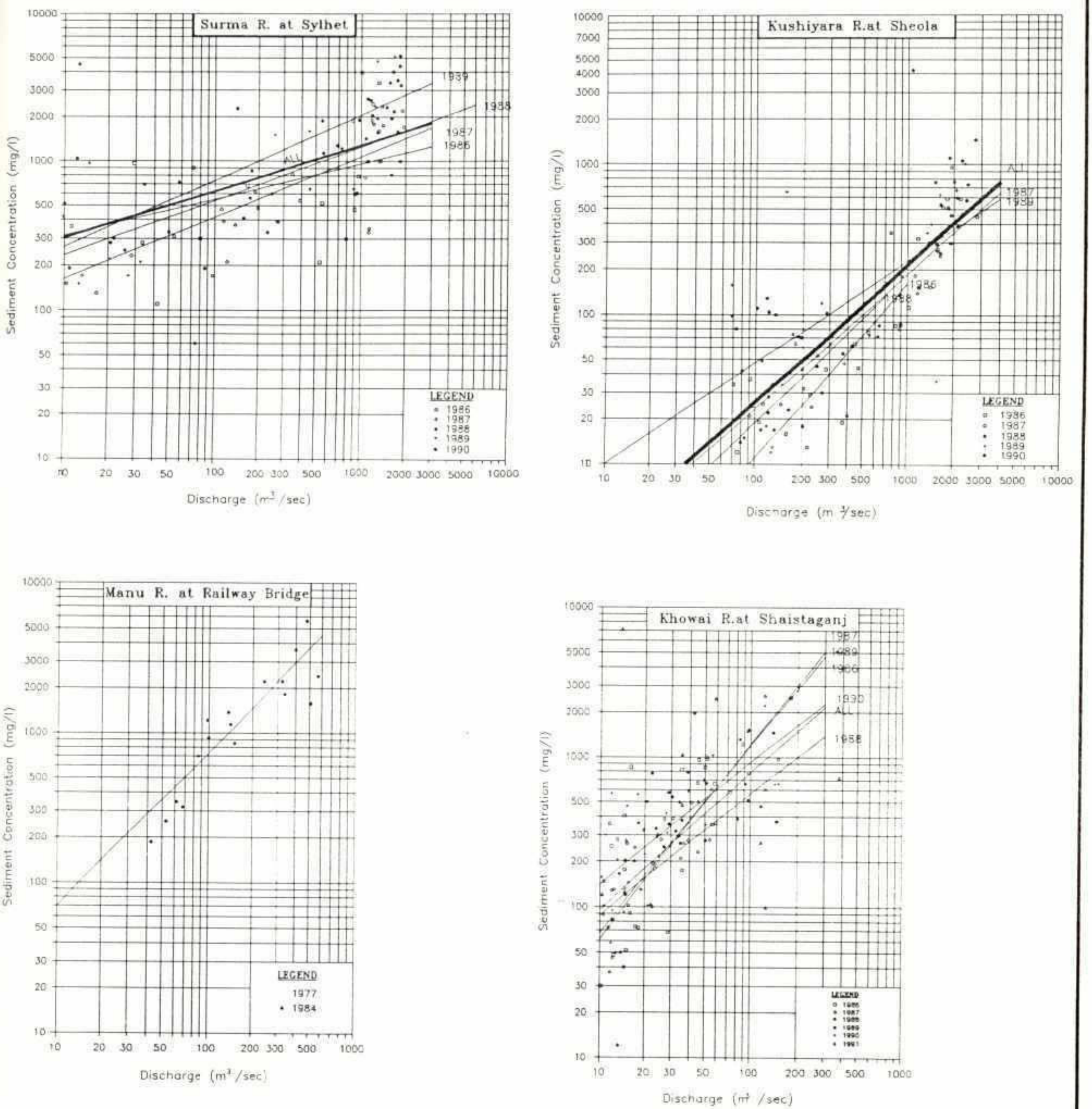


Northeast Regional Project

Sediment Sampling Station in Northeast Region

Prepared by: Tarek	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

Figure 34



Note :

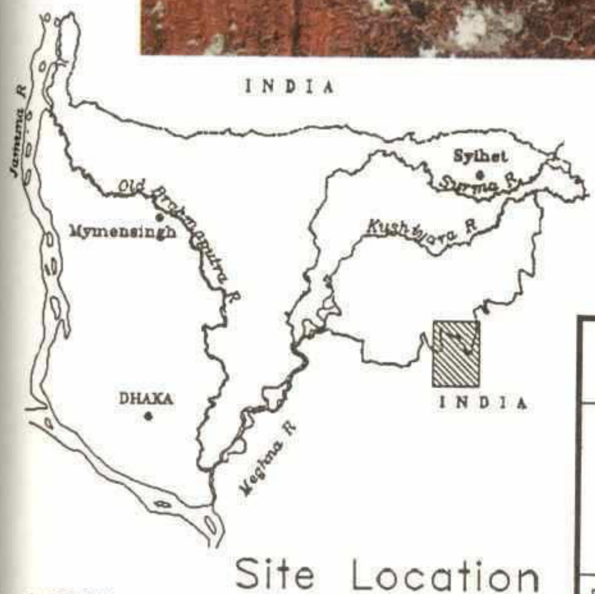
1. All data provided by BWDB

Northeast Regional Project

Suspended Sediment Rating Curves

Prepared by: Tarek	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-925.DWG



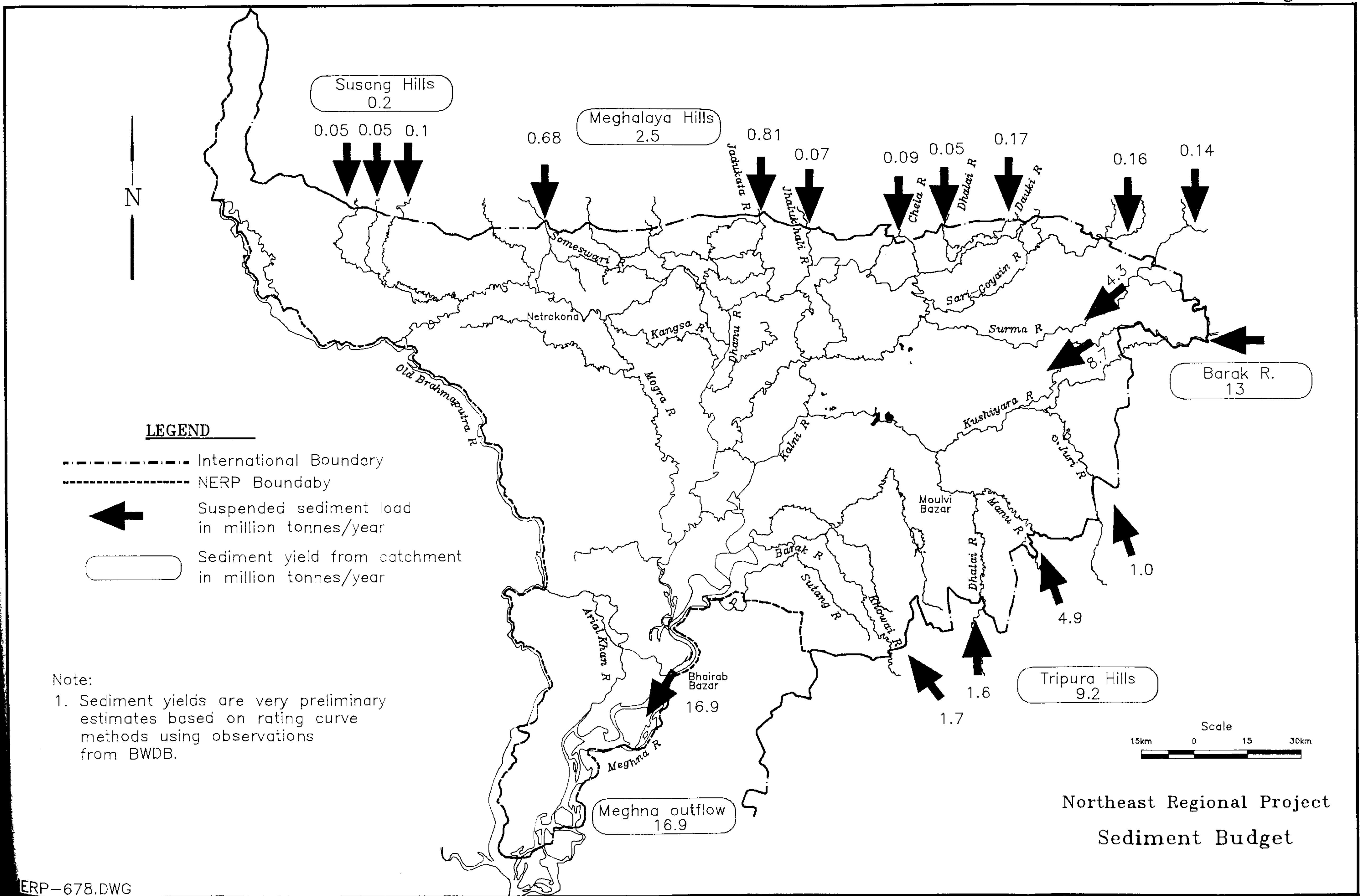
Northeast Regional Project

High Sediment Yields
Upper Dhalai River

Prepared by: DMc	May 1993

dm192.DWG

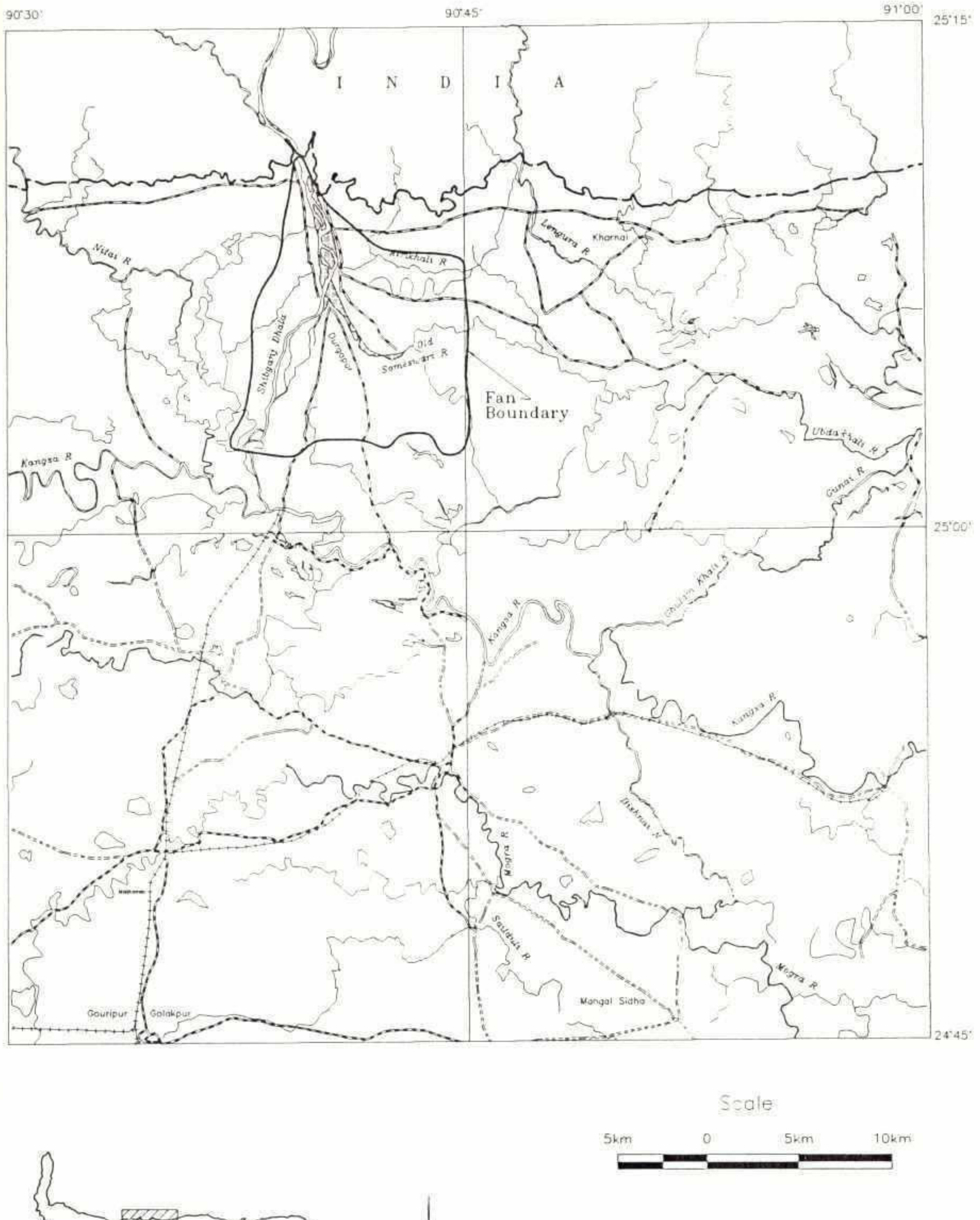
Figure 36

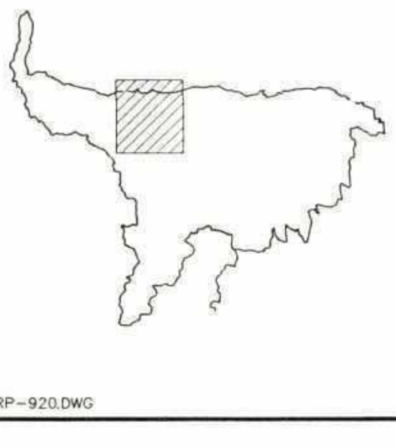


Northeast Regional Project

Sediment Budget

Figure 37



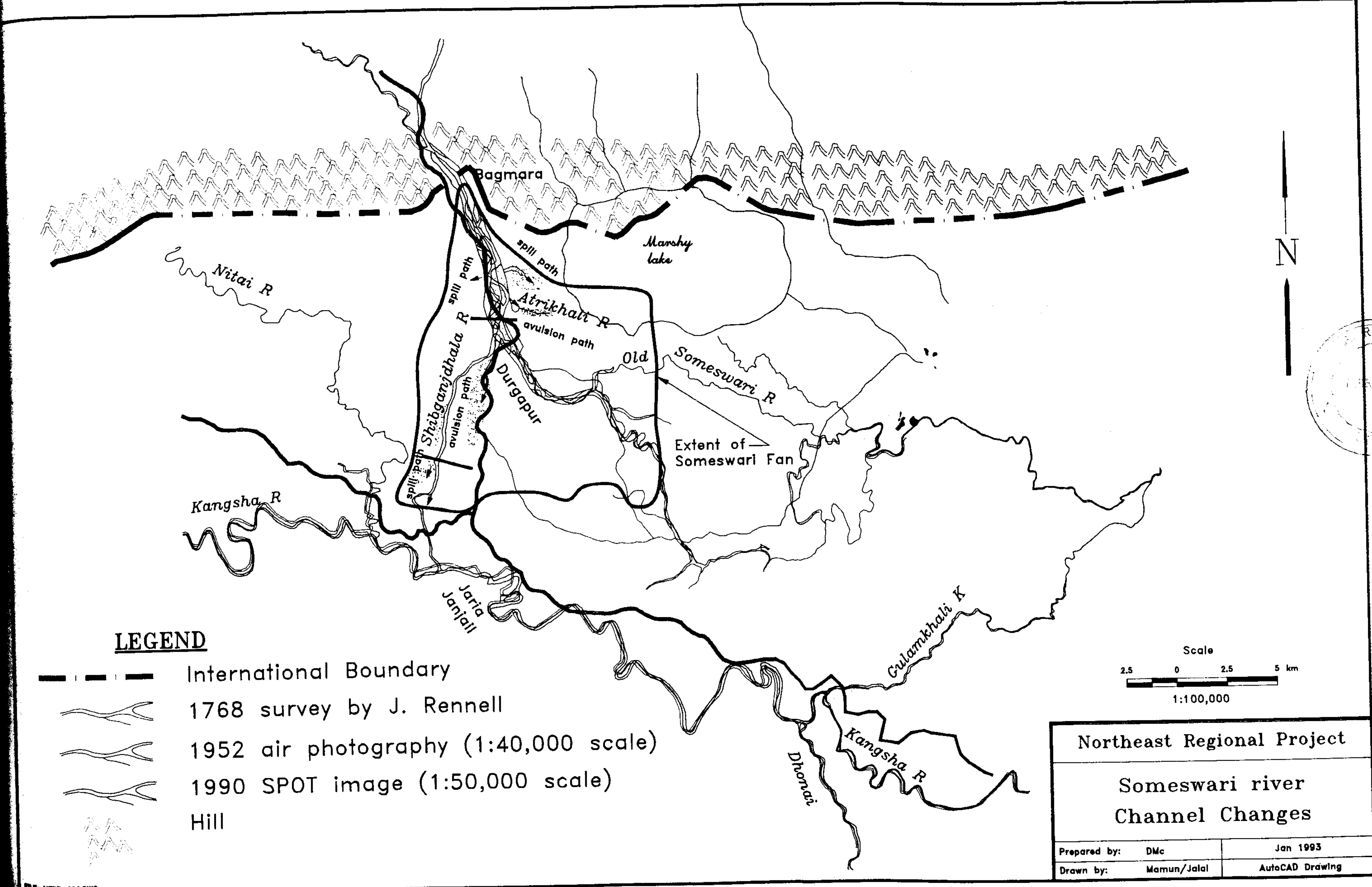


Northeast Regional Project	
Vicinity Map Someswari/Kangsha River	
Prepared by: DMc	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-920.DWG

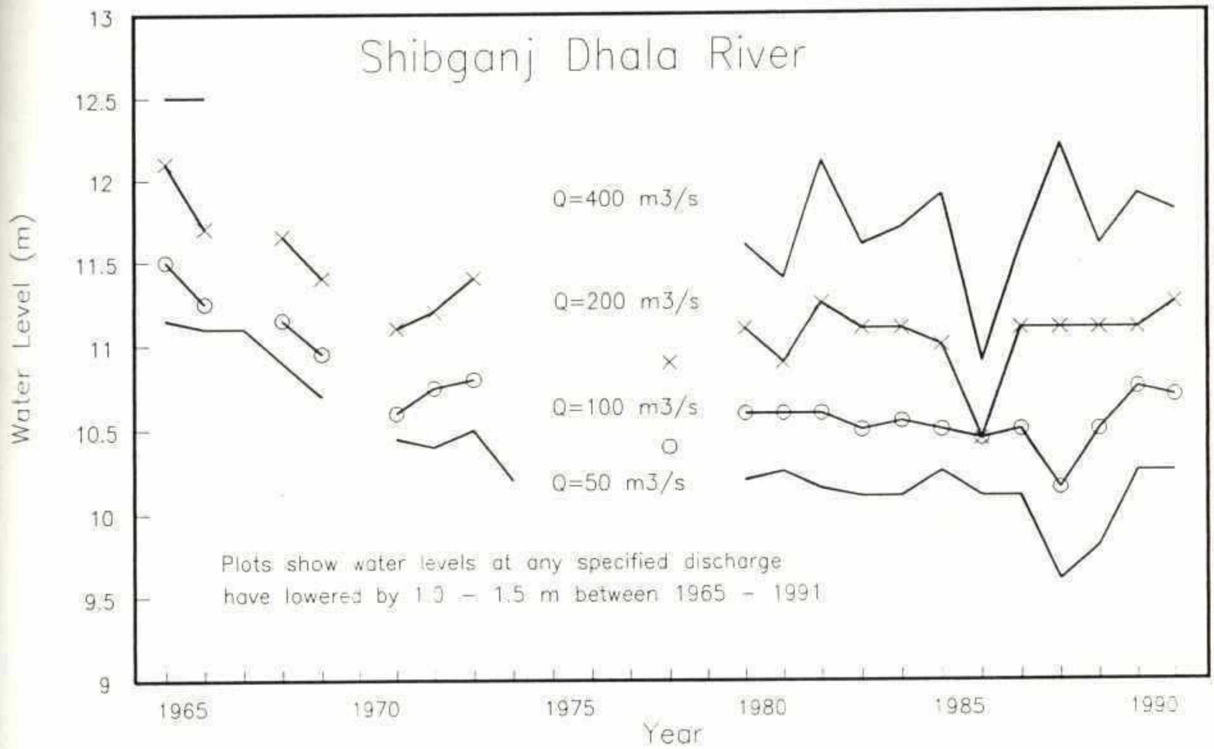
222

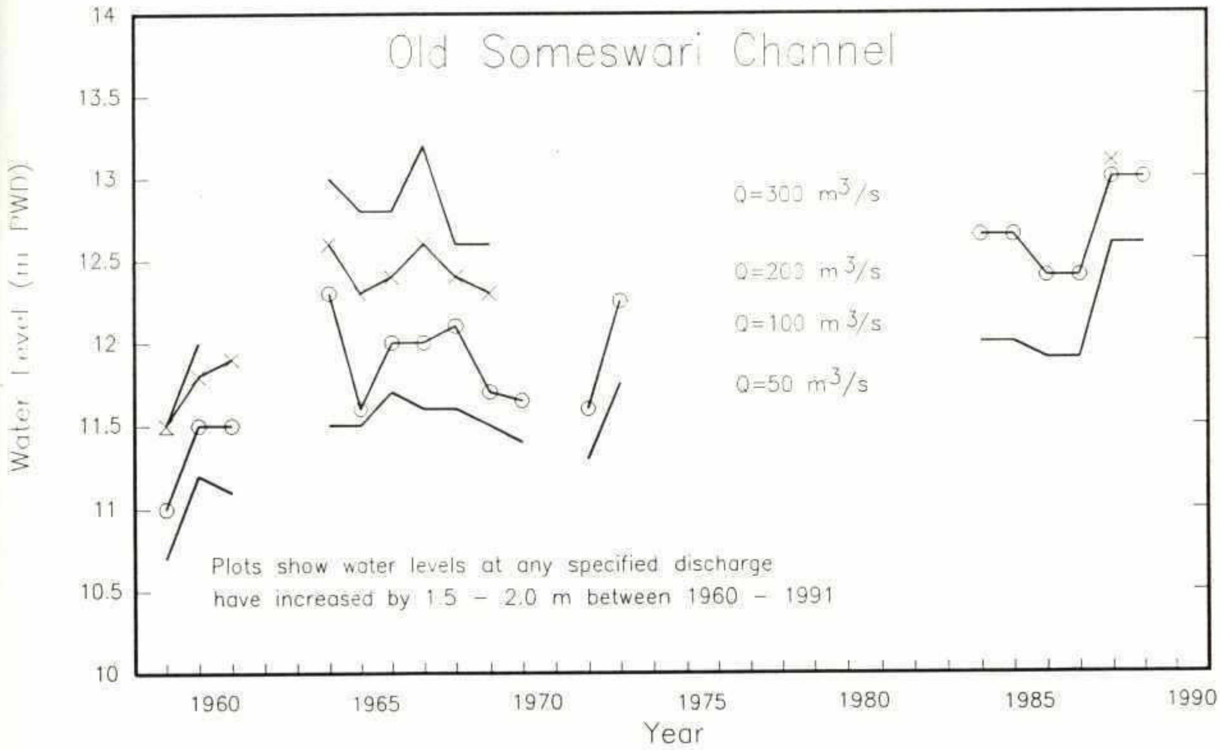
Figure 38



Northeast Regional Project	
Someswari river Channel Changes	
Prepared by: DMc	Jan 1993
Drawn by: Mamun/Jalal	AutoCAD Drawing

FILE: NERP-092.DWG





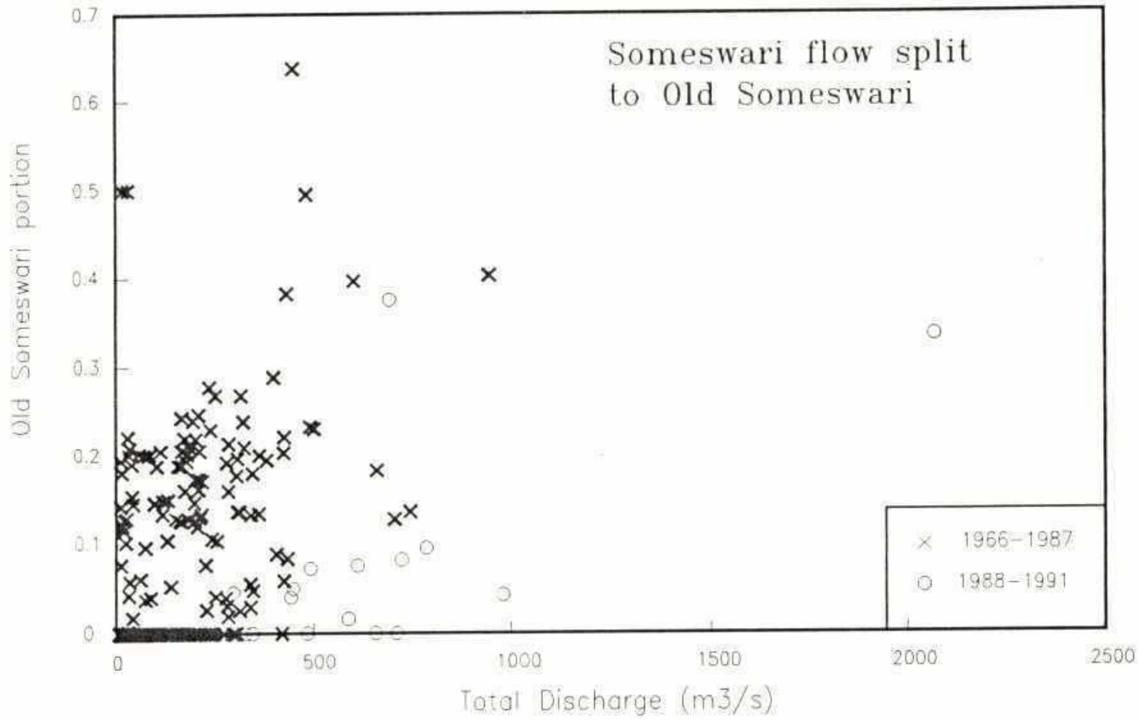
Note :

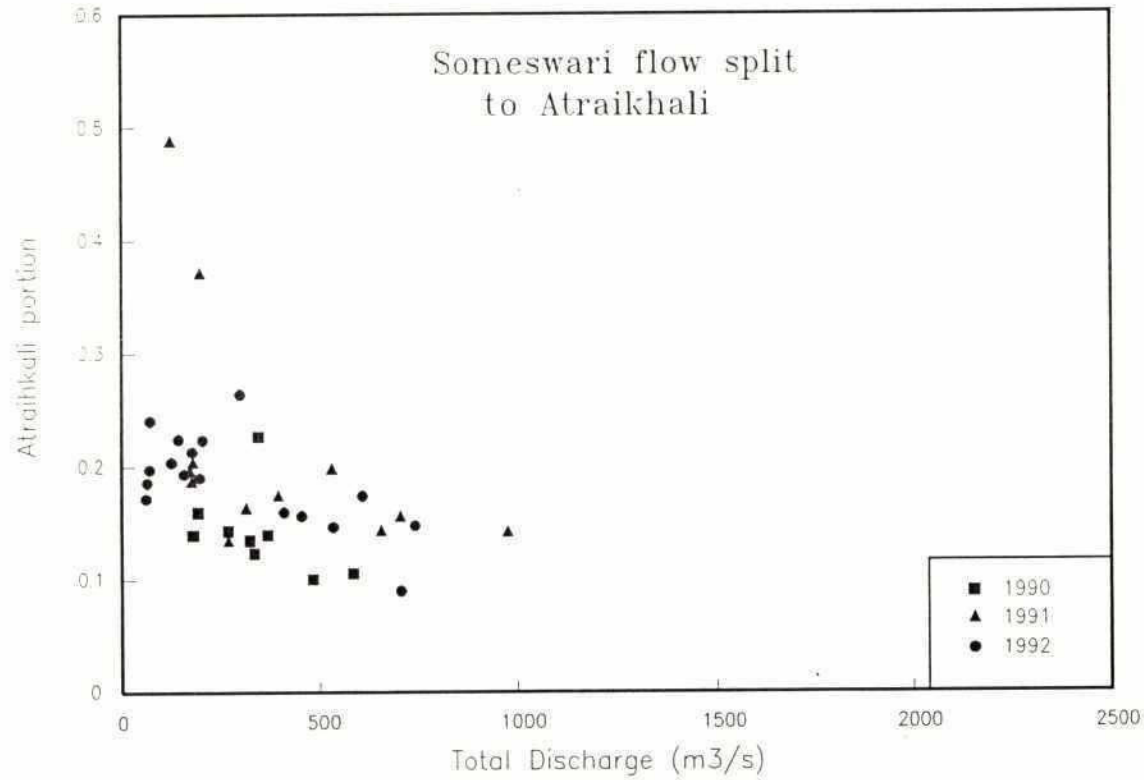
1. Specific guare plots show long–term vatiations in water levels for four specific discharges.
2. Plots wer constructed by comparing stage–discharge rating curves for each year of observation.

FILE: NERP–922.DWG

Northeast Regional Project	
Specific Gauge Someswari Fan	
Prepared by: DMc	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

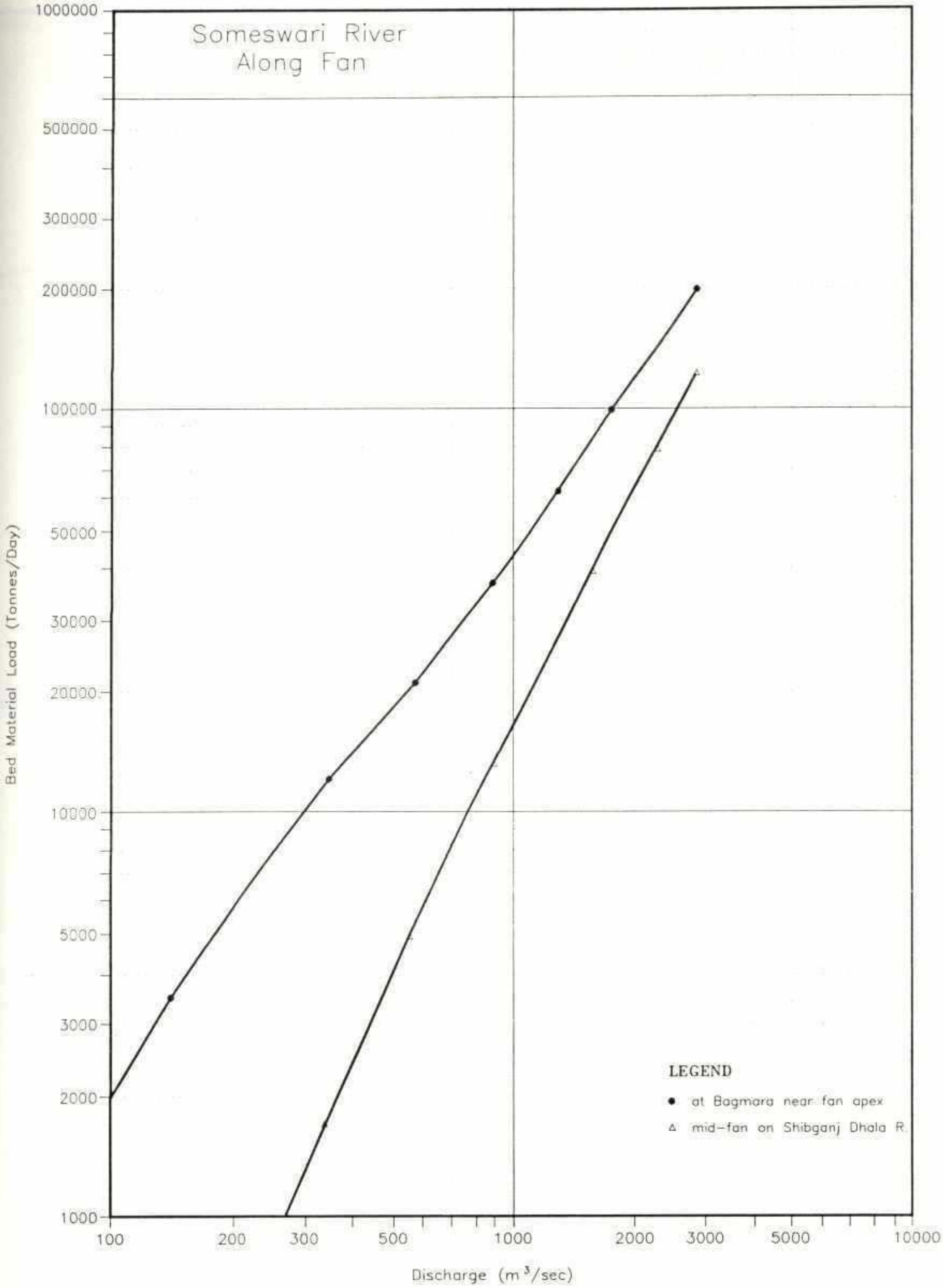
Figure 40





Northeast Regional Project	
Flow Split **Old Someswari/Atrikhali**	
Prepared by: DMc	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

FILE: NERP-924.DWG



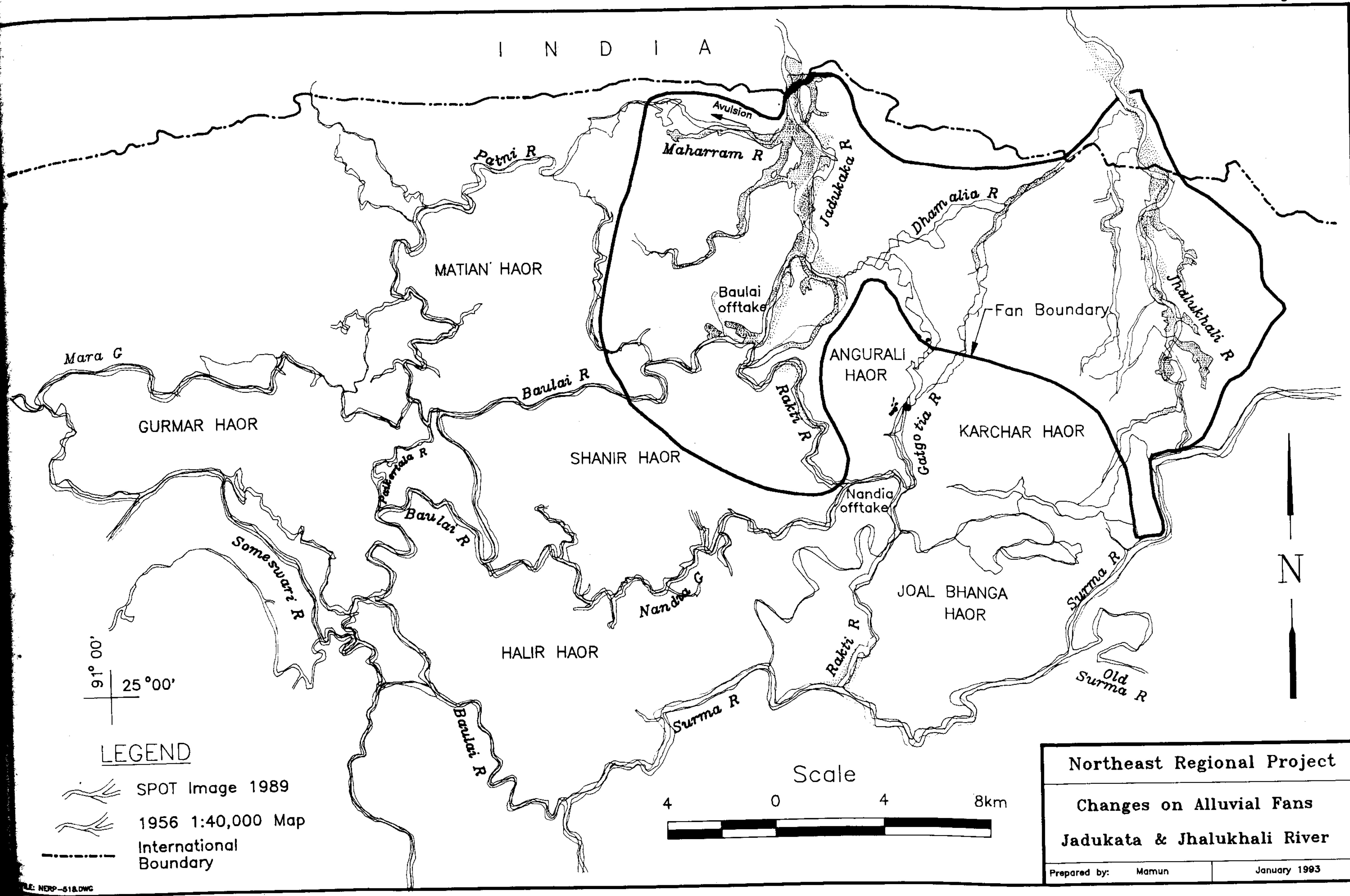
Note :

Sediment loads Computed by Ackers-White bed material equation

FILE: NERP-920.DWG

Northeast Regional Project	
Bed Material Loads on Someswari River	
Prepared by: DMc	December 1994
Computer Drafting by: Mamun	AutoCAD Drawing

Figure 42



Northeast Regional Project	
Changes on Alluvial Fans Jadukata & Jhalukhali River	
Prepared by: Mamun	January 1993

FILE: NERP-51&.DWG

Figure 43

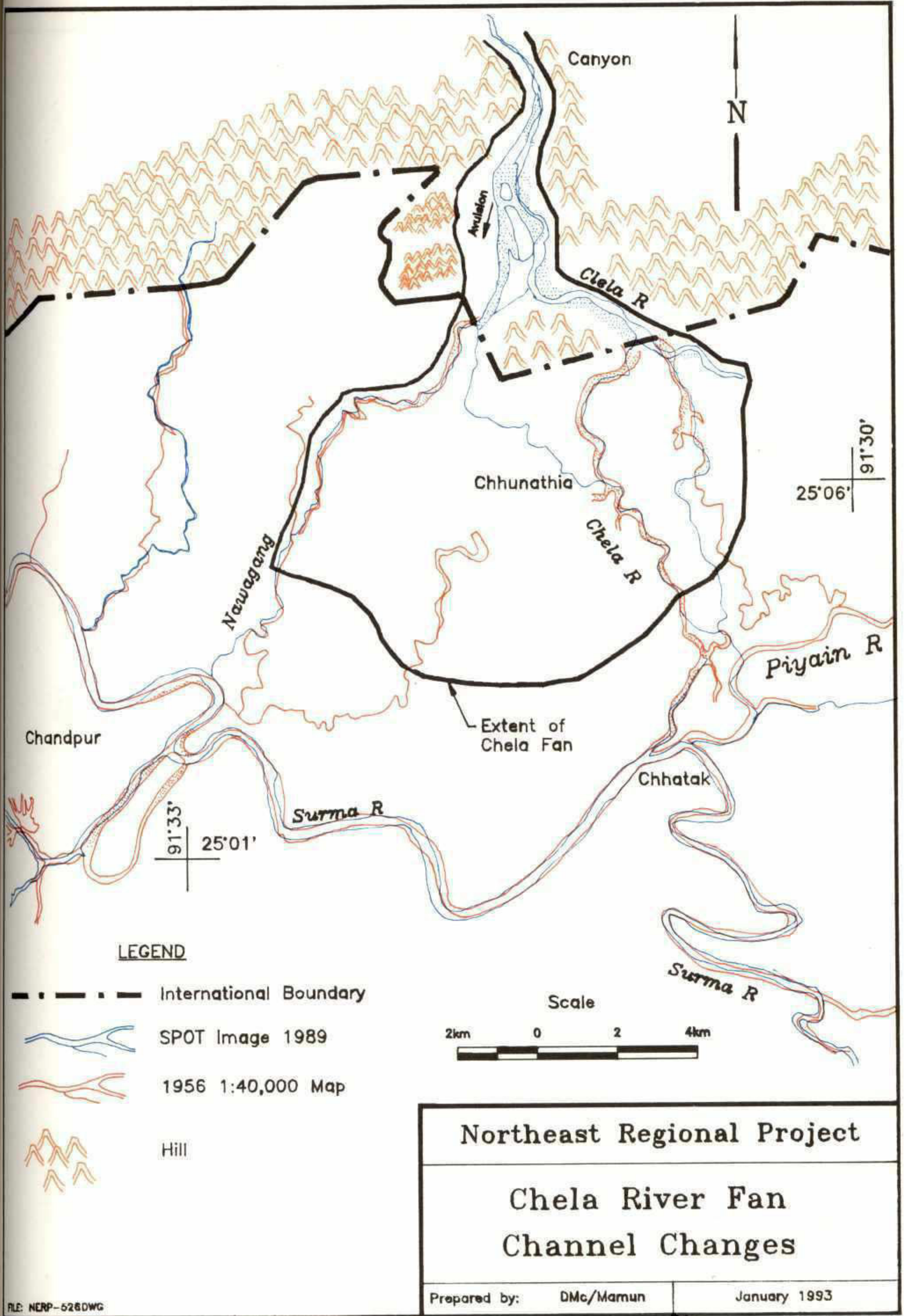
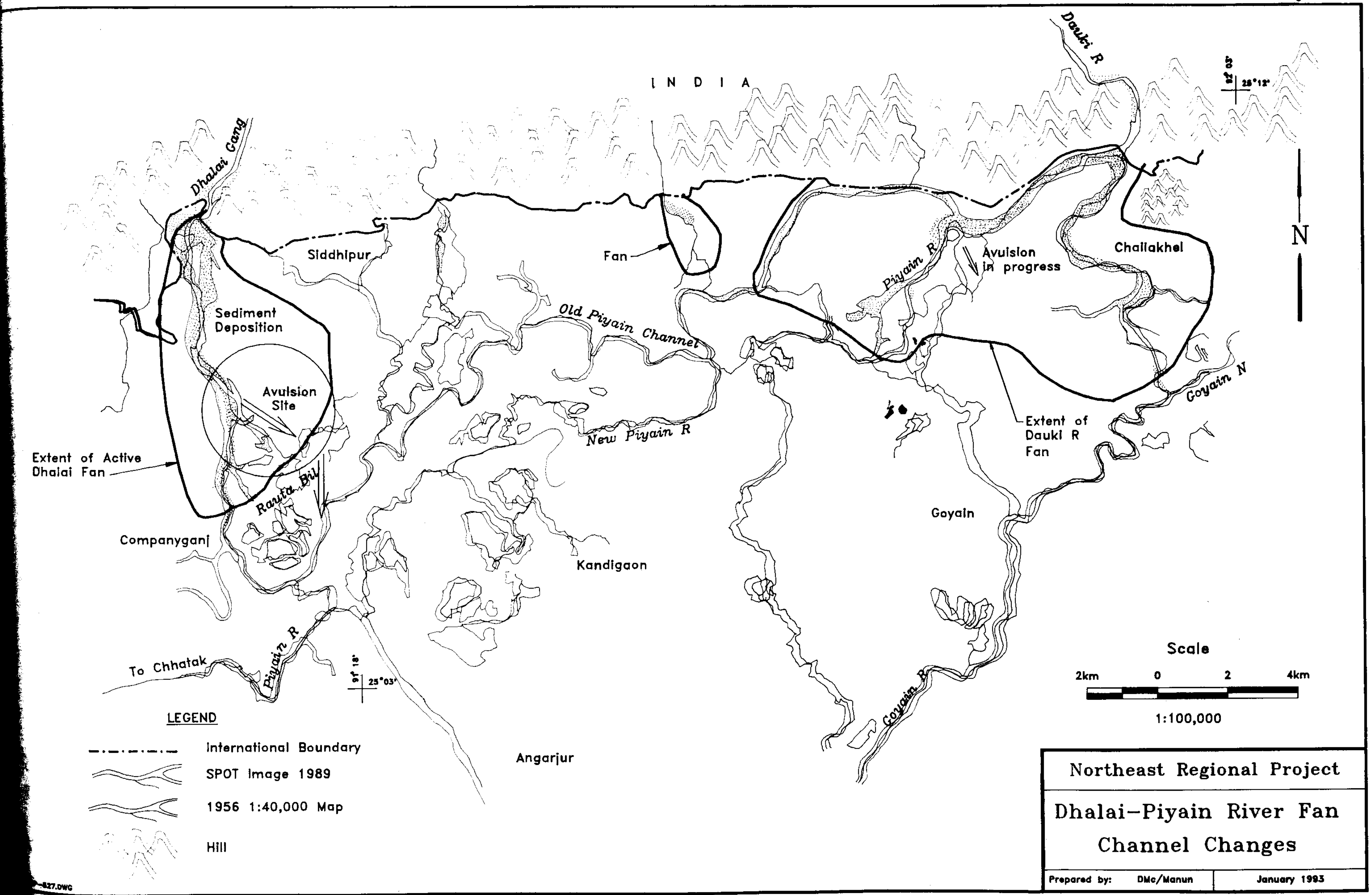

Canyon
N
Avulsion
Clela R
Chhunathia
91°30'
25°06'
Chela R
Nawagang
Piyain R
Extent of
Chela Fan
Chandpur
Chhatak
Surma R
91°33'
25°01'
Surma R
LEGEND
International Boundary
SPOT Image 1989
1956 1:40,000 Map
Hill
Scale
2km 0 2 4km
Northeast Regional Project
Chela River Fan
Channel Changes
Prepared by: DMc/Mamun
January 1993
FILE: NERP-526DWG

Figure 44



Northeast Regional Project

Dhalai–Piyain River Fan Channel Changes

Prepared by:	DMc/Manun	January 1993

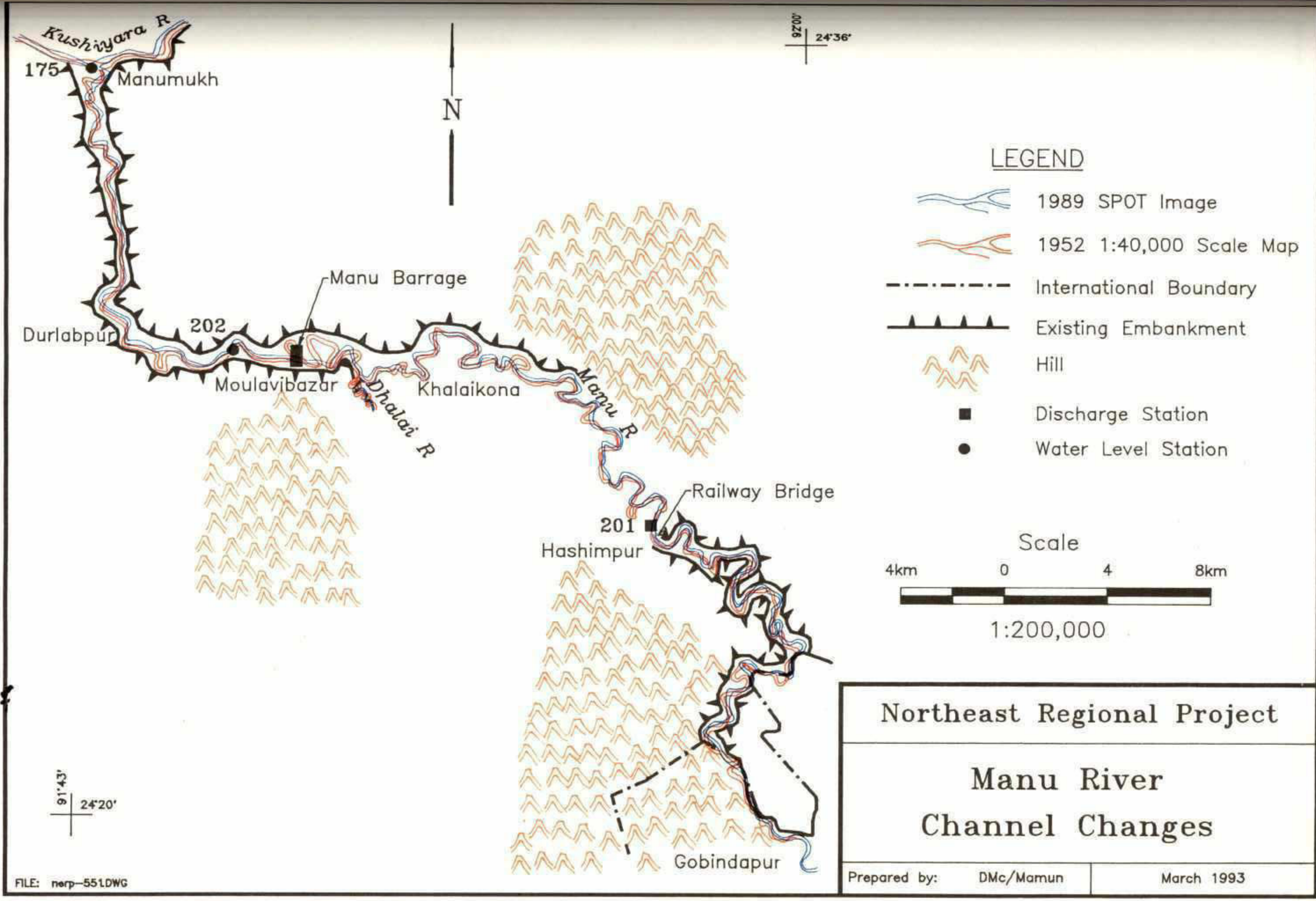
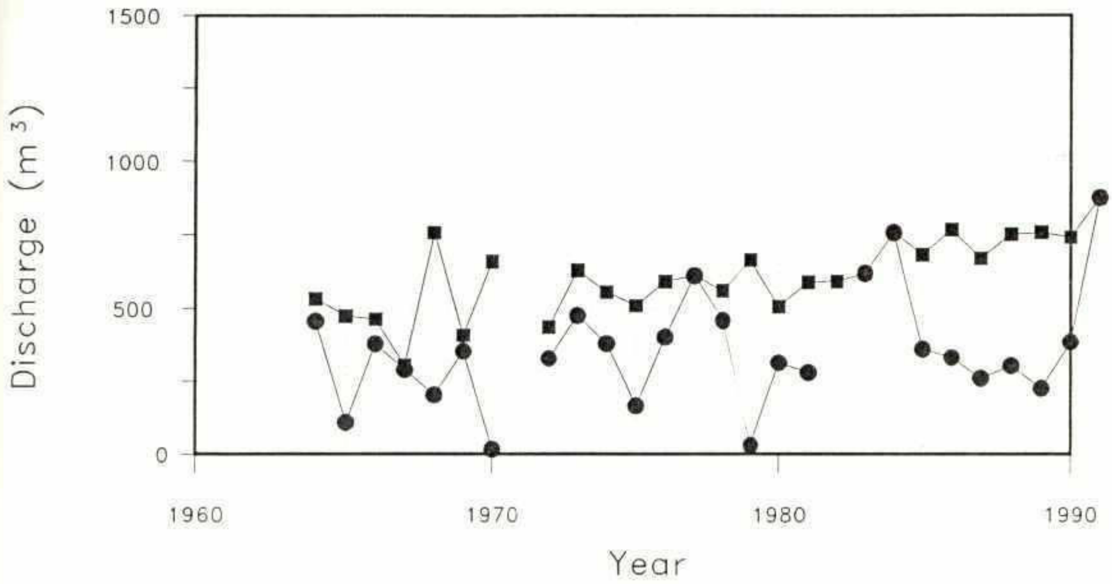
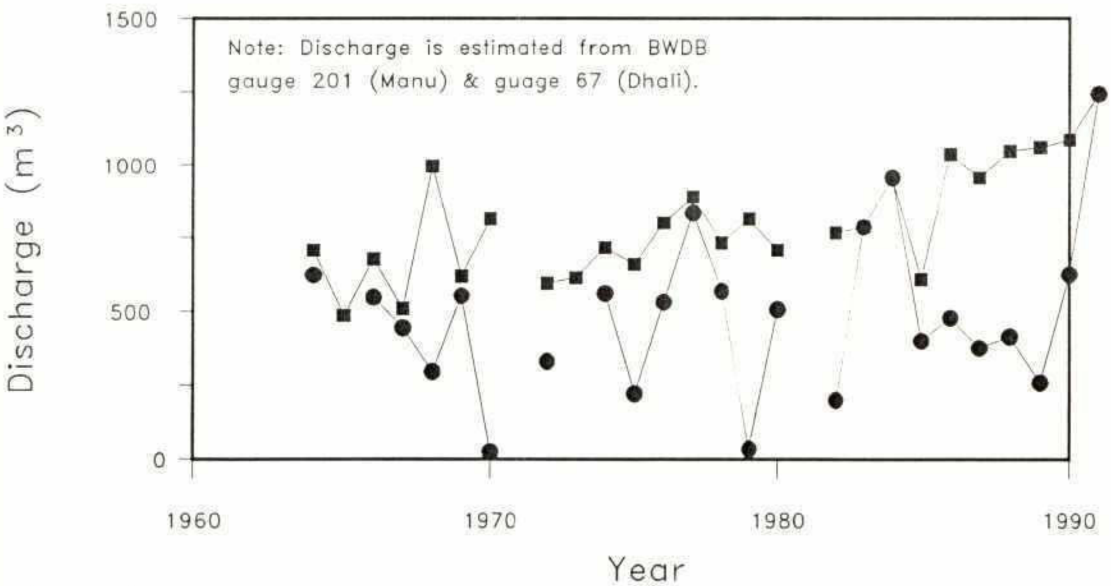

Kushiyara R
175
Manumukh
N
Durlabpur
202
Manu Barrage
Moulavibazar
Dhalai R
Khalaikona
Manu R
Railway Bridge
201
Hashimpur
Gobindapur
92°00'
24°36'
91°43'
24°20'
LEGEND
1989 SPOT Image
1952 1:40,000 Scale Map
International Boundary
Existing Embankment
Hill
Discharge Station
Water Level Station
Scale
4km 0 4 8km
1:200,000
Northeast Regional Project
Manu River
Channel Changes
Prepared by: DMc/Mamun
March 1993
FILE: nerp-551.DWG

Figure 45

Manu River at RR. Bridge (Gauge 201)



Manu River at Barrage



Legend

- ■ Maximum Annual
- ● Maximum Pre-Monsoon

Note:
Pre-monsoon season is the period from March 1 - May 15

Northeast Regional Project

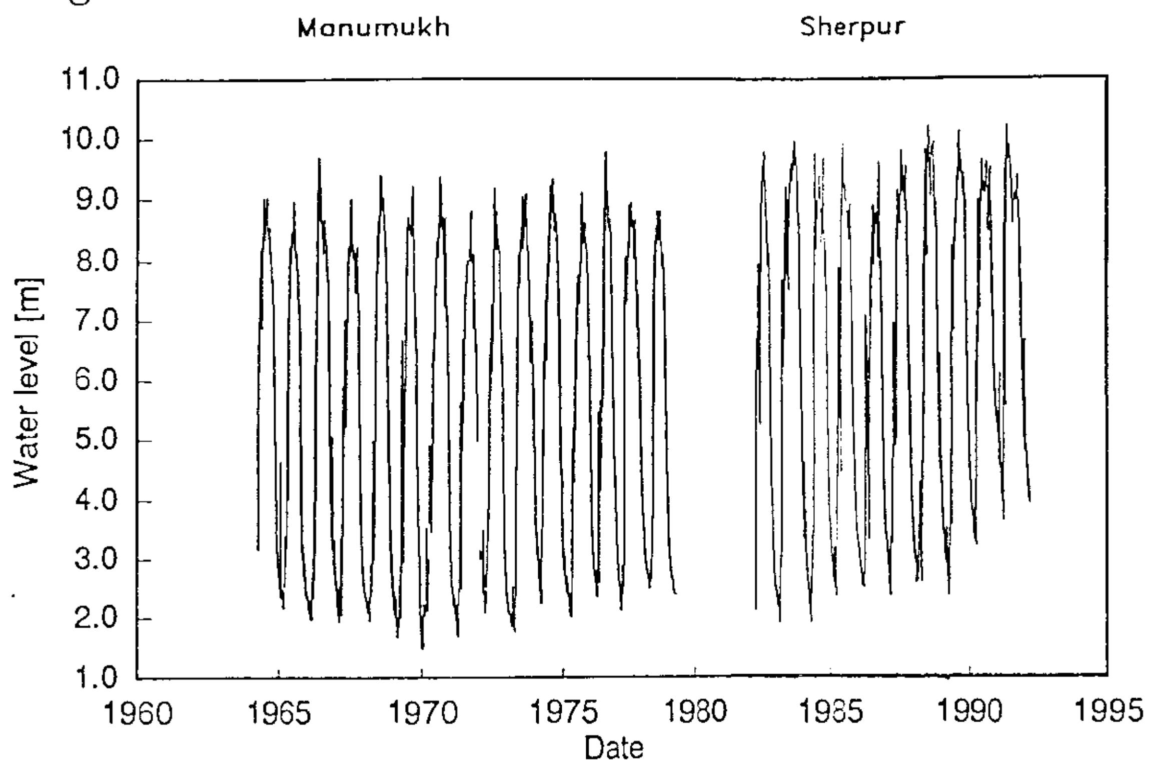
Annual Discharge Manu River

Prepared by: CHW | May 1993

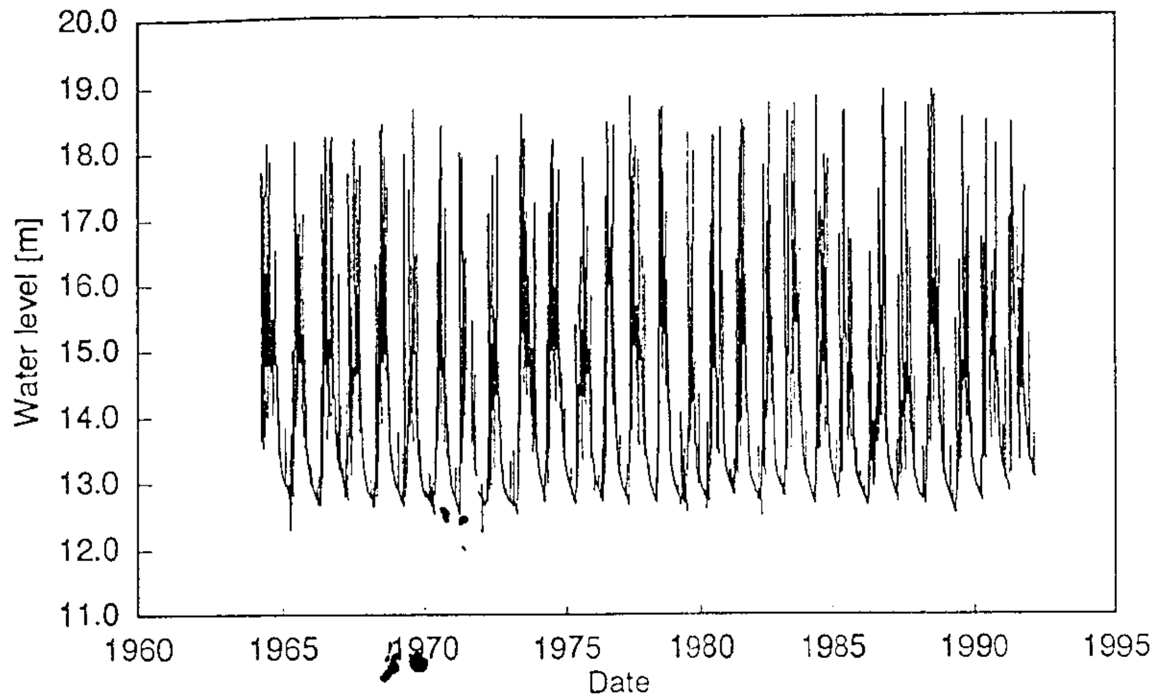
FILE: CHW-019.DWG

Figure 47

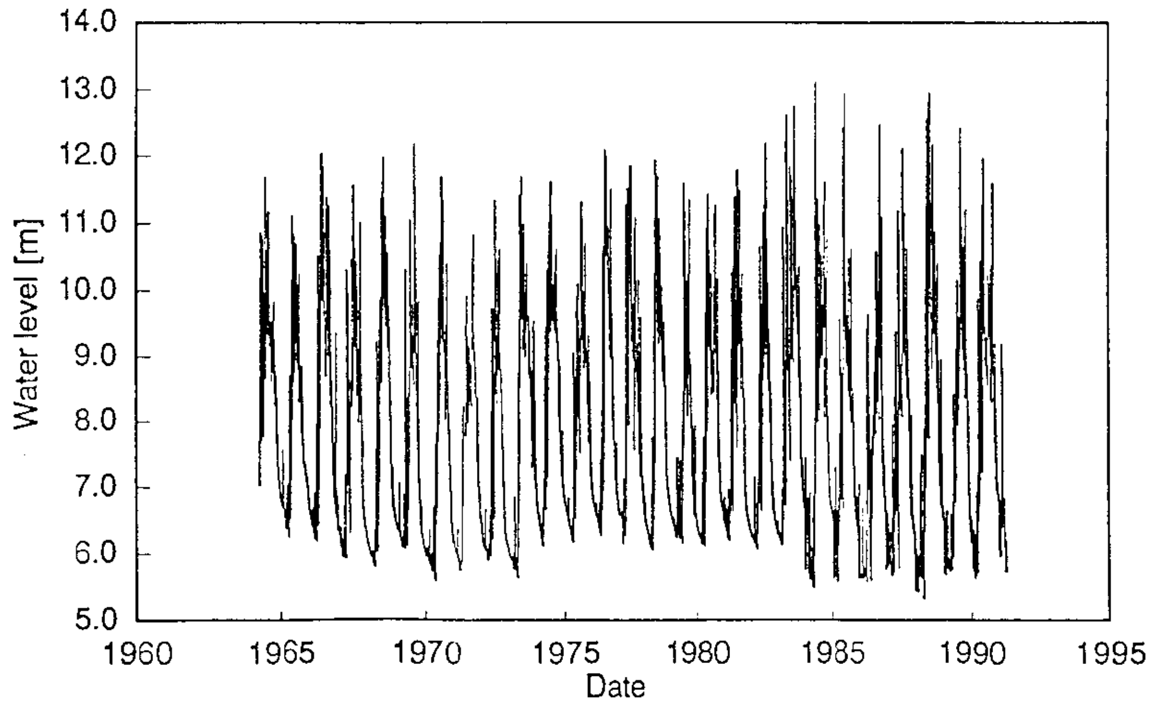
Gauge 175 KUSHIYARA R. at MANUMUKH/SHERPUR

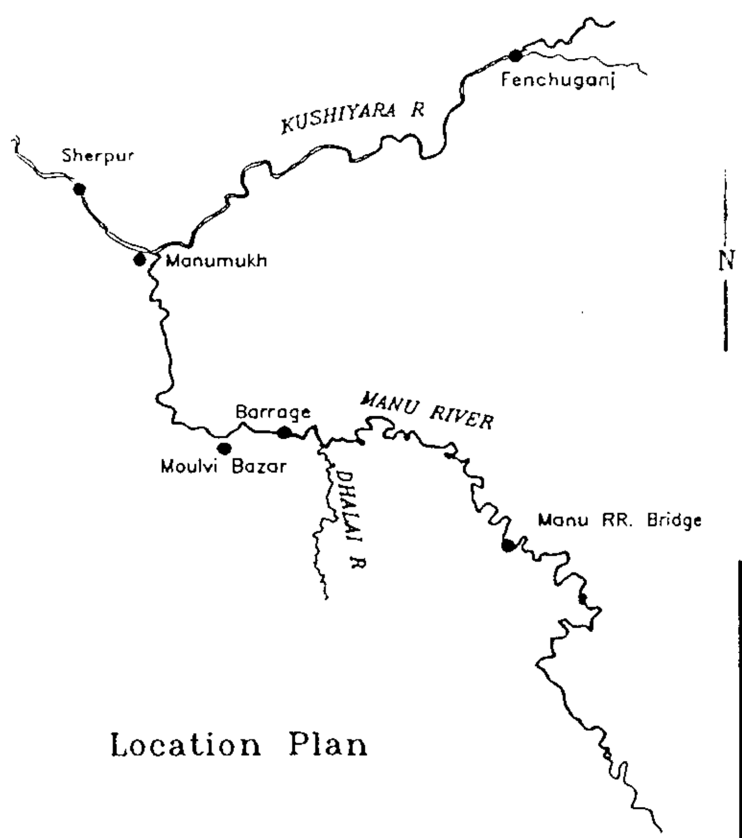


Gauge 201 MANU R. at MOULVIBAZAR



Gauge 202 MANU R. at MANU RR. BRIDGE



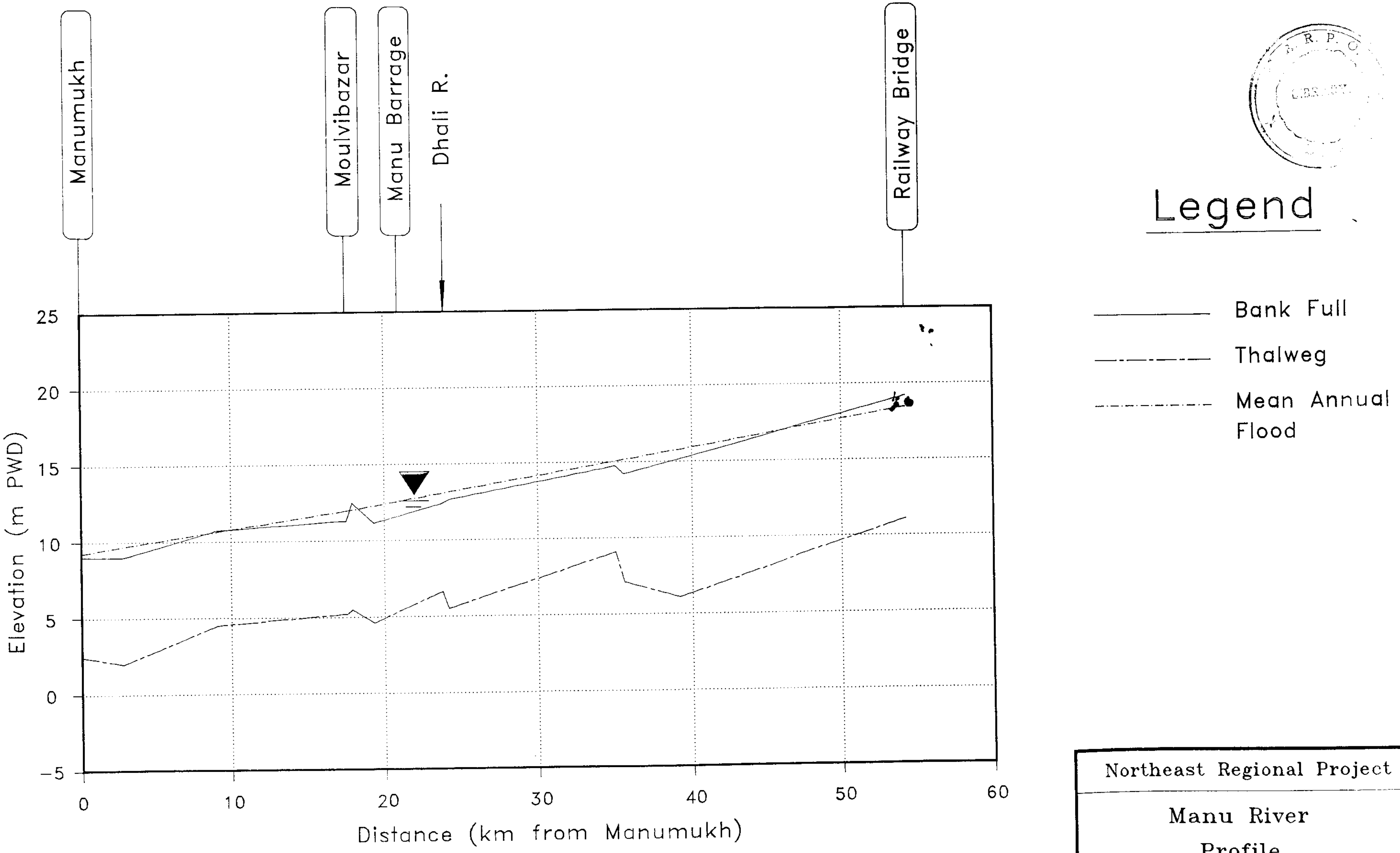


Location Plan

Northeast Regional Project	
Historic Water Levels Manu River	
Prepared by: CHW	May 1993

