Government of the People's Republic of Bangladesh
Bangladesh Water Development Board
Water Resources Planning Organization

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

KALNI-KUSHIYARA RIVER MANAGEMENT PROJECT FEASIBILITY STUDY

ANNEX A SEDIMENTATION AND MORPHOLOGY

Final Report
March 1998

SNC ♦ Lavalin International
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services

Canadian International Development Agency

2

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

Government of the People's Republic of Bangladesh
Bangladesh Water Development Board
Water Resources Planning Organization

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

KALNI-KUSHIYARA RIVER MANAGEMENT PROJECT FEASIBILITY STUDY

ANNEX A SEDIMENTATION AND MORPHOLOGY

Final Report
March 1998

SNC ♦ Lavalin International
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services

Canadian International Development Agency

ACRONYMS AND ABBREVIATIONS

BIWTA	Bangladesh Inland Water Transport Authority
BP	Before present
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
cm	centimetre
CO	Community Organizer
DTM	Digital Terrain Model
EPWAPDA	East Pakistan Water and Power development Authority
FAP	Flood Action Plan
FW	Future With Project
FWO	Future Without Project
GEV	General Extreme Value
GPS	Global Positioning System
ha	hectare
hr	hour
kg	kilogram
km	kilometre
KK	Kalni-Kushiyara
KKRMP	Kalni-Kushiyara River Management Project
LLW	Low Level Water
m	metre
NERP	Northeast Regional Water Management Project
PWD	Public Works Department
SWMC	Surface Water Modelling Centre
WSC	Water Survey of Canada

GLOSSARY

beel	floodplain lake that may hold water perennially or dry up during the winter season
boro	rice grown during the winter season
dhala	breaches across river banks
duar	scour hole in river bed which provides habitat for fish and river dolphins
haor	depression on floodplain located between two or more rivers
khal	channel
thana	geo-administrative unit under a district comprising several unions

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS i
GLOSSARY ii
TABLE OF CONTENTS iii
LIST OF TABLES v
LIST OF FIGURES vi

1. INTRODUCTION 1
   1.1 Purpose 1
   1.2 Scope 1
   1.3 Kalni-Kushiyara River System 1
   1.4 Annex Outline 3

2. AVAILABLE DATA 5
   2.1 Published Information 5
   2.2 Field Investigations 7

3. GEOMORPHIC SETTING 13
   3.1 Geology 13
   3.2 Topography 13
   3.3 Landforms 14
   3.4 Physiographic Units 14

4. HYDROLOGY 17
   4.1 Runoff 17
   4.2 Trends 18
   4.3 Flood Frequency 20

5. RIVER CHARACTERISTICS 25
   5.1 Kushiyara River, Amalshid to Sherpur 25
   5.2 Kushiyara River, Sherpur to Markuli 25
   5.3 Kalni River, Markuli to Ajmiriganj 27
   5.4 Kalni River, Ajmiriganj to Madna 27
   5.5 Dhaleswari River, Madna to Dilalpur 29
   5.6 Upper Meghna River near Bhairab Bazar 29

6. SEDIMENT TRANSPORT 31
   6.1 Terminology 31
   6.2 Sampling Program 31
   6.3 Sampling Equipment 31
   6.4 Sampling Procedures 32
   6.5 Observations 32
   6.6 Total Suspended Sediment Load 34
   6.7 Size Distribution of the Load 35
   6.8 Sediment Transport Predictions 43

7. LATERAL STABILITY ... 45
7.1 History of Channel Changes ... 45
7.2 Styles of Channel Instability ... 48
7.3 Future Erosion Hazards ... 50

8. VERTICAL STABILITY ... 53
8.1 General ... 53
8.2 Historic Channel Changes ... 53
8.2.1 Upper Kushiyara River ... 53
8.2.2 Lower Kushiyara/Kalni River ... 54
8.2.3 Dhaleswari River ... 57
8.2.4 Summary ... 60
8.3 Seasonal Variations ... 62
8.3.1 1993 Cross Section Comparisons ... 62
8.3.2 1994-1996 Hydrographic Survey Comparisons ... 62
8.3.3 Summary ... 64

9. FUTURE EVOLUTION OF THE RIVER ... 67
9.1 Assumptions ... 67
9.2 Kushiyara River, Fenchuganj to Sherpur ... 67
9.3 Kalni-Kushiyara River, Sherpur to Ajmiriganj ... 67
9.4 Kalni River - Ajmiriganj to Cherapur Khal ... 69
9.5 Lower Kalni-Dhaleswari River ... 73

10. PROJECT IMPACTS ... 75
10.1 Project Description ... 75
10.2 Hydrological Impacts ... 77
10.2.1 Discharge ... 77
10.2.2 Water Levels ... 78
10.3 Morphologic Impacts ... 79
10.3.1 Upper Kushiyara - Fenchuganj to Sherpur ... 79
10.3.2 Kushiyara River - Sherpur to Markuli ... 79
10.3.3 Kalni River - Markuli to Ajmiriganj ... 79
10.3.4 Ajmiriganj to Kadamchal ... 80
10.3.5 Kalni-Dhaleswari River Below Issapur ... 81
10.3.6 Downstream Impacts on Upper Meghna River ... 82
10.4 Long-term Bed Profile Response ... 83
10.4.1 Morphologic Models ... 83
10.4.2 Model Development ... 83
10.4.3 Model Verification ... 84
10.4.4 Idealized Channel Response ... 84
10.4.5 Alternative 1 ... 85
10.4.6 Alternative 2 ... 86
10.4.7 Channel Maintenance Requirements ... 87

REFERENCES ... 89

LIST OF TABLES

Table A.1 Kushiyara River System
Table A.2 Location of Key Sites
Table A.3 Summary of BWDB Hydrometric Measurements
Table A.4 Cross Section Monitoring on Kalni River, Markuli to Dilalpur
Table A.5 Hydrographic Surveys on Kalni-Kushiyara River
Table A.6 Summery of NERP Hydrometric Measurements
Table A.7 Radio-Carbon Dates of Floodplain Sediments
Table A.8 Seasonal Distribution of Runoff at Sherpur
Table A.9 Variations in Rainfall and Runoff
Table A.10 Flood Discharges on Kushiyara River
Table A.11 Flood Frequency Analysis of Discharges at Sherpur on Kushiyara River
Table A.12 Flood Frequency Analysis of Water Levels
Table A.13 Frequency of Historic Floods (Annual Maximum)
Table A.14 River Reach Classification
Table A.15 Discharges on April 6, 1996
Table A.16 Seasonal Variations in Bed Sediments on Kalni River
Table A.17 Summary of Sediment Sampling Program, 1995-1996
Table A.18 Suspended Sediment Measurements at Sherpur
Table A.19 Suspended Sediment Measurements at Markuli
Table A.20 Suspended Sediment Measurements at Ajmiriganj
Table A.21 Suspended Sediment Measurements at Shantipur
Table A.22 Suspended Sediment Measurements at Kadamchal
Table A.23 Size Distribution of the Suspended Load
Table A.24 Suspended Sediment Concentration Rating Curve Relations
Table A.25 Comparison of Predicted Loads by Rating Curve Methods
Table A.26 Long-term Load at Sherpur
Table A.27 Estimated Annual Load at Sherpur by Size Fraction
Table A.28 Predicted Sediment Transport Concentrations
Table A.29 Key Events on Kalni-Kushiyara River
Table A.30 Historical Erosion Rates
Table A.31 Erosion Hazards on Kalni-Kushiyara River
Table A.32 Channel Changes Between Fenchuganj and Manumukh
Table A.33 Hydraulic Geometry Comparisons on Kalni River (Page 1 of 2)
Table A.34 Seasonal Scour and Fill Between Ajmiriganj and Shanitpur Reach 8 Upper Half Volume
Table A.35 Seasonal Scour and Fill Between Ajmiriganj and Issapur
Table A.36 Future Erosion Along Kalni-Kushiyara River
Table A.37 Estimated Water Surface Slopes (mm/km)
Table A.38 Estimated Flow Split on Kalni-Dhaleswari River
Table A.39 Estimated Channel Changes on Kalni River
Table A.40 Summary of Channel Excavation Volumes
Table A.41 Discharges along Kalni-Kushiyara River
Table A.42 Properties of *Duars* Near Katkhal
Table A.43 Predicted Local Bed Levels at *Duars*
Table A.44 Maintenance Dredging after Project Completion

LIST OF FIGURES

Figure A.1 Project Area
Figure A.2 Map of Kalni-Kushiyara River
Figure A.3 NERP River Investigations
Figure A.4 Morphology Directorate Cross-Section Locations
Figure A.5 Tectonic Map of Bangladesh
Figure A.6 Quaternary Sedimentation in Bangladesh
Figure A.7 Land Elevations
Figure A.8 1988 Flood in the Northeast Region
Figure A.9 Landforms on Lowland Floodplains
Figure A.10 Anastomosing Channel Pattern on Lowland Rivers in the Central Basin
Figure A.11 Overbank Sedimentation at Koyer Dhala
Figure A.12 Channel Pattern on Flood Basin Lowlands
Figure A.13 Physiography
Figure A.14 Schematic Flow Distribution
Figure A.15 Maximum Daily Discharges Kushiyara River
Figure A.16 Changing Flood Plain and Channel Flows-Kushiyara River at Sheola
Figure A.17 Kushiyara River at Sheola - River Characteristics
Figure A.18 Kushiyara River at Sheola - Hydraulic Geometry
Figure A.19 Kushiyara River at Sherpur - River Characteristics
Figure A.20 Kushiyara River at Sherpur - Hydraulic Geometry
Figure A.21 Kalni River at Markuli - River Characteristics
Figure A.22 Kalni River at Markuli - Hydraulic Geometry
Figure A.23 Kalni River at Ajmiriganj - River Characteristics
Figure A.24 Kalni River at Ajmiriganj - Hydraulic Geometry
Figure A.25 Kalni River at Shantipur - River Characteristics
Figure A.26 Kalni River at Shantipur - Hydraulic Geometry
Figure A.27 Kalni River at Kadamchal - River Characteristics
Figure A.28 Kalni River at Kadamchal - Hydraulic Geometry
Figure A.29 Satellite Photo of Dhaleswari/Khowai River Junction
Figure A.30 Meghna River at Bhairab Bazar - River Characteristics
Figure A.31 Meghna River at Bhairab Bazar - Hydraulic Geometry
Figure A.32 Longitudinal Profile of Kalni-Kushiyara River
Figure A.33 Bed Material Characteristics along Kalni-Kushiyara River
Figure A.34 Classification of Sediment Transport in Rivers
Figure A.35 Sampling Days at Sherpur, Markuli and Ajmiriganj
Figure A.36 Suspended Sediment Rating Curves 1995-1996 - Sherpur, Markuli and Ajmiriganj
Figure A.37 Suspended Sediment Rating Curves 1995-1996 - Shantipur and Kadamchal
Figure A.38 Seasonal Hysteresis at Ajmiriganj
Figure A.39 Size Distribution of Suspended Sediment Samples
Figure A.40 Rennell's Map of the Northeast Region
Figure A.41 Evolution of the River Systems
Figure A.42 Kalni-Kushiyara River Channel Changes
Figure A.43 Kalni-Kushiyara River Channel Changes

Figure A.44 Channel Shifting near Shepur
Figure A.45 Channel Shifting near Markuli
Figure A.46 Channel Shifting near Katkhal
Figure A.47 Channel Widening on Kalni-Kushiyara River
Figure A.48 Meander Changes
Figure A.49 Rates of Erosion on Kalni-Kushiyara River
Figure A.50 Erosion Hazard
Figure A.51 Upper Kushiyara River Cross Section Comparisons
Figure A.52 Longitudinal Profile of Kalni-Kushiyara River (1963-1988)
Figure A.53 Bed Level Changes Kushiyara River
Figure A.54 Section M-38
Figure A.55 Section M-37
Figure A.56 Section M-36
Figure A.57 Section M-35
Figure A.58 Section M-34
Figure A.59 Section M-33
Figure A.60 Bed Level Changes on Dhaleswari River
Figure A.61 General Pattern of Deposition on Dhaleswari River
Figure A.62 Annual Water Levels Kushiyara River
Figure A.63 Annual Water Levels Kalni River
Figure A.64 Surma River Longitudinal Profile
Figure A.65 Water Levels Surma River
Figure A.66 Seasonal Variations in Bankfull Area
Figure A.67 General Plan of Kalni-Kushiyara River Surveys
Figure A.68 Scour and Fill near Ajmiriganj
Figure A.69 Cumulative Bed Level Changes Downstream of Ajmiriganj
Figure A.70 Future Without Project Scenario Kalni-Kushiyara Project
Figure A.71 Comparison of Slope on Kalni River & Cherapur Khal
Figure A.72 General Arrangements of River Improvement Works
Figure A.73 River Improvements and Platform Locations - Alternative 1
Figure A.74 Water Surface Profile (1:5 yr Flood) - Alternative 1 FW
Figure A.75 Channel Changes near Katkhal
Figure A.76 Potential Downstream Impacts
Figure A.77 Kalni-Kushiyara River Bankfull Properties
Figure A.78 Comparison of Channels Meghna River and Kalni River
Figure A.79 Channel Response to Dredging and Loop Cutting
Figure A.80 Long-term Bed Profile Response - Alternative 1

1. INTRODUCTION

1.1 Purpose

This Annex summarizes the sedimentation and morphologic investigations that were carried out for the feasibility study of the Kalni-Kushiyara River Management Project, (KKRMP). The investigation included:

- diagnosing the causes of recurring channel instability and sediment deposition along the lower Kalni-Kushiyara River;
- assessing future trends of river behaviour;
- assessing the feasibility of improving the river's overall stability;
- predicting the physical impacts of proposed channel improvements, and
- assessing the ongoing maintenance required for the project.

1.2 Scope

The investigations were carried out over the entire 300 km Kushiyara-Kalni-Dhaleswari-Meghna River system, with the work focused on the 110 km reach between Madna and Sherpur (Figure A.1). Field studies by NERP commenced in September 1992, as part of regional investigations of river processes (NERP, 1994). The scope of the work increased over time as interest in the Kalni River system intensified. Continuous hydrographic surveys of the river system started in September 1994, and hydrometric and sediment transport investigations were carried out in 1995 and 1996.

1.3 Kalni-Kushiyara River System

The Kalni-Kushiyara River system originates from the Barak River in India. The Barak River drains 25,260 km^2 of land in the Indian states of Assam, Manipur and Mizoram. The river then crosses into Bangladesh near Amalshid, and splits into the northward flowing Surma River and the southward flowing Kushiyara River. Below Amalshid, the river undergoes several name changes (Table A.1). All locations have been referenced to a chainage, which is measured along the river centreline. The chainage starts from the BWDB gauge on the Meghna River at Bhairab Bazar and proceeds upstream. Table A.2 summarizes the locations of key sites that are referenced in this text. A 1:10,000 map of the main study reach is included at the end of the report (Figure A.2).

The Sonai-Bardal River, Juri River and Manu River are the main left bank tributaries along the Kushiyara River between Amalshid and Sherpur. North of the river, the land slopes down into the low-lying Surma-Kushiyara Inter-basin. Water from this flood basin, which is drained by distributary channels such as Sada Khal, eventually flow into the Kushiyara River through Damrir Haor near Fenchuganj. Other major distributary channels, such as Barbhaganga Nadi and Itakhola Nadi, flow into Sadipur Khal. This is a major distributary channel that parallels the Kalni River north of Sherpur. These flows eventually enter the Darain River north of Ajmiriganj.

Downstream of Sherpur, the Kushiyara River flows westerly through the Suriya Channel until reaching Markuli. Before 1978, the Upper Kalni River collected runoff from the Surma-Kushiyara Inter-basin and drained southwards into the Kushiyara River at Markuli. In 1978 a closure was constructed across the Kalni River at Markuli, and the flows from the Inter-basin were diverted into the Darain River system.

Table A.1: Kushiyara River System

River Name	Reference Chainage (Km)	Extent
Kushiyara River	313 -163	Amalshid bifurcation to Bibiyana offtake near Sherpur
Kushiyara River	163- 133	Suriya channel to Markuli
Kalni River	133 -66	Markuli to Ratna/Khowai River junction
Dhaleswari River	66 -20	Ratna River junction to Ghorautra River confluence
Upper Meghna River	<20	Downstream of Ghorautra River confluence

Downstream of Markuli, the river is known as the Kalni River. It carries on in a southerly direction until it bifurcates at Issapur, with the shorter western branch called the Baida River. The Kalni River heads eastward through a series of bends and is joined by the Ratna/Khowai River near Madna. The Ratna River drains floodplain land south of Ajmiriganj, while the Khowai River is a major southward flowing Piedmont stream that drains the Tripura Hills in India. Downstream of this confluence, the Kalni River is known as the Dhaleswari River. Since this eastern branch has been gradually silting in, most of the flow during the dry season is now carried by the Baida channel. The Baida channel re-joins the Dhaleswari River south of Astagram. The river joins the Baulai River near Dilalpur and forms the Upper Meghna River.

Table A.2: Location of Key Sites

Feature	Kilometre	River	Comment
Bhairab Bazar	0.0	Meghna	BWDB gauge site
Madna	61.0	Dhaleswari	junction of Ratna R.
Issapur	72.4	Kalni	Kalni/Baida bifurcation
Abdullahpur	79.0	Kalni	village
Kadamchal	84.7	Kalni	NERP hydrometric station
Katkhal	93.5	Kalni	village
Shantipur	95.4	Kalni	NERP hydrometric station
Ajmiriganj	106.5	Kalni	BWDB hydrometric station
Koyer Dhala	115.4	Kalni	site of major spill/breach
Markuli	133.4	Kushiyara	closure blocks old Kalni R.
Sherpur	177.3	Kushiyara	BWDB gauge

1.4 Annex Outline

The Annex is organized as follows:

- Chapter 1, ***Introduction***, provides an introduction to the report and describes its scope;
- Chapter 2, ***Available Data***, summarizes the field investigations that were carried out for this feasibility study;
- Chapter 3, ***Geomorphic Setting***, describes the geological setting and the long-term evolution of the river system;
- Chapter 4, ***Hydrology***, summarizes the magnitude and frequency of discharges on the river from the Barak River bifurcation near Amalshid to the Meghna River confluence;
- Chapter 5, ***River Characteristics***, summarizes the geomorphic and hydraulic characteristics of the river;
- Chapter 6, ***Sediment Transport***, provides an assessment of suspended sediment transport at Sherpur, Markuli, Ajmiriganj, Shantipur and Kadamchal;
- Chapter 7, ***Lateral Stability***, summarizes the history of channel changes along the river, describes the main styles of channel instability and assesses the factors that govern instability;
- Chapter 8, ***Vertical Stability***, assesses the past vertical channel changes that have occurred, and provides a detailed sediment budget for the channel between Ajmiriganj and Issapur in order to illustrate the seasonal pattern of aggradation/degradation;
- Chapter 9, ***Future Evolution of the River***, attempts to forecast the most likely "future without" project scenario over the next 30 years;
- Chapter 10, ***Project Impacts***, summarizes the impacts of proposed project interventions (including loop cuts, erosion protection and channel re-excavation).

Some additional related information is contained in Annex B - Hydrodynamic Model, and Annex C - Engineering.

2. AVAILABLE DATA

2.1 Published Information

The main sources of published data are as follows:

BWDB Cross Sections
River channel cross sections were surveyed by the Bangladesh Water Development Board (BWDB) Morphology Directorate between 1980 and 1991. Copies of the cross sections were obtained from the regional office in Mymensingh. Information on bench marks, survey methods and data analysis were also obtained.

BIWTA Sounding Charts
The Bangladesh Inland Water Transport Authority (BIWTA) has carried out periodic soundings along the Meghna-Dhaleswari-Kalni-Kushiyara River system to assist in navigation and to plan channel maintenance work. Charts from 1963, 1975, 1977, 1988 and 1993 were obtained and used to assess deposition patterns.

BWDB Hydrometric Data
Hydrometric stations have operated in the project area since the 1950s. Table A.3 summarizes the period of records. The locations of these gauges are shown on Figure A.1. The key discharge stations include:

- Kushiyara River at Sheola (173);
- Kushiyara River at Sherpur (175.5), and
- Bhairab Bazar on Meghna River (273).

The key water level stations along the river system include:

- Kushiyara River at Amalshid (172);
- Kushiyara River at Fenchuganj (174);
- Kalni River at Markuli (270);
- Kalni River at Ajmiriganj (271);
- Dhaleswari River at Madna (272), and
- Dhaleswari River at Astagram on (272.1).

BWDB Sediment Transport Data
Since 1969, the BWDB has periodically measured the suspended sediment concentration in the Kushiyara River at Sheola and Sherpur, and at Bhairab Bazar in the Meghna River. Sediment sampling was also conducted during the period 1991-1993 at Sheola and Bhairab Bazar by the Surface Water Modelling Centre (SWMC) using a pump sampling technique.

Table A.3: Summary of BWDB Hydrometric Measurements

Station No.	Type	River	Station	Latitude (N)		Longitude (E)		Confirm	Date Installed	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	92	93
33	Q	Bhattakhal	Gobindaganga	24	56.2	91	41.5		1958	H	H	H	H	H	H	H		H	H	H	H	H	H	H	H	H	H												
67	Q	Dhalai	Kamalganj	24	21.4	91	51.1	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	S	S	S
71	T	Dhaleswari	Kalagachia	23	34.8	90	32.6	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	34.2	90	30.3	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	41.3	91	7.3	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	S	S	S
72 B	Q	Baulai	Sukdevpur	24	52.8	91	9.9	GPS																				C	C	C	C	C	C	C	C	C	S	S	S
73	T	Baulai	Itna	24	31.8	91	5.6	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	S	S	S
74	T	Ghorautra-Balulai	Dilalpur	24	11.2	90	58.6	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	S	S	S
135	Q	Juri	Juri	24	36.5	92	8.2	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	35.6	92	6.7	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	S	S	S
138	Q	Korangi	Sofiabad	24	17.5	91	33.0	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	S	S	S
157		Khowai	Ballah	24	5.0	91	36.0	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	S	S	S
158		Khowai	Chunarghat	24	12.1	91	31.8	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	S	S	S
158.1	Q	Khowai	Shaistaganj	24	16.4	91	28.6	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	S	S	S
159		Khowai/Barak	Habiganj	24	22.1	91	25.7	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	S	S	S
172	Q	Kushiyara	Amalshid	24	52.1	92	28.5	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	S	S	S
173	Q	Kushiyara	Sheola	24	53.4	92	11.4	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	S	S	S
173A	Q	Sada Khal	Sheola	24	53.8	92	10.7	GPS	1947	H		H	H	H	H	H	H	H	H	H	H	H	H															S	S
174	Q	Kushiyara	Fenchuganj	24	42.1	91	56.5	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	S	S	S
175	Q	Kushiyara	Monumukh	24	35.7	91	43.5	NERP	1949	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H				C											
175.5	Q	Kushiyara	Sherpur	24	37.7	91	41.0	GPS																				C	C	C	C	C	C	C	C	C	S	S	S
192	Q	Langla	Motiganj	24	18.3	91	40.9	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	S	S	S
201	Q	Monu	Monu R.R. bridge	24	25.7	91	56.6	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	S	S	S
202		Monu	Moulvi bazar	24	29.6	91	46.4	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	S	S	S
265	Q	Sonai-Bardal	Jaldhup	24	46.4	92	10.4	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	S	S	S
266	Q	Surma	Kanairghat	25	0.0	92	15.6	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	S	S	S
267	Q	Surma	Sylhet	24	53.2	91	52.3	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	S	S	S
268	Q	Surma	Chatak	25	2.2	91	39.9	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	S	S	S
269	Q	Surma-Meghna	Sunamganj	25	4.5	91	24.8	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	S	S	S
270	T	Kusiyara	Markuli	24	41.6	91	22.9	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		S	S	S
271	T	Kalni-Kushiyara	Ajmiriganj	24	33.2	91	13.7	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	S	S	S
272	T	Kalni-Kushiyara	Madna	24	20.1	91	14.3	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		S	S	S
272.1	T	Dhaleswari-Kushiyara	Astagram	24	16.3	91	6.0		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	S	S	S
273	TQ	Meghna	Bhairab bazar	24	2.7	90	59.7	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	S	S	S
274	T	Meghna	Narsingdi	23	55.1	90	43.8	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	38.9	90	37.6	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	36.1	90	37.4	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	28.7	90	35.7	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	17.0	91	24.2	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	S	S	S

Type: Q= Discharge, T= Water level (Tidal), TQ= Discharge (Tidal)
Observations: H= Hard copy, C= Computer copy, S= SWMC

2.

Mapping
The following maps and imagery were used for assessing channel shifting and channel evolution.

SPOT satellite imagery (1989-90)
These 1:50,000 false colour images are referenced to a Transverse Mercator Grid system. The rivers, *beels* and *haors* were digitized and converted to AUTO-CAD to provide a base map of the project area.

Airphotos (1983)
Black and white 1:50,000 scale air photos were provided to the project by Survey of Bangladesh.

Survey of Bangladesh 4"=1 mile topographic maps
These 1:15,840 scale maps were based on air photos taken in 1962/63 and field verification in 1964. Ground topography is represented with 0.3 m interval contours and spot levels. The maps provided excellent detail of channel and floodplain features. The channel, *beels* and main *khals* were digitized to provide a base map.

Survey of Pakistan 1:40,000 scale maps
These planimetric maps were based on air photos taken in 1952. Although no contour information was shown, the maps gave good resolution of the channel alignment.

District Maps 1 inch = 1 mile
Surveyed in 1912/13 and published in 1927, these 1:63,360 scale maps showed channel alignments and villages in the project area.

Rennell Survey
The Rennell's survey of 1758-1768 and his accompanying journal provide the earliest description of the rivers and topography in the region. The maps were originally referenced to latitude and longitude (measured relative to Calcutta). High quality reproductions of the maps were digitized, and then scaled and adjusted to fit the Survey of Bangladesh map sheets.

2.2 Field Investigations

Figure A.3 summarizes the main field investigations that were conducted by or with the assistance of NERP during the period 1993-1996.

Second Order Levelling Survey
A second-order levelling program was conducted in 1993-94 to check the elevation of water level gauges in the project area and to provide accurate benchmarks for future projects and studies. The program involved a level survey to second-order accuracy. Survey of Bangladesh conducted the survey, CIDA provided the funding and NERP provided a field monitor and administered the program.

River Cross Section Surveys
River cross sections were established to monitor annual and seasonal changes in bed levels on the Kushiyara River and Kalni River. Table A.4 and Figure A.4 summarize the location and frequency of the surveys. The monitoring included surveying five cross sections on the Kushiyara River upstream of Sherpur, five cross sections on the Kushiyara River between Sherpur and

Markuli and five cross sections on the Kalni River between Markuli and Kadamchal. Where possible, the cross sections were located at former BWDB sections to facilitate comparisons.

Additional cross sections were surveyed in the winter of 1995 and in 1996 at strategic locations on the Kushiyara River between Manumukh and Markuli, the Kalni River, the Dhaleswari River, the Baida River and Cherapur Khal. These cross sections were primarily used for hydraulic analysis and the hydrodynamic modelling (Annex B - Hydrodynamic Model). The cross sections extended from low water to at least 500 m into the floodplain.

Hydrographic Surveys
NERP developed a fast, accurate method for preparing hydrographic charts of the river bed. The river bed topography was represented on 1:10,000 scale maps with 1 m contours and spot elevations. The collection of charts has been reproduced as a separate annex (Annex M - Project Maps). Table A.5 summarizes the dates and extent of these surveys. In total, approximately 400 km of surveys were completed, including sounding approximately 850 cross section lines.

Hydrometric Measurements
Table A.6 summarizes the key sites where water level and discharge measurements were carried out in 1995 and 1996. The water level stations were established by installing a staff gauge and hiring a gauge reader to measure the levels four times daily. Miscellaneous discharge measurements were made at several key stations (on the Kalni River at Markuli, Ajmiriganj, Shantipur, Kadamchal and Cherapur Khal). The measurements were done throughout the dry season, and continued into pre-monsoon while the flows were confined within the main channel.

Suspended Sediment Measurements
Suspended sediment concentrations and loads were measured at Sherpur, Markuli, Ajmiriganj, Shantipur and Kadamchal in 1995 and 1996. The data were used to establish suspended sediment rating curves and to estimate the annual suspended sediment load.

In addition to these conventional measurements, a number of large (five litre) pump sample measurements were made at Sherpur, Markuli, Ajmiriganj and Shantipur. These samples were sent to the sediment laboratory at the SWMC to analyse the particle size distribution of the suspended load.

Floodplain Sedimentation
Estimates of floodplain deposition rates were made at 26 locations between Ajmiriganj and Madna over the 1995 monsoon season. This involved establishing reference pillars on the left and right floodplains during the pre-monsoon season. Collars were placed around the pillars and the initial ground surface level was measured. At the end of the post-monsoon season, the sites were re-visited and the change in ground level was estimated by measuring the amount of accretion on the collar.

Bed Material Sampling
Bed material samples were collected during several reconnaissance trips down the river between Sherpur and Madna, as well as from Bhairab Bazar on the Meghna River. The samples were collected from 75 sites in 1994 and 1995 using a conventional van Veen "grab" sampler. The samples were sent to the sediment lab at the SWMC for particle size analysis.

Sub-Surface Drilling
Twelve boreholes were drilled in the channel and floodplain between Ajmiriganj and Issapur in 1995 and 1996. The five boreholes on the floodplain were situated along the alignment of proposed loop cuts at Issapur and Katkhal. The seven boreholes in the main river channel were all located in the vicinity of Kakailseo and Gazaria.

The borings were made by percussion drilling using a 125 mm casing pipe. Seamless 50 mm diameter drill rods were used inside the cased hole. A chopping bit was attached to the lower end of the drill rods and the head of the pipe was connected to a water pump. Disturbed soil samples were collected at 0.5 m intervals to a depth of 6 m by means of a split spoon sampler.

Information from Community Organizers
The social team's community organizers (COs) provided detailed accounts from villagers about historic changes on the river, bank erosion and past work carried out by BWDB, BIWTA and other organizations. This "oral history" provided very useful checks and independent verification of many findings that were produced from the morphologic studies.

Table A.4: Cross Section Monitoring on Kalni River, Markuli to Dilalpur

	Dist (km)	1980	1981	1982	1986	1987	1990	1991	May 93	Jun 93	Jul 93	Sep 93	Dec 93	1994
M-22	28.0						X	X						X
M-23	34.0						X	X						X
M-25	47.0						X	X						X
M-26	54.0						X	X						X
M-27	61.0						X	X						X
M-28	70.0						X	X						X
M-29	77.0						X	X						X
M-30	82.0						X	X						X
M-31	88.0						X	X						
M-32	94.2								X	X	X	X	X	
M-33	99.9		X		X	X	X	X				X	X	
M-34	105.3		X	X	X	X	X	X				X	X	
M-35	112.0	X	X		X	X	X	X	X	X	X	X	X	
M-36	117.7	X	X	X	X	X	X	X	X	X	X	X	X	
M-36A	121.7								X	X		X	X	
M-37	123.4	X	X		X	X	X	X	X	X	X	X	X	
M-37A	126.2								X	X	X	X	X	
M-38	129.5	X	X	X	X	X	X	X	X	X	X	X	X	
M-39	134.7													
M-41	152.0													

Surveys from 1980-1991 by BWDB Morphology Directorate
Surveys from 1993 by NERP

Table A.5: Hydrographic Surveys on Kalni-Kushiyara River

Map #	Reach (km)	94A Sep 94	95A Feb 95	95B May 95	95C Jul 95	95D Sep 95	96A Feb 96
1	28.0-42.0						X
2	42.0-49.0						X
3	49.7-56.1		X				X
4	56.0-68.0					X	X
5	67.9-76.7		X			X	
6	76.4-84.3		X			X	
7	84.0-99.0	X	X		X	X	X
8	98.0-107.9	X	X		X		X
9	106.9-116.0	X	X		X		
10	114.9-126.3	X	X		X		
11	124.8-136.7		X		X		
12	136.5-147.5				X		
13	147.0-158.3				X		
14	157.0-171.9				X		
15	170.0-178.7				X		
16	178.1-183.5				X		

Table A.6 : Summery of NERP Hydrometric Measurements

Stn No	Station Name	River	Latitude		Longitude		1995									1996							
			Deg	Min	Deg	Min	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
B175-5	Sherpur	Kushiyara	24	27.4	91	41.0	S	S	S	S	S	S	S										
B270	Markuli	Kalni	24	41.7	91	22.9		S	S	S	S	S	S										
B271	Ajmiriganj	Kalni	24	32.5	91	13.7	S	S	S	S	S	S	S		S	S	S	S	S	S			
1	Ajmiriganj (closure)	Bheramohona	24	34.4	91	14.4	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
2	Aktar Bazar	Mahasingh	24	53.6	91	28.7	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W		
7	Durgapur	Bashira						W	W	W	W	W	W	W	W	W	W	W	W	W			
8	Ilaspur	F.P							W	W	W	W	W	W	W	W	W	W	W	W			
9	Jagannathpur	Naljur						W	W	W	W	W	W	W	W	W	W	W	W	W			
10	Khagapasha	Old Kushiyara	24	33.1	91	26.3	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
13	Madhabpur	Singli	24	37.5	91	32.5	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
15	Nilpur	Old Surma	24	59.7	90	23.3	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
18	Ratna	Ratna Shatal						W	W	W	W	W	W	W	W	W	W	W	W	W			
19	Shadipur	Shadipur Khal						W	W	W	W	W	W	W	W	W	W	W	W	W			
20	Terapasha	Bijna	24	33.1	91	36.5		W	W	W	W	W	W	W	W	W	W	W	W	W			
21	Katakhali	Kalni	24	37.3	91	18.2	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	
22	Shantipur	Kalni	24	28.9	91	11.2	W	W	W	W	W	W	W	W	S	S	S	S	S	W	W		
23	Kadamchal	Kalni	24	25.7	91	12.2	W	W	W	W	W	W	W	W	S	S	S	S	S	S	W	W	
24	Dhanpur	Gachiduar											W	W	W	W	W	W	W	W			
25	Gazaria	Kalni	24	32.1	91	13.3												S	S	S	S	S	S
26	Kakailseo	Kalni	24	30.6	91	12.2										S	S	S	S				
27	Kaisar	Cherapul khal	24	27.2	91	9.5								Q	Q	Q	Q	Q	Q	Q			

Legend :
B = Station corresponding to BWDB
S= Suspended sediment station (including discharge and water level)
Q = Discharge and water level
W = Water level only
Note : Discharge at sherpur estimated from published rating curves.

3. GEOMORPHIC SETTING

3.1 Geology

The landforms in the project area have evolved as a result of alluvial sedimentation into a slowly subsiding tectonic basin. Consequently, most of the project area is underlain by alluvial, lacustrine and deltaic deposits consisting of fine sand and silt/silty clay or peat deposits.

Figure A.5 shows the overall tectonic setting. The Sylhet Trough, which underlies most of the region, consists of 13 -20 km of alluvial and deltaic sediments underlain by much older gneiss and granitic rocks. This basin is bounded by the Shillong Plateau to the north, the Indian-Burman ranges to the east and the Indian Shield to the west. Rapid subsidence has occurred in the basin since Miocene times (22 million years BP, Before Present) 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). The southern and eastern portions of the Sylhet Trough are characterized by a series of north-trending folded anticlines. These anticlines, which consist primarily of Pliocene and Pleistocene age sedimentary rock (mainly Tipam and Dupi Tila sandstone), form the Tripura Hills along the southern border of the region.

Most of the sediments in the project are of Holocene age (the last 10,000 years). The rate of sedimentation in the region, in response to changes in sediment supply and runoff conditions, has probably varied considerably over time. Palynological studies have shown most of India and Bangladesh were much drier than presently at the time of world wide glacial maximums (around 18,000 years BP). Much more humid conditions prevailed from about 12,000 to 5,000 years BP in the Pluvial Epoch (Kutzbach, 1987).

Figure A.6 illustrates various stages of deltaic sedimentation. The earliest deltaic features in Holocene times are termed the "early Brahmaputra" deltas and are thought to have formed during the period 8000 - 4000 years BP. It can be seen that the early Brahmaputra delta extended about mid-way into the Sylhet Trough (to around Sunamganj). Under these conditions, sediment deposition from the Brahmaputra River on the north and west and from the Barak River on the east would gradually filled-in this embayment. This has produced a characteristic "bowl-shaped" basin, surrounded by higher floodplain lands. At this time the basin's southern outlet drained into the Old Meghna Estuary in the Bay of Bengal.