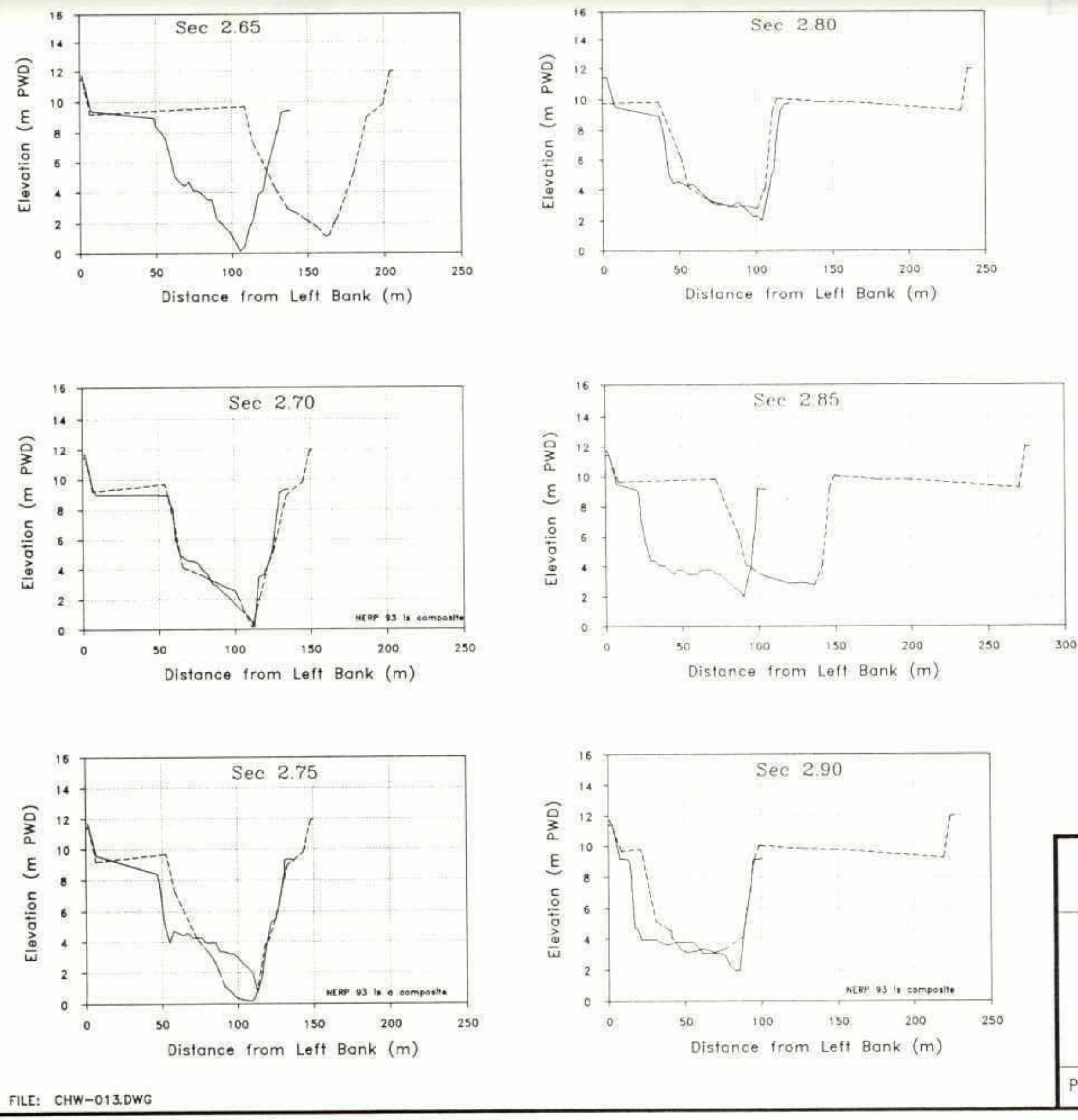
FILE: BORDLDWG

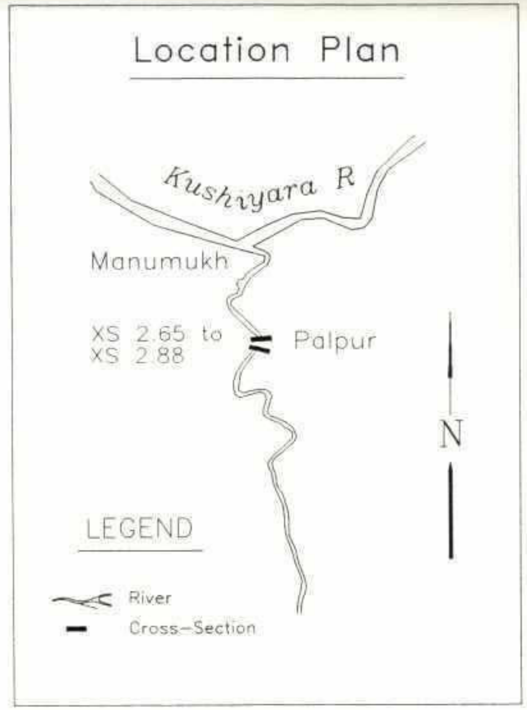
Figure 48



Northeast Regional Project	
Manu River Profile	
Prepared by: CHW	MaY 1993

FILE: CHW-017.DWG





LEGEND

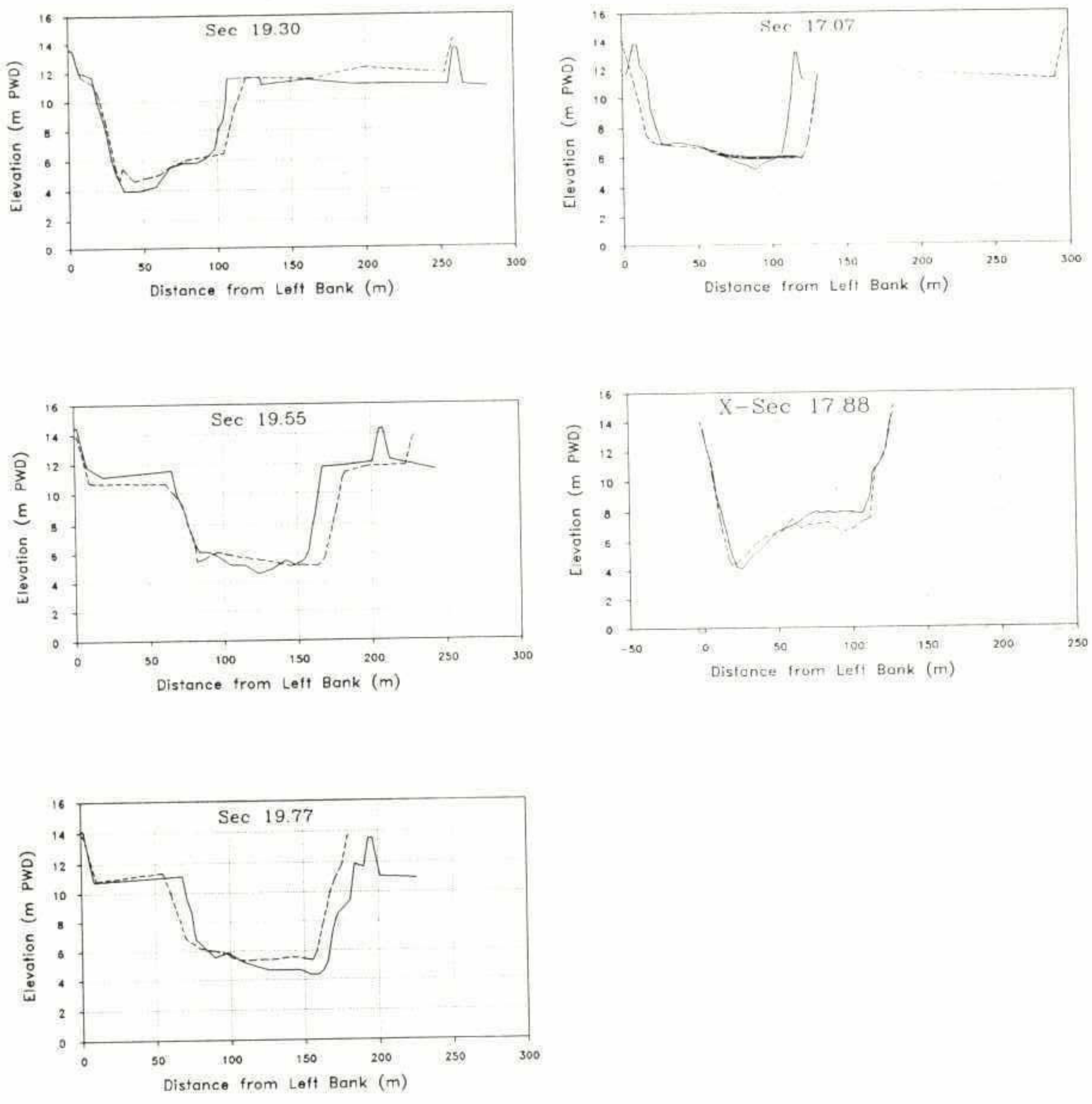
BWDB 1986 ———
NERP 1993 - - - - -

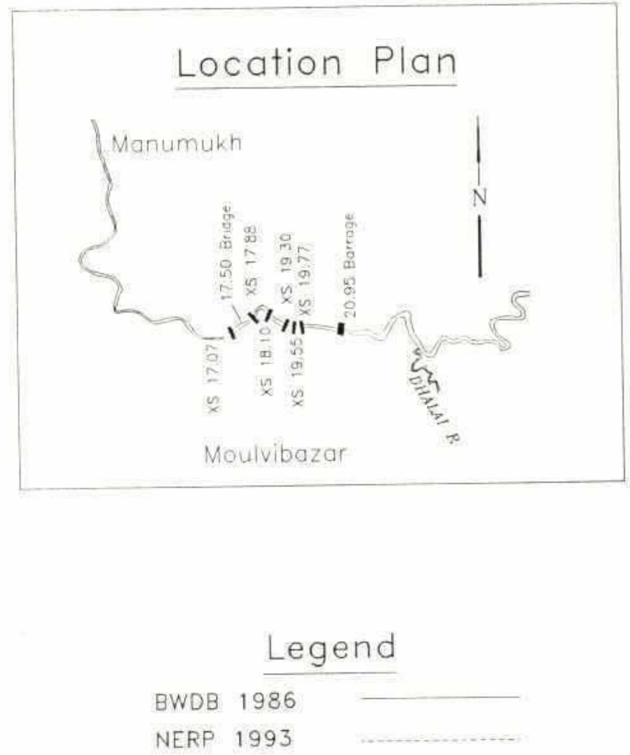
Northeast Regional Project

Manu River Cross-Sec. near Manumukh

Prepared by: CHW | May 1993

Figure 50





Northeast Regional Project

Manu River Cross-Sec. near Moulvibazar

Prepared by: CHW | May 1993

FILE: CHW-014.DWG

Figure 51

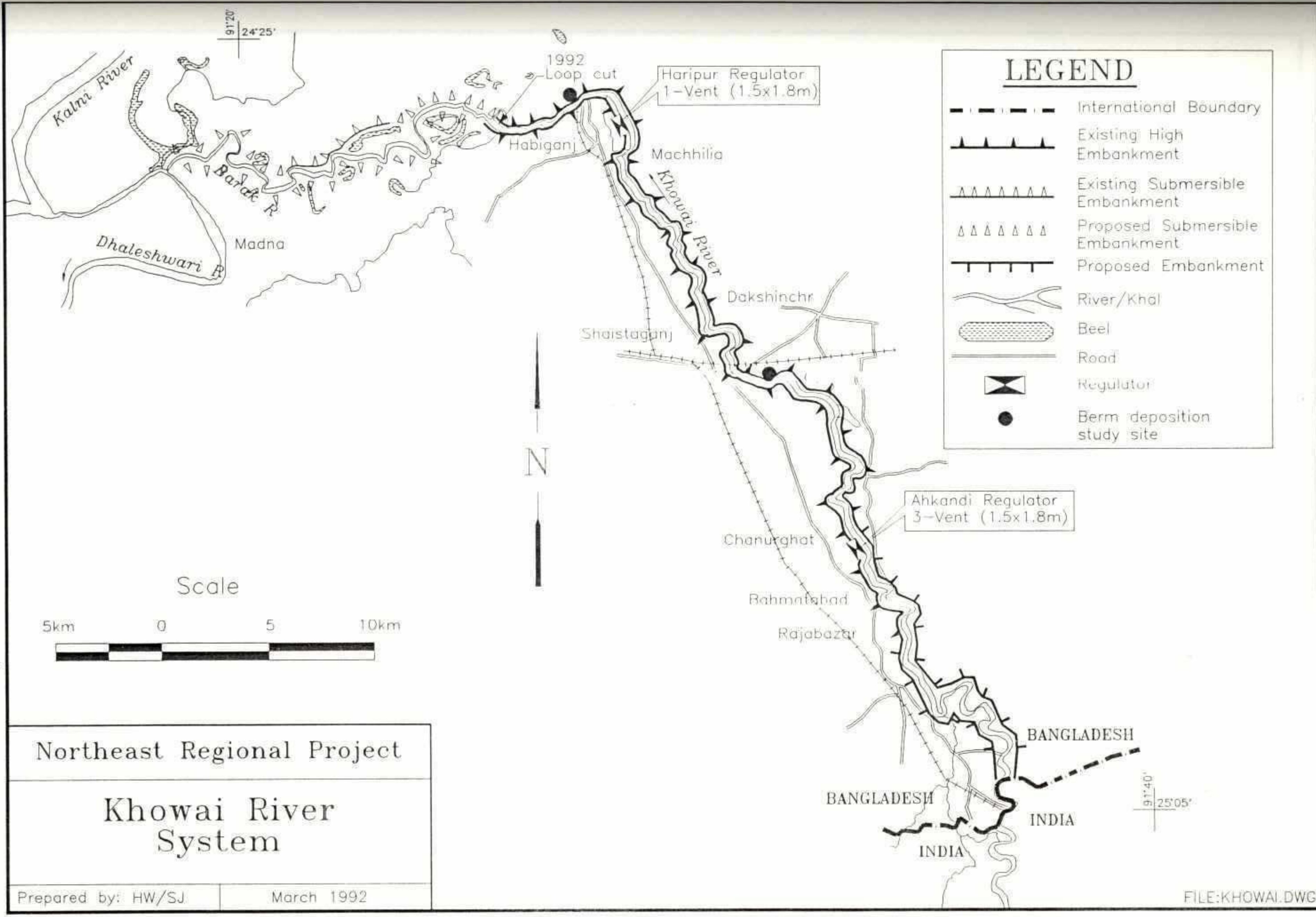
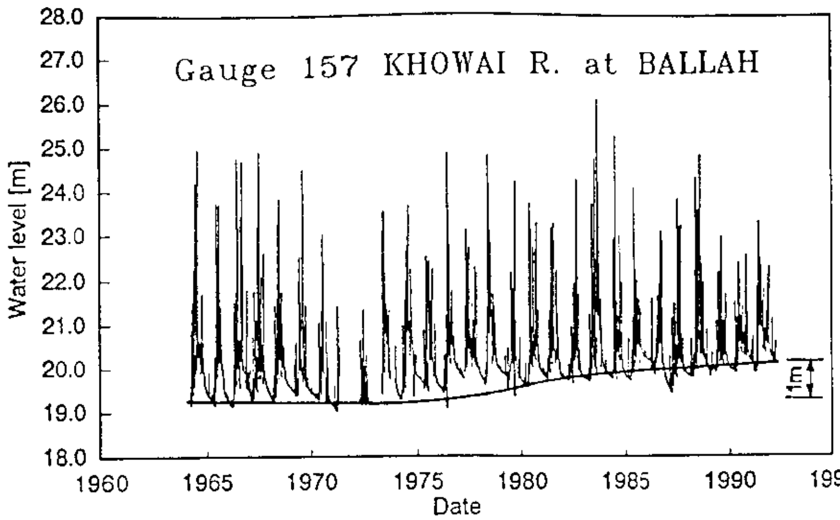
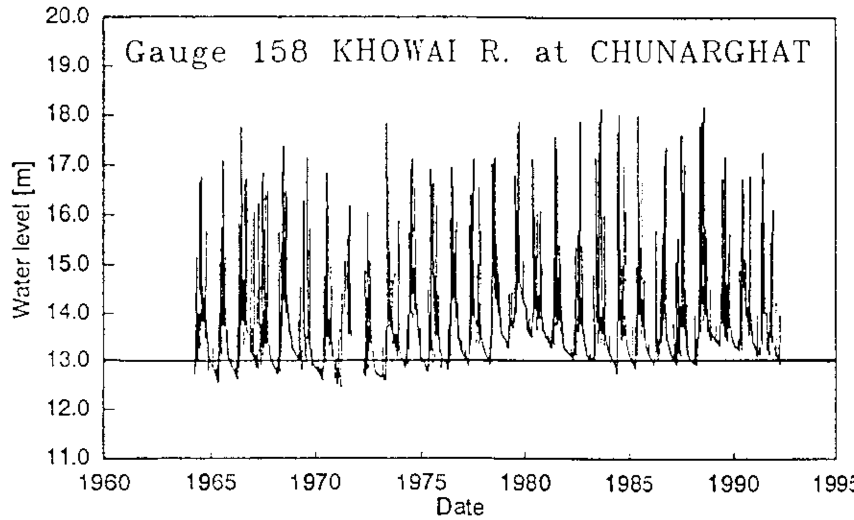
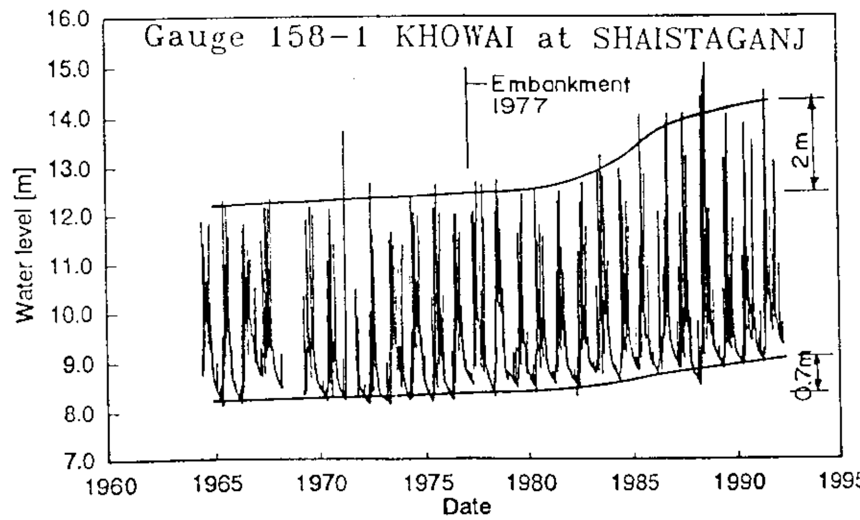
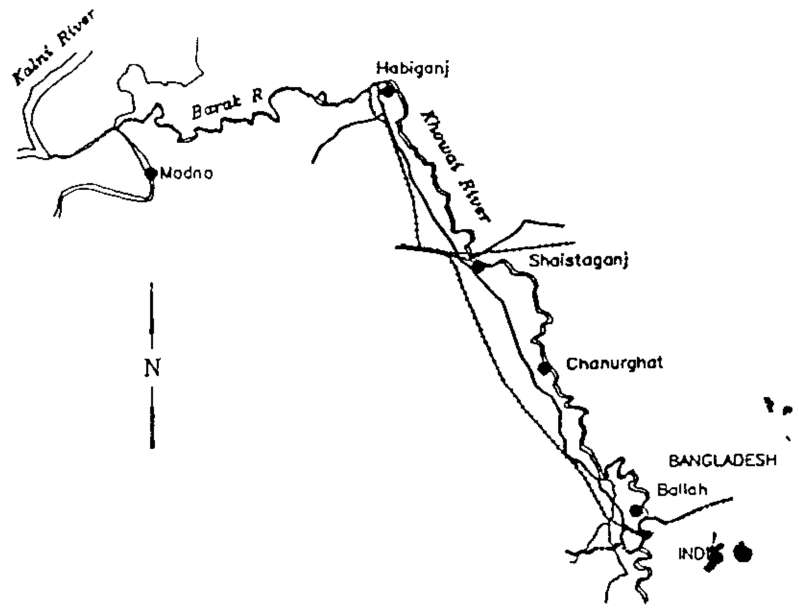

LEGEND
International Boundary
Existing High Embankment
Existing Submersible Embankment
Proposed Submersible Embankment
Proposed Embankment
River/Khal
Beel
Road
Regulator
Berm deposition study site
Kalni River
Baruk R
Dhaleshwari R
Madna
1992 Loop cut
Habiganj
Haripur Regulator 1-Vent (1.5x1.8m)
Machhilia
Khowai River
Dakshinchr
Shaistaganj
Ahkandi Regulator 3-Vent (1.5x1.8m)
Chanurghat
Rahmatabad
Rajabazar
BANGLADESH
INDIA
BANGLADESH
INDIA
N
91°20'
24°25'
91°40'
25°05'
Scale
5km
0
5
10km
Northeast Regional Project
Khowai River System
Prepared by: HW/SJ
March 1992
FILE:KHOWAI.DWG

Figure 52

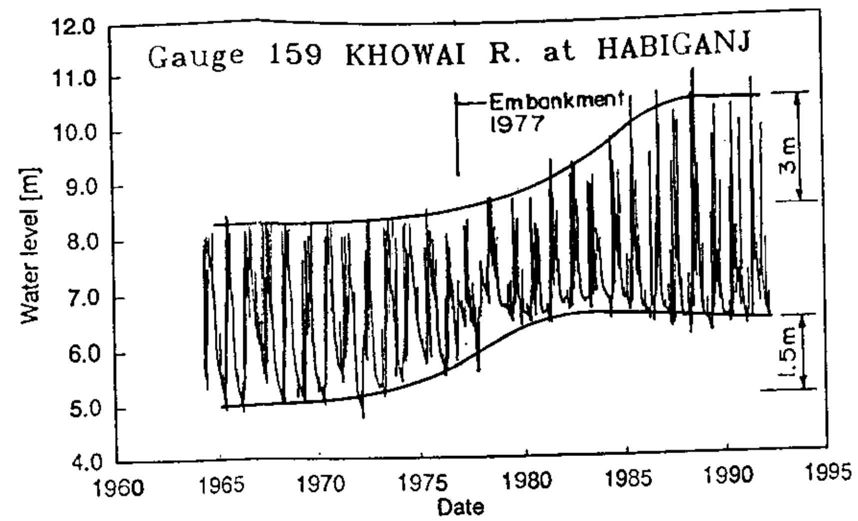


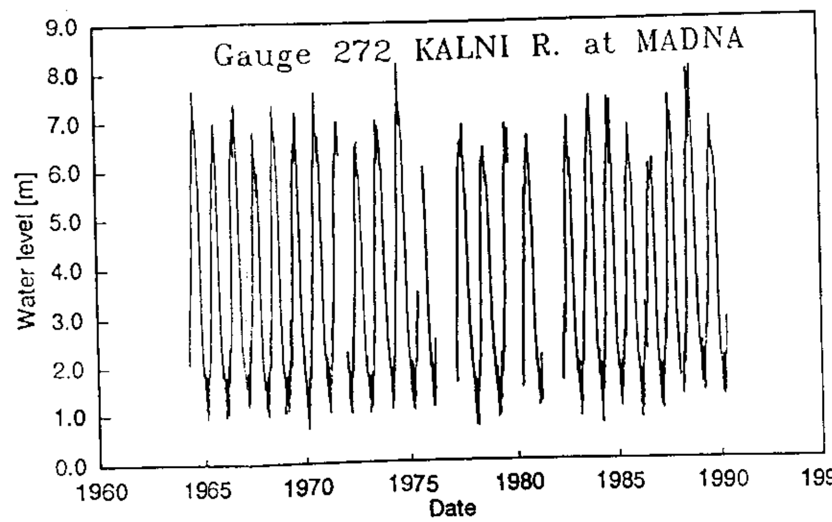






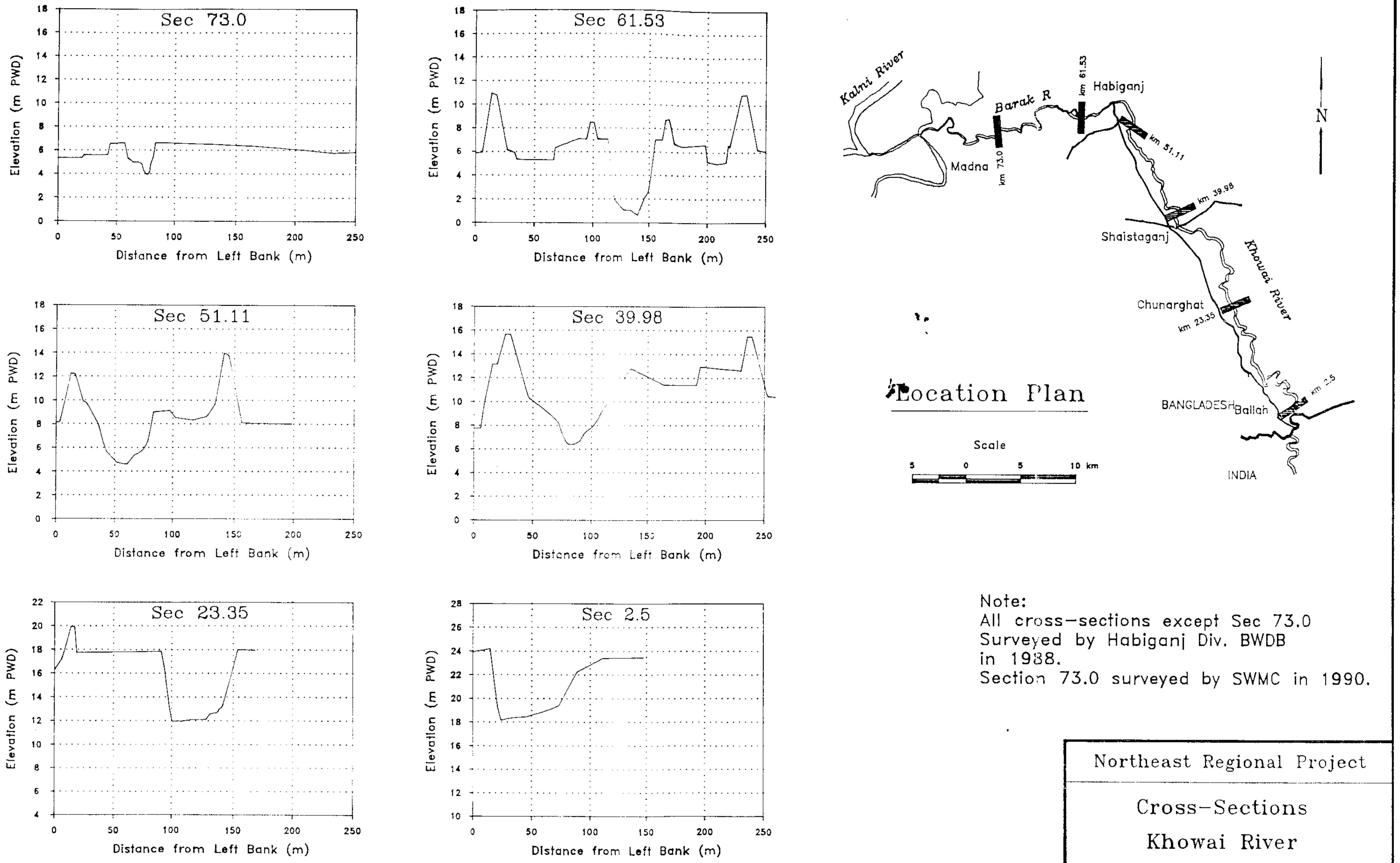
Location Plan





Northeast Regional Project	
Historic Water Levels Khowai River	
Prepared by: CHW	May 1993

FILE: BORD2.DWG

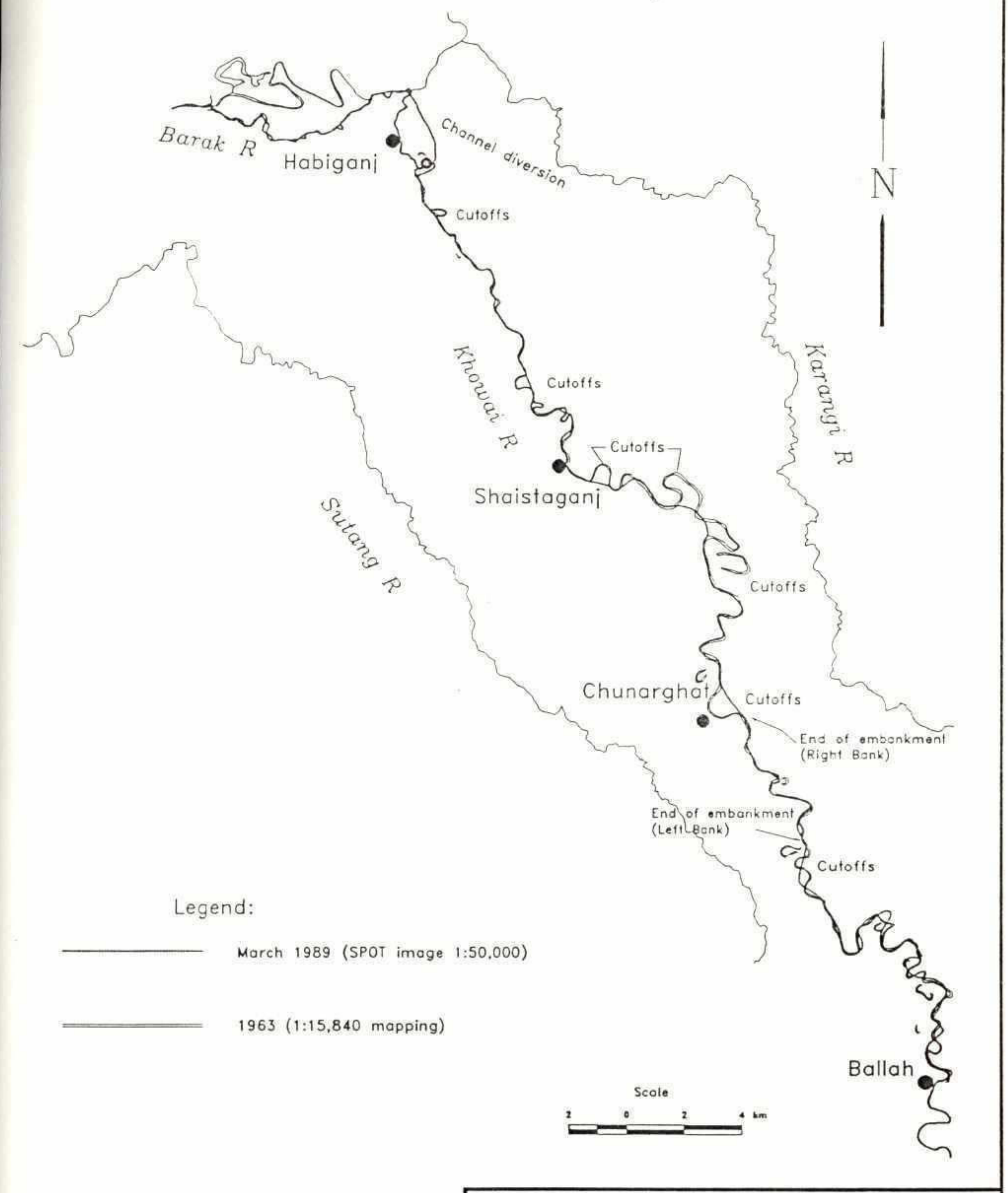


Note:
All cross-sections except Sec 73.0 Surveyed by Habiganj Div. BWDB in 1988.
Section 73.0 surveyed by SWMC in 1990.

Northeast Regional Project	
Cross-Sections Khowai River	
Prepared by: CHW	May 1993

FILE: DM-240.DWG

Figure 54



Northeast Regional Project

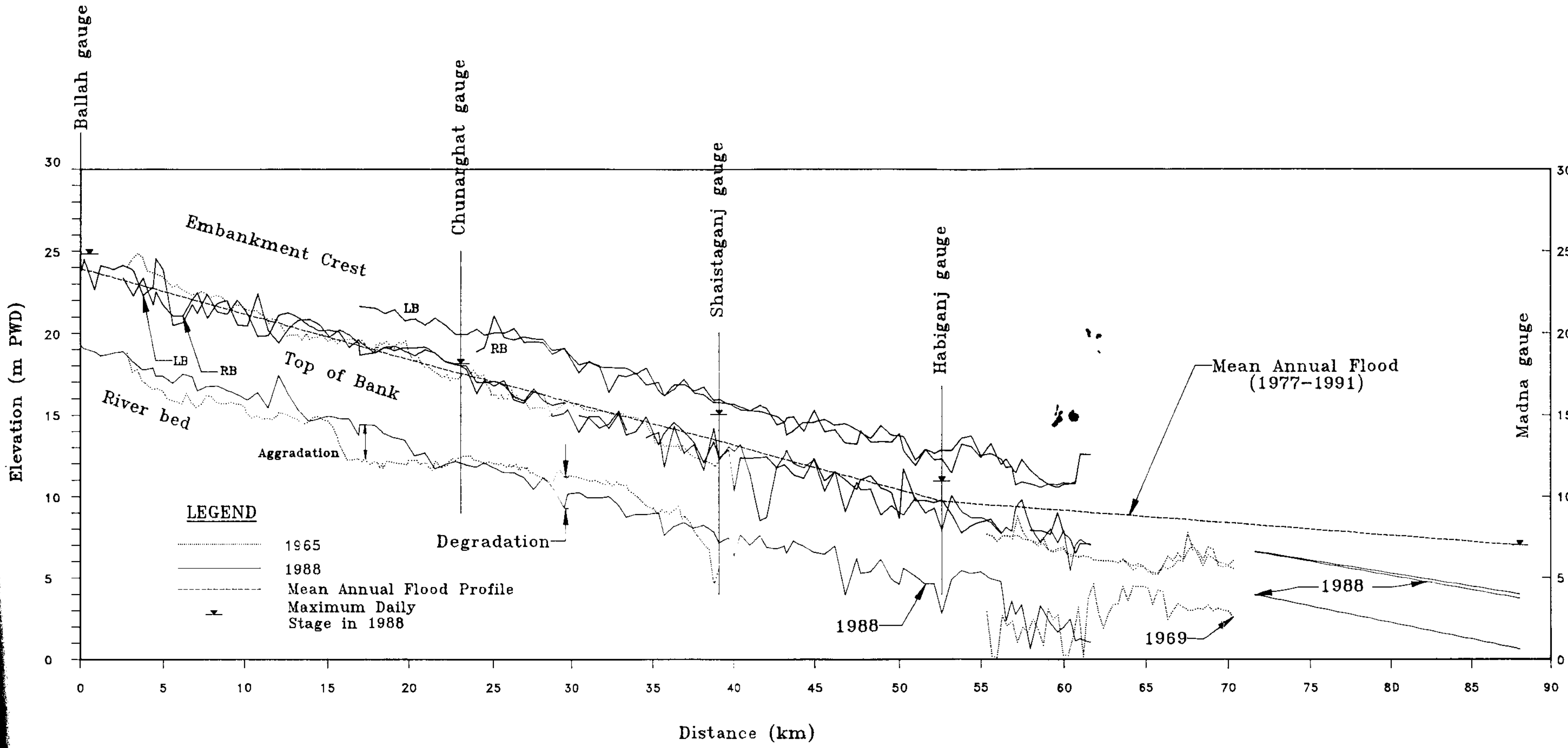
Channel Changes Along Khowai River

Prepared by: DMc Aug 1992

FILE: dm113.DWG

202

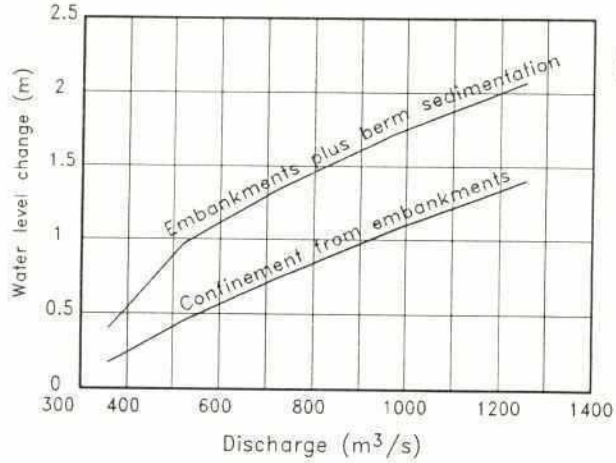
Figure 55



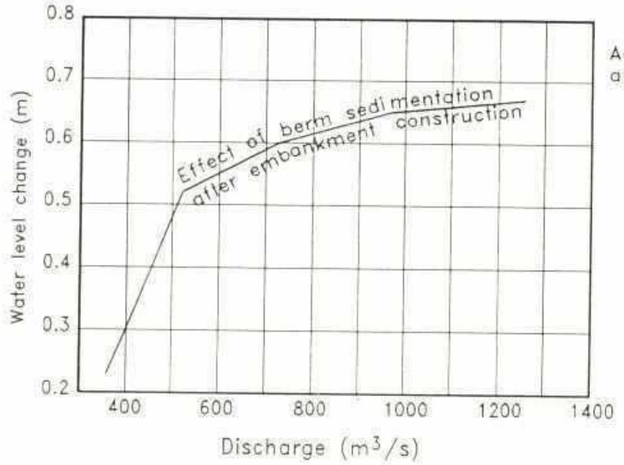
Note:
All chainages based on BWDB Habiganj W.D. Division Long Section of Khowai River showing Deep Channel Line dated 6/2/88

Northeast Regional Project	
Longuitudinal Profile of Khowai River	
Prepared by: DMc	December 1994
Computer Drafting by:Mamun	AutoCAD Drawing

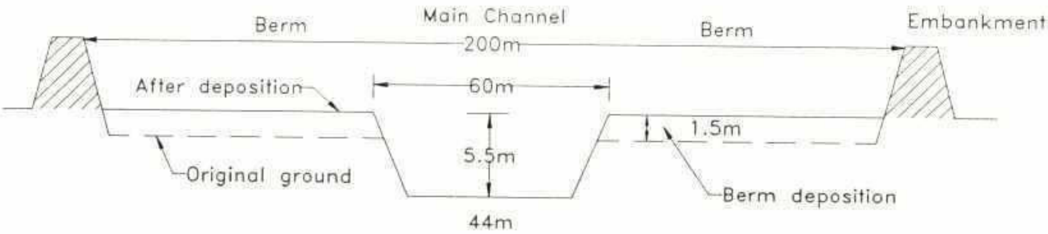
KHOPRO.DWG



Effect of embankments and berm sedimentation on water level.



Additional effect of berm sedimentation after embankments are constructed.



Note:

n_{Berm} = 0.06
n_{Chan} = 0.03
Slope = 0.00028

Khowai River near Habiganj

Northeast Regional Project

Impacts of Berm Sedimentation on Flood Levels

Prepared by: DMc/Tarek	December 1994
Drawn by: Jalal	AutoCAD Drawing

FILE: dm102.DWG

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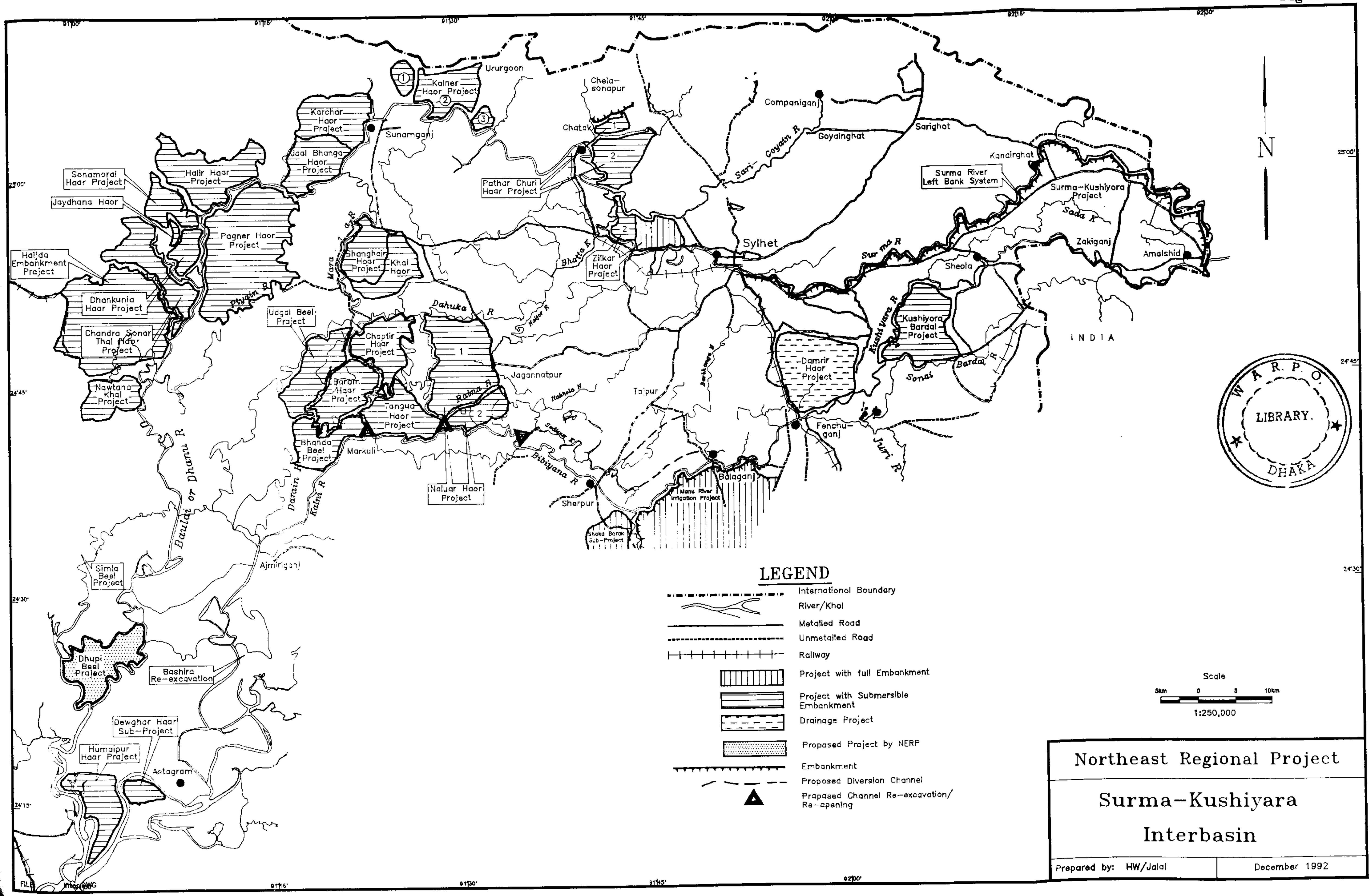
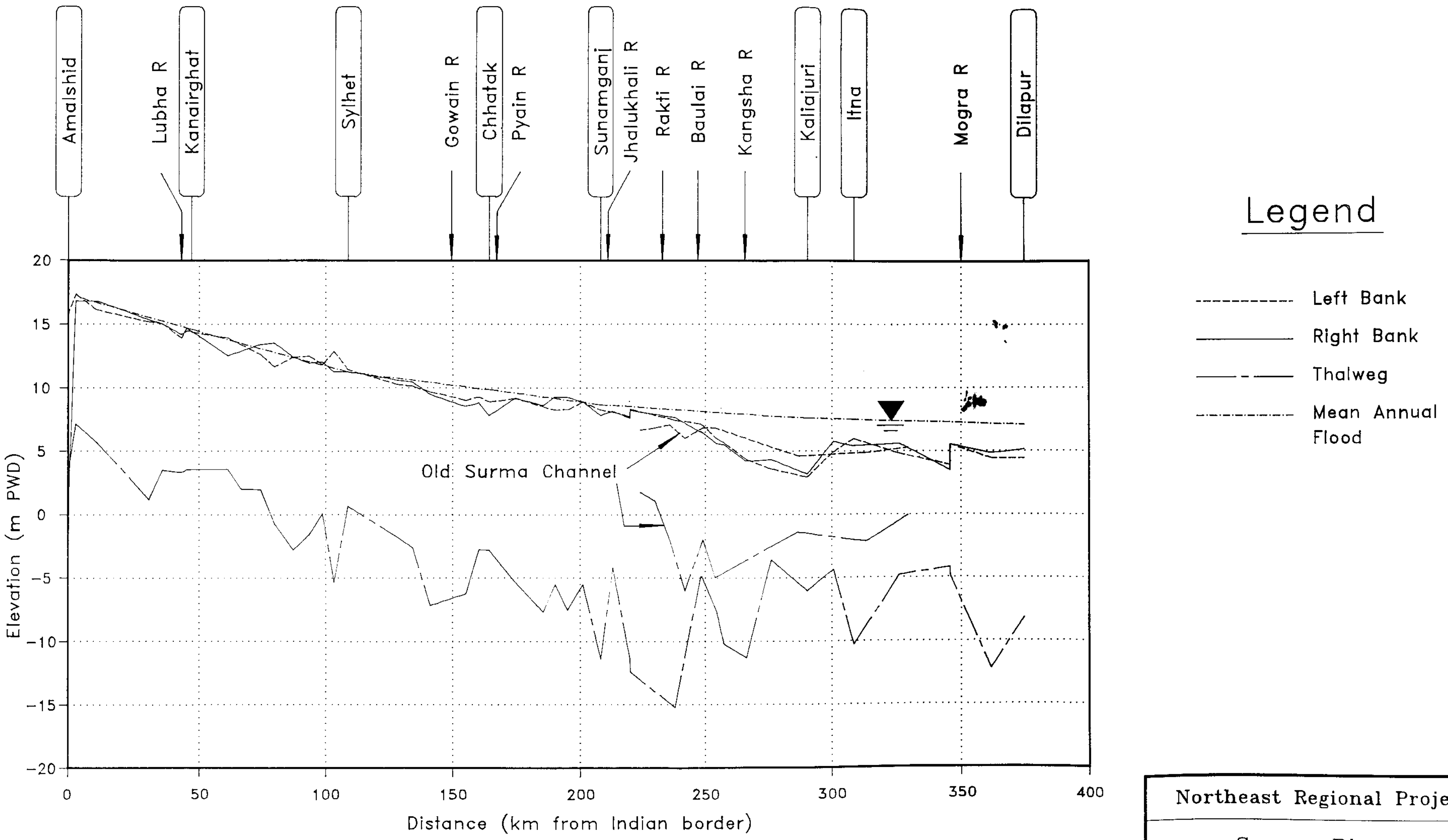
Figure 57



202

Figure 58



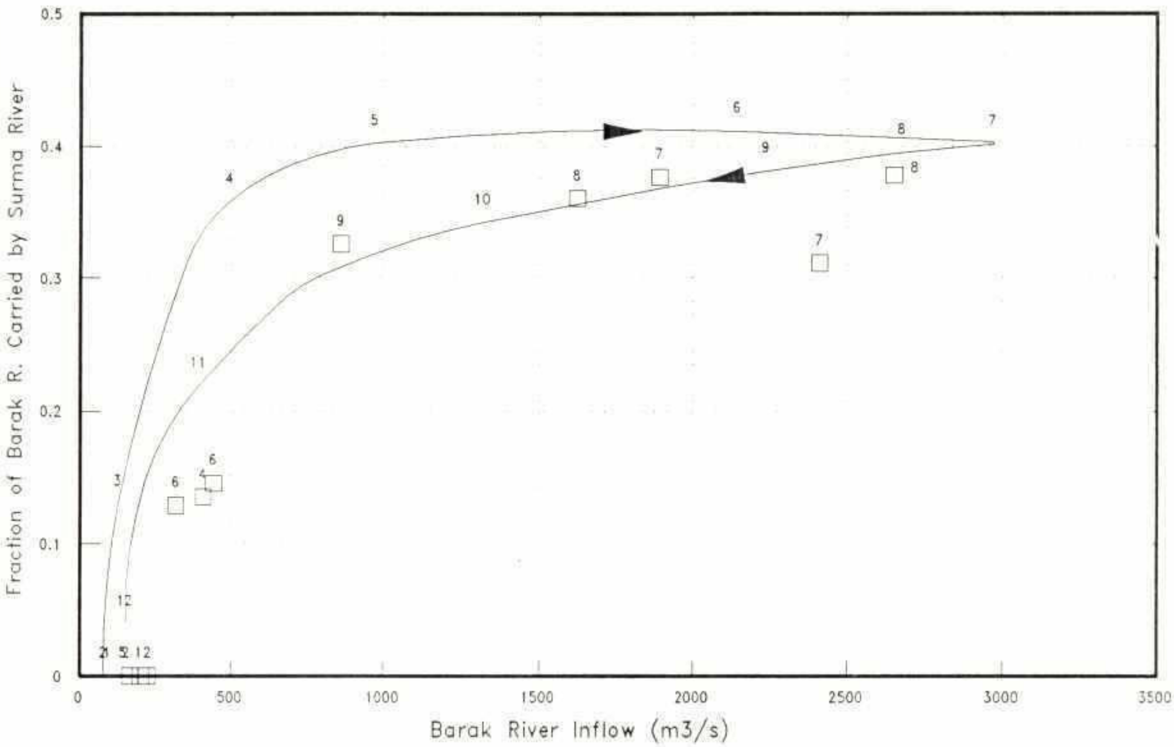
Northeast Regional Project

Surma River Profile

Prepared by: CHW | April 1993

FILE: SURPRO.DWG

Figure 59



Legend:

□ 1991-92 Observed

—— Estimated Longterm Mean 1964-1989

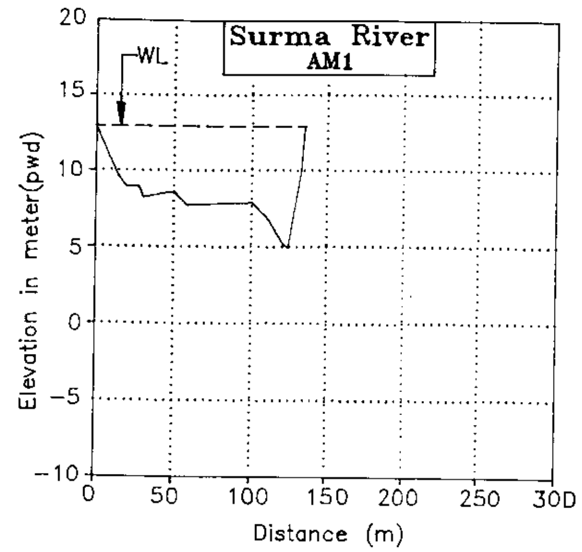
Note:

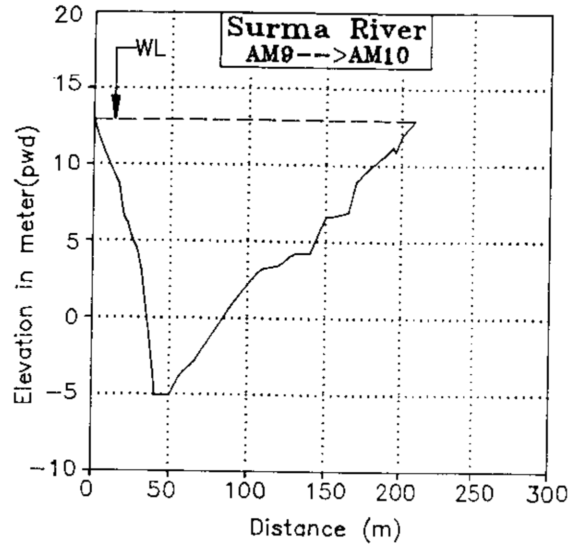
1. Numbers shown indicate month of observation

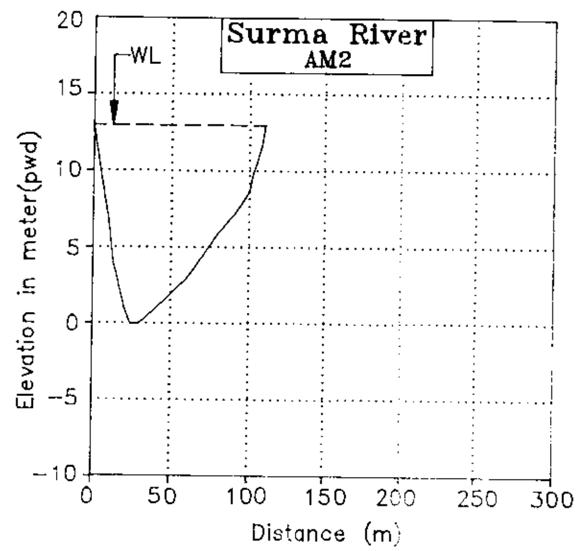
Northeast Regional Project	
Division of Flow at Amalshid	
Prepared by: dm	May 1993

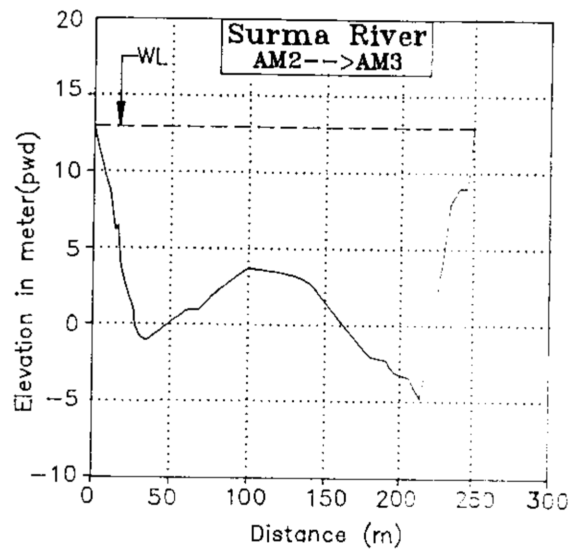
FILE: dm212.DWG

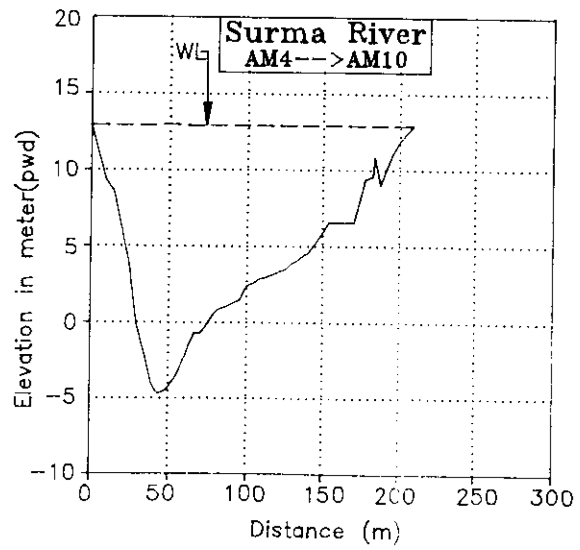
Figure 60

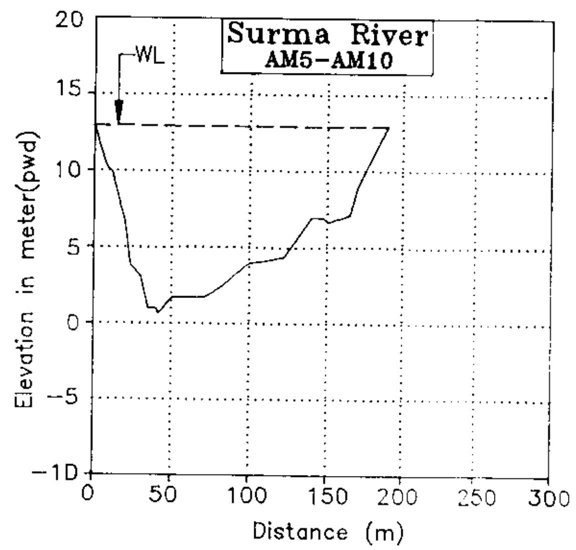


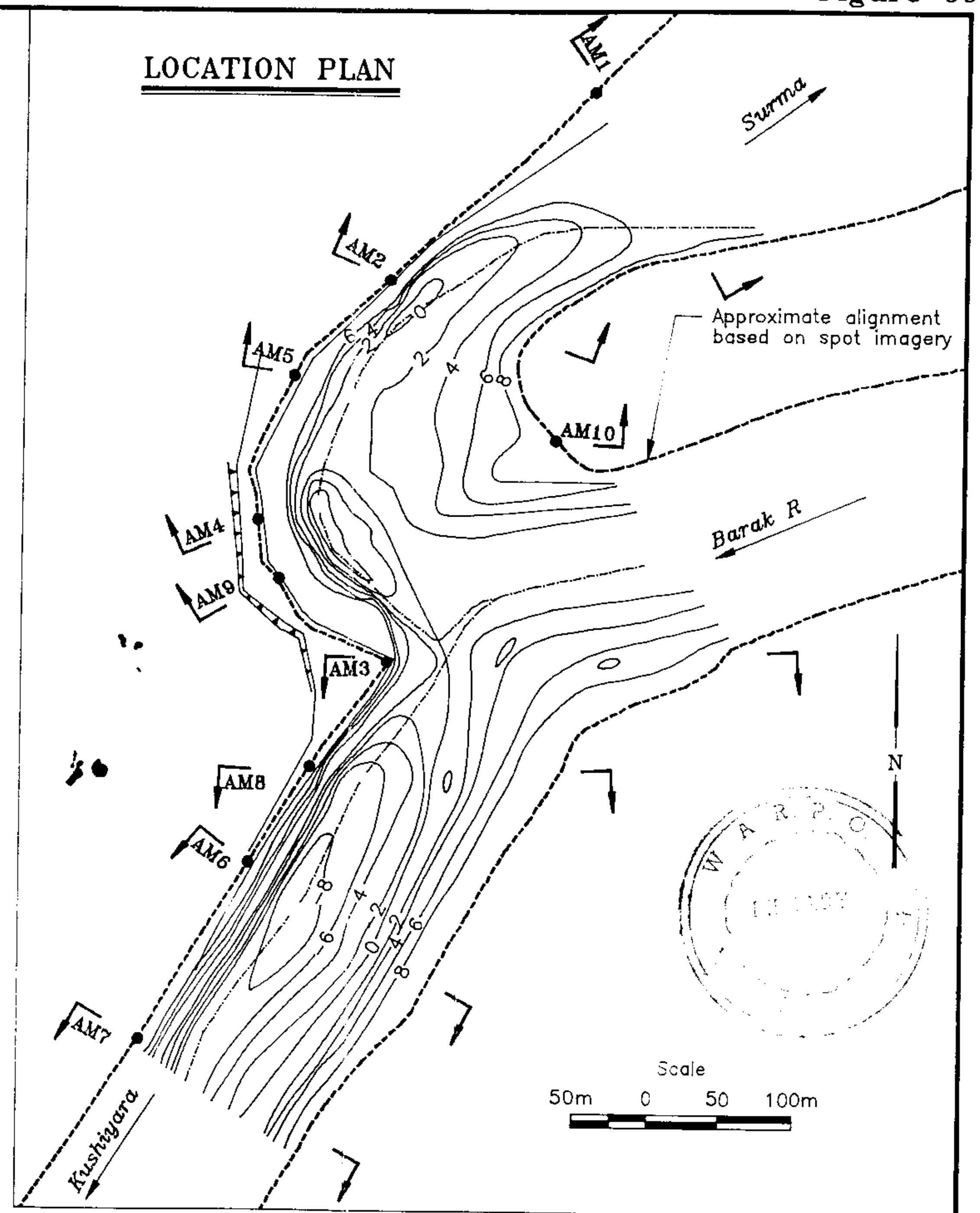










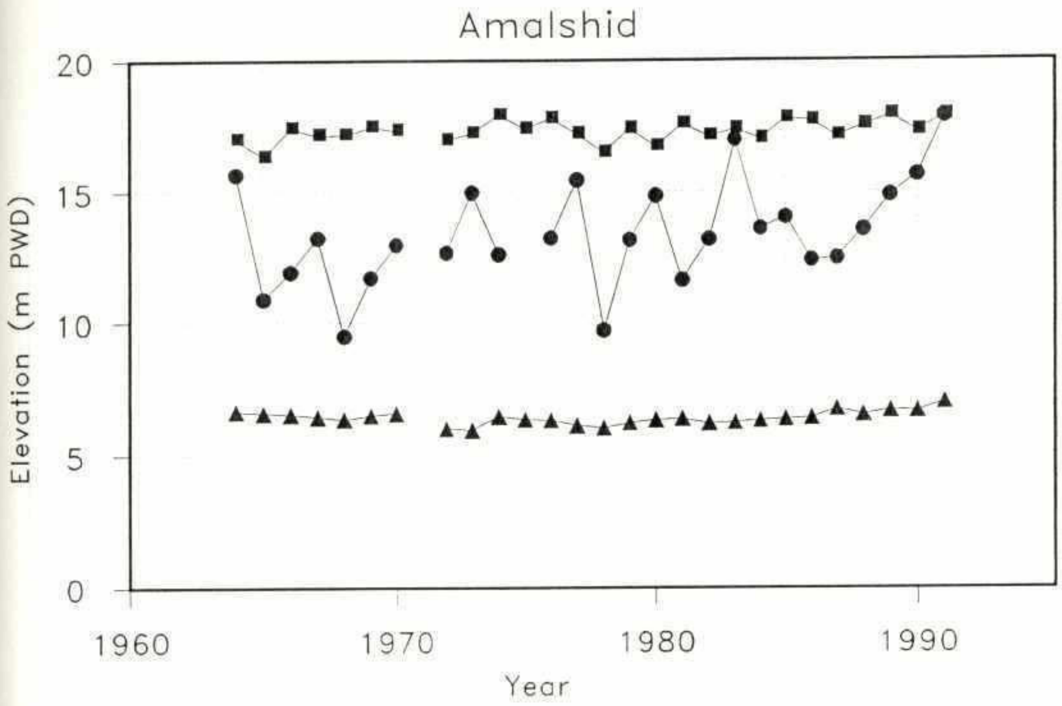


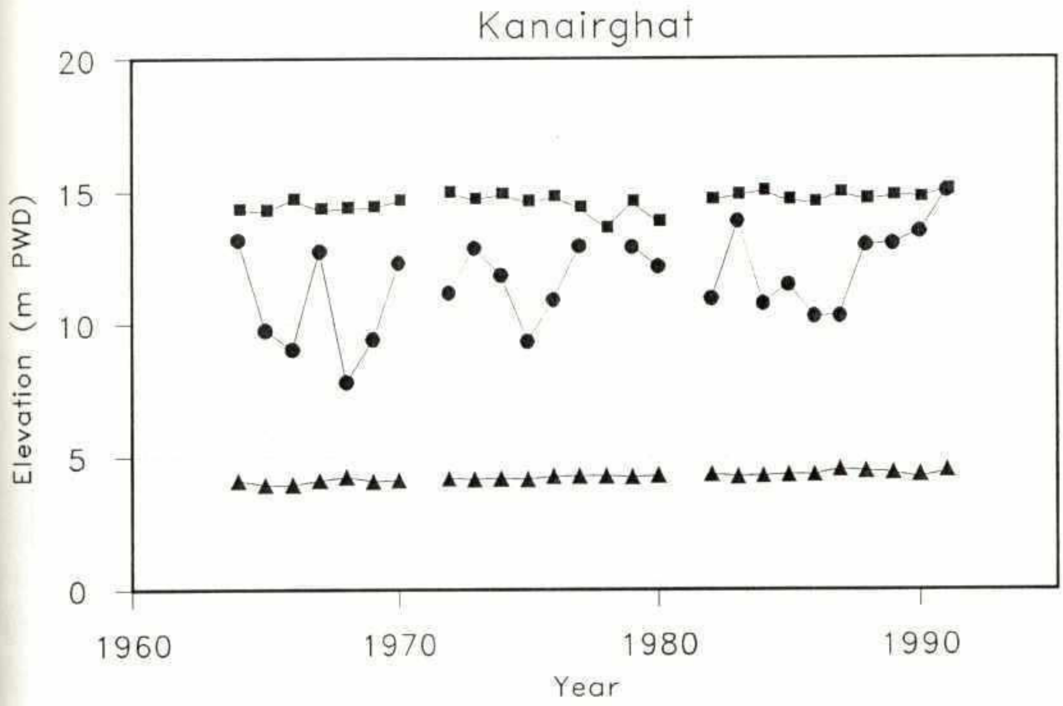
NOTE:-
WATER LEVEL 12.93m ON OCTOBER 26,1992

Northeast Regional Project	
Surma River Near Amalshid	
Prepared by: DMc/Tarek/Jalal	November 1992

FILE: AMAL-01DWG

Figure 61





Legend

- ■ Maximum Annual
- ▲ Minimum Annual
- ● Maximum Pre–Monsoon (Ending May 15)

FILE: DM205.DWG

Northeast Regional Project

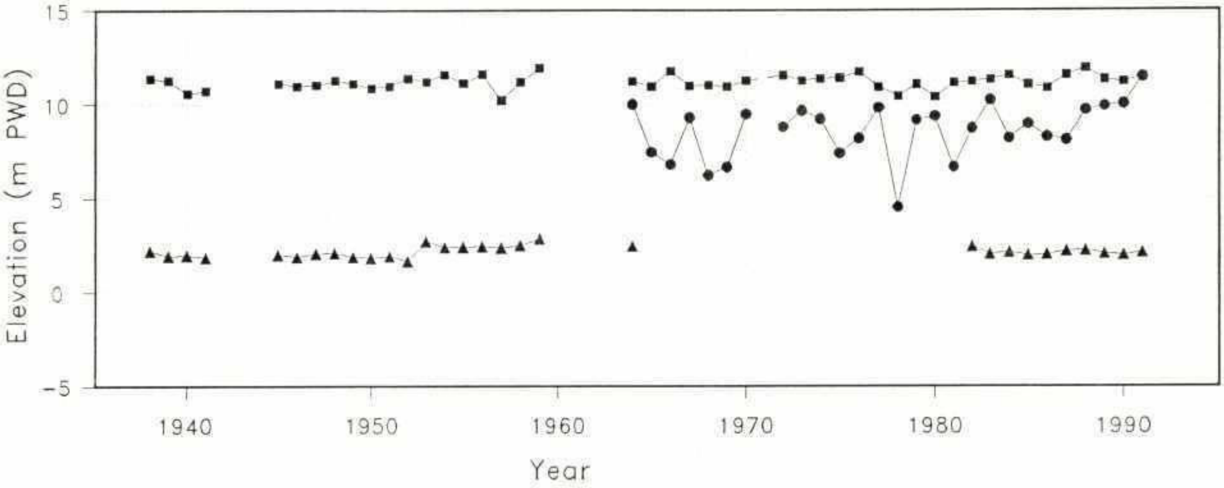
Annual Water Levels
Upper Surma River

Prepared by: CHW | May 1993

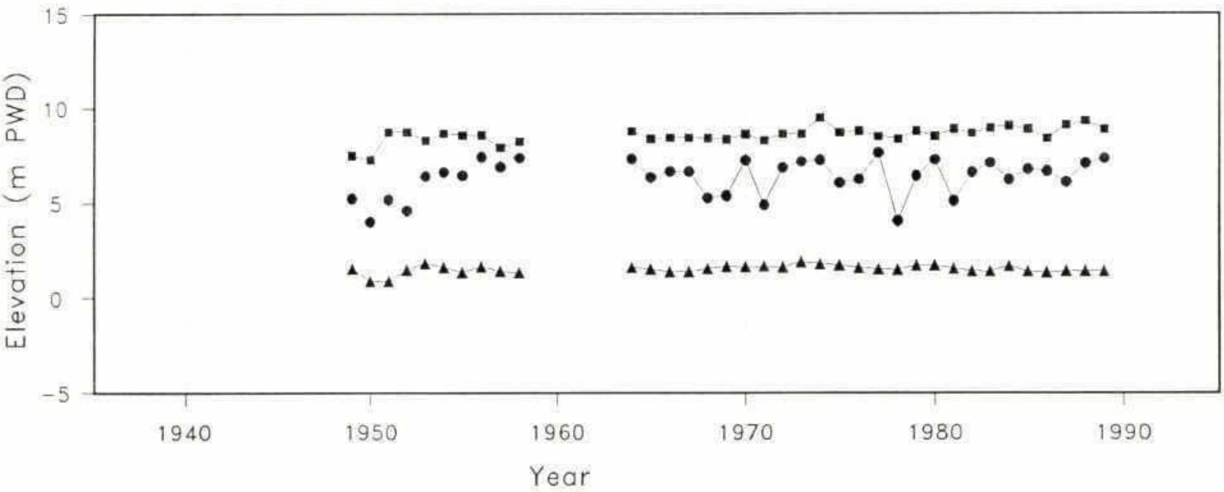
227

Figure 62

Sylhet



Sunamganj



Legend

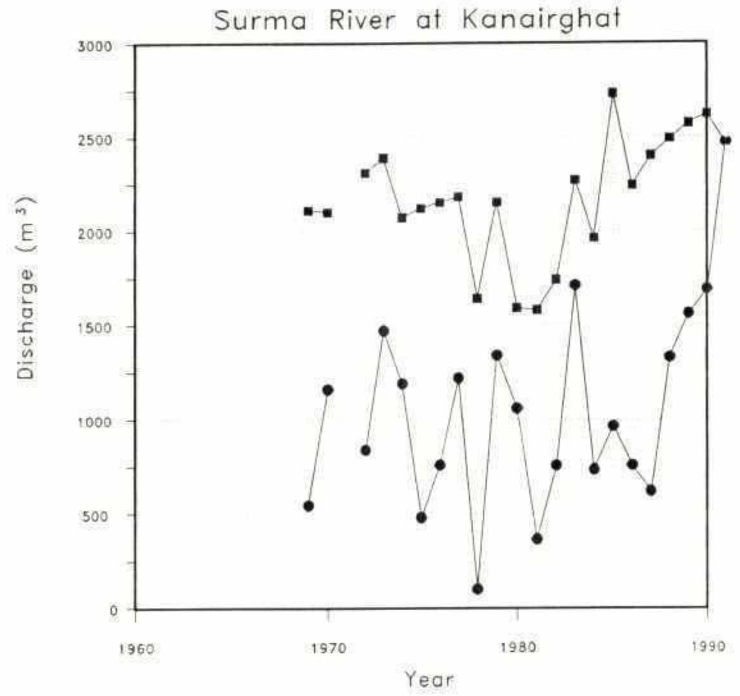
- ■ Maximum Annual
- ▲ Minimum Annual
- ● Maximum Pre-Monsoon

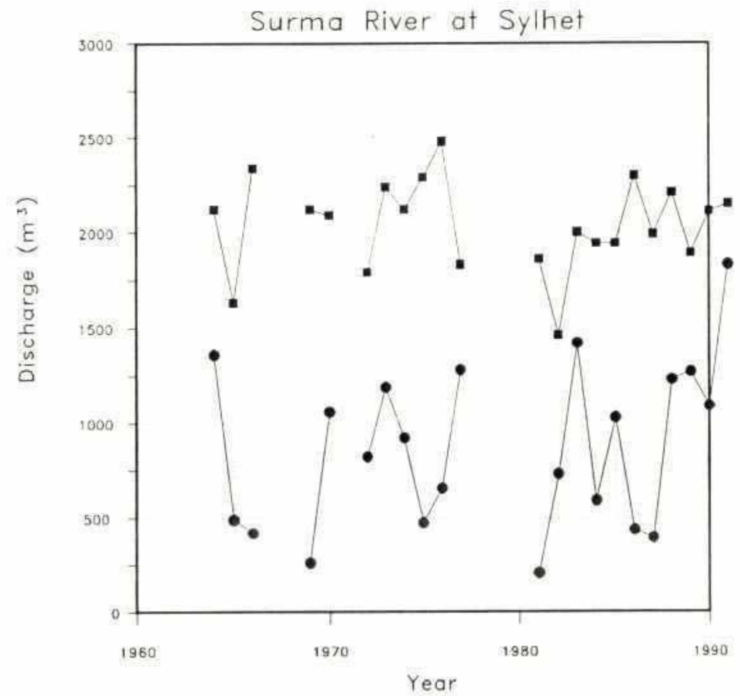
Northeast Regional Project

Water Levels
Surma River

Prepared by: CHW | May 1993

FILE: DM204.DWG





Legend

- ▪ Maximum Annual
- • Maximum Pre-Monsoon

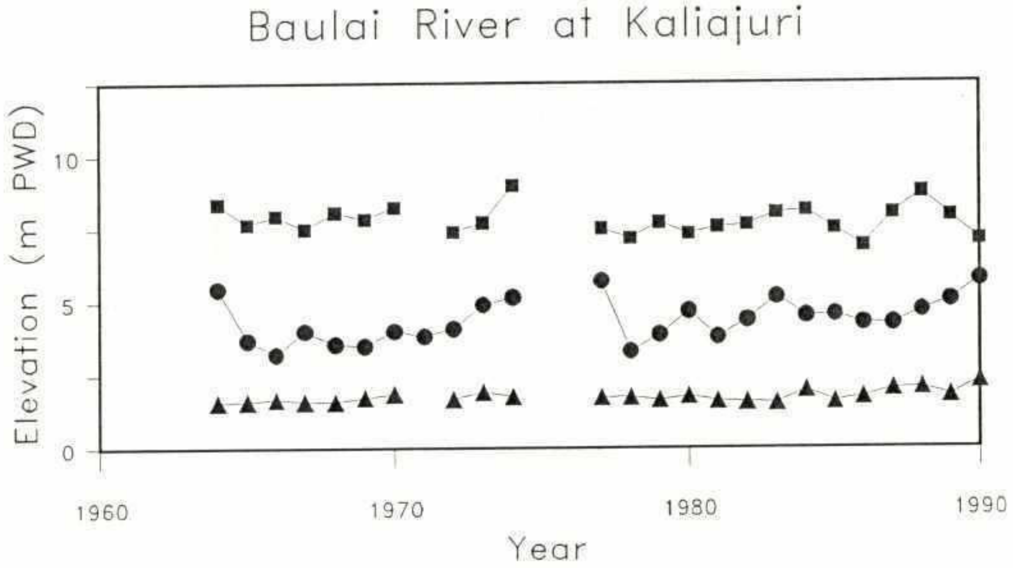
Northeast Regional Project

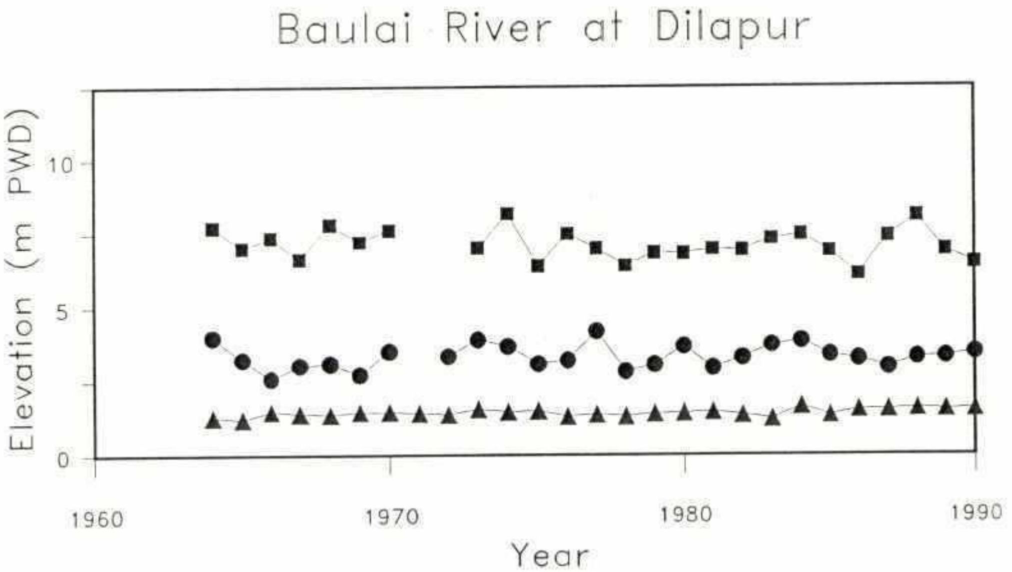
Annual Discharges
Surma River

Prepared by: DMc | May 1993

FILE: dm209.DWG

Figure 64





Legend

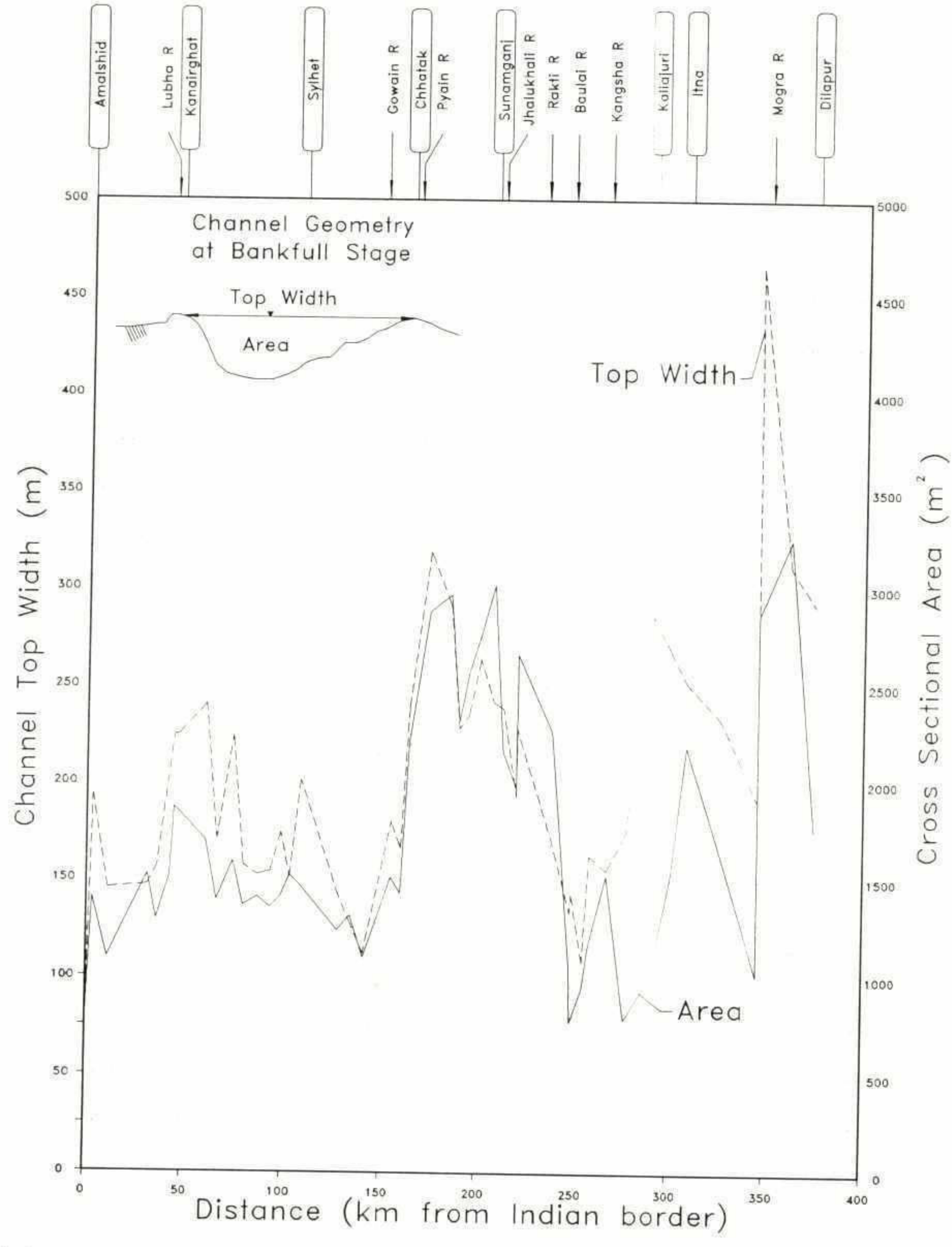
- ■ Maximum Annual
- ▲ Minimum Annual
- ● Maximum Pre-Monsoon

Northeast Regional Project

Annual Water Levels
Baulai River

Prepared by: DMc | May 1993

FILE: dm215.DWG



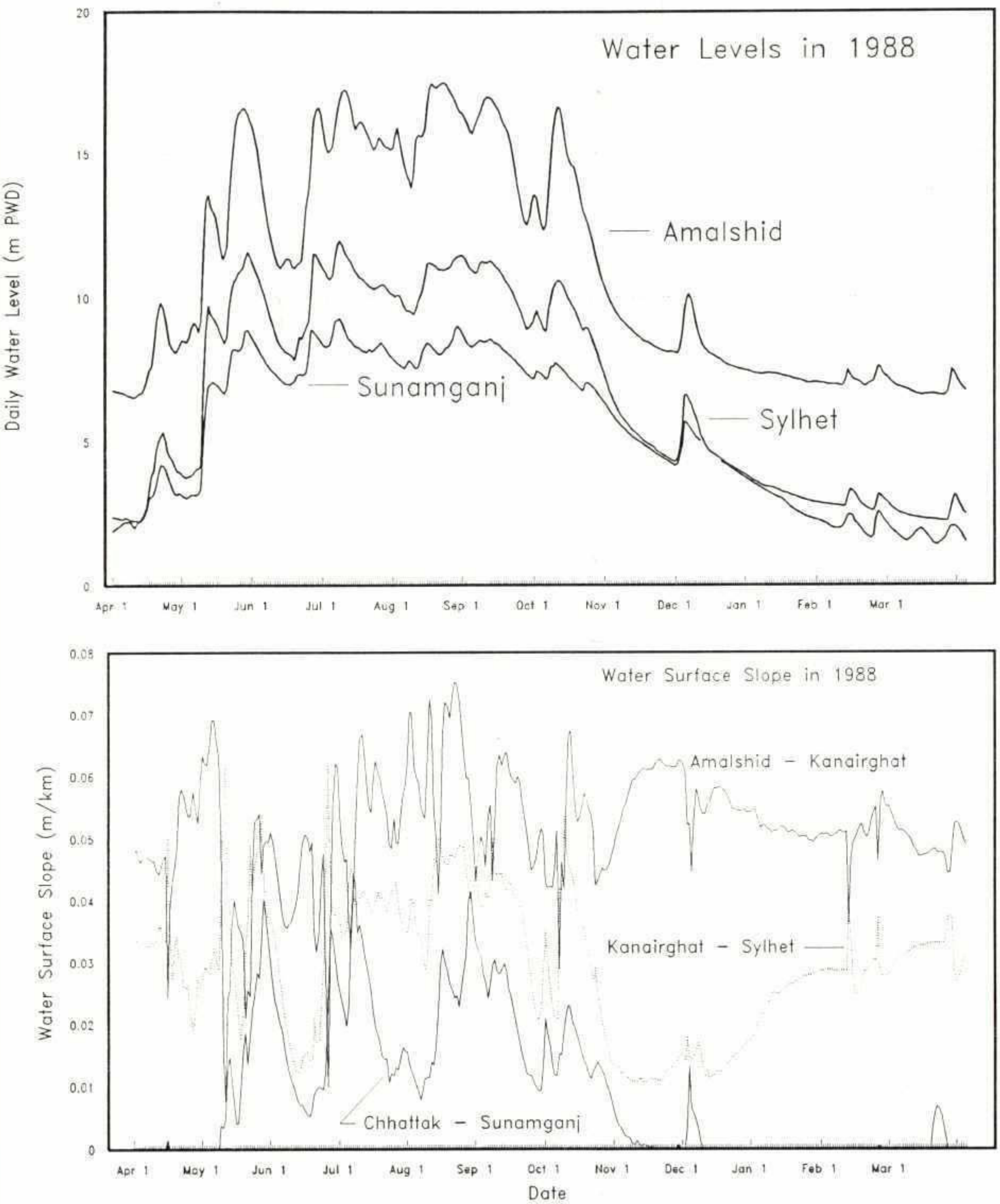
Note:
1. Cross Sections
Surveyed by SWMC (1990).