3.2 Topography

Figure A.7 shows the topography in the project area and illustrates the low-lying character of the land. Although the project lies over 200 km from the Bay of Bengal, approximately 80% of the project area lies below El. 7 m, and 50% of the land lies below El. 5 m. By comparison, floodplain land outside this region formed by the Brahmaputra or Ganges Rivers is typically at El. 10m - 20 m.

During an average flood in the monsoon season, water levels in the project area may exceed El. 7 m for over one month. During extreme floods such as 1988 or 1991, virtually all of the land remained deeply flooded for several months. The huge extent of inundation that can occur is illustrated in Figure A.8, which shows a satellite image of the region during the recession of the 1988 flood.

2 8

3.3 Landforms

Virtually all of the project area consists of alluvial floodplain and flood basin land occupied by the Kalni-Kushiyara River system. 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. Figures A.9 and A.10 illustrate some of the main alluvial features that characterize the project area.

"Levees" are wedge shaped ridges of sediment bordering stream channels, and highest on the convex (outer) side of meander bends. Levees are often the highest points of land on the floodplain, and may extend 3 - 5 m above the adjacent low-lying flood basin land. Natural levees are formed when flood water spills over bank. During overtopping, the reduced water velocities cause deposition of sediment. The rate of deposition decreases rapidly as the distance from the edge of the bank increase. Levees may have great social significance, since they usually provide the highest (and the only relatively flood-free) land for situating villages and settlements.

On most streams, flood water spills through distinct channel breaches or formerly silted-in *khals* that cut across the levees, rather than by sheet flow. These breaches (termed crevasses or *dhalas*) develop their own drainage system into the lower flood basins. Sand may be deposited as "crevasse splays" at the breaches (Figure A.11). Occasionally, the main rivers may shift through *khals* or re-occupy abandoned river channels. Such a shift or avulsion may induce major changes in drainage and channel instability.

Channel shifts and natural cutoffs produce "ox-bow" lakes, abandoned channels and *beels* (Figure A.12). These features may last for many decades, but will gradually fill-in as a result of overbank sedimentation. Infilling may be very rapid when these features are adjacent to active channels since channel breaches can scour large "slugs" of sediment which are deposited in the first slack water areas that are encountered.

Haors are characteristic features of flood basin areas that lie distant from the main river channels. These "inter-riverine" areas consist of dish shaped depressions within a perimeter of natural river levees. *Haor* lands are generally very low-lying (less than El. 4 m), featureless areas, which often contain permanent water bodies or *beels*. During the monsoon season, all of the *haor* areas remain deeply flooded for several months. The *haors* comprise the prime agricultural land of the project area, but their seasonal inundation is a constraint to agriculture. In most areas, only a *boro* (dry season) rice crop can be grown, and this is liable to damage by flooding in the pre-monsoon season. The *haors* and *beels* are also important fisheries habitats. When the *haors* are flooded at the beginning of the monsoon season, fish migrate into them from the main river systems to feed and spawn.

3.4 Physiographic Units

The river flows across three major physiographic sub-divisions (Figure A.13).

Eastern Surma-Kushiyara Floodplain
This land is mainly east of Sherpur and occupies the relatively higher parts of the Surma-Kushiyara floodplain. Land levels are typically El. 10-15 m PWD. The river channels are confined by natural levees that are 3 - 6 m above the adjacent flood basins. The levees consist of silty, clay loams or sandy, silty alluvium. Sediments in the adjacent flood basins are mainly clay or silt.

Sylhet Basin
This land unit occupies about 50 % of the project area and consists mainly of low-lying back swamp and flood basin land. It is traversed by a maze of distributary channels, abandoned channels, ox-bow lakes and active streams. The larger rivers are bordered by natural levees that are 3-4 m higher than the adjacent low-lands. Virtually all of this land lies below El. 6 m and is deeply flooded in the monsoon season. The land is characterized by large *haors* and permanently inundated *beels*. The main *haors* in the project area include Channai Haor, Chaiar Haor, Baram Haor, Tangua Haor, Bhanda Beel, Chaptir Haor, and Naluar Haor. Sediments in this unit consist primarily of medium - dark grey silt, silty sand and silty clay.

Estimates of long-term floodplain sedimentation rates in the Sylhet Basin were made by radio-carbon dating buried organic materials and peat deposits. These samples were collected from boreholes at Shanir Haor, Karchar Haor, Pagner Haor (north of the project area) and from an excavation on the right bank of the Kalni River near Sullah. At Karchar Haor, overlain by fine sand and silt, fragments of wood in a black, organic-rich silt were found 5.5 m below the ground surface (at El. -0.7 m PWD). The wood was established to be 4,644 years old. This means the floodplain sediments accumulated 5.5 m in 4,644 years. Large areas of peat sediments have also been found to underlie floodplain sediments on the right bank of the Kalni River, near Sullah. A sample of peat was collected from a depth of 3.6 m below the ground surface (El. 1.4 m PWD). This sample was determined to be 3,200 years old. This implies the floodplain north of Ajmiriganj has built-up at a rate of just over 1mm/year.

Table A.7 summarizes the rate of sediment accumulation on the floodplain. The average sedimentation rate from the four sites, which is around 1 mm / year, is reasonably consistent over the basin. This provides a rough estimate of the floodplain deposition rate in the Sylhet Basin over Holocene times. Since the ground surface in the Basin has remained close to sea level over the last 3,000-4,000 years, the rate of sedimentation must be approximately the same as the rate of ground subsidence. If the sedimentation rate was much greater than the rate of subsidence, then the floodplain surface would have built up to a much higher level.

Table A.7: Radio-Carbon Dates of Floodplain Sediments

Location of Sample	Dated Material	Age (Years)	Floodplain Thickness Over Dated Material (m)	Average Sediment Accumulation (mm/year)
Sullah on right bank of Kalni R.	Peat	3,200	3.5	1.1
Sonapur at Karchar Haor	Wood	4,644	5.5	1.2
Tahirpur at Shanir Haor	Wood	4,200	4.0	0.9
Kalner Haor	Peat	4,000	4.5	1.1

27

Old Meghna Estuarine Floodplain

This unit occupies the eastern part of Kishoreganj District and the western part of Habiganj District. It consists of almost level, nearly featureless floodplain land or shallow basins that were formed in earlier Holocene times by estuarine sedimentation. The sediments consist of predominately silty material, and land elevations range from El. 3 - 5 m PWD. The unit forms the left (western) bank of the Kalni River below Kadamchal and the Baida River, as well as the floodplain east of Ajmiriganj.

This land was formed at an earlier stage of development, when the region was predominantly estuarine. This old surface is being gradually re-worked by the Kalni River as it shifts across the earlier deposits. Lands in the Old Meghna Estuarine physiographic unit have not been subjected to channel instability or fluvial deposition in recent times, and represent stable areas with very low sediment supply.

4. HYDROLOGY

4.1 Runoff

Figure A.14 illustrates the variation in the mean daily discharge along the Kushiyara and Kalni River. The long-term mean discharge on the Barak River at Amalshid has been estimated at 1,008 m^3/s, with the flow into the Kushiyara branch amounting to 656 m^3/s (NERP, 1995). The long-term mean is 1,100 m^3/s at Sherpur and 1,535 m^3/s on the lower Dhaleswari River at its confluence with the Meghna River. The mean discharge on the Meghna River at Bhairab Bazar is 5,589 m^3/s, indicating that total contribution from the Kalni-Kushiyara system is 27%.

In Bangladesh, the "water year" (defined as beginning on 1 April and ending on 31 March) can be divided into 4 distinct seasons:

- pre-monsoon: (1 April - 15 May);
- monsoon: (16 May - 30 September);
- post-monsoon: (1 October - 30 November), and
- dry season: (1 December - 31 March 31).

These seasons are closely related to the normal dates of onset and withdrawal of the monsoon rains.

The pre-monsoon season is characterized by unstable weather conditions, including occurrences of intense tropical depressions and "nor-westers" which generate heavy localized rainfalls. Low magnitude pre-monsoon floods are contained within the channel banks, and enter the adjacent flood basins and *haors* through open spill channels and distributaries. Larger pre-monsoon floods overtop river banks and flood the back basins and floodplain by overland flow and through breaches and spills. These floods are relatively "flashy" and may last from a few days to about two weeks. The flood volumes are sufficient to fill the *haor* depressions and they are the cause of major crop damage in the region.

Flooding in the monsoon season normally lasts from July to October. High water is a result of large inflow volumes and backwater from the Lower Meghna River. During extreme events (such as in 1988 and 1993) virtually all of the project area is inundated (Figure A.8). Under these conditions a large portion of the discharge is conveyed by the floodplain, and velocities in the main channel are relatively low. Considerable damage may take place to village platforms at this time due to wave erosion. The high velocity of the winds can cause wave crests to reach up to 1.5 m. During the post-monsoon season, the water levels in the main rivers recedes. Water from the floodplain drains into the main channel through open *khals* and distributary channels. Water levels normally continue to recede over the dry season, and discharges are very low. Occasional local flash floods, caused by winter storms in the outlying hills, may occur between December and February. These floods rarely overtop the river banks, but the water can readily enter the *haors* because at this time of year there are numerous openings in the river banks.

Table A.8 shows the long-term seasonal distribution of runoff and average discharges at Sherpur.

28

Table A.8: Seasonal Distribution of Runoff at Sherpur

Season	Mean Discharge (m^3/s)	Mean Runoff (10^6 m^3)	Annual Runoff (%)
Pre-monsoon	1,152	6,074	17.4
Monsoon	1,952	20,577	59.0
Post-Monsoon	1,175	6,196	17.8
Dry Season	197	2,058	5.8
Year	1,100	34,906	100.0

4.2 Trends

A number of general investigations have been made to assess long-term changes in rainfall (NERP, 1995). NERP's regional investigations utilized 51 rainfall stations in Bangladesh and India, and examined long-term trends by comparing the rainfall between 1961-1990 with the average from 1901-1990. It was concluded that the 30-year (1961-1990) mean rainfall has increased by 10% during the 90-year period, and that the variability has doubled. No firm conclusions could be reached whether these changes represented a peak of some long-term climatic cycle or a monoclinal rise due to global climatic change. FAP-25 concluded that the last 30 years have been reasonably representative of long-term conditions, although small increases in runoff and rainfall were noted.

The following comments describe recent fluctuations in runoff and peak discharge on the Kushiyara River system using the available hydrological records for the period 1964-1993. This assessment was made to assist in interpreting recent patterns of channel instability, flooding and sedimentation that have occurred along the river.

Rainfall and Runoff
Table A.9 summarizes average rainfalls and daily discharges in various seasons between 1964 and 1993. The two rainfall stations (Zakiganj and Sheola) are situated on the Upper Kushiyara River near the Indian border. Discharges at Amalshid were synthesized from measured daily water levels (gauge 172) and stage-discharge rating curves. The computed mean inflow at Amalshid is about 10% higher than the mean flow estimated from water balance studies. The difference is due to the different periods of record used in each analysis as well as the different methods in estimating discharges.

Table A.9 shows that the period since 1982 has been characterised by greater rainfall and mean daily discharge, on average, than the period between 1964-1981. Furthermore, the changes in rainfall and discharge are reasonably consistent (both around +10%). The published mean daily discharge at Sheola shows the same trend; however, the magnitude of the increase is substantially higher than the increase in rainfall or discharge on the Barak River. All data show substantial increases in average rainfall and discharge during the dry and pre-monsoon seasons. For example, the mean daily discharge in the dry season at Sheola increased from 95 m^3/s in 1964-

২৯

1973 to 145 m^3/s in 1982-1993, while the dry season rainfall totals increased from 156 mm/year in 1964-1973 to 273 mm/year in 1982-1990. The corresponding changes in discharge and rainfall amount to +43% and +41% respectively.

Examination of the discharge and rainfall records shows the increases can be largely accounted for by four unusually wet years (1986,1988,1991, 1993). This clustering of unusual wet and dry years is characteristic of monsoon-driven weather systems.

Flood Discharges

Figure A.15 shows that the range of annual maximum discharges and pre-monsoon discharges at Sheola and Sherpur. The last decade has experienced an unusual sequence of high pre-monsoon floods and annual maximum floods. Table A.10 shows the average pre-monsoon flood discharge at Sheola was 804 m^3/s between 1964-1973 and 1,227 m^3/s between 1982-1993. The average annual maximum flood discharge increased from 1,816 m^3/s between 1964-1973 to 2,619 m^3/s between 1982-1993. The following comparisons illustrate the changes in flood discharges in relation to the mean annual flood (1964-1993):

Pre-monsoon flood at Sheola (gauge 173):

$\%\Delta Q_{1964\text{-}1973}$ = (804 -965) / 965 or -17%

$\%\Delta Q_{1982\text{-}1993}$ = (1,227-965) / 965 or +27%

$\%\Delta Q_{1964\text{-}1993}$ = (1,227-804) / 965 or +44%

Annual maximum flood at Sheola (gauge 173):

$\%\Delta Q_{1964\text{-}1973}$ = (1,816-2,225) / 2,225 or -18%

$\%\Delta Q_{1982\text{-}1993}$ = (2,619-2,225) / 2,225 or +18%

$\%\Delta Q_{1964\text{-}1993}$ = (2,619-1,816) / 2,225 or +36%

Two factors have contributed to this pattern: first, the closely spaced incidence of unusually wet years during the period 1988-93 (1988, 1991, 1993), which produced a clustering of extreme flows. There is no evidence to suggest that this pattern will persist. Second, the increase in flood discharges has coincided with reduced discharges in spill channels on the Upper Kushiyara floodplain (Figure A.16). This reduction in overbank flows and increased flow carried by the main channels is attributed mainly to construction of flood embankments and channel closures (NERP, 1995). EPWAPDA, 1966) described a major left bank closure 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".*

As a result of these works the left bank of the Kushiyara River was embanked continuously along the Indian border downstream of Amalshid. In the 1980's high embankments were also constructed along the left bank from Fenchuganj to Manumukh as part of the Manu River Irrigation Project. The right bank of the river was embanked from Amalshid to Sheola in order to reduce flooding in the interior floodplain (the Surma-Kushiyara inter-basin). Embankments have also been constructed 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. Stage records at Sheola show that the annual maximum water levels have risen by up to 1 m; mainly as a result of confinement effects.

4.3 Flood Frequency

Data series from Sheola and Sherpur were analyzed using the General Extreme Value distribution (GEV) by the maximum likelihood fitting procedure. At Sheola, 30 years of records from 1964 -1993 were used. At Sherpur, 14 years of records from 1982-1995 were available for analysis. Results of the flood frequency estimates are summarized in Table A.11. Given the apparent fluctuations in discharges and rainfall described in Section 4.3, considerable caution needs to be given to using flood frequency estimates based on short-term records.

Water levels have been measured at Sherpur, Markuli and Ajmiriganj. However measurements at Markuli (and even more significantly at Ajmiriganj) have been affected by past morphologic changes. The data at Ajmiriganj are judged to be non-stationary, which makes the water level records less reliable for extrapolating future conditions. Table A.12 summarizes a frequency analysis of historic water levels at Sherpur, Markuli and Ajmiriganj for the pre-monsoon and monsoon seasons respectively.

Table A.13 shows the frequency of some major floods at Sheola, Sherpur and Ajmiriganj. The annual floods at Sherpur in 1991 and 1993 had return periods of approximately 75 years and 35 years respectively. These events had return periods of less than 10 years at Ajmiriganj mainly because they occurred early in the season, before the Meghna River crested. The highest water levels at Ajmiriganj occurred in 1974 and 1988, and had approximate return periods of 50 and 25 years respectively.

Table A.9: Variations in Rainfall and Runoff

Total Rainfall in Specified Periods

Period	Annual (mm)		Pre-monsoon (mm)		Dry Season (mm)	
	Zakiganj	Sheola	Zakiganj	Sheola	Zakiganj	Sheola
1964 - 1973	3,859	4,128	907	874	144	156
1974 - 1981	3,794	4,086	1,046	958	241	193
1982 - 1993	4,273	3,815	1,105	1,050	252	237
1964 - 1993	3,958	4,467	1,024	967	212	197

Percentage change relative to long-term mean (1964-1993)

Period	Annual (%)		Pre-monsoon (%)		Dry Season (%)	
	Zakiganj	Sheola	Zakiganj	Sheola	Zakiganj	Sheola
1964 - 1973	-2.5	-1.0	-11.4	-9.6	-31.9	-21.0
1974 - 1980	-4.2	-7.6	+2.2	-0.9	+13.8	-1.8
1990 - 1993	+8.0	+8.2	+8.0	+8.6	+19.0	+20.4

Mean discharge in various periods (m^3/s)

Period	Annual (m^3/s)		Pre-monsoon (m^3/s)		Dry Season (m^3/s)	
	Amalshid	Sheola	Amalshid	Sheola	Amalshid	Sheola
1964 - 1973	1,064	581	417	282	102	95
1974 - 1981	1,070	649	478	332	104	100
1982 - 1993	1,172	793	828	536	165	145
1964 - 1993	1,108	684	596	396	128	116

Percentage change relative to long-term mean (1964-1993)

Period	Annual (%)		Pre-monsoon (%)		Dry Season (%)	
	Amalshid	Sheola	Amalshid	Sheola	Amalshid	Sheola
1964 - 1973	-4.0	-15.0	-29.9	-28.8	-19.9	-17.9
1974 - 1981	-3.4	-5.1	-19.9	-16.2	-18.3	-14.0
1982 - 1993	+5.8	+16.0	+38.9	+35.3	+29.6	+24.8

92

Table A.10: Flood Discharges on Kushiyara River

Period	Amalshid (172)[1]		Sheola (173)		Sherpur (175-5)	
	average (m^3/s)	maximum (m^3/s)	average (m^3/s)	maximum (m^3/s)	average (m^3/s)	maximum (m^3/s)
Pre-monsoon Flood Discharge						
1964 - 1973	930	1500	804	1580	-	-
1974 - 1981	921	1640	785	1680	-	-
1982 - 1993	1484	3780	1227	3250	1790	3471
1964 - 1993	1145	3780	965	3250	-	-
Annual Maximum Flood Discharge						
1964 - 1973	2941	3308	1816	2130	-	-
1974 - 1981	3137	3803	2144	2330	-	-
1982 - 1993	3236	3780	2619	3250	2746	3843
1964 - 1993	3113	3803	2225	3250	-	-

Note 1. discharges at Amalshid were estimated from synthesized records

Table A.11: Flood Frequency Analysis of Discharges at Sherpur on Kushiyara River

Type	Discharge (m^3/s)				
	Return Period				
	1:2 year	1:5 year	1:10 year	1:20 year	1:50 year
Pre-Monsoon	1,694	2,398	2,834	3,228	3,709
Annual Maximum	2,579	2,977	3,225	3,451	3,729

Table A.12: Flood Frequency Analysis of Water Levels

Location	Water level (m PWD)				
	Return Period				
	1:2 year	1:5 year	1:10 year	1:20 year	1:50 year
Pre-monsoon Water Levels					
Sherpur	7.45	8.42	8.80	9.04	9.24
Markuli	6.18	6.89	7.22	7.45	7.67
Ajmiriganj	4.50	5.10	5.45	5.75	6.11
Annual Maximum Water Levels					
Sherpur	8.97	9.16	9.31	9.39	9.50
Markuli	7.43	7.80	7.90	8.05	8.32
Ajmiriganj	7.42	7.49	7.78	7.95	8.20

Table A.13: Frequency of Historic Floods (Annual Maximum)

Rank	Year	Discharge (m^3/s)	Return Period (years)
Kushiyara River at Sheola			
1	1991	3,250	20
2	1983	2,960	7
3	1993	2,941	7
4	1986	2,820	5
Kushiyara River at Sherpur			
1	1993	3,843	75
2	1991	3,632	35
3	1988	2,860	5
4	1990	2,770	3
Kalni River at Ajmiriganj			
Rank	**Year**	**WaterLevel (m PWD)**	**Return Period (Years)**
1	1974	8.21	50
2	1988	8.02	25
3	1993	7.69	8
4	1970	7.68	8

5. RIVER CHARACTERISTICS

This chapter summarizes the hydraulic and geomorphic characteristics of the Kalni-Kushiyara River between Amalshid and its junction with the Baulai River near Dilalpur. The river has been sub-divided into reaches that display similar morphology. Morphologic characteristics have been classified in each reach in order to help interpret the main processes that govern river behaviour. Table A.14 and Figures A.17-A.31 summarize this analysis. Figure A.32 shows a longitudinal profile of the channel thalweg and water surface, while Figure A.33 summarizes the variations in bed material size along the river.

5.1 Kushiyara River, Amalshid to Sherpur

Figures A.17 to A.20 illustrate the river's morphologic characteristics in this reach.

The Kushiyara River flows mainly through the Kushiyara-Surma Floodplain physiographic unit, except for a short length between Fenchuganj and Manumukh, which is part of the Sylhet Lowlands. The river flows in a single, irregularly meandering sand-bed channel bordered by natural levees that are 3-4 m higher than the adjacent floodplain lands. The channel has an average top width of 150 m between Amalshid and Fenchuganj, 225 m between Fenchuganj and Manumukh and 240 m near Sherpur. Bankfull stage coincides closely to a mean annual flood (bankfull discharge is around 2,100 m^3/s between Amalshid and Manumukh and 2,600 m^3/s at Sherpur). The average channel depth at bankfull stage averages between 8-9 m. Deep scour holes occur at the outside of each bend, with maximum depths reaching up to 30 m at bankfull stage.

5.2 Kushiyara River, Sherpur to Markuli

Figures A.19 to A.22 illustrate the river's morphologic characteristics in this reach.

This reach encompasses the Suriya Channel of the Kushiyara River. The physiographic setting is transitional between the Eastern Surma-Kushiyara floodplain and the Sylhet Basin. The channel has an irregular, meandering pattern with a top width of 200 m. Deep scour holes (22 m below bankfull stage) have formed near the outer bank in the bends, while shoals are found in the straight portions between the bends.

Bed sediments in this reach consist primarily of very fine sand, typically with less than 10% silt content (Figure A.21). Based on a composite of ten samples, a representative grain size distribution is as follows:

D_{10}=0.06 mm
D_{35}=0.10 mm
D_{50}=0.13 mm
D_{65}=0.15 mm
D_{99}=0.25 mm

Longitudinal surveys show that during the pre-monsoon and monsoon season the bed is covered with dunes (typically 0.6 m in height but reaching up to 1 m), indicating active bed load transport. Bank sediments are primarily silt and silty clay.

Table A.14: River Reach Classification

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	Silty Clay	1.42	0.040 0.070 0.060	166 9.76 1410
Fenchuganj-Manumukh Km 95 - Km 130	Kushiyara Floodplain	Single channel; Irregular sinuous	Partly confined by embankments	Absent	Absent	Stable	progressing meander migration channel widening	0.18 0.16 0.13	Silty 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/straight due to loop cutting	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 9.10 2177
Suriya River- Markuli Km 152 - Km 180	Kushiyara Floodplain	Single channel; Irregular meanders	Unconfined	Absent	Absent	Degrading	major avulsion in 1960's ongoing widening and shifting due to loop cutting	0.11 0.10 0.088	Clay organic clay and silt	1.36	0.010 0.030 0.030	251 6.82 1711
Markuli- Dhaleswari River Km 180 - Km 235	Sylhet Basin	Split channel; Irregular sinuous	Unconfined	Absent	Few	Aggrading rapidly	channel widening and irregular shifting due to loop cutting	0.11 0.10 0.088	Silty Clay	1.12	0.022 0.080 0.008	335 4.10 1365
Dhaleswari River Km 235 - Km 271	Sylhet Basin	Single channel; Irregular meanders	Unconfined	Point bars	Common	Aggrading slowly	Irregular shifts and avulsion of distributary channels	0.11 0.10 0.088	Silty Clay	1.76	0.015 0.060 0.060	Na

The reach lies upstream of backwater control from the lower Meghna River (except during monsoon floods). Flows remain confined up to a 1:2 year monsoon flood flow.

5.3 Kalni River, Markuli to Ajmiriganj

Figures A.22 to A.25 illustrate the river's morphologic characteristics in this reach.

Downstream of Markuli the Kalni River flows through the low-lying Sylhet Basin. It is controlled by backwater from the Meghna River during the monsoon season. The channel is typically 250 m wide and 6 m deep at bankfull stage, and has an irregular channel pattern. Portions of this reach were re-aligned by loop cuts carried out by BWDB in the 1970s. Consequently, some sections now cut across former floodplain land and are partially confined by outcrops of peat and other cohesive sediments (Figure A.11).

Spills occur at several locations along the river, including Markuli (Km 132), Fayjullapur (Km 129.5), Tangua Haor (Km 119), Koyer Dhala (Km 115) and Pituakandi (Km 114.5). These spills divert water from the Kalni River into the north and south floodplain and cause serious crop damage during the pre-monsoon season. Direct field observations and hydrometric measurements in 1996 showed the spills typically occur at a discharge of around 1,600 m^3/s, which occurs well below the average bankfull level along the river. For example, the estimated bankfull discharge capacity near Markuli is around 1,950 m^3/s. In most cases, the spills occurred by breaching the outside of meanders bends and carried water and sediment onto the floodplain through active channels or *dhalas*.

Downstream of Markuli, the bed sediments become finer and much more variable in composition. This change is very abrupt (Figure A.33), with the sand ratio dropping from 90% to 10-15% in less than 10 km. The corresponding median grain size decreases from 0.13 mm (very fine sand) to 0.02 mm (medium silt). Since the river has been re-aligned in this reach, some of these very fine sediments are probably former floodplain deposits that have become re-exposed by scour.

5.4 Kalni River, Ajmiriganj to Madna

Figures A.23 to A.28 illustrate the river's morphologic characteristics in this reach.

The river becomes noticeably wider and shallower just upstream of Ajmiriganj (near Sullah). Representative channel dimensions for this reach are 300 m wide by 5 m deep at bankfull stage. The overall channel pattern is gently sinuous, interrupted by short unstable reaches containing channel branches. During the dry season and pre-monsoon season, the river is confined within its banks. Bankfull discharge at Ajmiriganj is around 1,750 m^3/s, which corresponds closely to a 1:2 year pre-monsoon flood. During the dry season and pre-monsoon season, the discharge decreases with distance downstream due distributary branches (Cherapur Khal at Km 80 and Baida channel near Issapur at Km 76). For example, measurements on 6 April 1996 indicated the flow in the Kalni River downstream of Issapur was only 36% of the flow at Ajmiriganj (Table A.15).

Table A.15: Discharges on April 6, 1996

Location	Km	Discharge (m3/s)	% of Discharge at Ajmiriganj
Ajmiriganj	106.5	1,485	100
Shantipur	95.4	1,337	90
Kadamchal (below Cherapur Khal)	84.7	1,100	74
Kalni River downstream of Issapur	72.0	528	36

The water surface slope averages 0.00004 (4 cm/km) in the pre-monsoon season, and can be virtually zero in the monsoon season when the lower Meghna River is flooded. At this time, the entire area resembles a shallow lake or delta (Figure A.8). Under these conditions, the velocities in the main channel are very low. Even though it is not possible to directly measure the discharge carried onto the floodplain during the monsoon season, an estimate can be made through hydraulic modelling investigations by considering the conveyance in the main channel and overbank sections of the river (Annex B - Hydrodynamic Model). The calculations indicated that during the peak of the 1993 flood, the flow in the main channel downstream of Ajmiriganj amounted to only 25% of the total flow in a 2,000 m wide cross section. During the height of the monsoon season when the backwater from the Meghna River causes the entire region to be deeply flooded, the discharge onto the floodplain greatly exceeds the flows in the main channel. Similar findings were also reported for the floodplain of the Baulai River near Sukdevpur (NERP, 1995).

The bed material becomes sandier with increasing distance downstream of Ajmiriganj (Figure A.33). However, the sediment composition is very variable. Back channels, slack water areas and sloughs consist mainly of silt and sandy silt. Main channel shoals and bars that are exposed at low water consist of clean, very fine sand with only a trace of silt. Representative grain size characteristics for these exposed bars are as follows:

D_{10} = 0.07 mm
D_{35} = 0.10 mm
D_{50} = 0.12 mm
D_{65} = 0.15 mm
D_{99} = 0.25 mm

These sediments are very similar to the sandy material found on the Kushiyara River upstream of Markuli. Samples from the main channel thalweg consist of a mixture of silt and sand. A representative grain size distribution for sediments near Shantipur is as follows:

D_{10} = 0.022 mm
D_{35} = 0.045 mm
D_{50} = 0.065 mm
D_{65} = 0.072 mm
D_{99} = 0.250 mm

Seasonal variations also occur in this reach, with the sediments containing appreciably less sand in the monsoon season. Table A.16 shows size characteristics near Gazaria and Kakailseo at the end of the dry season (in March) and near the end of the monsoon season (in September). It appears that during the monsoon season, when the river is subject to backwater control from the Meghna River, the river bed is blanketed with finer silt-sized sediments. As the tailwater level drops in the post-monsoon season, these silty deposits are flushed away and sandier materials are exposed. It appears that sand transport in this reach occurs only in the pre-monsoon and dry seasons, when backwater control from the Meghna River is absent.

Table A.16: Seasonal Variations in Bed Sediments on Kalni River

Location	Date	Sand %	Silt %	Clay %
Gazaria	September 1993	15	74	11
Gazaria	March 1995	100	0	0
Kakailseo	June 1993	19	68	13
Kakailseo	September 1993	50	49	1
Kakailseo	March 1995	100	0	0

Sub-surface borings show the stratigraphy is very variable and highly complex, with alternating deposits of fine sand, silty sand and silty clay. Outcrops of peat, organic-rich clay and silty clay were encountered at lower depths, in the range of El. -6 m PWD. These materials represent earlier estuarine and deltaic sediments that were deposited in earlier Holocene time.

5.5 Dhaleswari River, Madna to Dilalpur

The Kalni River splits near Issapur, with the western branch (the Baida channel) flowing through the Old Meghna Estuarine floodplain and the eastern branch through part of the Sylhet Basin (Figure A.29) . The Ratna/Khowai River enter this eastern branch near Madna. Downstream of this junction, the name changes to the Dhaleswari River. This reach has an irregular, split channel pattern with abandoned channels and ox-bows adjacent to the main channel. The river bed material is primarily very fine sand. The river is tidal at low flows, and water levels are controlled by backwater from the Meghna River. During the monsoon season, the area is deeply flooded and the river channel is completely submerged. The channel contains very deep sections (to El. -20 m); the cross sectional area is noticeably greater than the Kalni River.

5.6 Upper Meghna River near Bhairab Bazar

Figures A.30 and A.31 illustrate the river's morphologic characteristics in this reach.

The river occupies the former course of the Brahmaputra River. Consequently, in the sense that the present channel was formed by much higher discharges than are currently experienced, the river can be classified as an "under-fit" stream, The river has a split channel pattern, with one or two dominant meandering main channels divided by large semi-permanent islands. Substantial bank erosion has occurred in the past along the right bank at the outside of the meander bend near the Bhairab railway bridge.

The cross section at Bhairab Bazar is about 840 m wide and has an area of 14,000 m² at mean annual flood condition. Average depths are around 17 m, with maximum depths reaching up to 25 m at the outside of major bends. The river bed material is predominately fine sand. The river is tidal and subject to flow reversals during the dry season. During the monsoon, its level is controlled by backwater from the Padma River. Annual maximum water levels at Bhairab Bazar show a trend for lowering over the last few decades, even though the magnitude of flood discharges appears to have increased (Figure A.31). This trend probably is indicative of changes in downstream control or other longitudinal profile adjustments.

6. SEDIMENT TRANSPORT

6.1 Terminology

Sediment transport can be classified according to its source (as wash load or bed material load), mode of movement (suspension, saltation or traction) and by its method of measurement (Figure A.34). Wash load consists of fine sediment (usually silt and clay) that is supplied from mass wasting and erosion in the watershed or bank erosion. Its transport rate depends solely on the rate of supply, not on the stream's hydraulic capacity (which may be much greater than the rate of supply). Consequently, wash load sediments are not found in appreciable quantities in the river bed material. These finer sediments are flushed through the channel in suspension, and are deposited overbank on the floodplain or in deeply flooded *haors* and *beels* where the velocities are very low. The bed material load consists of sediments that form the channel bottom, and may be transported both in traction (as bed load) and in suspension (as suspended bed material load). Variations in the bed material load produce scour and aggradation along a river channel and govern its morphology. A suspended sediment sampler measures both the wash load and the suspended bed material load. Therefore, in order to separate the wash load from the bed material load, it is necessary to assess both the size distribution of the sediments in the channel bed (the bed material) and the size of the sediments in transport. The bed material's D_{10} size (Figure A.33) is commonly used to distinguish the wash load from the bed material load (Einstein, 1942).

6.2 Sampling Program

A sediment sampling program was run at Sherpur, Markuli, Ajmiriganj, Shantipur and Kadamchal in 1995 and 1996. Table A.17 summarizes the period of the observations at each station. Three of the sites (Sherpur, Markuli and Ajmiriganj) are permanent BWDB hydrometric stations, while temporary water level gauges were installed at Shantipur and Kadamchal. The measurements included suspended sediment concentration, size distribution of the suspended sediment, bed material size distribution, bed-form geometry and hydraulic characteristics (water level, discharge and channel velocity). The data were used to estimate the total suspended sediment load as well as to assess the seasonal distribution of the load and variations in sediment transport along the channel.

6.3 Sampling Equipment

Suspended sediment concentrations were measured using a US Geological Survey D-74 depth-integrating suspended sediment sampler, equipped with a 4.76 mm diameter orifice and 760 ml sample collection bottle. This sampler, which weighs approximately 35 kg, consists of a brass streamlined body (with a hollow chamber fitted with a sample bottle), air venting system and orifice. The sampler was operated with a standard US Geological Survey reel mounted on the bow of an anchored boat. The main advantage of this method is that the D-74 sampler is designed to provide an "iso-kinetic" sample of the suspended sediment and the samples are fully depth-integrated and discharge weighted (unlike pump sampler measurements). Furthermore, the number of samples that need to be collected is lower, which reduces costs and laboratory time.

The discharge at the time of sampling was determined by measuring point velocities and depths at the gauging line. Velocities were measured with a Price current metre. The sediment sampler was used as a weight to ensure the metre was aligned vertically. Horizontal positions were measured using a tag line.

82

6.4 Sampling Procedures

Field technicians were trained using the Water Survey of Canada "Training Program for Sediment Sampling" (WSC, 1991). The sampling procedure involved (1) determining the depth at the sampling vertical (2) estimating the allowable sampling time (3) lowering the sampler through the water column at the required rate to a point just above the bed level and then raising the sampler to the water surface (4) removing the sample bottle, recording the date, time, gauge height and location and then stowing the sample for subsequent lab analysis.

The samples were collected at quarter points across the channel at the same time as regular discharge measurements. The velocities were measured at 20% and 80% of the channel depth at approximately 15 to 20 verticals in the cross section. Water levels were recorded by reading a staff gauge. All elevations were referenced to the Survey of Bangladesh's Second Order Survey of 1993.

The sampling frequency was once every three or four days during high flows and up to once per week during low water.

The samples were sent to the sediment laboratory of the SWMC for analysis. The individual concentrations were averaged to produce a discharge-weighted average concentration and suspended sediment load. The data were used to establish suspended sediment rating curves and to estimate the annual suspended sediment load.

In addition to these conventional measurements, a number of large (five litre) pump sample measurements were made at Sherpur, Markuli, Ajmiriganj and Shantipur. These samples were sent to the sediment laboratory at the SWMC for analysis of the particle size distribution of the suspended load. The size analysis was made using a settling tube.

6.5 Observations

Figures 35 summarize the hydrographs during the period of observations and show the frequency of sampling over the year. Table A.17 summarizes the range of flows and sediment loads that were measured. Tables A.18 to A.22 summarize the observed total sediment concentrations, while Table A.23 summarizes information about the size distribution of the suspended load.

Year 1995 was representative of average flow conditions on the river, with the annual maximum daily flow at Sherpur having a return period of just under 2 years. The pre-monsoon flood occurred later than normal (on 20 May, which is outside the commonly accepted season that ends on 15 May). The magnitude of this event also corresponded closely to a 2 year return period for a pre-monsoon flood. In 1996 the pre-monsoon flood occurred on 6 April, and had a return period of 2 years at Sherpur and 1.6 years at Ajmiriganj.

Figures A.36 and A.37 show plots of suspended sediment concentration versus river discharge. The suspended sediment load was computed as:

$$G = 0.0864QC$$

where: G = Suspended sediment load (tonnes/day)
Q = Discharge (m^3/s)
C = suspended sediment concentration (mg/l)

Sherpur

Suspended sediment concentrations were measured during the period 4 April-14 October 1995. The concentrations ranged from as low as 25 mg/l during extreme low water, up to 1,555 mg/l during the rising stages of the monsoon season in June. The corresponding sediment loads ranged between 154-275,300 tonnes/day. The sediment rating curve shows a "looped" relation, indicating sediment concentrations were persistently higher in the rising stage of the flood season and lower during the later part of the monsoon and post-monsoon seasons. This feature is common when the major portion of the suspended sediment consists of wash load and indicates that the sediment supply is being exhausted over the course of the flood season.

Markuli:

Measurements at Markuli were made during the period 18 May-29 October 1995. The range in concentration and sediment load was very similar to that at Sherpur, with the highest measured sediment concentration reaching 1,367 mg/l on 2 July and the corresponding sediment load reaching 237,000 tonnes/day.

Ajmiriganj

The suspended sediment measurements at Ajmiriganj were made during the period April 1995-June 1996. However, discharges could not be accurately determined during the period 19 June -09 October 1995, when the river was spilling overbank. The highest sediment concentrations occurred in the pre-monsoon season, reaching 2,260 mg/l. A relatively consistent sediment rating can be applied to the period when the flows are confined within bank. However, sediment concentrations were observed to decrease to less than 100 mg/l throughout July in response to rising water levels on the Meghna River and increased overbank flooding. During this same time, the concentrations at Sherpur and Markuli were consistently in the range of 500-1,000 mg/l. This suggests considerable deposition occurred between Ajmiriganj and Markuli. Sediment concentrations at Ajmiriganj increased again in September, once the water levels began to lower and the river flows were confined again within its banks.

Shantipur

Suspended sediment concentrations were measured only during the dry season and pre-monsoon season during the period 18 December-4 April 1996. The concentrations were generally higher than those measured at Ajmiriganj during the same period, particularly at high flows. This would indicate sediment was being picked up between Ajmiriganj and Shantipur, either from erosion of bank materials or by scouring from the bed.

Kadamchal

This site is located downstream of Cherapur Khal, which is a major distributary channel that diverts water from the Kalni River to the Baulai River system. Regular measurements were carried out only during the period January-May 1996, when flows were confined within the bank. The highest concentrations reached up to 3,580 mg/l during a pre-monsoon flood event in April, when the discharge was 1,037 m^3/s. A reasonably consistent rating curve could be established for the dry season and pre-monsoon flows.

It is apparent that downstream of Ajmiriganj, sediment concentrations show a strong hysteresis during the monsoon season when the high backwater levels from the Meghna River cause sediment to drop out of suspension. This hysteresis is illustrated in Figure A.38 by plotting the observed sediment concentrations at Ajmiriganj versus the discharge (measured at Markuli). This deposition should cause the suspended sediment concentrations during the monsoon season to decrease with distance downstream. Simultaneous measurements were made at 4 sites (Ajmiriganj, Kadamchal, Abdullhapur and Madna) on 16 October 1995 for verification. At this time, the water levels in the lower river were still strongly affected by backwater from the Meghna River (water levels at Madna and Ajmiriganj were El. 5.27 m, and El. 5.60 m respectively). The concentrations decreased as follows:

Ajmiriganj:	677 mg/l
Kadamchal:	102 mg/l
Abdullahpur:	60 mg/l
Madna:	36 mg/l

Major losses occur at Cherapur Khal and the Baida channel near Issapur, so it is not possible to attribute all of the concentration changes to sediment deposition alone. Furthermore, the river gains considerable flow from the flooded *haor* areas in the downstream reaches at this time of year, which will also contribute to the reduced concentrations. Nevertheless, these measurements are indicative that during the monsoon season, the deeply flooded, backwater controlled reach of the river acts as a "settling basin" for the incoming suspended load.

Table A.17: Summary of Sediment Sampling Program, 1995-1996

Observations	Sherpur	Markuli	Ajmiriganj	Shantipur	Kadamchal
Period	04/04/95- 10/14/95	05/18/95- 10/29/95	04/05/95- 05/27/96	12/18/95- 04/14/96	12/18/95- 05/15/96
Days sampled	49	50	58	14	35
Total samples	147	143	126	42	35
Range of Q (m3/s)	71-2,632	603-2,586	120-2,300	109-1,400	99-1,423
Range of C (mg/l)	25-1,555	56-1,367	20-2,261	29-1,335	41-3,580
Range of G (tonne/day)	154-275,285	2919-237,000	319-389,480	454-161,400	405-320,800

6.6 Total Suspended Sediment Load

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

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

$$C_t = aQ_t^b$$

- 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) as:

$$g_t=KC_t$$

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

Table A.24 summarizes the rating curve regression equations that were developed for each station. The reliability of this method was tested by estimating the suspended loads over the period of measurements at Sherpur, Markuli, Ajmiriganj and Shantipur. The daily loads were then summed to provide monthly or seasonal totals. These rating curve estimates were then compared with the estimates from the direct measurements. During this period the measurements were typically made every three days. Concentrations on the missing days were estimated by interpolating between the measurements. Table A. 25 compares the two results. It can be seen that the values estimated by the rating curves agree reasonably closely with the estimates from the direct measurements. Therefore, it was considered reasonable to apply the rating curve for estimation purposes. Table A.26 summarizes the estimated long-term seasonal and annual load at Sherpur. This was based on published discharges over the period 1982-1989. The total suspended load is approximately 18 million tonnes/year, with transport in the monsoon season amounting to 71.7% of the annual total.

6.7 Size Distribution of the Load

A composite of all suspended sediment samples provided an average size distribution of 80% silt, 5% very fine sand and 15% clay (Figure A.33). There did not appear to be any noticeable difference in the size distribution between Sherpur and Ajmiriganj. This average size distribution was tentatively adopted to estimate the annual suspended sediment transport by size fraction at Sherpur (Table A.27).

The bed sediments at Sherpur and Markuli are composed almost entirely of sand (>0.063 mm) - silt and clay-sized sediments make up less than 10% of the bed composition (Figure A.33). Using the D_{10} bed material size as a criterion for defining wash load, all of the suspended sediment load finer than 0.063 mm (roughly 95% of the load) should be considered as wash load at Sherpur and Markuli and only about 5% is suspended bed material load. The annual suspended sediment load at Sherpur can be sub-divided as follows:

- total annual suspended load: 18×10^6 tonnes/year
- annual wash load: $0.95 \times 18 \times 10^6 = 17.1 \times 10^6$ tonnes/year
- annual bed material load: $0.05 \times 18 \times 10^6 = 0.9 \times 10^6$ tonnes/year

87

Table A.18: Suspended Sediment Measurements at Sherpur

Date	Water Level (m PWD)	Discharge (m^3/s)	Concentration (mg/l)	Suspended Load (tonne/day)
04Apr95	3.83	170	73	1,070
11Apr95	3.71	150	112	1,452
18Apr95	3.93	188	48	777
25Apr95	3.12	71	25	154
02May95	3.21	81	51	360
09May95	4.31	263	78	1,762
16May95	3.87	177	144	2,202
20May95	7.29	1,315	989	112,351
23May95	7.21	1,276	1,136	125,275
27May95	6.64	1,014	305	26,711
30May95	6.18	825	151	10,750
03Jun95	5.77	674	111	6,479
06Jun95	5.90	720	136	8,494
10Jun95	6.02	764	108	7,120
13Jun95	6.35	893	301	23,194
17Jun95	7.93	1,652	1,003	143,196
20Jun95	8.71	2,387	942	194,244
24Jun95	8.65	2,280	514	101,290
27Jun95	8.49	1,979	469	80,175
01Jul95	8.44	1,948	1,555	261,771
04Jul95	8.45	1,954	784	132,312
08Jul95	8.65	2,280	808	159,087
11Jul95	8.60	2,194	428	81,134
15Jul95	8.52	2,060	507	90,245
18Jul95	8.46	1,961	1,037	175,711
22Jul95	8.41	1,930	429	71,484
25Jul95	8.36	1,900	223	36,633
29Jul95	8.13	1,765	173	26,328
01Aug95	8.10	1,748	351	53,004
05Aug95	8.13	1,765	415	63,278
08Aug95	8.06	1,725	229	34,068
12Aug95	8.02	1,702	526	77,345
15Aug95	8.63	2,245	1,419	275,285
19Aug95	8.82	2,593	1,161	260,053
22Aug95	8.84	2,632	856	194,738
26Aug95	8.78	2,517	859	186,823
29Aug95	8.71	2,387	503	103,824
02Sep95	8.67	2,315	703	140,736
05Sep95	8.58	2,160	437	81,507
09Sep95	8.43	1,942	326	54,780
12Sep95	8.38	1,912	658	108,728
16Sep95	8.12	1,759	308	46,821
19Sep95	8.08	1,736	340	50,995
23Sep95	7.84	1,602	219	30,268
26Sep95	7.92	1,646	208	29,608
30Sep95	8.01	1,697	365	53,464
03Oct95	8.05	1,719	565	83,923
10Oct95	7.97	1,674	1,149	166,166
14Oct95	7.76	1,558	477	64,235
Maximum		**2,632**	**1,555**	**275,285**
Minimum		71	25	154

89

Table A.19: Suspended Sediment Measurements at Markuli

Date	Water Level (m PWD)	Discharge (m^3/s)	Concentration (mg/l)	Suspended Load (tonne/day)
18May95	5.04	853	144	10,645
21May95	6.51	1,287	391	43,496
24May95	6.39	1,174	755	76,612
28May95	5.88	909	152	11,970
31May95	5.53	856	92	6,827
04Jun95	5.42	786	71	4,800
07Jun95	5.43	738	74	4,739
11Jun95	5.50	812	65	4,528
14Jun95	6.10	1,075	399	37,107
18Jun95	7.05	1,986	862	147,952
21Jun95	7.36	2,408	911	189,503
25Jun95	7.29	2,205	890	169,498
28Jun95	7.23	2,065	582	103,778
02Jul95	7.20	2,008	1,367	237,023
05Jul95	7.34	2,183	856	150,022
09Jul95	7.42	2,587	586	131,041
12Jul95	7.40	2,360	413	84,198
16Jul95	7.35	2,205	527	100,477
19Jul95	7.31	1,953	741	125,116
22Jul95	7.25	1,656	579	82,815
26Jul95	7.18	1,578	146	19,909
30Jul95	7.14	1,567	178	24,060
02Aug95	7.12	1,551	401	53,732
06Aug95	7.08	1,548	344	45,959
09Aug95	7.03	1,501	303	39,338
13Aug95	7.09	1,549	598	80,064
16Aug95	7.28	1,996	754	130,100
20Aug95	7.37	2,395	1,092	226,080
23Aug95	7.33	2,251	911	177,272
27Aug95	7.30	2,073	787	140,993
30Aug95	7.24	1,849	743	118,719
03Sep95	7.21	1,788	698	107,780
06Sep95	7.17	1,728	580	86,561
10Sep95	7.15	1,577	697	94,891
13Sep95	7.08	1,479	625	79,863
17Sep95	6.95	1,469	420	53,307
20Sep95	6.89	1,353	348	40,660
24Sep95	6.89	1,352	580	67,707
27Sep95	6.89	1,306	235	26,522
01Oct95	6.91	1,356	349	40,845
04Oct95	6.87	1,279	497	54,971
08Oct95	6.80	1,215	277	29,075
11Oct95	6.83	1,292	715	79,871
15Oct95	6.64	1,224	292	30,890
18Oct95	6.54	1,142	174	17,144
22Oct95	6.14	888	152	11,653
25Oct95	5.97	762	112	7,356
29Oct95	5.62	603	56	2,919
Maximum		**2,587**	**1,367**	**237,023**
Minimum		**603**	**56**	**2,919**

Table A.20: Suspended Sediment Measurements at Ajmiriganj

Date	WL (m PWD)	Q (m^3/s)	C (mg/l)	Gsus (t/day)	Date	WL (m PWD)	Q (m^3/s)	C (mg/l)	Gsus (t/day)
05Apr95	2.53	135	57	667	23Oct95	5.31	1,339	306	35,401
10Apr95	3.39	262	28	637	26Oct95	5.07	1,031	179	15,945
17Apr95	3.65	314	38	1,021	30Oct95	4.96	912	107	8,431
24Apr95	3.14	219	38	728	18Dec95	3.62	305	48	1,252
01May9	3.02	201	28	488	21Dec95	3.52	287	73	1,815
06May9	3.59	253	38	822	26Dec95	3.45	268	20	468
15May9	3.17	258	43	950	28Dec95	3.40	254	31	689
19May9	4.94	895	810	62,646	01Jan96	3.24	239	29	606
22May9	5.51	1,654	752	107,394	04Jan96	3.14	214	30	562
25May9	5.44	1,536	766	101,701	08Jan96	3.09	207	25	446
29May9	5.15	1,124	246	23,902	11Jan96	3.07	203	31	543
01Jun95	4.99	942	127	10,363	14Jan96	2.98	190	34	564
05Jun95	4.99	942	129	10,461	17Jan96	2.90	181	52	814
08Jun95	4.96	910	93	7,323	22Jan96	2.85	174	44	657
12Jun95	5.57	1,188	181	18,538	25Jan96	2.73	164	26	368
16Jun95	5.20	1,761	461	70,084	29Jan96	2.68	158	44	606
19Jun95	6.15		1,533		01Feb96	2.64	153	24	319
22Jun95	6.66		473		05Feb96	2.58	144	34	428
26Jun95	6.69		214		08Feb96	2.52	137	45	537
29Jun95	6.62		250		12Feb96	2.44	127	37	404
03Jul95	6.68		559		15Feb96	2.39	120	39	405
06Jul95	7.07		21		26Feb96	3.01	210	53	966
10Jul95	7.23		26		01Mar96	3.48	296	121	3,102
13Jul95	7.21		34		04Mar96	3.26	243	47	989
17Jul95	7.16		25		07Mar96	2.98	196	36	608
20Jul95	7.10		59		11Mar96	2.70	162	53	748
24Jul95	6.96		58		14Mar96	3.31	255	67	1,476
27Jul95	6.89		49		18Mar96	5.04	810	201	14,035
31Jul95	6.77		72		21Mar96	4.80	517	147	6,548
03Aug95	6.61		273		25Mar96	4.24	345	84	2,495
07Aug95	6.53		225		28Mar96	4.66	653	114	6,460
10Aug95	6.39		328		01Apr96	5.44	1,321	930	106,171
14Aug95	6.61		224		04Apr96	5.67	1,733	1,083	162,107
17Aug95	6.89		74		08Apr96	5.51	1,403	469	56,882
21Aug95	7.10		58		11Apr96	5.19	1,139	329	32,377
24Aug95	7.07		92		15Apr96	4.67	699	205	12,347
28Aug95	6.98		181		18Apr96	4.49	509	93	4,082
31Aug95	6.78		272		23Apr96	4.37	474	67	2,742
04Sep95	6.70		280		25Apr96	4.46	518	92	4,097
07Sep95	6.61		247		06May96	4.79	763	63	4,122
11Sep95	6.63		933		10May96	4.79	846	382	27,907
14Sep95	6.27		859		13May96	5.28	1,268	281	30,841
18Sep95	6.09		902		16May96	5.58	1,994	2,261	389,480
21Sep95	6.03		302		19May96	5.61	1,837	1,681	266,834
25Sep95	6.17		480		20May96	5.60	2,040	1,776	312,975
28Sep95	6.07		620		23May96	5.50	1,850	1,382	220,841
02Oct95	6.11		643		26May96	5.34	1,383	743	88,812
05Oct95	6.10		334		27May96	5.33	1,320	417	47,599
09Oct95	5.93		815		30May96	5.18	1,163	762	76,606
12Oct95	5.83	2,300	1,383	274,830	02Jun96	5.68	1,975	1,952	333,014
16Oct95	5.65	1,915	618	102,252	03Jun96	5.68	1,975	1,893	322,921
19Oct95	5.42	1,506	545	70,915	06Jun96	5.75	2,121	1,125	206,087
Maximum							**2,300**	**2,261**	**389,480**
Minimum							**120**	**20**	**319**

Table A.21: Suspended Sediment Measurements at Shantipur

Date	Water Level (m PWD)	Discharge (m^3/s)	Concentration (mg/L)	Suspended Load (tonne/day)
18Dec95	3.09	275	74	1,762
21Dec95	2.99	261	48	1,089
25Dec95	2.95	250	92	1,997
28Dec95	2.88	238	45	930
01Jan96	2.73	226	48	937
04Jan96	2.63	210	39	705
08Jan96	2.60	206	29	523
11Jan96	2.59	202	63	1,099
14Jan96	2.49	181	69	1,077
17Jan96	2.40	175	55	828
22Jan96	2.40	169	79	1,147
25Jan96	2.28	151	102	1,332
29Jan96	2.21	138	99	1,186
01Feb96	2.39	134	76	884
05Feb96	2.37	129	41	454
08Feb96	2.36	124	75	801
12Feb96	2.25	112	47	455
15Feb96	2.18	109	82	767
26Feb96	2.52	201	150	2,612
01Mar96	3.09	288	171	4,255
04Mar96	2.92	238	145	2,983
07Mar96	2.72	188	73	1,181
11Mar96	2.48	153	72	955
14Mar96	2.86	234	178	3,590
18Mar96	4.25	736	496	31,502
21Mar96	4.10	626	234	12,652
25Mar96	3.66	352	114	3,462
28Mar96	3.88	536	545	25,249
01Apr96	5.06	1,154	1,183	117,946
04Apr96	5.28	1,400	1,335	161,392
Maximum		**1,400**	**1,335**	**161,392**
Minimum		**109**	**29**	454

Table A.22: Suspended Sediment Measurements at Kadamchal

Date	WL (m, PWD)	Q(obs) (m^3/s)	Conc. (mg/L)	Suspended Load (tonne/day)
19Dec95	2.57	250	146	3,145
22Dec95	2.55	223	77	1,479
26Dec95	2.55	212	75	1,370
29Dec95	2.41	199	51	885
02Jan96	2.24	180	65	1,009
09Jan96	2.19	174	55	827
12Jan96	2.15	170	72	1,059
15Jan96	2.06	152	68	898
18Jan96	1.99	141	54	654
23Jan96	2.00	127	65	709
26Jan96	1.92	122	123	1,301
30Jan96	1.81	120	73	751
03Feb96	1.97	116	99	995
06Feb96	2.00	120	49	508
09Feb96	2.00	116	44	445
13Feb96	1.89	101	46	405
16Feb96	1.82	99	63	539
27Feb96	2.31	167	405	5,839
02Mar96	2.46	223	272	5,249
05Mar96	2.34	174	115	1,724
08Mar96	2.22	156	71	959
12Mar96	2.10	129	41	456
16Mar96	3.33	561	1,542	74,752
19Mar96	3.50	624	858	46,241
24Mar96	3.13	313	463	12,519
27Mar96	2.86	263	224	5,097
30Mar96	3.65	821	1,195	84,722
02Apr96	4.06	1,037	3,580	320,822
09Apr96	3.97	1,001	3,082	266,626
16Apr96	3.51	503	755	32,814
24Apr96	3.39	379	535	17,523
26Apr96	3.41	393	291	9,877
07May96	3.84	609	184	9,688
11May96	3.96	985	326	27,716
14May96	4.26	1,423	908	111,664
Maximum		**1,423**	**3,580**	**320,822**
Minimum		**99**	**41**	**405**

Table A.23: Size Distribution of the Suspended Load

Station	Date	Gauge Ht (m)	C (mg/l)	D_{50}				% of Suspended Load >.048 mm[1]
				Size (mm)	Sand (%)	Silt (%)	Clay (%)	
Sherpur	Oct-10-95	7.97	1149	0.021	4	77	19	9
	May-19-96	7.98	892	0.015	1	76	23	4
	May-26-96	7.31	159	0.014	2	85	13	13
	Jun-02-96	8.28	1578	0.010	0	74	26	39
Markuli	Oct-08-95	6.91	272	0.021	16	70	14	26
	May-19-96	7.12	583	0.018	7	83	20	12
	May-26-96	6.54	208	0.018	4	79	17	14
	Jun-02-96	7.26	1578	0.010	0	74	26	39
Ajmiriganj	Oct-09-95	5.93	815	0.025	6	82	12	22
	May-19-96	5.61	1681	0.016	1	80	19	10
	May-26-96	5.34	743	0.019	0	78	22	8
	Jun-02-96	5.68	1578	0.010	0	74	26	3

Note[1] Material >0.048 mm settles as bed load material downstream of Ajmiriganj

Table A.24: Suspended Sediment Concentration Rating Curve Relations

Station	Rating Curve	R^2	SEE (Ln units)
Sherpur	$C = 1.022Q^{0.846}$	0.68	0.55
Markuli	$C = 0.000344Q^{1.924}$	0.72	0.44
Ajmiriganj	$C = .0325Q^{1.35}$	0.84	0.56
Shantipur	$C=0.1372Q^{1.237}$	0.70	0.53
Kadamchal	$C=0.07226Q^{1.448}$	0.75	0.65

Table A.25: Comparison of Predicted Loads by Rating Curve Methods

Station	Period	Measured (tonne/year)	Rating Curve (tonne/year)
Sherpur	Apr-01-95 to Oct-31-95	14,892,700	14,541,100
Markuli	May-01-95 to Sep-30-95	10,896,000	13,016,200
Ajmiriganj	Jan-01-96 to May-31-96	5,240,300	4,166,500
Shantipur	Jan-01-96 to Mar-31-96	528,000	512,500
Kadamchal	Jan-01-96 to May-14-96	4,825,400	3,985,100

Table A.26: Long-term Load at Sherpur

Season	Total Suspended Sediment (tonne/year)	Percent of Annual Load (%)
Pre-monsoon	2,014,600	11.2
Monsoon	12,891,900	71.7
Post-Monsoon	2,838,500	15.8
Dry Season	237,200	1.3
Annual	17,982,200	100

Table A.27: Estimated Annual Load at Sherpur by Size Fraction

Size Range (mm)		% of total	Annual Load (tonne/year)
> 0.063	sand	5	900,000
0.03 - 0.063	5.1+	25	4,500,000
0.01 - 0.03	5.1+	40	7,200,000
0.004 - 0.01	5.1+	15	2,700,000
< 0.004	clay	15	2,700,000
Total		**100**	18,000,000

Downstream of Ajmiriganj, as a result of deposition during the monsoon season, bed sediments contain appreciable amounts of medium-coarse silt. The size distribution of sediments in slack water areas and sloughs closely resembles the suspended sediment composition. Sediments deposited in the main active channel are coarser than the suspended load (Figure A.39). For example, in most bed samples, 90% of the sediment was coarser than 0.03 mm. In the suspended sediment samples at Ajmiriganj, only 30% was coarser than 0.03 mm. This implies roughly 70% of the suspended sediment load will still behave as wash load at Ajmiriganj, and can be flushed through the channel without being depositing on the bed. The corresponding wash load can be roughly estimated as follows:

- annual wash load at Ajmiriganj: $0.7 \times 18 \times 10^6 = 12.6 \times 10^6$ tonnes/year
- annual bed material load: $0.3 \times 18 \times 10^6 = 5.4 \times 10^6$ tonnes/year

6.8 Sediment Transport Predictions

Estimates of the bed material load can also be made using sediment transport equations when the hydraulic and sediment grain size can be specified. Although there are a large number of theoretical sediment transport equations, most are not applicable to fine sediments. However, the Engelund-Hansen equation has been successfully tested using data from very fine sand and silt bed channels (Nordin & McLean, 1988). Therefore, this equation was used for a series of test calculations at Ajmiriganj.

The hydraulic information (velocity, mean depth, bed width) was determined directly from the discharge measurements (Figure A.24). The water surface slope was measured from the water level gauges at Shantipur, Ajmiriganj and Markuli. Table A.28 summarizes the results of these computations and compares them with measurements in the dry season and pre-monsoon season. The rating curve estimates were derived from the measured sediment concentrations at the stations using the regression equations listed in Table A.24. These values were then multiplied by a factor of 0.3 to exclude the wash load portion of the load. These results show good agreement and provide some justification for applying the equation for predictive purposes.

Table A.28: Predicted Sediment Transport Concentrations

Q (m^3/s)	V (m/s)	d (m)	W (m)	Concentration (mg/l)		Difference (%)
				Engelund-Hansen	Rating Curve(1)	
Markuli						
500	0.26	11.87	159	47	16	193
1,000	0.48	12.21	170	89	61	45
1,500	0.69	12.42	176	131	133	15
1,750	0.78	12.50	179	147	179	18
2,000	0.88	12.56	181	167	232	28
Ajmiriganj						
500	0.63	4.17	192	64	45	42
1,000	1.06	4.70	200	114	115	<1
1,500	1.49	4.90	206	163	200	18
1,750	1.71	4.93	208	188	246	23
2,000	1.84	5.20	209	208	295	29
Shantipur						
500	0.91	3.69	148	93	52	79
1,000	1.40	4.54	156	159	122	30
1,500	1.80	5.12	161	216	202	7
1,750	1.98	5.36	163	243	244	<1
2,000	2.16	5.57	164	279	288	3
Kadamchal						
500	0.94	3.05	175	88	45	96
1,000	1.51	2.93	225	138	122	13
1,500	2.00	2.86	262	181	219	17
1,750	2.22	2.84	277	201	273	26
2,000	2.44	2.81	291	219	332	34

Notes:
1. Rating curve estimates are from measured sediment concentrations during the pre-monsoon season, multiplied by a factor of 0.3 to correct for the wash load component;
2. V is the mean velocity, d is the mean depth, W is the bed width
3. A water surface slope of 0.000035 was used for all calculations
4. D_{50} sediment size was 0.06 mm

99

7. LATERAL STABILITY

7.1 History of Channel Changes

Historical channel changes were assessed by reviewing available maps and satellite imagery as well as interviewing local villagers. All of the available maps were digitized and converted to a Transverse Mercator Projection using the Indian Zone 2B grid system. This grid was adopted earlier for both the 1990 SPOT imagery and the hydrographic surveying. The 1983 air photos were also digitized and adjusted by identifying known points on the photos and satellite imagery and then scaling and rotating the photos to match the known coordinates. The digitized channel positions were then overlaid to assess where major channel shifts or channel pattern changes had occurred.

The Rennell survey of 1768 showed the upper Kushiyara River was a distributary of the Barak River, and was smaller than the Surma River (Figure A.40). Rennell noted the upper Kushiyara River was "navigable only by small boats during the flood season". Furthermore, the map showed the river flowed down Sonai Bardal channel, meeting its present-day course near Fenchuganj. The Kalni River originated north of Ajmiriganj and joined the Kushiyara River at Markuli. The Surma River turned south just past Sunamganj and joined the Kalni/Kushiyara River at Ajmiriganj. The combined flow formed the Dhaleswari River and joined the Brahmaputra River just upstream of Bhairab Bazar.

The Brahmaputra River abandoned the 1768 course during the 19th century, leaving the runoff from the Upper Meghna River (essentially the Surma-Kushiyara River systems) to drain through the former channel (Figure A.41). The Surma River also developed a new westward channel (Nawa Gang) and joined the Baulai River. The former channel became known as Mora Surma (Old Surma River), and gradually carried less flow. A BWDB field report dated 8 May 1963 stated:

> *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"*

Maps from 1952 show the Kushiyara River followed its present course between Amalshid and Sherpur. Downstream of Sherpur, the river flowed through the Bibiyana River in a tortuously meandering channel with frequent distributaries and active *khals*. Downstream of Markuli, the river was called the Kalni River after receiving inflows from the southward flowing distributary channel.

Table A.29 summarizes the key events that have occurred on the Kalni-Kushiyara River. Figures 42-43 illustrate the channel changes since 1952. Detailed channel comparisons are shown in Figures 44-46. Table A.30 provides an estimate of the total land lost due to bank erosion downstream of Sherpur.

There has been a downstream progression of channel instability, starting near Sherpur in the 1950s and reaching Katkhal, 80 km downstream, in the 1990s.

a y

Table A.29: Key Events on Kalni-Kushiyara River

Date:	Location	Event
1955	Sherpur	loop cuts constructed (2)
1958-1970	Sherpur-Markuli	avulsion from Bibiyana channel into Suriya Khal
1978	downstream of Markuli	loop cuts constructed (3)
1980	Markuli	closure of Kalni River
1988		major flood
1991		major flood
1992	Ajmiriganj	Bheramohona closure constructed
1993		major flood
1993	Katkhal	natural cutoff initiates enlargement of Cherapur Khal

Table A.30: Historical Erosion Rates

Erosion due to Channel Shifting

River	Reach	Km	Erosion 1963-1995 (ha)	Erosion Rate 1963-1995 (ha/year)
Kushiyara	Sherpur-Bibiyana offtake	177-163	176	5.5
Kushiyara (Suriya Channel)	Bibiyana offtake - Markuli	163-133	555	17.4
Kalni	Markuli-Ajmiriganj	133-107	246	7.7
Kalni	Ajmiriganj - Kadamchal		269	8.4
Kalni	Kadamchal - Issapur		335	10.5
Kalni-Kushiyara	Sherpur-Issapur		1,581	49.4

Erosion due to channel widening

Location	Km	1955-1963		1963-1995		1955-1995	
		Avg. Width Change (m)	Eroded Area (ha)	Avg. Width Change (m)	Eroded Area (ha)	Avg. Width Change (m)	Eroded Area (ha)
Suriya channel	160-132	+52	135	+57	159	+109	294
Katkhal channel	96.5-92.5	-	-	+120	48	+120	48

Upper Kushiyara River - Amalshid to Sherpur

The overall channel pattern has remained stable during the last 40 years, although progressive meander migration has occurred at most bends. Meander shifting is most noticeable at Amalshid (NERP, 1994) and near Fenchuganj.

Bibiyana-Suriya Avulsion

In 1955 two artificial loop cuts were made by the local government near Sherpur (Figure A.44). The upstream cut (near Km 175) eliminated the large loop north of Sherpur and was made to reduce bank erosion at six nearby villages (Galimpur, Madhabpur, Shuirkons, Soydag, Kalnirchar and Charghor). The remnant of the cut-off loop is an ox-bow lake (Figure A.20). The second loop cut was made downstream to protect the village of Qusba. The Qusba loop cut re-directed the river's flow into a small *khal* (Jalalpur Khal). Over a period of three or four years this *khal* enlarged and began capturing a significant portion of the Kushiyara's flow. Local people from Jalalpur tried to stop the shift, but failed. Consequently, the river eventually established a new route (Suriya channel) through a series of minor distributary channels and *haors* until re-joining the Kalni River 30 km downstream near Markuli. This avulsion caused the destruction of several villages, including Jalalpur, Modipur and Alkadi, and caused serious erosion to Pilegaon, Nagargaon, and Raniganj. The Suriya channel shortened the river length between Sherpur and Markuli by around 22 km, so it is not surprising that this route captured the main flow from the Bibiyana channel.

Figure A.47 shows estimated channel widths (scaled from available maps and imagery) at various dates between 1952 and 1995. The 1952 maps show Suriya Khal had an average top width of 40-80 m before the shift. BIWTA sounding in the early 1970s shows the main navigation route in the dry season followed the Suriya channel, although it was still narrow at that time. Air photos in 1983 show the Suriya channel had enlarged to approximately 150 m. Overall, the channel widened by 109 m on average during the period 1955-1995, and eroded 294 ha of land in this 28 km reach (Table A.30).

Recent surveys show the Suriya channel has an average cross sectional area at bankfull stage of around 1,000 m^2. By comparison, the cross sectional area of Suriya Khal before the avulsion was probably less than 200 m^2. This means the volume of material eroded as a result of channel widening would have been in the order of:

$$30000 \times (1000-200) = 24 \times 10^6 \text{ m}^3.$$

Additional erosion also occurred due to shifting, since the new channel made many channel switches as it cut off bends and developed a new meandering pattern.

Big steamers were able to plie through the Bibiyana channel until 1960. The 4 inch =1 mile maps of 1964 show both the Bibiyana channel and the Suriya channel were open at that time, with the Bibiyana channel partially infilled with sediment. The old channel continued to fill-in with sediments during the 1980s and early 1990s. At present, about 80% of the former channel has filled-in, and can be used for cultivation.

Markuli Closure

Following the Suriya avulsion, pre-monsoon flooding problems increased downstream of Markuli. Up until that time, runoff from the Surma-Kushiyara Inter-Basin drained into the Upper Kalni River and flowed southwards into the Kushiyara River. After the avulsion, these flows were reversed and floods from the Suriya channel spilled into the Sylhet Basin. As a result, rapid siltation took place at the junction of the Kalni and Kushiyara Rivers near Markuli. Sedimentation also occurred on both sides of the Upper Kalni River in parts of Derai, Sullah, and Jagannathpur thana, which made the land uncultivable for *boro* crops. Local residents indicated that from 4 to 12 April 1977, the water of the Kushiyara River entered the upper Kalni and devastated *boro* crops in Baram Haor, Tangua Haor, Noluar Haor, Chhutirgaon Haor, Shashaier Haor, Dhopajura Haor and Chhayar Haor. In 1978 local officials decided to construct a closure at Markuli to prevent spills entering into the lowlands. Several attempts were made, and by 1982 a permanent closure was completed. After the closure was constructed, it was noticed that the water levels on the Kushiyara side (south) were up to 1.2 m higher than on the Kalni side (north). A review of water level measurements on the Kushiyara River at Markuli show a sudden jump in water levels after the closure was completed. Therefore, the structure reduced spills into the low-lying basins north of Markuli, but raised water levels on the Kushiyara River.

Loop Cuts Between Markuli and Ajmiriganj

Three loop cuts were constructed in January-February 1978 downstream of Markuli near Saudersili (Km 128), Doaya Beel (Km 122) and Pituakandi (Km 114). The work was carried out as part of a National Canal Digging Program and involved BWDB, BRAC, *thana* and Union officials. The purposes of the loop cuts were (1) to make the river more navigable (deeper) (2) to save transportation time and (3) to use the old course of the river as a fishery. The excavation work was completed in three weeks. The loop cuts were made by constructing a narrow pilot channel, closing the entrance to the old channel, and diverting the river into the new course. Figure A.45 shows that the pilot channel was still very narrow in 1989 and produced a noticeable constriction in the river. This constriction would have raised water levels upstream, which probably contributed to the increased flooding in the Kalni River near Markuli. It has taken more than 10 years and the occurrence of major floods in 1991 and 1993 for the pilot channels to enlarge to the natural channel width.

Katkhal Cutoff

Figure A.46 shows channel changes that have developed below Ajmiriganj. Surveys in 1927 and 1963 show the river had a split channel pattern below Ajmiriganj, with the main flow being carried in a series of sharp bends to the north of Katkhal village. Starting in the 1970s and 1980s, this channel began silting-in, and the minor eastern distributary began growing. The length of this distributary route was about 10 km shorter than the main channel, which allowed it to capture more of the flow. Subsequent widening caused two cutoffs, further accelerating the channel shift. By 1990 the distributary had turned into the main channel. During the period 1990-1993, bank erosion at the bend's outer (convex) bank triggered another cutoff, destroying the village of Shahebnagar (Figure A.46). This shift re-directed the main flow into Cherapur Khal, which at that time was a minor (30-40 m wide) distributary that connected the Kalni River to the Baulai system. The *khal* has enlarged to between 60-80 m in width and is now capturing up to 35% of the river's flow in the pre-monsoon season. Further enlargement of this *khal* could eventually lead to the abandonment of the lower Kalni River, which would seriously affect drainage conditions between Katkhal and Madna .

7.2 Styles of Channel Instability

The historic channel changes described above show that there are three characteristics styles of channel instability on the river.

Avulsions
Avulsions are rapid channel shifts which result in the development of a new river course and the abandonment of former channels. The shift from the Bibiyana channel into the Suriya channel and the ongoing shift into Cherapur Khal represent two examples of this process. Avulsions occur in reaches where the river has an anastomosing channel pattern, with one or more dominant channels and a number of branching distributaries or *khals*. Changes in channel alignment, downstream aggradation or erosion at the *khal*'s junction can all trigger the sudden shift from the main channel into the *khal*. Increases in flood flows are also likely to promote the development of avulsions. Whether or not the *khal* will enlarge and capture the main flow depends mainly on (1) the difference in gradient between the new channel and the old one (2) the erodibility of the banks along the *khal* and (3) whether the old channel fills-in with sediment. The new channel will eventually reach equilibrium when its geometry is adjusted to the discharges and sediment loads. Avulsions are one way in which the river responds to aggradation - channel deposition will take place up to a point when the river switches to a new location on the floodplain.