Northeast Regional Project	
Surma/Baulai River Channel Geometry	
Prepared by: dm	May 1993

FILE: dm217.DWG

220

Figure 66



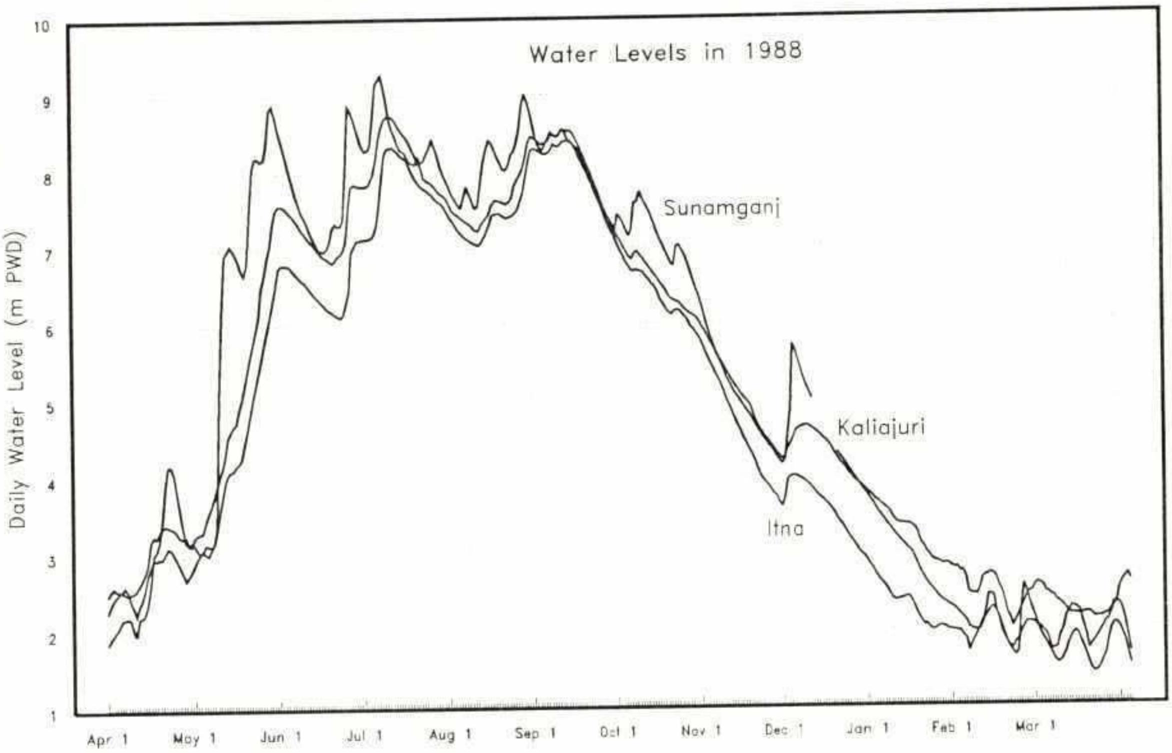
Northeast Regional Project

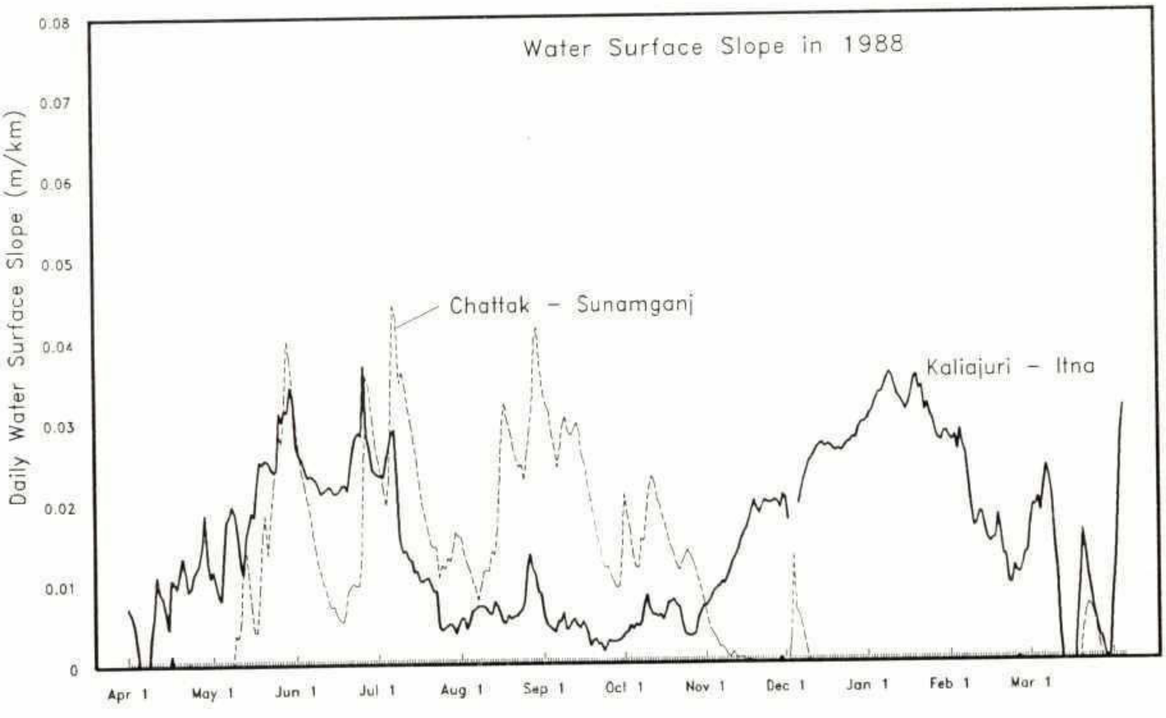
Water Level and Slope

Surma River 1988

Prepared by: DMc | May 1993

FILE: DM210.DWG





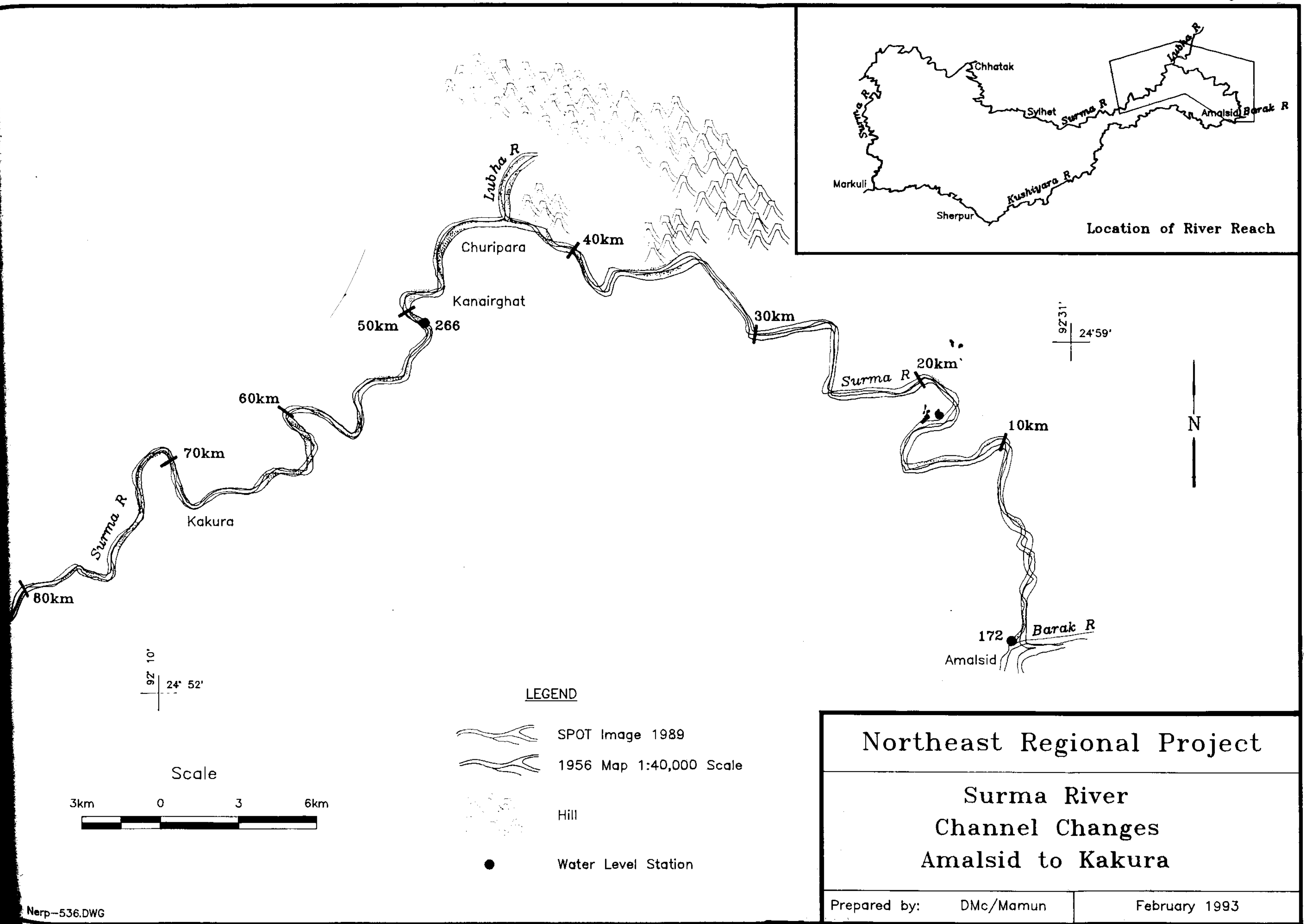
Northeast Regional Project

Water Level and Slope
Baulai River - 1988

Prepared by: DMc | May 1993

FILE: DM211.DWG

Figure 68

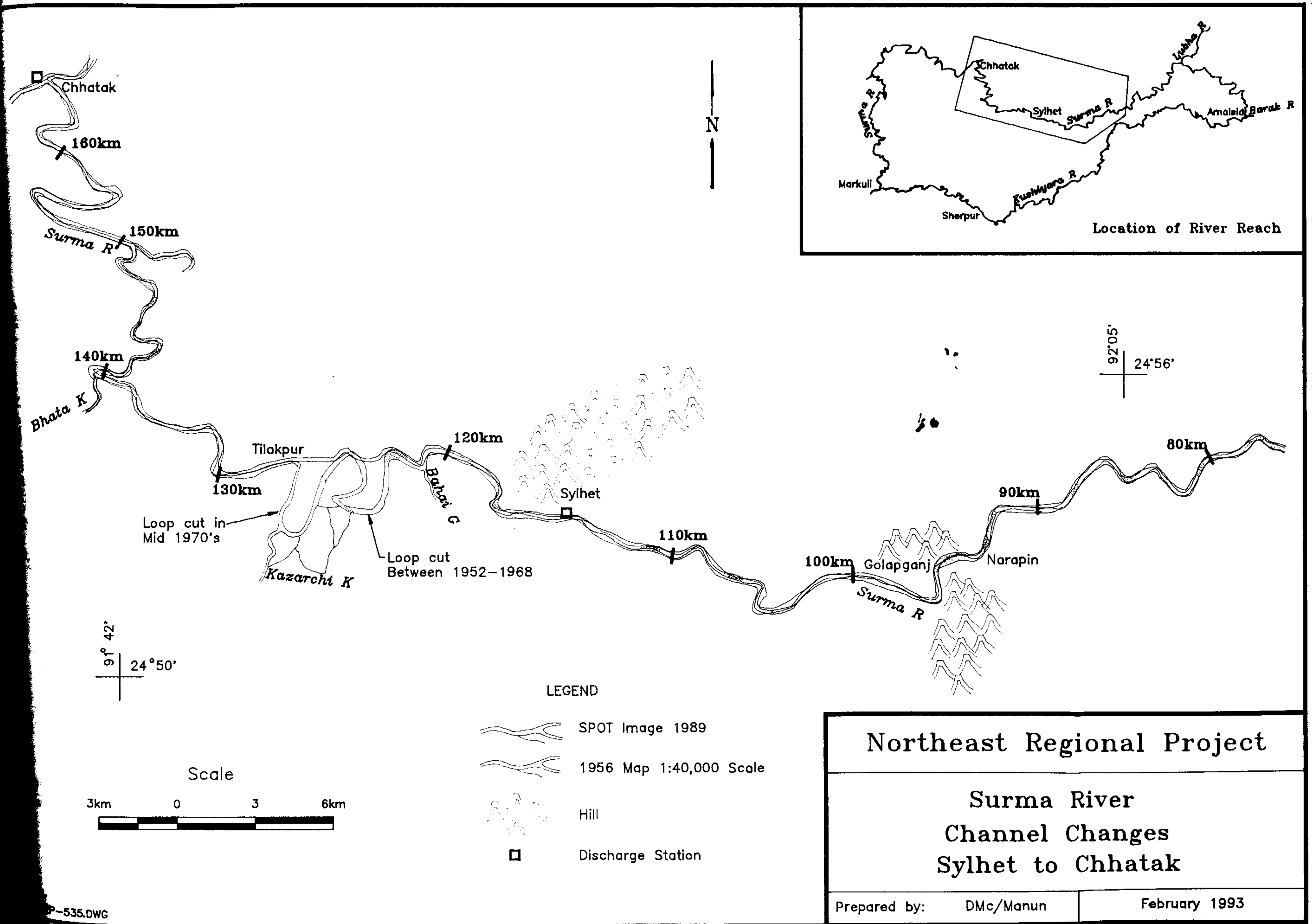


Northeast Regional Project

Surma River
Channel Changes
Amalsid to Kakura

Prepared by: DMc/Mamun | February 1993

Figure 69



Northeast Regional Project

Surma River
Channel Changes
Sylhet to Chhatak

Prepared by:	DMc/Manun	February 1993

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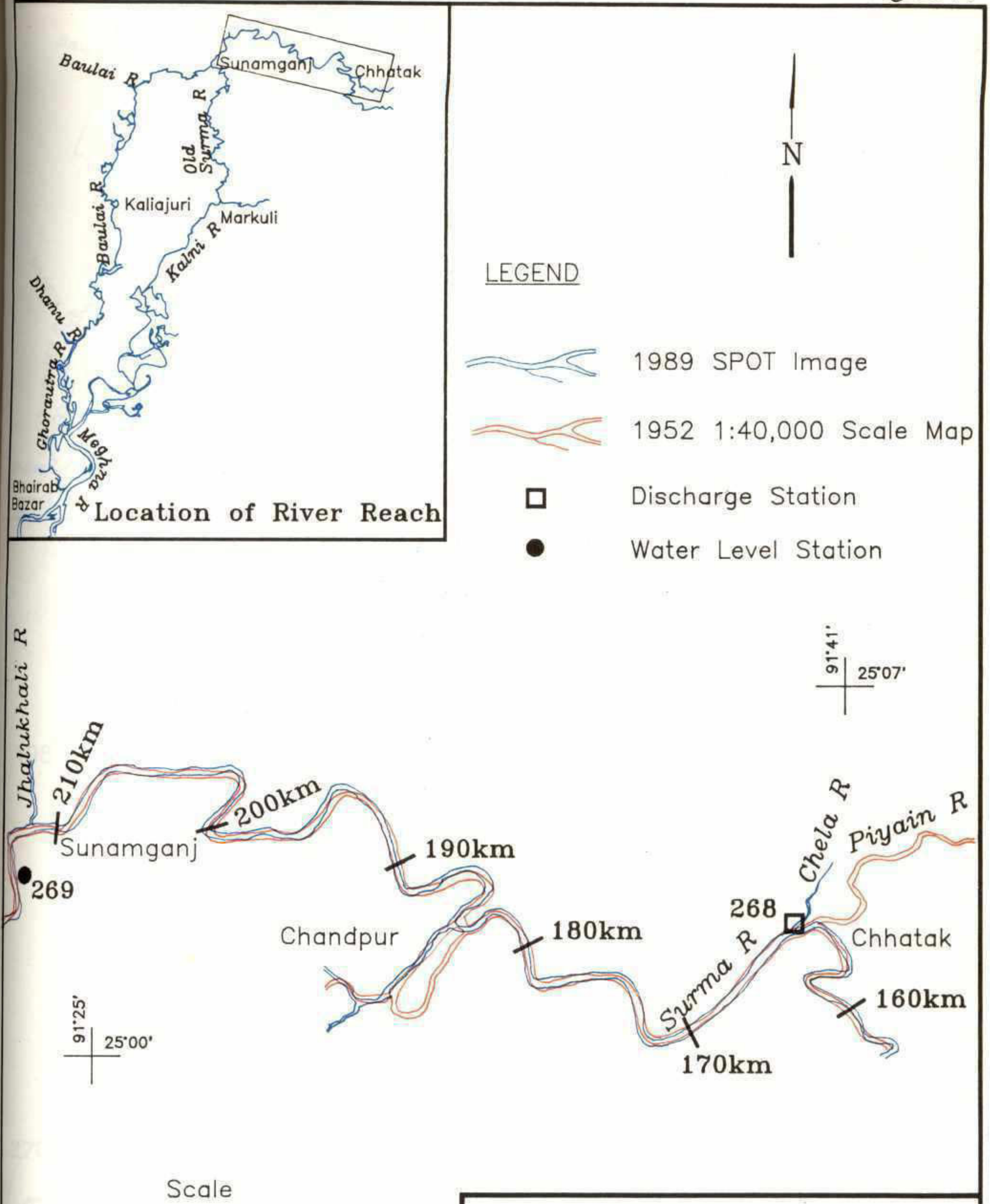
Figure 70



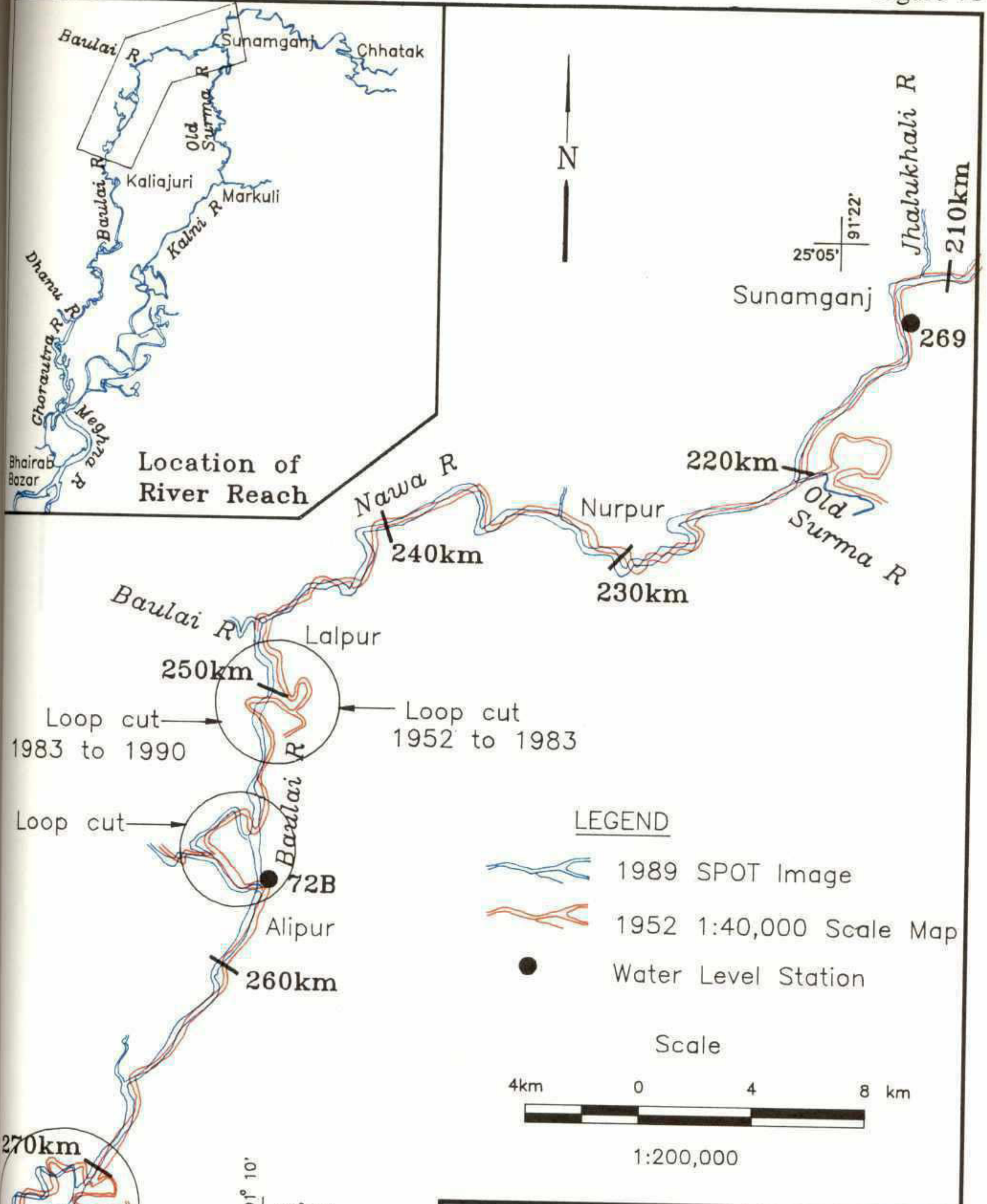
Northeast Regional Project

Surma/Baulai River
Chhatak to Sunamganj

Prepared by: DMc/Mamun | February 1993

228

Figure 71



Northeast Regional Project

Surma/Baulai River Sunamganj to Kaliajuri

Prepared by: DMc/Mamun | February 1993

Figure 72

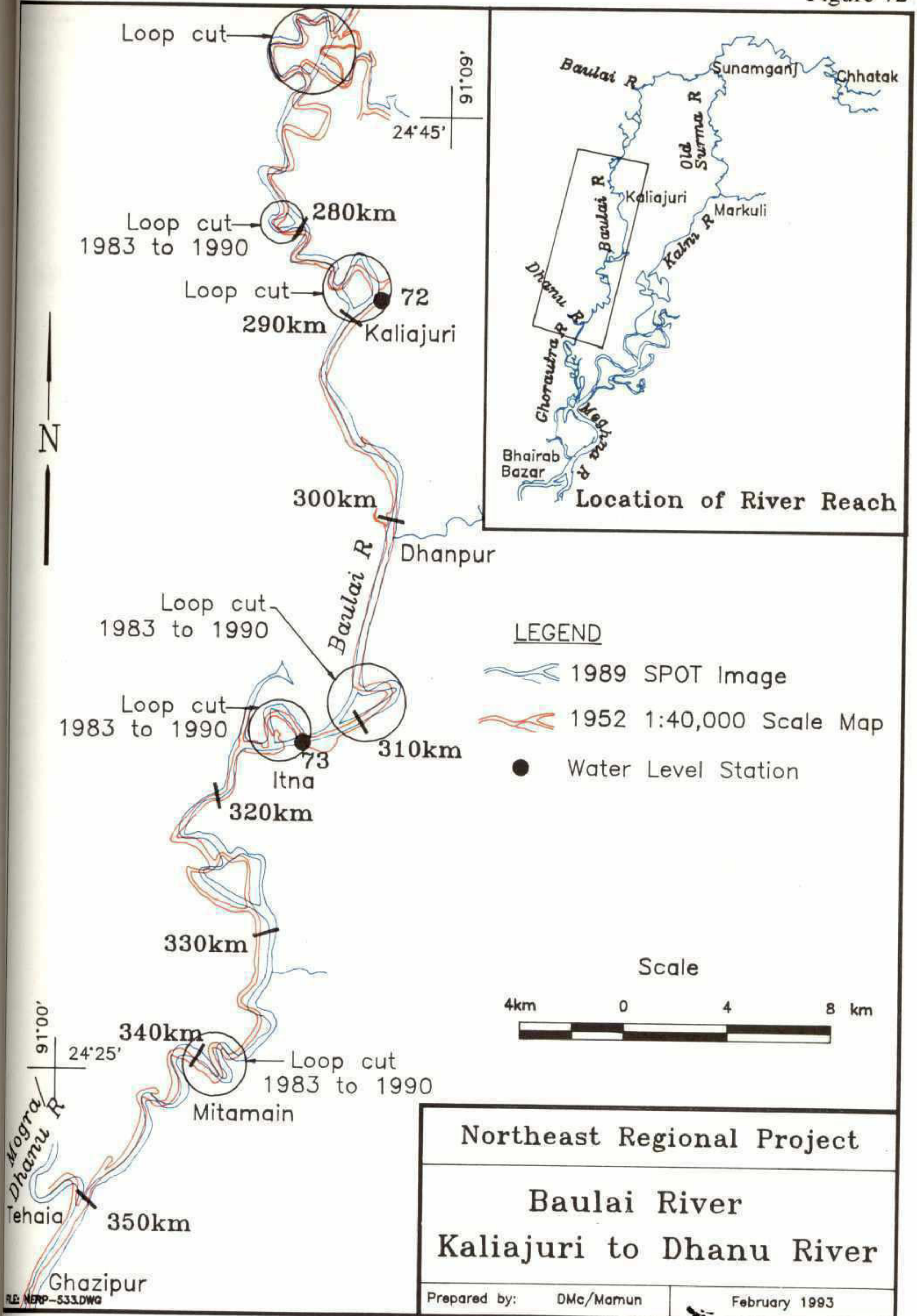
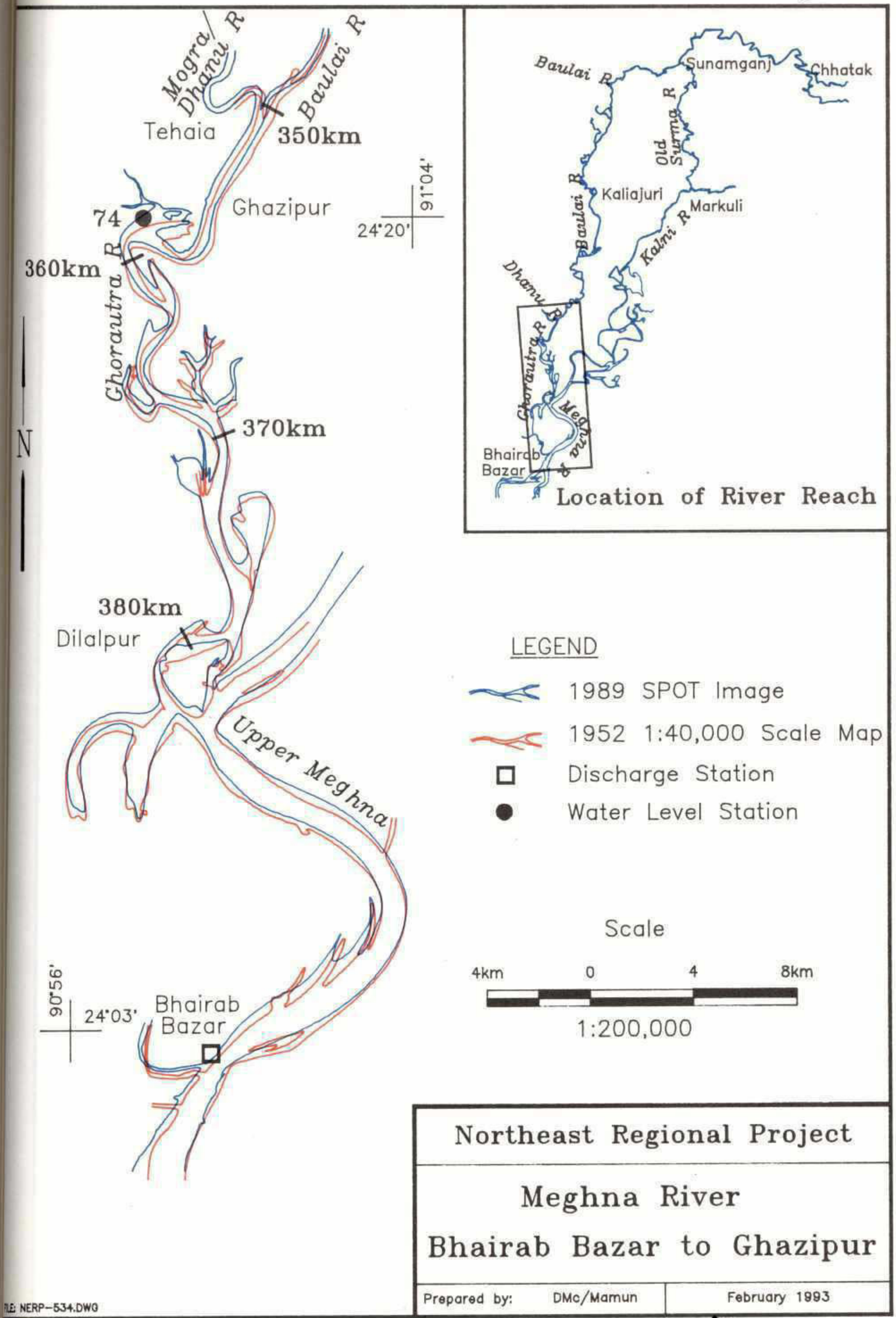
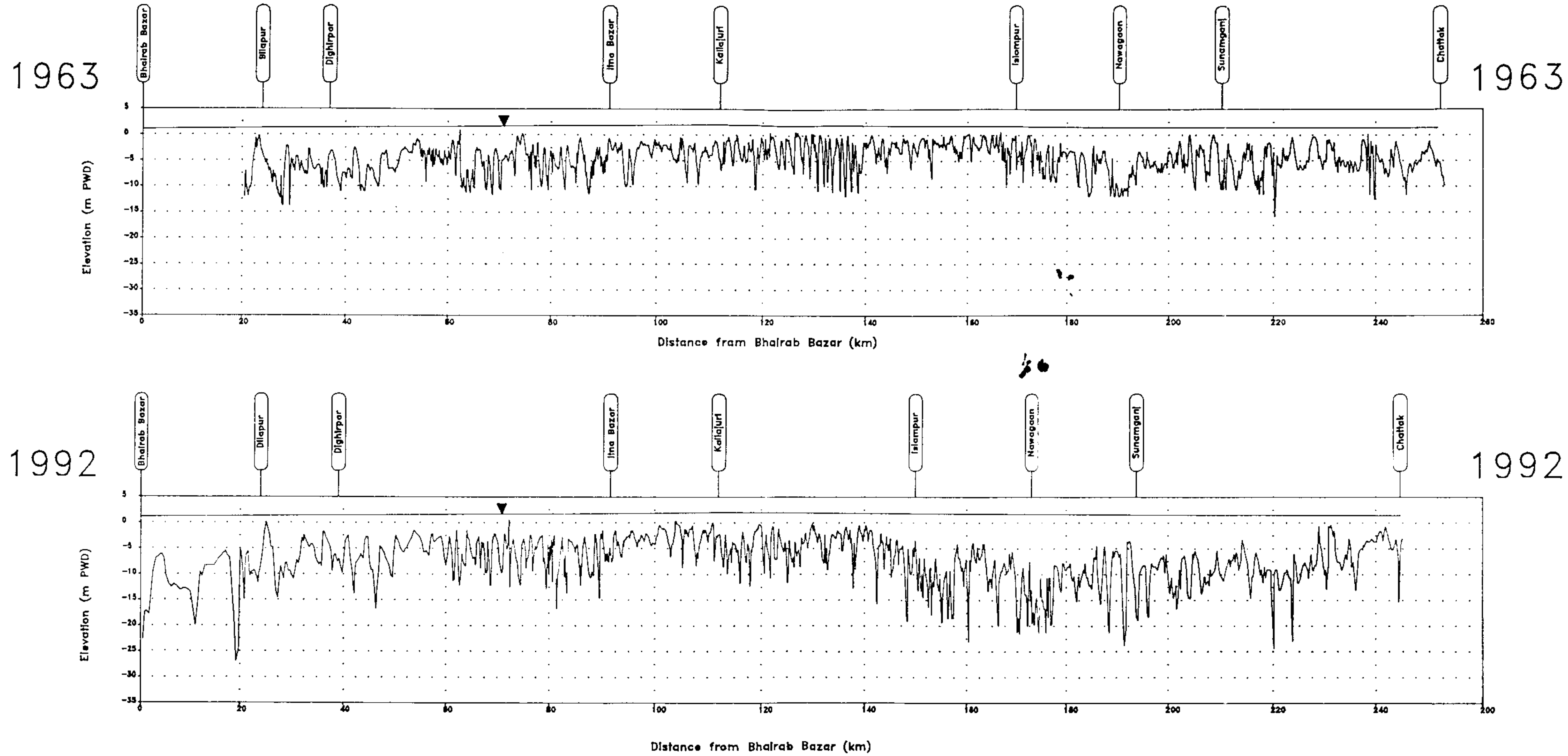

Loop cut
91°09'
24°45'
Loop cut
1983 to 1990
280km
Loop cut
72
290km
Kaliajuri
N
300km
Dhanpur
Baulai R
Loop cut
1983 to 1990
Loop cut
1983 to 1990
73
Itna
310km
320km
330km
340km
91°00'
24°25'
Loop cut
1983 to 1990
Mitamain
Mogra Dhanu R
Tehaia
350km
Ghazipur
FILE: NERP-533.DWG
Baulai R
Sunamganj
Chhatak
Old Surma R
Baulai R
Kaliajuri
Markuli
Kalni R
Dhanu R
Ghorautra R
Meghna R
Bhairab Bazar
Location of River Reach
LEGEND
1989 SPOT Image
1952 1:40,000 Scale Map
Water Level Station
Scale
4km
0
4
8 km
Northeast Regional Project
Baulai River
Kaliajuri to Dhanu River
Prepared by:
DMc/Mamun
February 1993

Figure 73



Mogra/ Dhanu R
Baulai R
Tehaia
350km
Ghazipur
91°04'
24°20'
74
360km
Chorautra R
370km
380km
Dilalpur
Upper Meghna
90°56'
24°03'
Bhairab Bazar
Baulai R
Sunamganj
Chhatak
Old Surma R
Kaliajuri
Markuli
Kalni R
Dhanu R
Chorautra R
Meghna R
Bhairab Bazar
Location of River Reach
LEGEND
1989 SPOT Image
1952 1:40,000 Scale Map
Discharge Station
Water Level Station
Scale
4km 0 4 8km
1:200,000
Northeast Regional Project
Meghna River
Bhairab Bazar to Ghazipur
Prepared by: DMc/Mamun
February 1993
FILE: NERP-534.DWG

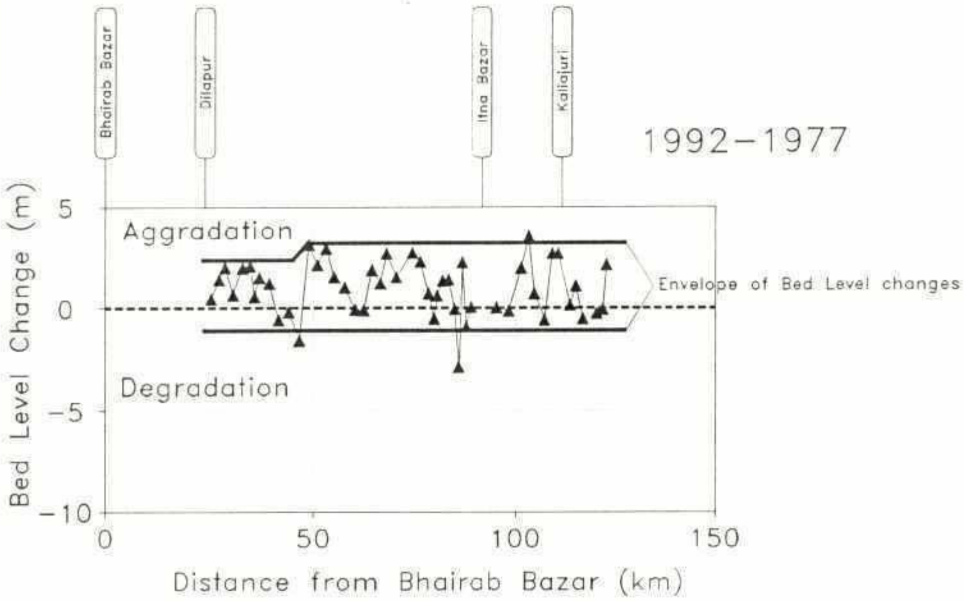
Figure 74

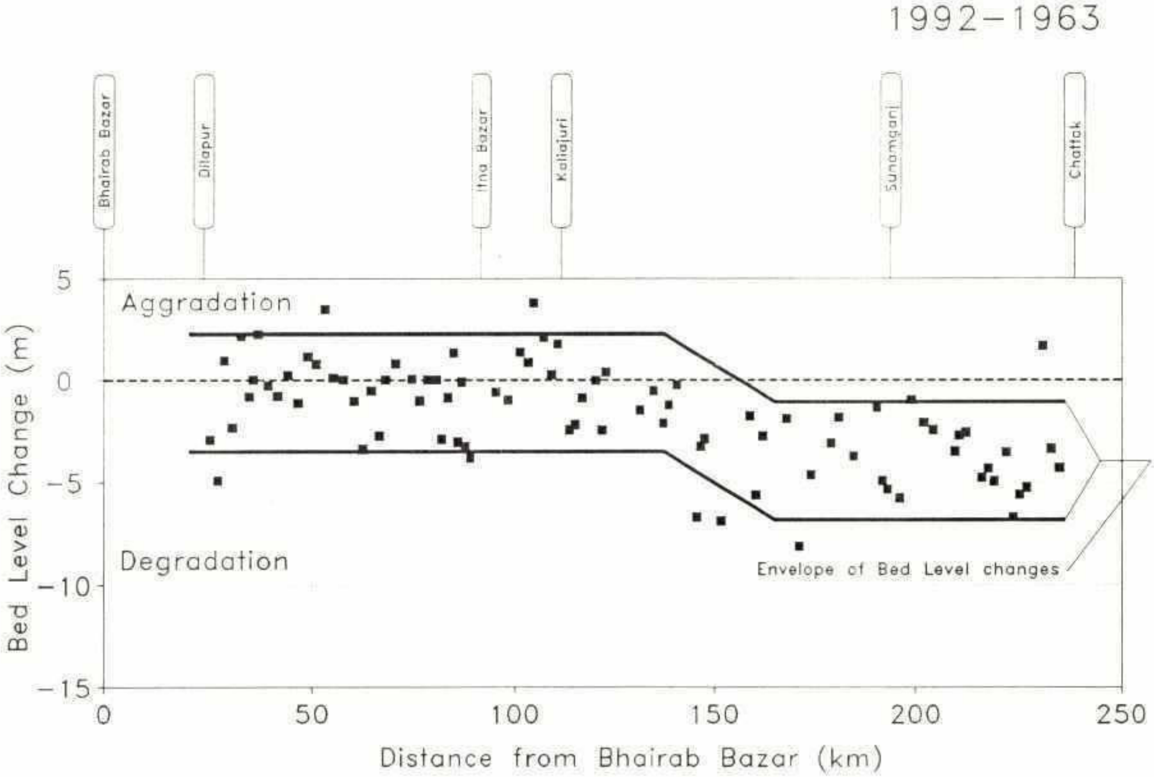


Note:
1. Bed levels from BIWTA navigation charts
2. Water level represents navigation Local Low Water

dm22LDWG

Northeast Regional Project	
Longitudinal Profile of Baulai River	
Prepared by: DMc	May 1993

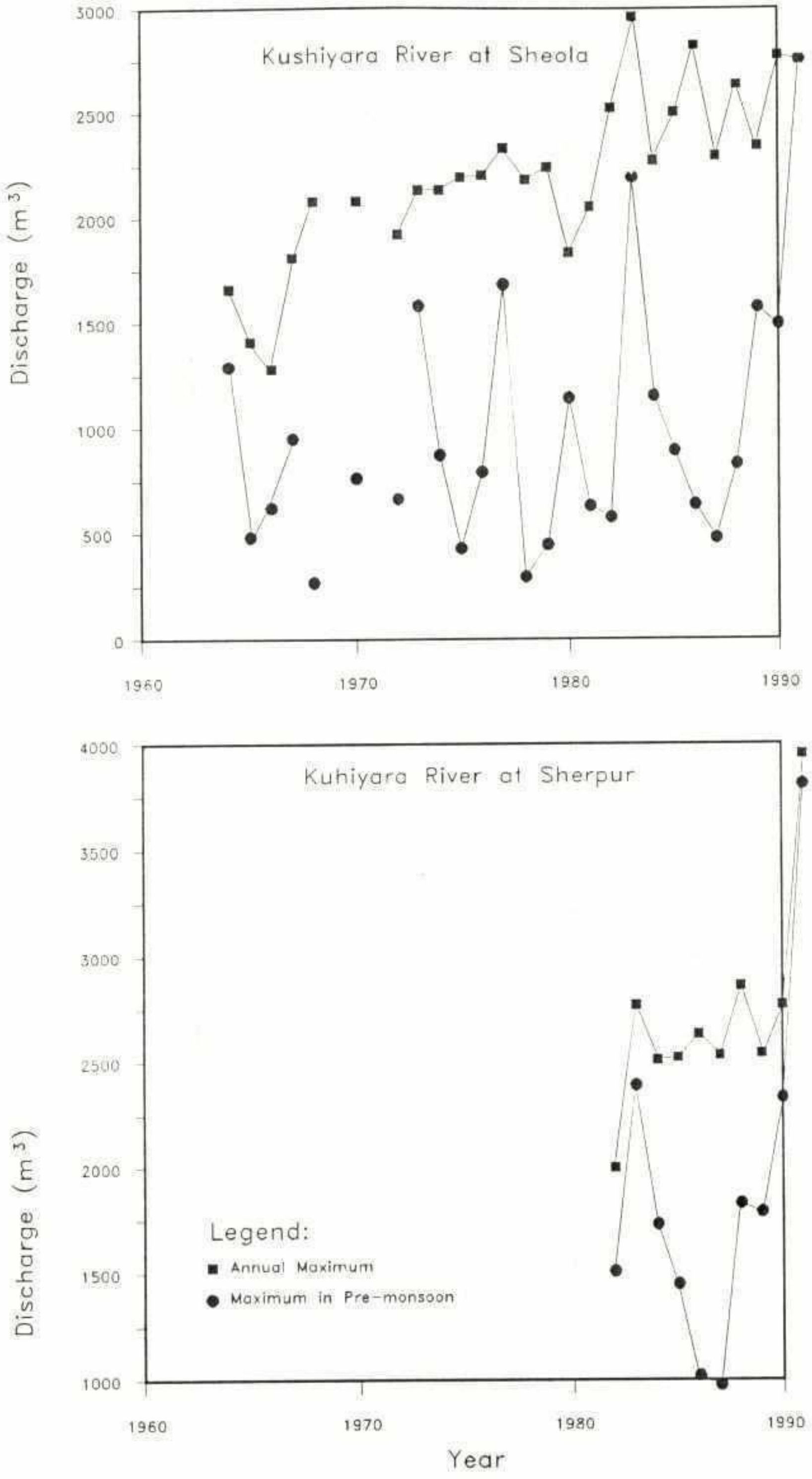




Northeast Regional Project	
Bed Level Changes Baulai River	
Prepared by: CHW	May 1993

FILE: dm238.DWG

Figure 76



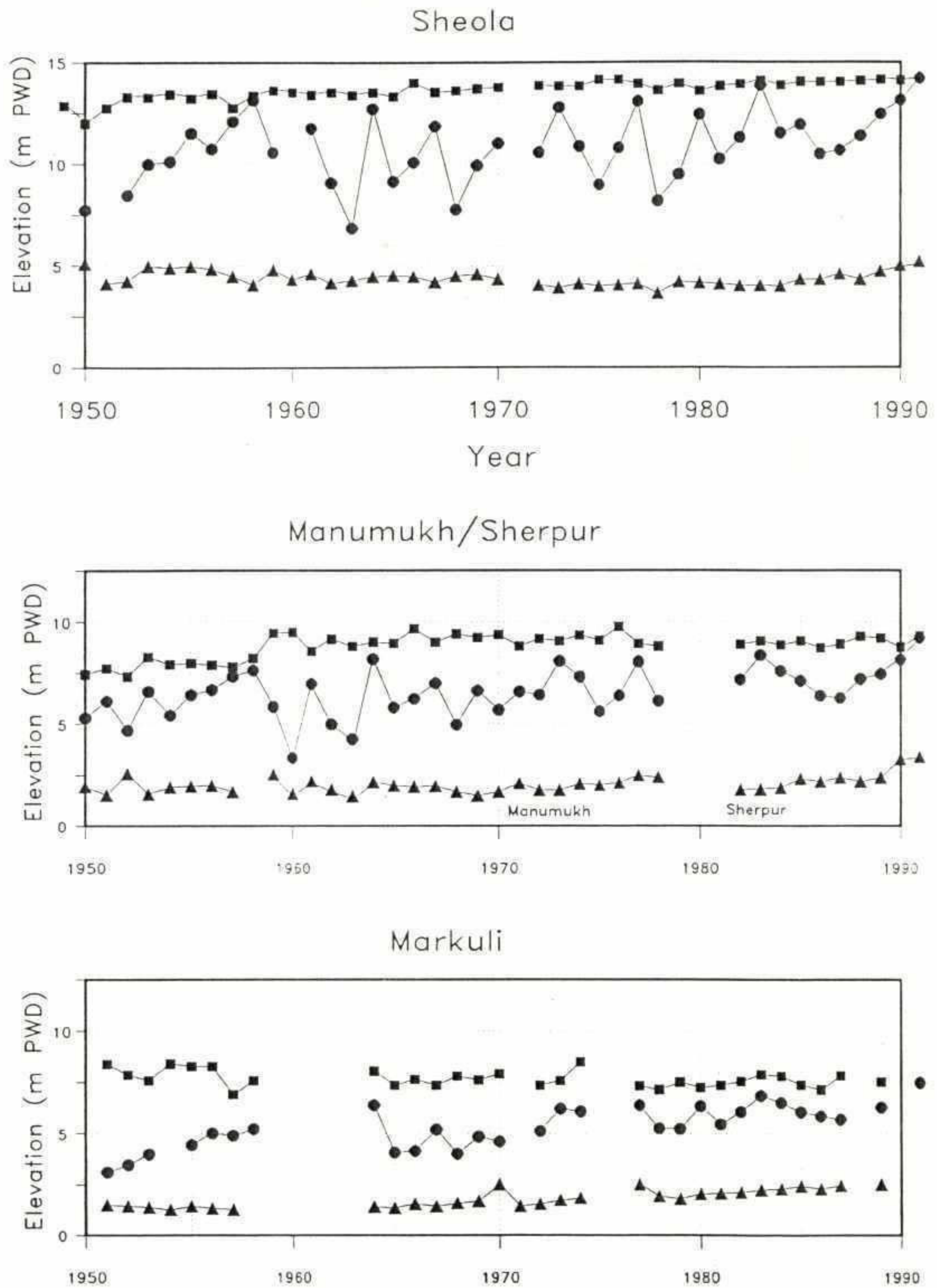
Note:
Pre-monsoon season is period
from March 1 – May 15

Northeast Regional Project

Annual Discharges
Kushiyara River

Prepared by: DGM | May 1993

FILE: DM223.DWG



Legend:
- ■ Maximum Annual
- ● Maximum Pre-Monsoon
- ▲ Minimum Annual

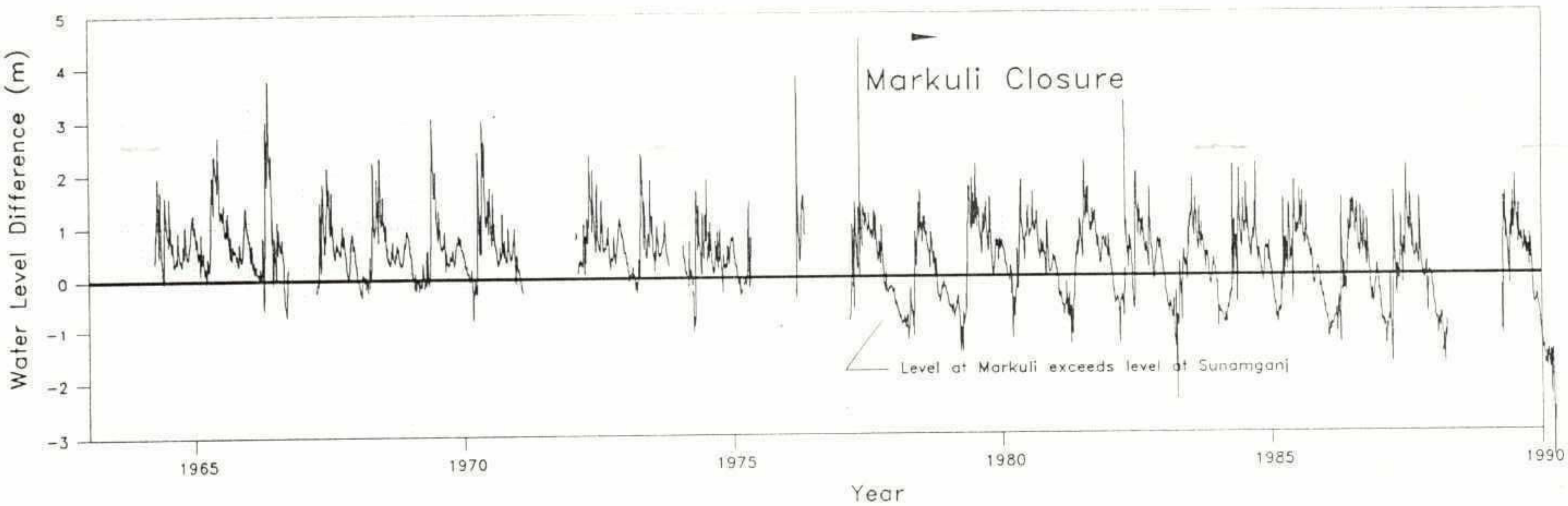
Northeast Regional Project

Annual Water Levels Kushiyara River

Prepared by: DMc	May 1993

FILE: dm203.DWG

Figure 78



Gauge Locations:

Note:
1. Daily water level differences computed as:
Water level on Surma R. at Sunamganj (#269) – water level on Kalni R. at Markuli (#270).

2. After 1978 water levels in pre-monsoon season are
Consistently higher at Markuli than at Sunamganj.

Northeast Regional Project	
Water Level Difference Sunamganj – Markuli	
Prepared by: DMc	May 1993

FILE: dm220.DWG

266

Figure 79

Note abandoned Bibyana R

Manu R.

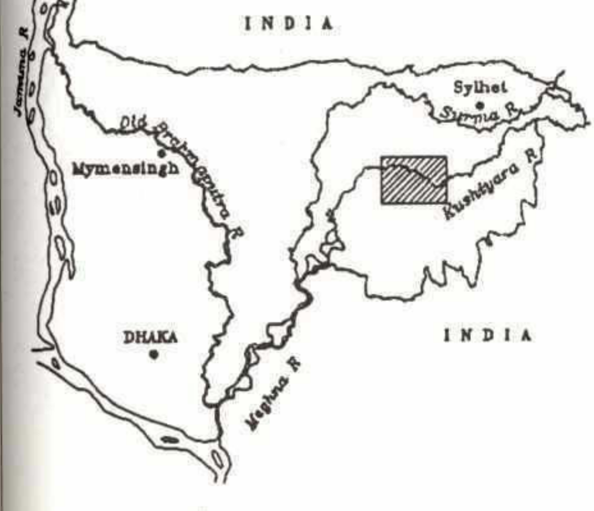
Scale

2 0 2 4 km

Approx.

N

Site Location



SPOT image 78P10

Northeast Regional Project

Kushiyara River
Near Sherpur

Prepared by: DMc	May 1993

FILE: dm193.DWG

FILE: dm220.DWG

Figure 80

Note Loop cuts and abandoned Bibyana R

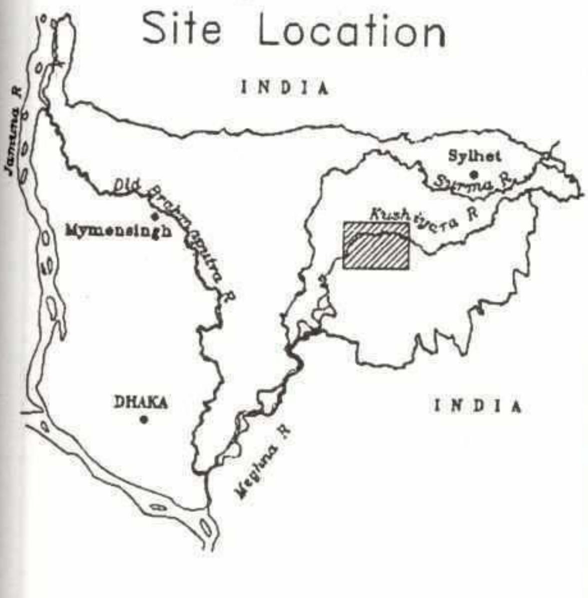
Scale

2 0 2 4 km

Approx.

N

Site Location



SPOT Image 78P6

Northeast Regional Project

Kalni River

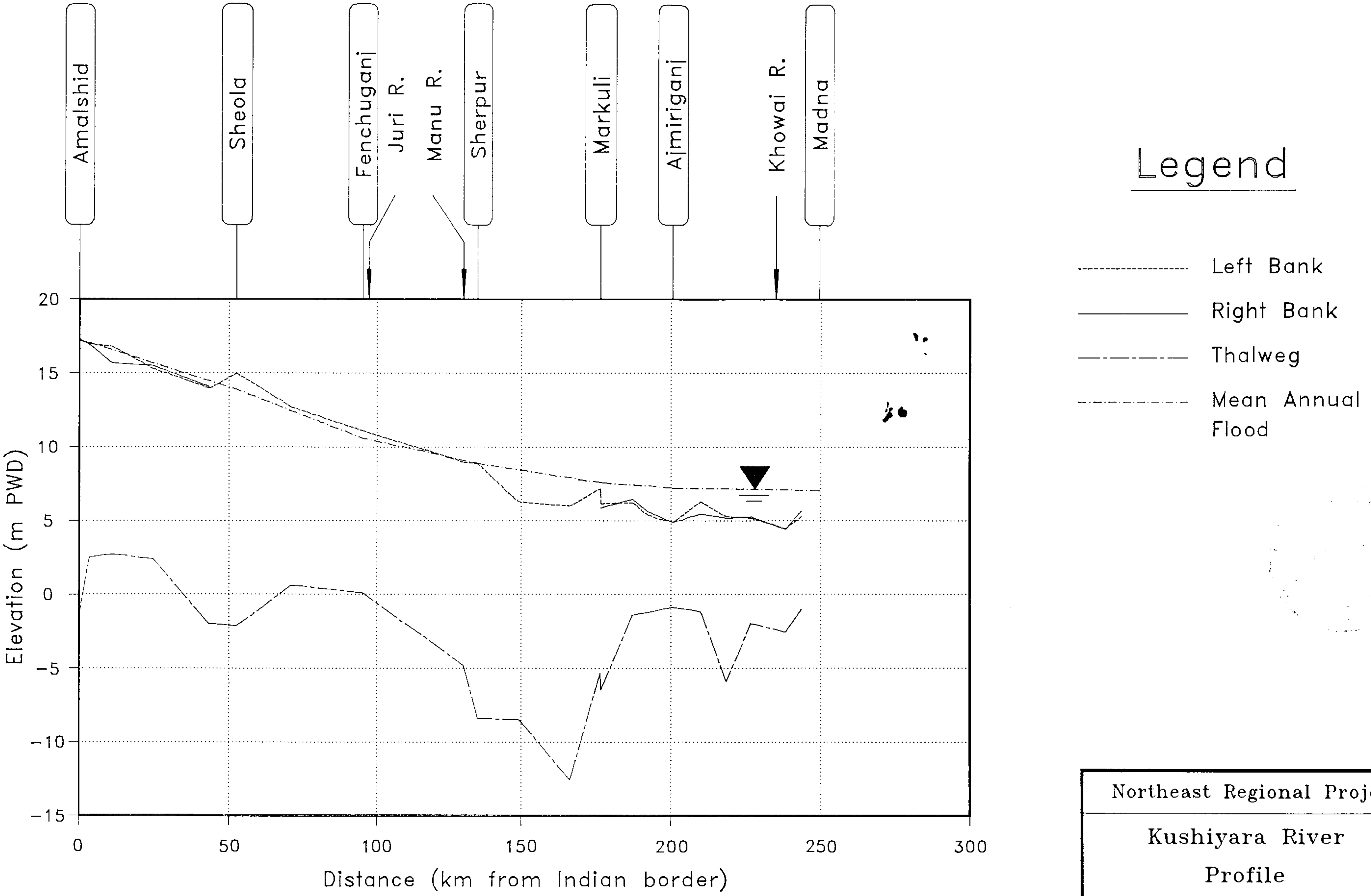
Near Markuli

FILE: dm194.DWG

Prepared by: DMc

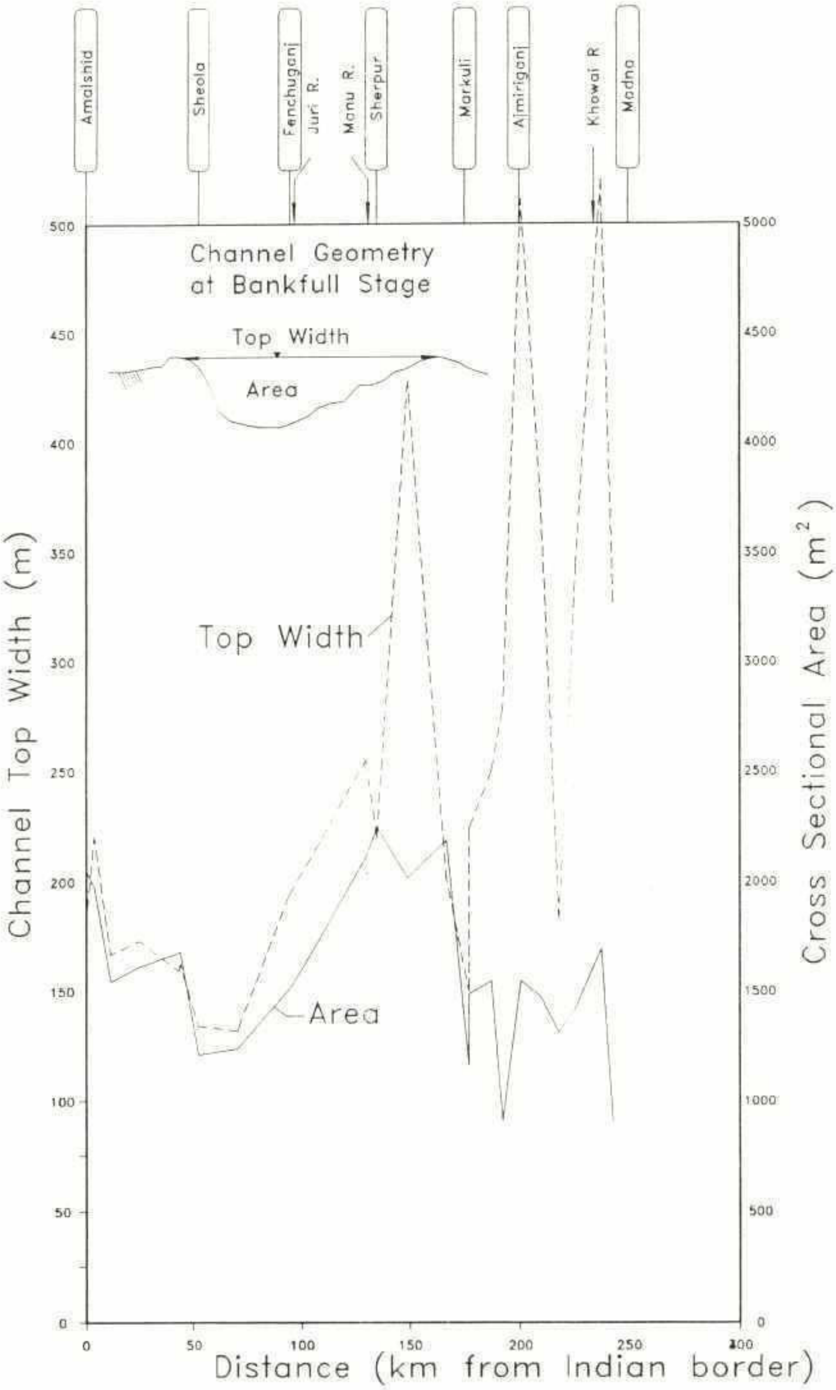
May 1993

Figure 81



Northeast Regional Project	
Kushiyara River Profile	
Prepared by: CHW	May 1993

FILE: KUSHPRO.DWG



Northeast Regional Project	
Channel Geometry Kushiyara /Kalni River	
Prepared by: DMc	May 1993

FILE: DM219.DWG

269

Figure 83

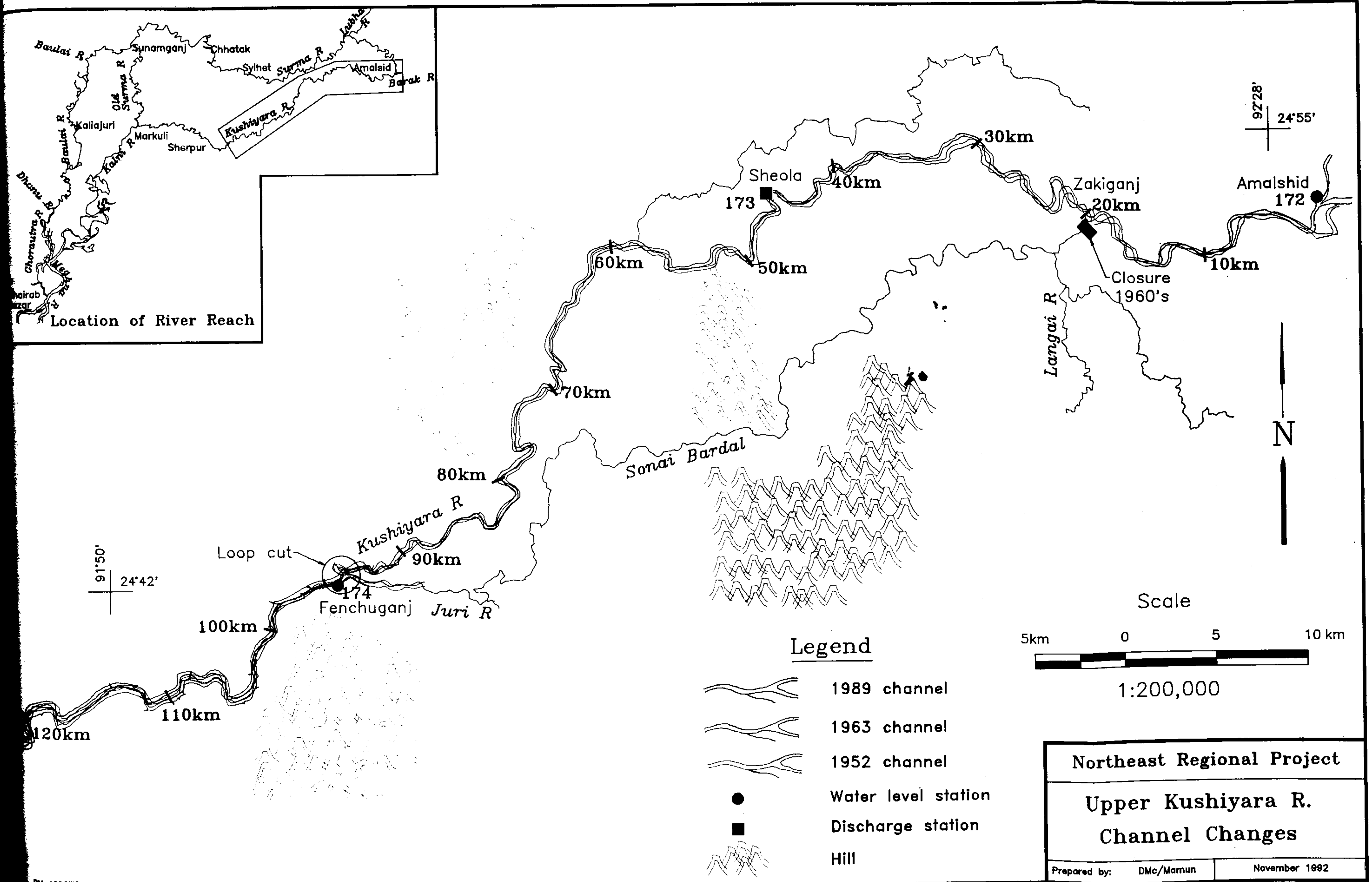


Figure 84

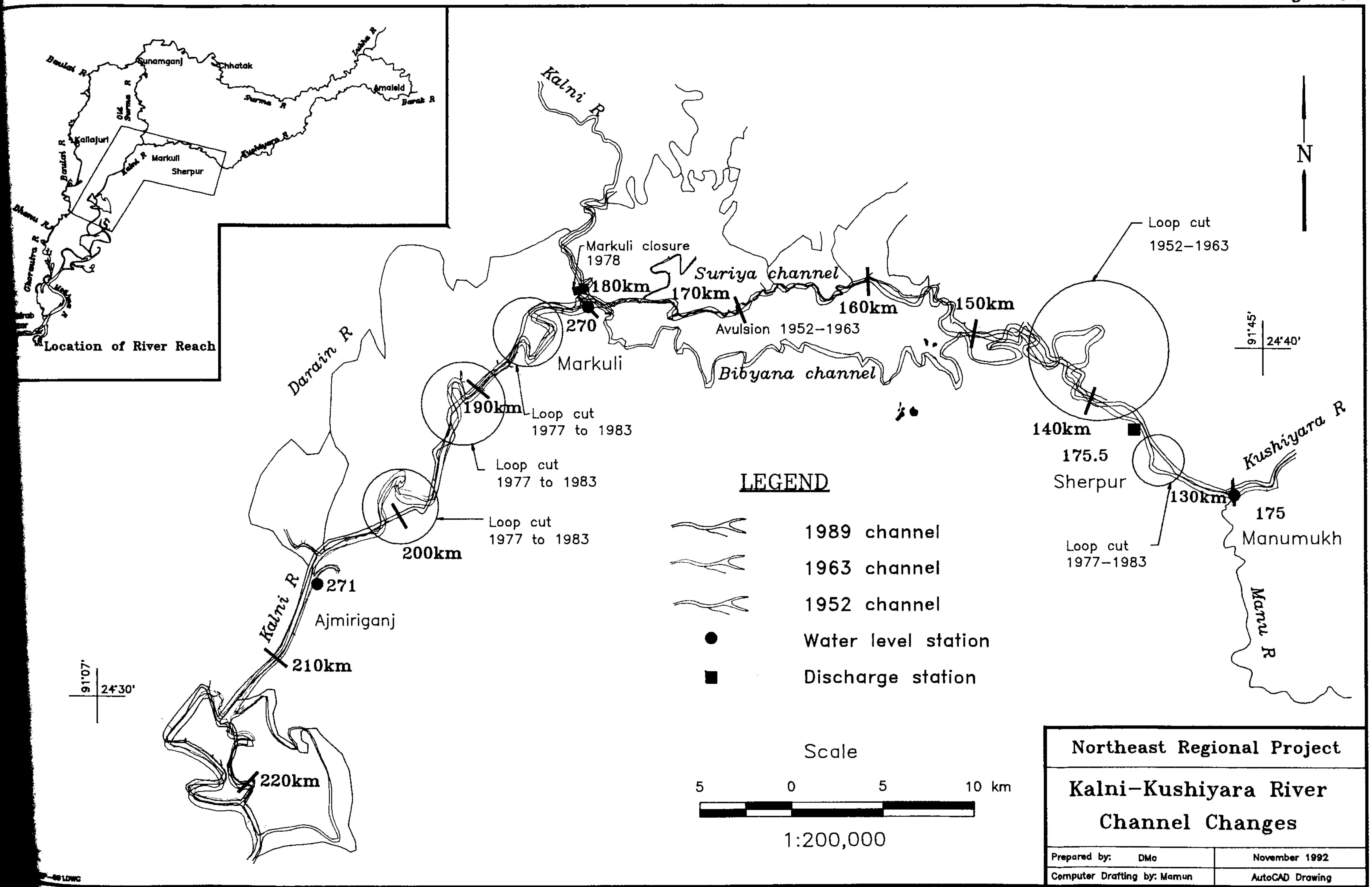
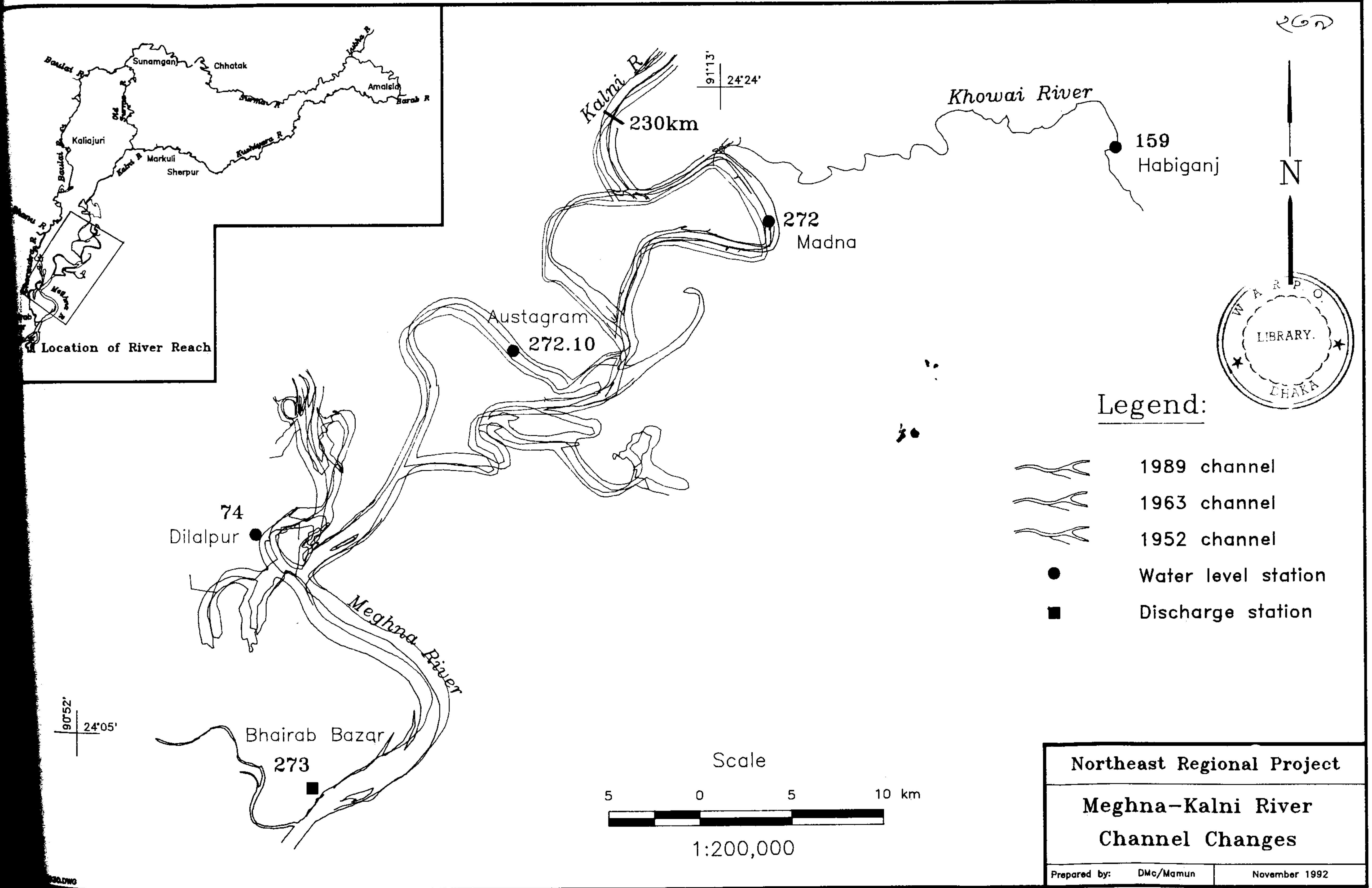

Baulai R
Sunamganj
Chhatak
Surma R
Amalsid
Barak R
Kushiyara R
Kallajuri
Markuli
Sherpur
Location of River Reach
Kalni R
Markuli closure
1978
180km
170km
Suriya channel
160km
150km
Loop cut
1952–1963
N
270
Avulsion 1952–1963
Markuli
Bibyana channel
Darain R
190km
Loop cut
1977 to 1983
Loop cut
1977 to 1983
140km
175.5
Sherpur
Kushiyara R
130km
175
Manumukh
Loop cut
1977 to 1983
200km
LEGEND
1989 channel
1963 channel
1952 channel
Water level station
Discharge station
Loop cut
1977–1983
271
Ajmiriganj
Kalni R
Manu R
91°07'
24°30'
91°45'
24°40'
210km
220km
Scale
5 0 5 10 km
1:200,000
Northeast Regional Project
Kalni–Kushiyara River
Channel Changes
Prepared by: DMo
November 1992
Computer Drafting by: Mamun
AutoCAD Drawing

Figure 85

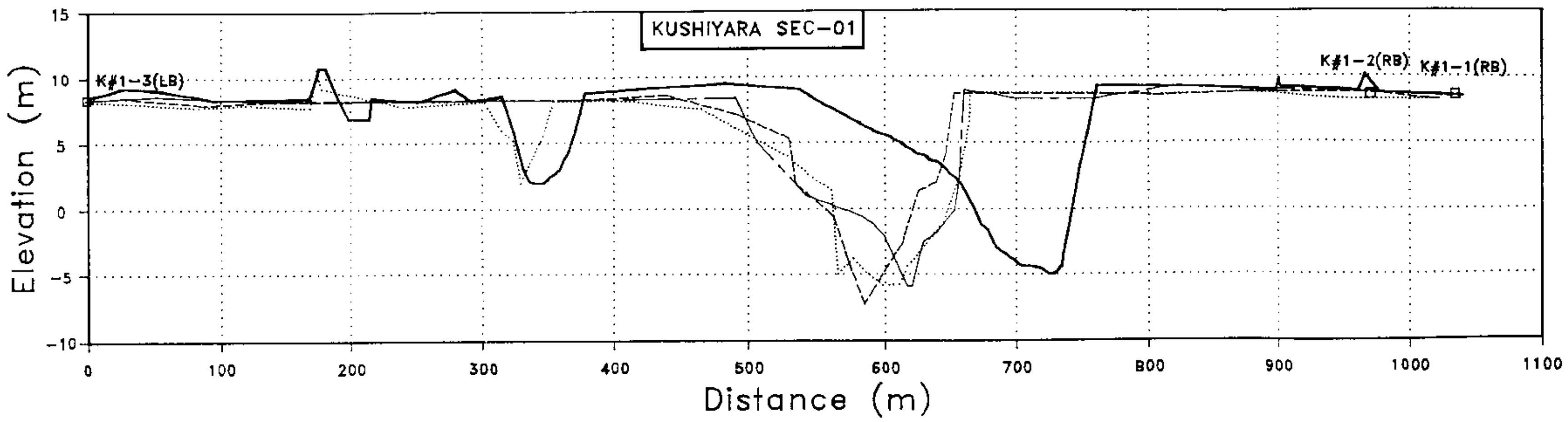


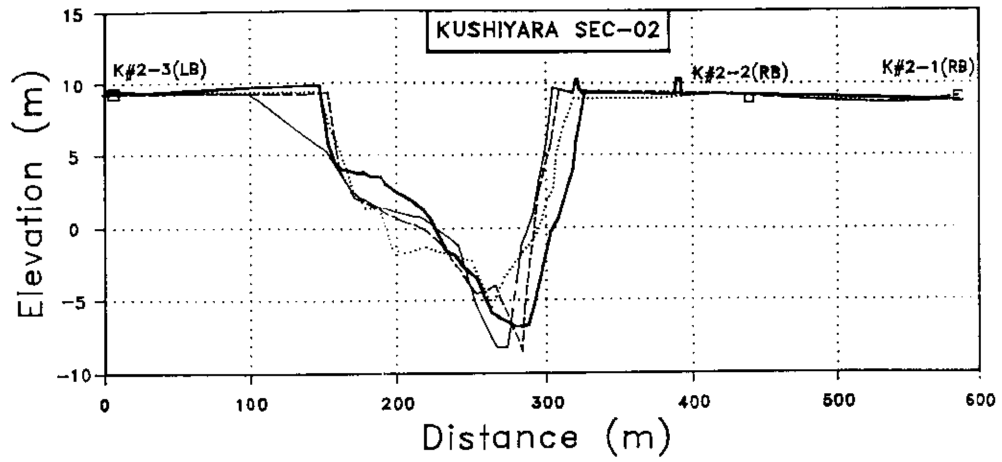
Northeast Regional Project

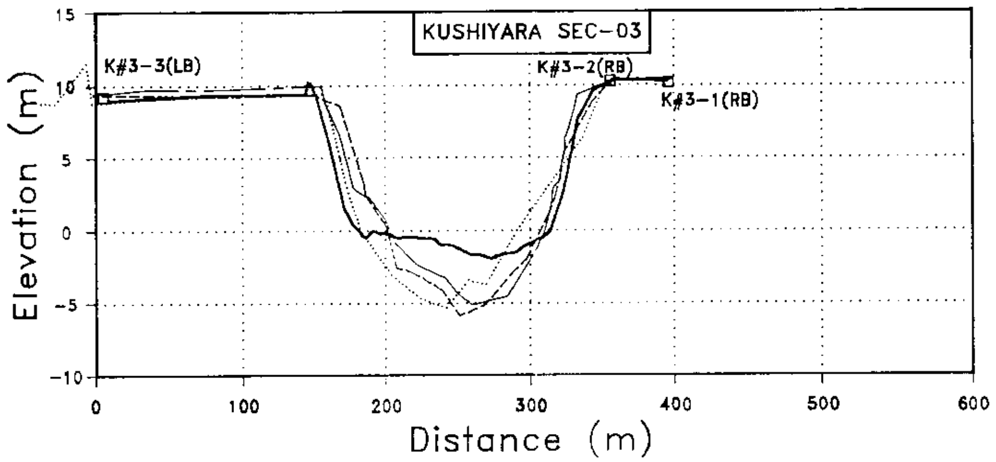
Meghna-Kalni River Channel Changes

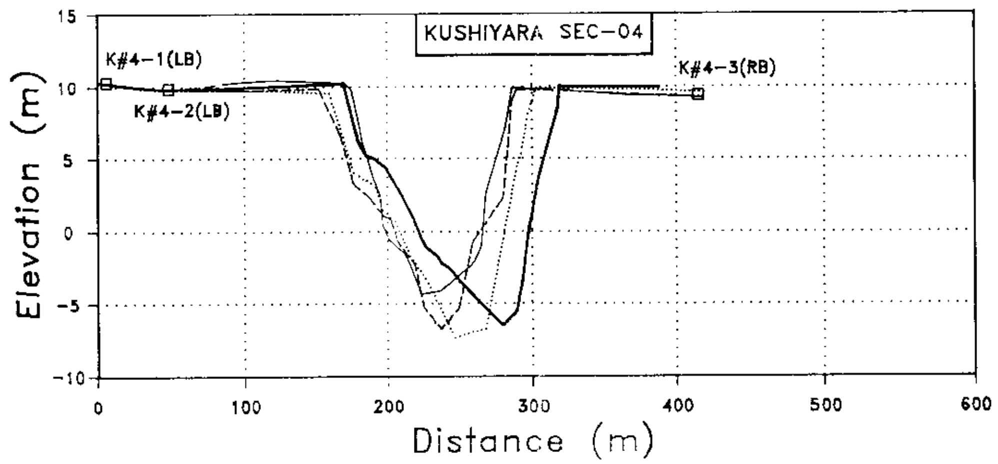
Prepared by:	DMc/Mamun	November 1992

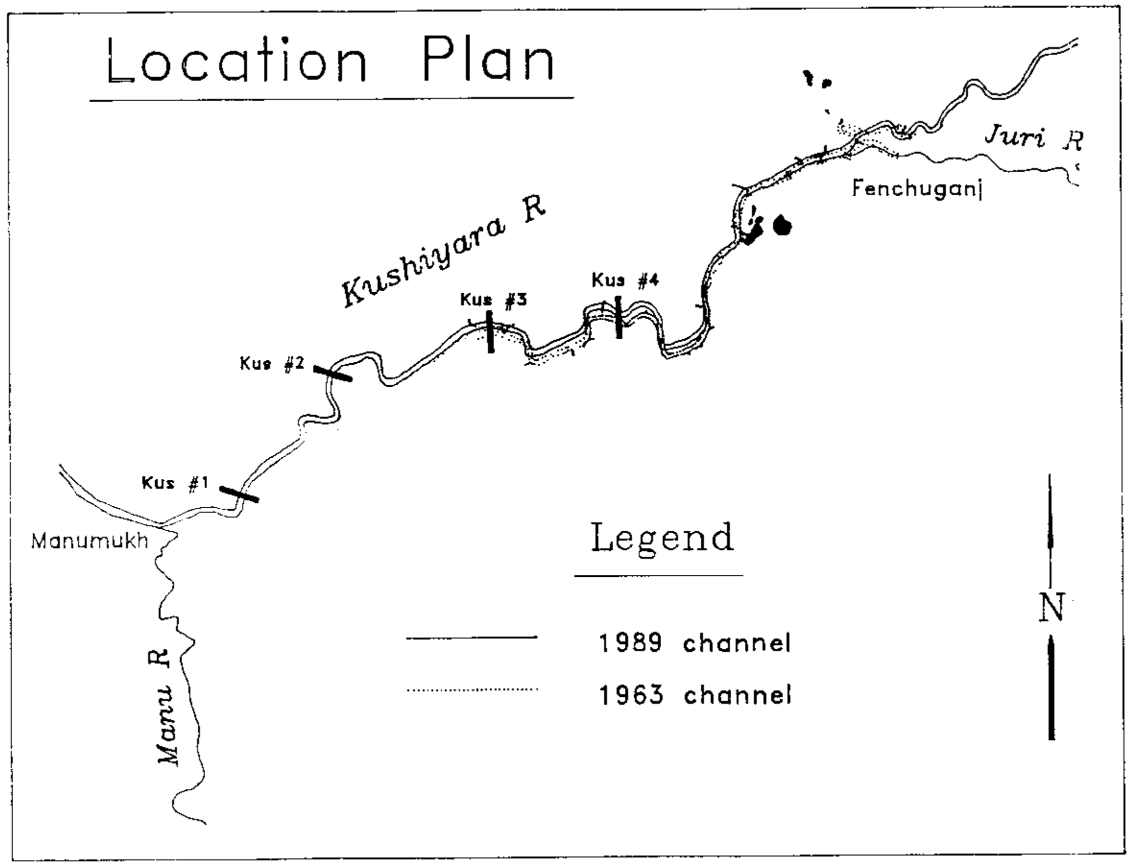
Figure 86











Legend

1969 cross-secrion
1972 cross-section
1978 crass-section
1993 crass-section

Northeast Regional Project

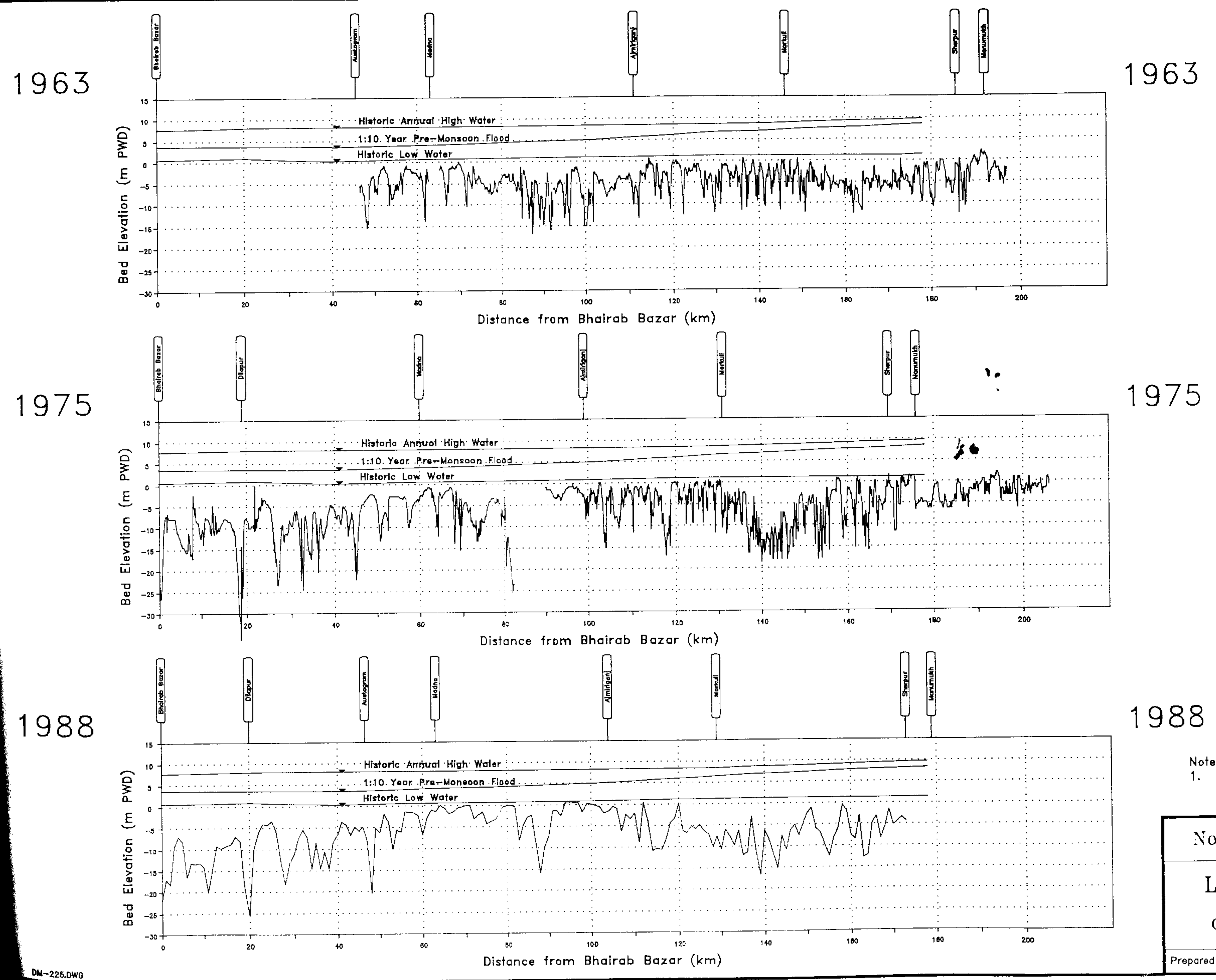
Kushiyara River Channel Comparison

Prepared by: CHW	May 1993

CHW-012.DWG

282

Figure 87



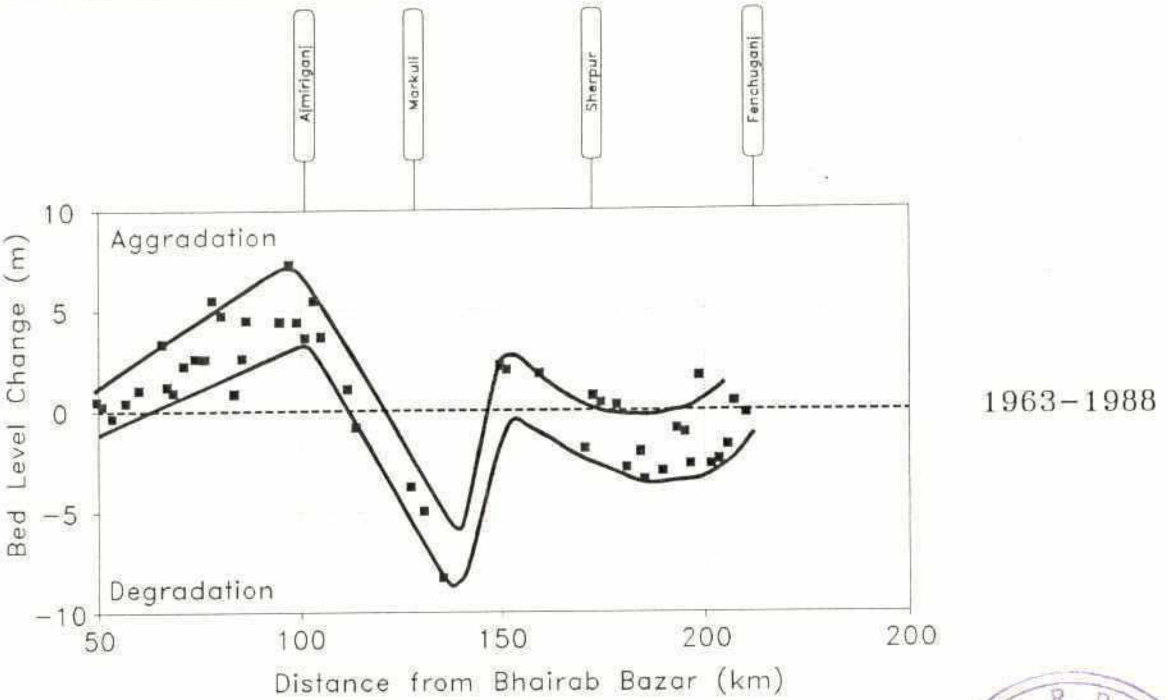
Note:
1. Bed levels from BIWTA navigation charts

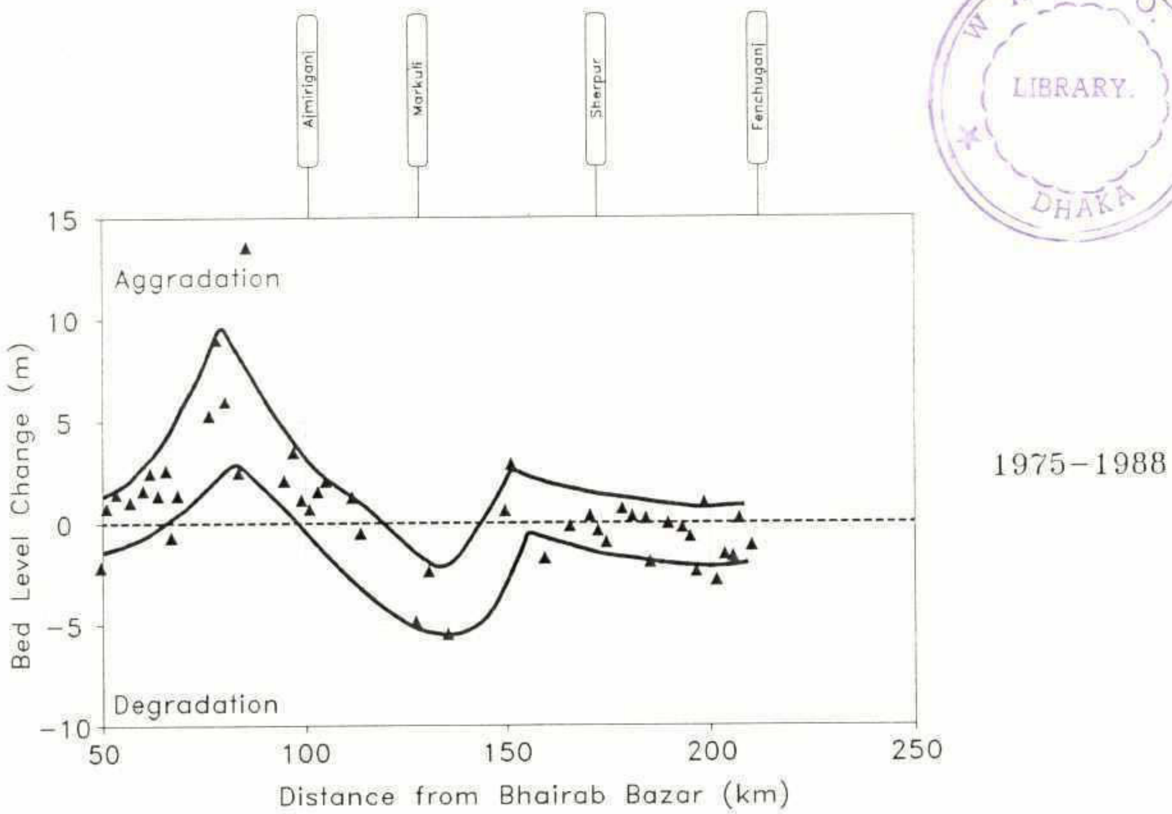
Northeast Regional Project

Longitudinal Profile of Kushiyara River

Prepared by: CHW | May 1993

Figure 88





Northeast Regional Project

Bed Level Changes
Kusiyara River

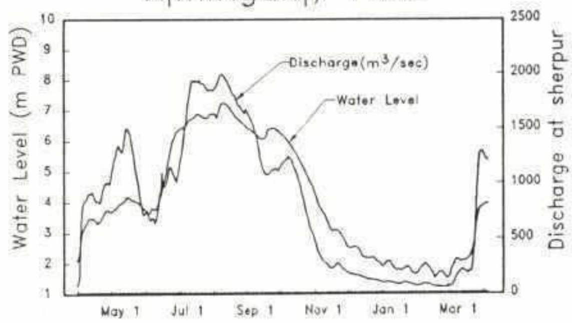
Prepared by: CHW | May 1993

FILE: dm-258.DWG

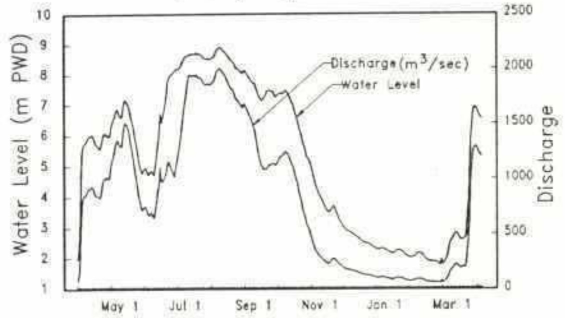
Figure 89

Water Level & Flow

Ajmiriganj, 1982

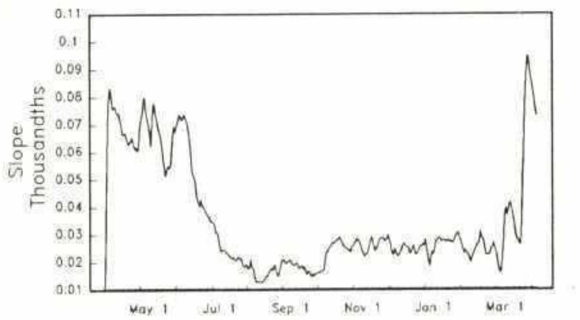


Sherpur, 1982

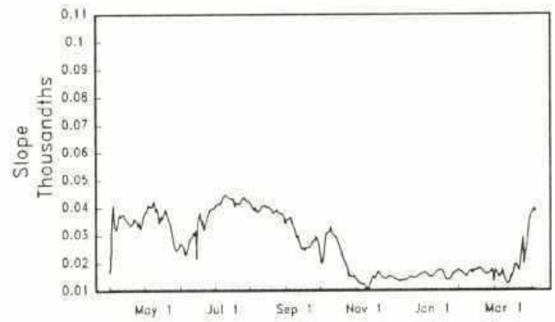


Water Surface slope

Ajmiriganj, 1982

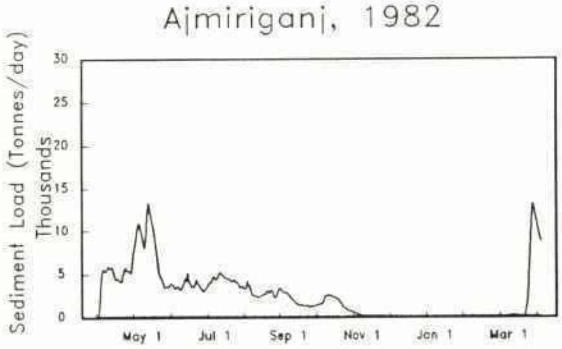


Sherpur, 1982

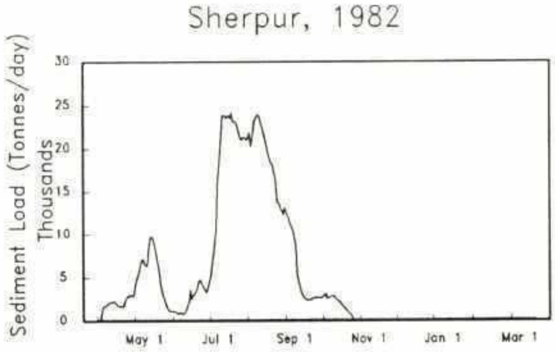


Bed Material Transport

Ajmiriganj, 1982



Sherpur, 1982



Northeast Regional Project

Sediment Routing

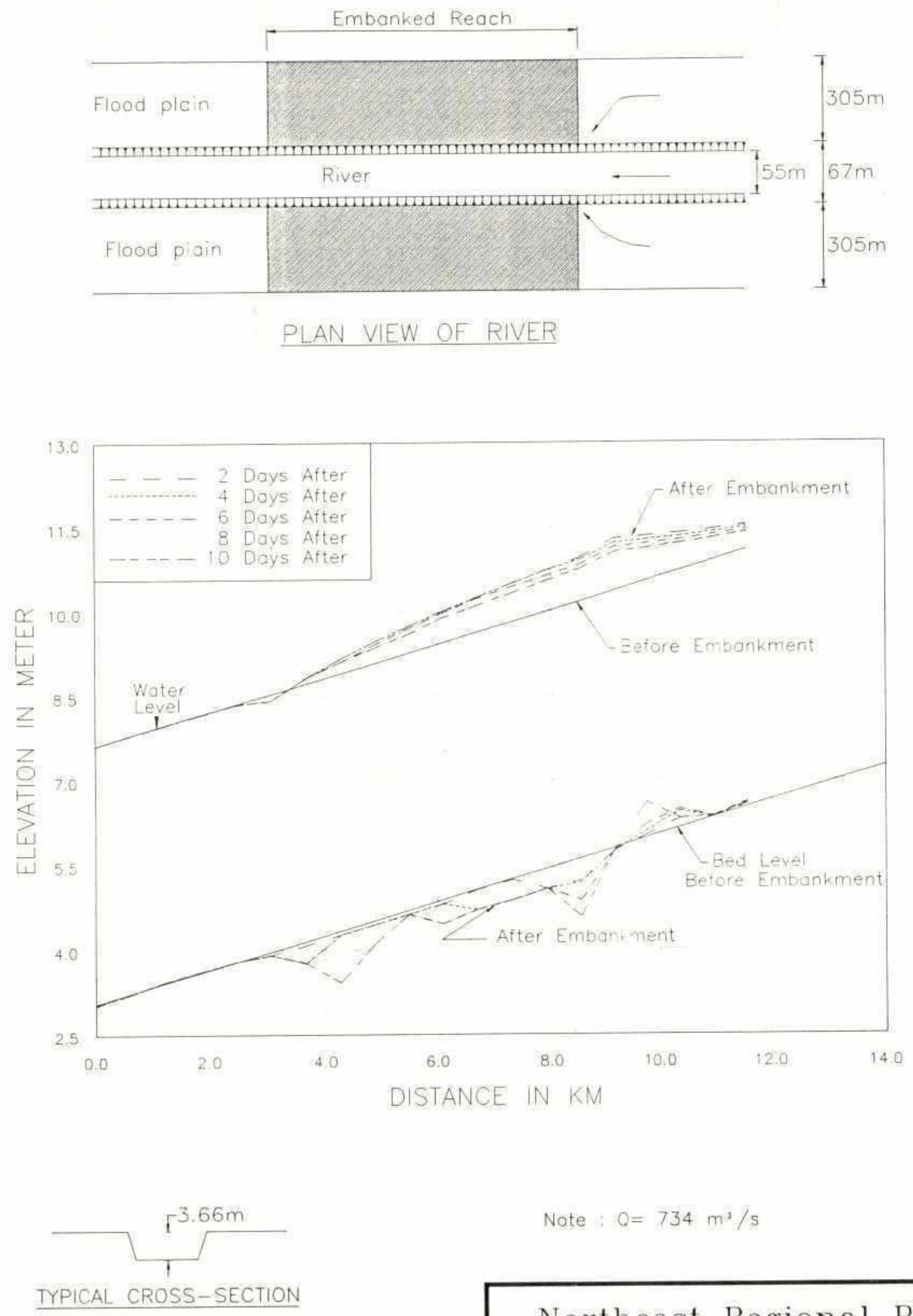
on Kalni River

Prepared by: DMc/Tarek | May 1993

FILE: DM-224.DWG

288

Figure 90



Note : Q= 734 m³/s

Simulation of channel Morphology and flood levels using HEC-6 Model Scour and Deposition in Rivers and Reservoirs

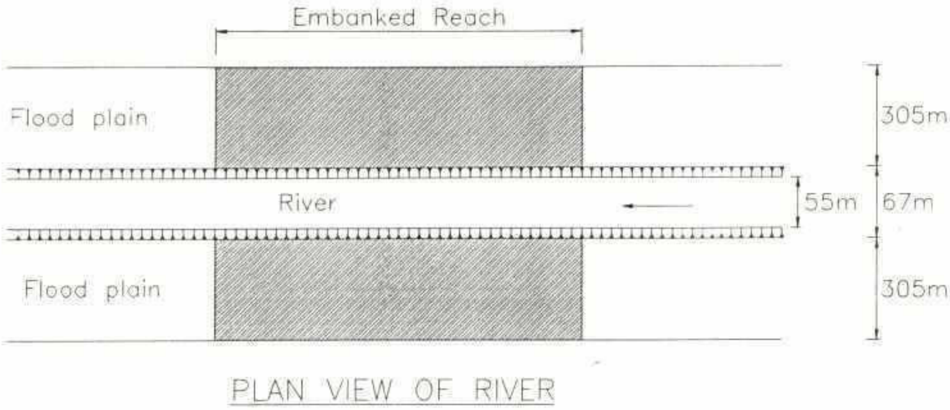
FILE: hec6.DWG

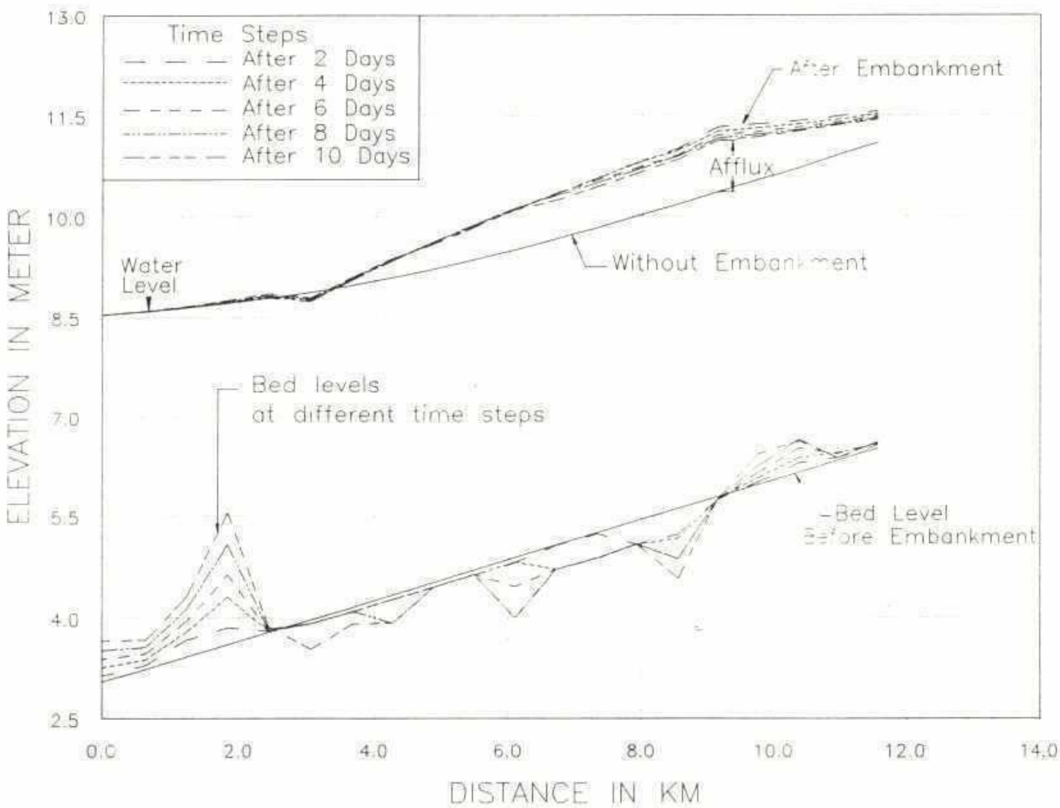
Northeast Regional Project

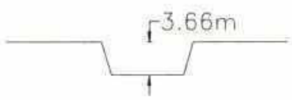
Impact of Embankments on Channel Morphology

Prepared by: DMc/Tarek | May 1993

Figure 91







TYPICAL CROSS-SECTION

Note : Q= 734 m³ /s

Simulation of channel Morphology and flood levels using HEC-6 Model Scour and Deposition in Rivers and Reservoirs

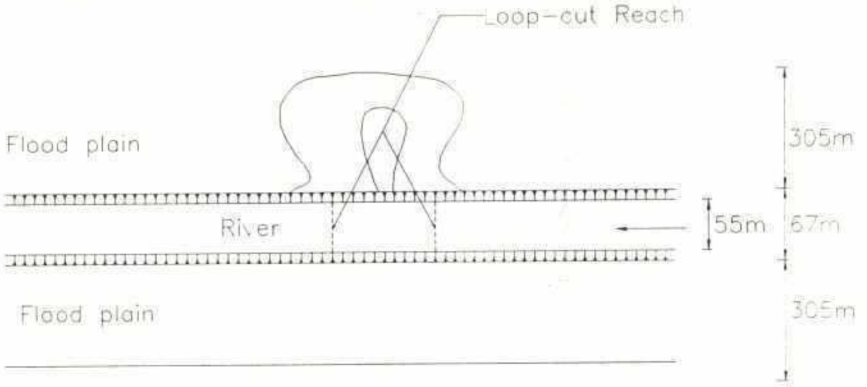
Northeast Regional Project

Impact of Embankments Under Backwater

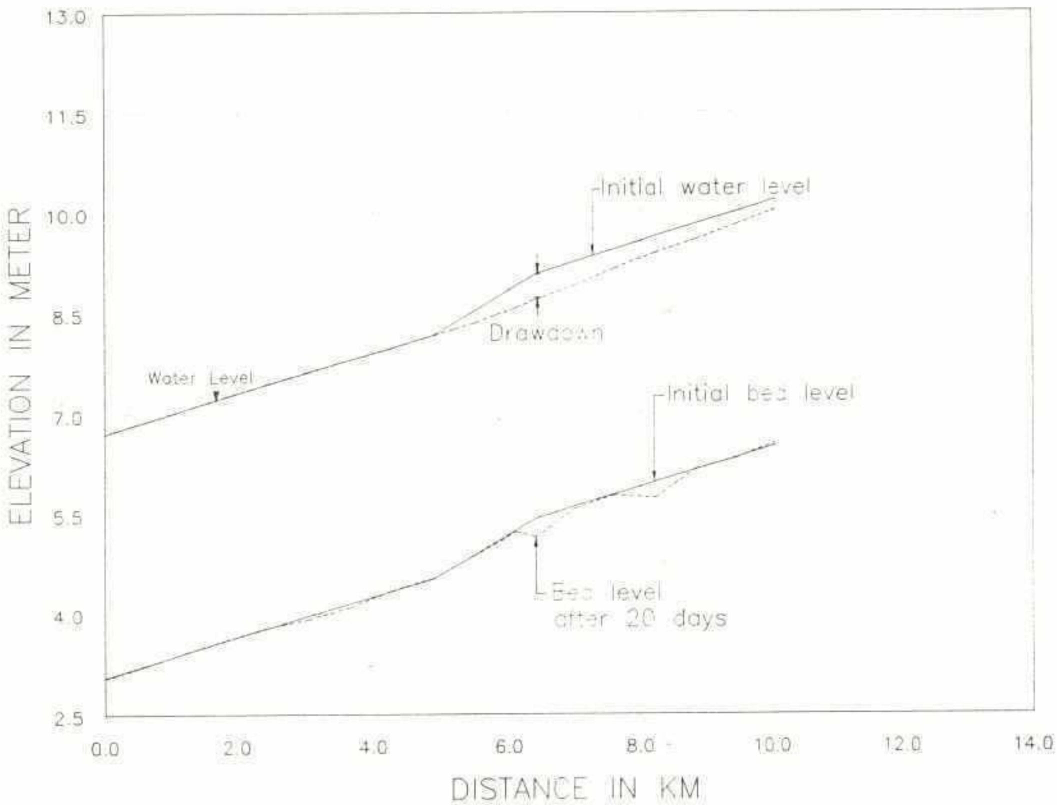
Prepared by:	DMc/Tarek	May 1993

FILE: Embank.DWG

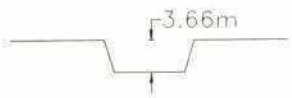
Figure 92



PLAN VIEW OF RIVER



Note: $Q = 339\ m^3/sec$



TYPICAL CROSS-SECTION

Simulation of channel Morphology and flood levels using HEC-6 Model Scour and Deposition in Rivers and Reservoirs

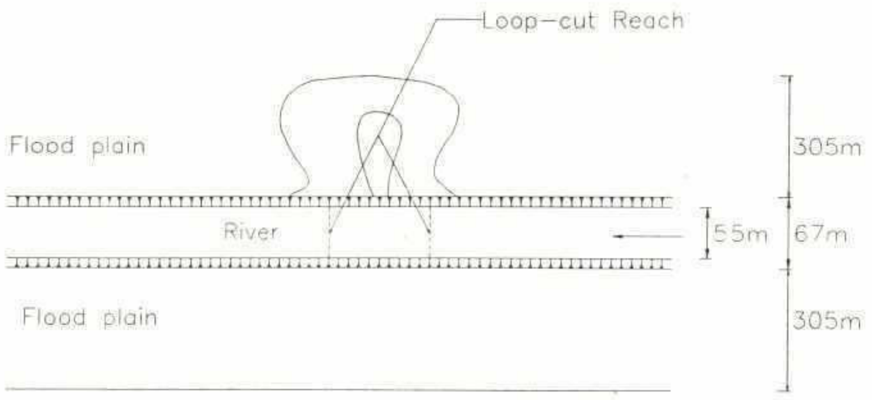
Northeast Regional Project

Impact of Loop Cuts Without Backwater

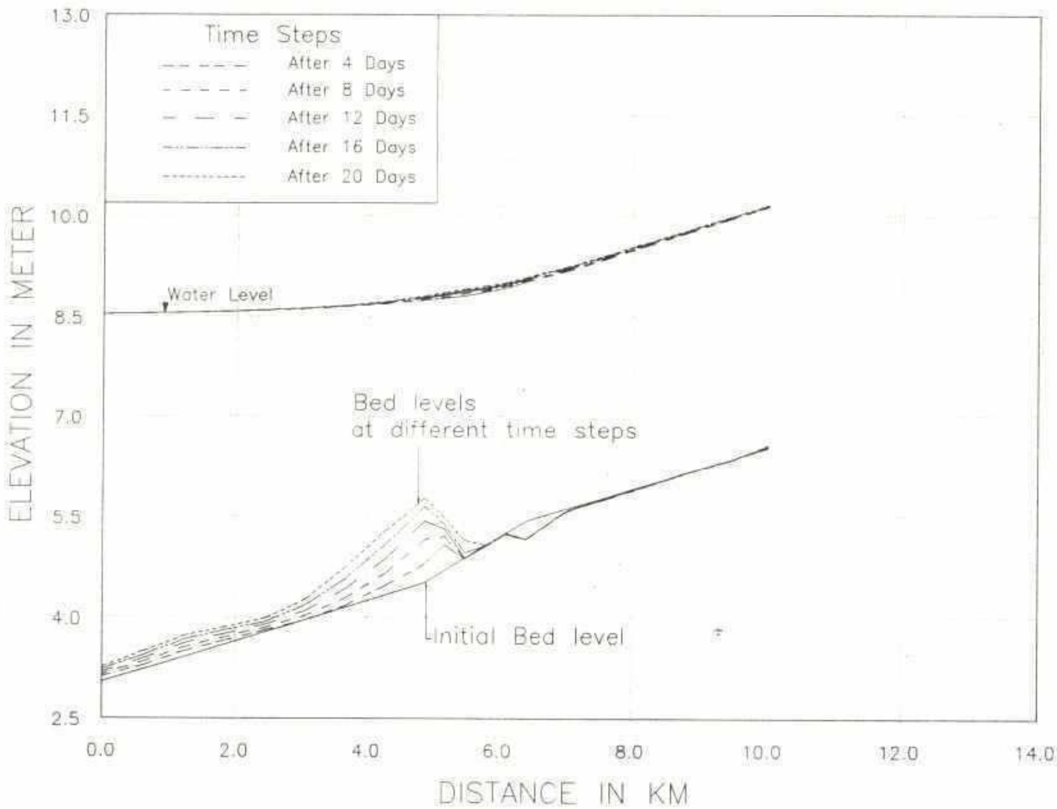
Prepared by: DMc/Tarek | May 1993

FILE: cutoff1.DWG

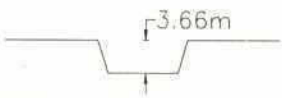
289



PLAN VIEW OF RIVER



Note: Q= 339 m^3/sec



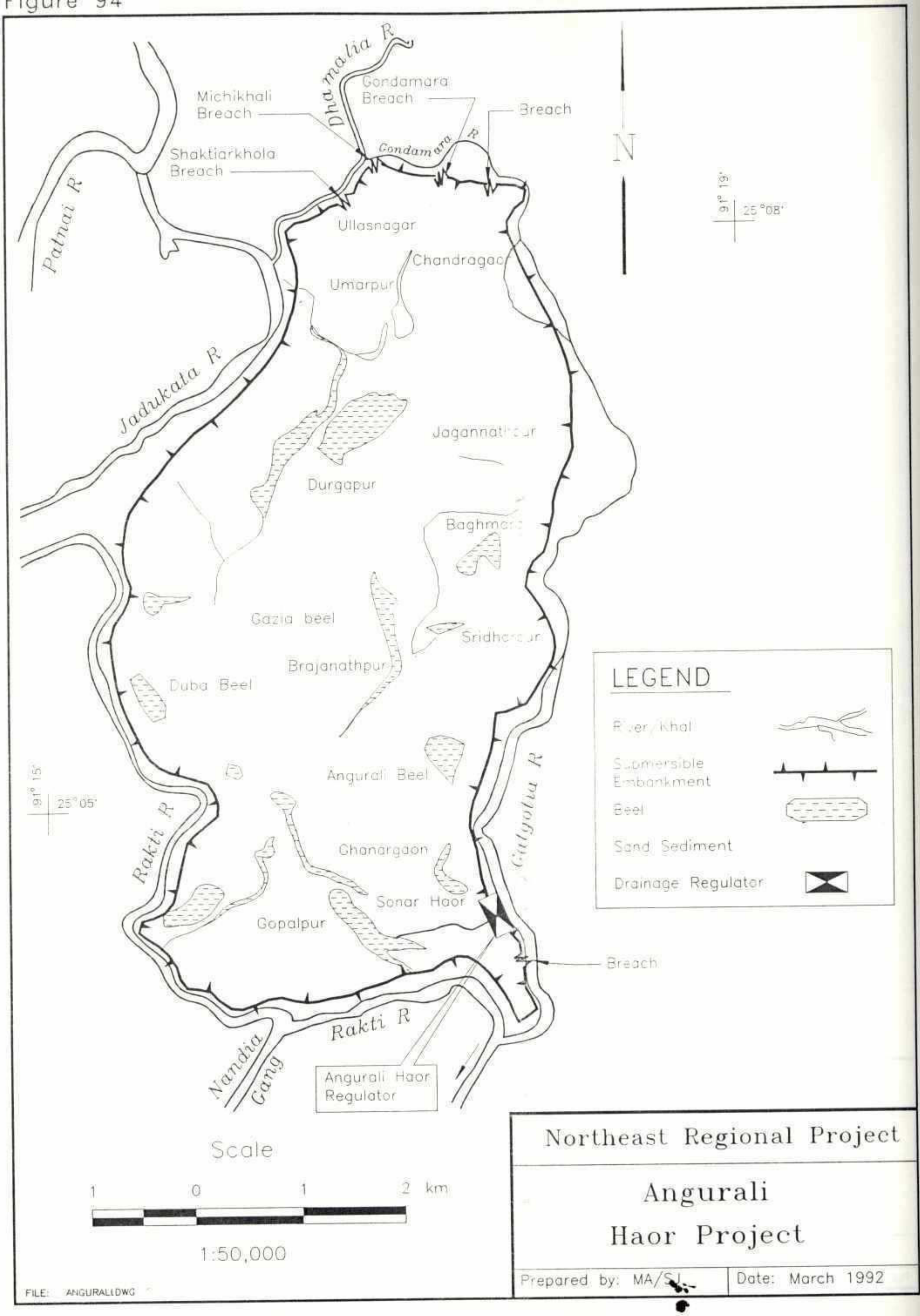
TYPICAL CROSS-SECTION

Simulation of channel Morphology and flood levels using HEC-6 Model Scour and Deposition in Rivers and Reservoirs

FILE: cutoff.DWG

Northeast Regional Project	
Impact of Loop Cuts Under Backwater	
Prepared by: DMc/Tarek	May 1993

Figure 94



Dhamalia R
Gondamara Breach
Michikhali Breach
Breach
Gondamara R
Shaktiarkhola Breach
Patnai R
N
91° 19'
25°08'
Ullasnagar
Chandragao
Umarpur
Jadukata R
Durgapur
Gazia beel
Brajanathpur
Duba Beel
Angurali Beel
Ghanargaon
Sonar Haor
Gopalpur
Breach
Rakti R
Gulgolia R
91° 15'
25°05'
Nandia
Gang
Angurali Haor Regulator
LEGEND
Submersible Embankment
Beel
Sand Sediment
Drainage Regulator
Scale
1 0 1 2 km
1:50,000
Northeast Regional Project
Angurali Haor Project
Prepared by: MA/SI
Date: March 1992
FILE: ANGURALI.DWG

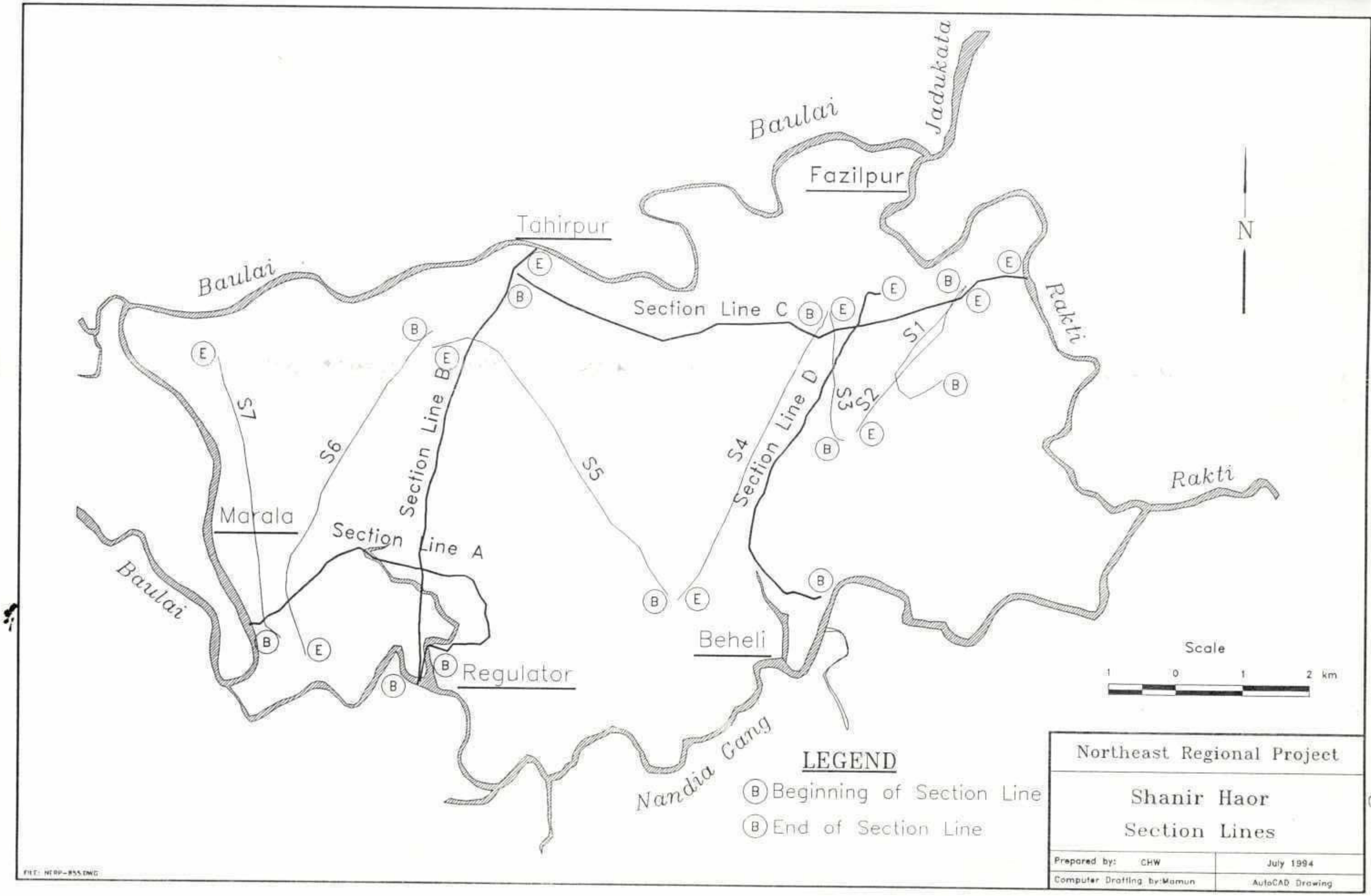
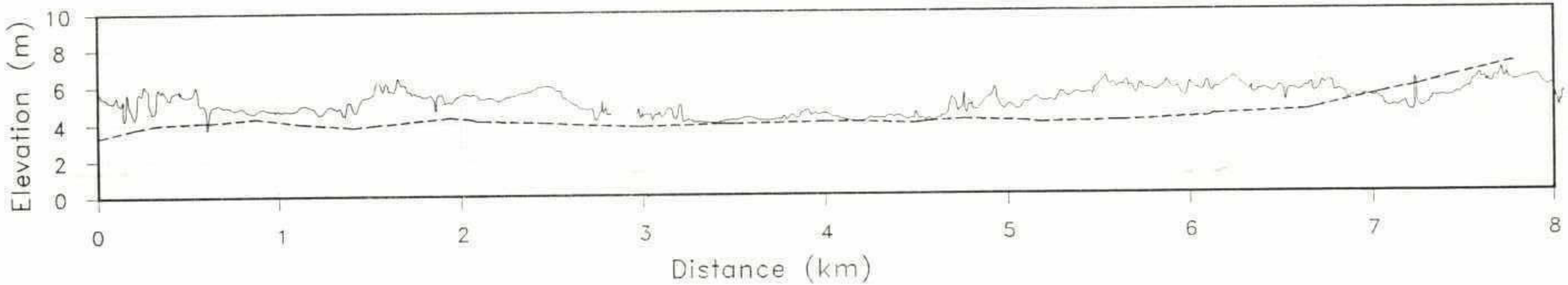
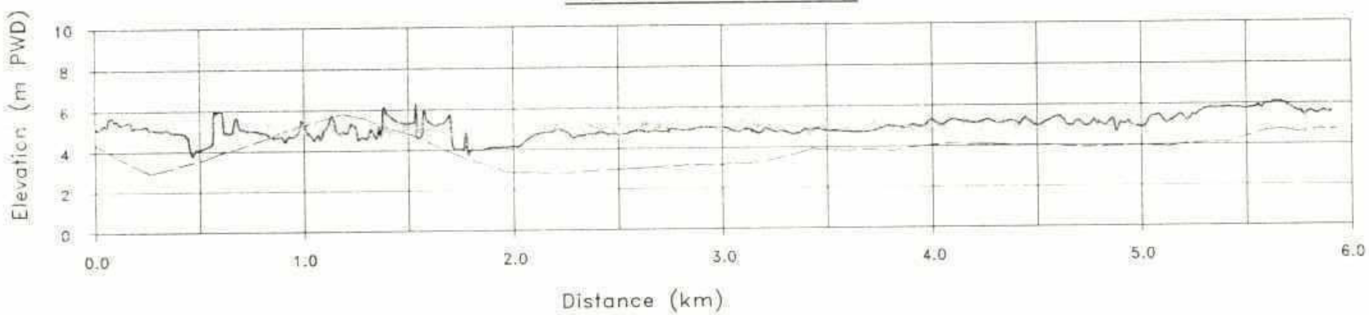

Baulai
Jadukata
Fazilpur
Tahirpur
Baulai
N
Rakti
Section Line C
S1
S2
S3
Section Line D
S4
S5
S6
S7
Section Line B
Marala
Section Line A
Baulai
Rakti
Beheli
Regulator
Scale
1 0 1 2 km
Nandia Gang
LEGEND
B Beginning of Section Line
B End of Section Line
Northeast Regional Project
Shanir Haor
Section Lines
Prepared by: CHW
July 1994
Computer Drafting by:Mamun
AutoCAD Drawing

Figure 95

Section Line : C



Section Line : D



LEGEND

——— NERP 1992/93

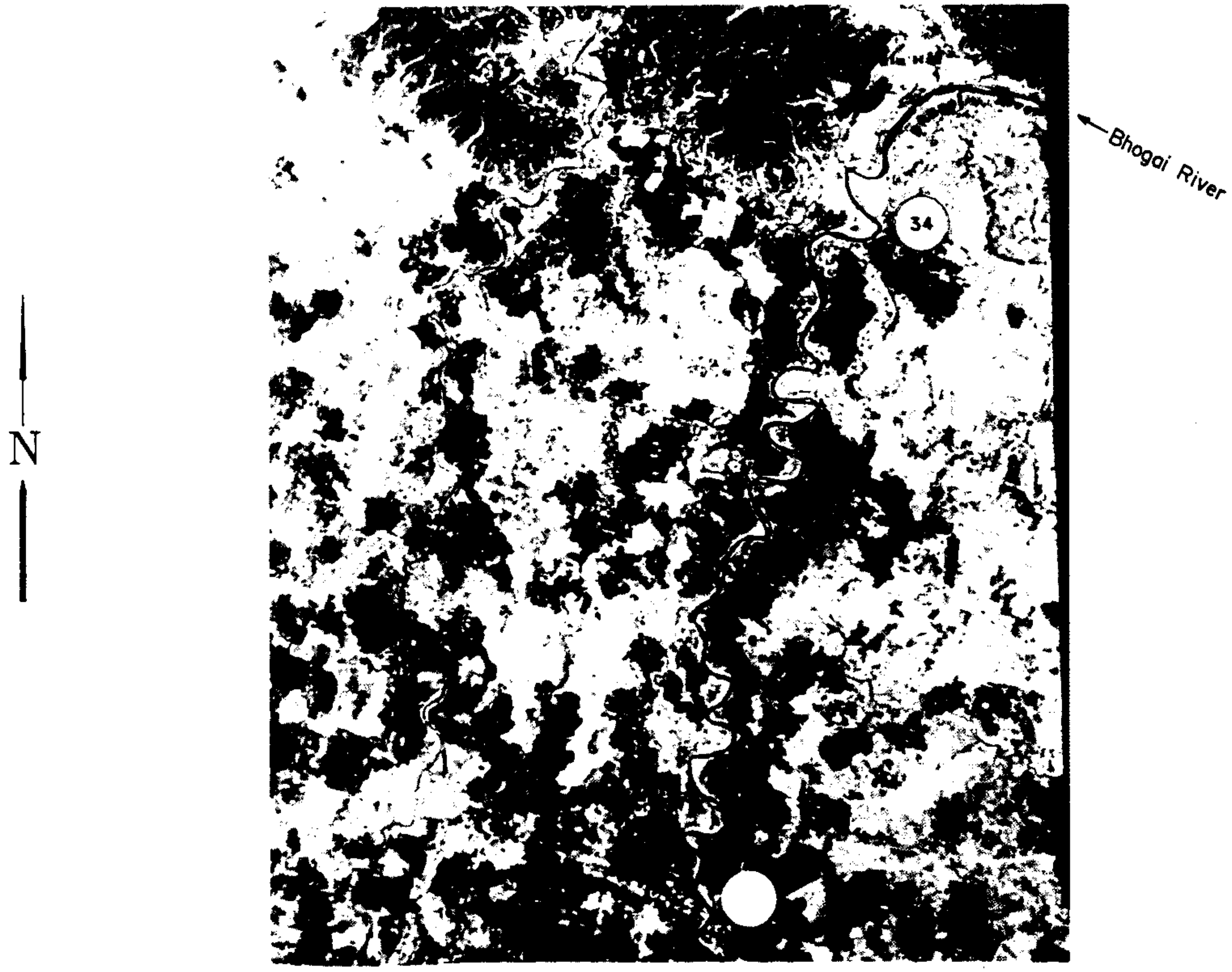
- - - - - 1963 (4" to 1 Mile Map)

Northeast Regional Project	
Longitudinal Profile of Shanir Haor	
Prepared by: CHW	December 1994
Computer Drafting by:Mamun	AutoCAD Drawing

ANNEX C

RIVER CATALOGUE

Figure C-1



River Characteristics:

1. Gauge Number: 34

2. Location:
   Lat. 25 11'23"N
   Lon. 90 13'08"E

3. Available Data
   Water Level: 1964–70,1971–93
   Discharge : 1964–68,1970,1972–80,1983–93
   Sediment: None

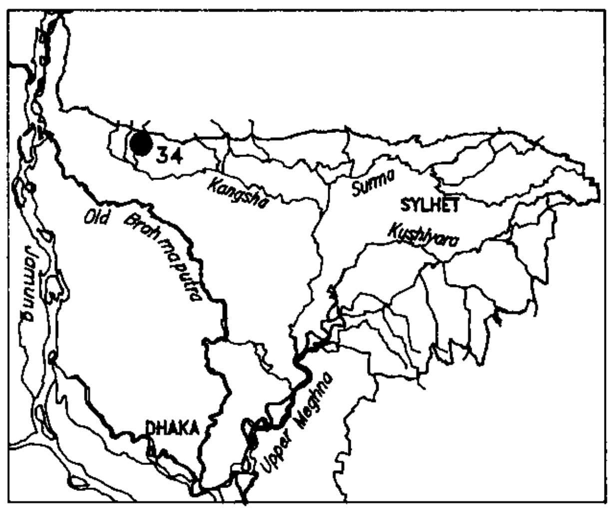
4. Physical Setting:
   Physiographic Unit: Piedmont Floodplain
   Agro–ecologic Zone: Northern & Eastern Hills
   Features: The river exits from the Susang Hills, India and flows in an alluvial floodplain with natural levees. A prominent paleo–channel can be seen heading eastwards from the canyon mouth.

5. Channel Pattern:
   Channel: Single channel with regular meanders
   Islands: None.
   Bars: Point bars at meander bends.
   Sinuosity: 1.55

6. Sedimentology
   Channel: Mainly medium sand, no gravel.
   Banks: Mainly fine sand and silt .

7. Pattern of Instability
   Slow, progressive erosion along the outer concave banks in bends. Appears to be aggrading slowly.

Viewing downstream from gauge site

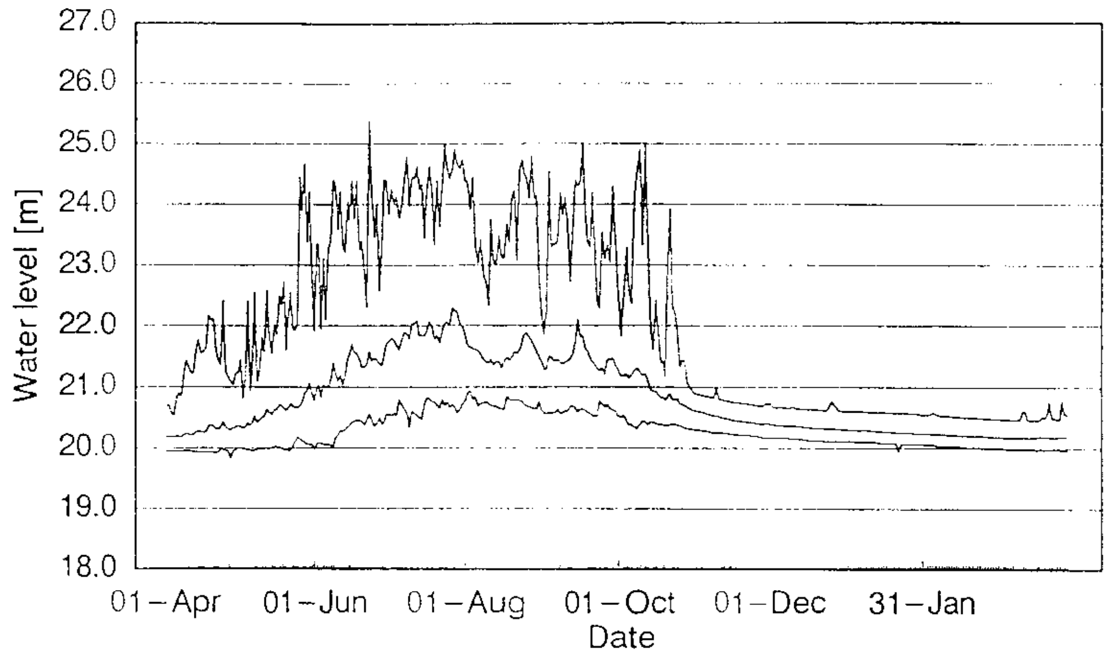


Site Location:

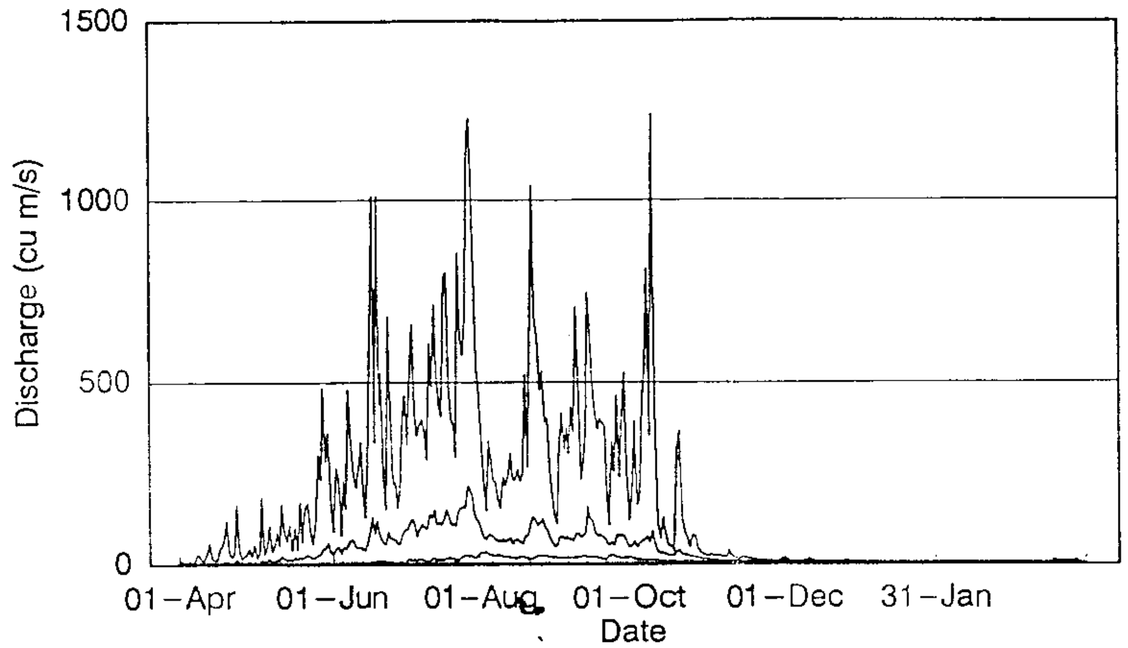
Northeast Regional Project	
Bhogai–Kangsha River at Nakuagon	
Prepared by: DMc	October 1994

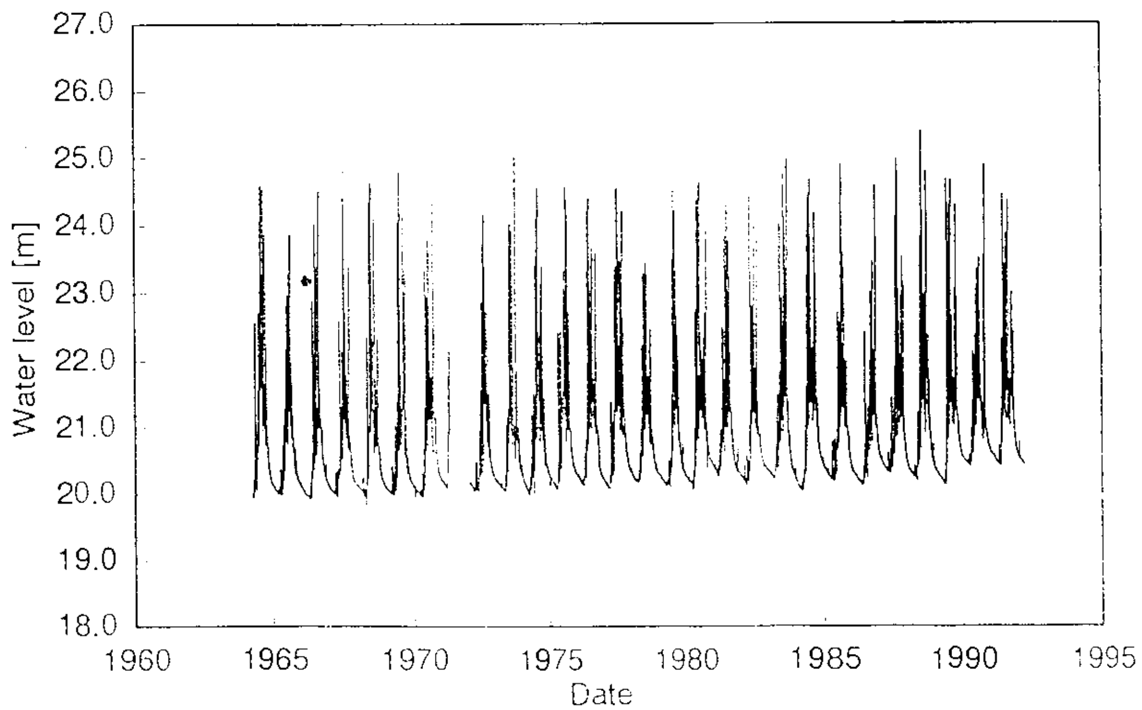
Figure C-2

Daily Minimum, Mean and Maximum Water levels

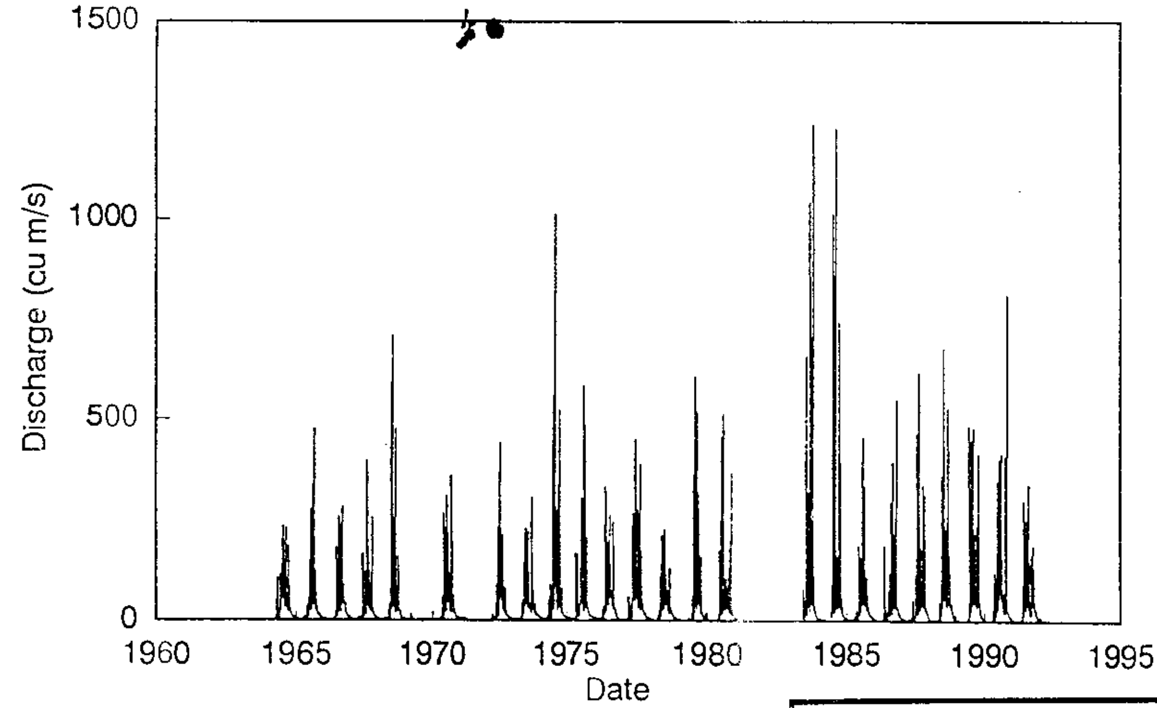


Daily Minimum, Mean and Maximum Discharges





Recorded Water Levels

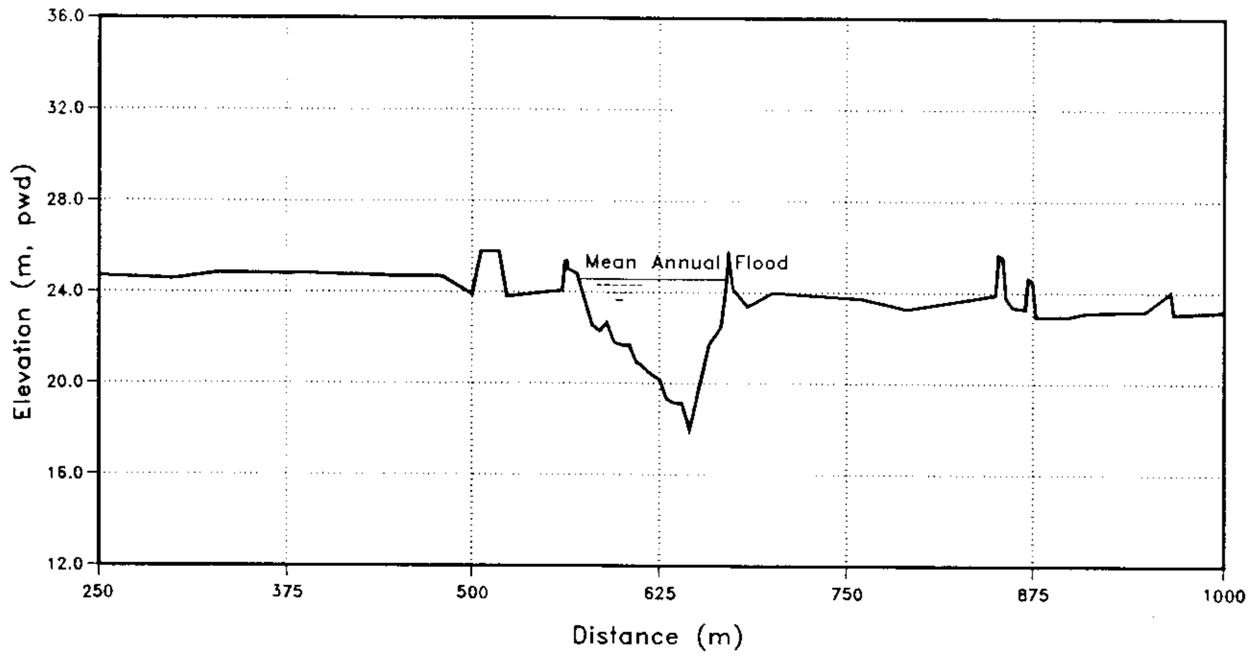


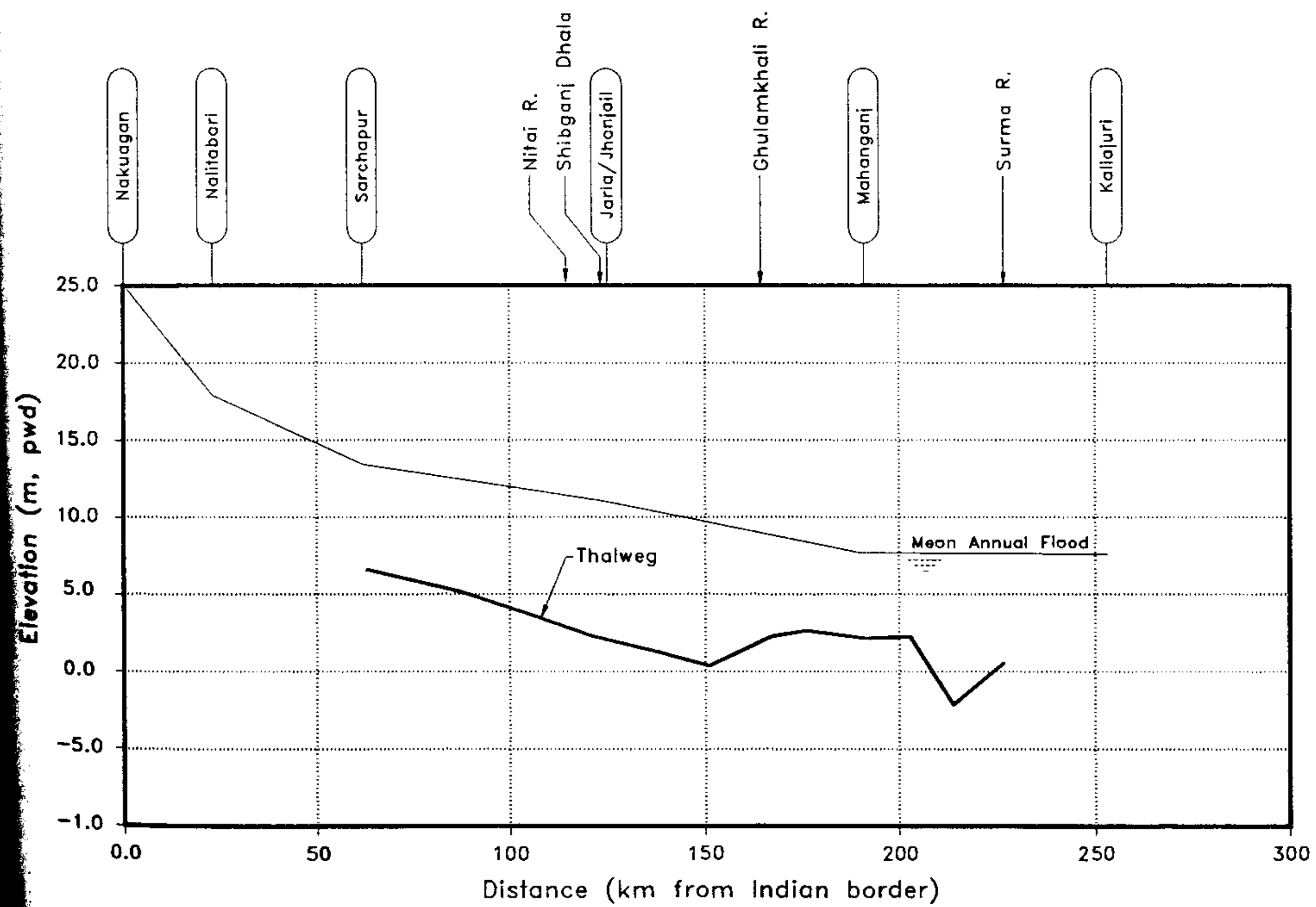
Recorded Discharges

Northeast Regional Project	
Bhogai- Kangsha River at Nakuagon	
Prepared by: Tarek	Nov'94
Drawn by: Tarek	AutoCAD Drawing

FILE: 34.DWG

Channel Properties





Slope (monsoon)= 28cm/km

Bed Material Size

D_{50} = 0.26mm

D_{35} = 0.21mm

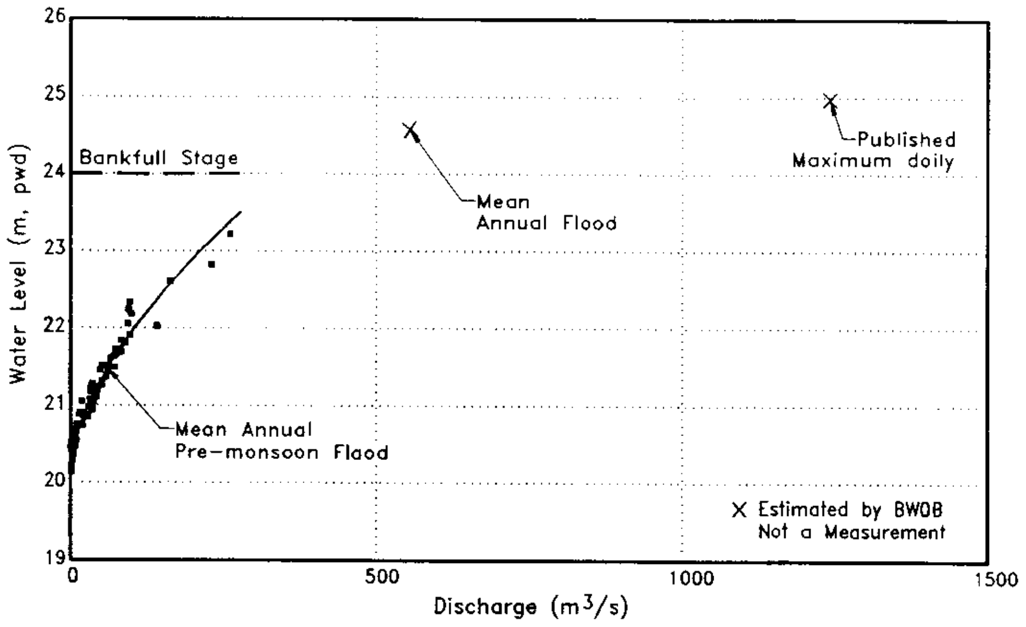
D_{10} = 0.15mm

Northeast Regional Project	
Bhogai-Kangsha River at Nakuagon	
Prepared by: DMc	November 1994

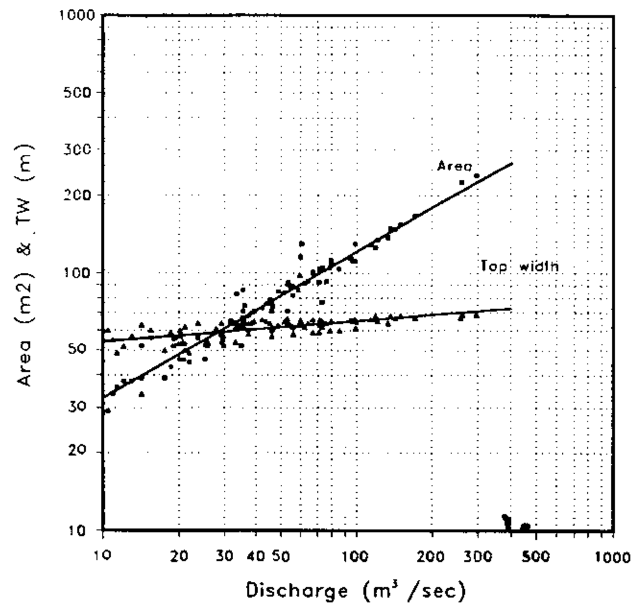
M34-3.DWG

Figure C-4

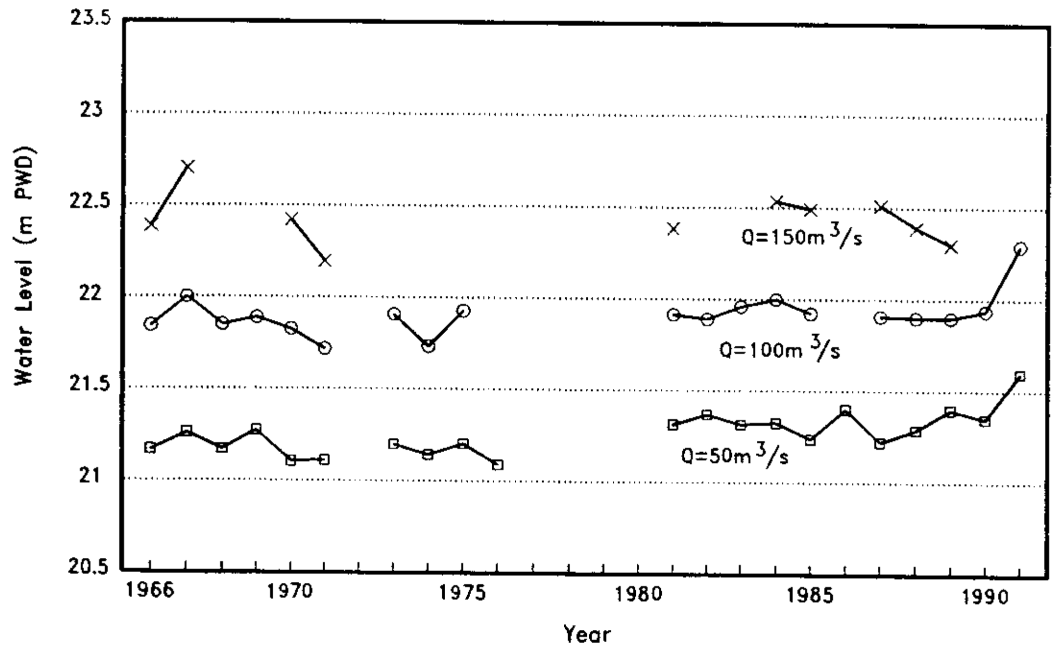
Rating Curve (1988–1991)

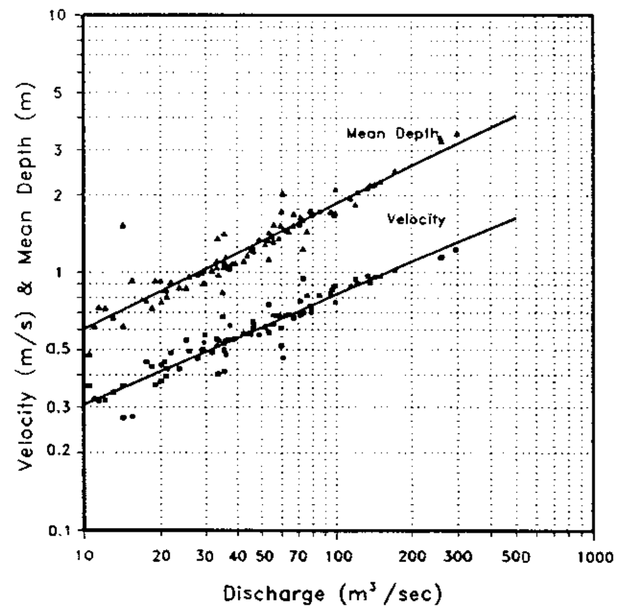


Hydraulic Geometry



Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 3.95$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge curve shows a raise in the rating curves by 0.4m between 1966 and 1991 for Q=50 and Q=100m³/s No systematic change occurred for Q=150m³/s

3. Hydraulic Geometry Relations

   $A = 8.73\ Q^{0.57}$
   $W = 44.71\ Q^{0.082}$
   $d = 0.195\ Q^{0.49}$
   $v = 0.114\ Q^{0.429}$

Condition	Q	A	W	d	v
1.	59	90	62.4	1.4	0.66
2.	555	323	75	4.3	1.72

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m³/s)
A= Area (m²)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

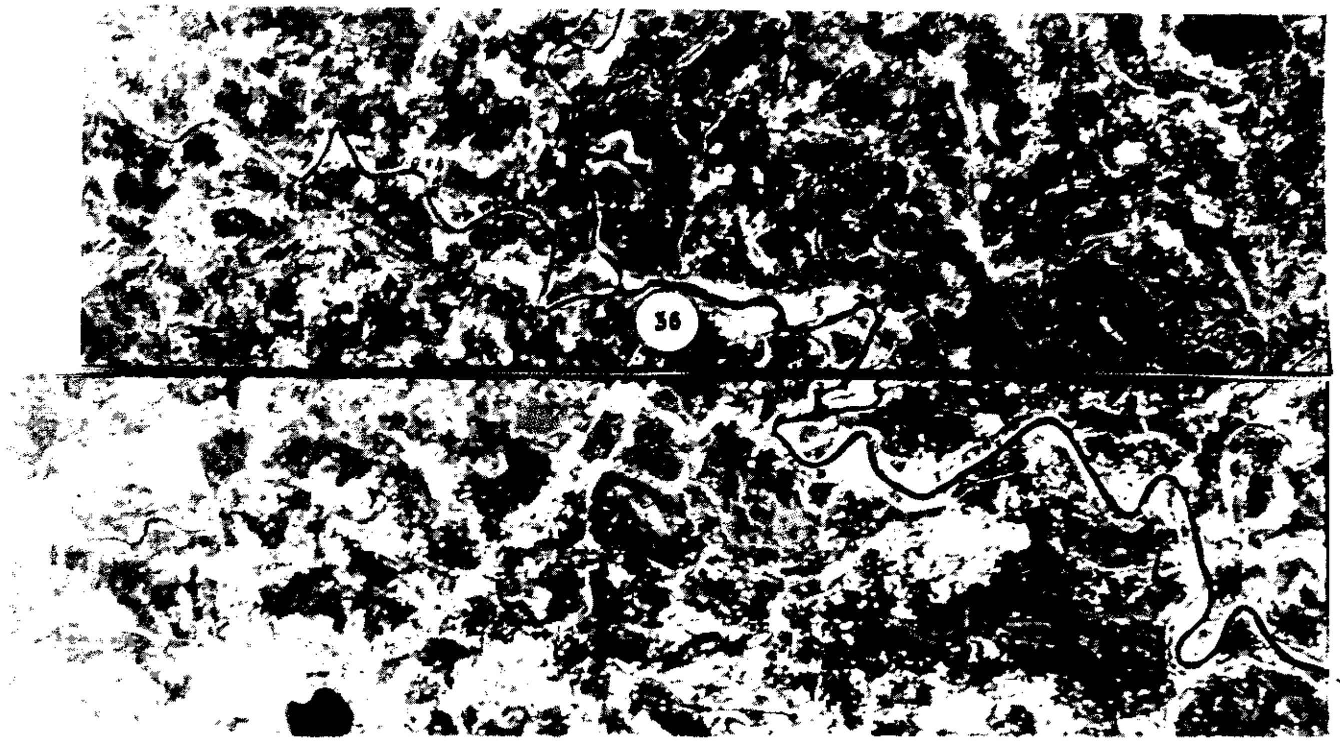
Northeast Regional Project

Bhogai River at Nakuagon

Prepared by:	DMc	November 1994

BD-34.DWG

Figure C-5



River Characteristics:

1. Gauge Number: 36

2. Location:
   Lat. 25 00'34"N
   Lon. 90 39'19"E

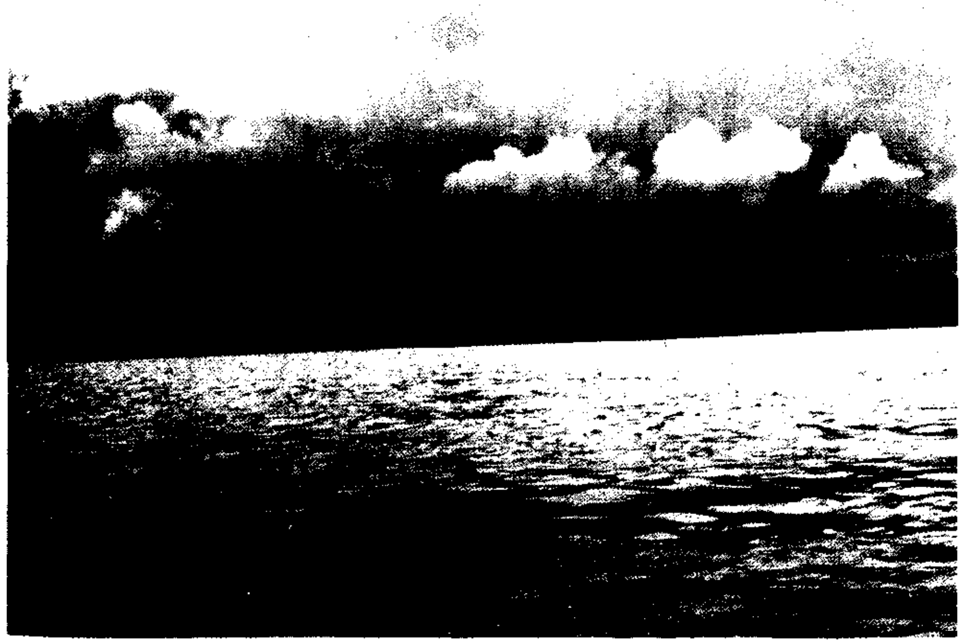
3. Available Data
   Water Level: 1964–1993
   Discharge : 1964–68, 1970,1972–81,1983–1993
   Sediment: None

4. Physical Setting:
   Physiographic Unit: Lowland Floodplain
   Agro-ecologic Zone: Northern & Eastern Piedmont Plains
   Features: The river occupies a former spill channel from the Brahmaputra River (Khoria River). The channel widens abruptly below Shibganjdhala R. which enters 1 km upstream from the north.