Breaches
Dhalas form at the outer (convex) banks of bends, when the river breaches its natural levee and cuts a spill channel into the adjacent low-lying flood basin. These breaches result in large amounts of sediment being eroded from the bank and deposited in the nearby *beels* and *haors*. These features are mainly found upstream of Ajmiriganj, probably because the flows are still confined in the pre-monsoon and monsoon seasons, so that when a breach occurs there is sufficient head difference between the river and floodplain to generate high velocity spills. Downstream of Ajmiriganj, backwater effects reduce the head difference between the main channel and floodplain so that spills do not have sufficient velocity to scour a new *dhala*.

Figure A.11 illustrates this process at Koyer Dhala, 10 km upstream of Ajmiriganj. This channel developed after the Paharpur loop cut was constructed when overbank spills were directed into Koiya Beel, located on the left bank, immediately south of the pilot channel. The spills caused increased sedimentation and by 1985 the low-lying floodplain had filled-in by between 1.5-2.4 m. Increased pre-monsoon flood damages were also experienced in this area. The flood of 1988 formed a permanent spill channel (*dhala*). This channel was blocked in 1992 by the local people, however, it breached again in 1995.

Meander Migration
Progressive meander migration is driven by secondary currents in bends, with point bar deposition on the inner (convex) bank and scour along the outer (concave) bank. Figure A.48 illustrates the common types of meander shifting. These include (a) extension (b) translation (c) rotation and (d) conversion to a compound form. Meanders may progress until forming a natural cutoff - either by gradual evolution through a neck cutoff or by a rapid shift through a chute cutoff .

The rate of shifting has been found to depend on several factors, including:

- bend geometry- the radius of curvature of the bend (R) and channel width (W);
- hydraulic conditions (discharge, shear stress on the bank, scour depth);
- geotechnical properties (bed and bank materials, pore water pressure in bank), and
- local conditions (vegetation, local protective works, structural loading of the slope).

Estimates of bank erosion rates were made at each bend between Sherpur and the Meghna River confluence using the historic mapping between 1964 and 1995. The radius of curvature, average top width and distance of bank retreat was estimated at each bend. Figure A.49 shows the erosion rate was largely governed by the bend radius / channel width ratio (R/W). The erosion rate was found to increase rapidly when R/W < 3. Furthermore, at R/W ratios < 2 the probability of developing a neck cutoff became very high. This relation provides a means for assessing the threshold of meander instability in any bend on the river.

Bank erosion in meanders was observed to often take place during the declining stages of the flood (post-monsoon season), when the water level in the river was dropping quickly and the banks and floodplain were still saturated. The sudden draw-down triggered slope failures in the over-steepened silty-clay bank materials. Bank erosion was also observed to occur during the period April-May, when the water surface slope was steepest and the channel velocities were highest.

Channel Widening

Channels may erode their banks and widen in response to increased discharges if flow is captured from another branch or distributary. The enlargement of the Suriya channel after the Bibiyana avulsion, the growth of the distributary channel near Katkhal in the 1980s and the ongoing widening of Cherapur Khal west of Katkhal are all examples of this process.

Channel widening has also occurred in response to upstream changes in flood discharges due to increased rainfall, closure of upstream spill channels or confinement of overbank flows from embankments. For example, repeat cross section surveys on the Kushiyara River between Sheola and Fenchuganj show the channel enlarged slightly during the period 1970-1991, probably in response to the increased flood discharges that have occurred in the last decade.

Ultimately, the channel should reach an equilibrium condition when it adjusts its geometry to the incoming discharge and sediment load. The time period required for this adjustment to be completed can not be established analytically. However, based on the observations from the Suriya Channel and at Katkhal, it appears that at least 15 years are required to reach final equilibrium.

7.3 Future Erosion Hazards

Table A.31 summarizes sites of active bank erosion and channel instability. The locations are identified on Figure A.50. There are three main areas at risk between Sherpur and Issapur:

Suriya Channel - Raniganj to Markuli

The meander pattern in this reach appears to be still adjusting to the increased channel width after the avulsion. As a result, many of the original small bends from Suriya *Khal* are now being destroyed through natural cutoffs. Cutoffs at Km 168 (Site 1) and Km 161 (Site 2) appear inevitable, and will probably end up producing a more stable overall channel alignment. Active bank erosion is also occurring along the outer (concave) banks of most meander bends, and is threatening to seriously damage the villages of Raniganj and Markuli. Active breaching and *dhala* formation occurs on the right bank of Akkilshah Bazar. Other *dhalas* have been temporarily closed by local people, however, the effectiveness of these works during a major flood is not certain.

Kalni River at Koyer Dhala

There is a risk of continued breaching and spills through Armather Dhala on the right bank and through Koyer Dhala on the left bank. If Koyer Dhala breaches again, *boro* crops in the entire areas of Ajmiriganj and Baniachang Thana and one third of Nabiganj Thana could be ruined.

Kalni River near Katkhal

The natural cutoff downstream of Katkhal is directing the main flow of the river into Cherapur Khal and is now diverting up to 35% of the Kalni River into the Baulai-Ghorautra River system. The *khal* will continue to enlarge in response to the increased flow. However, the overall route through the Baulai-Ghorautra system is slightly longer (67 km) than through the Kalni-Dhaleswari channel (61 km), which reduces the likelihood of a full avulsion taking place. However, even if the flow split stabilized at 35%, the corresponding regime width of the channel is around 100 m, which is still considerably wider than at present. If a complete avulsion occurred, the *khal* would enlarge to a width of around 200 m and bank erosion and channel shifting would occur along more than 50 km of the lower Baulai River system.

Table A.31: Erosion Hazards on Kalni-Kushiyara River

#	Name	Km	Bank	Process	Comments
1		168.5-165.0	LB	Mg	Bank erosion along outside of bend threatening to make chute cutoff
2		161.0-156.0	LB	Mg	Bank erosion threatening to make chute cutoff, spills & breaching into Itakhola Nadi
3	Raniganj	153.0	RB	Mc	Rotation of meander bend threatening to erode Raniganj town
4	Balisri	149.5	LB	Ma	Extension of meander bend creating erosion along outside of bend. Spills in 1991,93 & 95
5		144.0	RB	B	Spill and breaching through *khal* in 1985,89,91,92,93,94 &95
6	Akkilshah Bazar Dhala	139.0	LB	B	Breach at sharp bend into Katma Beel. Major spills in 1985,89,91,92,93,94 & 95
7	Markuli	133.0	LB	Ma	Extension of meander bend eroding outer bank and threatening to destroy Markuli town
8	Fayjullapur	129.5	RB	B	1991 breach formed 200 m wide dhala., closed successfully by BWDB in 1993
9	Tangua Dhala	119.0	RB	B	1988 flood formed dhala, spills in 1989,90,91, closed by BWDB in 1991
10	Khoyer Dhala	115.0	LB	B, Ma	Dhala formed after loop cut constructed. re-recurring spills in to Kaia *beel* since 1988 flood, extension of meander bend is increasing bank erosion & threatening to enlarge spills
11	Pituakandi	114.5	RB	B, Ma	Breaches in 1984,85, 88,89,90,91. Closed by Union Parashad in 1992. Extension of meander bend continuing to create new erosion.
12	Bheramohona	109.0	RB	B	Artificial canal constructed in 1987, enlarged into dhala after 1988 flood, spills caused major flood damage in 1990, 91,92. Permanent closure in 1992/93.
13	Shantipur	97.0	RB	Mb	Downstream translation of meander+ channel widening has caused erosion on right bank
14	Cherapur Khal	90.0	RB	A	Channel shift near Kadamchal has re-directed flow into Cherapur Khal, initiating channel widening and diversion of flow into Baulai River
15	Anwarpur	83.0	LB	Ma	Point bar deposition on right bank is causing meander extension, resulting in erosion on left bank and threatening the town of Anwarpur
16	Issapur	72.0		A	Deposition in Dhaleswari channel is encouraging flow diversion into Baida River channel

LEGEND:
Erosion Process
A=Avulsion
B=Breach
Mx=meanders migration (see Figure A.47 for definition of meander migration types)

8. VERTICAL STABILITY

8.1 General

This chapter provides an assessment of (1) long-term aggradation and degradation and (2) seasonal patterns of scour and fill. Aggradation and degradation refer to long-term bed profile adjustments that produce general bed level changes over many kilometres. Scour and fill refer to localized bed level changes (over a few channel widths) that may occur over relatively short periods of time (such as a single flood event or season).

The river has been responding to several events in recent times, including (1) the avulsion from the Bibiyana channel into the Suriya channel during the 1960s (2) loop cuts between Markuli and Ajmiriganj in the 1980s and (3) changes in runoff pattern and (4) local protective works, embankment construction and channel closures. Although the overall response of the channel can be assessed, it is not always possible to isolate the effect of each factor separately.

The analysis of vertical channel changes was made primarily by comparing past river cross sections or hydrographic charts with recent survey information. The Morphology Directorate of BWDB is responsible for monitoring the river and has conducted routine cross section surveys on it since 1964. BWDB provided good cooperation in compiling the early records and in explaining their survey methodology. An effort was made to compile all available historic data. Table A.4 summarizes the information that was made available to the project. Good cooperation was also provided by other organizations, particularly BIWTA and SWMC. In 1993, an intensive river monitoring program was started to obtain more recent information to document channel changes. In 1994 this program was expanded to include comprehensive hydrographic charts of the entire river.

Vertical channel changes were also assessed by preparing "specific gauge" plots using hydrometric records at Sheola (gauge 173) and Sherpur (gauge 175-5). This involved plotting the stage-discharge rating curves for each year of observations, and plotting the trend in water levels for various specified discharges. Systematic rating curve shifts are then attributed to aggradation or degradation downstream of the gauge. The analysis could not be applied to the Kalni River since the hydrometric stations on this reach have recorded only water levels.

8.2 Historic Channel Changes

The following sections summarize historical bed level changes in three reaches:

- Upper Kushiyara River (from Sheola to Sherpur);
- Lower Kushiyara River (Suriya channel) and Kalni River from Markuli to Issapur, and
- Dhaleswari River below Madna.

8.2.1 Upper Kushiyara River

Specific Gauge Analysis, Sheola and Sherpur
Figure A.18 shows the specific gauge plot at Sheola on the Upper Kushiyara River for the period 1962-1992. At flows of 500 and 1,000 m^3/s, the water level has lowered by around 1 m over the last 30 years. Figure A.20 shows the specific gauge plot at Sherpur. The first miscellaneous

discharge measurements at Sherpur did not start until after 1970 (daily discharges were not published until 1982). This shorter record makes it more difficult to assess trends. However, at discharges of 1,000 m^3/s and 1,500 m^3/s, the water level dropped by around 0.8 m over the last 20 years. Therefore, these results imply that either the channel downstream of the gauges has enlarged or the slope has steepened. It should be noted that the shift to the Suriya channel reduced the overall river length between Sherpur and Markuli by approximately 20 km. This would have effectively steepened the profile and initiated upstream degradation.

Cross Section Comparisons, Fenchuganj to Manumukh
Figure A.51 and Table A.32 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. Three of the four cross sections showed net enlargement of the channel between 1969 and 1993, while one section showed minor filling. These results generally confirm the specific gauge analysis. The available evidence suggests the channel upstream of Sherpur has remained relatively stable over the last 25 years, with a tendency towards channel enlargement or degradation. There is no evidence to indicate any significant aggradation has occurred.

8.2.2 Lower Kushiyara/Kalni River

BIWTA Navigation Charts
BIWTA navigation charts from 1963, 1975, 1977, and 1988 were analyzed. The surveys extended from the Meghna River up to at least Sherpur, sometimes as far as Fenchuganj. The charts show spot depths and the extent of the low-water channel at various scales ranging between 1:12,000-1:12,500. The earlier charts showed only a centreline profile, while the 1988 charts showed several depths across the channel. All depths were referenced to a local low water level (LLW), which was established from measured water levels at BWDB hydrometric gauges (Madna, Ajmiriganj, Markuli or Sherpur). Bed elevations were estimated from the spot depths (D) and published LLW values:

$$Z = LLW - D$$, where Z is the bed elevation in m, PWD datum

Although these data are probably less accurate than cross sections, they provide very useful information on the river bed topography; particularly for assessing the river's longitudinal profile.

Figure A.52 shows bed levels in 1963 and 1988 along the Kalni River and Suriya channel between Madna and Sherpur. Figure A.53 shows 1 km average bed level <u>changes</u> during the period 1975-1988 and 1963-1988.

The soundings show considerable degradation (up to 5 m) occurred along the Suriya River between Sherpur and Markuli in response to the shift from the Bibiyana 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.

Table A.32: Channel Changes Between Fenchuganj and Manumukh

Cross Section	Area (m^2)	Top Width (m)	Mean Depth (m)	Thalweg Level (m PWD)
1-1969	1,420	170	8.35	-5.93
1-1972	1,336	214	6.23	-7.30
1-1973	1,348	164	8.22	-8.63
1-1978	1,649	262	6.29	-5.83
1-1993	1,429	212	6.73	-5.92
2-1969	1,569	207	7.58	-8.25
2-1972	1,507	155	9.70	-8.50
2-1973	1,523	183	8.33	-9.87
2-1978	1,541	172	8.98	-5.43
2-1993	1,644	178	9.24	-6.81
3-1969	1,714	177	9.66	-5.16
3-1972	1,738	198	8.77	-5.96
3-1973	1,668	249	6.70	-9.11
3-1978	1,792	189	9.50	-5.34
3-1993	1,660	191	8.70	-2.00
4-1969	1,022	110	9.28	-4.36
4-1972	1,226	135	9.06	-6.80
4-1973	1,274	146	8.76	-8.23
4-1978	1,342	125	10.72	-7.32
4-1993	1,370	147	9.32	-6.52

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 has occurred between 1963 and 1988 in the reach downstream of Ajmiriganj. Most of this aggradation has developed since 1975. Figure A.53 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 of Ajmiriganj, so that the sediment deposition has developed in the form of a 50 km long "wedge" between Ajmiriganj and the junction of the Dhaleswari/Baida River below Madna.

Cross Section Comparisons- Markuli to Ajmiriganj
The BWDB's cross sections in this reach include:

- two on Kushiyara River between Sherpur and Markuli;
- seven on Kalni River between Markuli-Katkhal, and
- ten on the lower Kalni/Dhaleswari River.

The cross sections were surveyed with a depth sounder, and horizontal positioning was determined by theodolite or sextant. Permanent hubs are maintained on the river, although many of these are periodically destroyed by river erosion and/or changes on the floodplain. Consequently, it is not always possible to relate some of the earlier cross sections. The cross sections are summarized in tabular form for every year since 1986. For earlier years the data are available as plotted cross sections.

NERP established permanent cross sections for bed level monitoring in 1993 in the following reaches:

- two on the Kushiyara River between Sherpur and Markuli;
- nine on the Kalni River between Markuli and Katkhal, and
- eight on the lower Kalni/Dhaleswari River.

Most of these sections were made at BWDB lines in order to compare with the earlier surveys. The cross-sections are shown in the location plan (Figure A.4). Longitudinal profiles were also surveyed on each occasion in order to document whether bed forms were present.

Permanent concrete pillars were established on the banks to assist in positioning. The water depths were measured using a depth sounder. Initially, horizontal positioning was carried out using a "Topofil" tag-line. The cross sections were surveyed first left bank to right bank, then a second line was run from right bank to left bank. The two cross section plots were superimposed and a smooth line was drawn to average out any discrepancies resulting from boat drift or positioning errors. All benchmarks were tied in to the Survey of Bangladesh's Second Order Levelling control.

The cross sectional area, top width at bankfull stage, mean bed level and thalweg level were determined for each section. Table A.33 summarizes the results of these calculations.

M-38 (Figure A.54)
This section was first surveyed in 1991. All of the surveys appear consistent and show the channel is rectangular. The cross section enlarged slightly since 1991.

M-37 (Figure A.55)
The channel is approximately rectangular though there has been considerable lateral shifting. The channel enlarged substantially between 1981-1986. Both the channel area and top width have remained approximately constant since 1986. The section shows some aggradation on the floodplain, varying between one and two meters.

M-36 (Figure A.56)
There are several inconsistencies with these data. The cross sections have two very distinct shapes. The 1985-86 and 1989-90 sections have a symmetrical shallow channel, while the 1979-80 and 1991-93 sections have a pronounced triangular shape. The 1979-80 and 1986-87 are

deeper, while the remaining sections are shallower. It is likely that some of these apparent differences are caused by mis-alignment of surveys, and not actual channel changes.

M-35 (Figure A.57)
This cross section is located on the pilot channel that was excavated for the 1978 loop cut near Pirojpur. The surveys record the gradual enlargement of the pilot cut and the infilling of the former main channel (by 1986/87 it had virtually disappeared).

Table 33 shows the area of the new channel increased from 1,316 m^2 in 1980 to 1,469 m^2 in 1990. The area has remained approximately constant since then. The new main channel has enlarged to approximately the same area as the former channel before the loop cut, though the section is wider and shallower than the previous one. These surveys show that the pilot channel required at least 12 years to enlarge to its full size.

M-34 (Figure A.58)
All surveys show the cross section was rectangular. The area of the channel decreased from 1,457 m^2 to 556 m^2 between 1980-1993, and then enlarged to 650 m^2 in 1995. The average bed level shows a similar pattern, rising by 1.6 m between 1980-1993, then dropping by nearly 1 m. Floodplain levels have fluctuated, but show no systematic change.

M-33 (Figure A.59)
All sections seem to line-up well, and show a similar rectangular channel. There is a trend of infilling between 1980-1993, then general scour between 1993-1995. The average bed levels show a similar trend. They rise by over 2.5 m between 1981-1993, then drop by 1.5 m afterwards. The channel area also decreased over time (except in 1989-90), while the top width increased. This implies that the channel is filling-in, while the banks are eroding. Floodplain levels showed no overall pattern of change.

8.2.3 Dhaleswari River

The Dhaleswari River starts at the junction of the Ratna/Khowai River, just upstream of Madna, and extends for a distance of 38 km until it joins up with the Ghorautra/Baulai River and becomes the Upper Meghna River (Figure A.1). Hydrometric measurements and hydrodynamic model predictions indicate the Dhaleswari branch carries less than half of the total inflow during pre-monsoon flow conditions. During the dry season the Dhaleswari channel is blocked by shoals and most flow is carried by the Baida channel. Local residents claim the Dhaleswari branch is gradually "dying" and the channel is filling-in. Evidence of this process can be seen at the large island opposite Madna. Satellite photos in 1991 show this feature was a sparsely vegetated low-lying shoal. By 1995 local inhabitants were cultivating rice on it.

Figure A.60 shows average bed level changes in the reach from the Issapur bifurcation to the point where the Baida channel re-joins the Dhaleswari River. The comparisons were made using surveys from 1963, 1975 and 1988. These results show the average bed level has aggraded by 1-2 m over the 20 km length of channel. The amount of aggradation decreases down the channel, being greatest near the bifurcation (Km 73) and near zero at the Baida/Dhaleswari junction (Km 49).

Table A.33: Hydraulic Geometry Comparisons on Kalni River (Page 1 of 2)

Section	Year	Bankfull El. (m PWD)	Area (m^2)	Top Width (m)	Mean Depth (m)	Avg. Bed El. (m PWD)	Thalweg El. (m PWD)
M-33	1981	5.30	1,826	355	5.1	0.16	2.0
	1986	5.30	1,271	327	3.9	1.41	0.0
	1987	5.30	1,270	336	3.8	1.52	1.0
	1990	5.30	1,367	371	3.7	1.62	1.0
	1991	5.30	1,163	381	3.1	2.25	0.0
	May 93	5.30	1,091	260	4.2	1.10	3.8
	Jun 93	5.30	633	278	2.3	3.02	1.5
	Jul 93	5.30	657	323	2.0	3.27	1.6
	Feb 95	5.30	895	346	2.6	2.71	1.0
M-34	1981	4.00	1,457	434	3.36	0.64	1.0
	1982	4.00	1,083	372	2.9	1.09	1.0
	1986	4.00	0	484	2.4	1.62	2.0
	1987	4.00	923	476	1.9	2.06	0.0
	1990	4.00	1,105	433	2.6	1.45	0.0
	1991	4.00	0	407	1.8	2.22	0.0
	Jun 93	4.00	5.3e-287	253	2.2	1.80	1.2
	Jul 93	4.00	389	237	1.6	2.36	1.6
	Feb 95	4.00					
M-35	1980	4.00	1,316	233	5.6	-1.65	-5.0
	1981	4.00	745	204	3.7	0.35	-4.0
	1986	4.00	730	205	3.6	0.44	-1.0
	1987	4.00	180	147	1.2	2.78	-1.0
	1980	4.50	218	70	3.1	1.39	-5.0
	1981	4.50	470	71	6.6	-2.14	-4.0
	1986	4.50	866	245	3.5	0.96	-1.0
	1987	4.50	1,090	268	4.1	0.43	-1.0
	1990	4.50	-70e+213	524	2.8	1.70	-0.0
	1991	4.50	361	302	1.2	3.30	-1.0
	May 93	4.50	1,411	185	7.6	-3.13	-7.1
	Jun 93	4.50	1,371	118	11.6	-7.12	-10.9
	Jul 93	4.50	1,253	176	7.1	-2.62	-9.2

Table A.33: Hydraulic Geometry Comparisons on Kalni River (Page 2 of 2)

Section	Year	Bankfull El. (m PWD)	Area (m^2)	Top Width (m)	Mean Depth (m)	Avg. Bed El. (m PWD)	Thalweg El. (m PWD)
M-36	1980	5.00	1,357	273	4.97	0.03	-5.0
	1981	5.00	871	219	3.98	1.02	-2.0
	1982	5.00	826	246	3.36	1.64	-2.0
	1986	5.00	721	178	4.05	0.95	-1.0
	1987	5.00	1,134	193	5.88	-0.88	-5.0
	1990	5.00	766	198	3.87	1.13	-1.0
	1991	5.00	629	183	3.44	1.56	-2.0
	Jul 93	5.00	1,360	174	7.82	-2.82	-8.8
	1995	5.00					
M-37	1980	4.90	714	196	3.64	1.26	-0.0
	1981	4.90	800	268	2.99	1.91	-1.0
	1986	4.90	1,130	229	4.93	-0.03	-2.0
	1987	4.90	1,191	240	4.96	-0.06	-2.0
	1990	4.90	1,146	251	4.57	0.33	-1.0
	1991	4.90	1,050	254	4.13	0.77	0.0
	May 93	4.90	1,169	215	5.44	-0.54	-2.1
	Jun 93	4.90	1,138	225	5.06	-0.16	-2.8
	Jul 93	4.90	1,263	207	6.10	-1.20	-4.9
	1995						
	1991	6.00	1,345	166	8.12	-2.12	-5.0
	May 93	6.00	1,456	184	7.91	-1.90	-4.0
	Jun 93	6.00	1,504	190	7.92	-1.90	-4.5
	Jul 93	6.00	1,567	178	8.80	2.83	-6.4
	1995	6.00					

90

Comparisons were also made between the 1995 hydrographic surveys and BIWTA's 1988 navigation charts. Figure A.61 shows the general pattern of deposition that has occurred. It appears the channel has continued to infill, with up to 1 m of deposition occurring just upstream of Madna.

It is believed that this reach's main source of sediment is the Kalni River, since the greatest amount of deposition has actually occurred upstream of the Ratna/Khowai junction. It appears most of the sediment supplied from the Khowai River is deposited on the broad, low-lying floodplain between Habiganj and Madna (NERP, 1994). Figure A.29 shows that the lower Khowai channel decreases rapidly in size downstream of Habiganj due to spilling and backwater effects from the Meghna River. Consequently, the channel's capacity to transport sediment is also greatly reduced by the time it reaches Madna. If the Khowai River was adding substantial amounts of sediment, then the prominent ox-bow lake at the Khowai/Ratna junction would have filled-in with sediment very quickly. The fact that such landforms have persisted for many decades indicates the sediment supply to this area is low. Further developments on the Khowai River, such as extension of embankments downstream of Habiganj, could flush more sediment downstream and ultimately increase sedimentation problems on the Dhaleswari River.

8.2.4 Summary

Channel changes upstream of Sherpur have been relatively minor over the last 30 years, with minor channel enlargement in the reach between Manumukh and Fenchuganj. The bed has degraded in the reach between Sherpur and Markuli in response to the Bibiyana channel avulsion.

In the order of 25,000,000 m^3 of sediment was deposited below Ajmiriganj between 1963 and 1988. This corresponds to an average deposition rate of roughly 1,000,000 m^3/year. Re-surveys of BWDB cross sections also show the average bed level rose significantly downstream of Ajmiriganj between 1980-1993. It appears the reach between Ajmiriganj and Katkhal started to lower again between 1993-1995. Aggradation has occurred in the Dhaleswari branch from the Baida bifurcation near Issapur to the point where the Baida re-joins, 24 km downstream. Downstream of the Baida junction, the channel deepens appreciably and does not appear to have experienced notable deposition in recent times.

Several factors have contributed to the bed level changes between Sherpur and Madna. First, the avulsion from the Bibiyana River into Suriya Khal caused rapid degradation between Sherpur and Markuli in response to the steeper slope. The avulsion also caused more of the Kushiyara River flows to be carried by a single channel, whereas previously the flow was divided amongst distributaries. This would also have contributed to degradation in this reach. The sand and silt fraction of these eroded sediments was deposited in the low gradient, backwater controlled reach below Ajmiriganj. In fact, the eroded volume from the Suriya channel is comparable to the total aggradation that has occurred below Ajmiriganj. The 1980 closure at Markuli has blocked flood flows from the Kushiyara River entering into the low-lying inter-basin land. Previously, this opening diverted sediment-laden water into the flood basins where it would have eventually settled out. Furthermore, construction of various polder projects in the 1980s between Markuli and Ajmiriganj (Tangua Haor Project, Baram Haor Project, Bhanda Beel Project, Chaptir Haor Project) has also confined the river flows in the pre-monsoon and early monsoon season, which has probably reduced overbank sedimentation and flushed more sediment into the downstream reaches.

Finally, there has been an unusual number of large floods during the period 1986-1993, which has increased the sediment inflows in recent years. However, the interviews with local people and evidence from surveys all indicates that the aggradation below Ajmiriganj had already occurred before these major floods. Therefore, the main effect of these recent floods has been to accelerate some of the channel adjustments that were already going on in response to earlier channel changes. For example, floods in 1988, 1991 and 1993 have speeded up channel widening in the loop cuts between Markuli and Ajmiriganj and accelerated the natural cutoff near Katkhal.

Other possible causes for the increased channel instability and flooding problems have been experienced in recent years include:

- increased sediment yield from the headwaters in India, and
- regional tectonics in the Sylhet Depression

If these processes have significantly affected the Kalni-Kushiyara River, then similar impacts would also be expected along the Surma-Baulai River. This is because both rivers originate from the Barak River system in India, and both rivers have a similar geomorphic setting. However, the available evidence indicates that the recent changes on the Kalni-Kushiyara River have been much greater than on the Surma-Baulai River. The different responses are illustrated in Figures A.62 to A.65.

Figures A.62 and A.63 show the trend in annual maximum, pre-monsoon maximum and annual minimum water levels at Sherpur, Markuli, Ajmiriganj and Madna on the Kalni-Kushiyara River. Pre-monsoon flood levels at Markuli and Ajmiriganj have increased by an average of 1.2 m and 1.0 m respectively since 1975. At Markuli, the maximum pre-monsoon water level has been increasing in a remarkably consistent fashion since the 1950's, at an average rate of 8.5 cm/year. The minimum recorded water levels at Ajmiriganj and Markuli have also increased consistently over the last 30 years. These levels rose an average of 1 m in 25 years (4 cm/year) until 1988, then increased abruptly another metre between 1988 and 1993. The corresponding minimum discharges show no systematic change until 1988, after which the flows nearly doubled. The 4 cm/year rise between 1964-1988 is believed to reflect morphologic changes (since the discharge was approximately constant), while the increase since 1988 is believed to be due to a combination of hydrologic and morphologic changes. At Madna, which is situated downstream of the de-stabilized reach, no systematic changes in pre-monsoon water levels or minimum water levels can be observed.

Figure A.64 shows a longitudinal profile of the Surma-Baulai River, along with water surface profiles in the dry-season, pre-monsoon season and monsoon season. The minimum depth in the dry season along the Baulai River is at least 4 m. Corresponding water depths along the Kalni River typically average less than 1 m. Therefore, the lower Surma-Baulai channel does not exhibit the same pattern of shoaling and aggradation as in the Kalni River. Figure A.65 shows trends in water levels on the Surma River at Sylhet and Sunamganj. Pre-monsoon flood levels and annual minimum water levels on the Surma River show no noticeable trends over time.

Therefore, in spite sharing a common headwaters in India and having a similar geomorphic setting, the two river systems have behaved very differently over the last 30 years. Only the Kalni-Kushiyara River has experienced systematic increases in water levels and significant shoaling. This strongly suggests that local factors have been mainly responsible for the recent pattern of instability along the river.

d2

The computed mean inflow at Amalshid is about 10% higher than the value estimated from the water balance studies. The difference is due to the different periods of record used in the analysis and the different methods for estimating discharges.

8.3 Seasonal Variations

Downstream of Markuli the strong backwater control produces pronounced seasonal variations in water surface slope, sediment transport and channel bed material. As a result, the bed levels also undergoes substantial fluctuations. Seasonal changes in channel topography were monitored by carrying out repeat surveys over the 1993 and 1995 seasons. The 1993 monitoring involved re-surveying the twelve cross sections between Markuli-Katkhal (M-38 to M32). Monitoring in 1994-96 involved comparing successive hydrographic surveys between Ajmiriganj and Abdullahpur.

8.3.1 1993 Cross Section Comparisons

Repeat surveys were carried out at the twelve cross section monitoring lines (M-32 through M-38) in May 1993, June 1993, July 1993, September 1993 and December 1993. The maximum daily discharge in 1993 reached 3,843 m^3/s at Sherpur on 23 June, and was estimated to have a return period of 20 years. The maximum discharge in the pre-monsoon season had an estimated return period of 2 years.

The cross sections were first plotted as overlays to assess any changes. The bankfull area was then determined in order to estimate the amount of scour and fill that occurred. Figure A.66 summarizes bankfull area changes at three cross sections near Ajmiriganj (M-33, M-34, M-35). These plots show the cross sectional area fluctuated seasonally, with the minimum occurring in the months of July-September. The monsoon season infilling typically amounted to 200-300 m^2, which corresponds to a deposition volume of 200,000-300,000 m^3/km. The channel scoured during the post-monsoon and dry season, so that by December, the cross sectional area had returned to the initial value of May 1993.

8.3.2 1994-1996 Hydrographic Survey Comparisons

The hydrographic surveys in 1994-1996 provided more detailed information, allowing estimation of seasonal volumes of sediment deposition and scour. These surveys were carried out on five occasions between September 1994 and February 1996. Table A.5 and Figure A.67 summarize the date and extent of each survey. The 1:10,000 scale charts are reproduced in Annex M - Project Maps and Engineering Drawings.

The surveys were made by installing a Global Positioning System (GPS), digital depth sounder and lap top computer in a river survey boat to collect simultaneous values of water depth and horizontal position. A second GPS was installed in Ajmiriganj as a base station in order to differentially correct the mobile unit's positions. This allowed the surveys to be carried out to an absolute accuracy of 5 to 10 m during most operations. Custom software was written to convert the data into AUTO-CAD format for initial plotting and verification. The digital terrain model and mapping program EMXS-CAD was then used for producing final AUTO-CAD files.

The survey data was analyzed by creating a digital terrain model (DTM) of the river bed topography for each date using the program "Surfer for Windows". The DTM uses the scattered topographic data (X,Y,Z values) to generate an interpolated representation of the surface on a regular grid. Changes between surveys were estimated by subtracting the two surfaces- positive differences represent deposition, while negative differences represent scour. Particular attention had to be given to ensure that only the area common to the two surveys was compared. This was achieved in the program by "blanking out" the outlying areas. Total scour and fill volumes were estimated by summing the individual values at each grid node.

The most frequent repeat surveys covered the nine kilometre reach from just upstream of Ajmiriganj to below Kakailseo. The map sheet was divided into two reaches, the upper reach extending from Km 108-102 and the lower reach extending from Km 102-98. Table A.34 summarizes the total scour, total fill and net channel change at various dates during the period September 1994-February 1996. The net channel changes (fill minus scour) are plotted in Figure A.68. These results confirm the bed scours and fills seasonally, with net deposition occurring in the monsoon season and net scour occurring in the remainder of the year. The volumes of sediment that were eroded during the period September 1994-February 1995 amount to roughly 1.9 million m^3, which represents an increase in cross sectional area of just over 200 m^2. The net volume deposited between February-September 1995 amounted to 1.5 million m^3, which means that overall, the bed degraded by 0.4 million m^3 in 1995.

The volume changes can be expressed in terms of an overall sediment budget for the river channel by applying the sediment continuity equation:

$$q_i - q_o = -\frac{\Delta V}{\Delta t}$$

where q_i and q_o are the volumetric sediment transport into and out of the reach, ΔV is the volumetric change determined from successive surveys of the control volume and Δt is the time period between surveys. The river channel can be sub-divided into a number of reaches, and the output from one reach can be used to estimate the inflow to the next reach downstream. In this manner the sediment transfers between reaches can be defined.

Table A.35 and Figure A.69 summarize the estimated volume changes along the 30 km reach of the Kalni River during two time periods: February 1995-September 1995 and September 1995-February 1996. The volume calculations show 942,600 m^3 of net deposition took place between Km 107-Km 92 during the period February-September 1995 and 3,342,300 m^3 of erosion occurred in the same reach during the period September 1995-February 1996. Approximately 300,000 m^3 of this volume (under 10%) was caused by localized dredging at Kakailseo, the remainder (roughly 3 million m^3) occurred as a result of channel bed erosion in the post-monsoon season and dry season. This means the channel between Ajmiriganj and Katkhal experienced overall degradation of around 2 million m^3 during the period February 1995-February 1996. It is expected that this degradation represents a localized reaction to the recent natural cutoff and re-opening of Cherapur Khal.

8.3.3 Summary

During the monsoon season, when backwater control from the Meghna River reduces the river's slope and velocity, fine sediment (mainly fine silt) is deposited in the channel and overbank downstream of Ajmiriganj. As the tailwater is lowered during the post-monsoon season and dry season, the slope and velocity increases, allowing the river to cut through the sediments. This river is unusual, since in most cases the channel geometry and morphology are governed by flood flows, while at low flows the bed is inactive. In this reach, the flow and sediment transport outside of the monsoon season play an important role in scouring out the channel. Therefore, although this lower reach is primarily depositional in character, an approximate equilibrium can be maintained.

Table A.34: Seasonal Scour and Fill Between Ajmiriganj and Shanitpur
Reach 8 Upper Half Volume

Period	Fill m^3	Scour m^3	Net Change m^3	Cumulative m^3
Sep 94-Feb 95	50,000	968,500	-918,500	-918,500
Feb 95-Jul 95	1,076,000	113,900	962,100	43,600
Jul 95-Sep 95	720,600	217,800	502,800	546,400
Sep 95-Feb 96	0	1,249,700	-1,249,700	-703,300
Sep 94-Feb 96	1,846,600	2,549,900	-703,300	

Reach 8 Lower Half Volume

Period	Fill m^3	Scour m^3	Net Change m^3	Cumulative m^3
Sep 94-Feb 95	110,700	1,180,000	0	0
Feb 95-Jul 95	124,000	411,200	-287,200	-1,356,500
Jul 95-Sep 95	443,200	150,500	292,700	-1,063,800
Sep 95-Feb 96	7,800	854,800	-847,000	-1,910,800
Sep 94-Feb 96	685,700	2,596,500	-1,910,800	

৭৫

Table A.35: Seasonal Scour and Fill Between Ajmiriganj and Issapur

Feb 95 to Sept 95 - Volume						
Reach	km d/s end	Km u/s end	Fill m^3	Scour m^3	Net m^3	Cumulative m^3
8U	102.0	107.0	901,400	2,700	878,700	878,700
8L	100.0	102.0	181,300	159,100	22,200	900,900
7-1	96.5	100.0	130,600	417,200	-286,600	614,300
7-2	94.0	96.5	96,500	254,400	-157,900	456,400
7-3	92.0	94.0	535,500	49,300	486,200	942,600
7-4	90.5	92.0	343,400	34,700	308,700	1,251,300
7-5	86.5	90.5	943,000	0	943,000	2,194,300
7-6	85.0	86.5	475,900	118,400	357,500	2,551,800
6	77.0	85.0	1,293,000	97,000	1,196,000	3,747,800
5-U	75.5	77.0	347,700	0	347,700	4,095,500
5-L	70.0	75.5	529,000	31,600	497,400	4,592,900

Sept 95 to Feb 96 - Volume						
Reach	km d/s end	Km u/s end	Fill m^3	Scour m^3	Net m^3	Cumulative m^3
8U	102.0	107.0	0	1,249,700	-1,249,700	-1,249,700
8L	100.0	102.0	7,800	854,800	-847,000	-2,096,700
7-1	95.5	100.0	57,000	836,000	-779,000	-2,875,700
7-2	94.0	96.5	54,400	72,900	-18,500	-2,894,200
7-3	92.0	94.0	195,500	643,600	-448,100	-3,342,300
7-4	90.5	92.0				
7-5	86.5	90.5				
7-6	85.0	86.5				
6	77.0	85.0				
5-U	75.5	77.0				
5-L	70.0	75.5				

9. FUTURE EVOLUTION OF THE RIVER

This chapter provides an assessment of the future morphologic characteristics of the river system if no new interventions are carried out. This represents the "future without" project scenario (FWO). Given the past history of channel instability over the last 30 years, it is difficult to accurately predict the future morphologic characteristics of the Kalni-Kushiyara River system. Avulsions and channel shifts are highly complex processes that may be triggered by the chance occurrence of events and are not entirely deterministic. Therefore, any forecast into the future will be somewhat speculative. This assessment was made primarily by interpreting the pattern of channel instability and sedimentation that has been occurring in historic times and by using available sediment transport-based methods to verify the results.