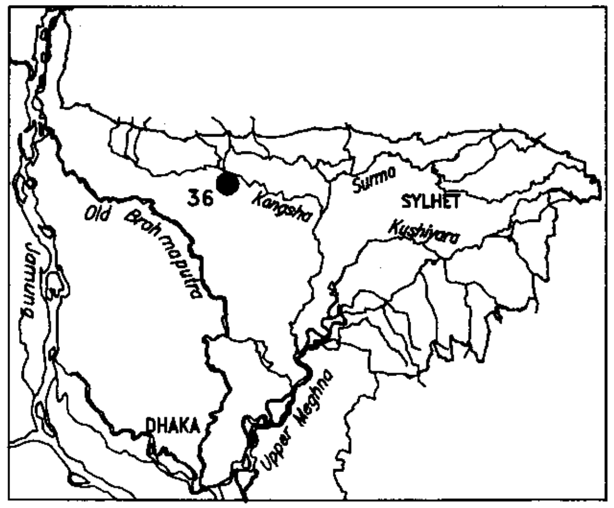
5. Channel Pattern:
   Channel: Single channel with highly irregular bends.
   Islands: None.
   Bars: None.
   Sinuosity: 1.90

6. Sedimentology
   Channel: Mainly fine sand.
   Banks: Mainly silt, silty sand .

7. Pattern of Instability
   Accelerated erosion since Someswari R. avulsed into Shibganj dhala R. in 1960's. Kangsha R. has experienced aggradation, which has led to led to infilling of the old Kangsha channel and expansion of the Ghulamkhali channel downstream of Jaria. This instability is continuing to occur.



View to left bank near metering section

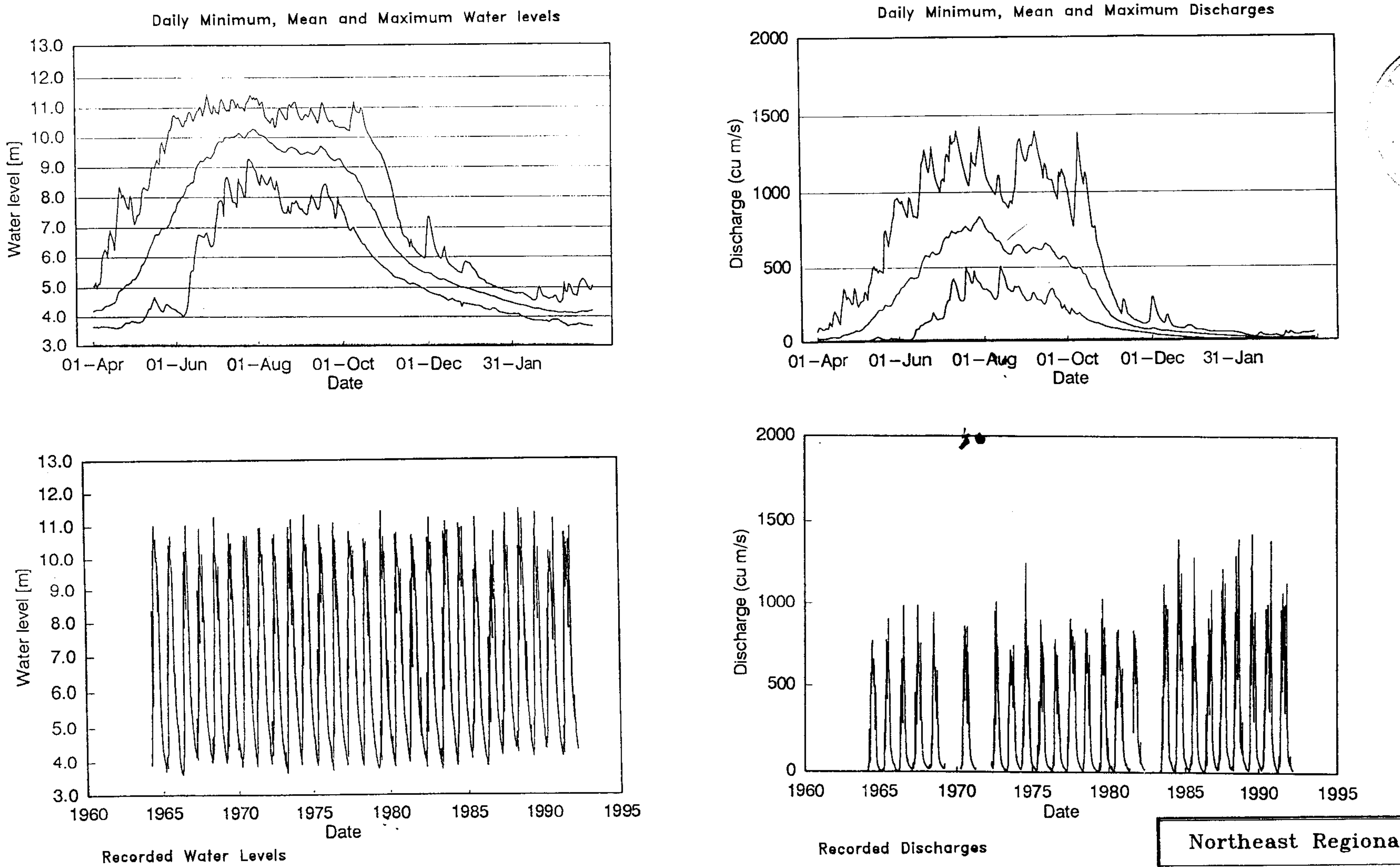


Site Location:

Northeast Regional Project	
Kangsha River at Jaria Janjail	
Prepared by: DMc	October 1994

-LDWO

Figure C-6

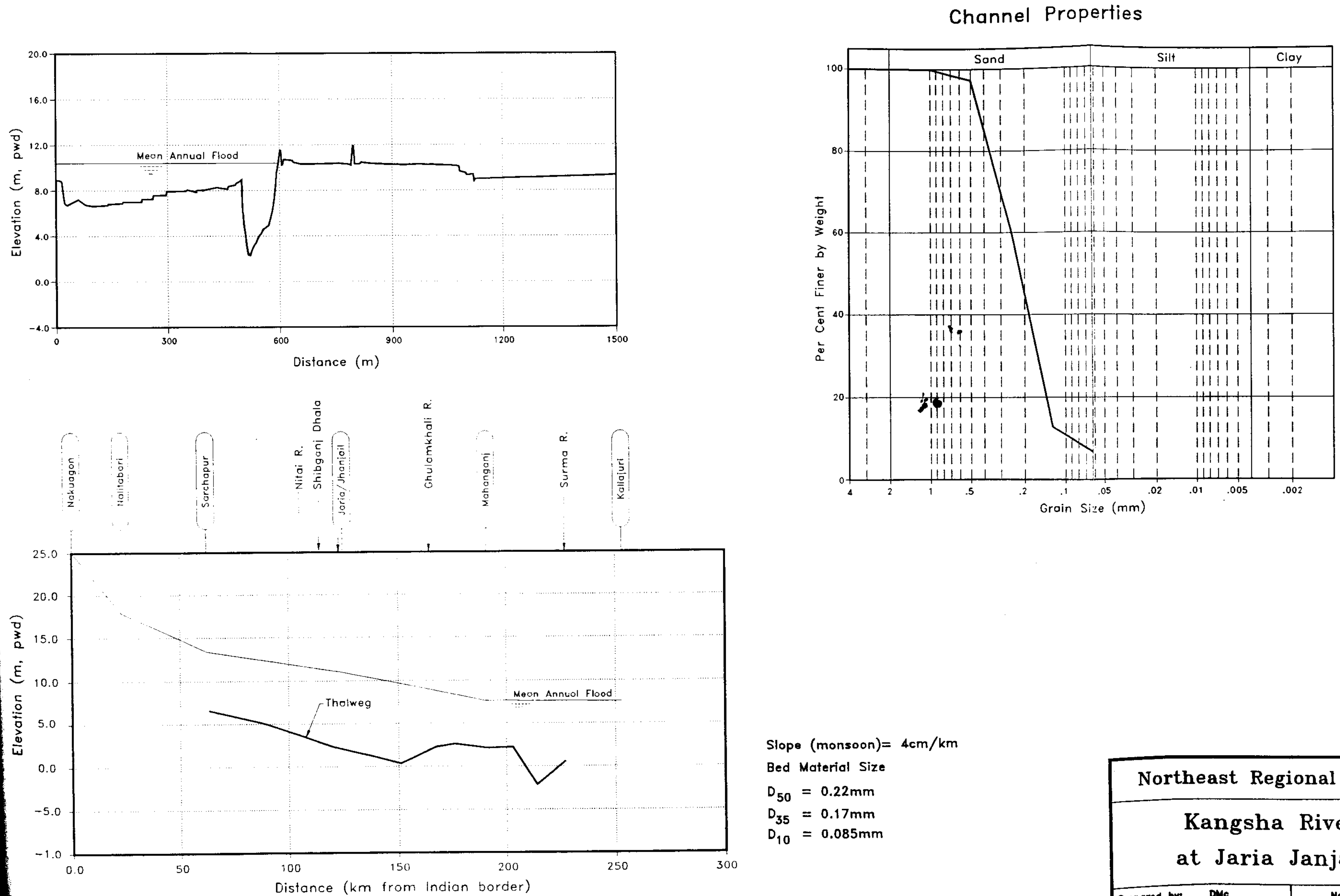


Northeast Regional Project			
Kangsha River at Jaria Jhanjail			
Prepared by:	DMc/Tarek	October 1994	
Drawn by:	Jalal	AutoCAD Drawing	

36.DWG

Figure C-7

Channel Properties



Slope (monsoon)= 4cm/km

Bed Material Size

D_{50} = 0.22mm

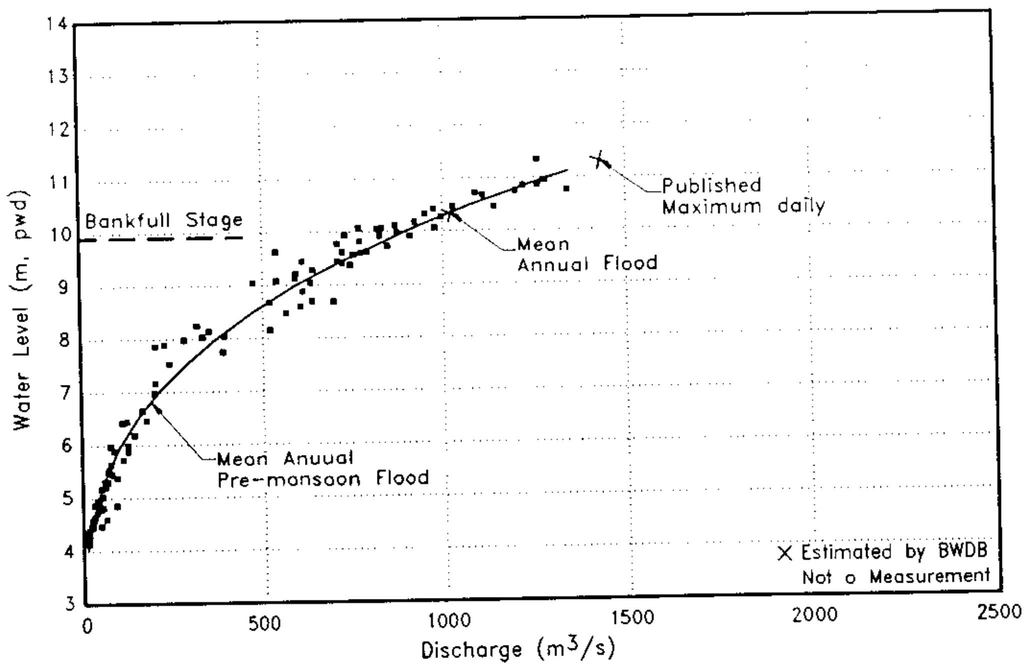
D_{35} = 0.17mm

D_{10} = 0.085mm

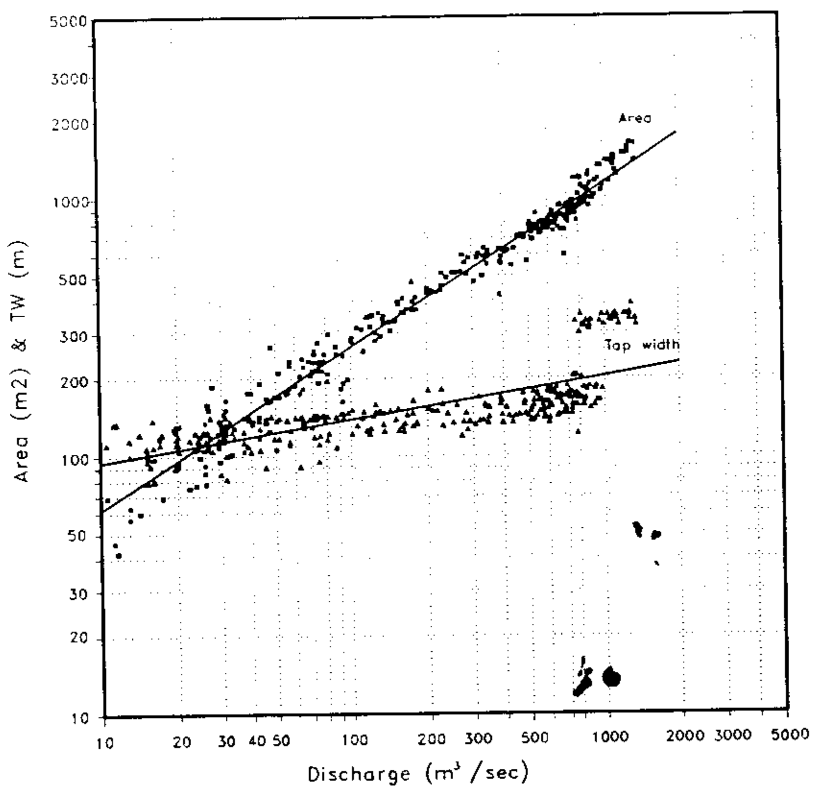
Northeast Regional Project	
Kangsha River at Jaria Janjail	
Prepared by: DMc	November 1994

M36-3.DWG

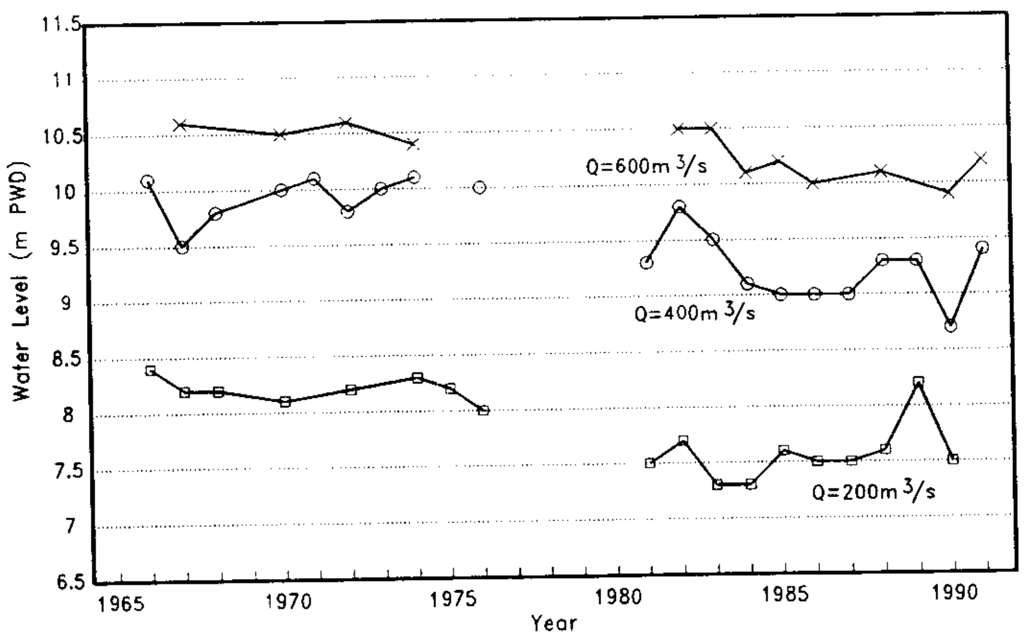
Rating Curve (1988–1991)

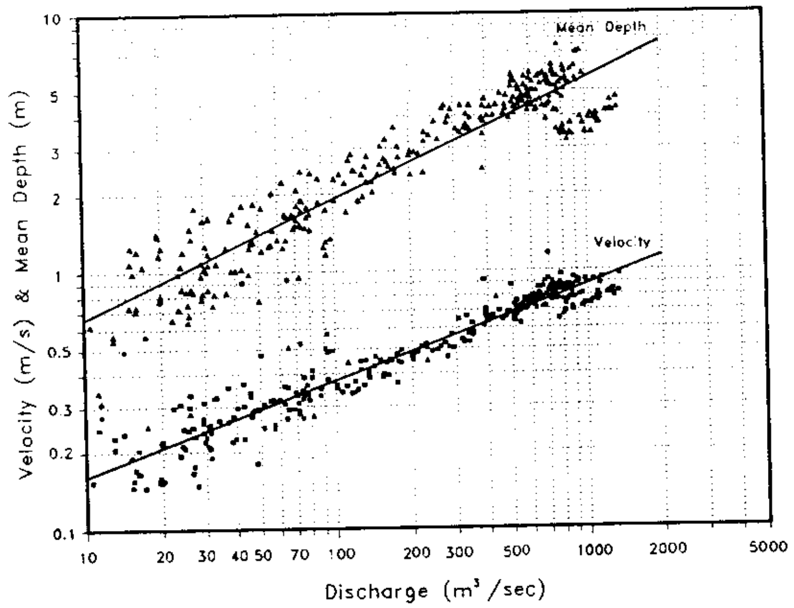


Hydraulic Geometry



Historic Variation in Stage Discharge Relations
(Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.07$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plots were steady between 19966–1977 and lowered by 0.5 – 1.0m since 1977.

3. Hydraulic Geometry Relations

   $A = 14.53 Q^{0.63}$
   $W = 64.49 Q^{0.166}$
   $d = 0.225 Q^{0.465}$
   $v = 0.069 Q^{0.369}$

Condition	Q	A	W	d	v
1.	207	420	156.2	2.7	0.49
2.	1041	1162	204	5.7	0.90

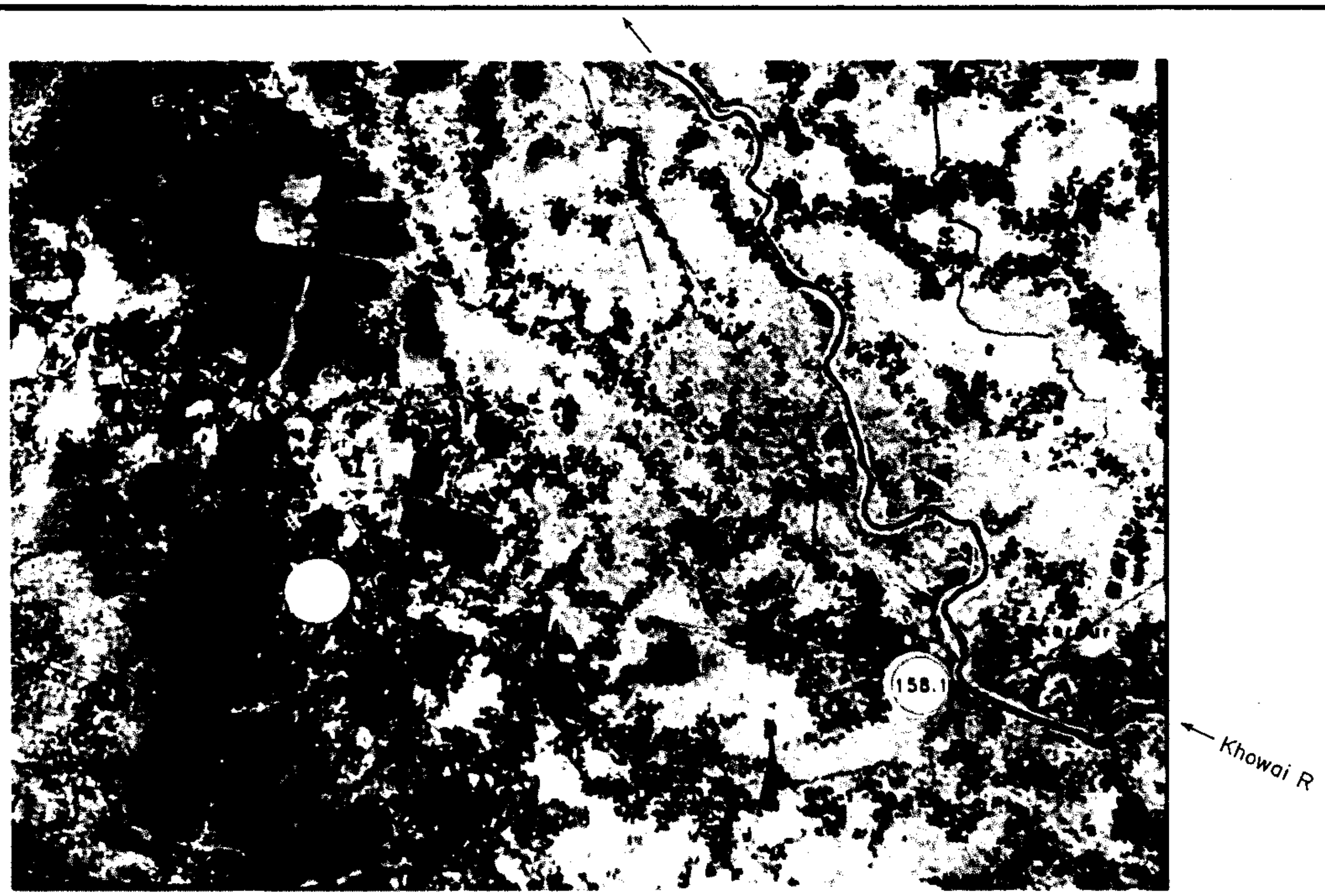
1. Mean annual pre-monsoon flood
2. mean annual Flood
Q= Discharge (m3/s)
A= Area (m2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

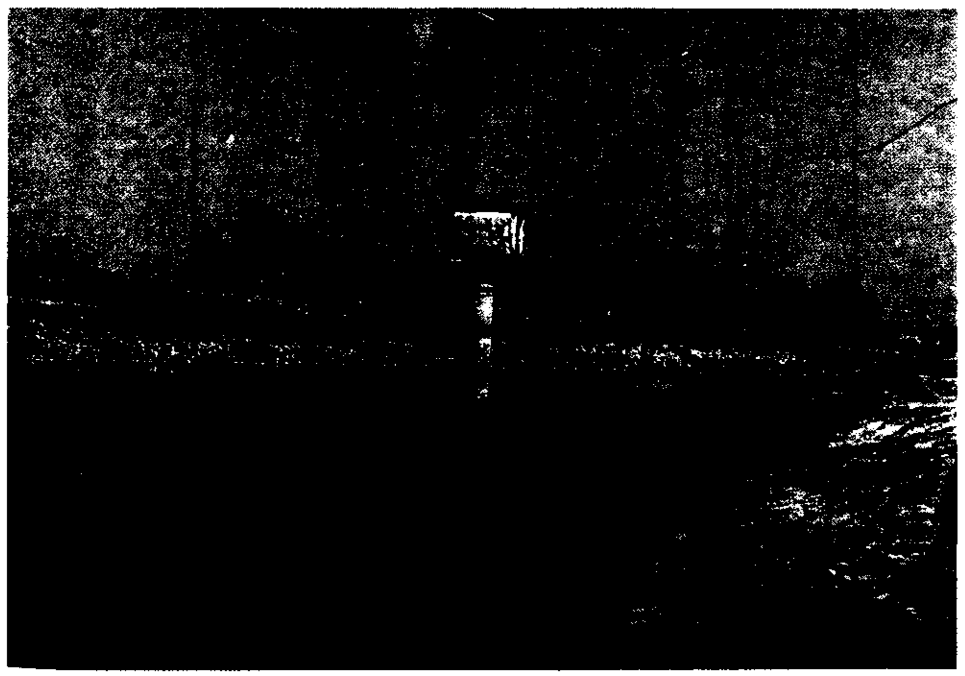
Northeast Regional Project

Kangsha River
at Jaria Janjail

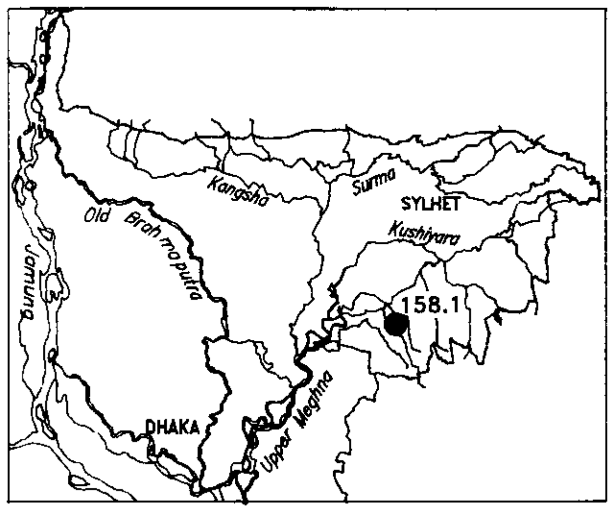
Prepared by: DMc | November 1994

Figure C-9





Auto-gauge downstream of Shaistaganj



Site Location:

River Characteristics:

1. Gauge Number: 158-1

2. Location:
Lat. 24 16'23"N
Lon. 91 28'35"E

3. Available Data
Water Level: 1964-67, 1969-70, 1972-93
Discharge : 1964-70, 1972-93
Sediment: 1964, 1966-69, 1975-93

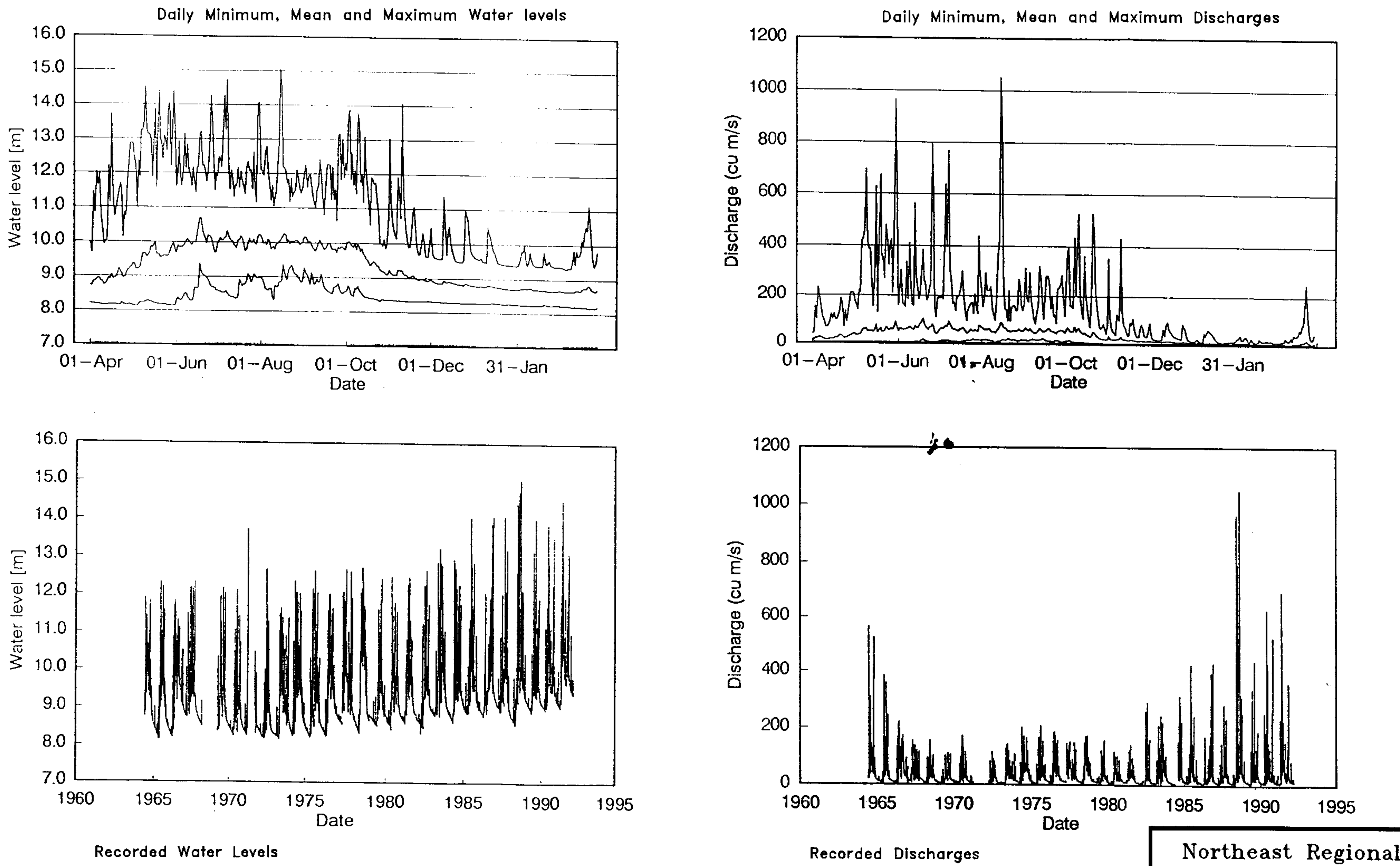
4. Physical Setting:
Physiographic Unit: Piedmont Floodplain
Agro-ecologic Zone: Northern & Eastern Piedmont Plains
Features: The channel is confined by flood control embankments from Chunarghat to below Haripur. The channel has also been straightened and re-located near Habiganj. The channel appears perched above the surrounding floodplain.

5. Channel Pattern:
Channel: Single, nearly straight confined channel.
Islands: None.
Bars: None.
Sinuosity: 1.34

6. Sedimentology
Channel: Mainly fine sand.
Banks: Mainly fine sand, silty sand and silt on berms

7. Pattern of Instability
Erosion and scour at bends has caused embankment breaching in some years. Up to 2 m of deposition has occurred on berms since embankment construction. The channel appears to have enlarged due to higher flood flows after embanking. Major spills into Karangi R. continue to occur upstream of Chunarghat.

Northeast Regional Project	
Khowai River at Shaistaganj	
Prepared by: DMc	October 1994



Northeast Regional Project

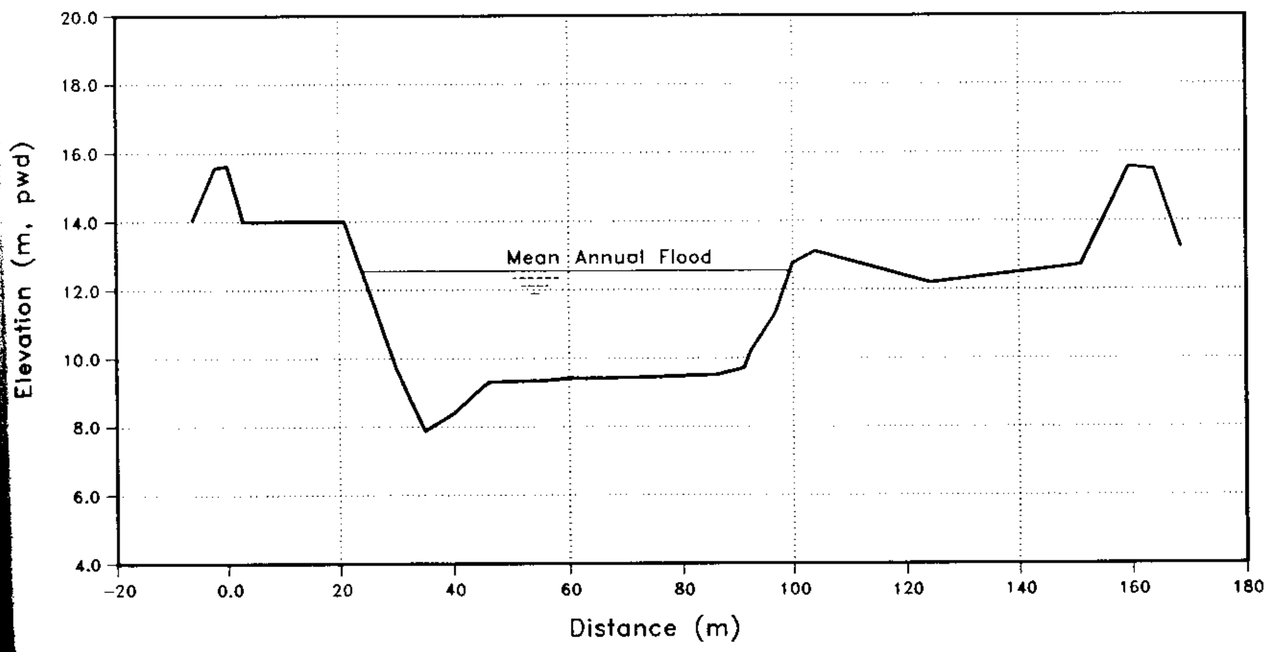
Khowai River
at Shaistaganj

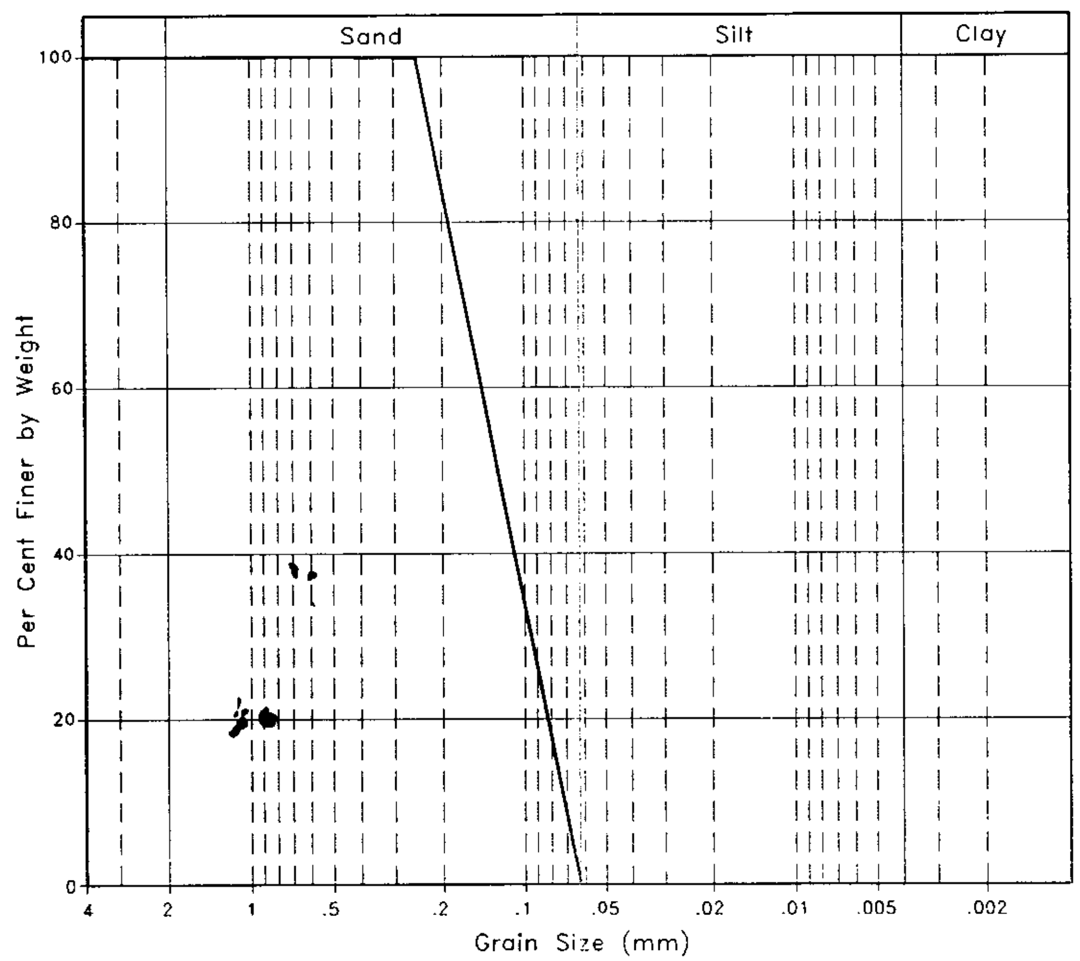
Prepared by:	DMc/Tarek	October 1994
Drawn by:	Jalal	AutoCAD Drawing

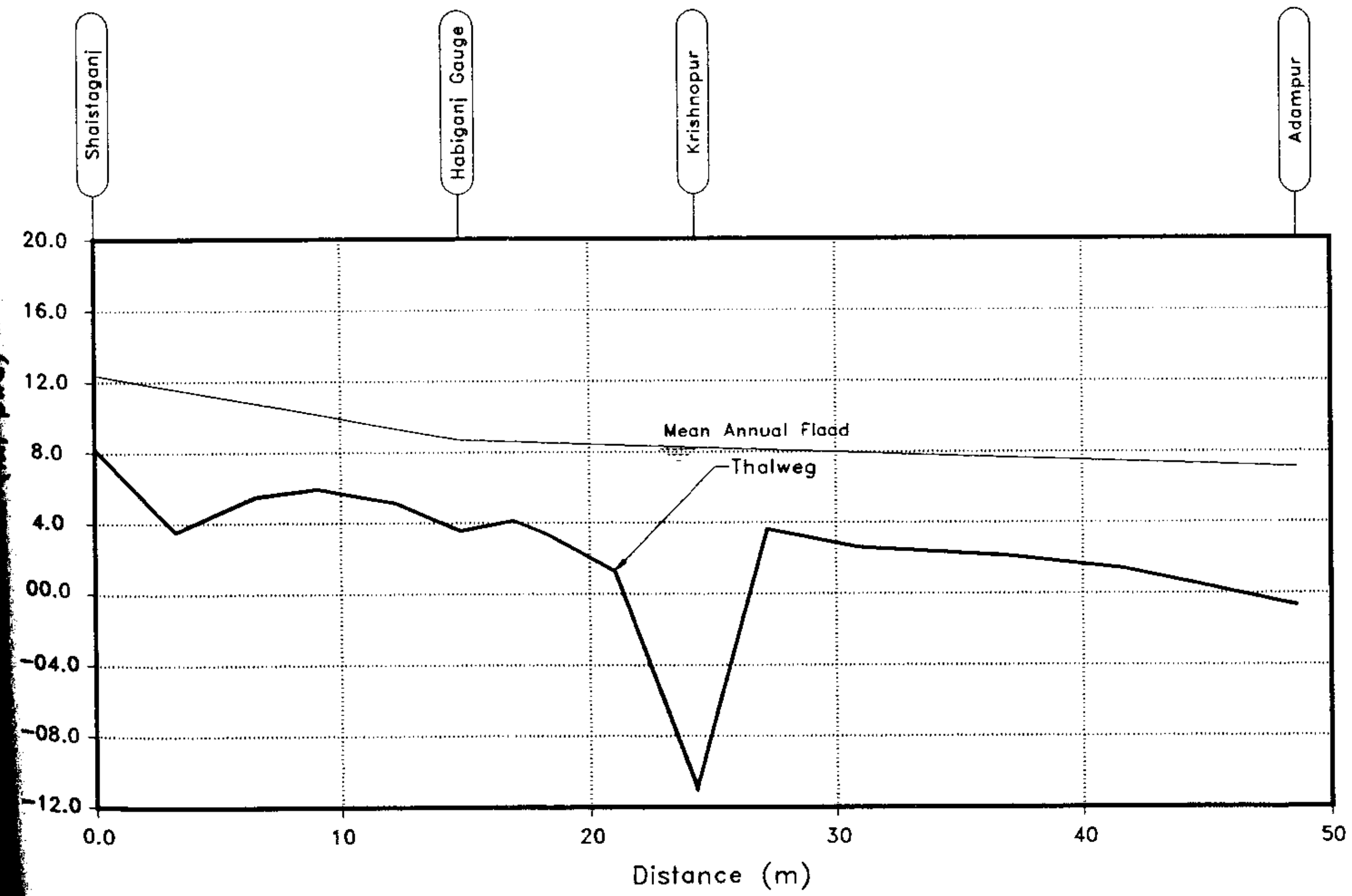
158.DWG

Figure C-11

Channel Properties







Slope (monsoon)= 28cm/km

Bed Material Size

D_{50} = 0.13mm

D_{35} = 0.10mm

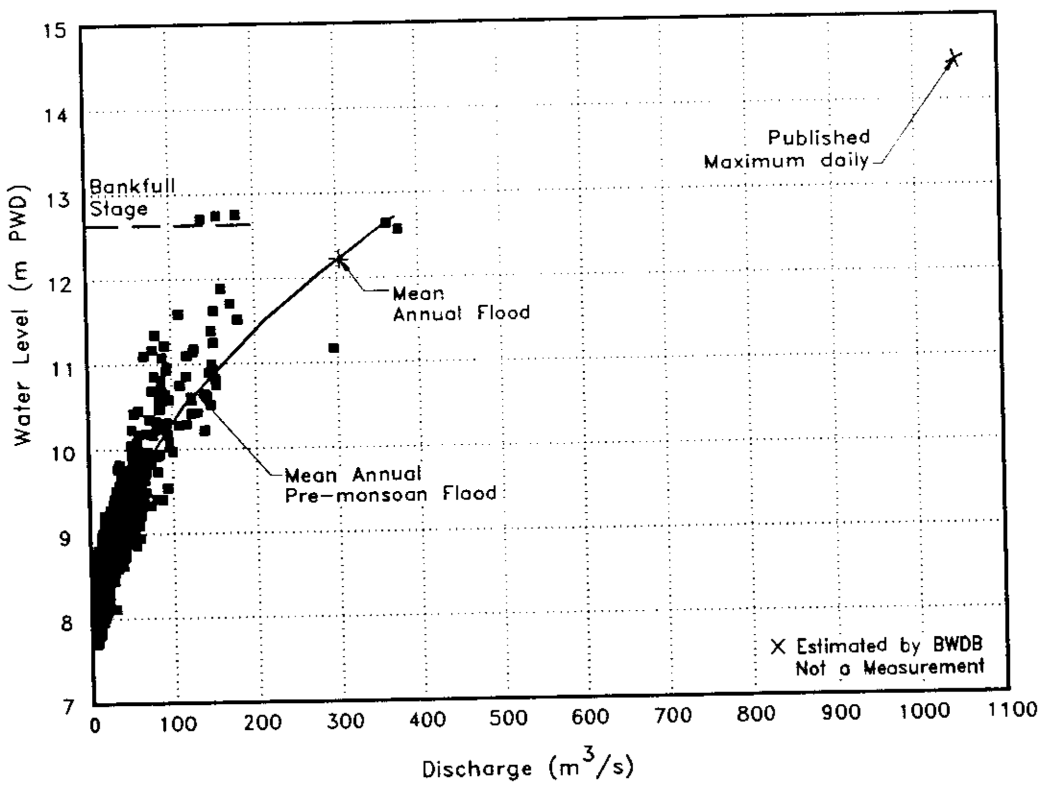
D_{10} = 0.06mm

Northeast Regional Project	
Khowai River at Shaistaganj	
Prepared by: DMc	November 1994

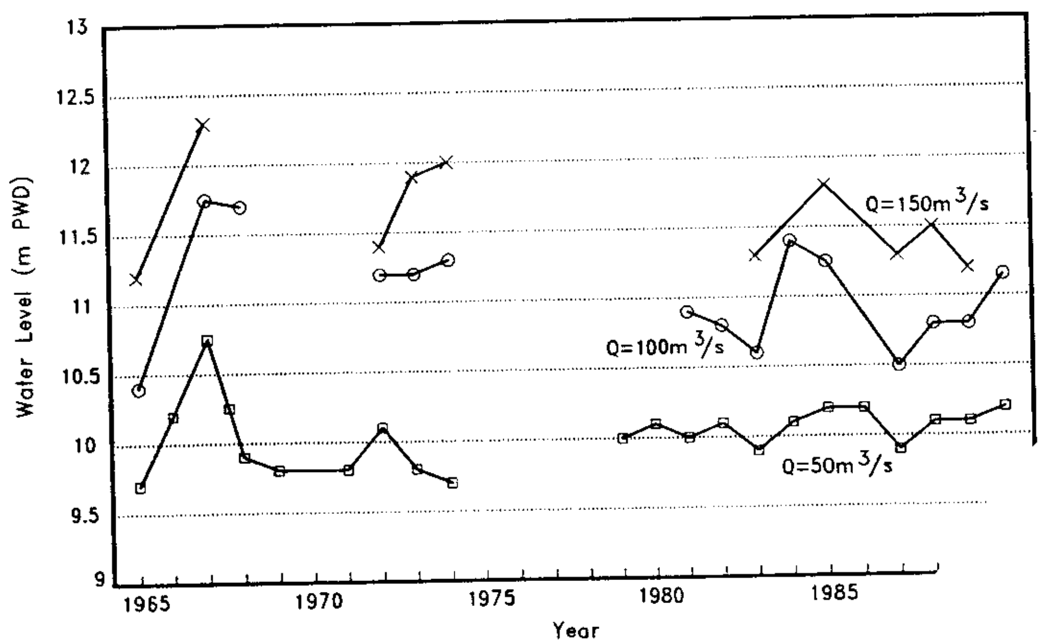
M138-3.DWG

Figure C-12

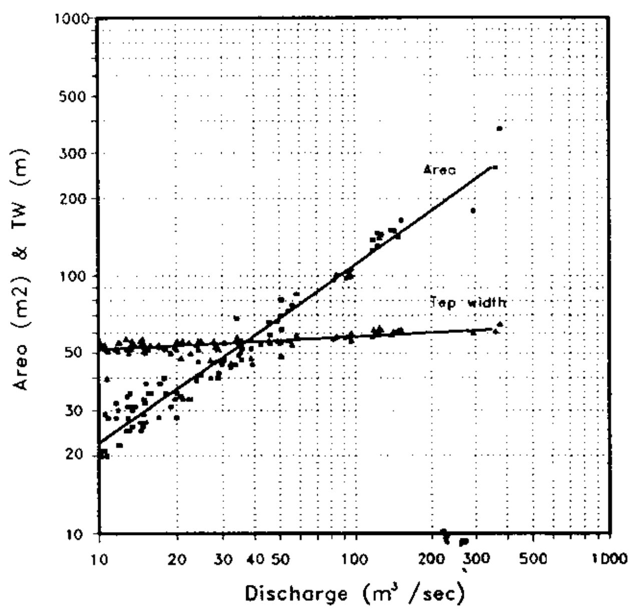
Rating Curve (1964-1989)

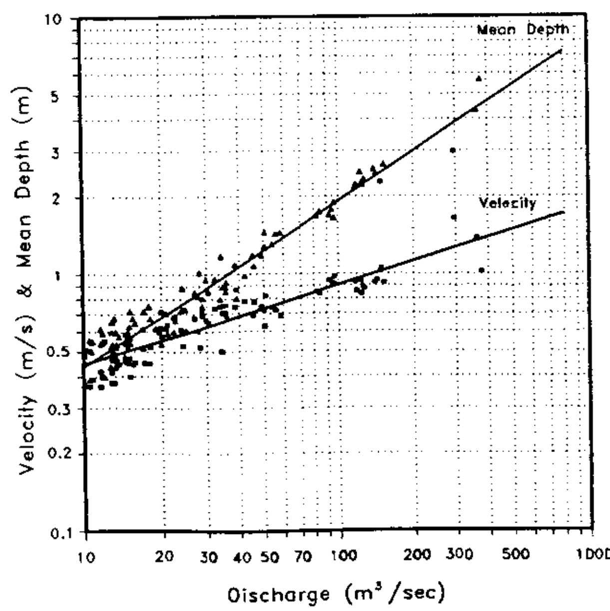


Historic Variation In Stage Discharge Relations (Specific Gauge Analysis)



Hydraulic Geometry





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 2.79$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows irregular shifts in rating curves around 1966 followed by lowering (for high flows) since 1972.

3. Hydraulic Geometry Relations

   $A = 4.54\,Q^{0.69}$
   $W = 46.0\,Q^{0.05}$
   $d = 0.10\,Q^{0.64}$
   $v = 0.22\,Q^{0.307}$

Condition	Q	A	W	d	v
1.	130	133	58.7	2.3	0.98
2.	303	239	61.2	3.9	1.27

1. Mean annual pre-monsoon flood
2. mean annuel Flood

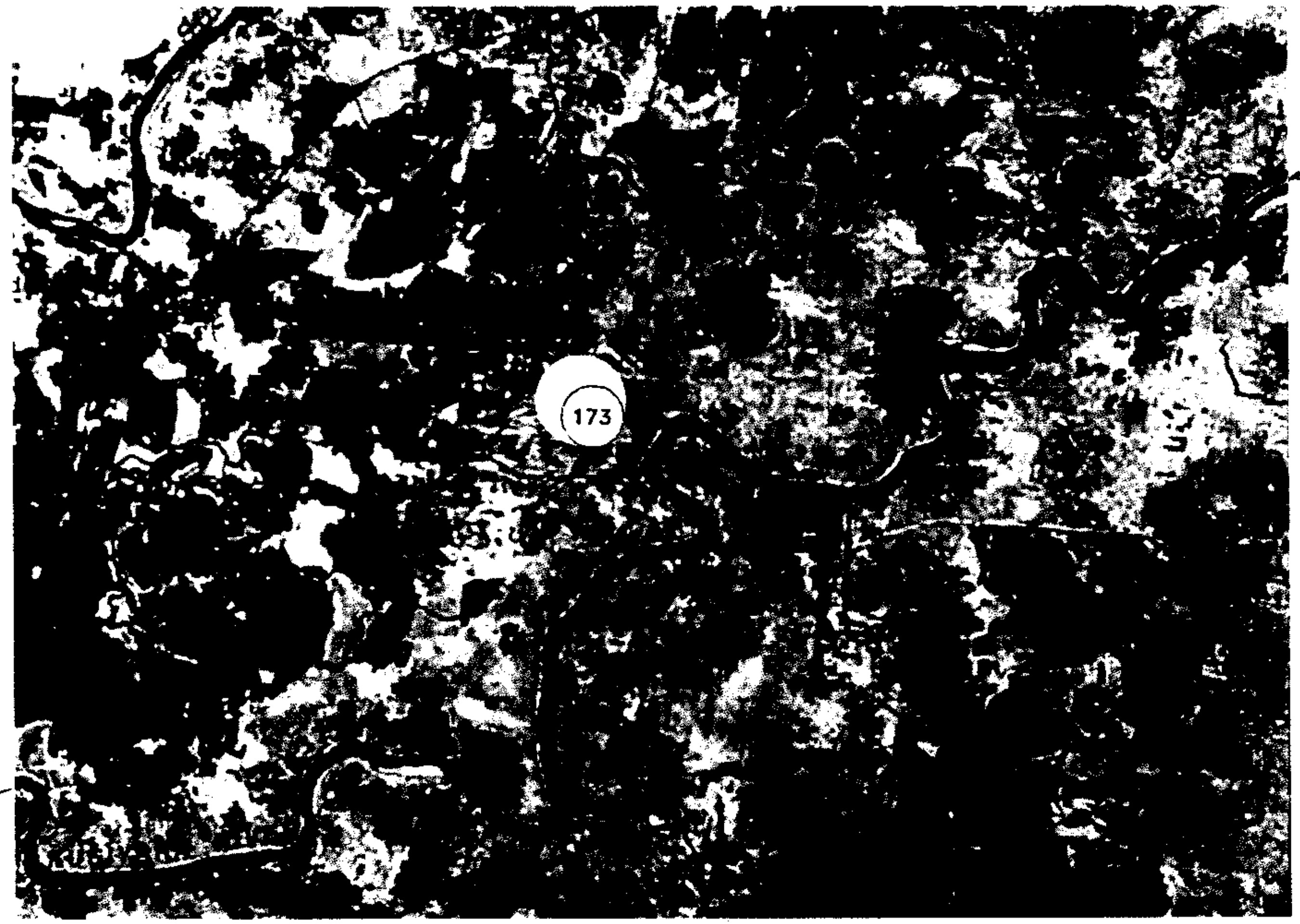
Q= Discharge (m3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

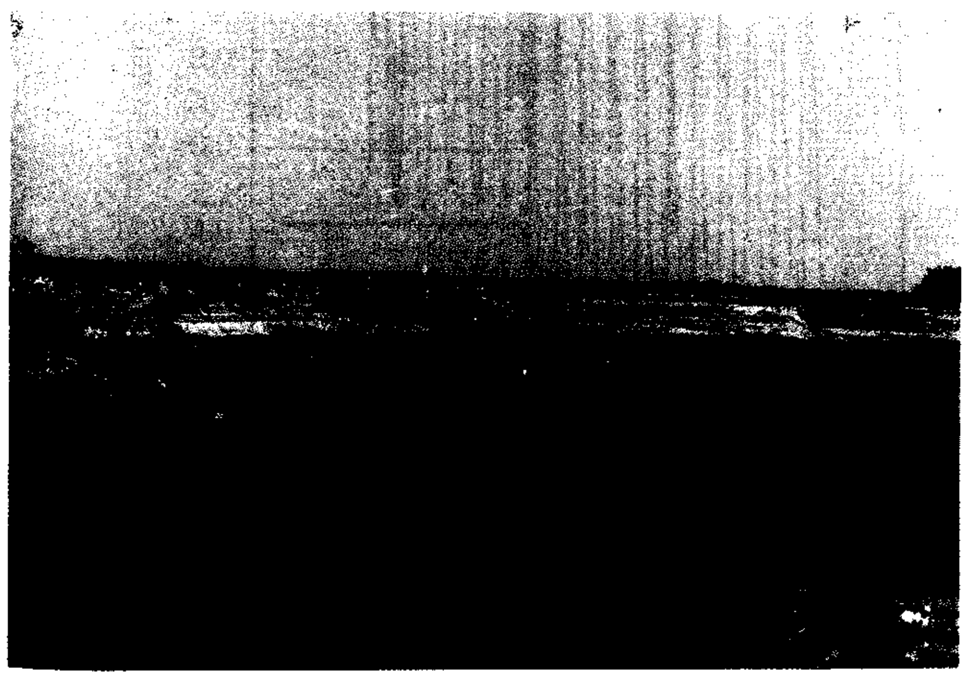
Northeast Regional Project	
Khowai River at Shaistaganj	
Prepared by: DMc	Oct 94

FILE: BD-158.DWG

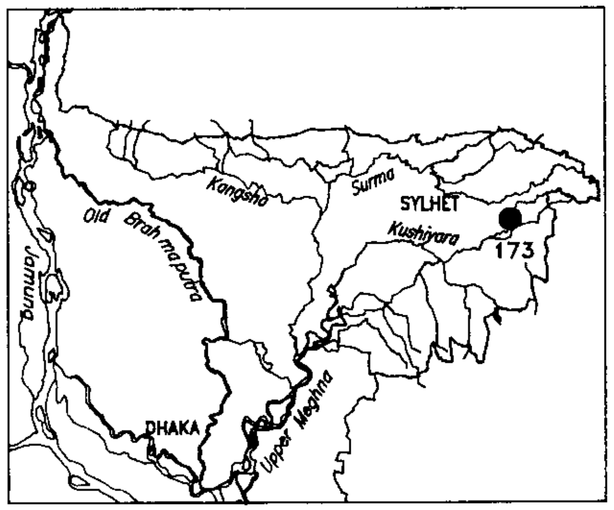
248

Figure C-13





View upstream along right bank



Site Location:

River Characteristics:

1. Gauge Number: 173

2. Location:
   Lat. 24 53'24"N
   Lon. 92 11'27"E

3. Available Data
   Water Level: 1964–93
   Discharge : 1964–70,1972–93
   Sediment: 1964–70,1972,1974–93

4. Physical Setting:
   Physiographic Unit: Lowland Floodplain
   Agro-ecologic Zone: Eastern Surma–Kushiyara Floodplain
   Features: The river is bounded by the low-lying Surma–Kushiyara inter-basin on the north. Local flood control embankments have been constructed along both banks.

5. Channel Pattern:
   Channel: Single, irregular low sinuosity bends.
   Islands: None.
   Bars: Poorly developed point bars
   Sinuosity: 1.42

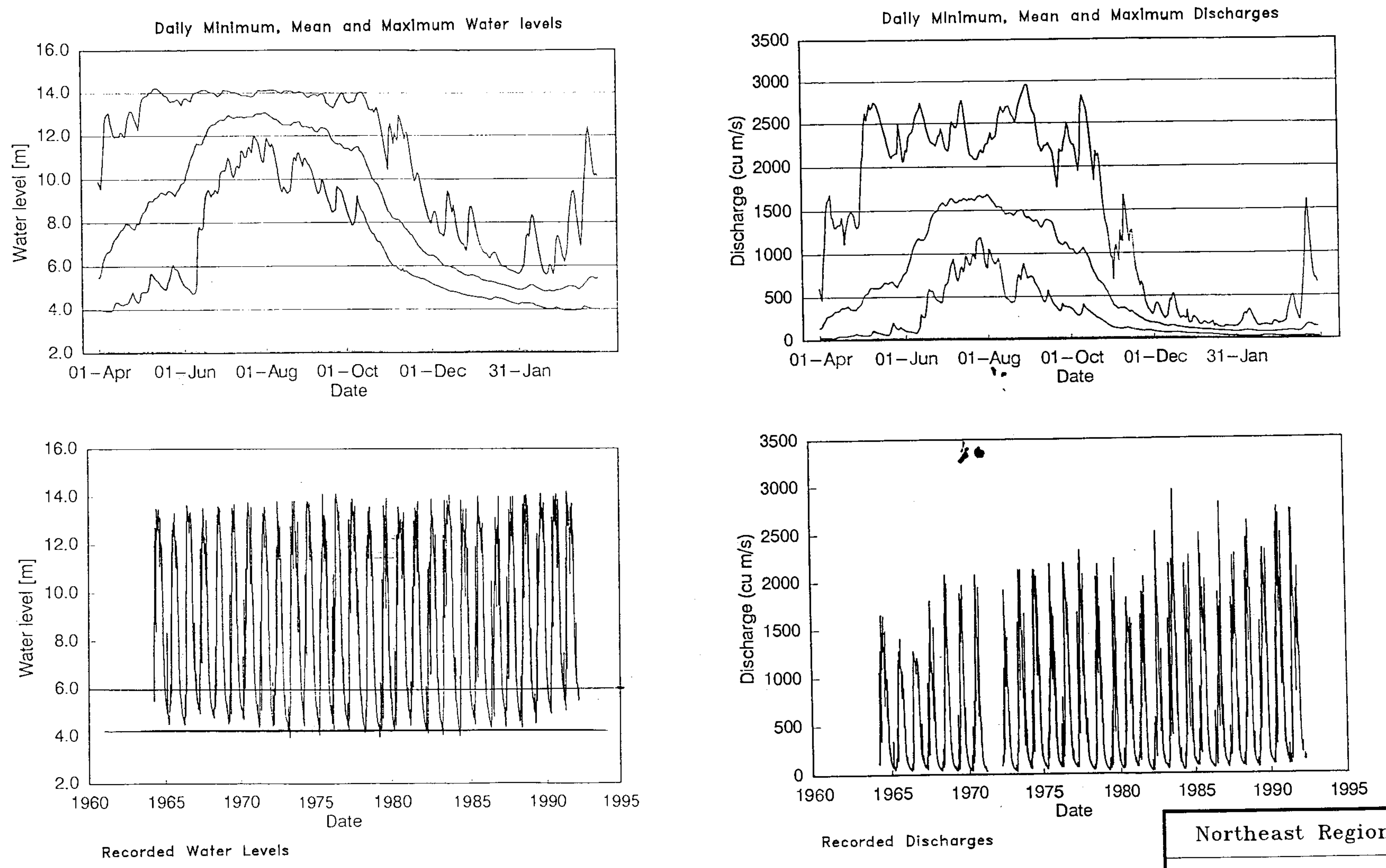
6. Sedimentology
   Channel: Mainly fine sand, with dune-bed in flood season.
   Banks: Mainly silty clay, silt

7. Pattern of Instability
   Progressive erosion at outside (concave) side of bends. Channel appears to be widening and enlarging in response to increased flood flows in recent years. Overall, river is relatively stable and changes are gradual.

Northeast Regional Project	
Kushiyara River at Sheola	
Prepared by: DMc	October 1994

173–LDWC

Figure C-14

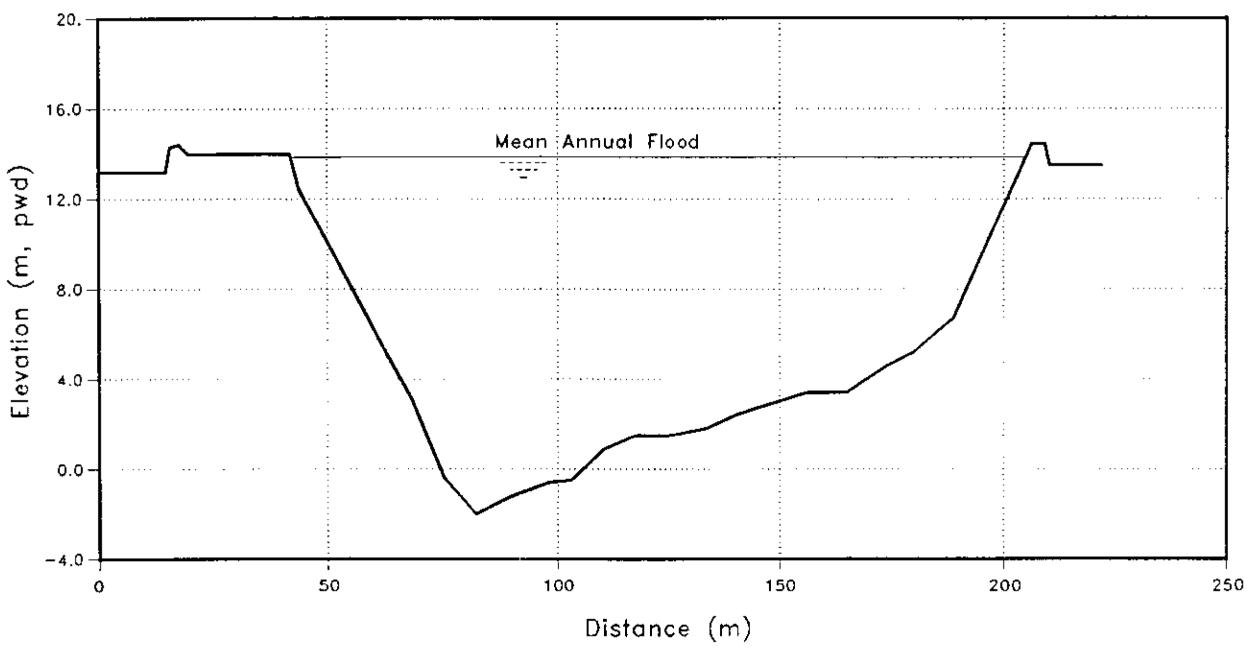


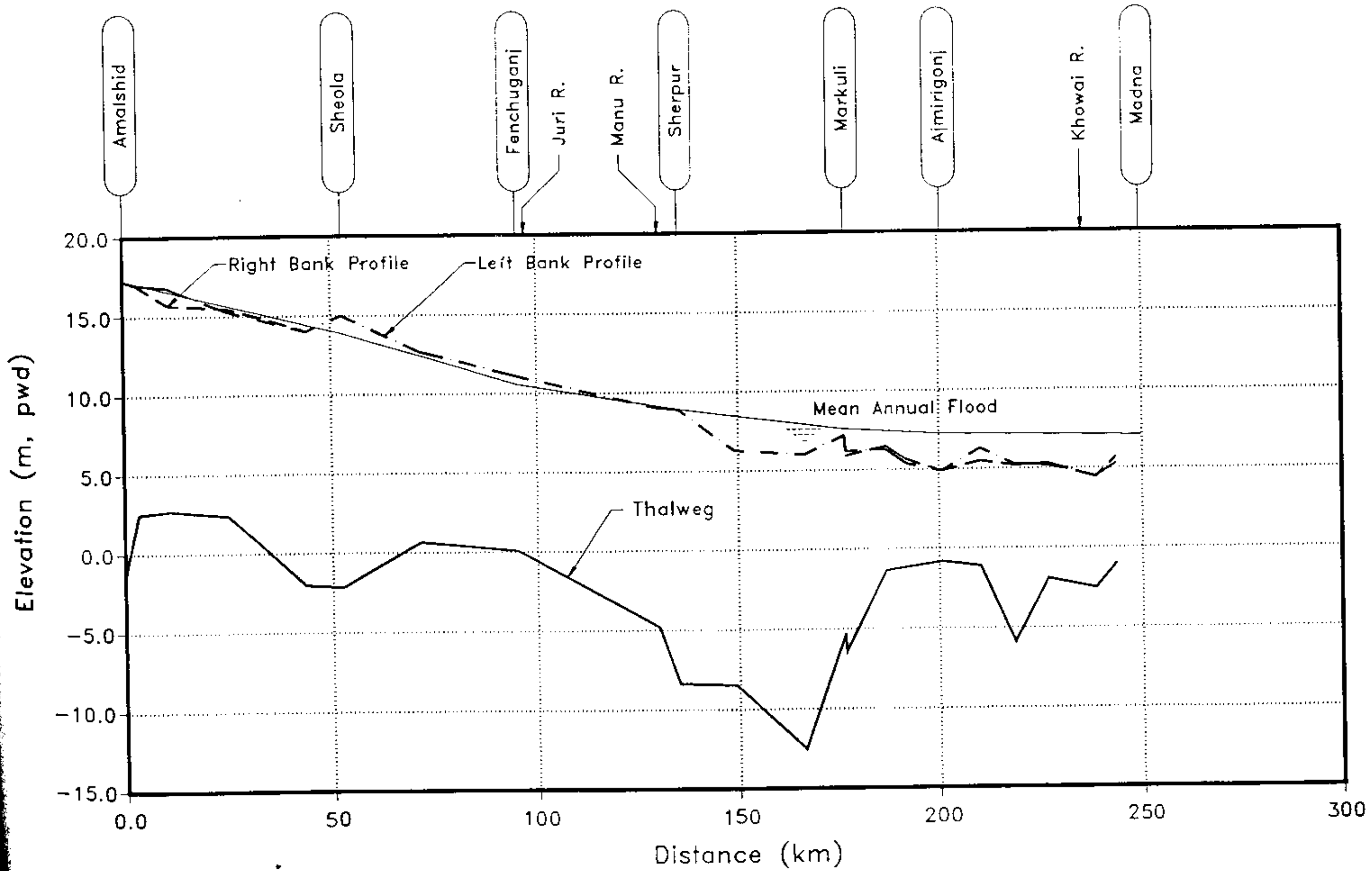
Northeast Regional Project	
Kushiyara River at Sheola	
Prepared by: DMc/Tarek	October 1994
Drawn by: Jalal	AutoCAD Drawing

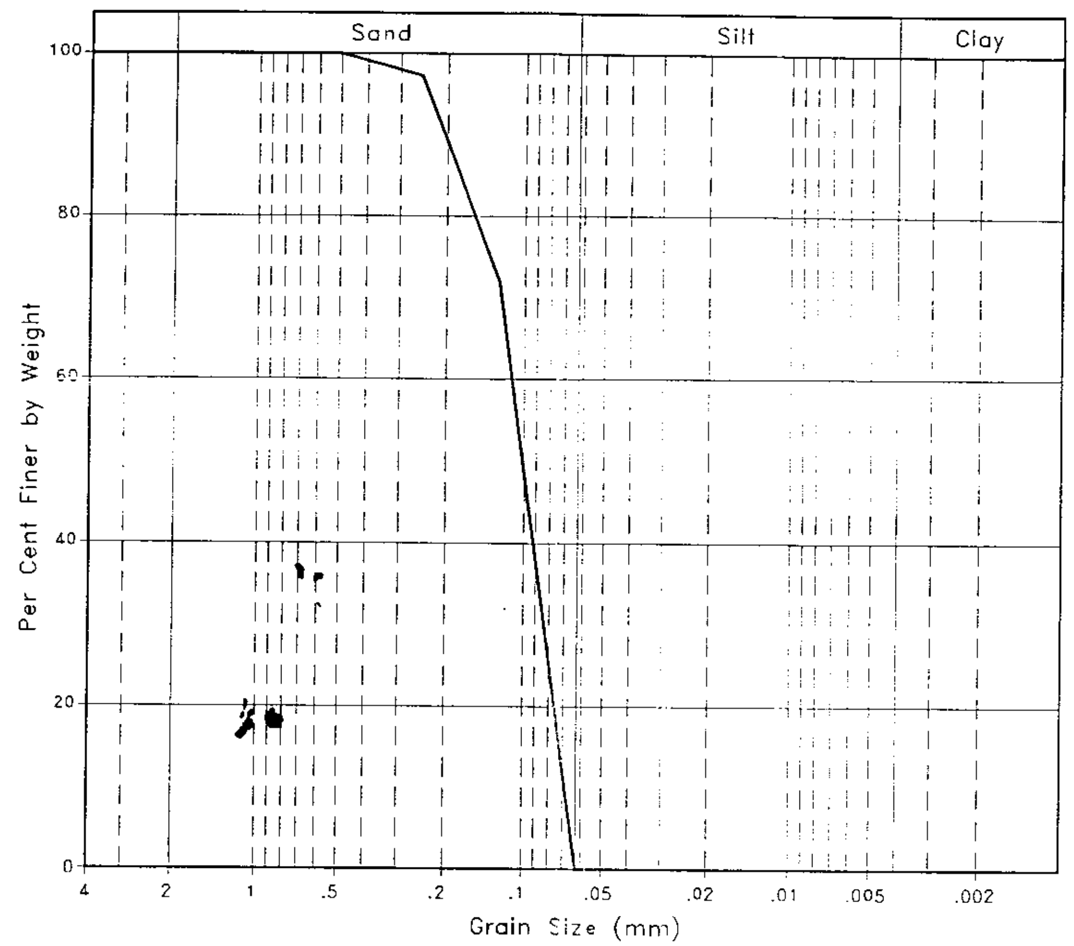
FILE: 173.DWG

Figure C-15

Channel Properties







Slope (monsoon)= 6cm/km

Bed Material Size

D_{50} = 0.10mm

D_{35} = 0.088mm

D_{10} = 0.068mm

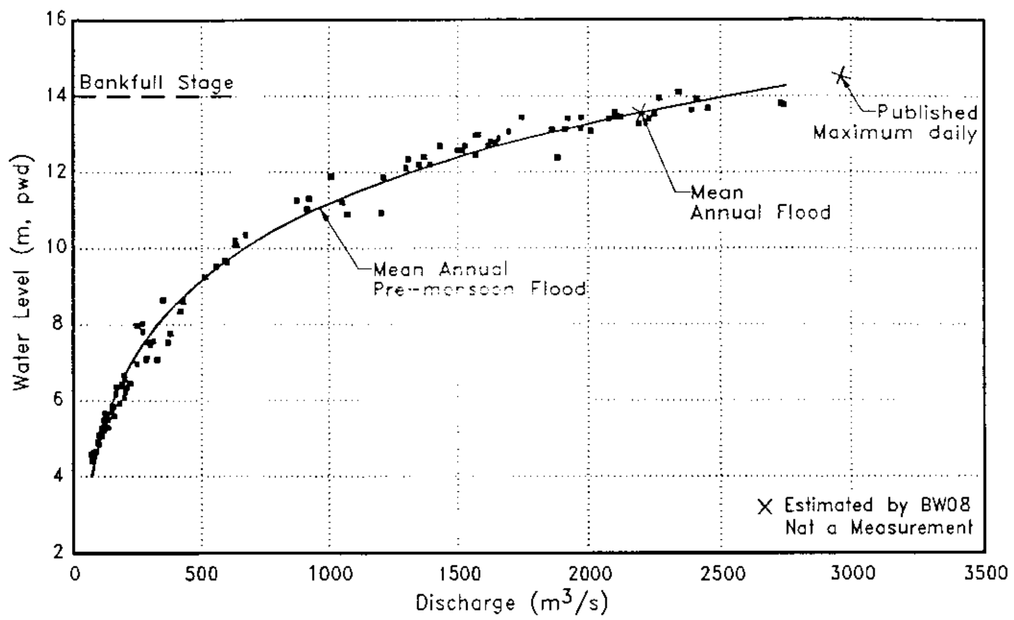
Northeast Regional Project

Kushiyara River at Sheola

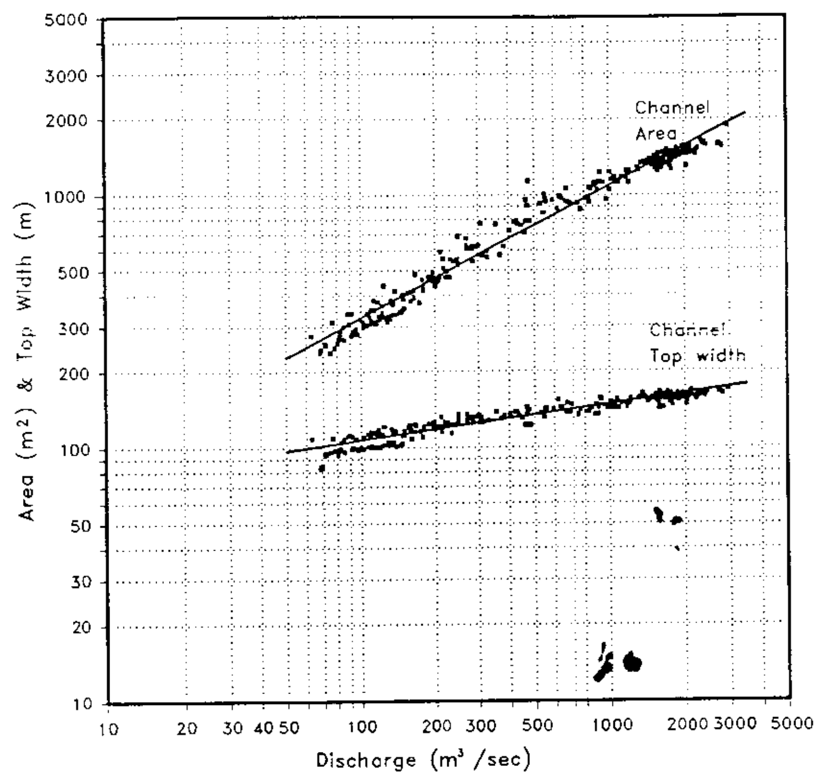
Prepared by: DMc	November 1994

FILE: M173-3.DWG

Rating Curve (1988–1991)



Hydraulic Geometry



COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.08$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows rating curves have lowered between 0.5 – 1.0m since 1961.

3. Hydraulic Geometry Relations

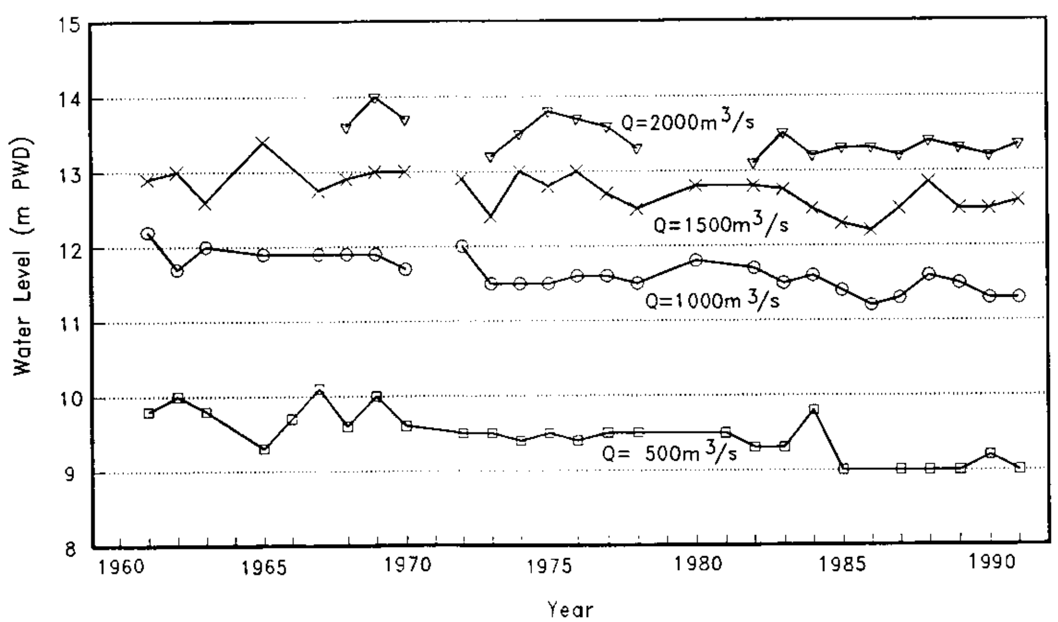
   $A = 29.34\,Q^{0.52}$
   $W = 56.7\,Q^{0.14}$
   $d = 0.52\,Q^{0.39}$
   $v = 0.034\,Q^{0.48}$

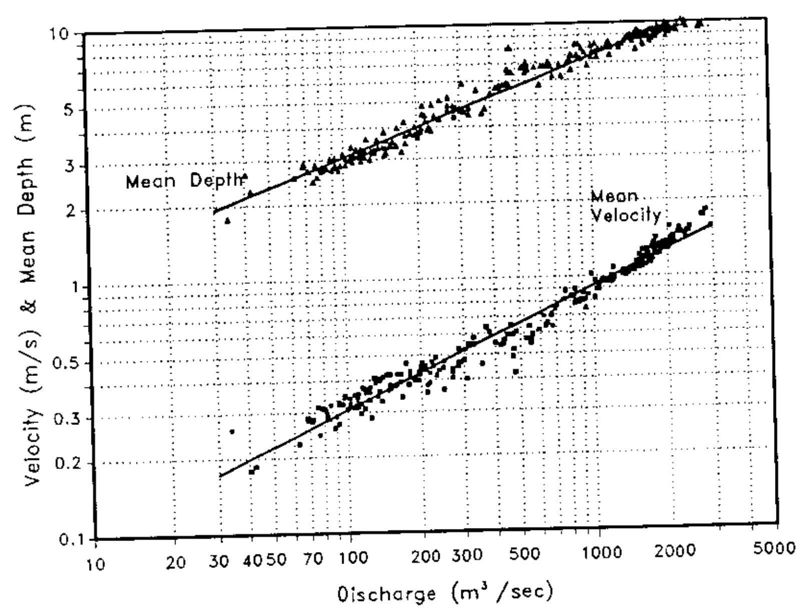
Condition	Q	A	W	d	v
1.	966	1066	145	7.3	0.91
2.	2198	1638	163	10.1	1.34

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





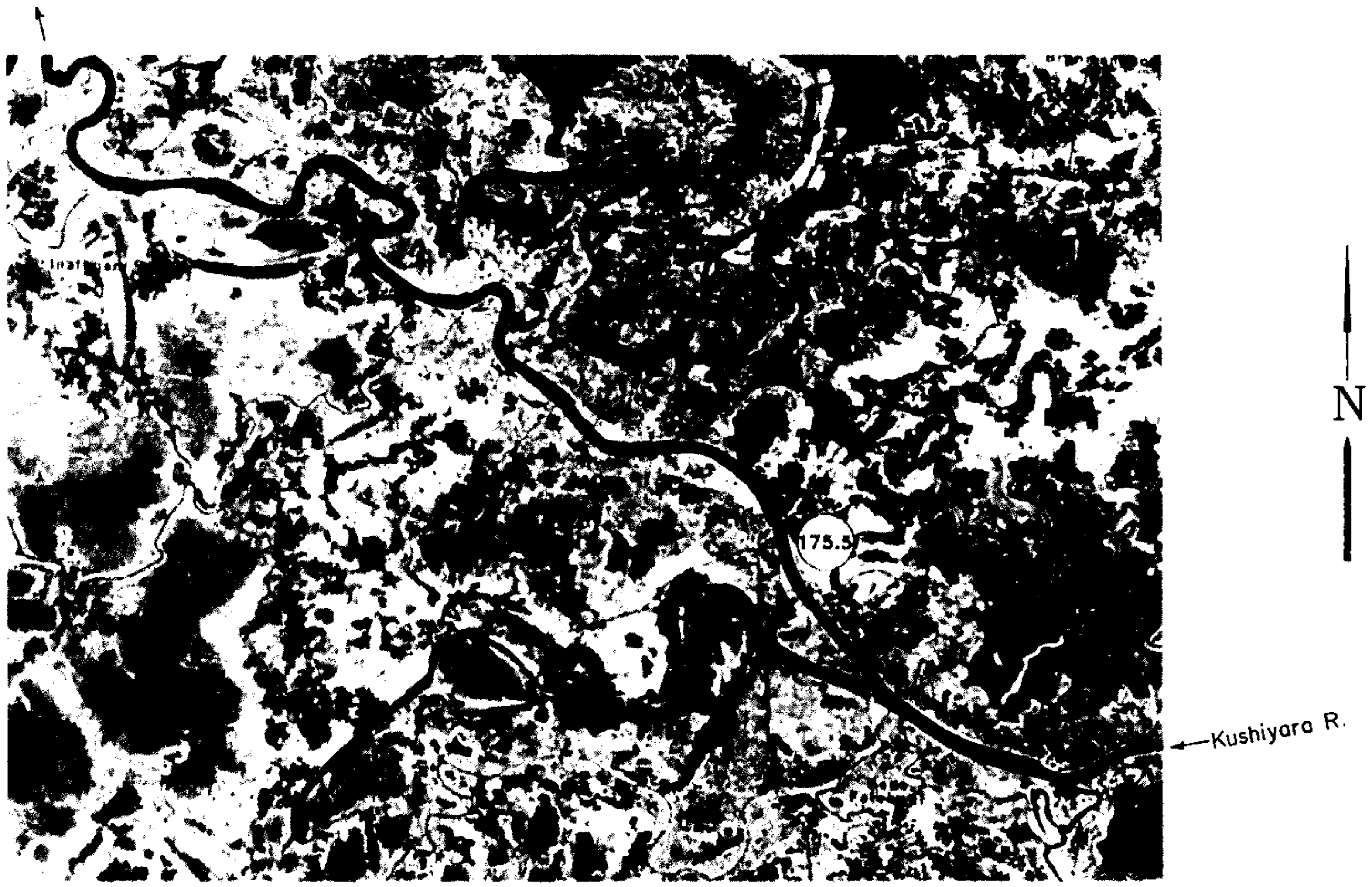
Northeast Regional Project

Kushiyara River at Sheola

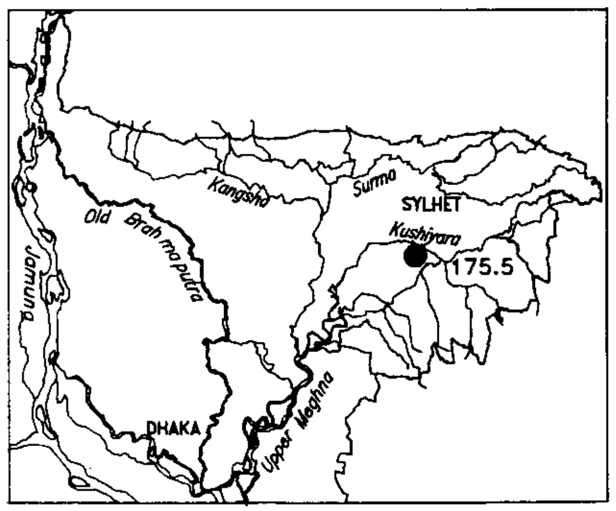
Prepared by: DMc	November 1994

BD-173.DWG

Figure C-17



Eroding right bank downstream of bridge



Site Location:

River Characteristics:

1. Gauge Number: 175.5

2. Location:
   Lat. 24 37'39"N
   Lon. 91 40'58"E

3. Available Data
   Water Level: 1982–1993
   Discharge : 1982–93
   Sediment: 1968,1973–81,1983–93

4. Physical Setting:

   Physiographic Unit: Surma–Kushiyara Floodplain

   Features: Unconfined alluvial channel incised into lowland floodplain which slopes away into floodbasins and haor topography

5. Channel Pattern:

   Channel: Single, irregular sinuous channel with oxbows.
   Islands: None.
   Bars: None.
   Sinuosity: 1.25

6. Sedimentology

   Channel: Mainly fine sand. Bed is covered with dunes (up to 1.5 m height) during flood flows.

   Banks: Mainly silt and silty clay.

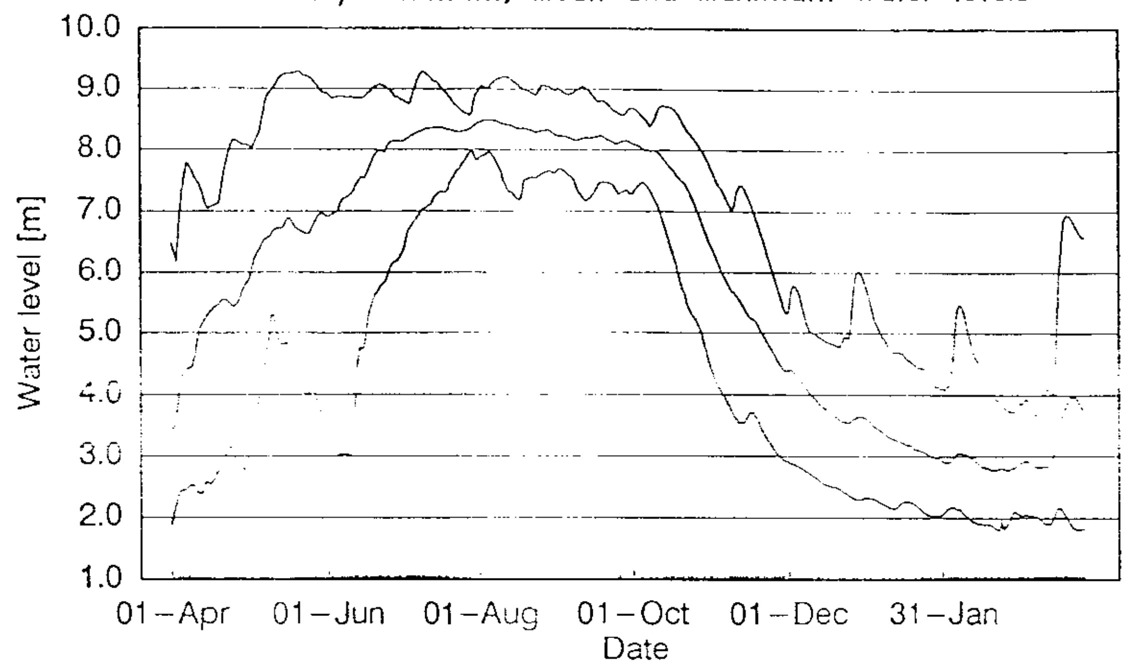
7. Pattern of Instability

   Slow, progressive erosion along the outer concave banks in bends. There has been more rapid shifts and erosion in the vicinity of artifical loop cuts. A major avulsion took place into the Suriya R. in the 1960's. The channel has been widening and enlarging in response to increased flood flows in recent years.

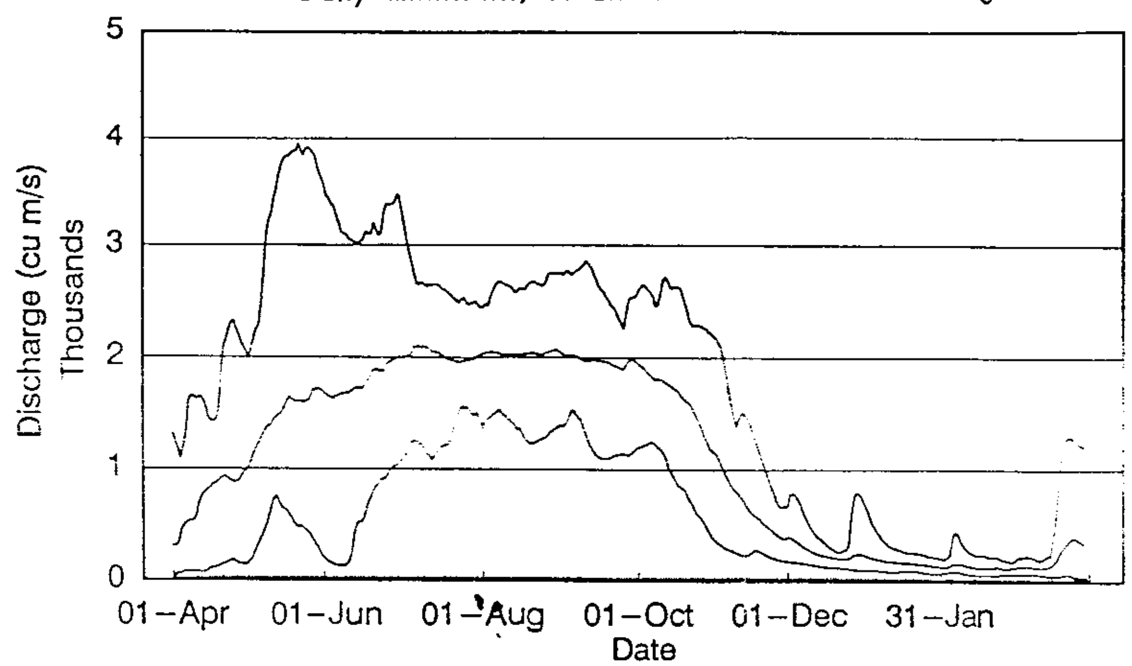
Northeast Regional Project	
Kushiyara River at Sherpur	
Prepared by: DMc	October 1994

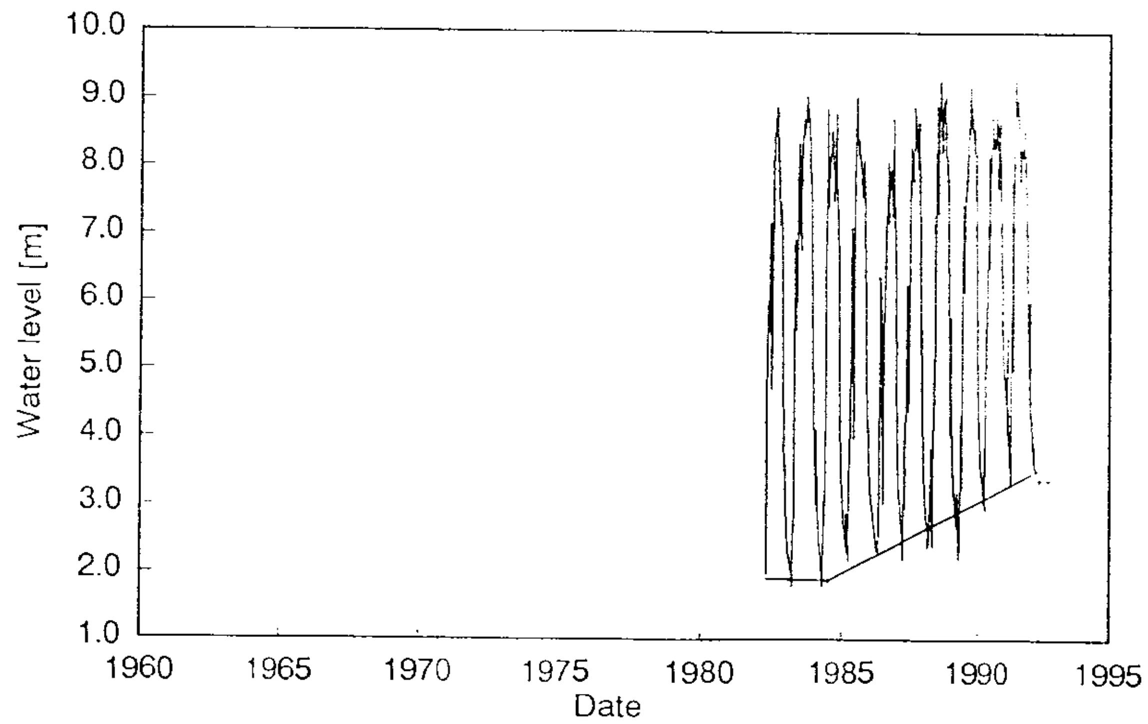
Figure C-18

Daily Minimum, Mean and Maximum Water levels

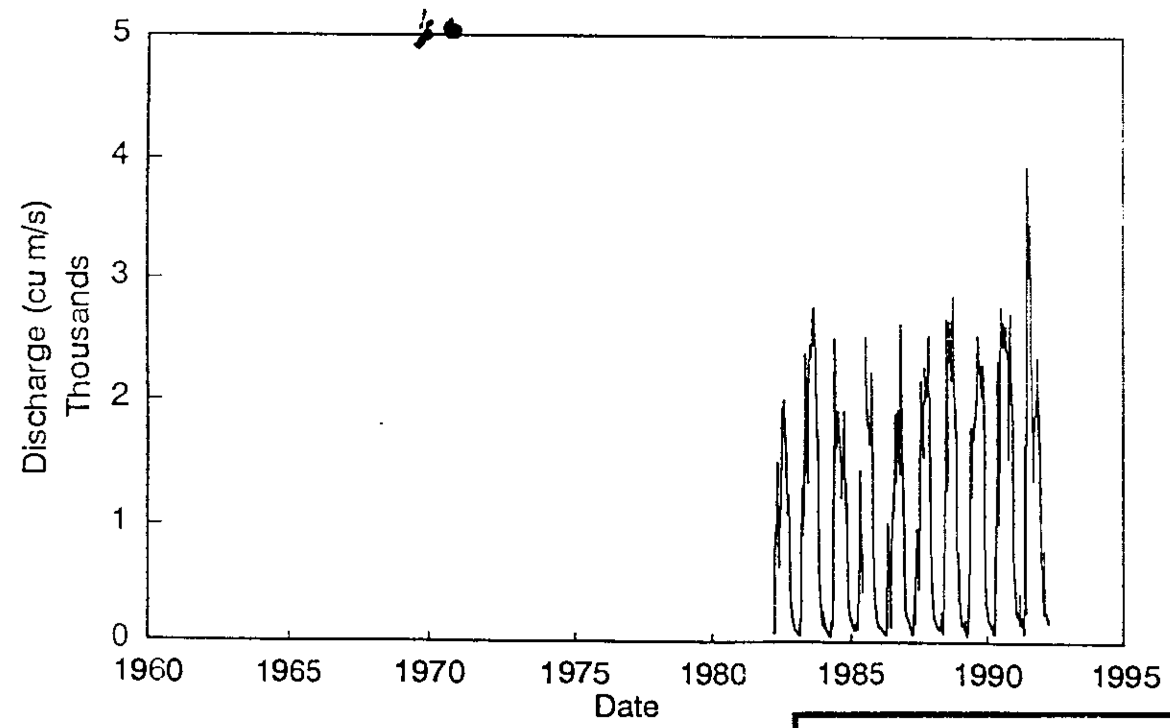


Daily Minimum, Mean and Maximum Discharges





Recorded Water Levels

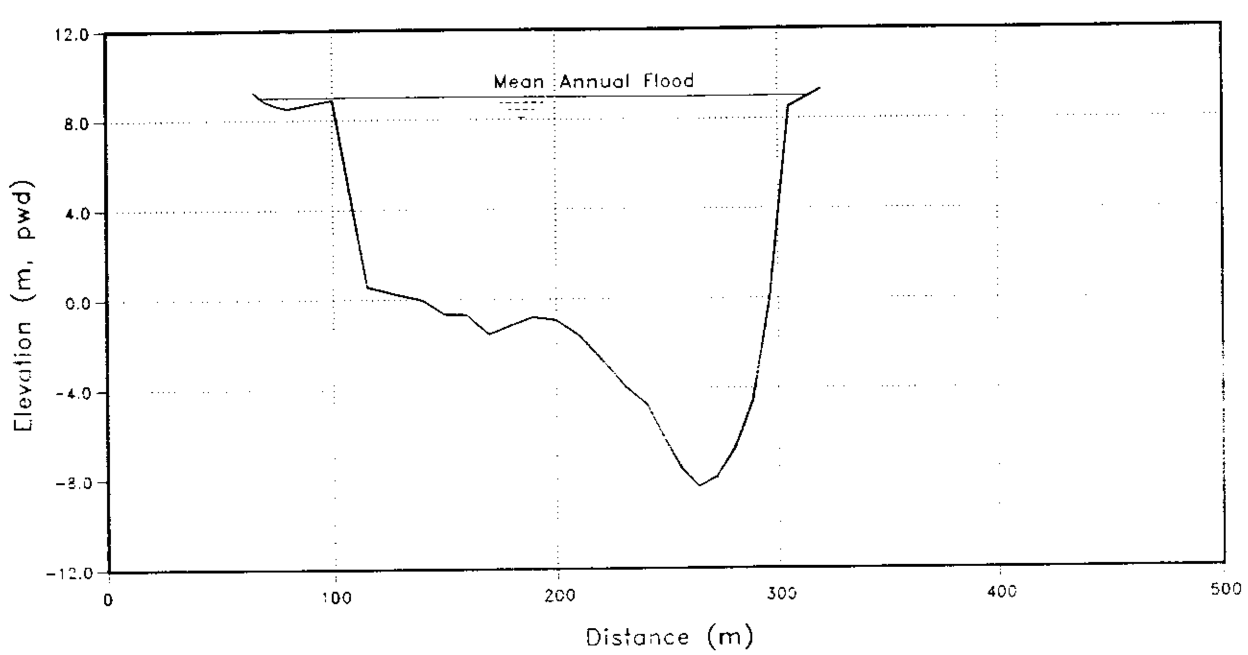


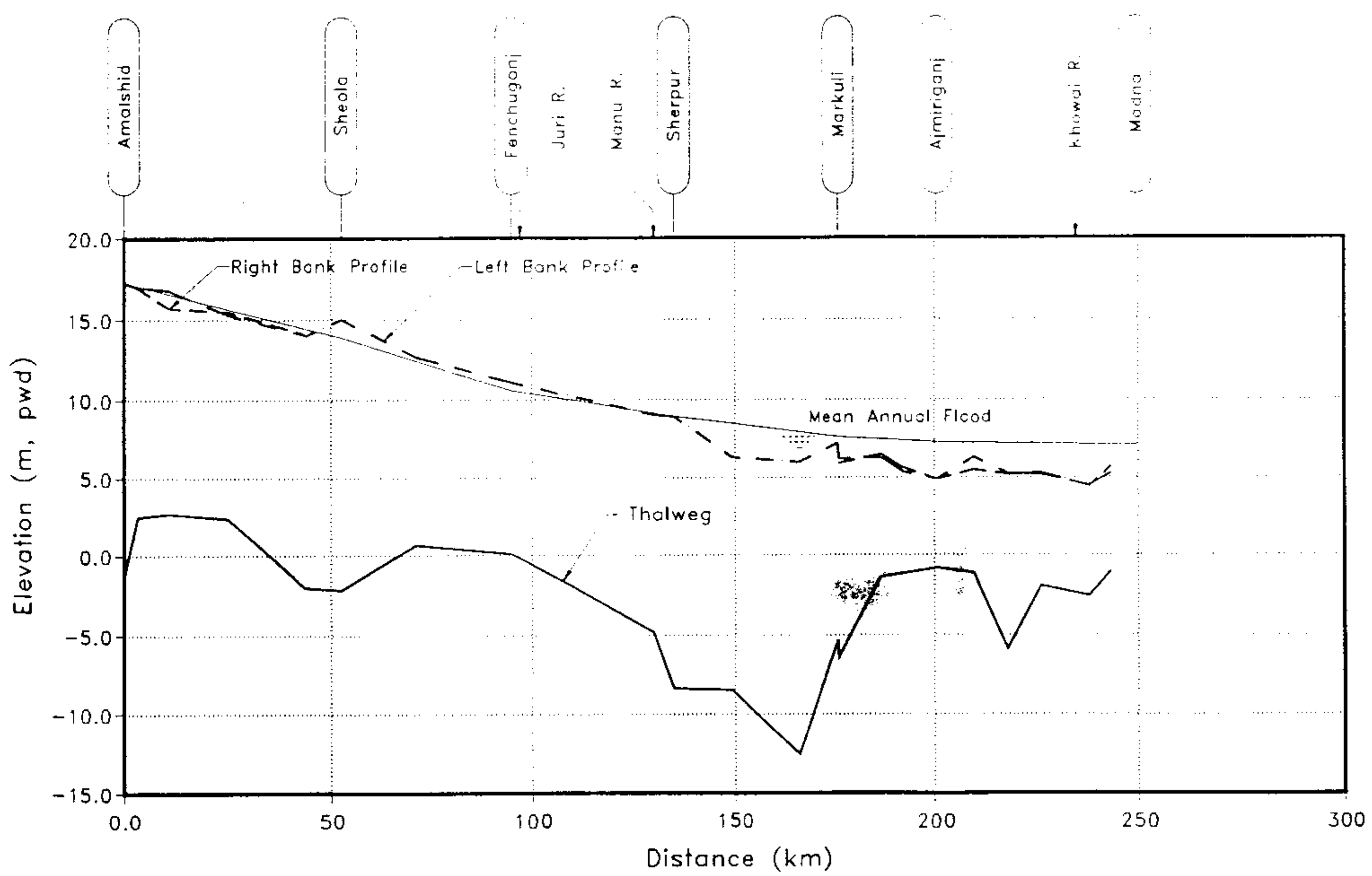
Recorded Discharges

Northeast Regional Project		
Kushiyara River at Sherpur		
Prepared by:	DMc/Tarek	October 1994
Drawn by:	Jalal	AutoCAD Drawing

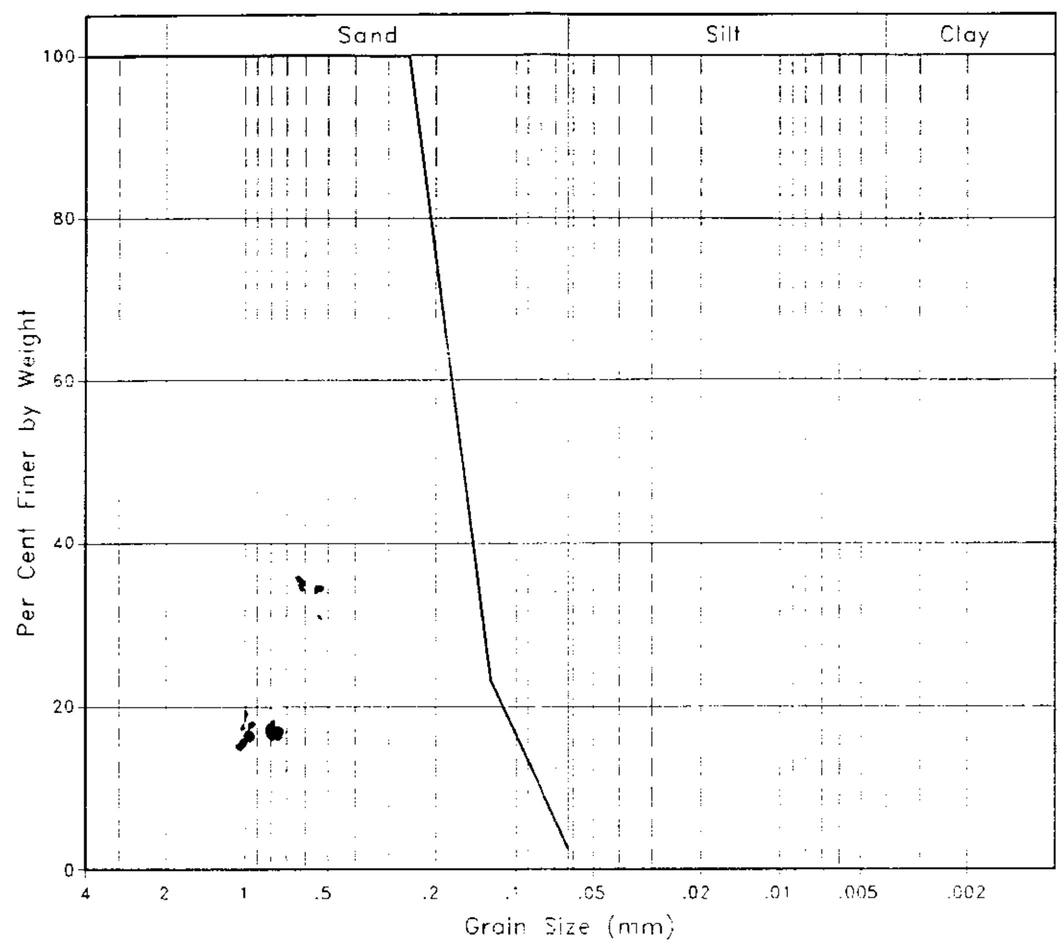
175.DWG

Figure C-19





Channel Properties



Slope (monsoon)= 4cm/km

Bed Material Size

D_{50} = 0.16mm

D_{35} = 0.14mm

D_{10} = 0.077mm

Northeast Regional Project

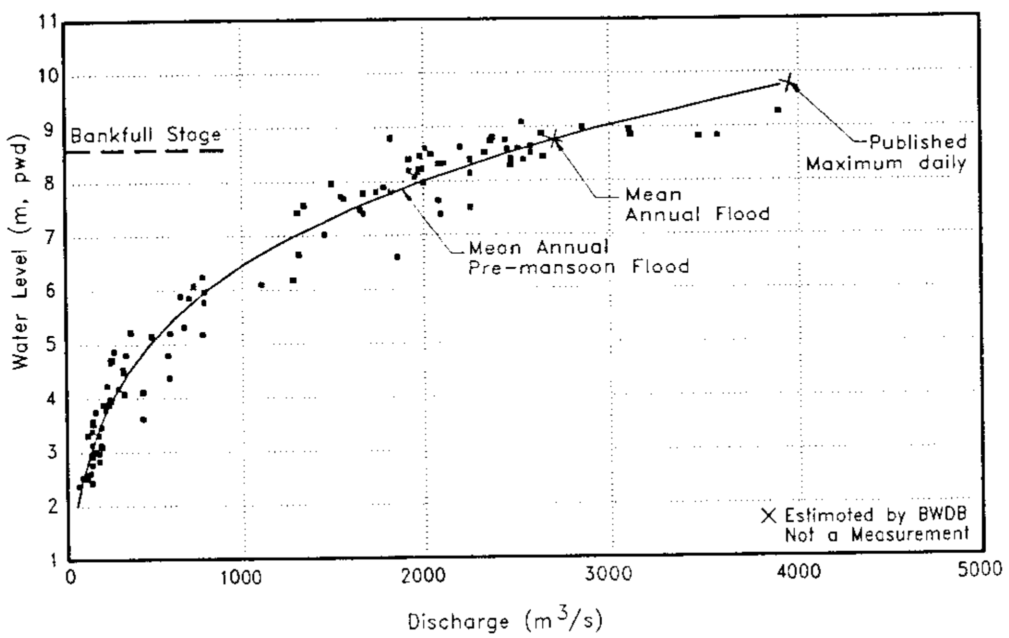
Kushiyara River at Sherpur

Prepared by: DMc | November 1994

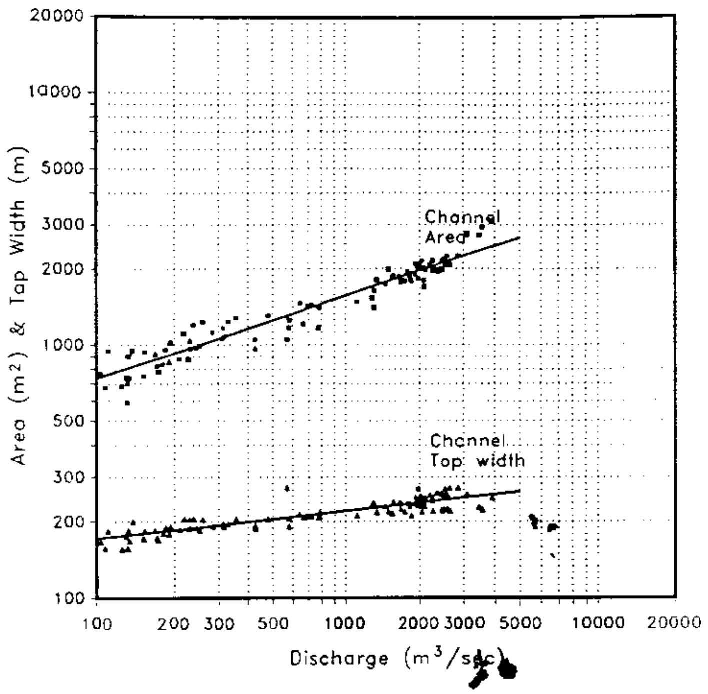
FILE: M1755-3.DWG

Figure C-20

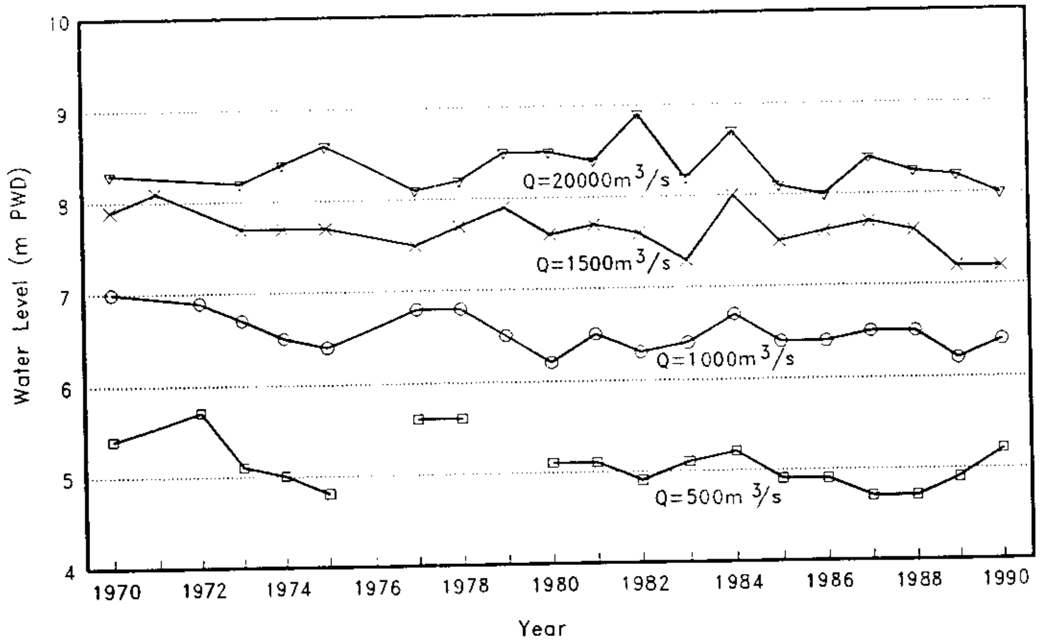
Rating Curve (1988–1991)

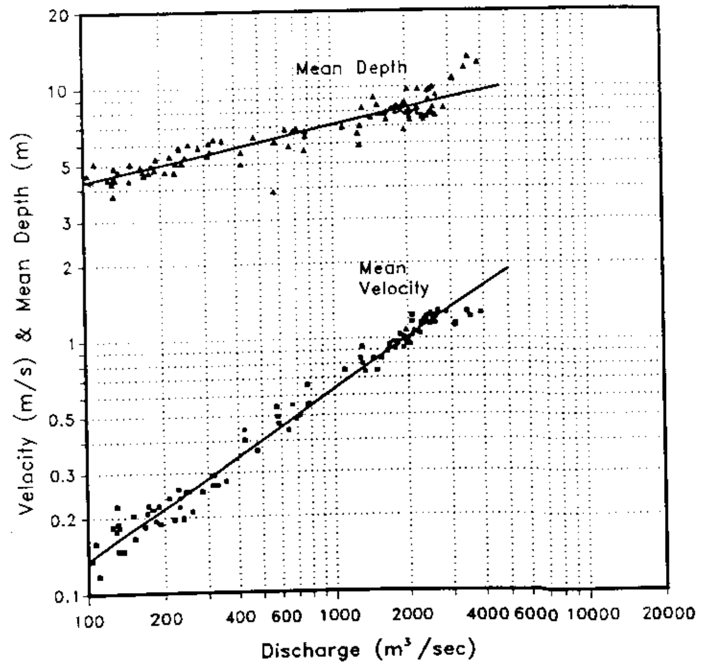


Hydraulic Geometry



Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.02$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows rating curves have lowered 0.5m on average between 1970–1990.

3. Hydraulic Geometry Relations

   $A = 162.07\,Q^{0.329}$
   $W = 103.68\,Q^{0.109}$
   $d = 1.563\,Q^{0.219}$
   $v = 0.006\,Q^{0.671}$

Condition	Q	A	W	d	v
1.	1884	1933	236.7	8.17	0.97
2.	2708	2178	246.3	8.84	1.24

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m³/s)
A= Area (m²)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

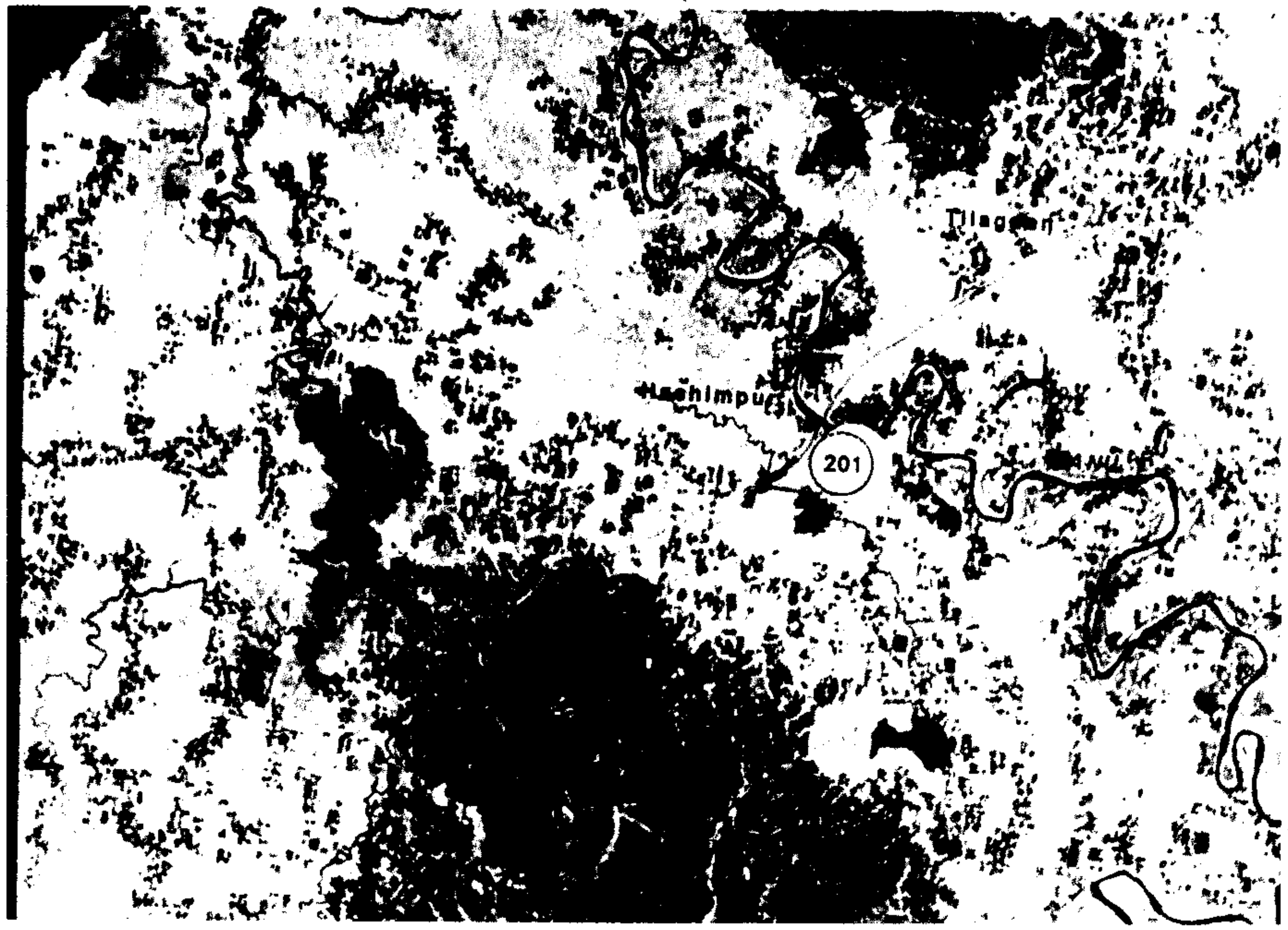
Northeast Regional Project

Kushiyara River at Sherpur

Prepared by: DMc | Oct 94

FILE: BD-175.DWG

Figure C-21



River Characteristics:

1. Gauge Number: 201

2. Location:
   Lat. 24 25'43"N
   Lon. 91 56'35"E

3. Available Data
   Water Level: 1964–70,1972–93
   Discharge : 1964–70,1972–93
   Sediment: 1977–84

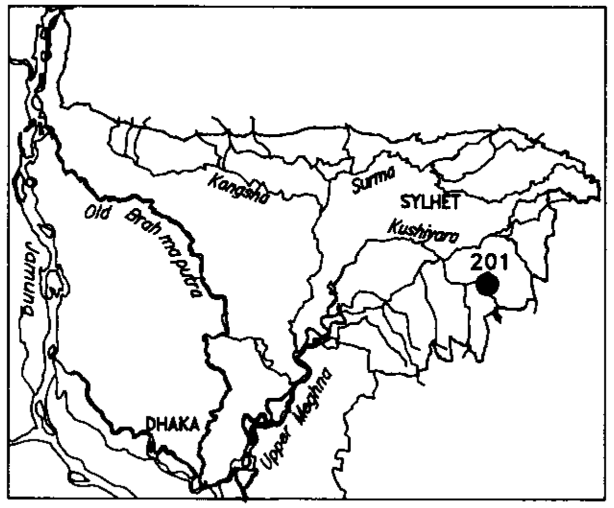
4. Physical Setting:
   Physiographic Unit: Piedmont Floodplain
   Agro-ecologic Zone: Northern & Eastern Piedmont Plains
   Features: The river occupies a long, narrow valley between parralel ridges and is occasionally confined by Pliocene/Pleistocene sandstone hills. Natural levees are 2–3 m above the surrounding flood basins.

5. Channel Pattern:
   Channel: Single, irregular meandering channel
   Islands: None.
   Bars: Prominent sandy point bars
   Sinuosity: 2.20

6. Sedimentology
   Channel: Mainly fine–medium sand. The bed becomes covered by dunes during flood flows.
   Banks: Mainly silt and silty sand

7. Pattern of Instability
   Progressive erosion along the outer concave banks in bends. There is evidence of channel enlargement due to recent high floods. The headwaters of the Manu R. appears to be undergoing very high rates of sediment production.

15km downstream of gauge; note Pleistocene bedrock outcropping on right bank



Site Location:

Northeast Regional Project

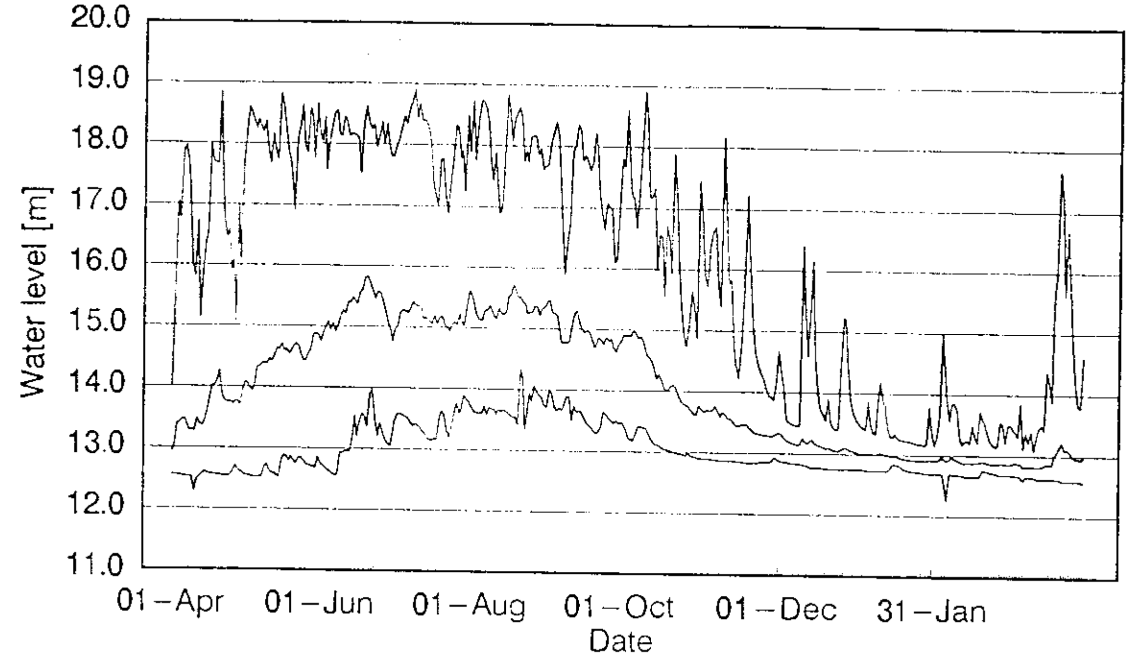
Manu River at Rail Crossing

Prepared by: DMc | October 1994

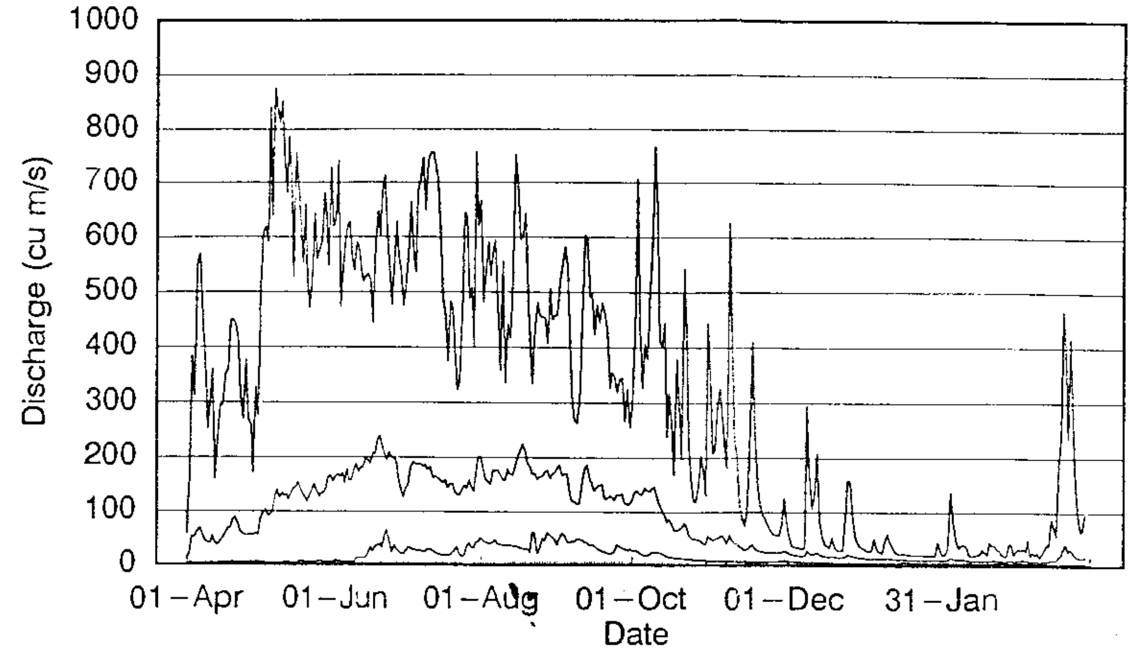
...1-1.DWG

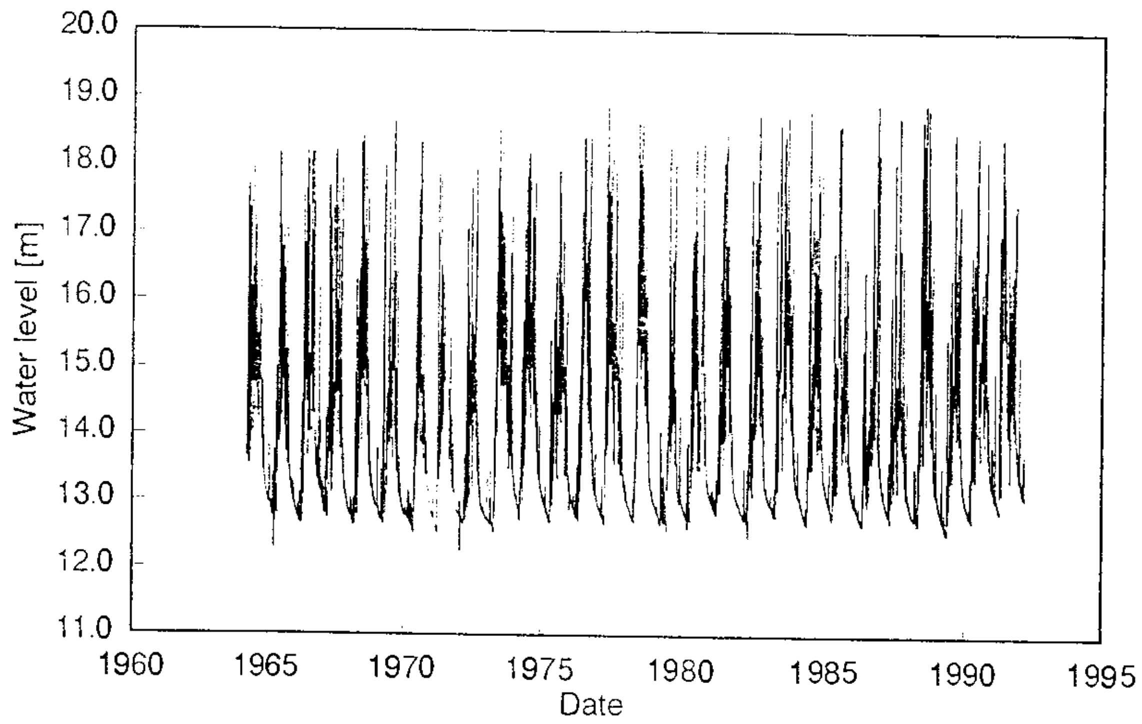
Figure C-22

Daily Minimum, Mean and Maximum Water levels

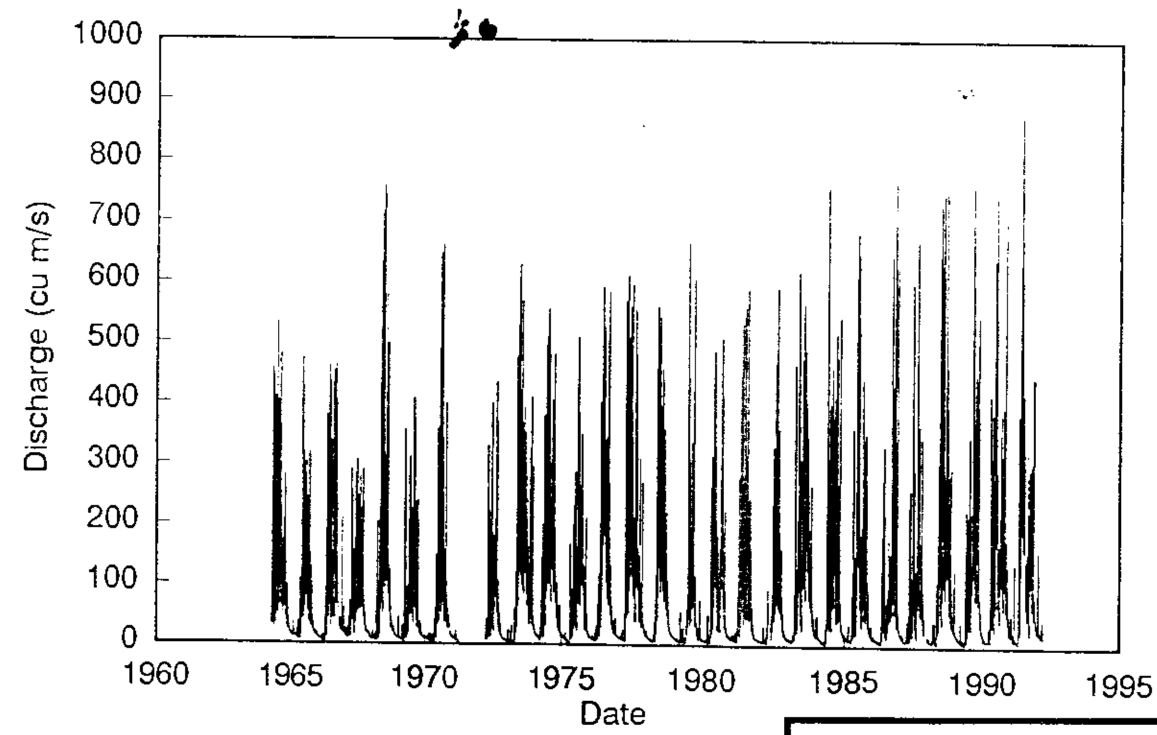


Daily Minimum, Mean and Maximum Discharges





Recorded Water Levels



Recorded Discharges

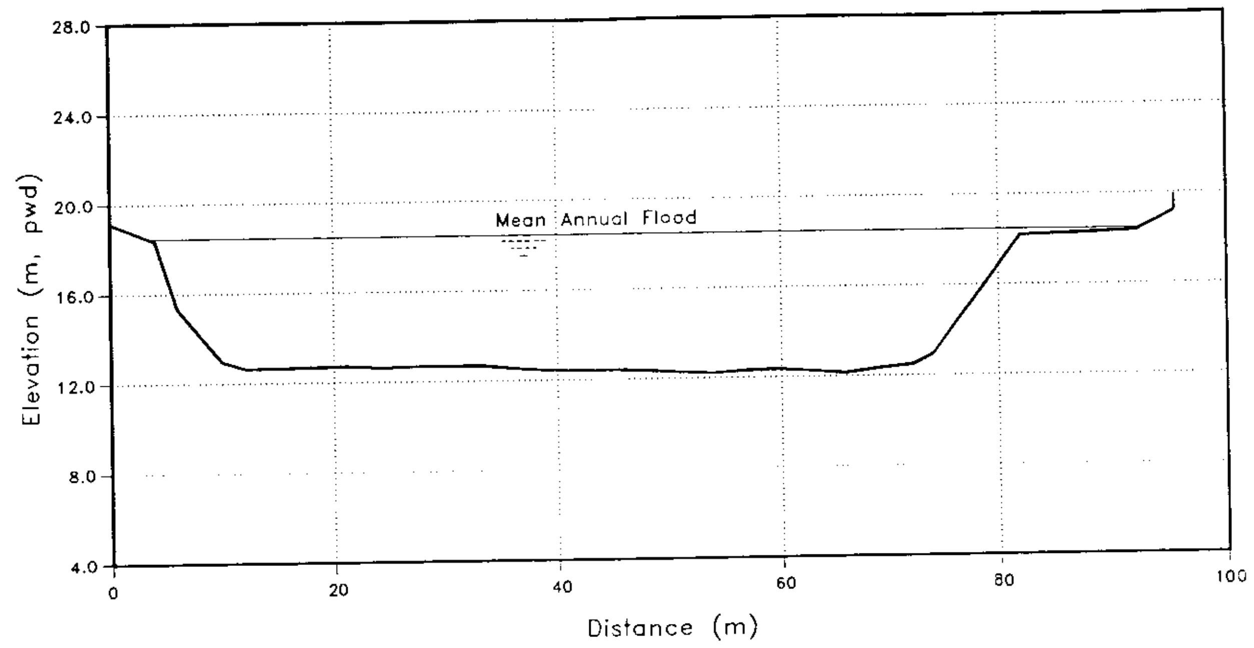
Northeast Regional Project

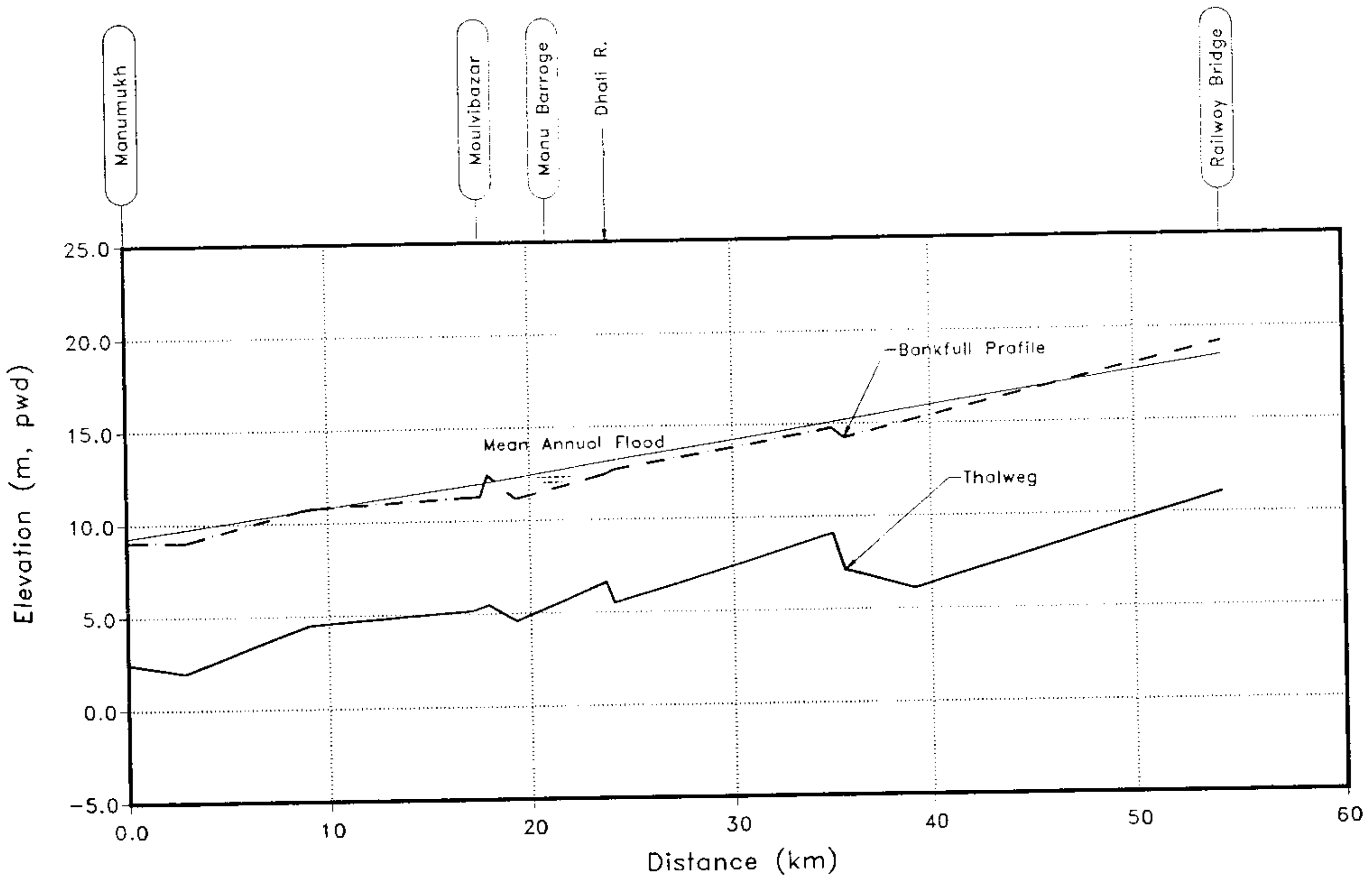
Manu River
at Rail Crossing

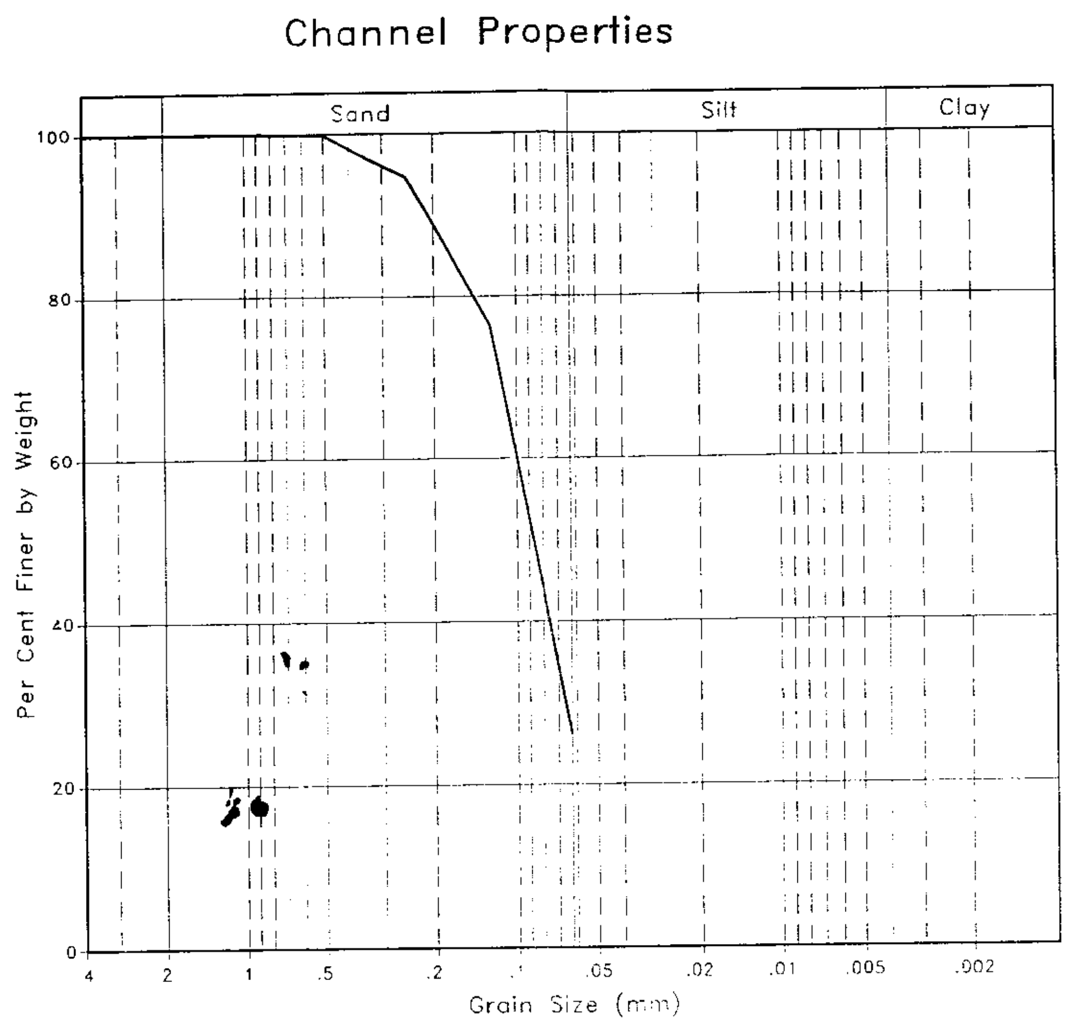
Prepared by:	Tarek	Nov'94
Drawn by:	Jalal	AutoCAD Drawing

FILE: 201DWG

Figure C-23







Slope (monsoon)= 18cm/km

Bed Material Size

D_{50} = 0.087mm

D_{35} = 0.071mm

D_{10} = 0.062mm

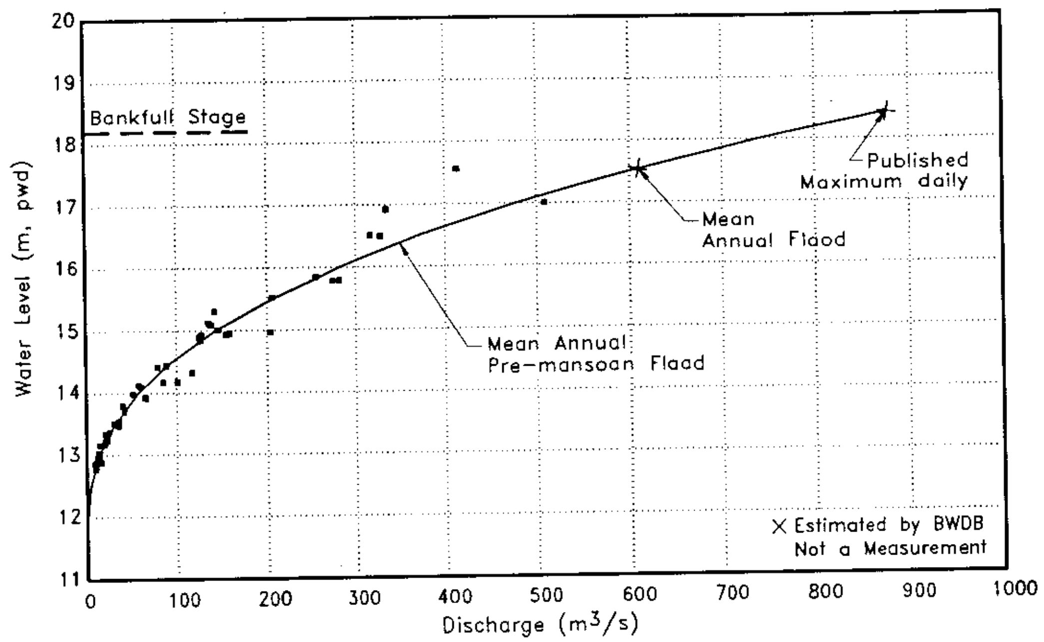
Northeast Regional Project	
Manu River at Rail Crossing	
Prepared by: DMc	November 1994

FILE: M201-3.DWG

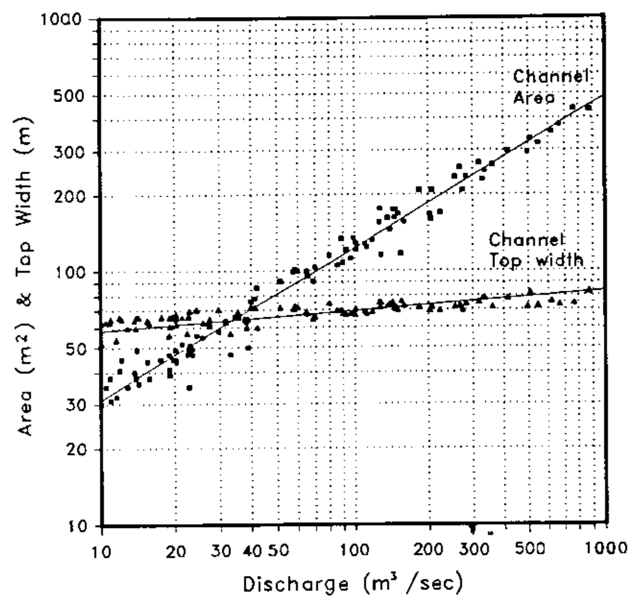
29

Figure C-24

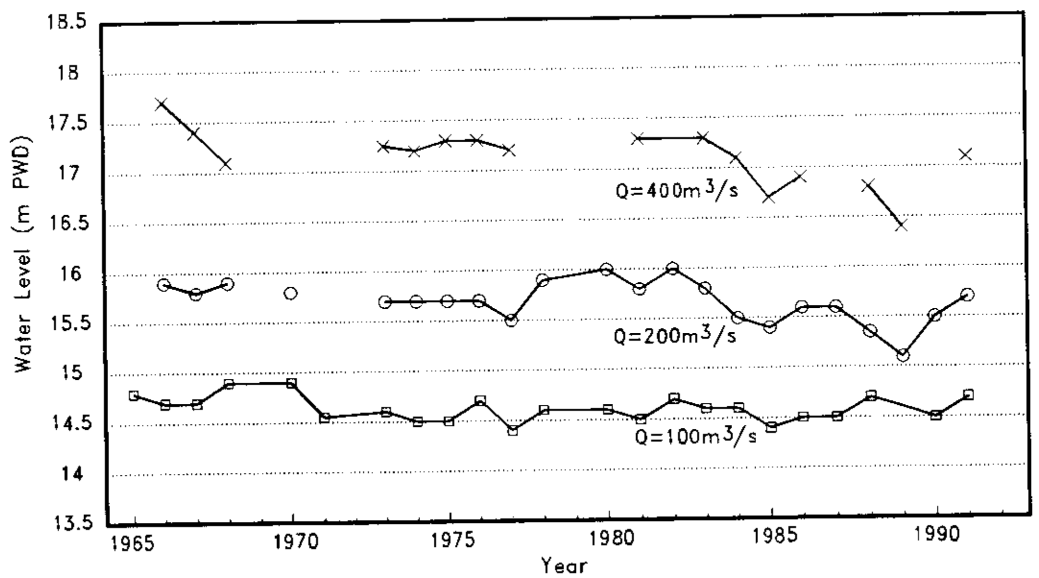
Rating Curve (1990–1992)

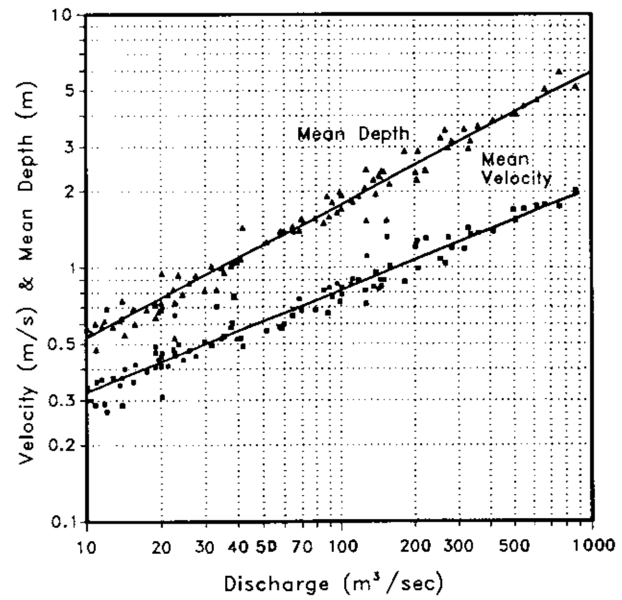


Hydraulic Geometry



Historic Variation in Stage Discharge Relations
(Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.002$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows rating curves have lowered by 0.3 –0.8m since 1966.