9.1 Assumptions

The time frame considered in this analysis extends over a 30 year planning period to the year 2026. It was assumed that present water management practices would continue in the project area, with the main focus on maintenance of the existing submersible embankment projects. No other major new initiatives in the project area were considered.

It was also assumed that the hydrological and sediment transport characteristics at the upstream boundaries of the project area would remain approximately similar to the conditions that have existed over the last decade. Practically, this means that no major new developments are considered on the Upper Kushiyara River, Baulai River or Khowai River systems.

A major water resource project on the Barak River at Tipaimukh in India has been proposed. To date, information provided through the Joint River Commission on the proposed operating characteristics of Tipaimukh dam has been very limited. A very preliminary assessment of the potential impacts from this development was provided previously (NERP, 1993). The assessment showed that the dam could significantly alter the hydrologic regime of the Kalni-Kushiyara River, and could potentially produce both positive impacts (reduced monsoon floods and reduced sediment inflows) and negative impacts (high post-monsoon flows). It was assumed that Tipaimukh Dam will not be constructed within the time frame considered in this investigation.

9.2 Kushiyara River, Fenchuganj to Sherpur

The specific gauge records and channel survey data shows the channel in this reach appears to have remained relatively stable overall, probably slowly degrading somewhat over the last 30 years. The morphologic changes have probably been a response to the higher discharge regime that has been experienced in recent years. These changes will probably slow down over time as the river approaches a new equilibrium. The river has not experienced major lateral instability although progressive meander migration has caused local erosion in some locations. The pattern of lateral channel changes will remain similar to the present situation.

9.3 Kalni-Kushiyara River, Sherpur to Ajmiriganj

Spills, river bank breaching and bank erosion will continue to occur between Sherpur and Ajmiriganj. The magnitude and frequency of these spills will be governed largely by the occurrence of major floods. However, it is expected that the rate of bank erosion and channel

98

widening in this reach will begin to decline in comparison to the last 30 years. This reach underwent an almost continuous series of de-stabilizing events up until the early 1980's, including the Suriya avulsion, the closure of the old Kalni River channel at Markuli and loop cutting near Markuli. These channel adjustments will continue until the river reaches a new equilibrium. Future channel widening is expected to be minor. However, the meander pattern appears to be still in a state of adjustment, since in some places the river is still flowing along the tortuously meandering course of the former Suriya Khal. Consequently, we expect the river to eventually increase the size of its meander pattern by eliminating short radius bends through natural cutoffs.

Figure A.70 shows the general scenario that is expected to develop. This alignment, although very tentative, was based on the interpretation of past channel shift patterns, and estimation of future bank positions using the relation between bank erosion rate and meander geometry shown in Figure A.49. Table A.36 summarizes the anticipated location of future bank erosion problems in this reach. Given the very low R/W ratios of the bends near Digalbagh (Km 168), Jalalpur (Km 159) and Alagadi (Km 157), it appears natural cutoffs in these locations are inevitable. This will cause short-term bank erosion problems between Sherpur and Markuli, but after the new channels are established could eventually produce a more stable channel pattern.

Table A.36: Future Erosion Along Kalni-Kushiyara River

#	Name	Km	Bank	Process	Comments
1		168.5-165.0	LB	Mf	Bank erosion along outside of bend threatening to make chute cutoff
2		161.0-156.0	LB	Mf	Bank erosion threatening to make chute cutoff, spills & breaching into Itakhola Nadi
3	Raniganj	153.0	RB	Mc	Rotation of meander bend threatening to erode Raniganj town
4	Balisri	149.5	LB	Ma	Extension of meander bend creating erosion along outside of bend.
5		144.0	RB	B	Spill and breaching through khal
6	Akkilshah Bazar Dhala	139.0	LB	B	Breach at sharp bend into Katma Beel causing major pre-monsoon spills
7	Markuli	133.0	LB	Ma	Extension of meander bend eroding outer bank. Will eventually destroy Markuli town
8	Fayjullapur	129.5	RB	B	*Dhala* presently closed but could re-open after flood
9	Tangua Dhala	119.0	RB	B	*Dhala* presently closed but could re-open after flood
10	Koyer Dhala	115.0	LB	B, Ma	Bank erosion and breaching at dhala expected to increase in the future. Magnitude of pre-monsoon spill will increase over time.
11	Pituakandi	114.5	RB	B, Ma	Bank erosion and breaching will re-open *dhala* in the future. Magnitude of spills expected to increase over time.

LEGEND:
Erosion Process
A=Avulsion
B=Breach
Mx=meanders migration (see Figure A.48 for definition of meander migration types)

It is expected that the shifting near Akkilshah Bazar and Koyer Dhala will cause the magnitude of pre-monsoon spills to increase in these areas.

9.4 Kalni River - Ajmiriganj to Cherapur Khal

Since 1993, the main instability on the river has occurred downstream of Ajmiriganj, and it is expected that this situation will continue in the future. The channel shift at Katkhal and deposition further downstream along the Kalni River has caused flow to re-open a *khal* (Cherapur Khal) and caused it to enlarge rapidly over the last three years.

The 1990 satellite photo shows Cherapur Khal had a width of approximately 30 m near its junction with the Kalni River and gradually widened up to approximately 100 m at its junction with Lamakhara River (Figure A.27). This second channel drains the Inter-Basin land between the Old Surma River and the Baulai River. Past this junction, Cherapur Khal diminished in size again to around 30 m and flowed for another 5 km until joining the Baulai River near the village of Dhaki.

After the channel shift near Katkhal, the entrance to Cherapur Khal enlarged to an 80 m wide by 4 m deep rectangular channel. Hydrometric measurements on May 14, 1996 showed the cross sectional area near bankfull conditions was around 265 m^2 and the channel was carrying 330 m^3/s. Up to 35% of the Kalni River flow is presently being diverted into the Baulai River system during the dry season and pre-monsoon season. An important question is whether the *khal* will continue to expand, which could cause the Kalni River to permanently shift into the Baulai River system. Such an avulsion could produce far reaching changes to the river system, and could generate a new series of flooding and sedimentation problems to people living along the Cherapur Khal- Baulai River and on the lower reaches of the Kalni-Dhaleswari River.

The main factors that will determine whether the *khal* will capture more of the Kalni's flow are as follows:

- the water surface slope between the Kalni River at the Cherapur Khal offtake and Baulai River at the downstream junction with the *khal*;
- the erodibility of the bank and bed material along the *khal*;
- the conveyance of the lower Baulai River downstream of the *khal*, and
- local sedimentation patterns at the *khal* offtake and on the Baulai River below the *khal*'s outlet

Some appreciation of the likelihood can be made by comparing the distances along the Baulai River and Kalni River, from the *khal*'s offtake to the junction of the rivers at Dilalpur.

Cherapur Khal offtake on Kalni River to Dilalpur junction via Cherapur Khal, Baulai River = 64 km
Cherapur Khal offtake on Kalni River to Dilalpur junction via Kalni-Baida River = 59 km

The shortest overall route for the Kalni River is still along the present channel alignment via the Baida channel. Therefore, assuming similar channel conveyance existed along both routes, it is unlikely that the Kalni River would be captured by the Baulai system. However, aggradation on the Kalni River downstream of Katkhal has reduced the conveyance on this reach of the river. This aggradation has increased the water levels at the *khal*'s offtake, forcing more water through it into the Baulai River. The water surface slopes at various locations on the two rivers was estimated from BWDB's historic water level data and from NERP's field measurements:

Kalni River at Ajmiriganj (BWDB 271)
Kalni River at Madna (BWDB 272)
Baulai River at Itna (BWDB 73)
Baulai River at Dilalpur (BWDB 74)

Daily water levels at the offtake of Cherapur Khal on the Kalni River were estimated as follows:

$WL_1 = WL_{271} - (WL_{271}-WL_{272})*d_1$, where

WL_{271} is the water level at Ajmiriganj, WL_{272} is the water level at Madna, d_1 =19.5km/45.5 km

Daily water levels at the outlet of Cherapur Khal on the Baulai River were estimated as follows:

$WL_2 = WL_{73} -(WL_{73}-WL_{74})*d_2$, where

Where WL_{73} is the water level at Itna, WL_{74} is the water level at Dilalpur, d_2 =16.5km/45km

The slope on Cherapur Khal was then computed as:

$S_{cher} = (WL_1-WL_2)/d_3$ where

d_3 is the overall length of the *khal* (13 km)

Table A.37 compares the water surface slopes on the *khal* and on the Kalni River below Ajmiriganj.

Table A.37: Estimated Water Surface Slopes (mm/km)

Year	Pre-monsoon Season		Dry Season	
	Cherapur Khal mm/km	Kalni River mm/km	Cherapur Khal mm/km	Kalni River mm/km
1991	60	40	42	35
1992	20	20	80	50
1993	100	50	55	40
1994	70	50	60	40

Figure A.71 shows the seasonal variations in slopes on the two reaches. Theses results show that there is a substantial gradient along the *khal* from the Kalni to the Baulai River in the dry season and the pre-monsoon season. Furthermore, the water surface slope on the *khal* is substantially steeper than the slope on the Kalni River. The results confirm that the present hydraulic conditions on the Kalni River are encouraging flow diversion into the Baulai River.

During the monsoon season, when most of this area is deeply flooded, the water surface slopes on both rivers becomes very low. The slope on the *khal* can reverse in the monsoon, indicating discharges from the floodplain and main channels may drain back into the Kalni system at some times. However, it is expected that the conditions in the pre-monsoon and dry season will determine the channel's geometry, since these flows will be mainly confined within the banks. During the monsoon season the floodplain will be deeply flooded by up to 3 m (Figure A.8), and the channel conveyance will become only a small fraction of the floodplain's (NERP, 1995).

The banks along Cherapur Khal are relatively low, totally unprotected and consist primarily of silt and silty loam materials. Bed levels in the *khal* are presently at around El. 0 m PWD. By comparison, the low water channel in the Kalni River below Katkhal reach up to El. 2 m at some of the major shoals. Given the erodible nature of the *khal*'s banks, the difference in bed levels on the *khal* and the river, and the difference in gradients along the *khal* and the lower Kalni River, it appears likely that the *khal* will continue to enlarge and capture more of the Kalni's flow over the next 30 years.

Predictions of future width changes are approximate, with the most reliable guidance available from the observed hydraulic geometry on the river and from empirical Regime equations.

Approach 1: Template Method

Assume the *khal* will become similar to the branch of the Kalni River channel near Katkhal. This channel has widened from a minor *khal* in the 1970's, to the dominant channel. Surveys in 1993 were made when it was approaching a stable width. Compared to other parts of the river which have been silting-in, it has a relatively incised cross sectional shape.

average top width = 250 m
mean depth = 3.4 m
cross sectional area = 900 m^2

Approach 2: Regime Equation:

Assume channel forming discharge =5 year pre-monsoon flood, and assume 75% of flows will be carried by the new channel

Q = 0.75* 2300 = 1,690 m^3/s
top width = 200 m
mean depth = 3.5 m
cross sectional area = 750 m^2

The two methods provide reasonably consistent results. However, it was decided that Approach 1 should be adopted, since it was based on actual observed channel conditions.

It is expected that the channel will degrade over time in response to the higher discharges. This will eventually flatten the slope along the *khal* until the gradient become comparable to the present situation on the Kalni River.

Assuming the tailwater at the Baulai River junction remains unchanged, the overall slope flattening (Δz) can be estimated approximately as follows:

Δz = (Si - Sf)* Δx, where
Si = the initial *khal* slope (60 mm/km)
Sf = the final *khal* slope (40 mm/km)
Δx = the total length of the *khal* (13.5 km)
Δz = 270 mm

Therefore, the overall longitudinal profile adjustment will be relatively minor.

The total land lost (A_e) along the *khal* due to channel widening can be estimated roughly as follows:

A_e = dW*dX, where
dW is the expected width change (250 - 80 = 170 m)

Approximate bank erosion due solely to channel enlargement will be around 230 ha. The total amount of sediment eroded from the banks (V_b) can be estimated approximately as:

V_b = dW*h* x, where
h = the average height of the banks (3.6 m)

Based on this estimate, approximately 8 million m^3 of material could be eroded from the *khal* due to the channel widening. This material would be deposited in the Baulai River and in various *beels* and lowlying areas on the floodplain as a result of new channel breaching. Therefore, it is likely that the channel widening would trigger new channel instability and *dhalas* along the route. The time scale required for these changes to be completed will depend on the sediment transport capacity of the *khal* during the pre-monsoon and dry seasons, the pattern of discharges that are experienced and the erodibility of the bank materials. It is assumed that no enlargement will take place in the monsoon season, when the area is deeply flooded. Some guidance can be found from the measured suspended sediment loads on the Kalni River. This rough calculation is as follows:

Sediment load at Ajmiriganj - Jan-May 1996 = 5.2 million tonnes/year or 3 million m^3/year
Bank material composition - primarily silt > 0.03 mm
Percentage of suspended load > 0.03 mm = 70%
Sediment load at Ajmiriganj > 0.03 mm = 2.1 million m^3/year
Present flow split into *khal* - 30%
Present sediment load by *khal* - 30% x 2.1 million = 0.6 million m^3/year
Sediment load assuming future 66% flow split = 1.4 million m^3/year
Average sediment load carried by *khal* during enlargement (q_s) - 1.0 million m^3/year
Estimated time required to transport eroded bank materials = V_b/q_s
= 8 million m^3/ 1 million m^3/year = 8 years

This figure is only indicative of the time scale required for the morphologic change. The period is somewhat shorter than the time required for the *khal* near Katkhal to enlarge to its present size (10 to 15 years) or for the previously constructed loop cut channels near Markuli to enlarge to their full section (around 13 years). In fact, there is no satisfactory analytical method available for computing the rate of bank erosion or lateral channel changes. In view of this situation, it is better to rely on the direct evidence that has been documented from field observations. Therefore, 15 years has been tentatively adopted as the time period required for the shift to be completed.

9.5 Lower Kalni-Dhaleswari River

Downstream of the Cherapur Khal diversion, Kalni River flows will be decreased substantially in the dry season and pre-monsoon season. Previous studies (Chapter 8) has shown that the lower reach experiences considerable seasonal scour and fill, with deposition in the monsoon season, then subsequently cutting through the deposits in the following dry season and pre-monsoon season. Reducing the dry season and pre-monsoon flows will alter this pattern of scour and fill and should cause further sedimentation along the lower reach of the river and a further reduction of the channel cross section. It is expected that the main response will be aggradation of the river bed, rather than channel narrowing. The extent of this deposition was estimated by using a similar approach to the analysis outlined above for Cherapur Khal. By diverting flow into Cherapur Khal, the channel-forming or dominant discharge will be reduced. A preliminary hydraulic analysis was made with the MIKE-11 hydrodynamic model to assess the magnitude of the flow changes after the *khal* enlarged. The analysis with the MIKE-11 model is described separately in Annex B - Hydrodynamic model, and will not be repeated here. It was found the flow split to the lower Kalni River was reduced from 65 % to around 30%. The estimated 1:2 year pre-monsoon discharge along the main channel will be reduced from 1,430 m^3/s to 600 m^3/s. In the future, the flows in the main channel of the Kalni River will be similar to the conditions that are presently experienced in the lower Kalni-Dhaleswari River channel (between Issapur and Shibpur). Therefore, the present-day channel geometry on the reach of the lower Kalni-Dhaleswari River channel can be used as a template for representing the future conditions between Kadamchal and Issapur. Following this approach, the future geometry was estimated.

Table A.38: Estimated Flow Split on Kalni-Dhaleswari River

Location	River	Distance (km)	Discharge	
			Present (m^3/s)	FWO (m^3/s)
Ajmiriganj	Kalni	107.0	1,790	1,790
spill into khal	Cherapur Khal	89.5	360	1,190
Kadamchal - Issapur	Kalni	86.0	1,430	600
at bifurcation	Kalni-Dhaleswari	71.0	470	200

Table A.39 summarizes the change in channel geometry. It was estimated that the cross section of the Kalni River will be reduced by 400 m^2, downstream of Cherapur Khal. It was assumed this will occur primarily due to a rise in the river bed, rather than a decrease in the top width. The corresponding average bed rise amounts to around 1.5 m.

K8

Table A.39: Estimated Channel Changes on Kalni River

Average Bankfull Geometry	Present	Future	Change
Area (m^2)	1000	600	-400
Top Width (m)	250	240	-10
Mean Depth (m)	4.0	2.5	-1.5

The time scale for these changes will be determined primarily by the time required for the *khal* to widen. It is expected that once the *khal* captures more of the flows, deposition will occur very rapidly along the lower river. This is because the amount of sediment that can be deposited in the monsoon season is relatively large in comparison to the volume of sediment deposited on the channel bed. For example, the total volume of material contained in a 1.5 m layer of sediment deposited over a 300 m wide, 40 km long reach is around 18 million m^3. By comparison, the sediment load in the monsoon season was estimated to be in the order of 15 million tonnes/year which represents an in-situ volume of roughly 10 million m^3/year. Even if a substantial fraction of the load is deposited over bank, it would only require a few years for the channel to infill to the future condition.

In conclusion, it appears likely that if no interventions are made, Cherapur Khal could enlarge further and could eventually capture more than 50 % of the flow in the dry season and pre-monsoon season. This would induce further aggradation on the lower Kalni River, since the "channel-forming" discharges would be greatly reduced. However, the channel would continue to carry flow in the monsoon season and post-monsoon season. The Kalni channel would resemble the shallow reach of the present-day Dhaleswari branch near Madna.

10. PROJECT IMPACTS

This chapter provides an assessment of the physical response of the Kalni-Kushiyara River to the engineering interventions proposed in the KKRMP in order to represent the "future with project" condition (FW). The response of the channel will be determined primarily by changes to the pattern of discharge and sediment transport along the river induced from the project. Because stability and ecological problems have arisen in many past flood control projects, any attempt to modify a natural channel requires careful assessment. This analysis was guided by the observations of channel response from past interventions including the Suriya avulsion, loop cuts upstream of Ajmiriganj, and the recent flow diversion at Cherapur Khal. In addition to this "geomorphic" approach, a one-dimensional morphologic model (HEC-6) was used to simulate the long-term bed profile response to the project. This mathematical model simulates river bed erosion and deposition by computing the sediment transport at various locations along the channel and then re-distributing the sediment according to the continuity equation (HEC, 1976). The simulations were carried out to represent a number of years by inputting hydrographs of inflowing discharge and sediment load. Although neither the "geomorphic approach" or the "modelling approach" will give exact results, using both in combination should improve the reliability of the predictions.

10.1 Project Description

The main objectives of the project's river engineering components are:

- to improve the river's stability by preventing further channel shifting into Cherapur Khal;
- to establish a more stable alignment that can be maintained without the need for additional major stabilization works;
- to reduce damage to agriculture by controlling pre-monsoon floods and improving post-monsoon drainage;
- to reduce erosion damage to settlements and agriculture along the floodplain, and
- to increase the water depth in the dry season in order to improve navigation.

The focus of the work extends along the 150 km reach of the river between Fenchuganj (Km 217) to the junction of the Dhaleswari - Baida channels below Kalma (Km 47). Figures A.72 and A.73 show the general arrangement of work that has been proposed. The main features of the project include a combination of bank protection and low levees upstream of Ajmiriganj and channel re-alignments, channel excavation and bank protection downstream of Ajmiriganj. Two alternatives were assessed:

- Alternative 1, includes constructing two loop cuts - one at Katkhal near the instability around Cherapur Khal and a second further downstream near Issapur at the bifurcation of the Baida River and Kalni-Dhaleswari River, and

- Alternative 2 eliminated the Issapur loop cut and instead, proposed additional excavation along the Dhaleswari River.

These alternatives are virtually identical upstream of Issapur. Therefore, this assessment includes a detailed description of impacts for Alternative 1. Following this, Alternative 2 is examined by highlighting only the impacts that differ significantly from Alternative 1.

Bank Protection Works
Local bank protection will be constructed at three critical breaches between Raniganj and Ajmiriganj to reduce major pre-monsoon spills and to control bank shifting. These sites include:

- right bank near Akkilshah Bazar (Km 138);
- left bank at Koyer Dhala (Km 115.5), and
- right bank at Pituakandi (Km 114.5).

The protection will consist of a stone rip-rap revetment with a launching apron to prevent undermining. The stone will extend only up to the top of the bank so that it will not confine floods in the monsoon season.

Levees
Low levees and land grading will be required in localized reaches between Raniganj Bazar (Km 152) and Markuli (Km 132) to prevent spilling of pre-monsoon floods into cropped areas. The maximum height of the levees is 1.0 m, including 0.3 m of freeboard. The levees will replace the bunds constructed annually by local farmers to protect their crops from flood damage. The levees will not impede the present drainage pattern as the slope of the land is away from the river channel.

Katkhal Loop Cut
A loop cut will be constructed near Katkhal to develop a more stable bend and to prevent the main flow from being directed into Cherapur Khal. The river's overall length will be shortened by 5.5 km. Bank protection and retard structures will be constructed at the *khal* entrance and along portions of the Kalni River to prevent channel changes that could re-activate the *khal*. The *khal* will remain open so that post-monsoon drainage will not be impeded.

Previous loop cuts carried out by local authorities upstream of Ajmiriganj were made by excavating a small pilot channel, then diverting the flow into the new course. This caused a local flow constriction as well as erosion problems upstream and downstream from the cut. In this project, the new channel will be excavated to its full cross section to avoid these problems.

Channel Excavation- Issapur to Ajmiriganj
Table A.40 summarizes the design parameters for the excavated channel. The total excavation volumes, excluding any work associated with loop cut construction is estimated to be 6.2 million m3.

Suction cutter dredgers will be used for the excavation, with the spoil pumped into permanent disposal chambers on the floodplain.

The average depth of excavation ranges between 2.5 to 5 m, and the increase in channel cross sectional area averages around 380 m^2 and ranges between 300 - 500 m^2 (Table A.40). This will increase the channel's cross sectional area at bankfull stage by around 20-30%.

Table A.40: Summary of Channel Excavation Volumes

Location	Reach (km)	Grade Level (m PWD)	Excavated Volume (m^3)	Average Increase in Area (m2)	Increase in Bankfull Area (%)
Issapur	72.7-76.5	-3.0	1370000	370	44
	76.6-79.0	-3.0	710,000	280	33
Abdullahpur	79.0-81.0	-3.0	951,000	480	48
Kalimpur	81.0-83.0	-3.0	764,000	380	38
Kadamchal	84.5-86.5	-2.5	426,000	210	20
Rahala	97.5-98.8	-2.0	670000	515	44
Kakailseo	98.8-102.3	-2.0	543000	160	15
Shahanagar	102.3-104.5	-2.0	572000	260	18
Ajmiriganj	104.5-107.0	-2.0	448000	180	13
Total			**6,454,000**		

Issapur Loop Cut
This loop cut will shorten the channel by about 16.5 km (compared to the silted-in Kalni-Dhaleswari route). A closure will be constructed on the Kalni branch just downstream of Issapur in order to block sediment-laden water from entering into the reach below Madna. The lower end of the Kalni-Dhaleswari branch will be excavated and will remain open in order to improve drainage from the Ratna-lower Khowai River system which flows into the Kalni River at Madna. The shorter channel will steepen the profile and lower the upstream water levels during the dry season and pre-monsoon season. The steeper gradient should also contribute to making the channel more "self-scouring".

10.2 Hydrological Impacts

10.2.1 Discharge

The impacts to the discharge regime were estimated from the MIKE-11 hydrodynamic model (Annex B). The project is not expected to significantly alter the discharges upstream of Sherpur (Km 177) or downstream of the Baulai-Dhaleswari River junction (Km 20) at any time of the year. Therefore, the main reach where discharges will be modified extends over the 157 kilometres between Sherpur and the Dhaleswari-Baulai River junction. The project is not expected to significantly alter the main channel discharges during the monsoon season since none of the proposed works will confine or affect the monsoon flood flows. The impacts will be largely restricted to changes in the pre-monsoon and dry season discharges.

The project interventions will modify the magnitude and frequency of discharges in the pre-monsoon season, particularly in the reach downstream of Markuli. This is because the major pre-monsoon spill channels will be closed, which will reduce flows into the floodplain and cause the main channel to carry more of the river's total discharge. Table A.41 summarizes the estimated pre-monsoon flood discharges at various points along the river under the "future with", "future without" and present condition. Due to the confinement of the flow, the peak discharge at Ajmiriganj is expected to increase above present conditions by 16.7% at the 2-year pre-monsoon flood and by 26.8% at the 5-year pre-monsoon flood. Downstream of Cherapur Khal, the flows will be approximately the same as at present. These flows are substantially higher than the predicted FWO project situation which forecasts a substantial diversion of flow into the Baulai River system. Therefore, the project prevents Cherapur Khal from capturing the flow of the Kalni River and becoming the dominant channel.

Flows in the Baida River channel below Issapur will be reduced substantially from the present condition, since most discharge will be carried by the newly constructed channel. However, the "future with" and "future without" flows in the Baida channel are approximately the same. Downstream of the Baida/Dhaleswari River junction the discharges will be the same as the present.

Table A.41: Discharges along Kalni-Kushiyara River

Location	2-year Pre-monsoon Flood Discharge (m^3/s)			5-year Pre-monsoon Flood Discharge (m^3/s)		
	Present Condition	FWO	FW	Present Condition	FWO	FW
Sherpur	1,704	1,700	1,700	1,705	1,705	1,705
Markuli	1,556	1,287	1,661	1,661	1,661	1,661
Below Koyer Dhala	1,417	1,153	1,625	1,625	1,625	1,625
Ajmiriganj	1,378	1,143	1,609	1,609	1,609	1,609
Below Cherapur Khal	976	330	1,311	1,311	1,311	1,311
Baida River channel	565	323	300	300	300	300

10.2.2 Water Levels

The project's impacts will be greatest during the dry season and pre-monsoon season, when the river slopes are steepest; and close to negligible during the monsoon season when the gradients are controlled by the downstream level of the Meghna River. Figure A.74 shows a longitudinal profile of the 1:5 year pre-monsoon flood levels and the bank levels. This profile shows the project will be able to maintain the water levels below the top of the bank except in localized areas just upstream of Katkhal and near Kadamchal. Consequently, all major upstream spills will be eliminated due to the development of the project. The project will lower 1:5 year pre-monsoon flood levels by 0.35 - 0.45 m between Madna and Ajmiriganj in spite of the increased discharge carried by the main channel. Upstream of Markuli the lowering will be negligible during peak pre-monsoon flood conditions. Peak pre-monsoon flood levels will be lowered on the floodplain by around 0.4 - 0.6 m northeast of Madna and by 0.3 - 0.4 m northwest of Ajmiriganj on the right bank of Kalni-Kushiyara River, and near Cherapur Khal.

Monsoon flood levels will not be lowered significantly by the channel improvements. The project has a major impact on post-monsoon and dry-season water levels on the Kalni - Kushiyara River, with levels lowering by up to 1.5 m between Ajmiriganj and Markuli (Figure A.74). Dry season water levels at Fenchuganj will be lowered by between 0.7 to 1.0 m. Post -monsoon levels on the Ratna floodplain were lowered by around 0.5 m in mid-December.

10.3 Morphologic Impacts

The following comments summarize the expected impacts of the proposed project on the channel morphology. For this discussion, the river has been sub-divided into six reaches and the impacts are summarized by reach.

10.3.1 Upper Kushiyara - Fenchuganj to Sherpur

Except for local navigation dredging, no major works will be carried out in this reach. However, water levels in the dry season will be lowered by as much as 1.0 m at Fenchuganj. This will return the water levels to comparable conditions that were experienced in the 1960's -70's. It is expected that the low flow channel will cut down through local shoals in some areas, particularly at the mid-channel "crossings" that occur in straight reaches between meander bends. Some downcutting may also occur in the lower reaches of tributaries such as Juri River and Manu River. This may cause adjacent sloughs to dry out.

10.3.2 Kushiyara River - Sherpur to Markuli

Levees and local bank protection work will be constructed along portions of this reach. Downstream improvements will lower pre-monsoon flood levels at Markuli by about 0.4 m.

The proposed flood control works will reduce the frequency and magnitude of pre-monsoon spills and breaches downstream of Raniganj (Km 152). This will reduce the deposition of sediment "splays" into the adjacent flood basins and distributary channels in this reach. Minor adjustments may occur in the meander pattern in response to the installation of bank protection. However, these changes will be very small in comparison to the natural pattern of channel shifting. The channel is already very deep in this reach. Therefore, no major impacts are expected as a result of lower water levels in the dry season.

10.3.3 Kalni River - Markuli to Ajmiriganj

Local bank protection and navigation dredging will be carried out in this reach. Under the present condition and the assumed "future without" condition, spills in the pre-monsoon season cause the discharges in the main channel to decrease in the downstream direction between Markuli and Ajmiriganj. When the project is completed, these pre-monsoon spills will be virtually eliminated in most years, causing the magnitude of pre-monsoon flood discharges to increase downstream of Markuli. The dominant or channel-forming discharge will be increased from about 1,650 m^3/s to around 1,900 m^3/s. During the first decade of operations, the channel may tend to widen slightly. Simple Lacey "Regime" Theory" equations indicate the increase in width could reach up to 15 m. Meander migration and bank erosion may also be accelerated temporarily. However, once the river adjusts to the higher flows a new equilibrium will be established.

10.3.4 Ajmiriganj to Kadamchal

This reach will be affected by Katkhal loop cut, channel excavation and the modified pre-monsoon discharge regime. The project is designed to prevent the river from developing a new avulsion into the Baulai River through Cherapur Khal. Consequently, the drainage system in the lower Baulai/Ghorautra River system will not experience a major episode of channel instability, bank erosion and sedimentation. Furthermore, the lower Kalni River below Cherapur Khal will continue to carry most of the river's flow.

Localized bank erosion is expected downstream of the Katkhal loop cut between Bishorikona and Kadamchal in response to the new flow pattern. The erosion should cease after the river adjusts to the new upstream alignment.

There are six deep *duars* (scour holes at bends or points of flow impingement) near Katkhal that are considered to be key fisheries habitat (Figure A.75). Concerns were raised about how these sites would be affected by the channel re-alignment in this reach. Properties of these scour holes are summarized in Table A.42.

Table A.42: Properties of *Duars* Near Katkhal

Site Number	Kilometre	Location	Bed level in scour hole (m PWD)		Depth in the dry season (m)	
			Thalweg	Average	Maximum	Average
1	96.5	Shantipur	-11.8	-8	14.2	10.4
2	95.5	Mathabpur	-9.6	-6	12.0	8.4
3	92.0	Shahebnagar	-13.4	-8	15.8	10.4
4	90.0	Cherapur Khal	-8.2	-4	10.6	6.4
5	89.0	Kanchanpur	-3.0	-1	5.4	3.4
6	86.5	Nayakurar Kandi	-10.8	-8	13.2	10.4

The expected channel depths at these sites were estimated using observations on channel topography and bed levels in other reaches of the river. Guidance was also provided from the Blench Regime equation:

$$d_r = Z\sqrt[3]{\frac{q^2}{F_b}}$$

where d_r is the maximum depth, Z is the ratio of maximum depth/average depth, q is the discharge per unit width and F_b is a bed sediment size parameter. The geometry was calculated for a dominant discharge corresponding to a 2 year pre-monsoon flood. Table A.43 summarizes the expected changes that will occur at each *duar* in the area.

The greatest impacts will be experienced at Site 2, which will be effectively cutoff by the loop cut. The closure near Shantipur should reduce sedimentation rates to the bend so it is unlikely that it will infill completely. The re-aligned channel will also create a new *duar* opposite Kaisar as a result of flow impingement along the right bank The estimated properties are as follows:

thalweg level = -8.0 m PWD
average bed level = -3.0 m
maximum depth in the dry season = 10.4 m
average depth in the dry season = 5.4 m

Table A.43: Predicted Local Bed Levels at *Duars*

Site	Kilometre	Location	Bed level in scour hole (m PWD)		Depth in the dry season (m)	
			Thalweg	Average	Maximum	Average
1	96.5	Shantipur	-8	-3	10.4	5.4
2	95.5	Mathabpur	-3	-1	5.4	3.4
3	92	Shahebnagar	-10	-4	12.4	6.4
4	90	Cherapur Khal	-6	-4	8.4	6.4
5	89	Kanchanpur	-2	-1	4.4	3.4
6	86.5	Nayakurar Kandi	-8	-6	10.5	8.4

Note: water level in dry season = 2.4 m PWD

10.3.5 Kalni-Dhaleswari River Below Issapur

The closure near Issapur will reduce flows down the Kalni-Dhaleswari branch between Issapur and Kalma. After the closure is constructed the only flow to this reach will be from the Khowai/Ratna Rivers which enter near Madna (Figure A.29). The long-term mean discharge on the Khowai River at Shaistaganj is 38 m^3/s, which is only a small fraction of the flow on the Kalni River.

Sedimentation rates in this 19 km long reach should be reduced in comparison to the present and "future without project" condition, since the closure will prevent sediment-laden water from the Kalni River from depositing material in the reach. The channel between Madna and Kalma will gradually narrow over time in response to the lower discharge regime and proposed land filling along the right bank near Adampur (Figure A.73). The channel bottom will be maintained at El. -1.5 m PWD through maintenance dredging operations.

A potential deposition problem could develop over time near the junction of the Ratna/Khowai Rivers just upstream of Madna. With the lower discharges in this reach, sediment supplied from these tributaries could deposit at the junction . Sedimentation processes on the Khowai River were investigated as part of a regional investigation of Northeast rivers (NERP, 1994). Based on suspended sediment sampling by BWDB at Shaistaganj, the annual load was estimated to be 1.7 million tonnes/year, of which about 80% was transported in the monsoon season.

The Khowai River deposits most of its sediment load on the broad, low-lying floodplain just below Habiganj (25 km upstream of the Kalni junction) when it spills overbank. The spilling is caused by the reduction in slope below Habiganj and by backwater control from the Meghna River during the monsoon season. The loss of discharge and sediment causes the Khowai River to drastically reduce in size - from a top width of 60 m near Habiganj to less than 20 m near its junction with the Kalni River. Further evidence of very low sediment transport rates in the lower reach of the Khowai and Ratna channels can be found by comparing the historical changes at the large ox-bow lakes that occur near the junction of the Kalni River near Madna (Figure A.29). Since flows from the Ratna and Khowai River spill into these features, they should effectively trap sediments from these streams. However, these ox-bow lakes have remained remarkably unchanged over the last 40 years, and do not appear to have filled-in appreciably.

Therefore, based on these considerations, it is believed that sedimentation at the mouth of the Khowai/Ratna River junction will be low. Furthermore, sediment deposition, if it occurs, can be removed periodically during maintenance dredging.

In both the "future with" and "future without" project scenario, the Baida channel is expected to carry less discharge than at present. In the case of the FWO scenario, the reduction in flow will be caused by the upstream diversion to the Baulai River. In the case of the FW scenario, the reduction in flow will be caused by diversion of flow to the new channel. The Baida channel is expected to gradually develop a smaller cross sectional area than at present. This will probably occur by growth of point bars at meander bends and increased frequency of shoals. As a result, the active channel will shrink over time.