3. Hydraulic Geometry Relations

   $A = 7.85\ Q^{0.598}$
   $W = 49.76\ Q^{0.073}$
   $d = 0.158\ Q^{0.525}$
   $v = 0.127\ Q^{0.402}$

Condition	Q	A	W	d	v
1.	350	260	76	3.41	1.35
2.	609	362	79	4.6	1.68

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Northeast Regional Project

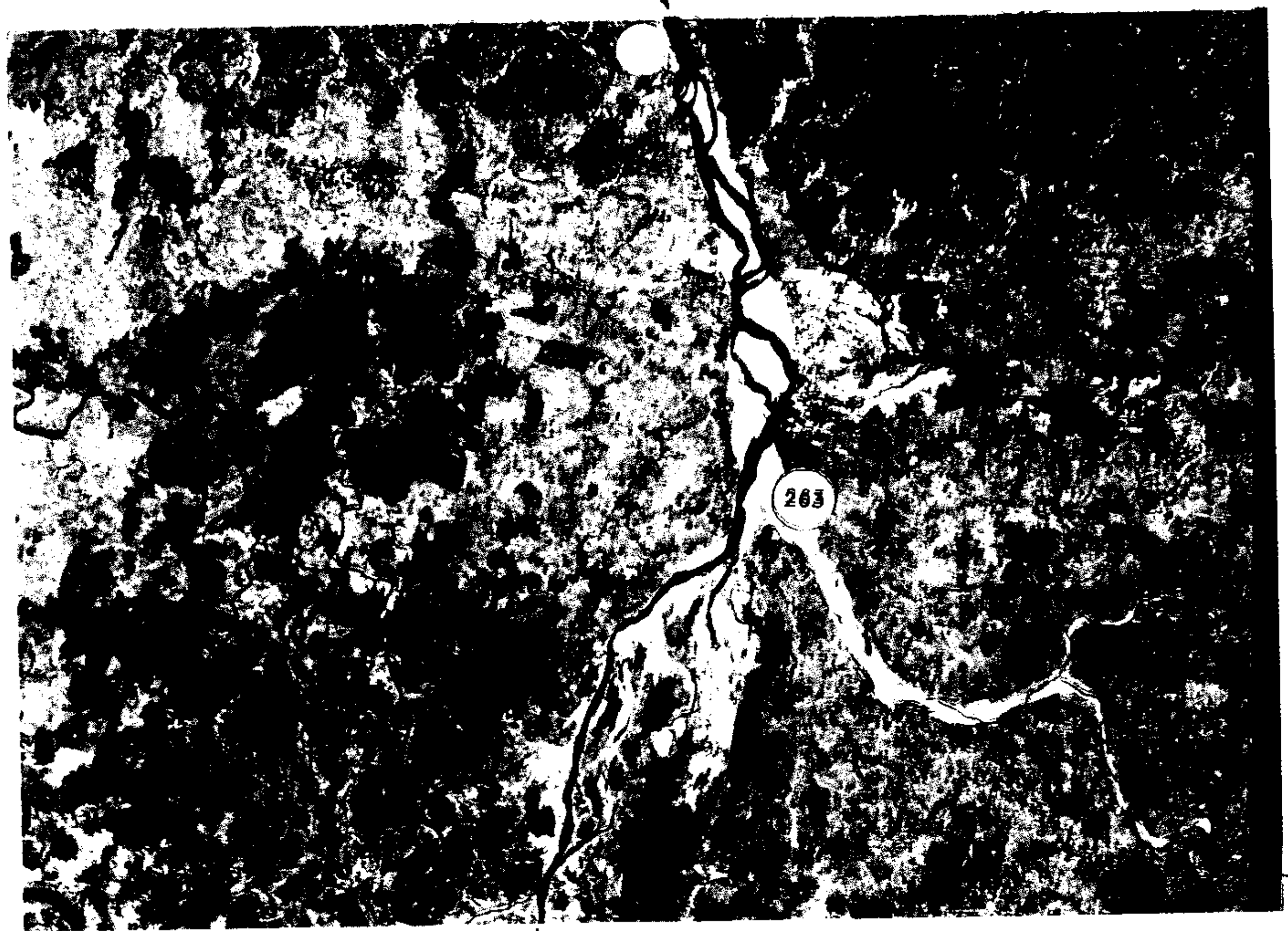
Manu River
at Rail Crossing

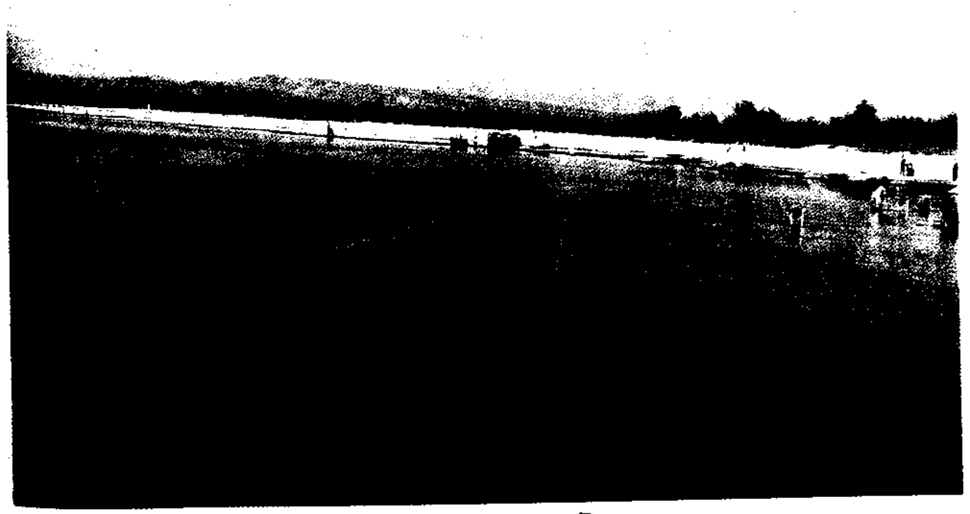
Prepared by: DMc | November 1994

FILE: 9D-20LDWG

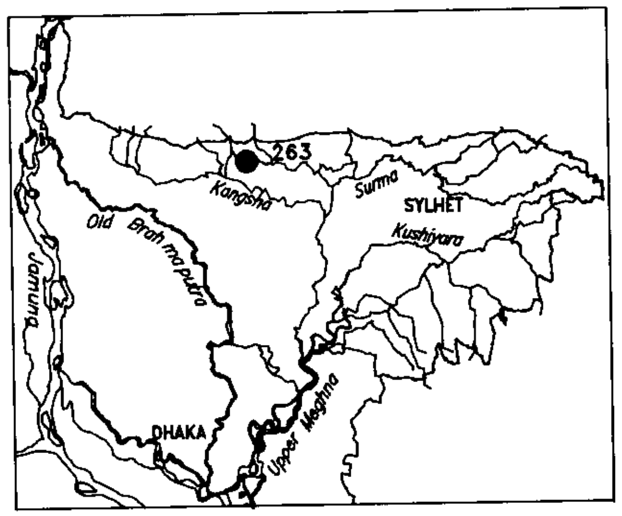
297

Figure C-25





Someswari R. near Durgapur



Site Location:

River Characteristics:

1. Gauge Number: 263

2. Location:
Lat. 25 06'35"N
Lon. 90 40'18"E

3. Available Data
Water Level: 1964–93
Discharge : 1964,1966–70,1972–78,1983–93
Sediment: 1963–64,1992

4. Physical Setting:

Physiographic Unit: Alluvial Fan
Agro–ecologic Zone: Northern & Western Piedmont Plains

Features: The Somewari R. exits from a mountainous canyon in India and develops a broad, low gradient alluvial fan over 138 km² of lowlying land. At present, the main channel (Shibganjdhala) heads south joining Kangsha R. just upstream of Jaria Janjail. Abandonment of the Old Someswari R. commenced in the mid–1960's.

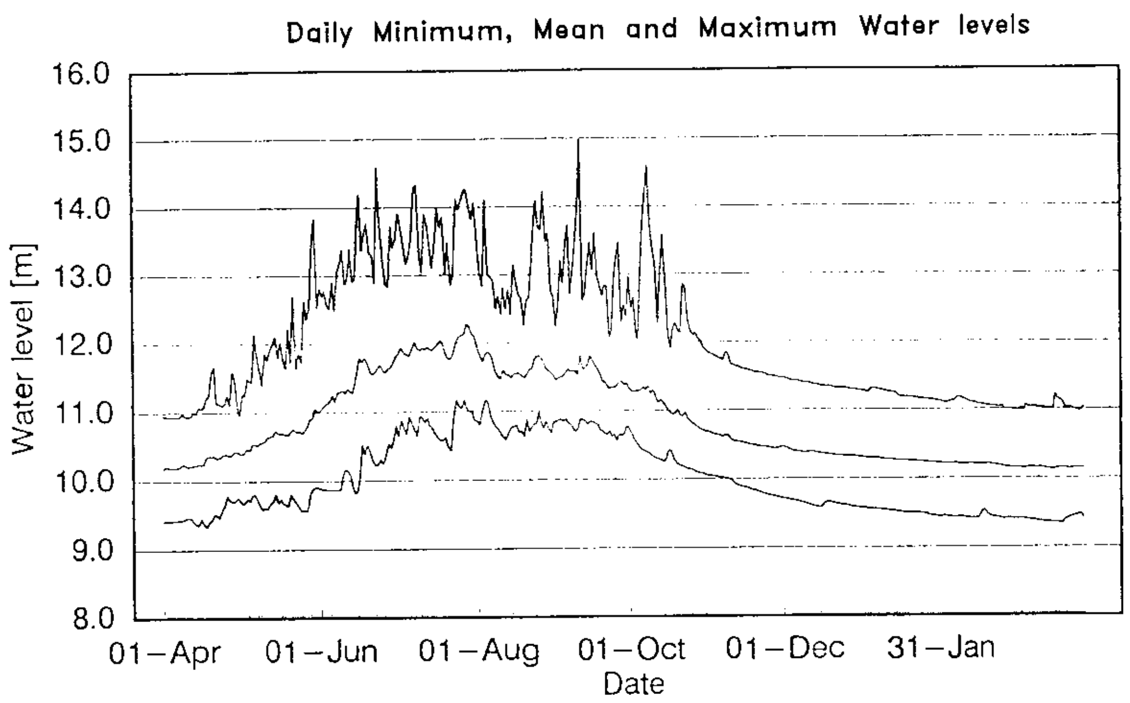
5. Channel Pattern:
Channel: Upper Someswari R. is braided; Shibganjdhala R. has a single straight channel.
Bars: Mid–channel bars, sand waves, sand sheets.
Sinuosity: 1.12

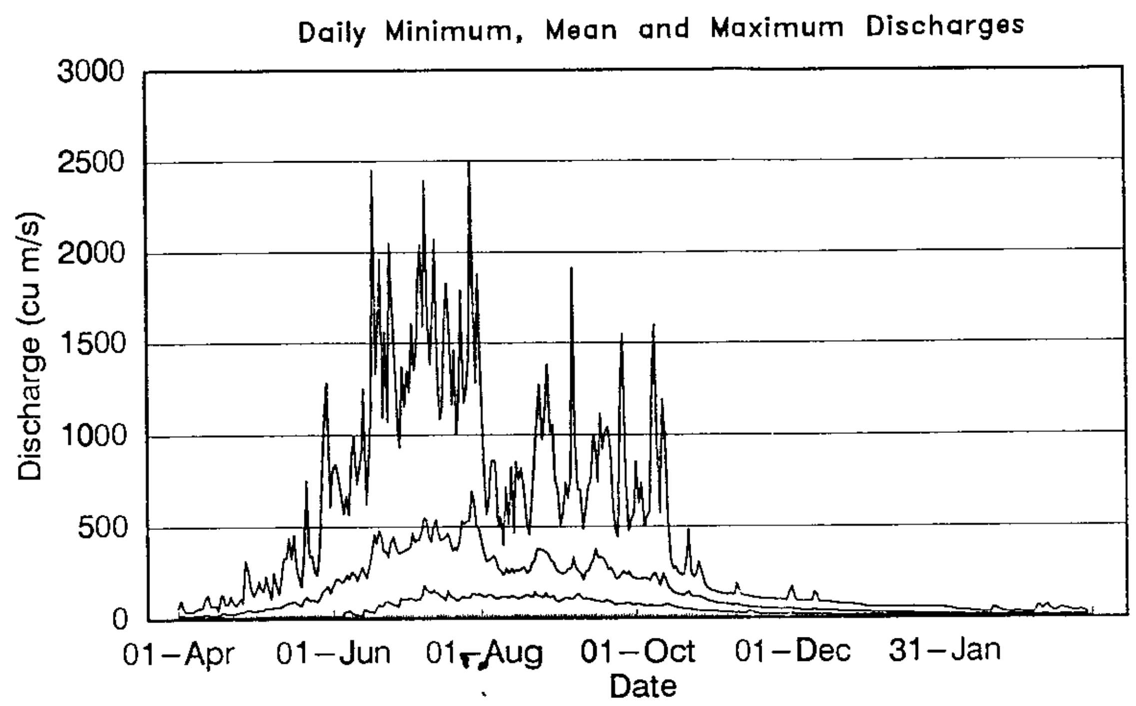
6. Sedimentology
Channel: Mainly coarse–medium sand.
Banks: Mainly silt and silty sand

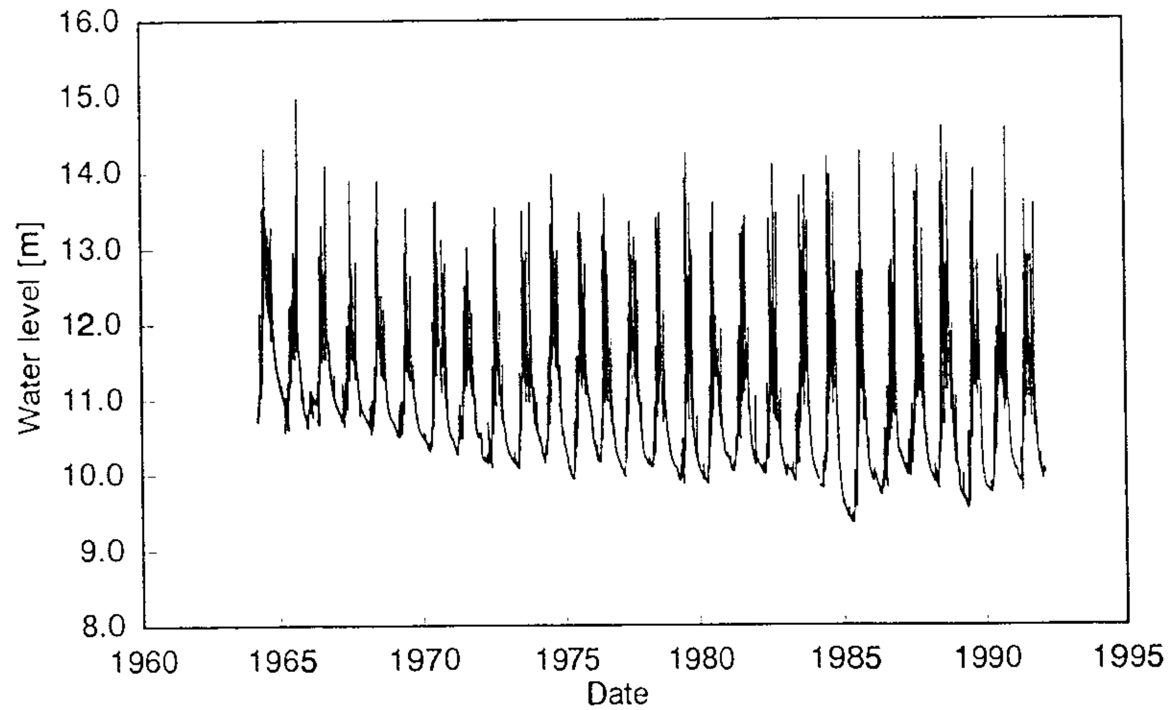
7. Pattern of Instability
A major new avulsion is occurring upstream of Durgapur through the Atrikhali channel. Sand deposition is occurring on the floodplain of the Shibganj Dhala River causing channel shifting and bank erosion.

Northeast Regional Project	
Someswari River at Durgapur	
Prepared by: DMc	October 1994

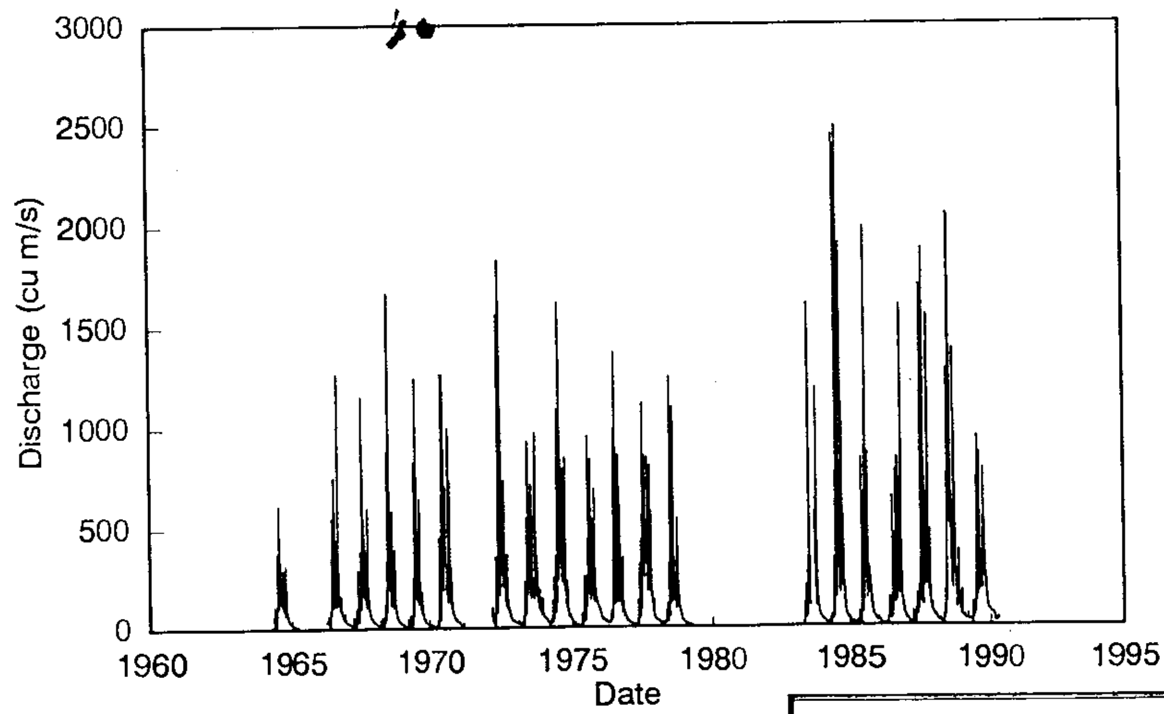
263-LDWG







Recorded Water Levels

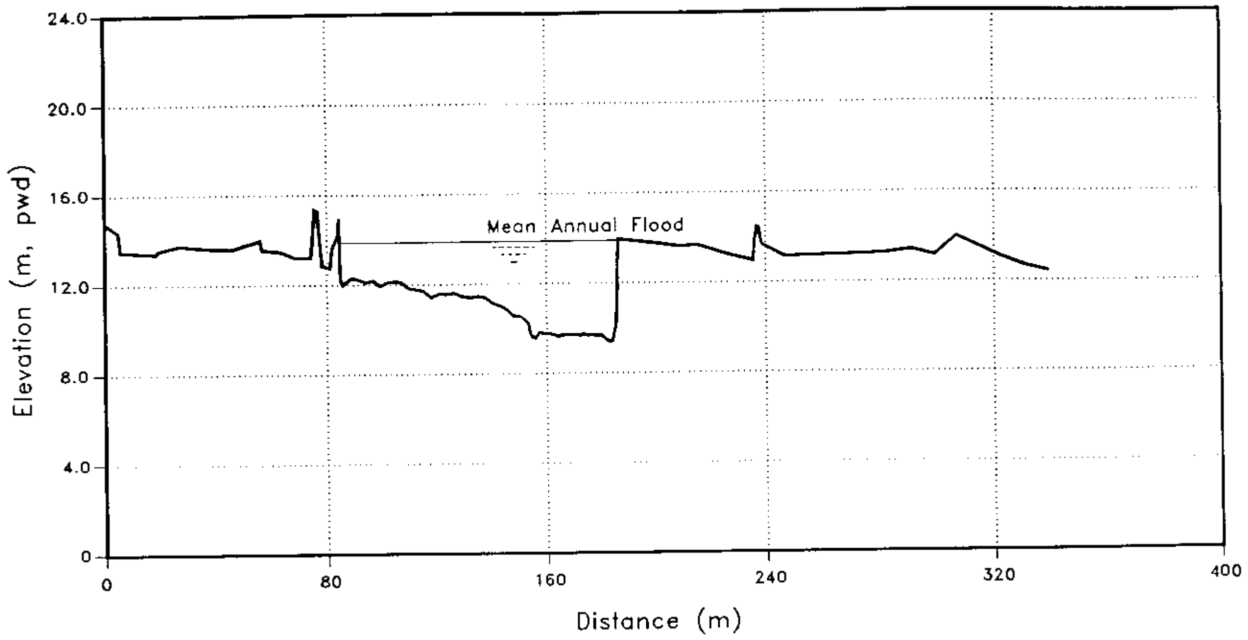


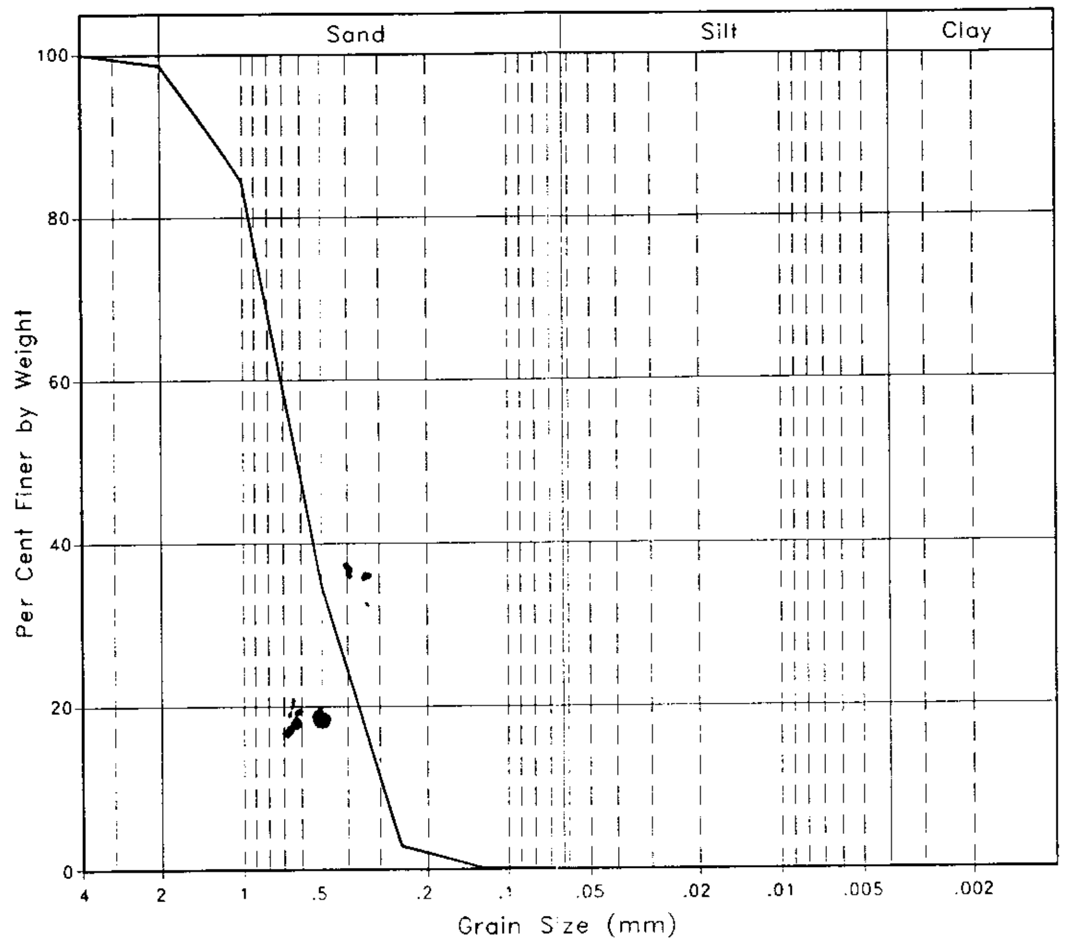
Recorded Discharges

Northeast Regional Project	
Someswari River at Durgapur	
Prepared by: DMc/Tarek	October 1994
Drawn by: Jalal	AutoCAD Drawing

FILE: 263.DWG

Channel Properties





Slope= 50cm/km [Bagmara-Durgapur]

Slope= 15cm/km [Durgapur-Jaria]

Bed Material Size

D_{50} = 0.62mm

D_{35} = 0.50mm

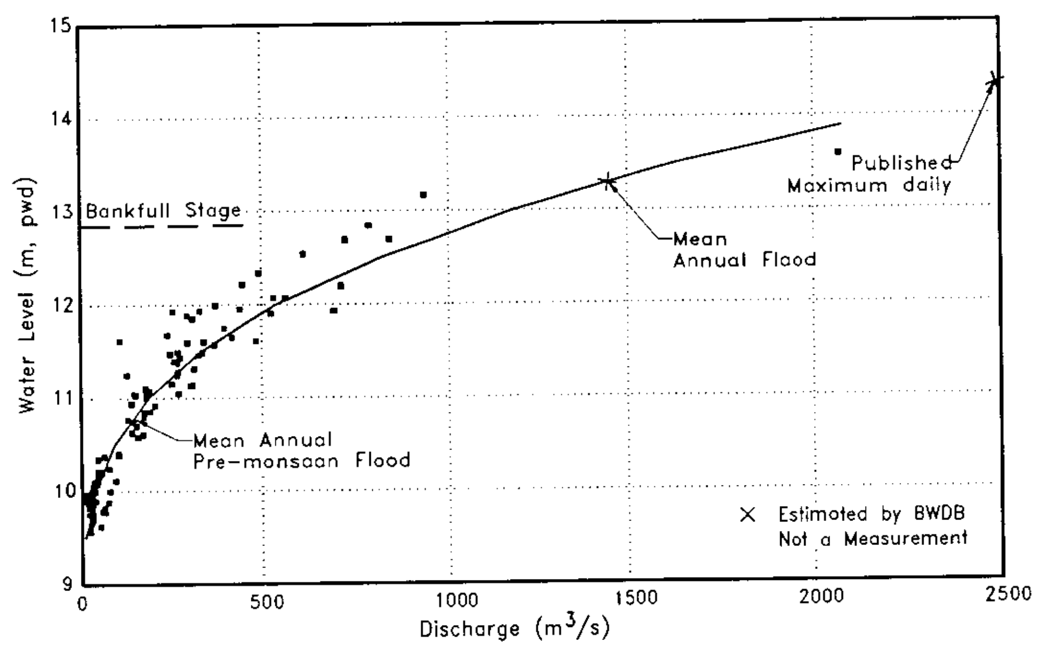
D_{10} = 0.29mm

Northeast Regional Project	
Someswari River at Durgapur	
Prepared by: DMc	November 1994

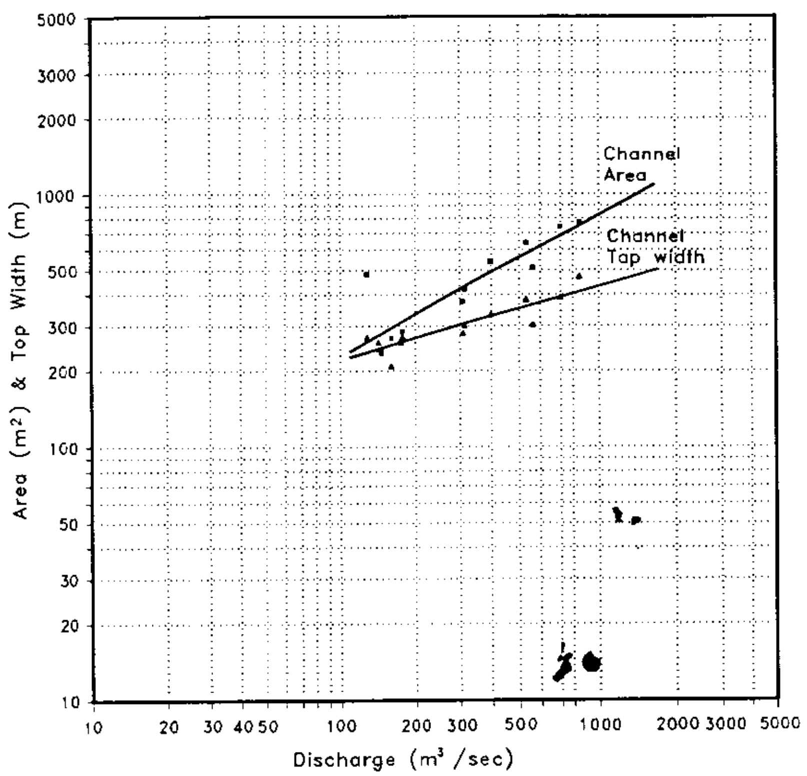
FILE: M283-3.DWG

Figure C-28

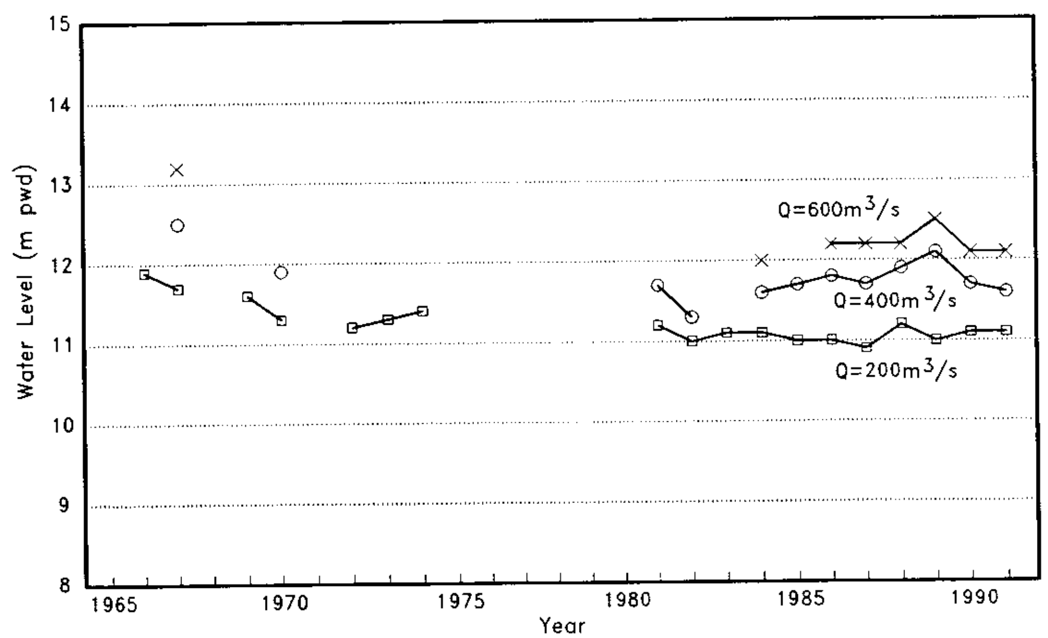
Rating Curve (1988–1991)

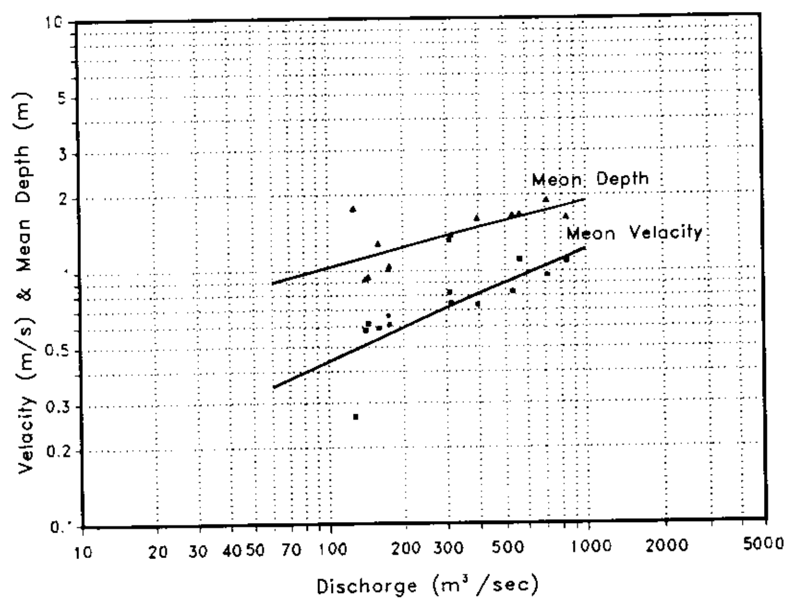


Hydraulic Geometry



Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.20$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows rating curves have lowered by 1.0 –1.5m between 1965–1991.

3. Hydraulic Geometry Relations

   $A = 17.82Q^{0.554}$
   $W = 58.27Q^{0.289}$
   $d = 0.306Q^{0.264}$
   $v = 0.056Q^{0.446}$

Condition	Q	A	W	d	v
1.	147	282	247	1.14	0.52
2.	1446	1000	479	2.1	1.45

1. Mean annual pre–monsoon flood
2. mean annual Flood

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Northeast Regional Project

Shibganj Dhala River at Durgapur

Prepared by: DMc | November 1994

FILE: BD-263.DWG

Figure C-29

N

River Characteristics:

1. Gauge Number: 266

2. Location:
   Lat. 25 00'00"N
   Lon. 92 15'33"E

3. Available Data
   Water Level: 1964–70,1972–80,1982–93
   Discharge : 1969–70,1972–93
   Sediment: None

4. Physical Setting:

   Physiographic Unit: Lowland Floodplain
   Agro–ecologic Zone: Eastern Surma Kushiyara Floodplain
   Features: The river is occasionally confined by bedrock tilas on its north bank. A major paleo–channel heads west from Kanairghat (Naya N, Lain N). This is the site of a major right bank spill into the Sari–Gowain R. system.

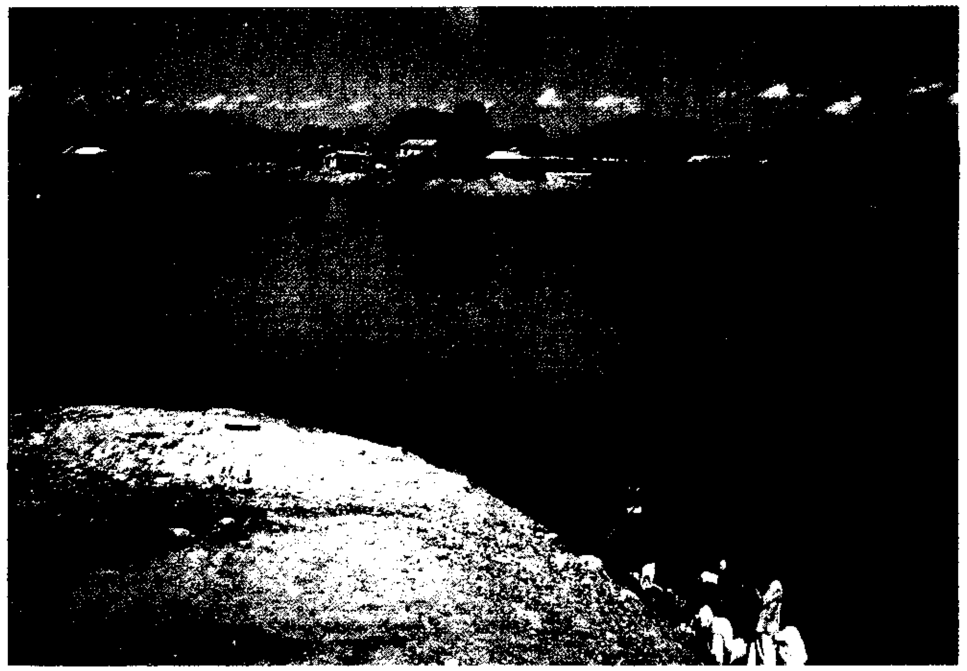
5. Channel Pattern:

   Channel: Single, irregular & confined meandering channel
   Islands: None.
   Bars: Prominent sandy point bars
   Sinuosity: 1.45

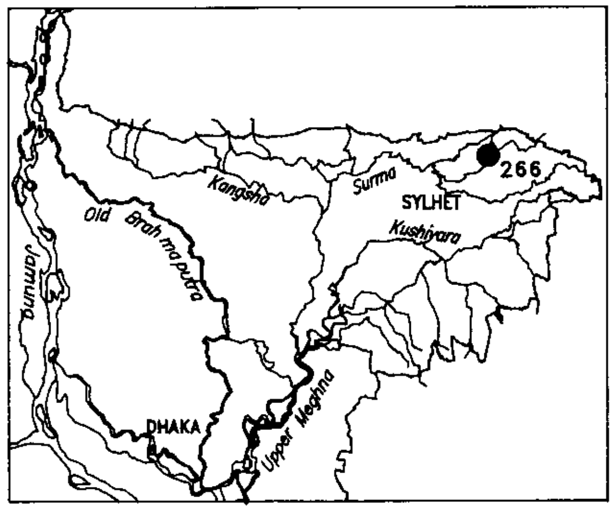
6. Sedimentology
   Channel: Mainly fine–medium sand. The bed becomes covered by dunes during flood flows.

   Banks: Mainly silt and silty sand

7. Pattern of Instability
   Slow progressive erosion along the outer concave banks in bends. The channel appears to be stable overall. Spills occur on the right bank at Kanairghat and into Kakura khal, 17 km downstream on the left bank. This khal has enlarged dramatically in recent years.



View to right bank upstream of gauge

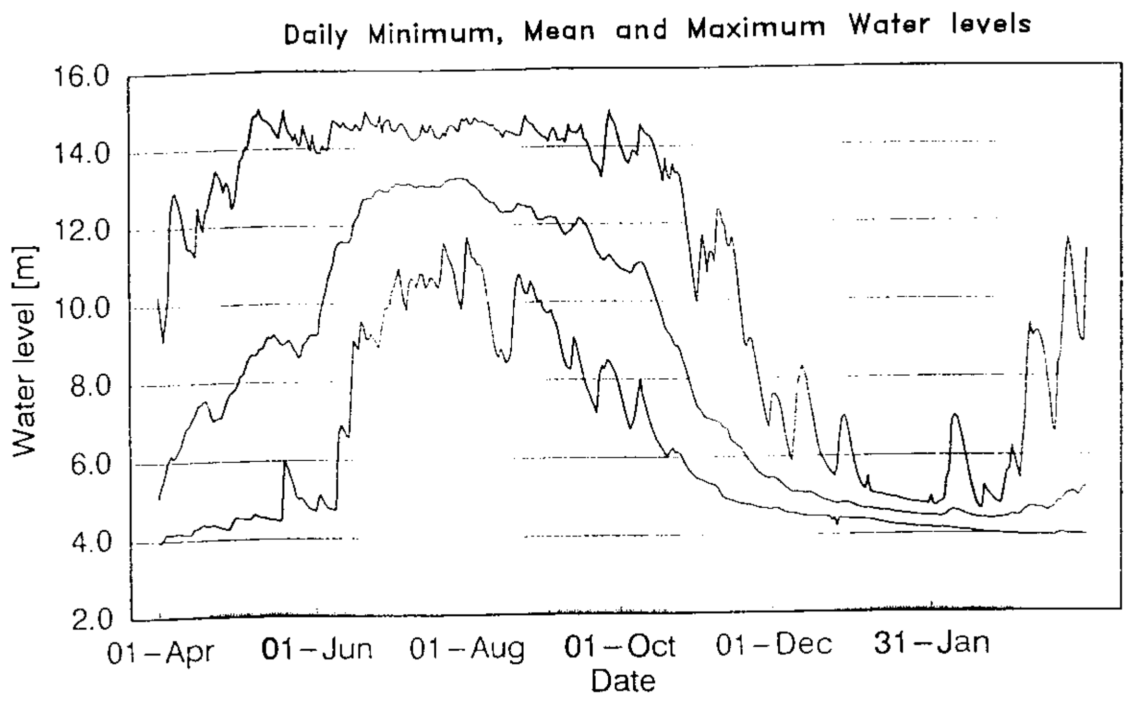


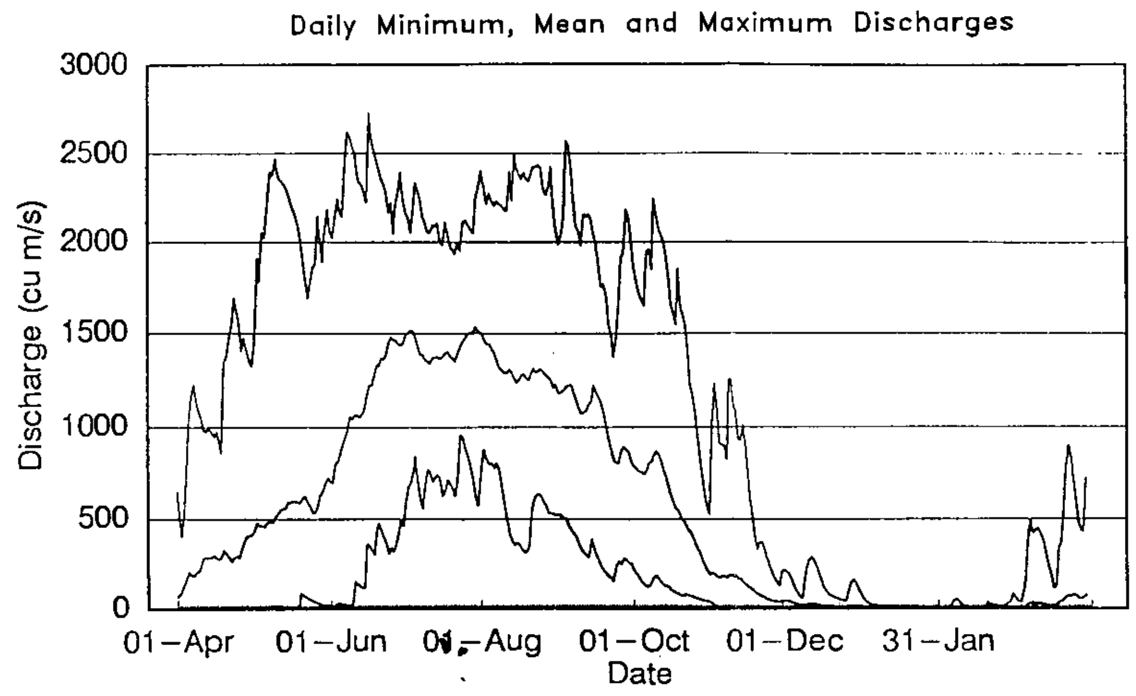
Site Location:

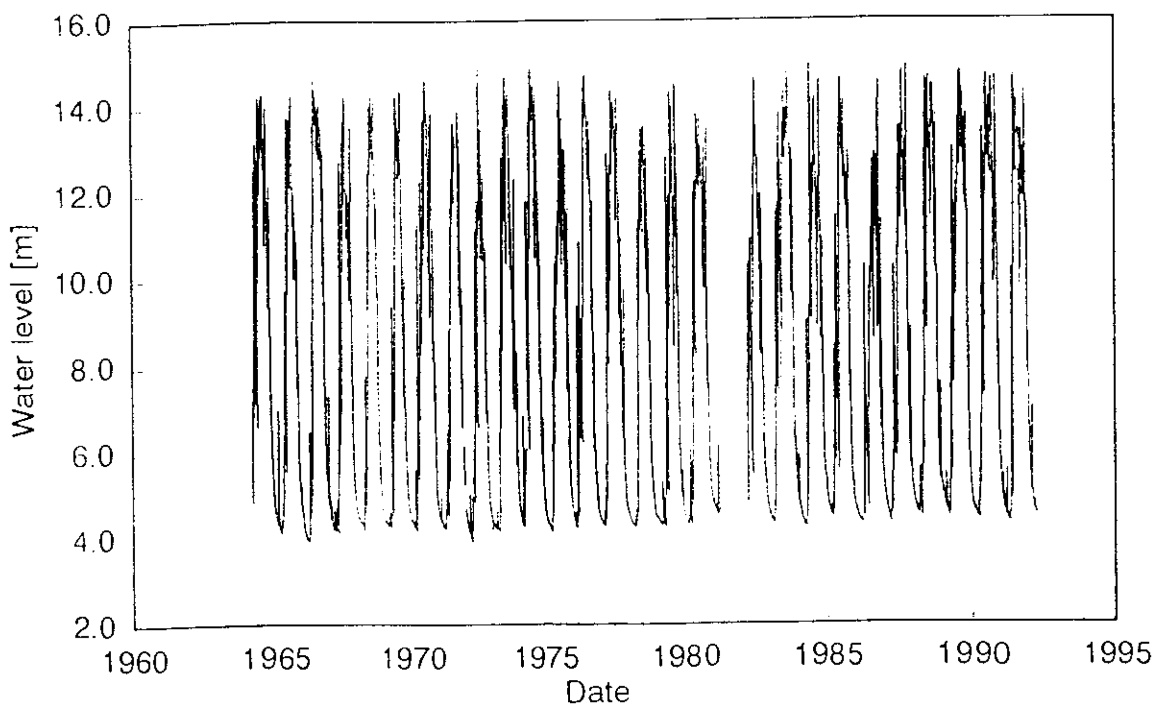
Northeast Regional Project	
Surma River at Kanairghat	
Prepared by: DMc	October 1994

M266–LDWG

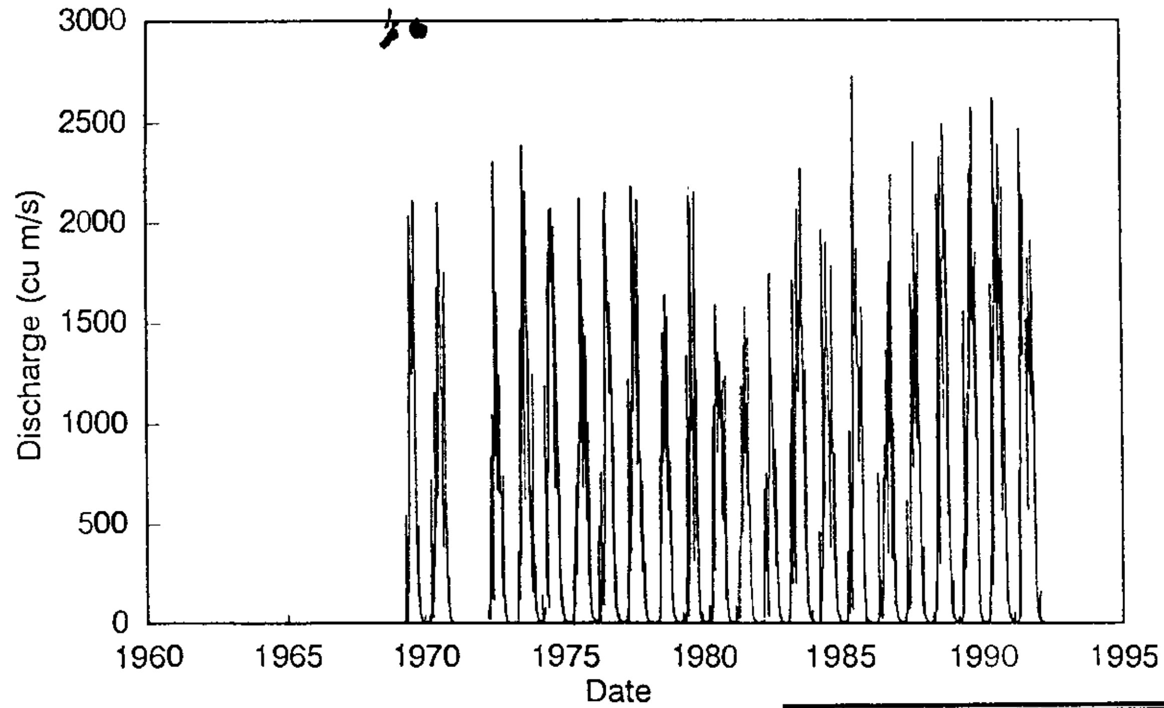
Figure C-30







Recorded Water Levels

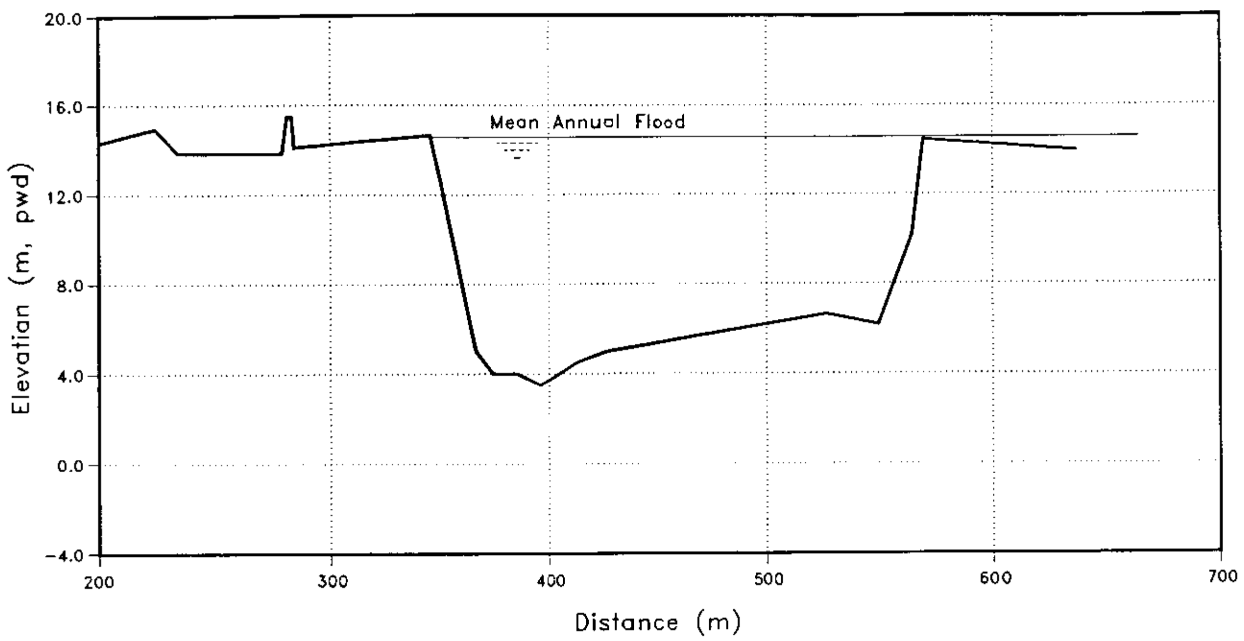


Recorded Discharges

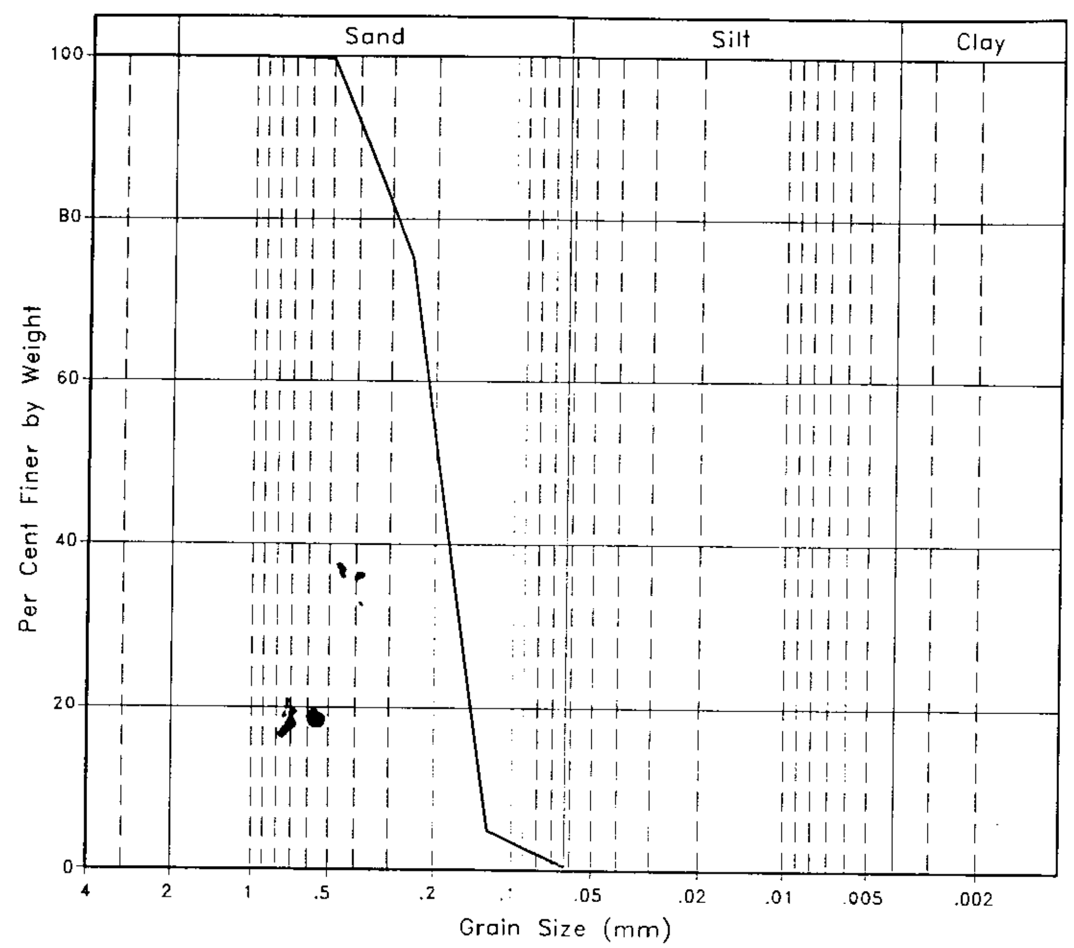
Northeast Regional Project	
Surma River at Kanairghat	
Prepared by: DMc/Tarek	October 1994
Drawn by: Jalal	AutoCAD Drawing

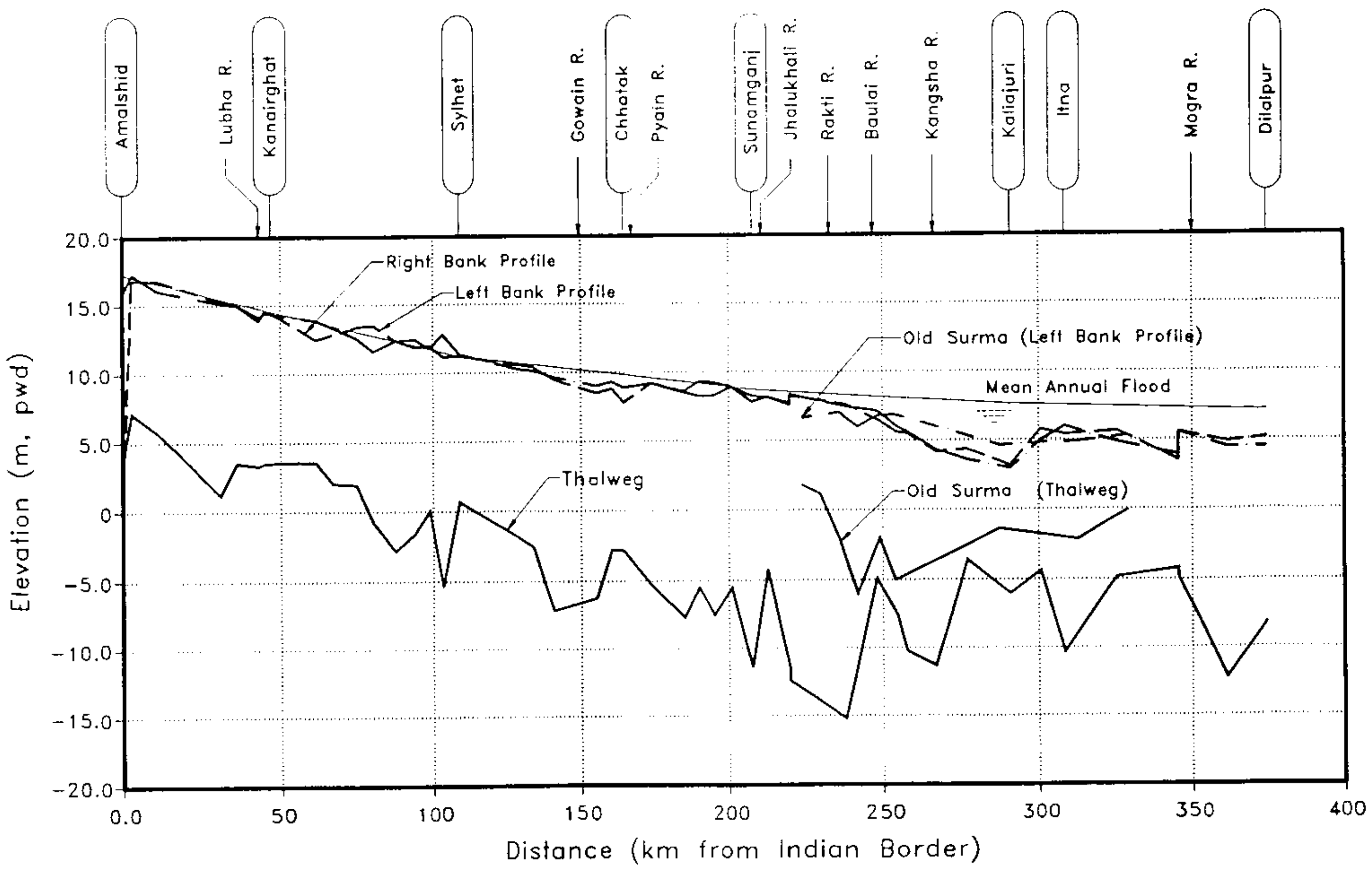
FILE: 268.DWG

Figure C-31



Channel Properties





Slope (monsoon)= 4cm/km

Bed Material Size

D_{50} = 0.20mm

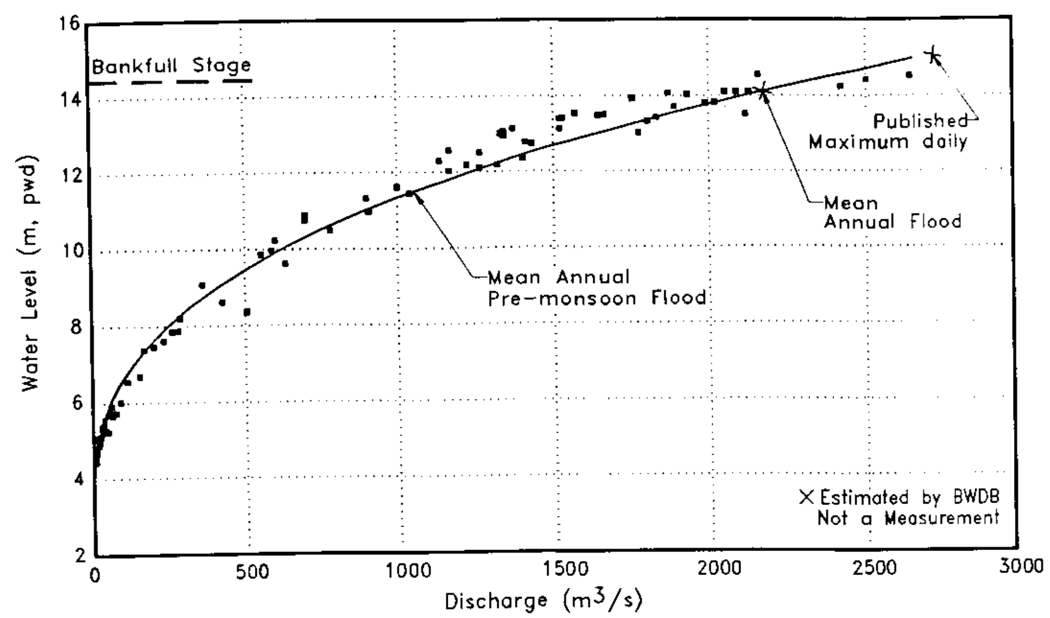
D_{35} = 0.17mm

D_{10} = 0.15mm

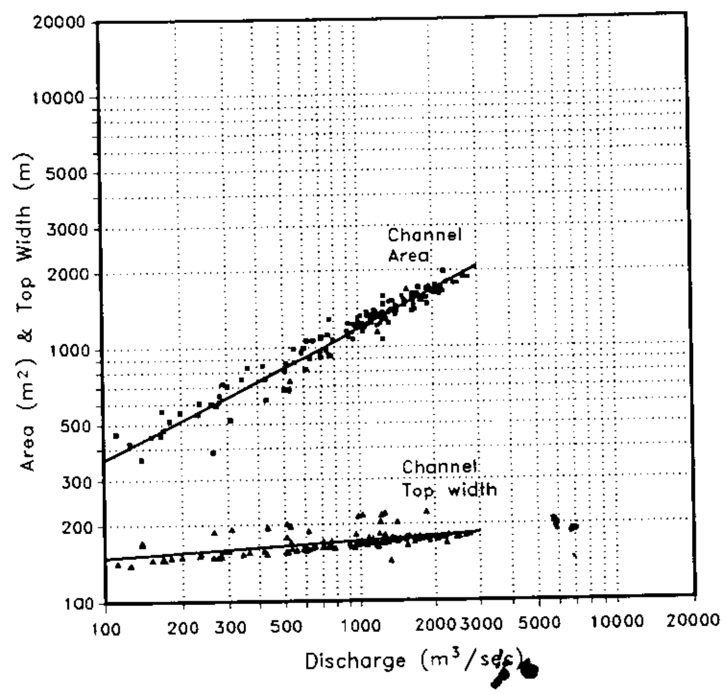
Northeast Regional Project	
Surma River at Kanairghat	
Prepared by: DMc	November 1994

FILE: M266-3.DWG

Rating Curve (1988–1991)



Hydraulic Geometry



COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.03$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows no change in rating curves at high flows.

3. Hydraulic Geometry Relations

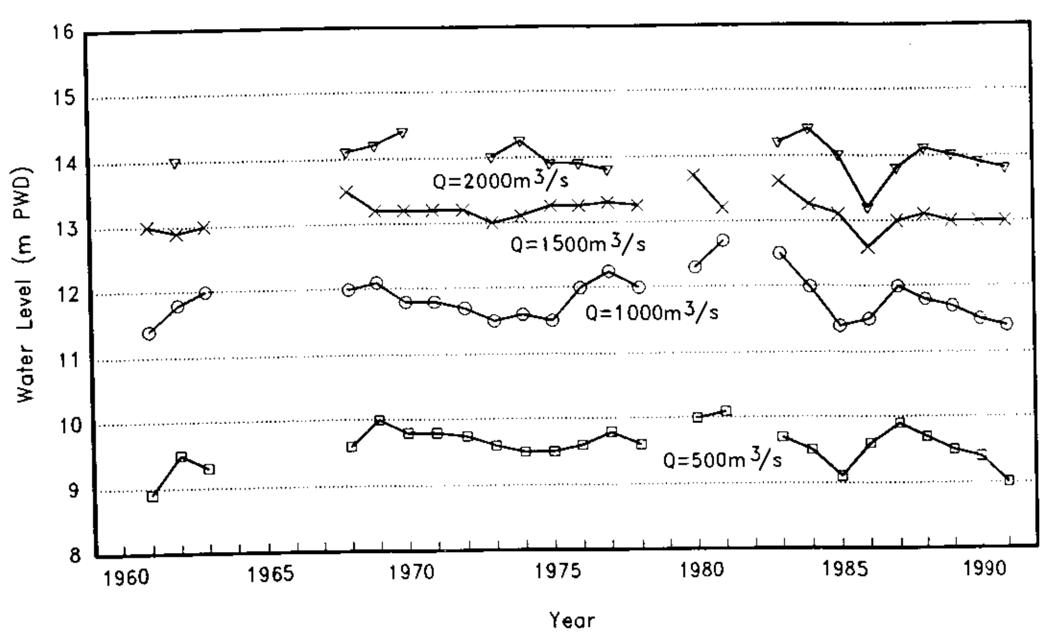
   A $= 33.900\,Q^{0.514}$
   W $= 111.72\,Q^{0.063}$
   d $= 0.303\,Q^{0.451}$
   v $= 0.029\,Q^{0.486}$

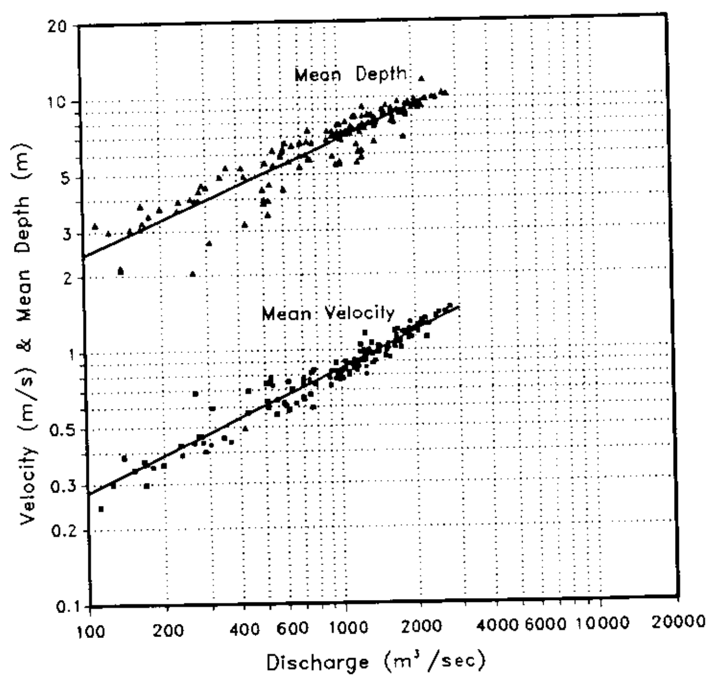
Condition	Q	A	W	d	v
1.	1051	1211	173	7.02	0.87
2.	2176	1760	181	9.75	1.24

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





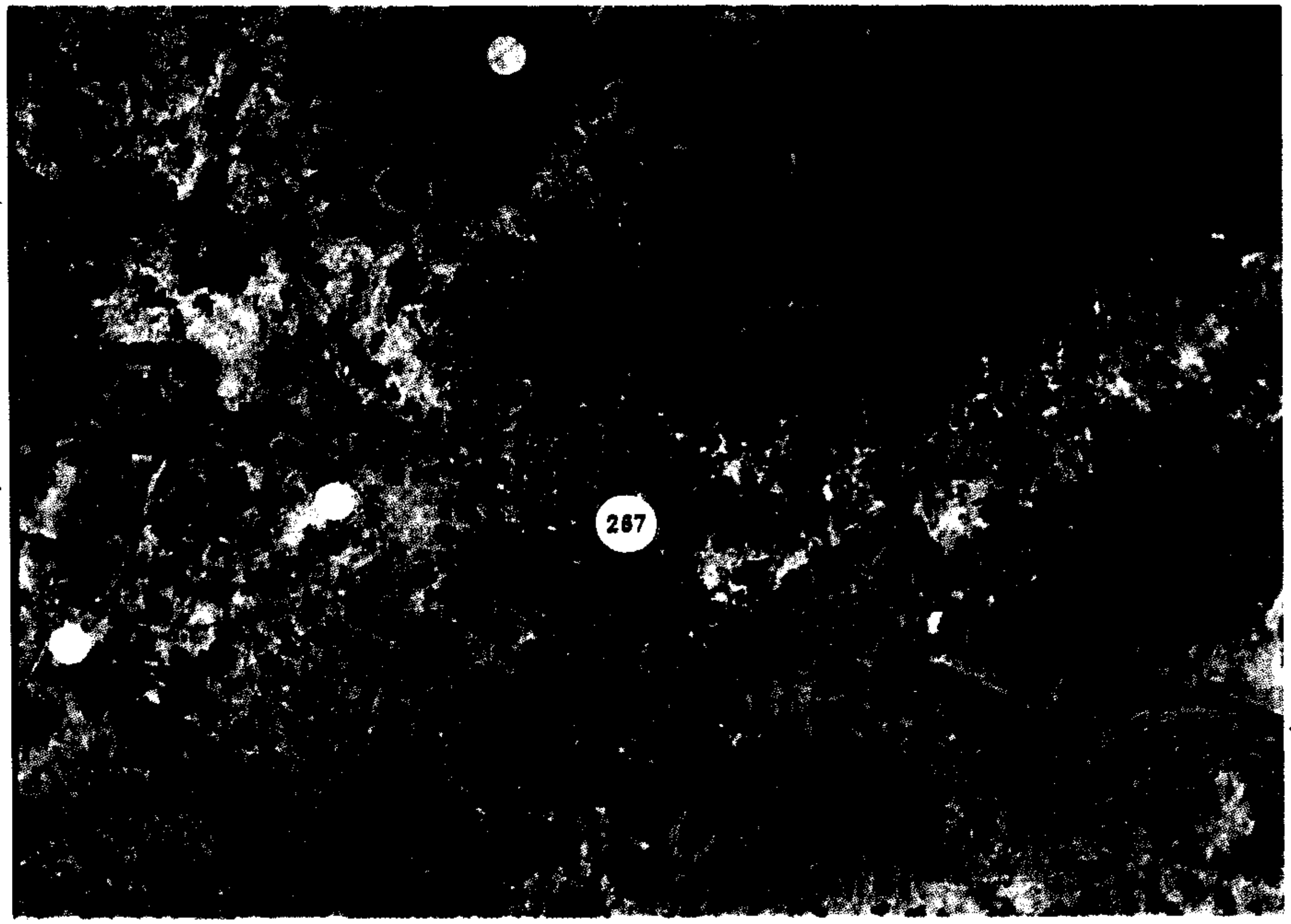
Northeast Regional Project

Surma River at Kanairghat

Prepared by: DMc | November 1994

FILE: BD-266.DWG

Figure C-33



River Characteristics:

1. Gauge Number: 267

2. Location:
   Lat. 24 53'14"N
   Lon. 91 52'16"E

3. Available Data
   Water Level: 1964–70,1972–93
   Discharge : 1964–66,1969–70,1972–77,1981–93
   Sediment: 1964–70,1972–82, 1984–93

4. Physical Setting:

   Physiographic Unit: Lowland Floodplain
   Agro-ecologic Zone: Eastern Surma Kushiyara Floodplain
   Features: The river is occasionally confined by bedrock on its north bank. The channel appears to be stable in this reach. Two major loop cuts were constructed downstream of Sylhet in the 1960's and 1970's.

5. Channel Pattern:

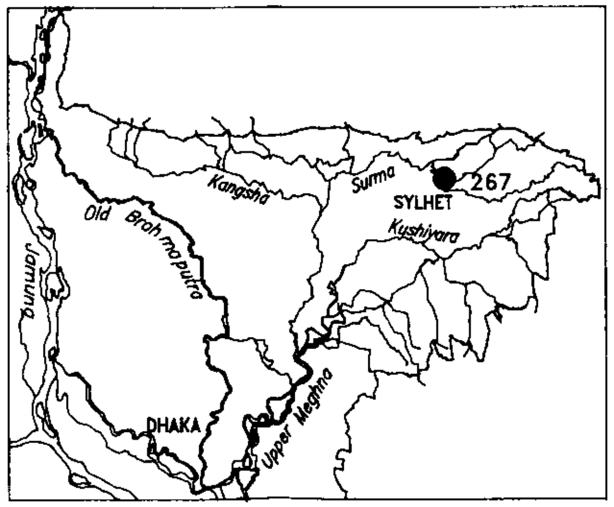
   Channel: Single, irregular & confined meandering channel
   Islands: None.
   Bars: None
   Sinuosity: 1.32

6. Sedimentology
   Channel: Mainly fine sand.

   Banks: Mainly silt and silty sand

7. Pattern of Instability
   Slow progressive erosion along the outer concave banks in bends. The channel appears to be stable.