10.3.6 Downstream Impacts on Upper Meghna River

Sedimentation rates are expected to temporarily increase downstream of the Issapur loop cut, particularly in the 8 km long reach of the Dhaleswari River immediately downstream of Kalma. Therefore, studies were made to assess whether the new channel alignment would significantly impact sedimentation processes and morphology further downstream. As shown in Figure A.76, the Issapur loop cut is located 33 km upstream from the river's junction with the Baulai River, near Dilalpur. The Upper Meghna River carries the combined flow of the Kalni-Dhaleswari and Baulai River. The mean discharge at Bhairab Bazar is 5,589 m^3/s, which is over four times the estimated total runoff from the Kalni River system at Dilalpur. Figure A.74 shows the bed profile drops rapidly below Madna as the river approaches the junction with the Baulai River - from around El. +2 m PWD to less than El. -15 m. Figure A.77 shows the variation in channel properties along the Kalni-Kushiyara River and the abrupt increase in channel size at the junction with the Upper Meghna River. For example, at present, the cross sectional area at bankfull on the lower Kalni River is around 1,000 m^2 and after excavation it will be around 1,500 m^2. The channel area increases to around 3,000 m^2 on the lower Dhaleswari River near Dilalpur and then jumps to around 11,000 m^2 on the Meghna River at Bhairab Bazar.

The difference in scale between the Kalni River at Ajmiriganj and the Upper Meghna River channel is illustrated in Figure A.78.

Bed material samples from the Meghna River at Bhairab Bazar showed the bed sediments consisted of fine sand and very fine sand will very little silt. The median (D_{50}) size and the D_{10} size were 0.1mm and 0.06 mm respectively. Based on the usually accepted criteria for wash load (D_{10}), it appears silt and clay are transported as wash load on the Meghna River and are flushed through the channel without depositing. Therefore, it is primarily the sand fraction of the incoming sediment load that could be deposited in the channel. The total suspended sand load on the Kalni River was estimated to be approximately 1 million tonnes/year (section 6.6), which corresponds to a deposited volume of around 0.6 million m^3. By comparison, the channel volume on the lower Dhaleswari River between Kalma and the Upper Meghna River near Dilalpur occupies a total volume of around 250 million m^3. Therefore, the storage volume for sediment in the channel is roughly 350 times the incoming annual sand load that could potentially be deposited.

In summary, given that the proposed modifications on the Kalni River are relatively minor, and are primarily intended to stabilize the channel, it is unlikely that the project will have much impact on a much larger channel such as the Meghna River.

10.4 Long-term Bed Profile Response

10.4.1 Morphologic Models

In this investigation, the computer program "HEC-6" was used to provide assessments on the long-term bed profile response to the project. This program was developed at the Hydrologic Engineering Center, US Army Corps of Engineers. The program was designed to analyze scour and deposition by modelling the interaction between the water-sediment mixture, the sediment material forming the river bed and the hydraulics of the flow. The program is a one-dimensional, steady flow model and is not intended for assessing lateral channel processes such as scour in bends or meander migration. The river channel is described by a series of cross sections that are sub-divided into two parts - the movable bed portion and the fixed portion. The bed material grain size characteristics are then specified for each cross section. The sediment transport at each cross section is calculated from the computed hydraulic parameters. Several different equations including Ackers-White, Toffaletti, and Einstein can be used. By entering a sequence of water discharges at the upstream boundary and water levels at the downstream boundary, an annual hydrograph can be simulated. The program is capable of representing tributary inflows, flow branches and diversions.

The basic input data include:

- geometric data, including cross sections, reach lengths, and channel roughness (0.02-0.03);
- sediment data, including the inflowing sediment load data and gradation of bed material, and
- hydrologic data, including water discharges, downstream water levels and flow durations.

10.4.2 Model Development

A 100 km reach of the river was represented in the model, extending from Markuli to near Dilalpur on the Upper Meghna River. The channel cross section geometry along the river was simplified by adopting an average cross section shape and using this as a template for various reaches along the river. The adopted cross sections were defined so they had the same bankfull properties as the surveyed sections shown in Figure A.76. The overbank floodplain was extended for a distance of approximately 1 km on each bank of the river. Spacing between cross sections was set between 2.5 and 5.0 km. The hydraulic roughness of the main channel (Manning's n values) varied between 0.02 and 0.03.

The 1995 discharge hydrograph from Markuli was used to represent the sequence of flows in the river. The water levels at Astagram were used for the downstream boundary. The hydrograph was sub-divided into ten day time steps during the pre-monsoon and monsoon season and 20 day time steps in the dry season. The flow split at Cherapur Khal and at the Baida bifurcation were specified from the results of the fixed bed MIKE-11 hydrodynamic model runs.

The inflowing sediment loads were based on the suspended sediment rating curves developed from observations in 1995 and 1996 (section 6.6). The sediment load was represented by a single sand size (0.08 mm) and a silt size (0.04 mm). The remaining fine silt and clay load was assumed to behave as wash load and was excluded from the analysis.

10.4.3 Model Verification

Proper representation of the channel topography and hydraulic roughness were tested by running a number of "fixed bed" backwater profiles and comparing the computer water levels to the observed water levels at NERP's hydrometric stations between Madna and Markuli. Adequate calibration was achieved with the ideal cross sections during the pre-monsoon season and dry season. The water levels tended to be over-estimated upstream of Ajmiriganj, possibly because it was assumed there were no flow losses between Sherpur and Markuli.

Verification of the model's representation of sediment transport and deposition was made by simulating the 1995 annual hydrograph and comparing the predicted bed response to the observed patterns of scour and fill that were observed downstream of Ajmiriganj (section 6.7).

10.4.4 Idealized Channel Response

Loop Cuts

Re-alignment of meandering streams has been widely used in the past to increase hydraulic capacity and to reduce loss of land from bank erosion. This re-alignment usually involves eliminating selected meander bends by excavating loop cuts. The increased capacity results from increased slope, bed lowering due to degradation and from reduced eddy losses. In environments with relatively stable meanders, flat gradients, and erosion-resistant banks, channels may be re-aligned without serious consequences. In environments where the banks are predominately sand, slopes are steep and sediment loads are high, straightening meandering streams has led to serious problems of channel degradation and bank erosion. Based on morphologic studies and observation of past channel changes, the Kalni River has a sufficiently flat gradient and relatively erosion resistant bank material so that individual loop cuts can be constructed without seriously de-stabilizing the channel.

Figure A.79 illustrates the idealized channel adjustments that occur after a loop cut on the Kalni River downstream of Ajmiriganj. The simulated bed levels shows a transient wave of degradation heads upstream from the cut and temporary aggradation occurs downstream of it. Over a period of a few years, the downstream bed levels return to their pre-project condition, while the upstream bed levels are permanently reduced by an amount equal to $(L_0 - L_f)*S_f$, where L_0 and

L_f are the initial and final channel lengths and S_f is the uniform slope that develops after the channel adjusts to the loop cut. Given the flat slopes that exist on the river, the risk of experiencing excessive degradation is very small unless the channel is shortened tremendously by complete re-alignment of the channel pattern. For example, the steepest slopes in the reach between Madna and Ajmiriganj typically average around 0.00006 or only 6 cm/km. Shortening the river by 10 km will produce a long-term profile adjustment of around 0.6 m upstream of the cut. Therefore, water level lowering due to degradation from loop cuts on the Kalni River is expected to be relatively small.

Channel Enlargement
Channel enlargement can be achieved by deepening the channel's bottom, increasing the bottom width, flattening the side slopes, side berm excavation or a combination of these methods. The two main potential problems with channel excavation are related to sediment deposition and bank instability. If the channel carries substantial sediment loads and if the cross section provided to meet flood control requirements is much greater than its natural "regime" dimensions, then the section may infill with sediment deposits in a relatively short time period. Consequently, the flood capacity may not be achieved without ongoing maintenance excavation. Figure A.79 illustrates the idealized pattern of infilling in an excavated trench on the river. It can be seen that the trench behaves like a sediment trap, with deposition occurring at the head of the excavation and temporary degradation occurring downstream of it. After a period of time the bed return to their pre-dredging levels. Therefore, unless the modified channel is capable of properly conveying the post-project sediment loads, ongoing maintenance dredging will be required to sustain the improved channel cross section.

10.4.5 Alternative 1

This alternative was represented in the model by including the loop cuts at Issapur and Katkhal and lowering the bed levels between Issapur and Ajmiriganj to the proposed dredge grade. The first simulation extended over one annual hydrograph. The model results were then reviewed and the predicted bed levels were used as the starting conditions for the next year's simulation. The runs were repeated in this fashion to simulate an additional six years of flows. It was assumed that no maintenance dredging was carried out during this period.

Figure A.80 shows the predicted changes in the longitudinal profile over a period of six years. The distances on this profile have been modified from the present NERP chainages, since the two loop cuts shorten the channel's overall length by up to 22 km.

The bed degraded in the ten km reach upstream of Ajmiriganj, in response to the lower water levels in the pre-monsoon season and dry season. This suggests that the proposed excavation near Ajmiriganj (448,000 m^3) may not be required since the bed will lower anyway. Excavation could be deferred for two years and a monitoring program could be carried out during this time to assess actual dredging requirements in this reach. Between Ajmiriganj and the entrance to the Katkhal loop cut, the bed slowly aggraded until approaching an approximate equilibrium at El. -1.5 m. The present bed level in this reach is El. 0. 0 m. Downstream of the Katkhal loop cut, in the reach between Kadamchal (km 68 on Figure A.80) and Abdullahpur (km 63 on Figure A.80) the bed aggraded. more rapidly. Two years after the initial excavation, the bed rose to El. -1.0 m and after four years the bed had returned to near the present level. Further downstream, near the entrance to the Issapur loop cut, the bed profiles lowered abruptly. Aggradation occurred immediately downstream of the Issapur loop cut. However, this deposition was restricted to within five kilometres of the lower end of the new channel. No general bed aggradation occurred downstream of this point.

The model showed that channel maintenance dredging will be required, particularly in the 10 km reach downstream of Katkhal loop cut to preserve the improved channel conveyance. The requirements for maintenance dredging were estimated by calculating the volume of excavation that would be needed to maintain the bed elevations near the required grade line. The model was then re-run with the channel dredged in each dry season. It was found that in the two years of opening the loop cut, the total volume of re-excavation averaged 1.5 million m^3/year. Later on, as the transient effects of the loop cut dissipated the total re-excavation averaged around 1.0 million m^3/year.

10.4.6 Alternative 2

With Alternative 2, the Issapur loop cut was eliminated and additional channel excavation was carried out along the branch of the lower Kalni-Dhaleswari River between Issapur and Shibpur. All other components were identical to Alternative 1. These modifications were made to the model and then the simulations were re-run using the same set of boundary conditions as for Alternative 1.

Figure A.81 shows the predicted bed profiles over a number of years, if no channel maintenance excavation was carried out. The distances shown on this figure differ from the present NERP chainages upstream of Shantipur, due to the Katkhal loop cut which shortens the channel's length by 5.5 km. The bed response near Ajmiriganj was similar to Alternative 1, with general bed lowering occurring after the project was completed. The bed also aggraded downstream of Katkhal loop cut in the reach between Kadamchal (km 85) and Abdullahpur (Km 80). The present bed levels in this reach average about El. 0.6 to 1.0 m. The initial dredged bed level was at El. -3 m. Without any maintenance dredging, the bed levels rose to between El.-1.0 m to El. -0.5m after two years, and after four years the levels were up to El. +0.5 m. Aggradation continued to occur downstream on the lower Dhaleswari-Kalni River branch between Issapur (km 72) and Shibpur (km 56). Five years after dredging, this deposition infilled the bed back to near its present elevation. This alternative had no impacts on bed levels downstream of Shibpur, since all of the sediment was deposited further upstream.

The model showed that channel maintenance dredging will be required to preserve the improved channel conveyance, particularly in the 10 km reach downstream of Katkhal loop cut and in the lower Kalni-Dhaleswari reach. The requirements for maintenance dredging were estimated by calculating the volume of excavation that would be needed to maintain the bed elevations near the required grade line. The model was then re-run with the channel dredged in each dry season. It was found that in the two years of opening the loop cut, the total volume of re-excavation averaged 2.4 million m^3/year. Following this, as the transient effects of the loop cut dissipated, the total re-excavation averaged around 1.8 million m^3/year.

10.4.7 Channel Maintenance Requirements

Given the inherent uncertainties with sediment transport predictions, the morphologic modelling computations can only provide indicative results for estimating future channel maintenance requirements. It was decided to use the results of the predictions as baseline estimates, then carry out a sensitivity analysis during the project's economic evaluation to assess the impact of variations in maintenance dredging on the overall project economics.

Table A.44 summarizes tentative estimates of maintenance dredging volumes by reach after the project is completed. With Alternative 1, the greatest need for maintenance dredging will be in the 7 km reach downstream of the Katkhal loop cut between Bishorikona and Kadamchal (Km 87-85), downstream of Issapur loop cut on the Dhaleswari River (Km 49-42), and below Kalimpur (Km 82-79) on the lower Kalni River. No major re-excavation is expected immediately upstream of the loop cuts, since these reaches will degrade after the new channels are opened. With Alternative 2, continuous maintenance dredging will be required between Shibpur and Issapur (Km 56-72) on the Dhaleswari River, from Abdullapur to Kalimpur on the lower Kalni River (Km 76-82) and downstream of Katkhal loop cut from Bishorikona to Kadamchal (km 87-85).

Table A.44: Maintenance Dredging after Project Completion

Location	Reach (Km)	Maintenance dredging ('000 m^3/year)	
		Alternative 1	Alternative 2
Kalma	47-52	200	
Shibpur	54-58	100	200
Adampur	63-66	100	300
Islampur	68-71		400
Issapur			300
Abdullapur		600	600
Total		**1,000**	**1,800**

The pilot project dredging near Gazaria and Kakailseo villages in 1995-1996 and the subsequent monitoring that was carried out, provides some additional information on the expected maintenance requirements for channel excavation. This monitoring is described in the Pilot Dredging Project Completion Report (Annex-J). The monitoring was carried out from September 1995 (pre-project) until September 1996 (post-project), while most of the dredging was completed between January and May 1996. The total excavation amounted to approximately 450,000 m^3. After one full monsoon season, about 50% of the excavated volume had filled in, and the bed levels were still around 1 to 2 m lower than pre-dredging conditions.

REFERENCES

Church, M, Kellerhals, R. and Ward, P., 1985: "*Sediment in the Pacific and Yukon Region: review and assessment*" Water Survey of Canada, 250 pp.

BWDB, 1973: "*Upper Kushiyara Project, Revision and updating of Feasibility Report*", Government of Bangladesh, Bangladesh Water Development Board, Volume 1 Main Report.

Day, T. and Spitzer, M., 1985: "*Sediment station analysis, Oldman River near Brocket*" Environment Canada, Water Survey of Canada.

EPWAPDA, 1966: "*Report on Feasibility Study of the Upper Kushiyara Project in Sylhet District*", East Pakistan Water and Power Development Authority, May 1966.

Einstein, H. A., Anderson, A. G., Johnson, J.W., 1940: "*A Distinction between Bed Load and Suspended Load in Natural Streams*", Trans. American Geophysical Union, pp. 628-633. tional Symposium on River Sedimentation, Nanjing, China.

Einstein, H.A., 1942: "*Formulas for the Transportation of Bed Load*", Transactions of the American Society of Civil Engineers, Vol. 107, pp. 561-573.

Geological Survey of Bangladesh, 1990: "*Geology of Bangladesh Map*".

Johnson and Alam, 1991: "*Sedimentation and Tectonics of Sylhet Trough, Bangladesh*" Geological Society of America Bulletin.

Kellerhals, R., Abrahams, A. and von Gaza, H., 1974: "*Possibilities for using sediment rating curves in the Canadian Sediment Survey Program*", University of Alberta report REH/74/1.

Kutzbach, J., 1987: "*The Changing Pulse of the Monsoon*" *Monsoons,* ed. J. Fein and P. Stephens, J. Wiley & sons Ltd, p. 247-268.

LaTouche, T. H. (ed), 1910: "*The Journals of Major James Rennell during his surveys of The Ganges and Brahmaputra Rivers 1764 to 1767*", The Asiatic Society, Calcutta, 248p.

Morgan J. and McIntire, 1959: "*Quaternary Geology of the Bengal Basin, East Pakistan and India*", Bull. Geological Society of America, 70, pp. 319-342.

Nordin and McLean, 1988: "*Application of Engelund-Hansen Equation in matehmatical models*", International Conference on River Sedimentation, Beijing, China, 1998.

NERP, 1995: "Surface Water resources of the Northeast region", Specialist Study, Northeast Regional Water Management Project, Canadian International Development Agency, June 1995 (Revised August 1995).

NERP, 1994: "*River Sedimentation and Morphology , Final Report*",Northeast Regional Water Management Project, Canadian International Development Agency, December 1994.

200

Shukla, J., 1987: "*Inter annual Variability of the Monsoon*", *Monsoons,* ed. J. Fein and P. Stephens, J. Wiley & sons Ltd, p. 247-268.

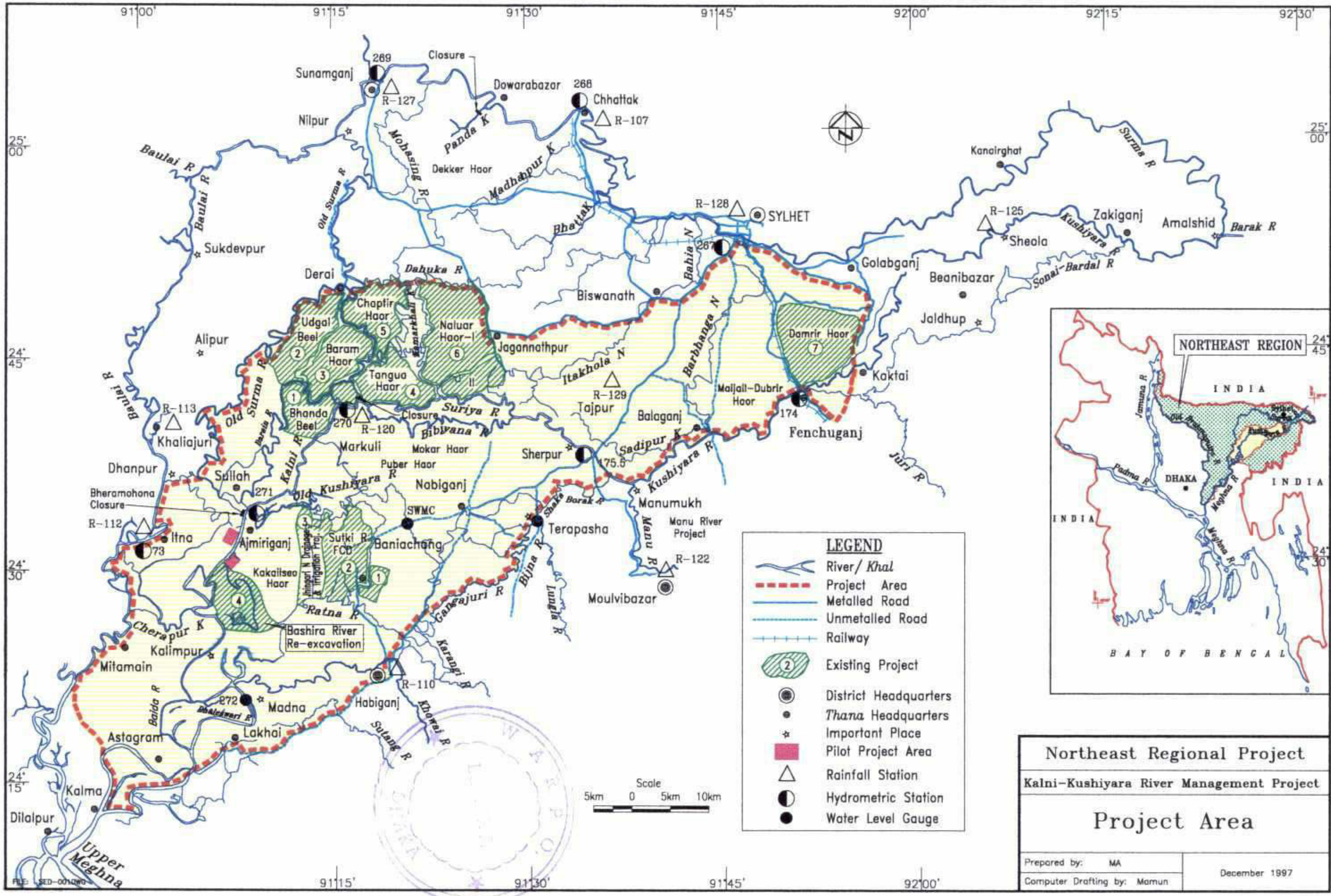
Smillie G. and Koch R., 1984: "*Bias in Hydrologic Prediction using Log-Log Regression Model*", American Geophysical Union Fall Meeting.

Thompson, M., Church, M., Joe, H., 1987, "*Statistical Modelling of Sediment Concentration*", Sediment Survey Section, Water Survey of Canada, Water Resources Branch, Ottawa, 59pp.

WSC, 1989: "*Suspended sediment sampling*", Training Manual #27, Water Survey of Canada, Water Resources Branch, Environment Canada, Ottawa, 123 pp.

FIGURES

Figure A.1



Northeast Regional Project

Kalni-Kushiyara River Management Project

Project Area

Prepared by: MA

Computer Drafting by: Mamun

December 1997

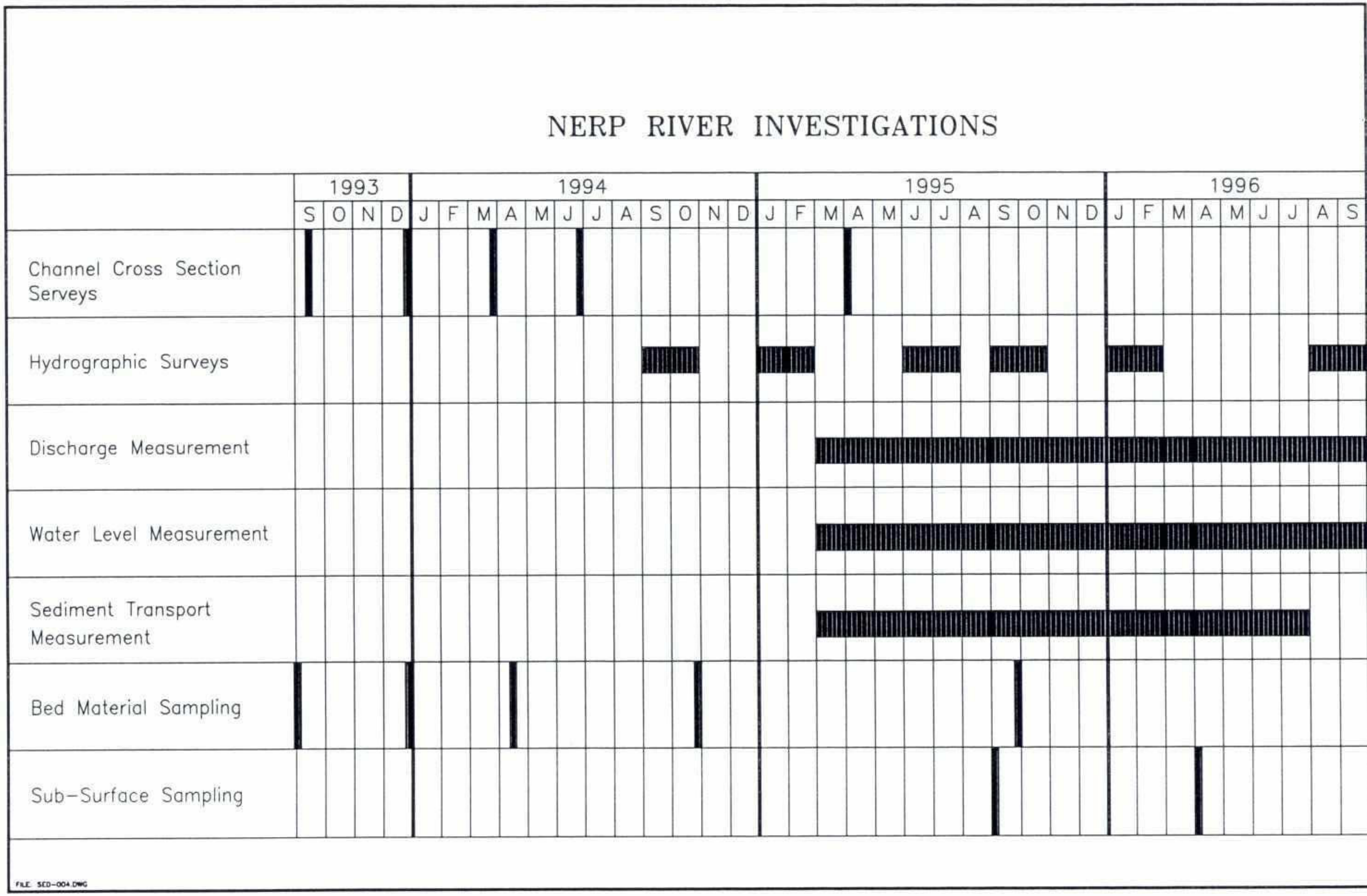

NERP RIVER INVESTIGATIONS
1993
1994
1995
1996
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
Channel Cross Section Serveys
Hydrographic Surveys
Discharge Measurement
Water Level Measurement
Sediment Transport Measurement
Bed Material Sampling
Sub-Surface Sampling
FILE SED-004.DWG

Figure A.3

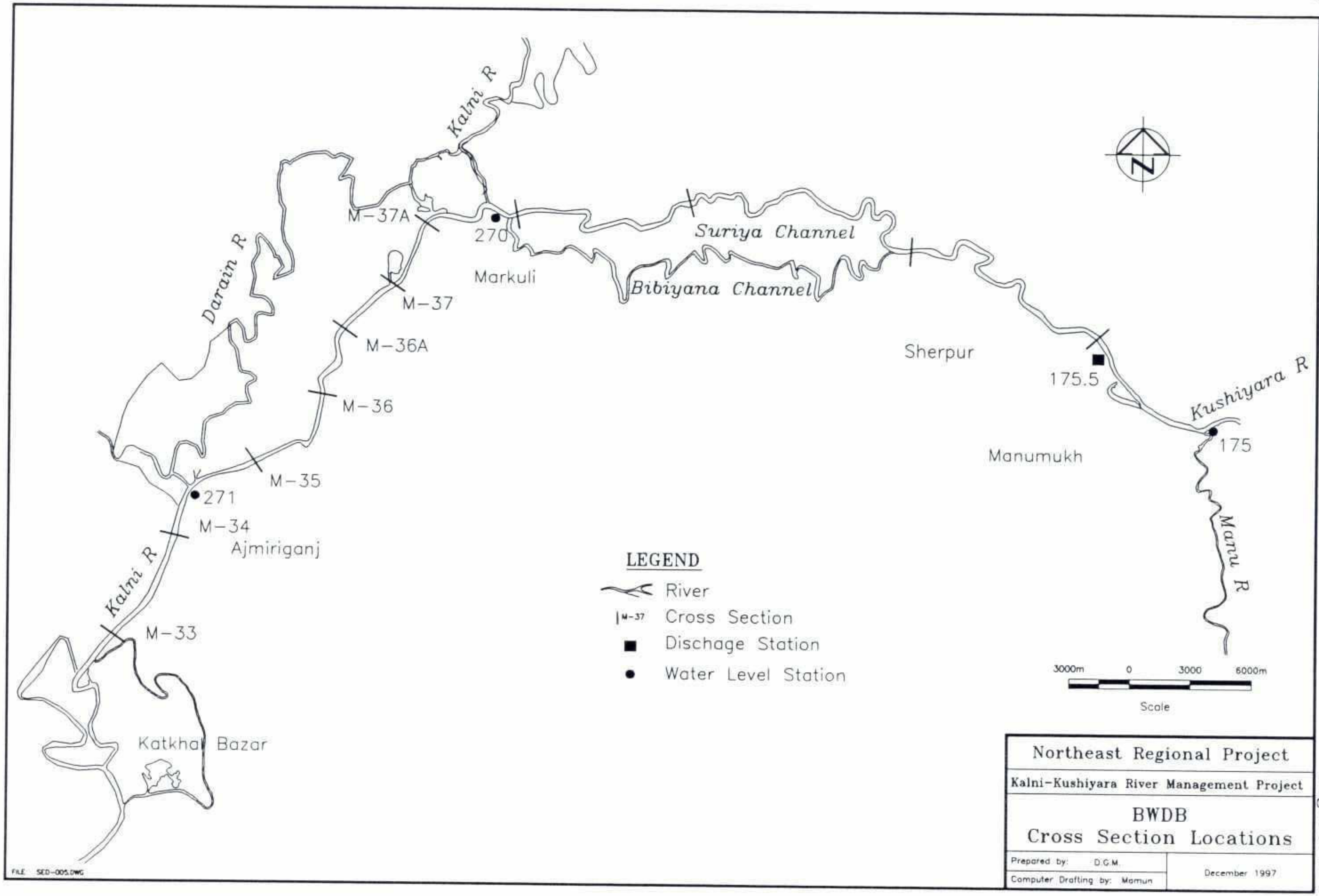
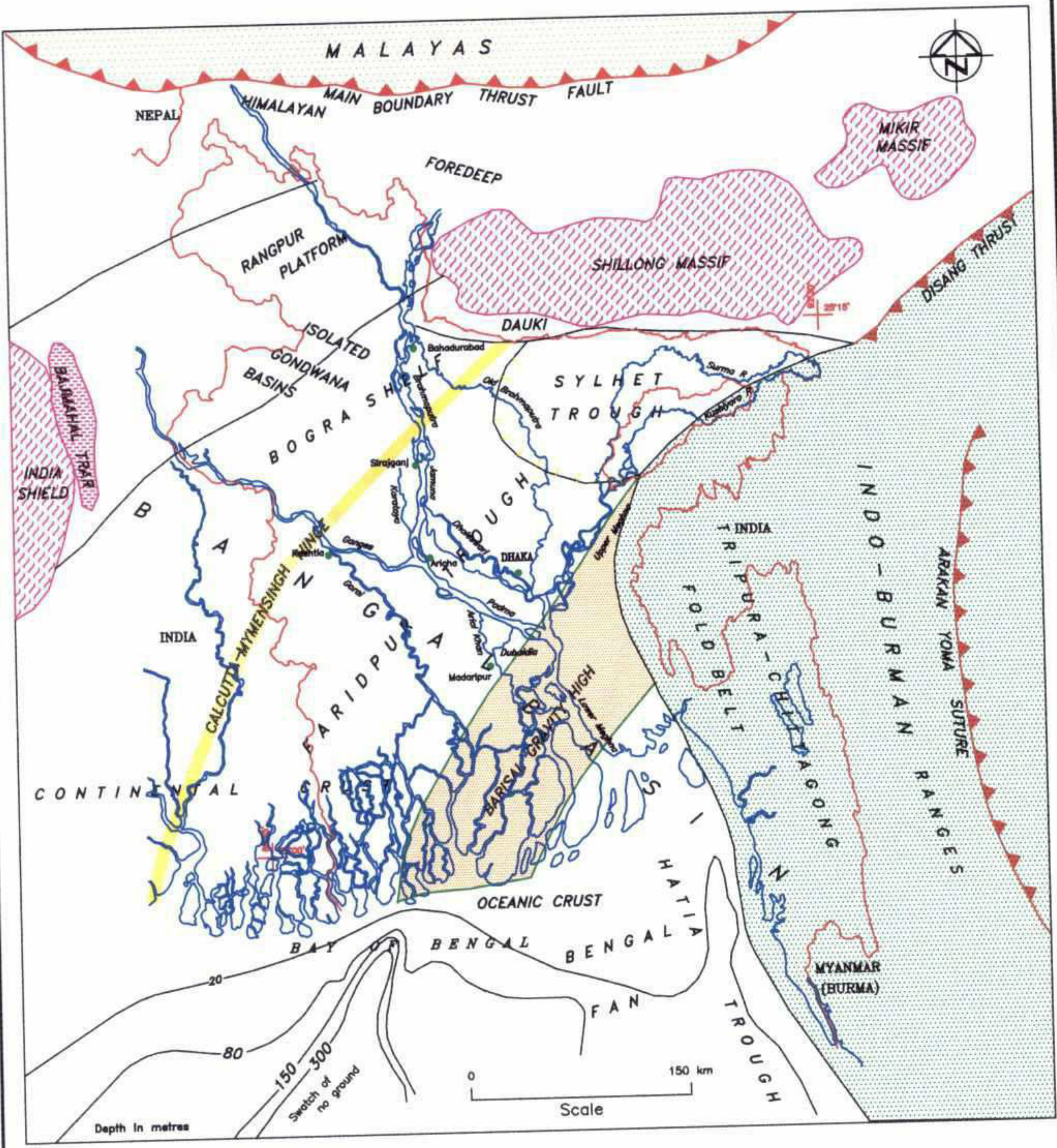

Kalni R
M-37A
270
Suriya Channel
Bibiyana Channel
Markuli
Darain R
M-37
M-36A
M-36
M-35
271
M-34
Ajmiriganj
Kalni R
M-33
Katkhal Bazar
Sherpur
175.5
Kushiyara R
175
Manumukh
Manu R
LEGEND
River
M-37 Cross Section
Dischage Station
Water Level Station
3000m 0 3000 6000m
Scale
Northeast Regional Project
Kalni-Kushiyara River Management Project
BWDB
Cross Section Locations
Prepared by: D.G.M.
Computer Drafting by: Mamun
December 1997
FILE SED-005.DWG

Figure A.4

Figure A.5

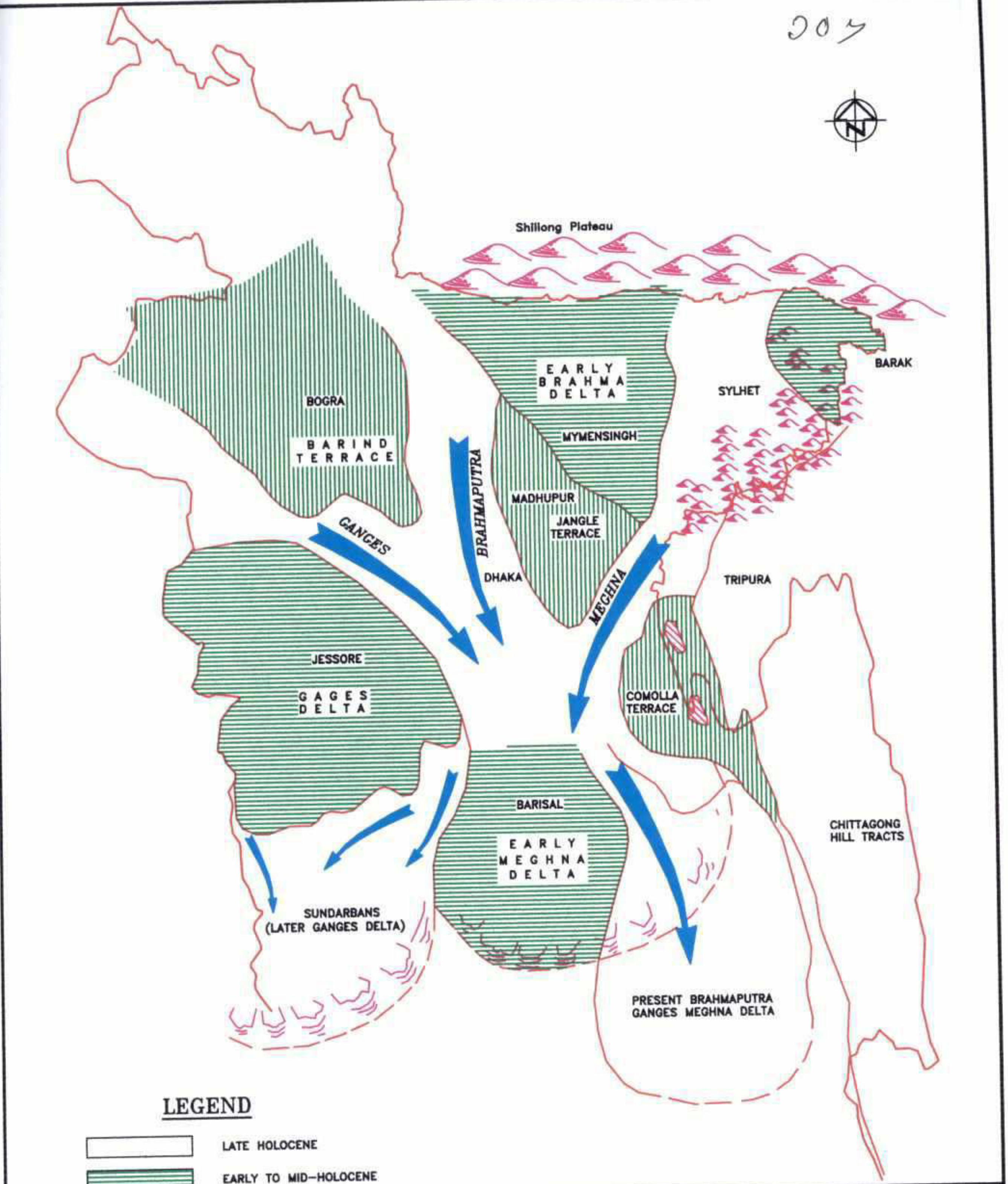


Note:-
Reproduced from Geological Survey of Bangladesh (1990)