View upstream towards Sylhet



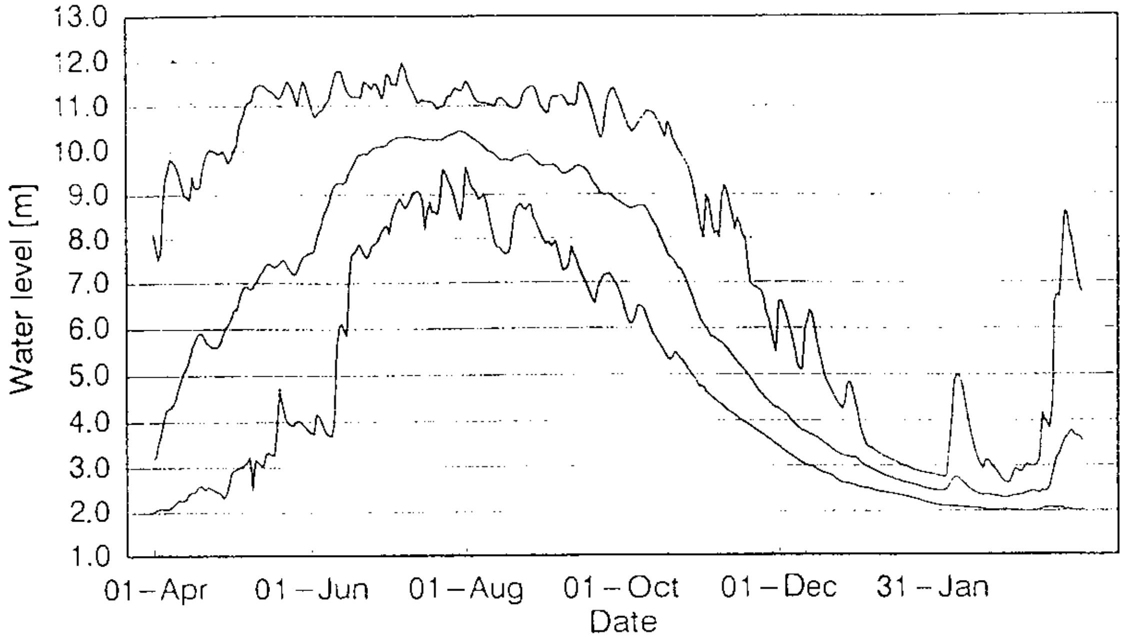
Site Location:

Northeast Regional Project	
Surma River at Sylhet	
Prepared by: DMc	October 1994

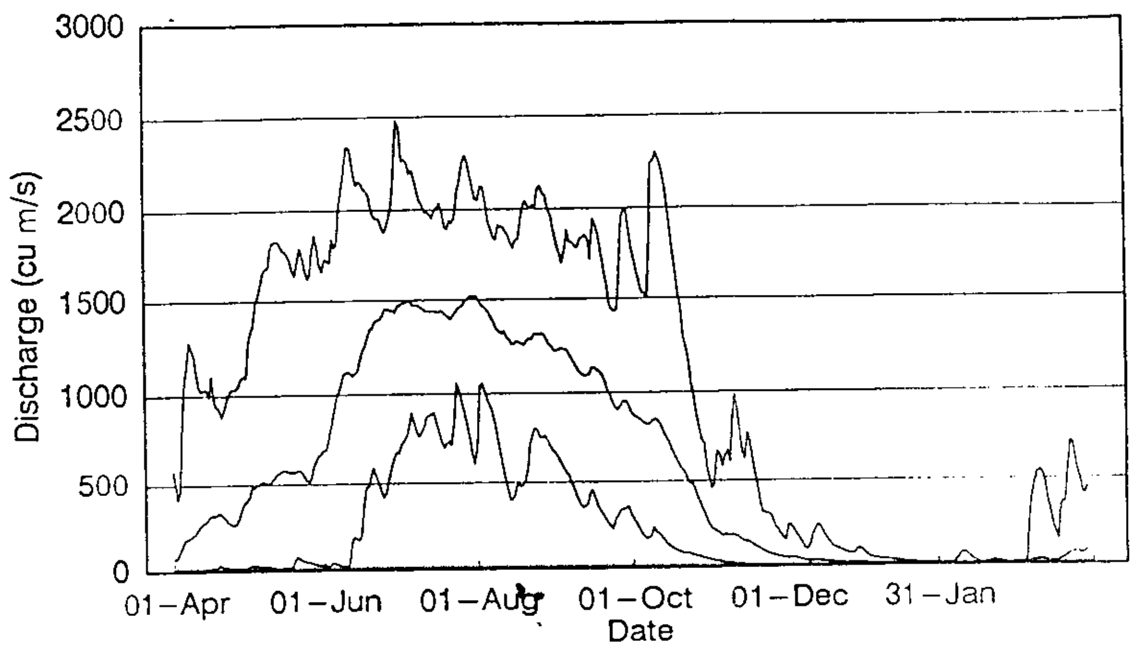
M267-LDWD

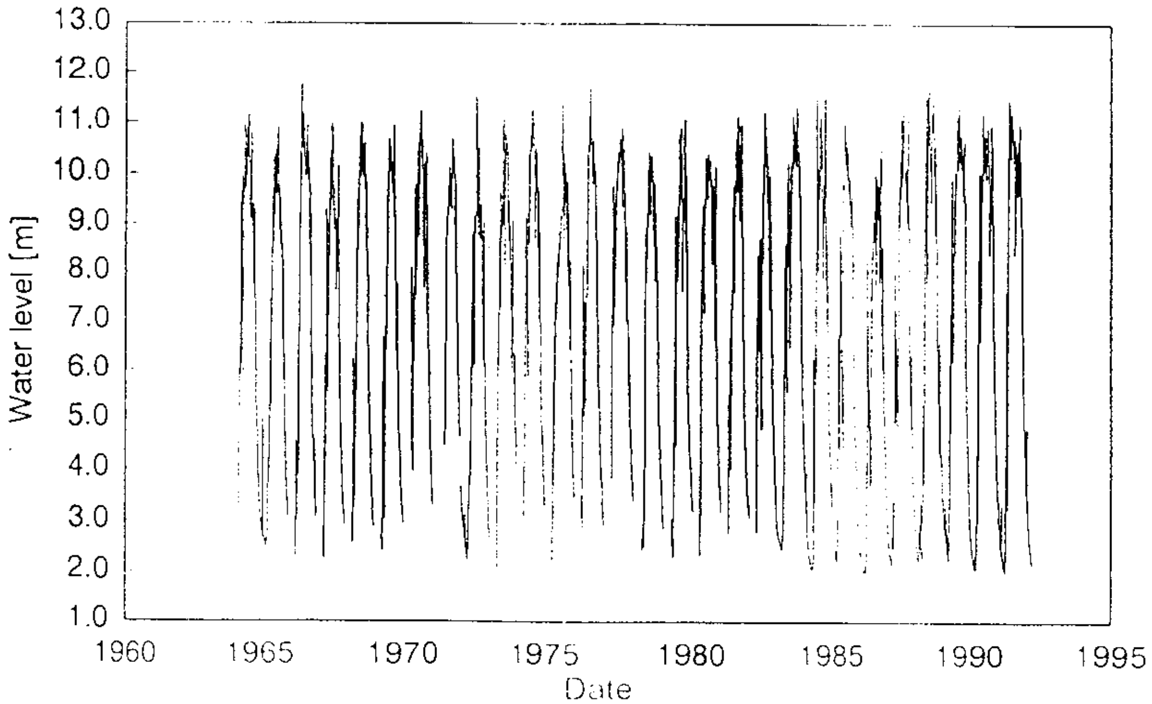
Figure C-34

Daily Minimum, Mean and Maximum Water levels

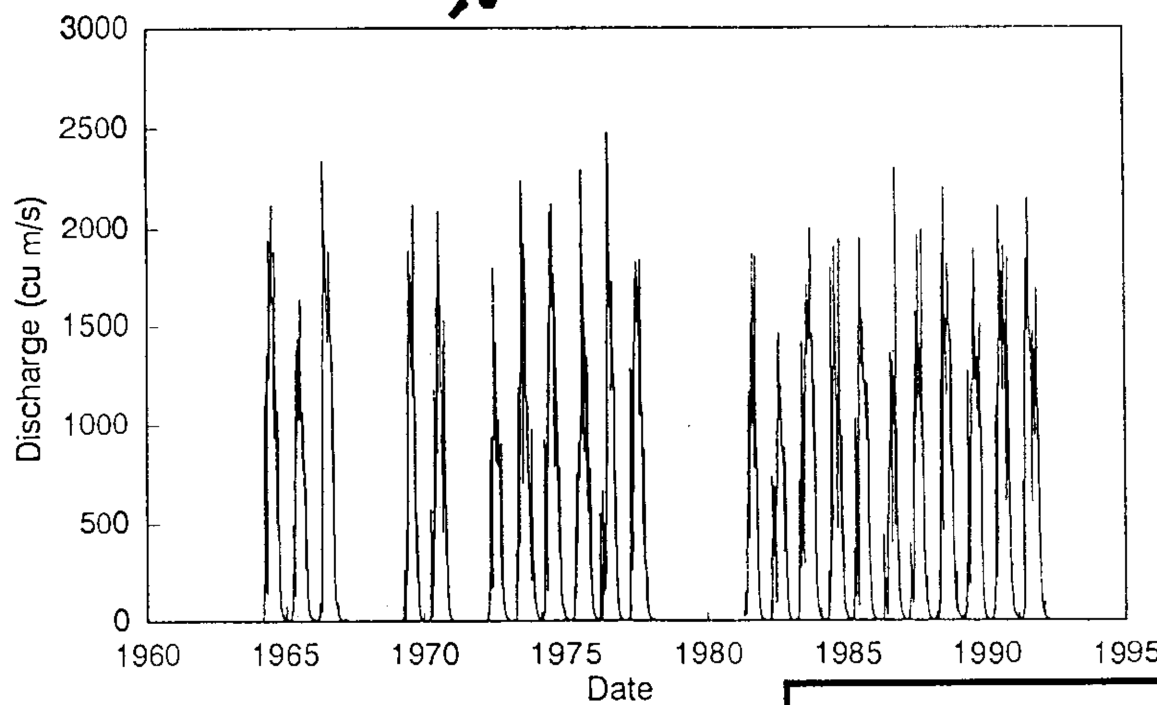


Daily Minimum, Mean and Maximum Discharges





Recorded Water Levels



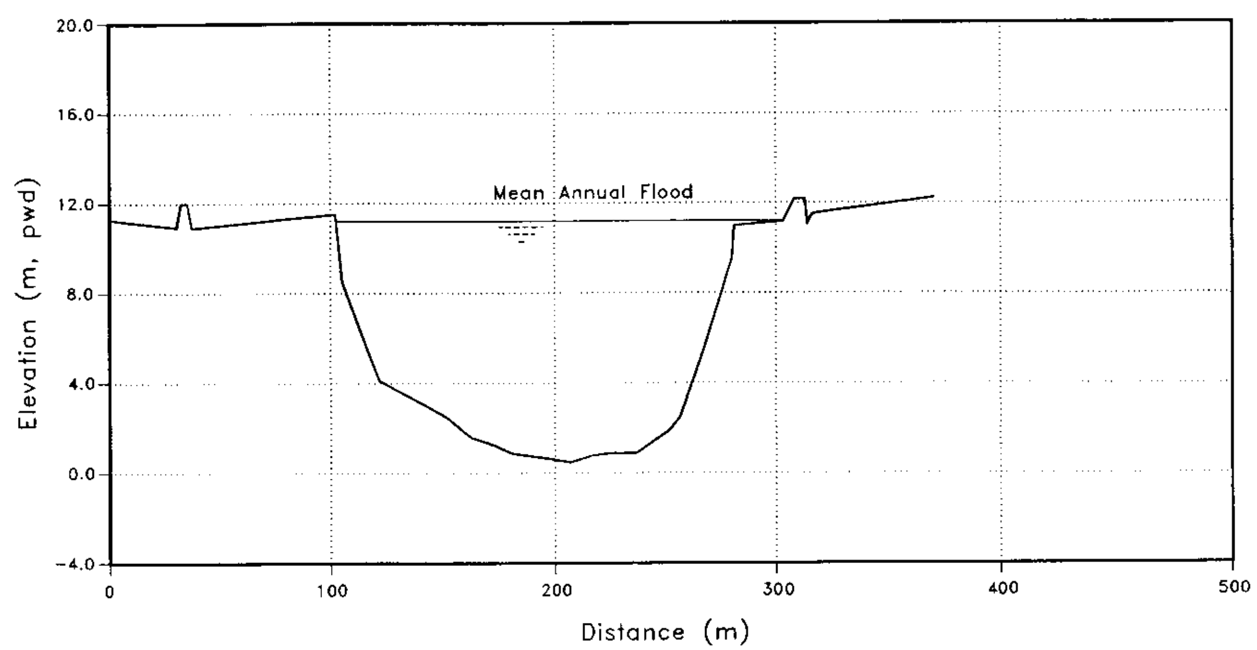
Recorded Discharges

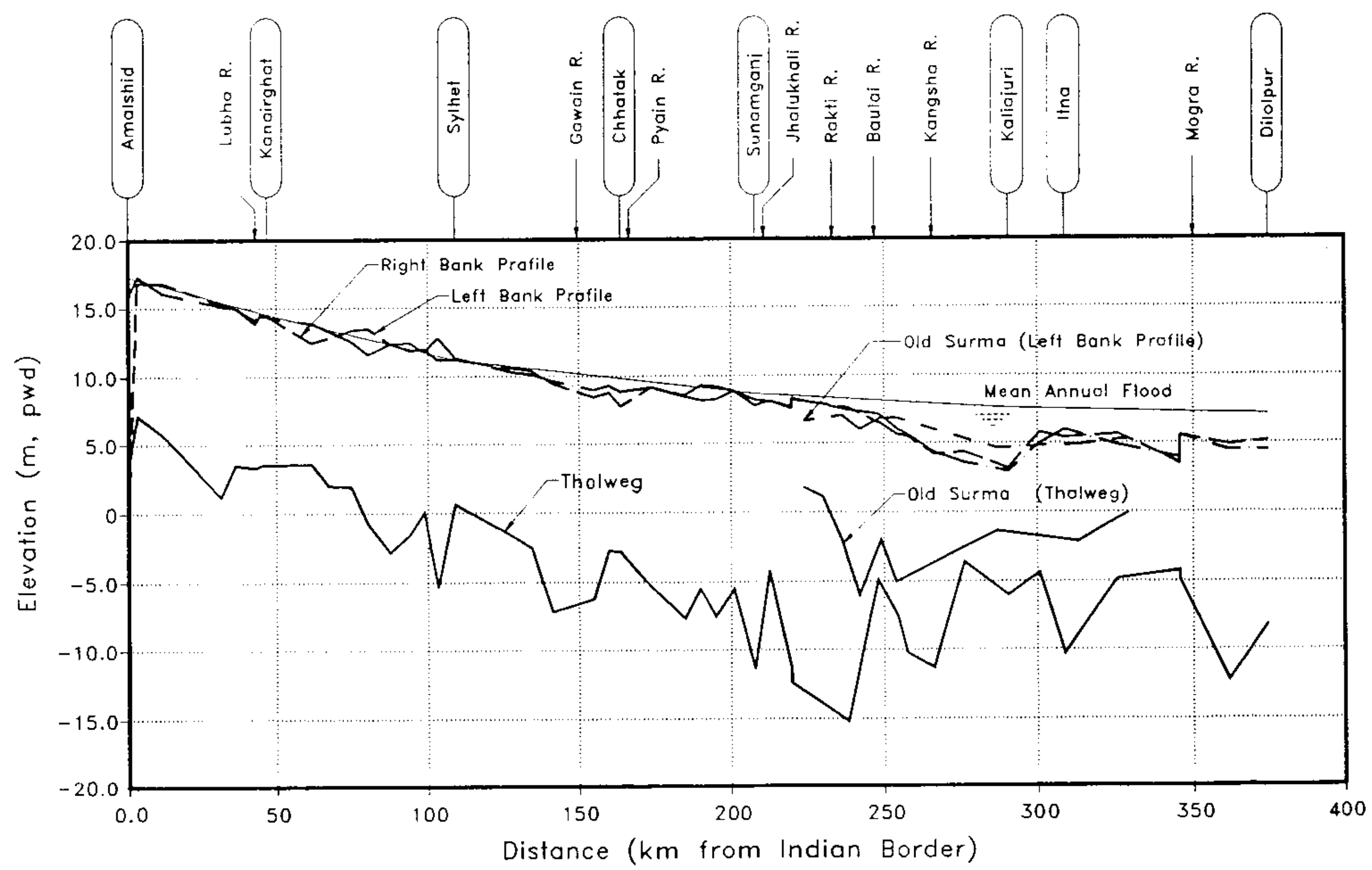
Northeast Regional Project		
Surma River at Sylhet		
Prepared by:	DMc/Tarek	October 1994
Drawn by:	Jalal	AutoCAD Drawing

FILE: 287.DWG

Figure C-35

Channel Properties





Slope (monsoon)= 4cm/km

Northeast Regional Project

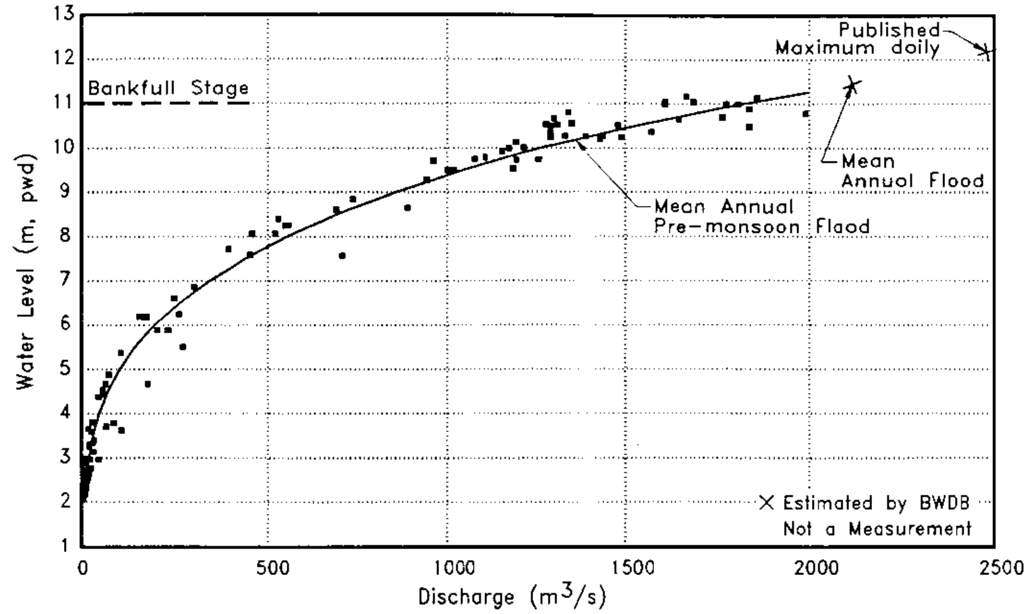
Surma River at Sylhet

Prepared by: DMc | November 1994

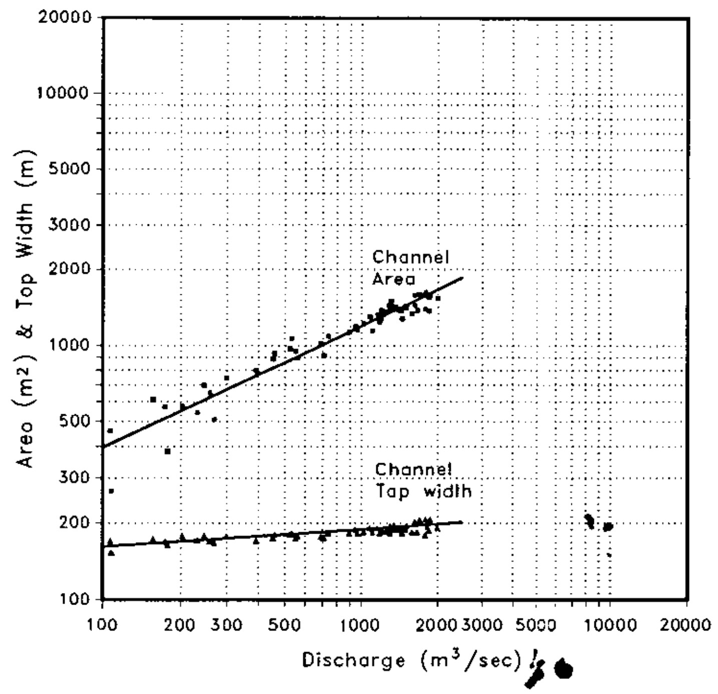
FILE: M267-3.DWG

Figure C–36

Rating Curve (1988–1992)



Hydraulic Geometry



COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.02$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows abrupt drop in rating curves around 1956 and gradual rising trend (17mm/year) since 1966.

3. Hydraulic Geometry Relations

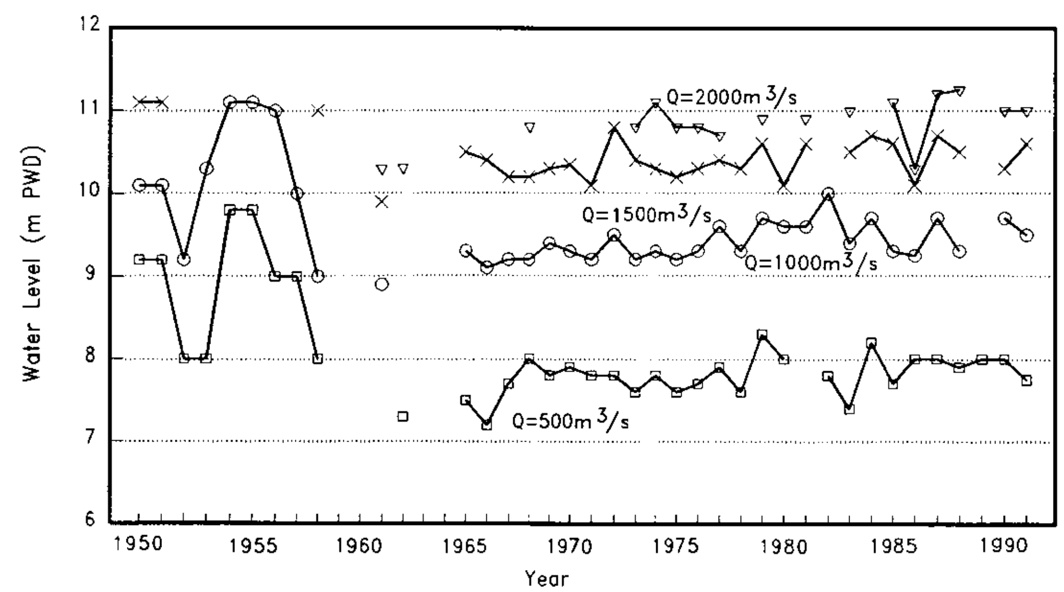
   $A = 43.65\,Q^{0.48}$
   $W = 121.29\,Q^{0.062}$
   $d = 0.36\ Q^{0.417}$
   $v = 0.023\,Q^{0.521}$

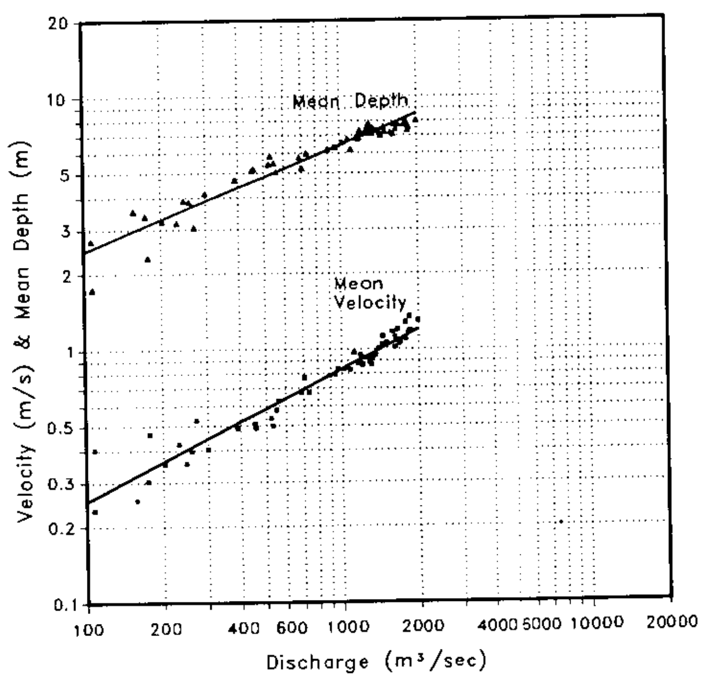
Condition	Q	A	W	d	v
1.	1360	1386	190	7.3	0.98
2.	2120	1715	195	8.8	1.24

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m³/s)
A= Area (m²)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





Northeast Regional Project

Surma River at Sylhet

Prepared by: DMc	November 1994

FILE: BD-267.DWG

Figure C-37

River Characteristics:

1. Gauge Number: 268

2. Location:
Lat. 25 11'23"N
Lon. 90 13'08"E

3. Available Data
Water Level: 1964–70,1971–93
Discharge : 1962–63,1965–77
Sediment: None

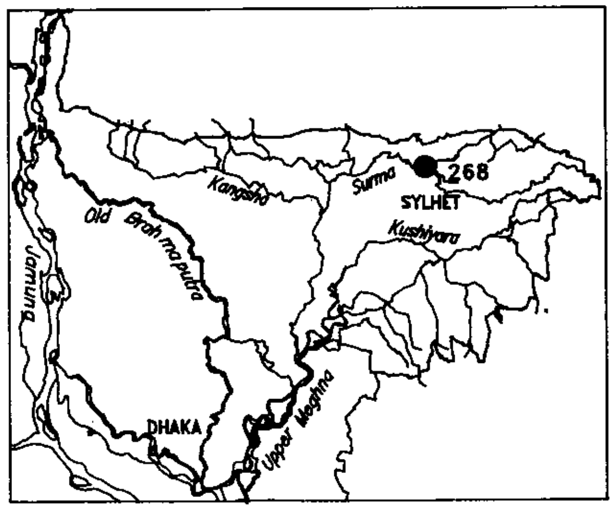
4. Physical Setting:
Physiographic Unit: Lowland Floodplain
Agro–ecologic Zone: Surma–Kushiyara River Floodplain
Features: The river is bounded on the north by the Chela River alluvial fan and the Piyain River, which occupies a major paleo–channel of the ancient Surma River. The Surma channel widens abruptly below this junction. Spills from the Surma flow southwards into the Central Basin through several major khals.

5. Channel Pattern:
Channel: Single, irregular highly sinuous channel.
Islands: None.
Bars: None
Sinuosity: 1.55

6. Sedimentology
Channel: Fine sand
Banks: Mainly silt, silty clay

7. Pattern of Instability
Overall channel pattern has remained stable since the Rennells' survey of 176B. Loop cuts have been constructed upstream and downstream of Chhattak in the 1960's and 70's.


View upstream showing Surma/Piyain R. confluence



Site Location:

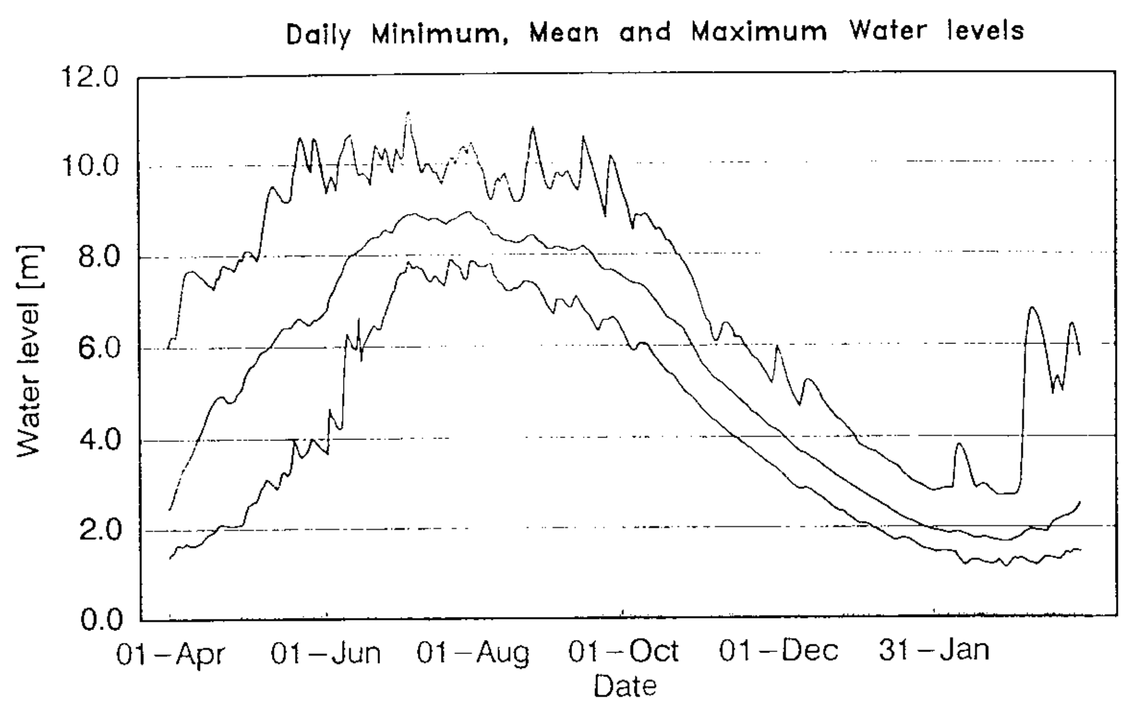
Northeast Regional Project

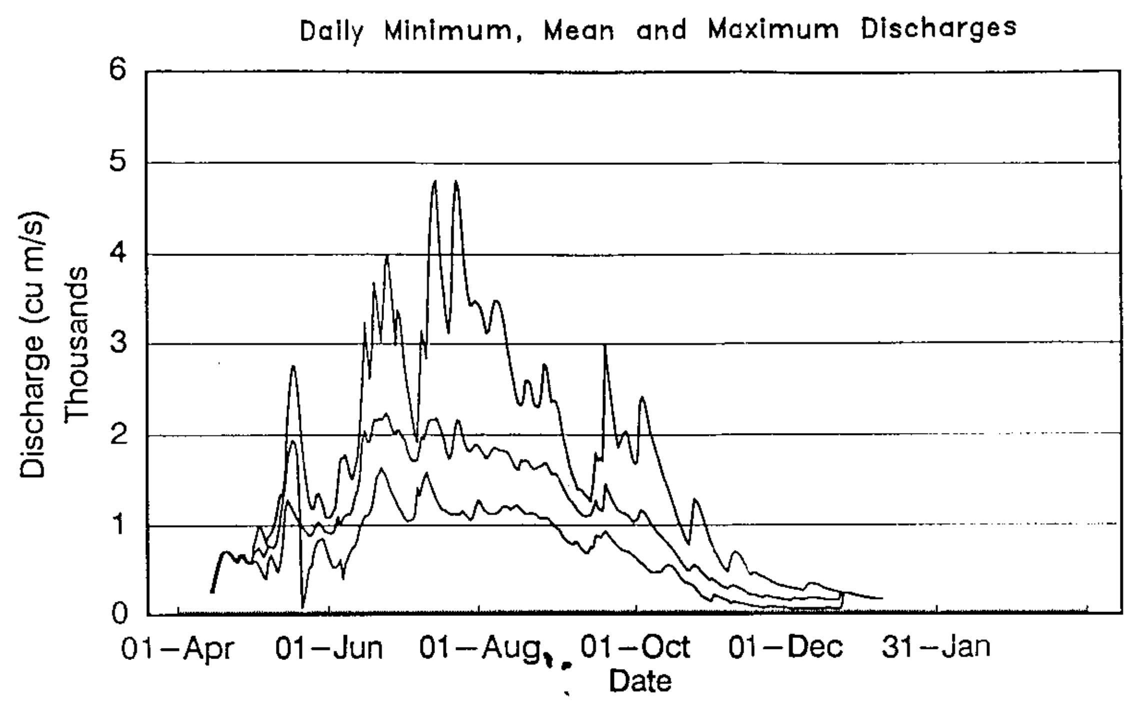
Surma River
at Chhatak

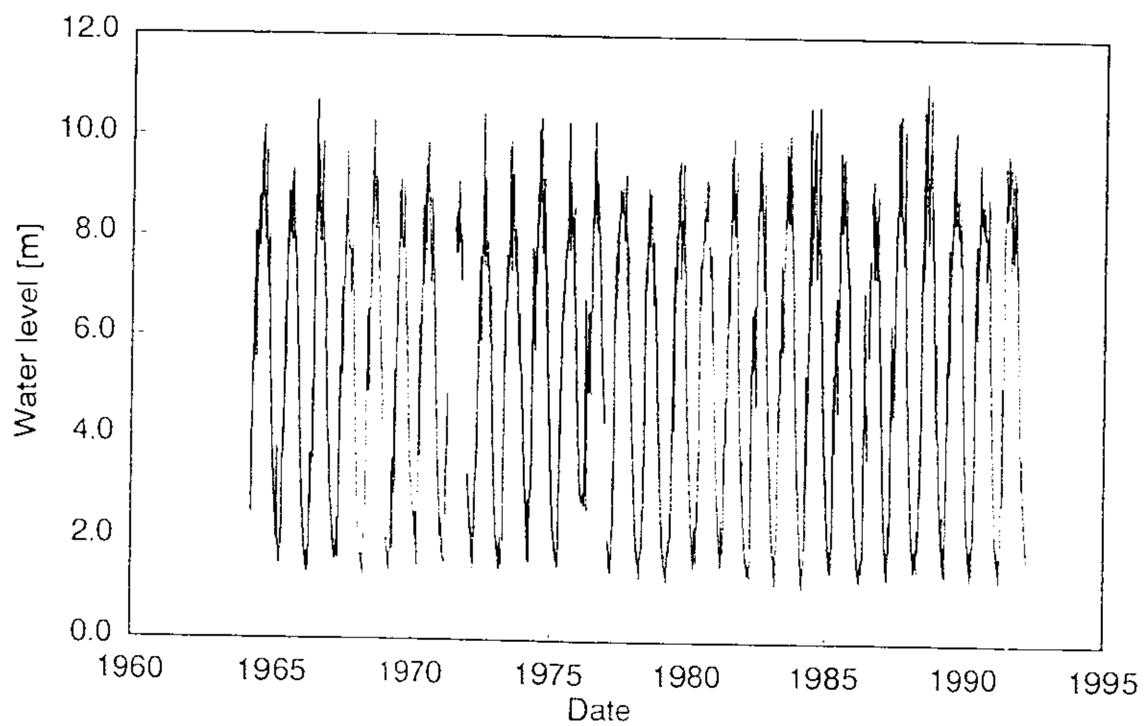
Prepared by: DMc	October 1994

FILE: M268–LDWG

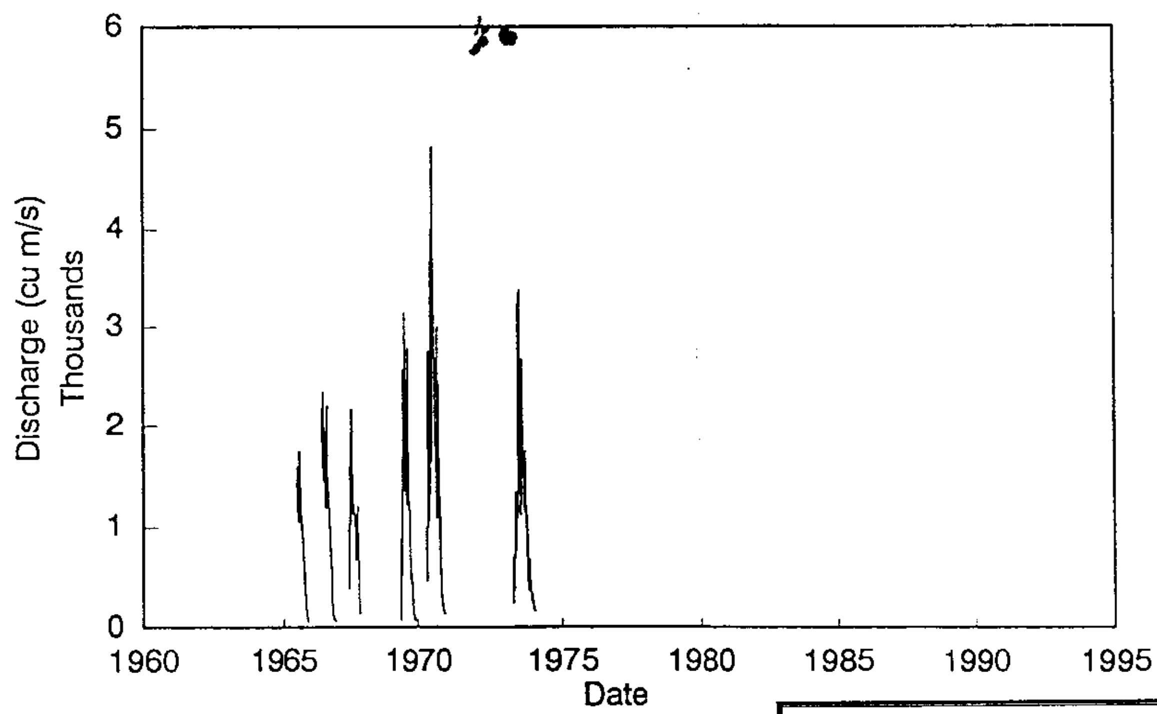
Figure C-38







Recorded Water Levels



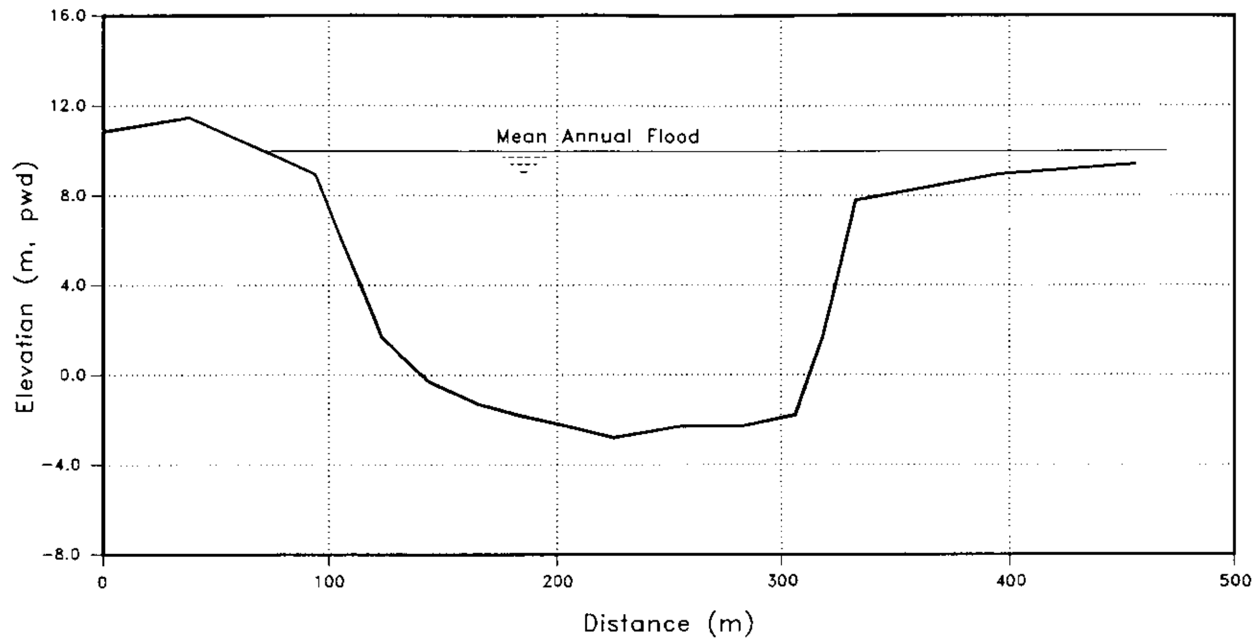
Recorded Discharges

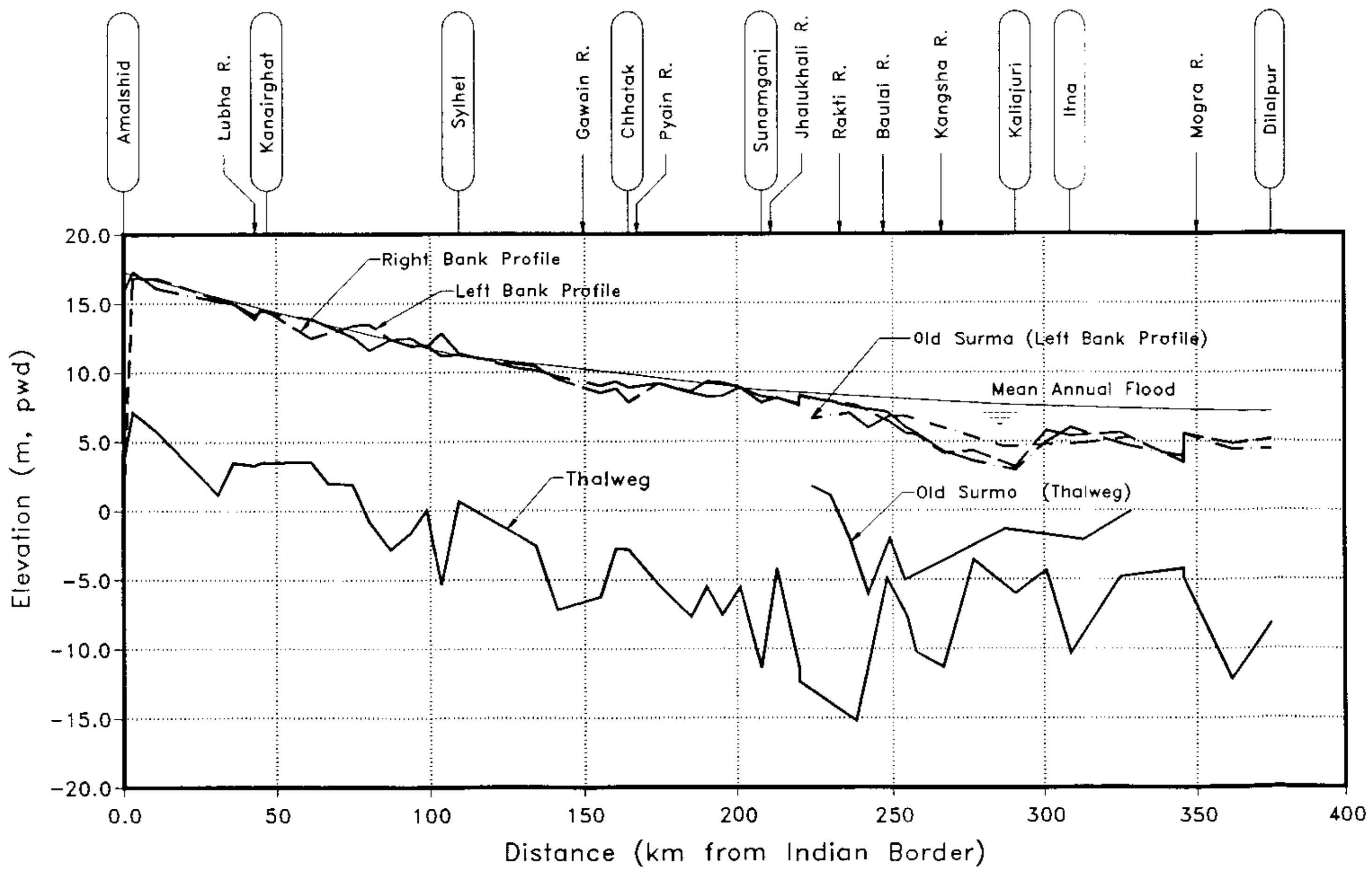
Northeast Regional Project			
Surma River at Chhatak			
Prepared by:	DMc/Tarek	October 1994	
Drawn by:	Jalal	AutoCAD Drawing	

FILE: 268.DWG

Figure C-39

Channel Properties





Slope (monsoon)= 2.6cm/km

Bed Material Size

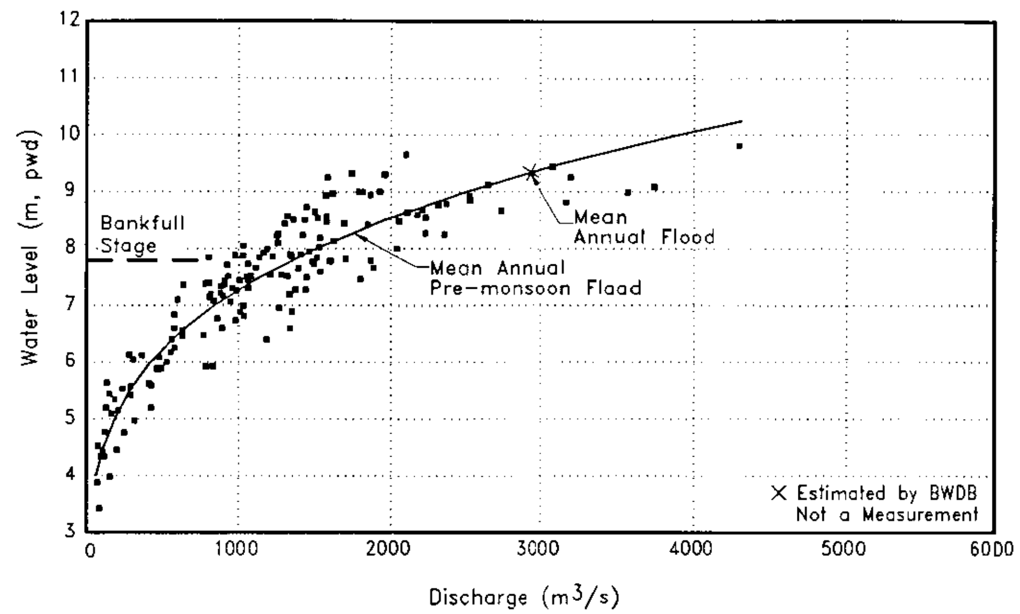
D_{50} = 0.16mm

D_{35} = 0.13mm

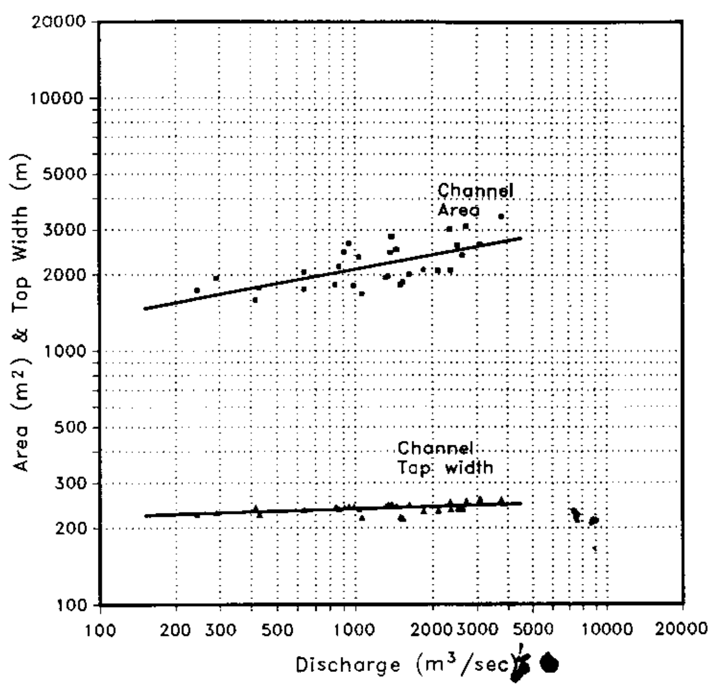
Northeast Regional Project	
Surma River at Chhatak	
Prepared by: DMc	November 1994

FILE: M268-3.DWG

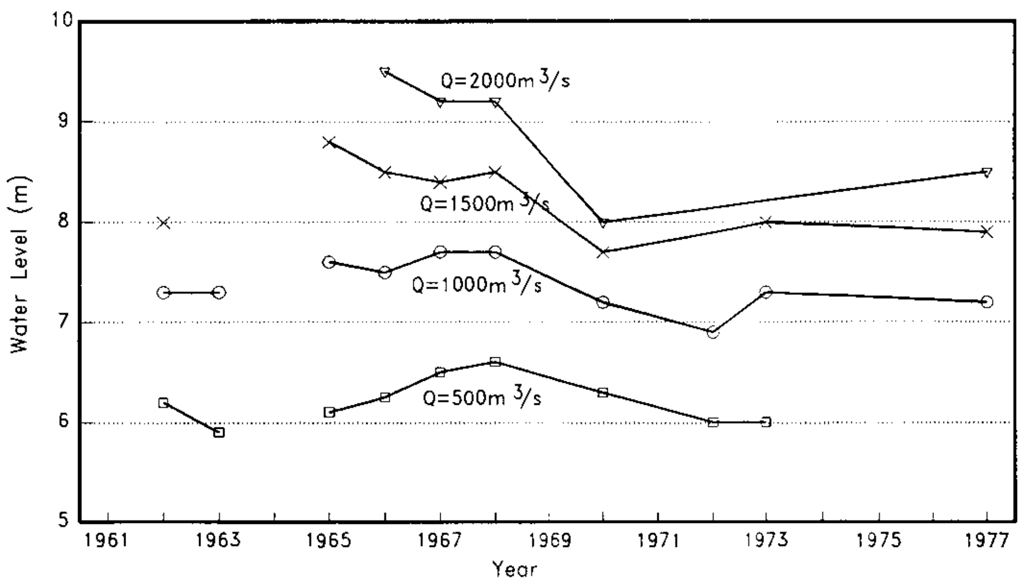
Rating Curve (1961-1977)

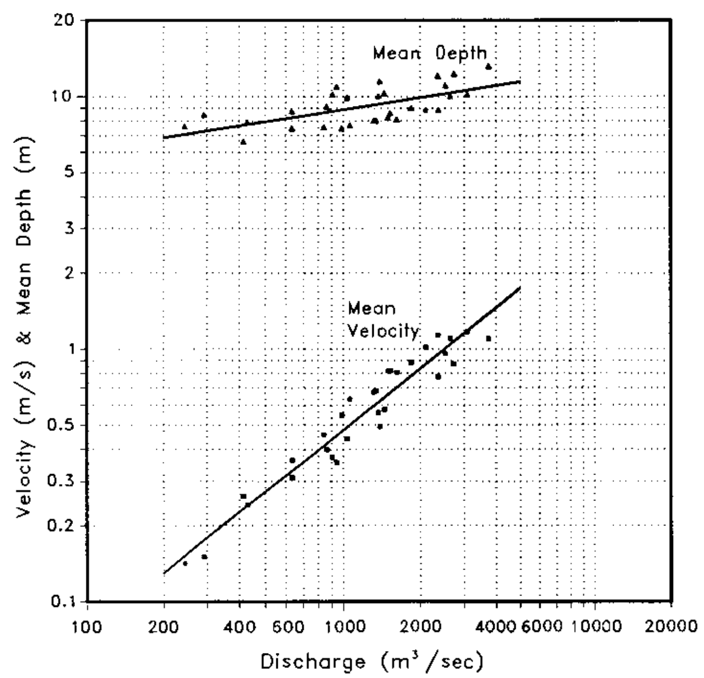


Hydraulic Geometry



Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)





COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.12$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Specific gauge plot shows a drop in rating curves around 1968.

3. Hydraulic Geometry Relations

   $A = 567.47 Q^{0.19}$
   $W = 193.09 Q^{0.03}$
   $d = 02.94 Q^{0.16}$
   $v = 0.002 Q^{0.81}$

Condition	Q	A	W	d	v
1.	1753	2337	241	9.7	0.75
2.	2929	2576	245	10.5	1.14

1. Mean annual pre-monsaan flood
2. mean annual Flood

Q= Discharge (m3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

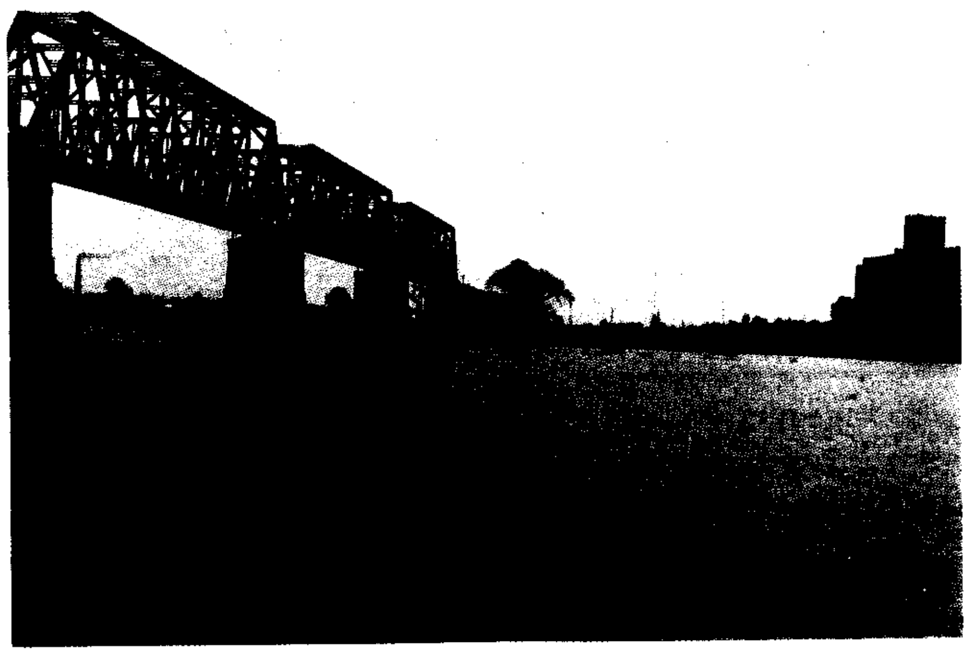
Northeast Regional Project

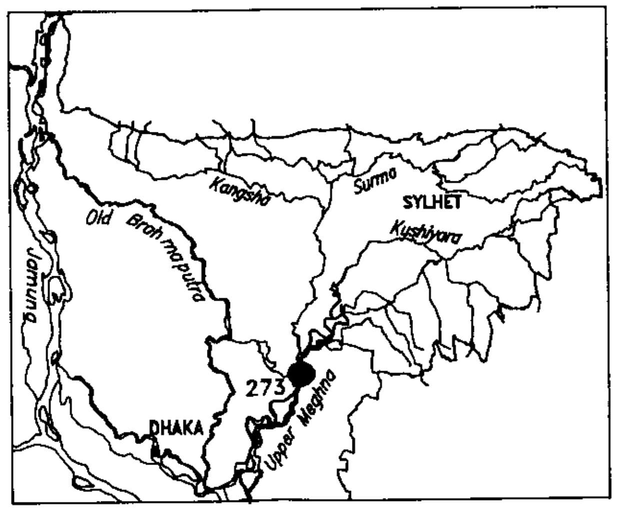
Surma River at Chhatak

Prepared by: DMc | November 1994

FILE: BD-268.BWG

Figure C-41


View to left bank, downstream of gauge



Site Location:

River Characteristics:

1. Gauge Number: 273

2. Location:
   Lat. 24 02'41"N
   Lon. 90 59'40"E

3. Available Data
   Water Level: 1964–70,1972–93
   Discharge : 1964–70,1972–76,1981–93
   Sediment: 1964–70,1972–82, 1984–93

4. Physical Setting:

   Physiographic Unit: Lowland Floodplain
   Agro–ecologic Zone: Middle Meghna River Floodplain

   Features: The Meghna River is the main outlet for the NE Region. Below Bhairab, the river occupies the former channel of the Brahmaputra R., which shifted westwards into its present course nearly 200 years ago.

5. Channel Pattern:

   Channel: Split, "anastomosing" channel with irregular meanders
   Islands: Frequent major islands downstream of Bhairab
   Bars: Shoals and point bars
   Sinuosity: 1.33

6. Sedimentology
   Channel: Mainly fine sand.

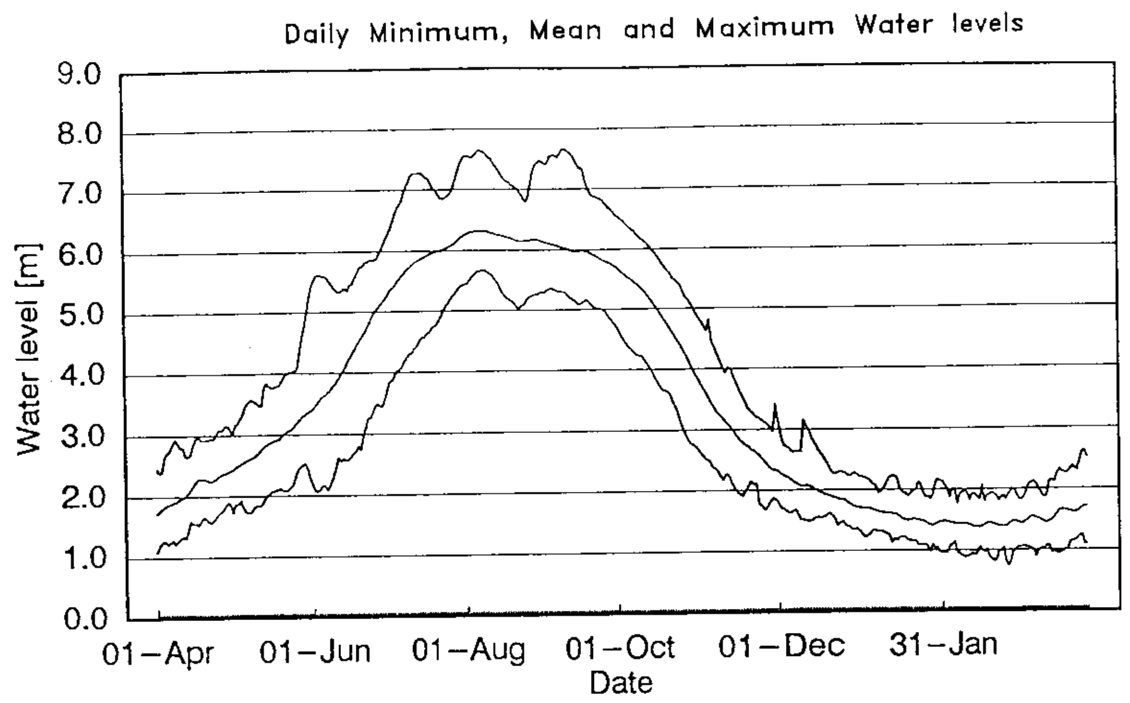
   Banks: Mainly silt and silty sand

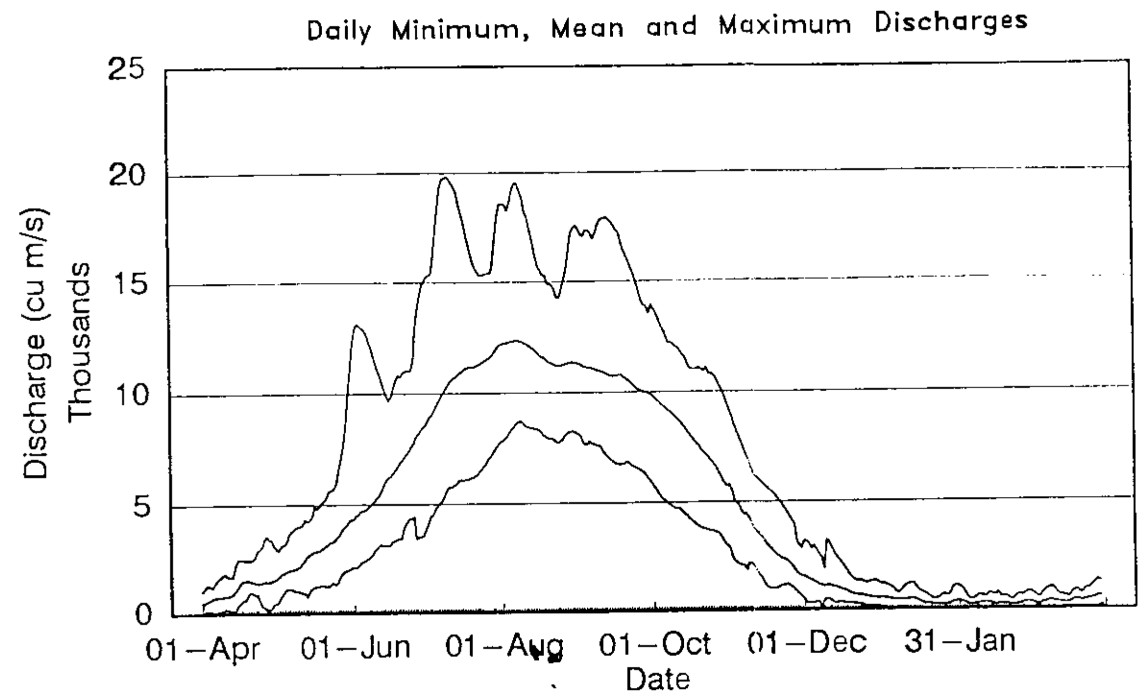
7. Pattern of Instability
   Rapid meander progression at Bhairab causing erosion to floodplain land, & undermining of town protection. Downstream of Bhairab, the distributary channels appear to be subject to periodic instability, shifting and infilling.

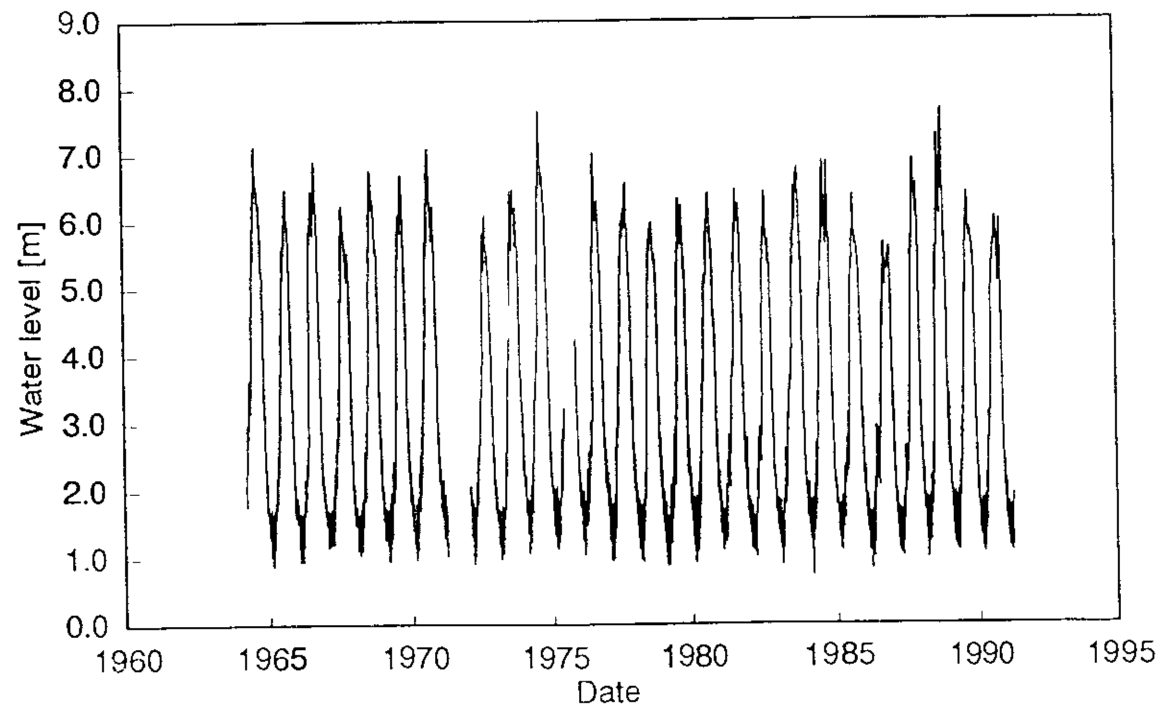
Northeast Regional Project	
Meghna River at Bhairab Bazar	
Prepared by: DMc	October 1994

FILE: M273–LDWG

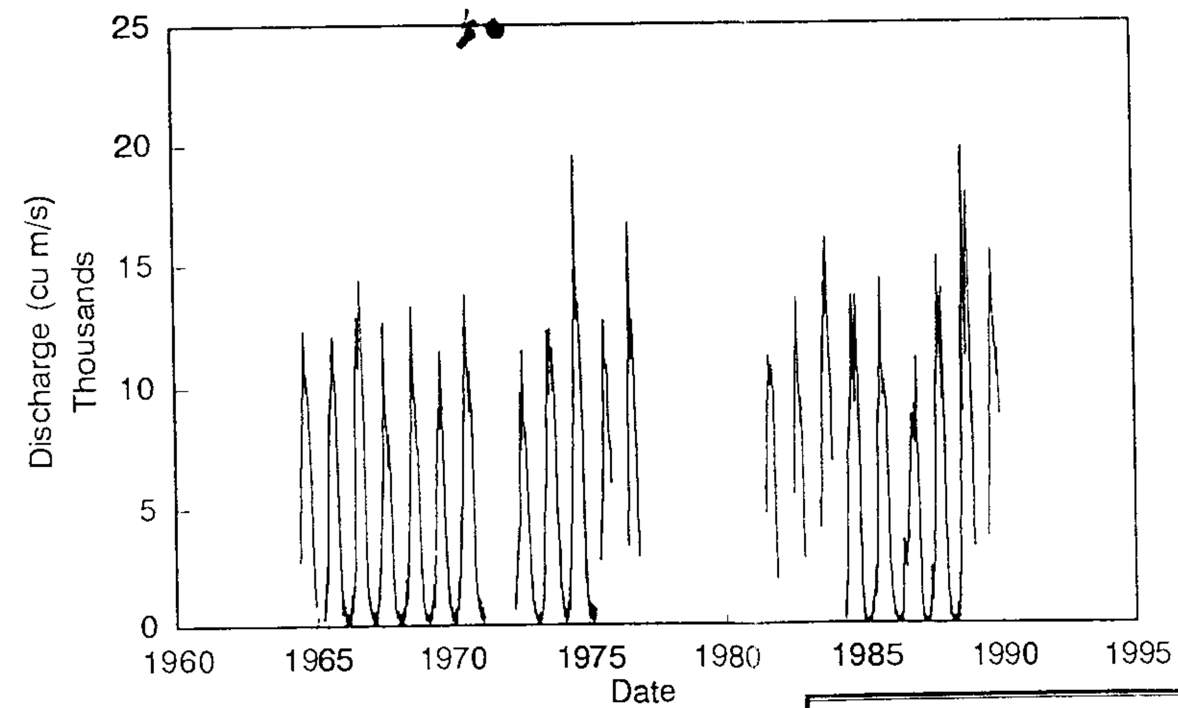
Figure C-42







Recorded Water Levels

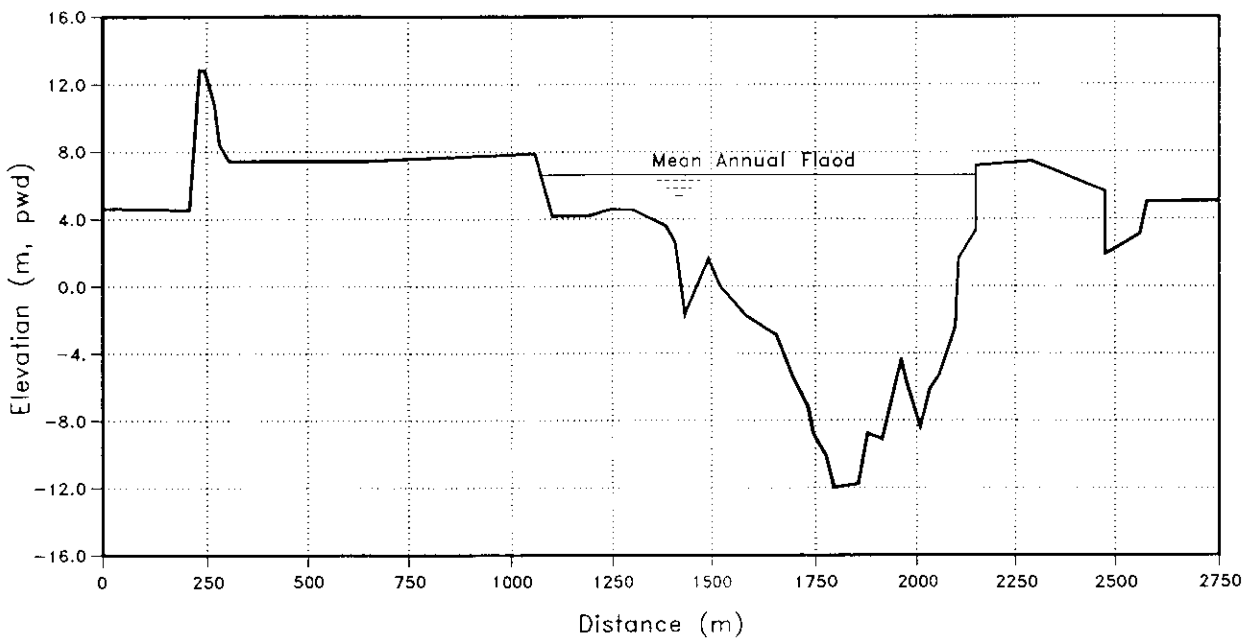


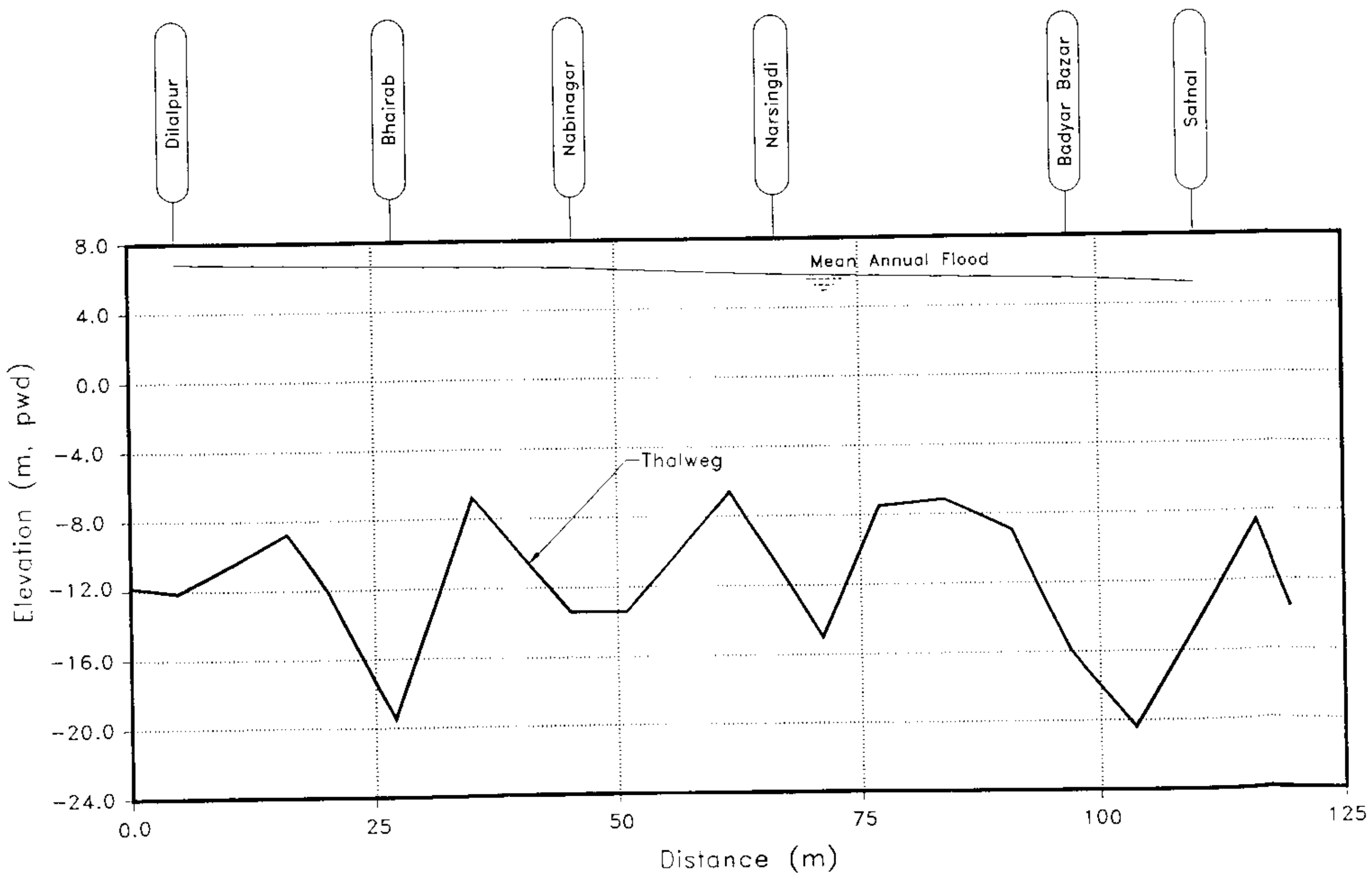
Recorded Discharges

Northeast Regional Project			
Meghna River at Bhairab Bazar			
Prepared by:	DMc/Tarek	October 1994	
Drawn by:	Jalal	AutoCAD Drawing	

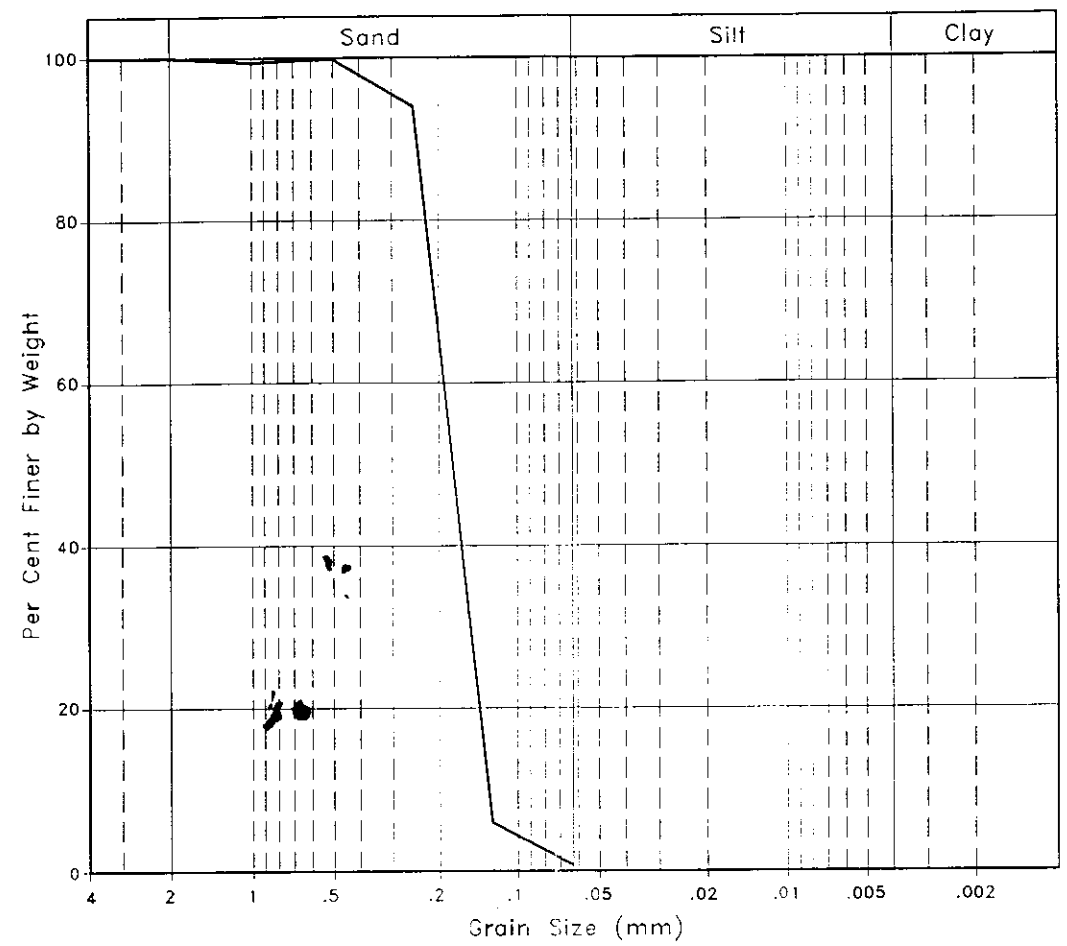
FILE: 273.DWG

Figure C-43





Channel Properties



Slope (monsoon)= 0.8–1.9cm/km(Varies seasonally)

Bed Material Size

D_{50} = 0.12mm

D_{35} = 0.095mm

D_{10} = 0.06mm

Northeast Regional Project

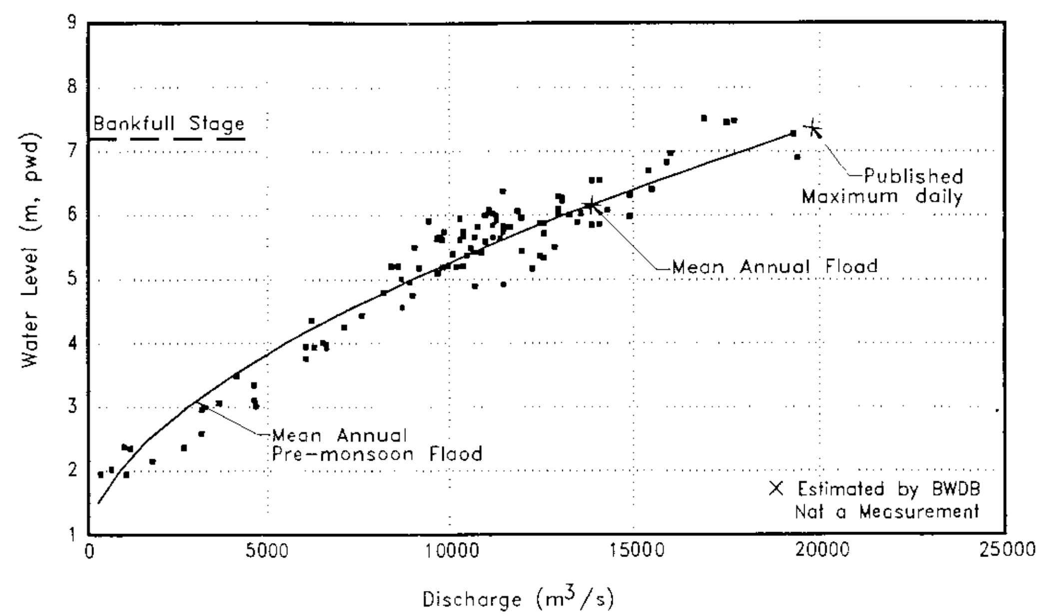
Meghna River
at Bhairab Bazar

Prepared by: DMc | November 1994

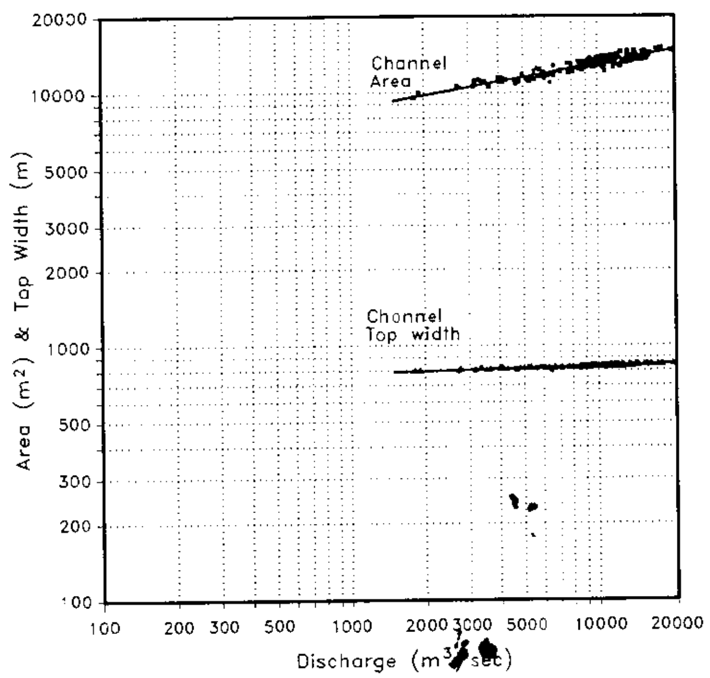
FILE: M273-3.DWG

Figure C-44

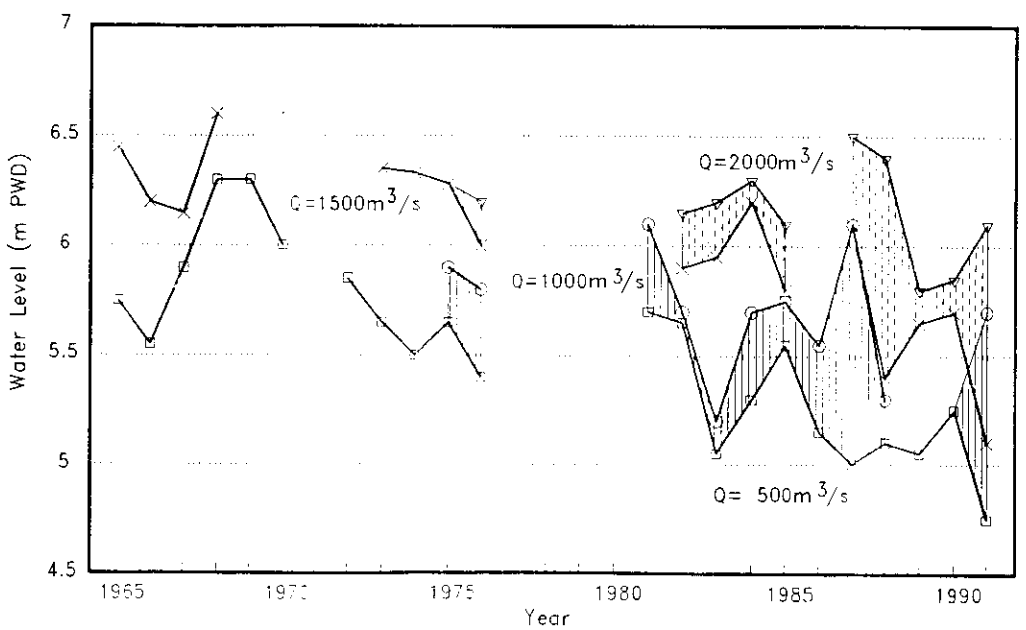
Rating Curve (1988–1992)



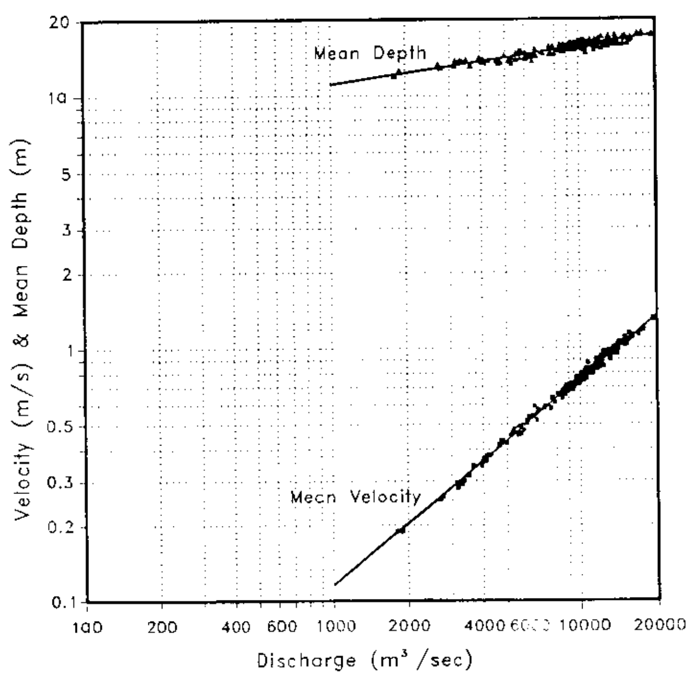
Hydraulic Geometry



Historic Variation in Stage Discharge Relations (Specific Gauge Analysis)



Note: After 1975, stage discharge relations show a seasonal hysteresis due to backwater conditions from the lower Meghna River.



COMMENTS

1. $\frac{QMAXpub}{QMAXobs} = 1.02$

   Rating curve must be extrapolated to estimate monsoon flood flows.

2. Water levels are affected by backwater at all flows, Rating curves after 1975 show looping and hysteresis. The specific gauge plot show ratings curves have lowered by nearly 1m since 1981.

3. Hydraulic Geometry Relations

   $A = 2491.4Q^{0.18}$
   $W = 642.45Q^{0.029}$
   $d = 3.902Q^{0.15}$
   $v = 0.0004Q^{0.82}$

Condition	Q	A	W	d	v
1.	3003	10552	806	13.1	0.28
2.	13883	13906	842.5	16.51	1.0

1. Mean annual pre-monsoon flood
2. mean annual Flood

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Northeast Regional Project

Meghna River at Bhairab Bazar

Prepared by: DMc | Oct 94

FILE: BD-273.DWG