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Tectonic Map of Bangladesh	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Jalal	

FILE: SED-006.DWG

Figure A.6



LEGEND

- LATE HOLOCENE
- EARLY TO MID-HOLOCENE
- LATE PLEISTOCENE
- EARLY PLEISTOCENE
- DIRECTION OF SEDIMENT TRANSPORT

Northeast Regional Project

Kalni-Kushiyara River Management Project

Quaternary Sedimentation in Bangladesh

Prepared by: D.G.M.	December 1997
Computer Drafting by: Jalal	

FILE: SED-007.DWG

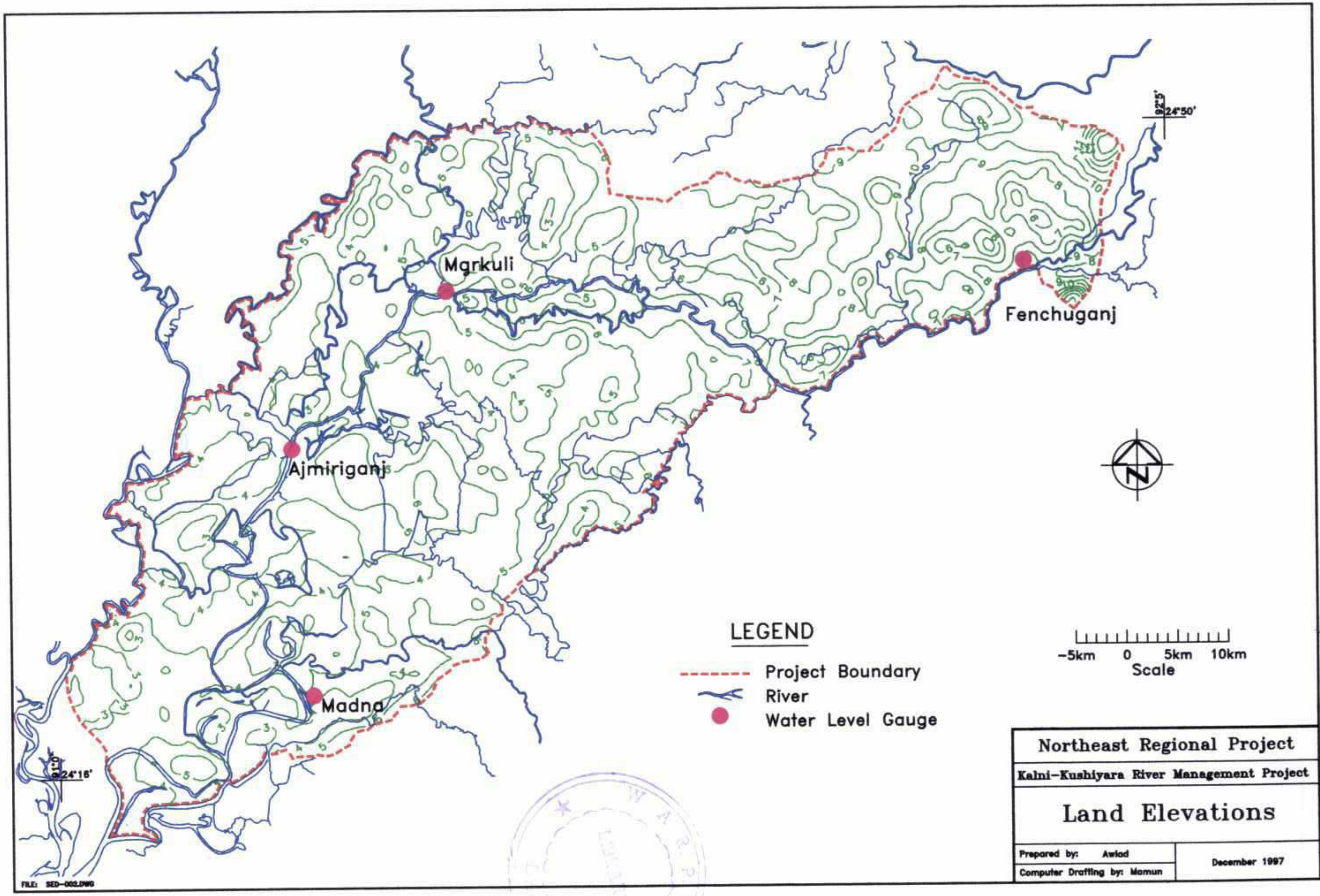
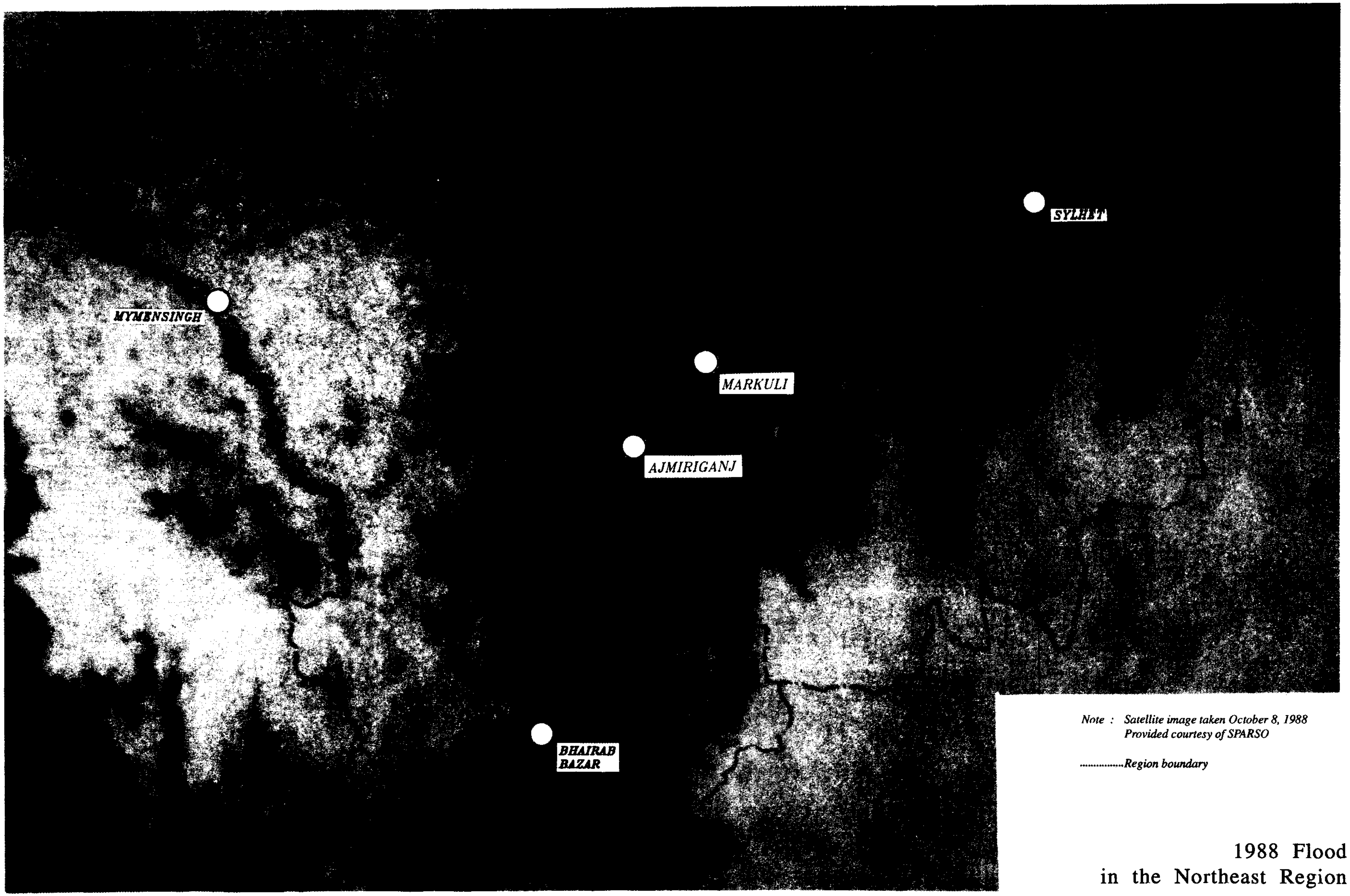

Fenchuganj
Markuli
Ajmiriganj
Madna
24°50'
24°16'
LEGEND
Project Boundary
River
Water Level Gauge
-5km 0 5km 10km
Scale
Northeast Regional Project
Kalni-Kushiyara River Management Project
Land Elevations
Prepared by: Awlad
Computer Drafting by: Mamun
December 1997
FILE: SED-002.DWG

Figure A.7

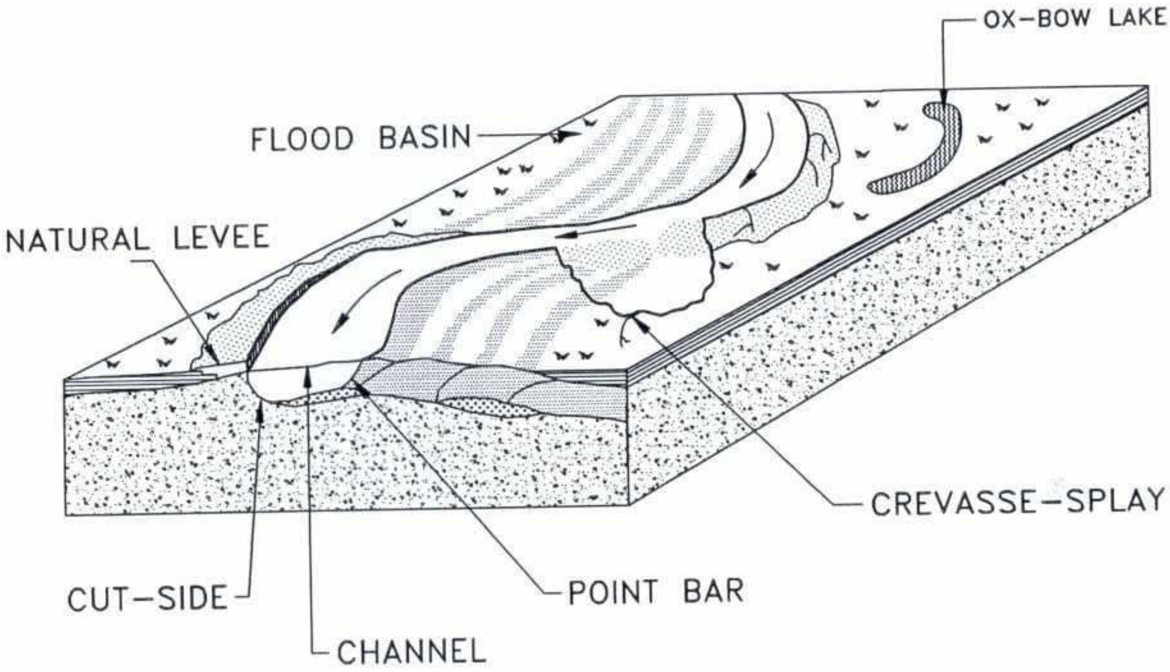


Note : Satellite image taken October 8, 1988
Provided courtesy of SPARSO

.................Region boundary

1988 Flood
in the Northeast Region

Figure A.9



Northeast Regional Project

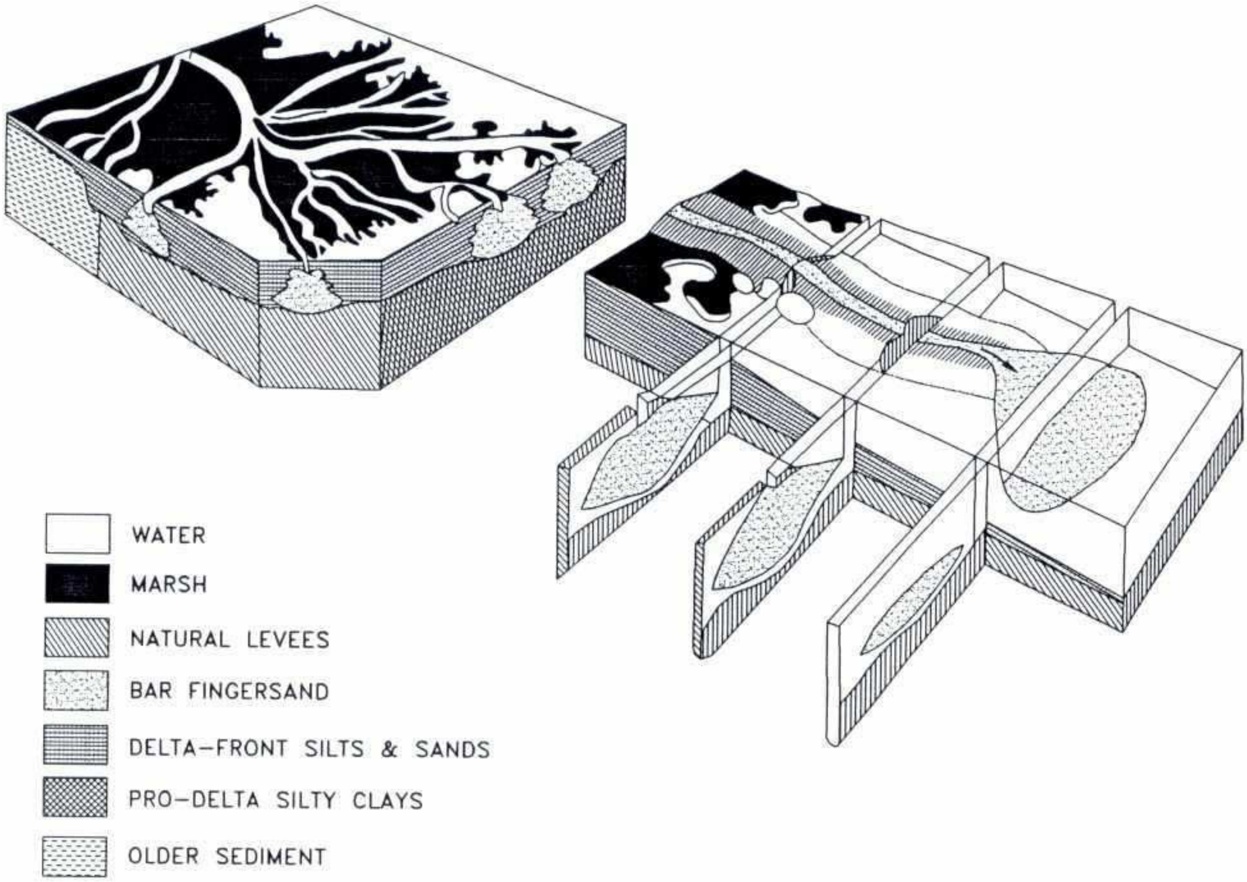
Kalni-Kushiyara River Management Project

Landforms on
Lowland Floodplains

Prepared by: D.G.M.	December 1997
Computer Drafting by: Jalal	

FILE: SED-008.DWG

220



Growth of a "Bird's Foot Delta", characterzed 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.

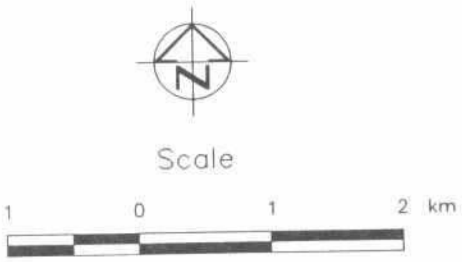
Northeast Regional Project

Kalni-Kushiyara River Management Project

Anastomosing Channel Pattern on Lowland River in the Central Basin

Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-081.DWG



Northeast Regional Project

Kalni-Kushiyara River Management Project

Overbank Sedimentation at Koyer Dhala

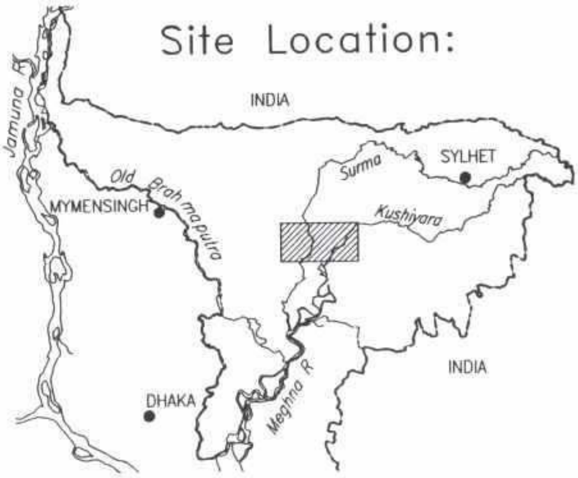
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

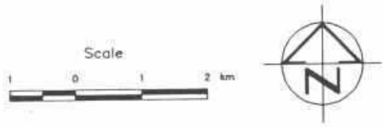
FILE: SED-A11.DWG

Baulai River

Kalni River

Site Location:

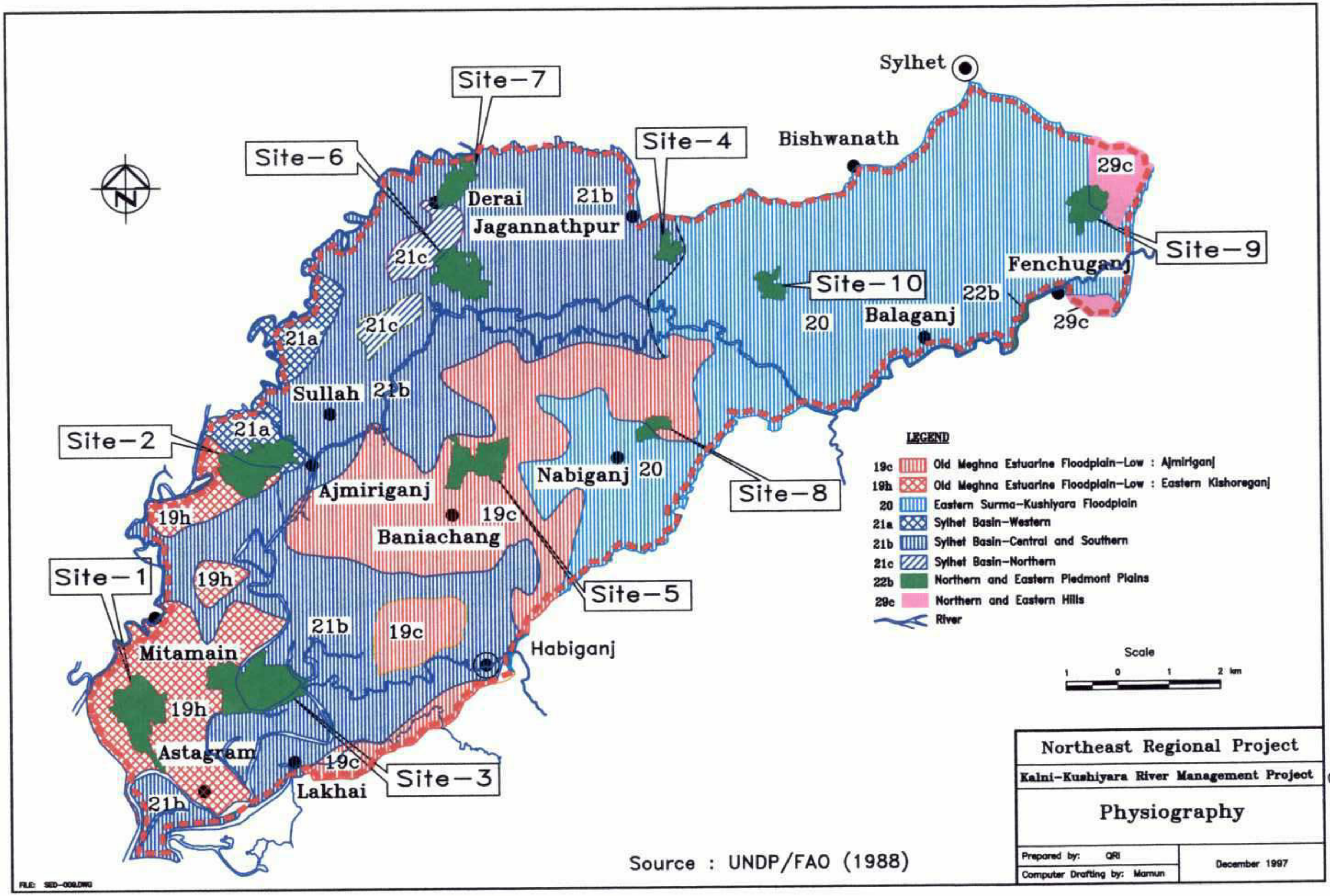




Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Channel Pattern Flood Basin Lowlands	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

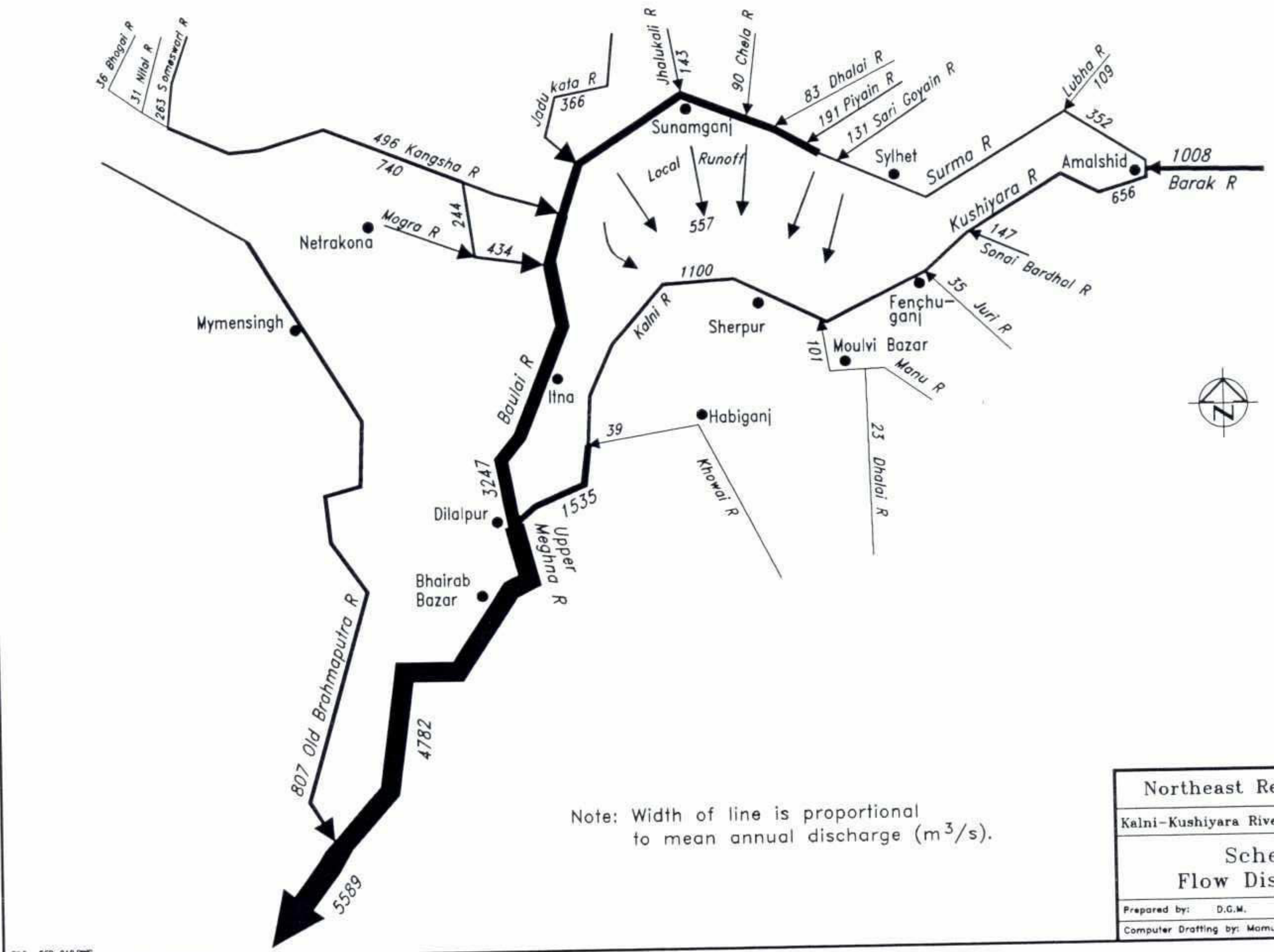
FILE: KALNI011.DWG

Figure A.13



Northeast Regional Project
Kalni-Kushiyara River Management Project
Physiography
Prepared by: QRI
Computer Drafting by: Mamun
December 1997
Source : UNDP/FAO (1988)
LEGEND
19c Old Meghna Estuarine Floodplain-Low : Ajmiriganj
19h Old Meghna Estuarine Floodplain-Low : Eastern Kishoreganj
20 Eastern Surma-Kushiyara Floodplain
21a Sylhet Basin-Western
21b Sylhet Basin-Central and Southern
21c Sylhet Basin-Northern
22b Northern and Eastern Piedmont Plains
29c Northern and Eastern Hills
River
Scale
1 0 1 2 km
Sylhet
Bishwanath
Balaganj
Fenchuganj
Derai
Jagannathpur
Sullah
Ajmiriganj
Baniachang
Nabiganj
Habiganj
Mitamain
Astagram
Lakhai
Site-1
Site-2
Site-3
Site-4
Site-5
Site-6
Site-7
Site-8
Site-9
Site-10
FILE: SED-009.DWG

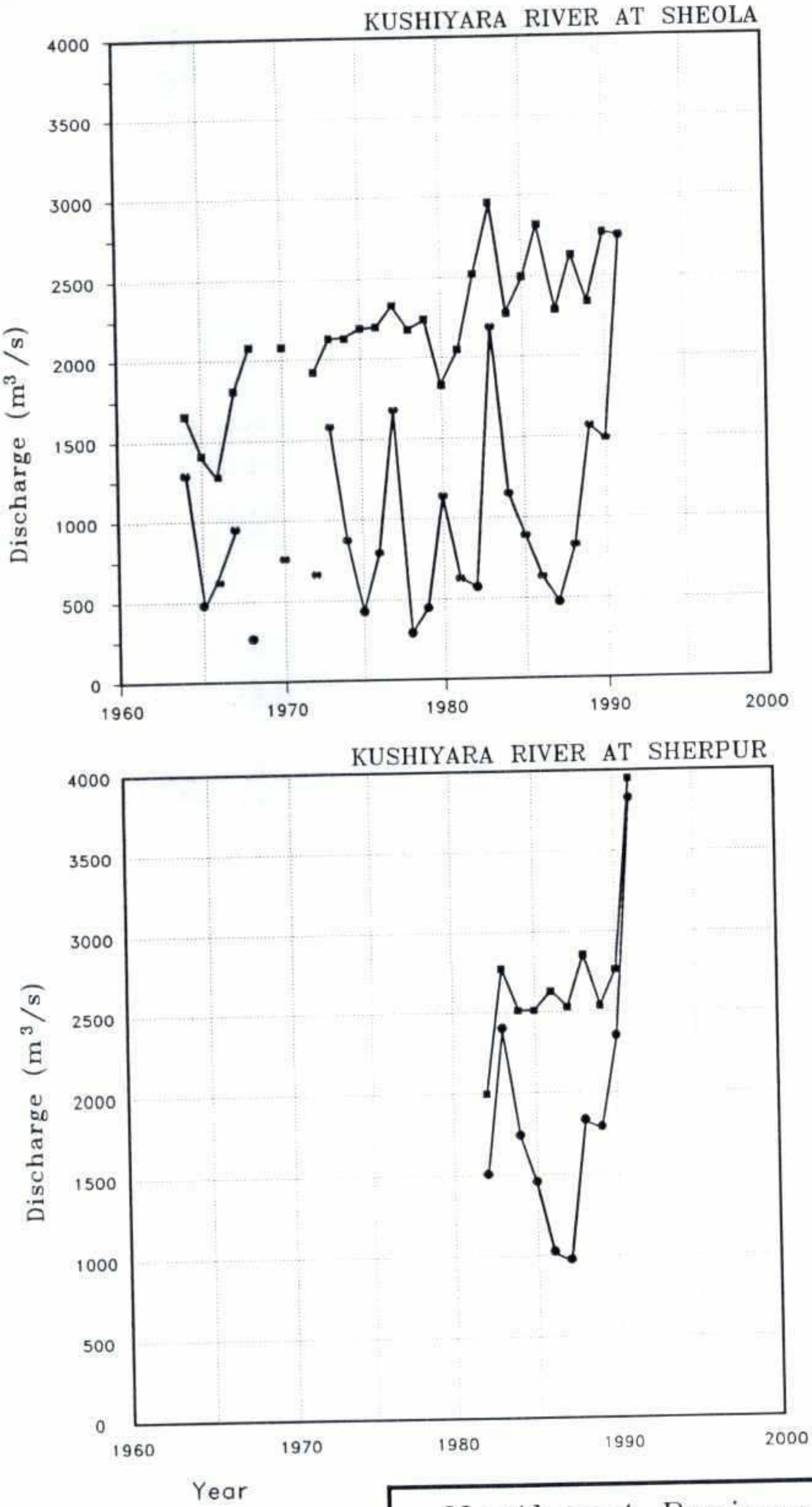
Figure A.14



Note: Width of line is proportional to mean annual discharge (m^3/s).

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Schematic Flow Distributtion	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

DD 8

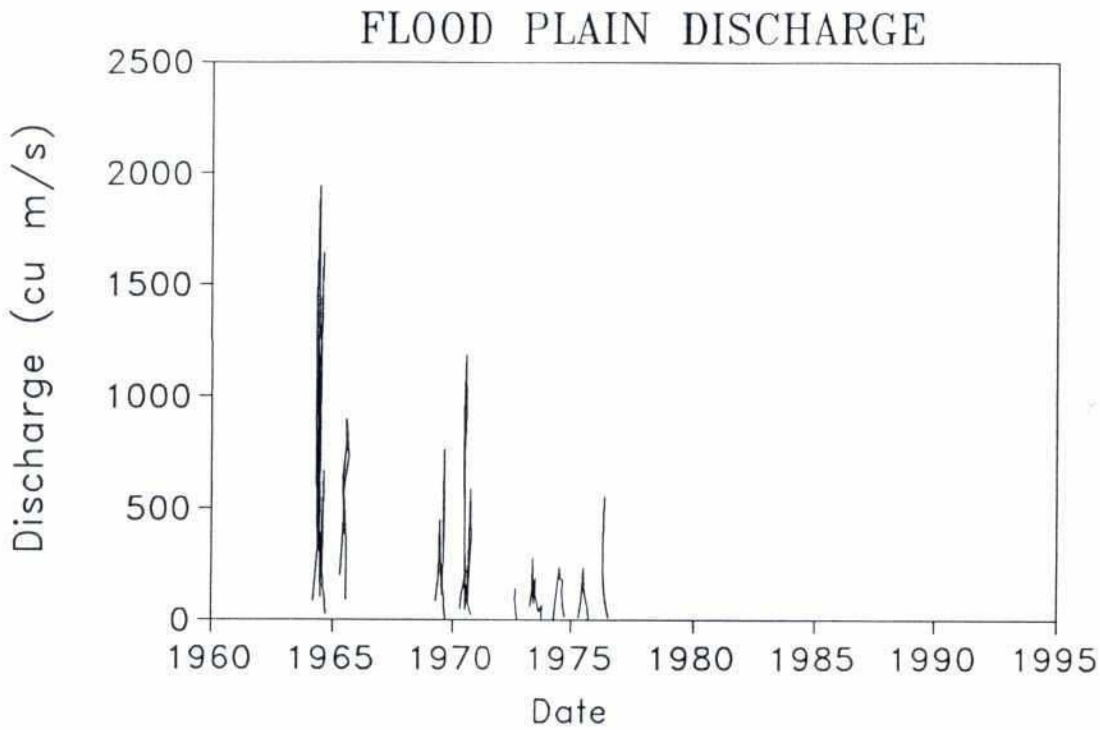


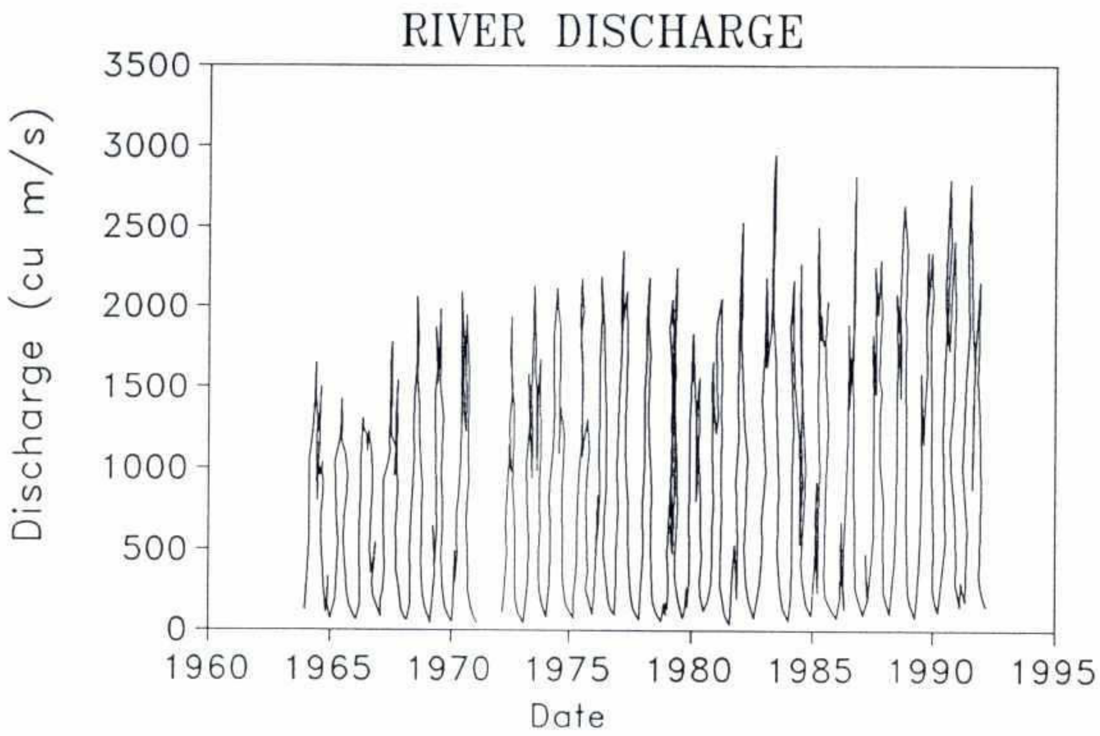
LEGEND
- ■ Annual Maximum
- ● Maximum in Pre-monsoon

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

Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Maximum Daily Discharges Kushiyara River	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-011.DWG



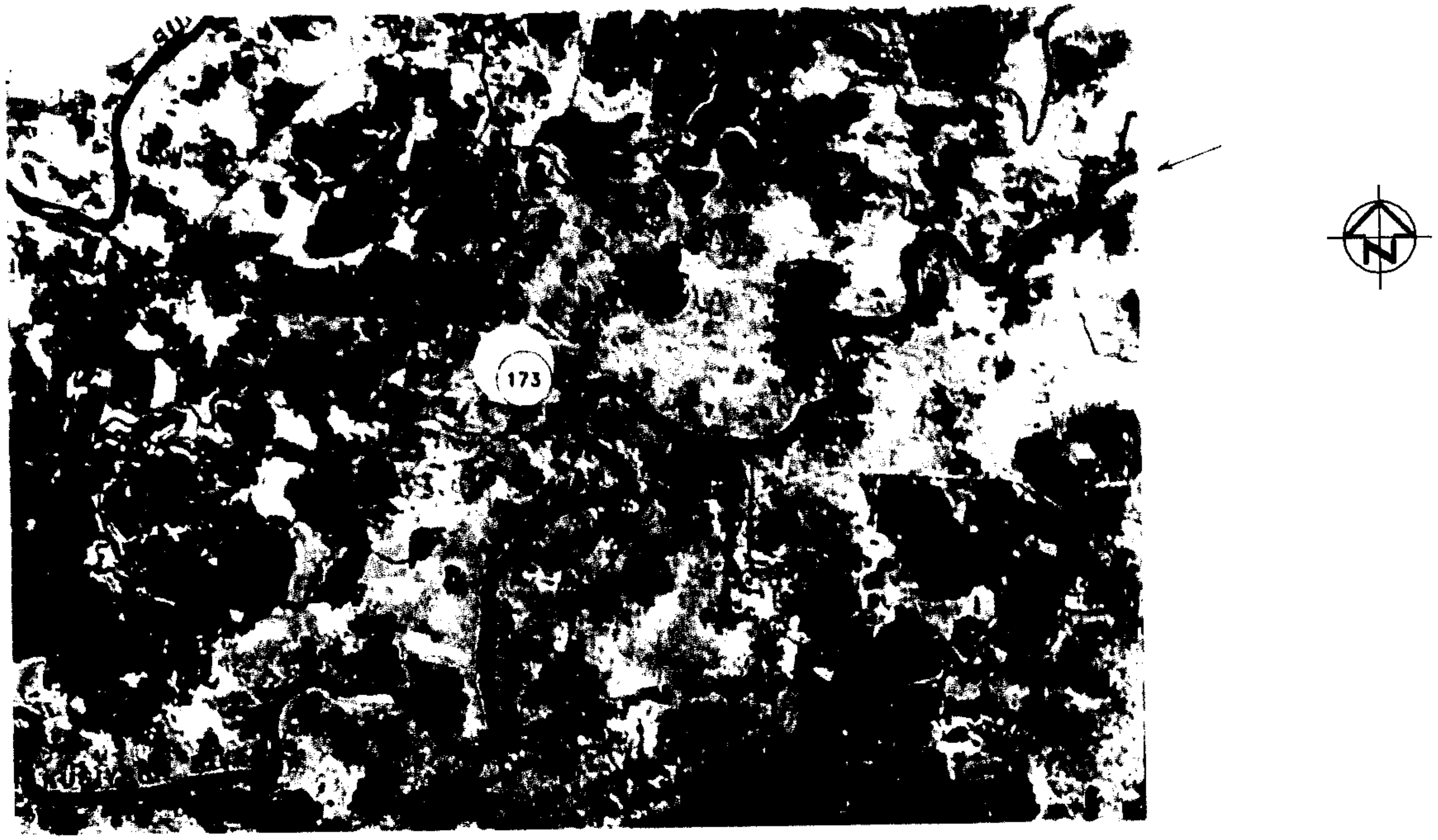


Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Changing Flood Plain and Channel Flows Kushiyara River at Sheola	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-061.DWG

Figure A.17

229



River Characteristics:

1. Gauge Number: 173

2. Location:
   Lat. 24 53'24"N
   Lon. 92 11'27"E

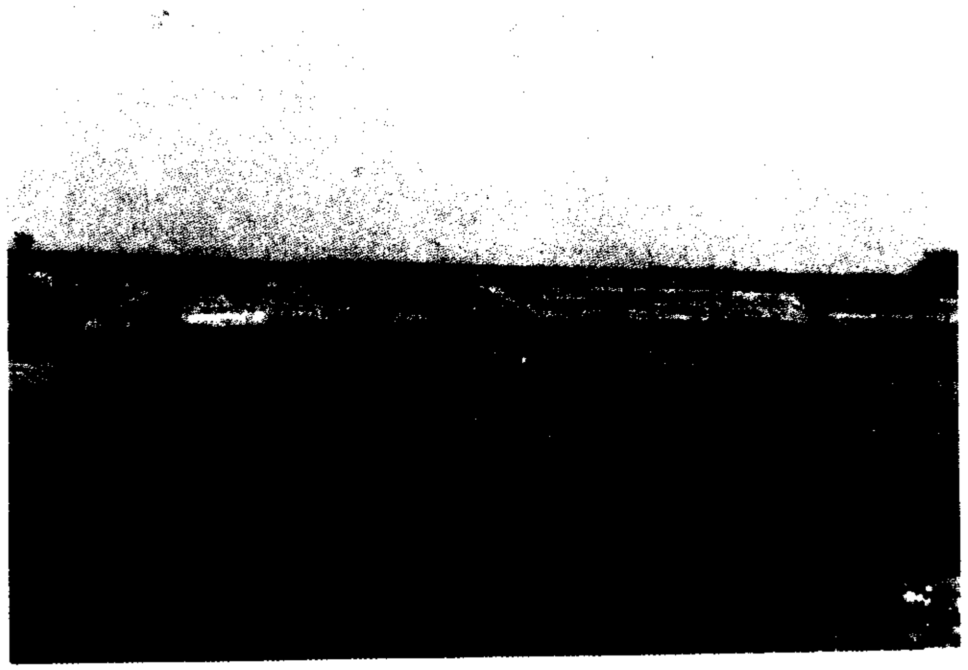
3. Available Data
   Water Level: 1964–93
   Discharge : 1964–70,1972–93
   Sediment: 1964–70,1972,1974–93

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.

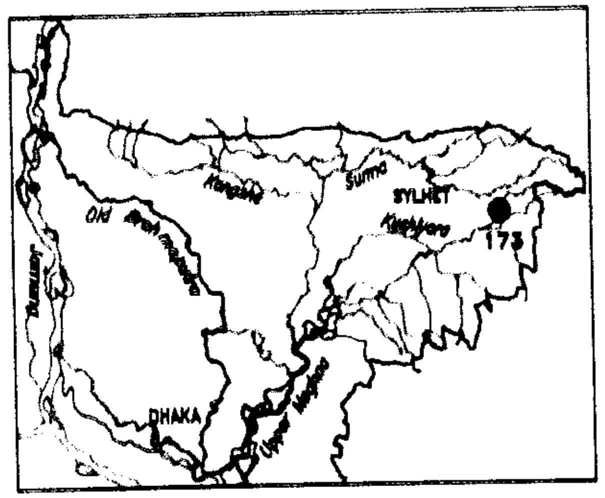
5. Channel Pattern:
   Channel: Single, irregular low sinuosity bends.
   Islands: None.
   Bars: Poorly developed point bars
   Sinuosity: 1.42

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.



View upstream along right bank

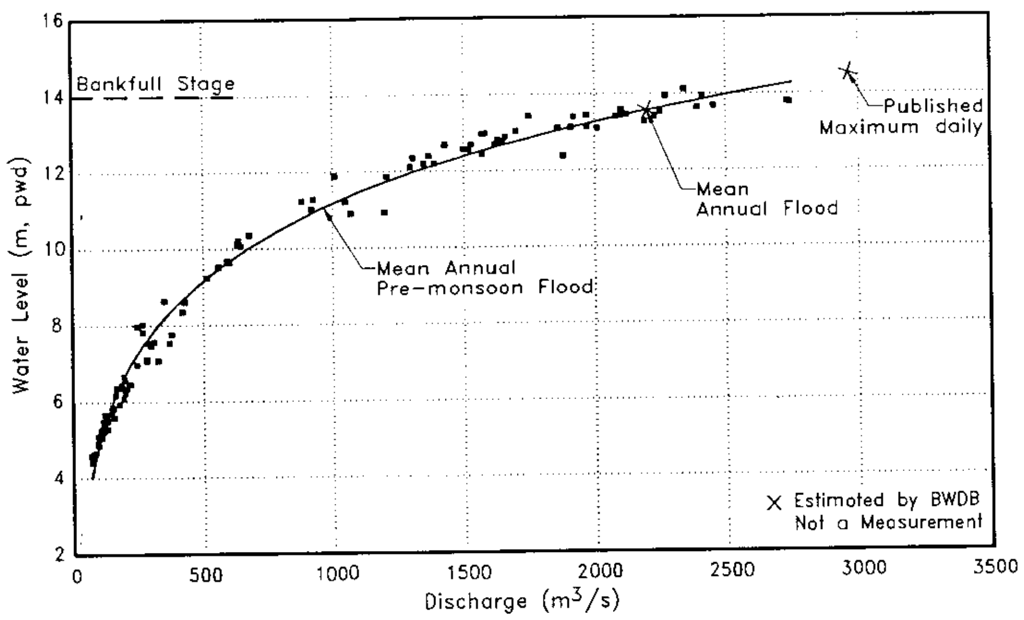


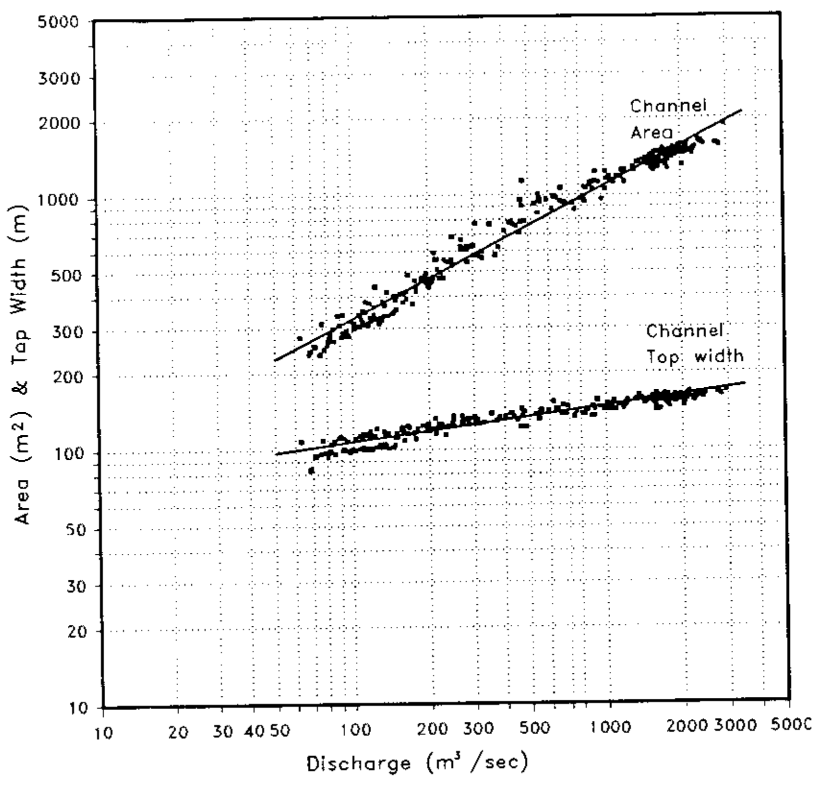
Site Location:

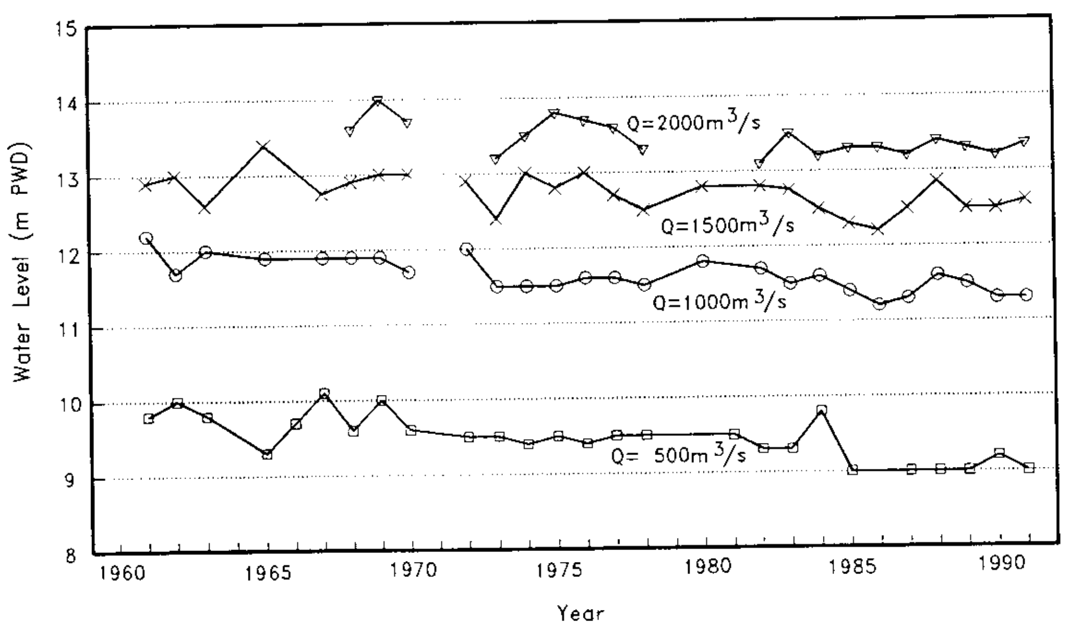
Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Kushiyara River at Sheola	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

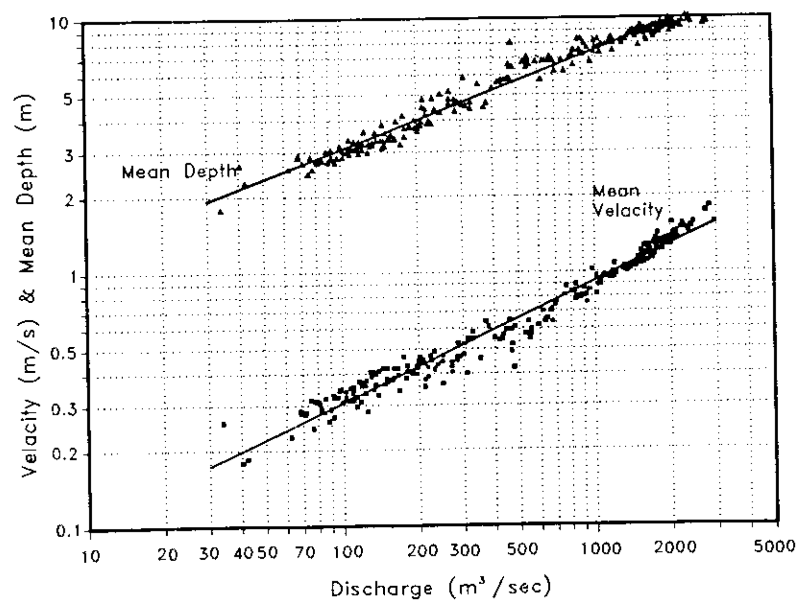
FILE: SED-068.DWG

Figure A.18









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)

Northeast Regional Project

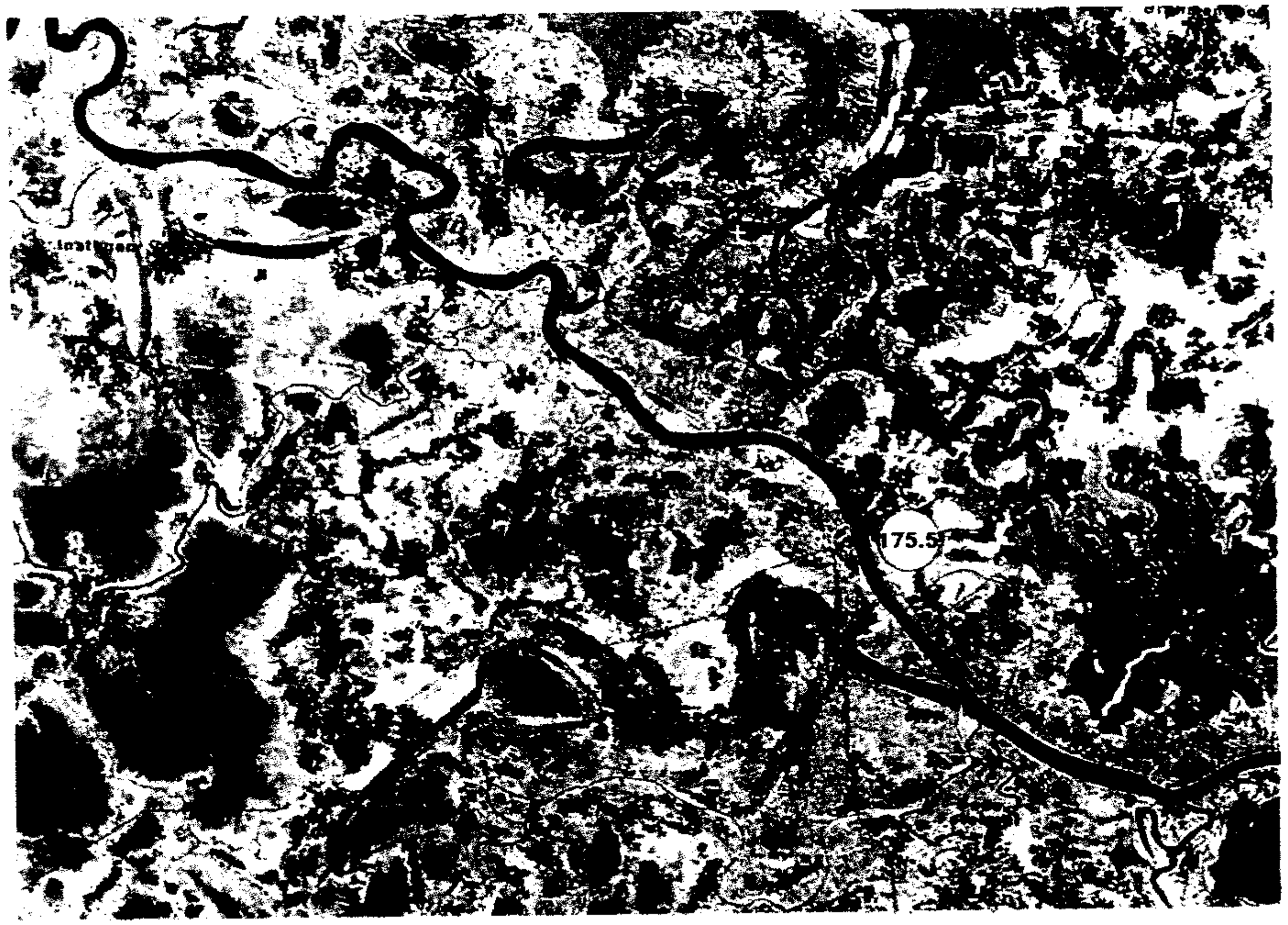
Kalni-Kushiyara River Management Project

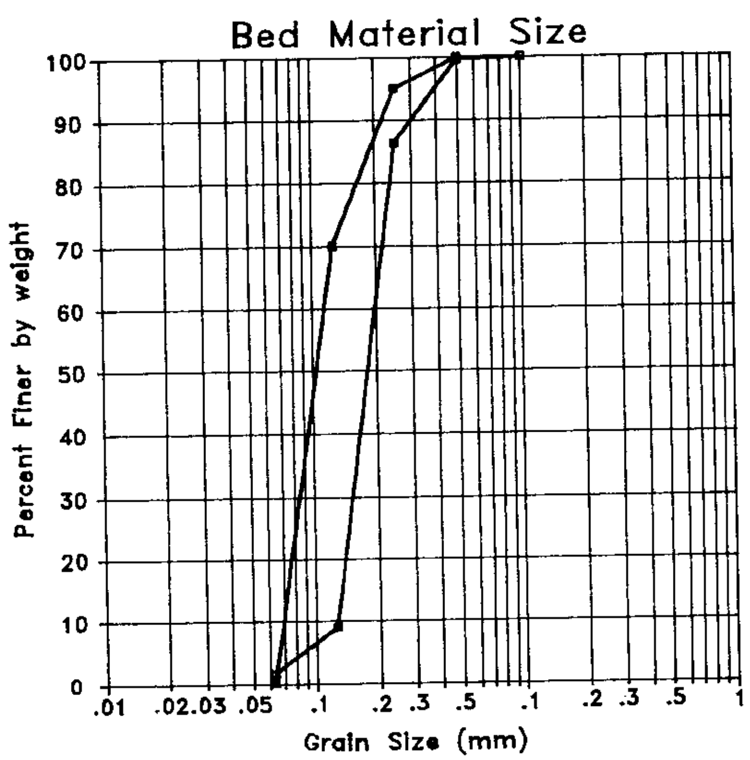
Kushiyara River at Sheola

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: BD-173.DWG

১১৯





River Characteristics

1. Gauge Number: 175.5
2. Location: Km 177.4
   - Lat. 24°37'39" N
   - Long. 91°40'58" E
3. Available Data
   - Water Level: 1982–1995
   - Discharge: 1982–1995
4. Physical Setting
   - Physiographic Unit: Surma–Kushiyara Floodplain
   - Features: Unconfined alluvial channel incised into lowland floodplain.
5. Channel Pattern
   - Channel: Single, irregular, sinuous channel with ox–bows.
   - Bars: Minor point bar development on convex sides of bends.
   - Sinuosity: 1.25
6. Sedimentology
   - Channel: Mainly very fine sand. Bed is covered with dunes (upto 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 artificial loop cuts. A major avulsion occurred downstream of Shepur in the 1960's when the river abandoned the Bibyana channel and occupied the Surlya channel. The river has been widening and enlarging in response to increased flood flows in recent years.

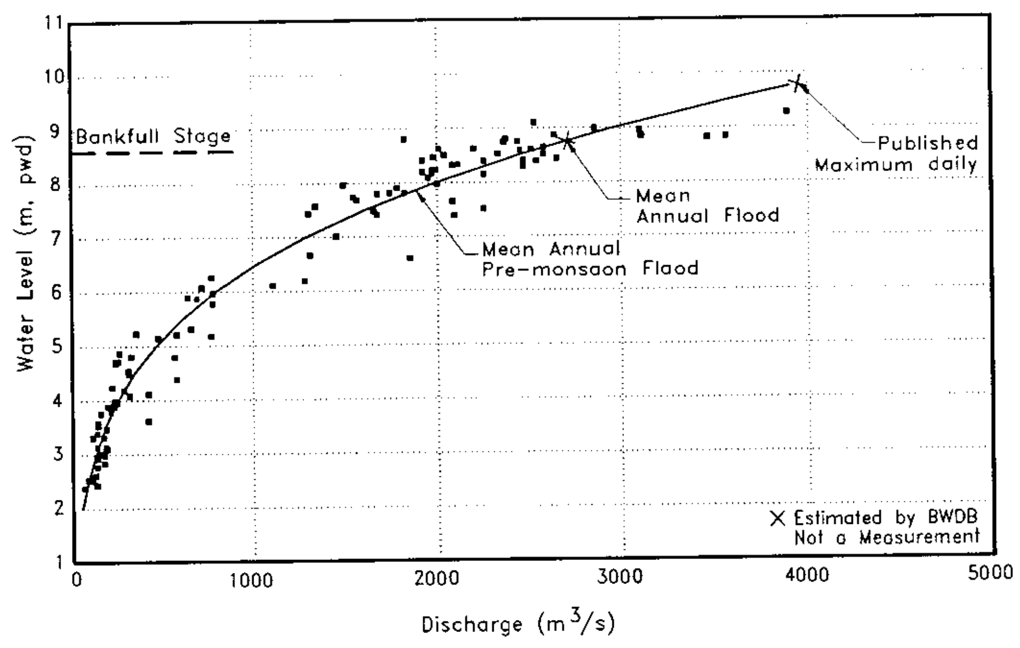
Northeast Regional Project

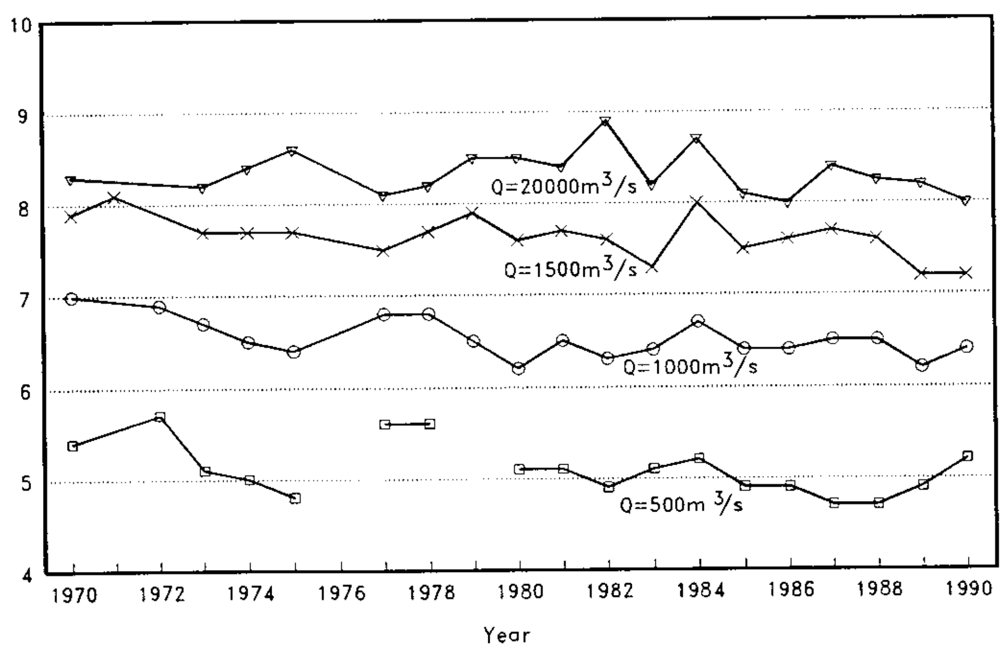
Kalni–Kushiyara River Management Project

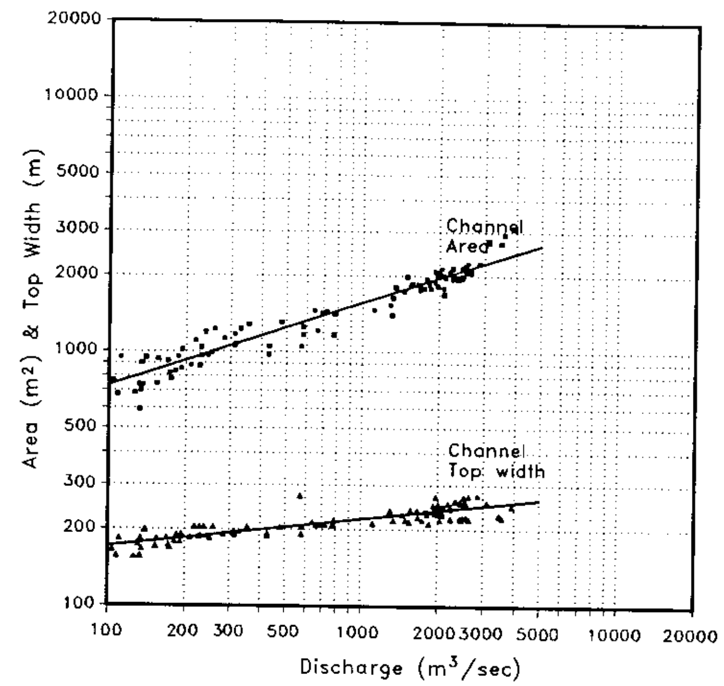
Kushiyara River at Sherpur

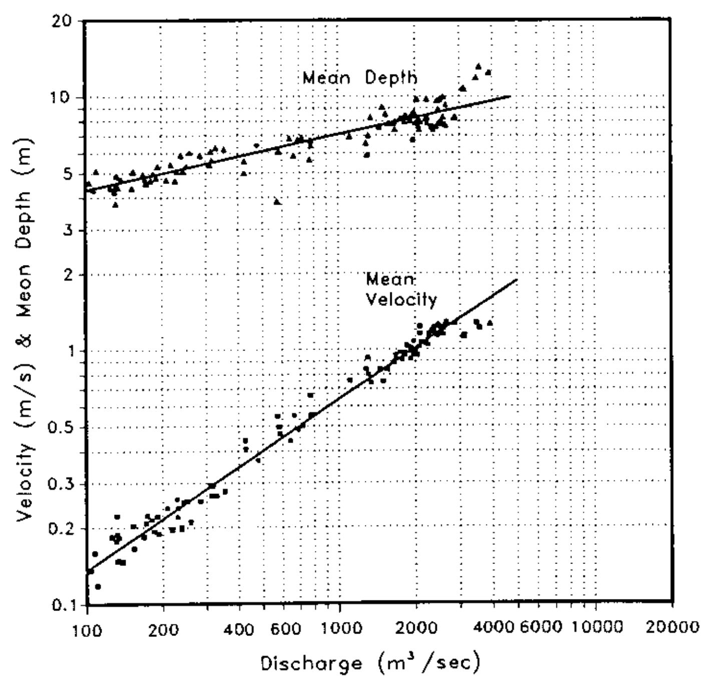
Prepared by: D.G.M./Tarek	December 1997
Computer Drafting by: Mamun	

FILE: KK-SHE.DWG









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 (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

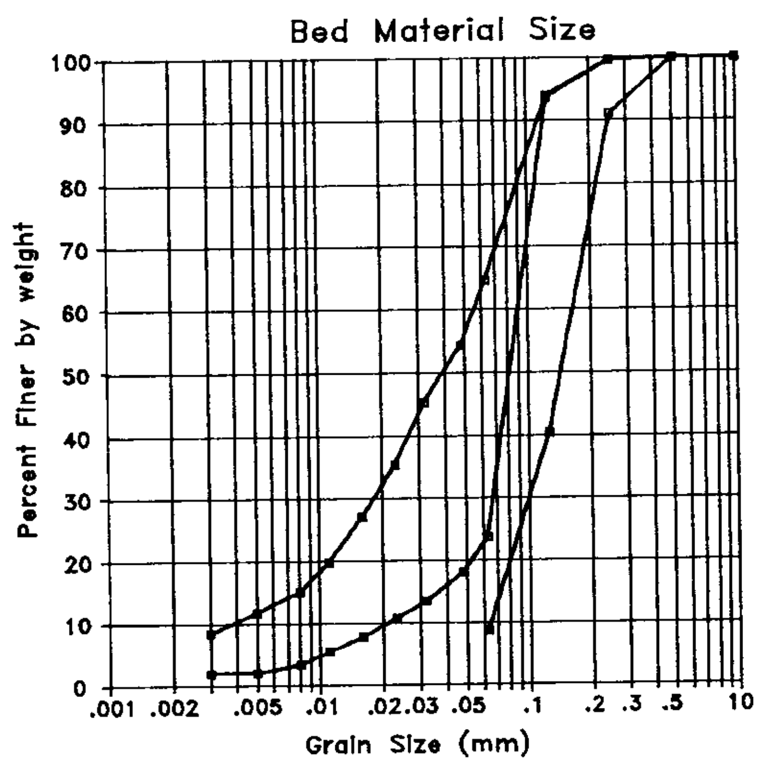
Northeast Regional Project

Kalni-Kushiyara River Management Project

Kushiyara River at Sherpur

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-070.DWG



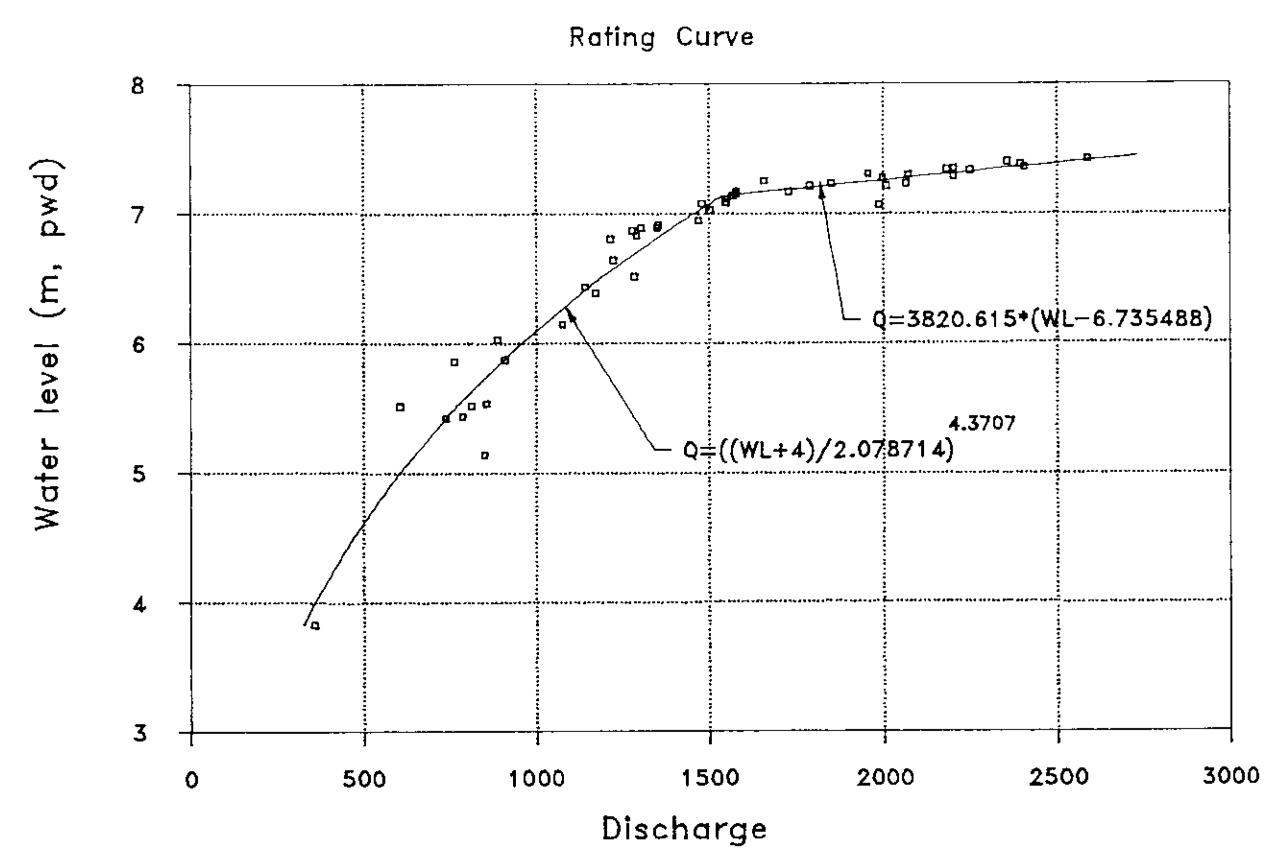
River Characteristics

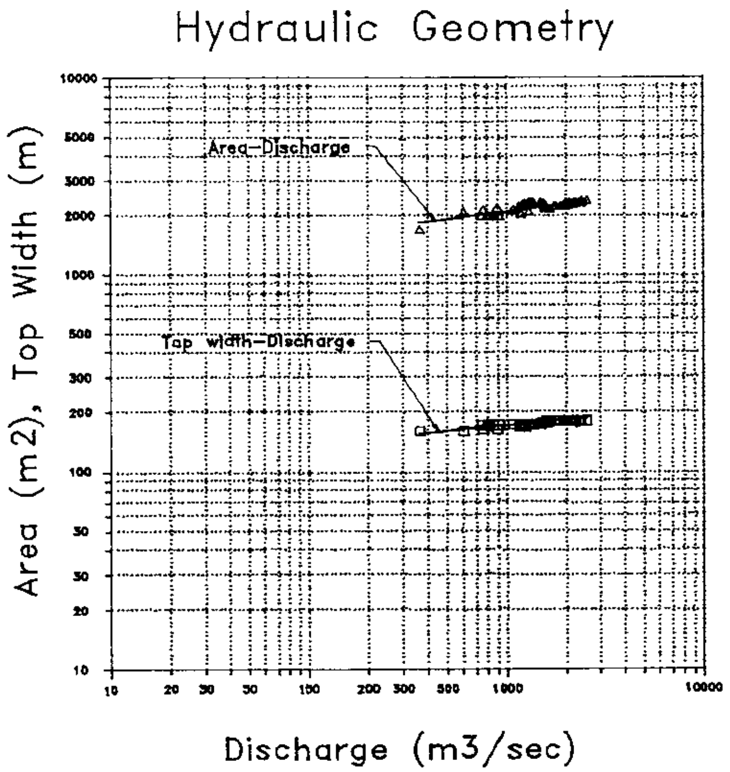
1. Gauge Number: 270
2. Location: Km 133.4
   - Lat. 24°41'41" N
   - Long. 91°22'55" E
3. Available Data
   - Water Level: 1964–1996
4. Physical Setting
   - Physiographic Unit: Surma–Kushiyara Floodplain
   - Features: Unconfined alluvial floodplain slopes away into low–lying floodbasins and haor areas. The river is bounded by the the former Bibiyana channel to the south and the old Kalni River channel to the north.
5. Channel Pattern
   - Channel: Single, irregularly meandering channel, partially straightened by past loop cuts
   - Bars: Minor point bar development on convex sides of bends. Mid–channel shoals in straight reaches between bends.
   - Sinuosity: 1.35
6. Sedimentology
   - Channel: Mainly very fine sand. Bed is covered with dunes during the monsoon and pre–monsoon season. Downstream of Markuli the river flows through fine silt and silty clay floodplain sediments.
   - Banks: Mainly silt and silty clay
7. Pattern of Instability: The river made a major shift from the Bibyana channel into the Suriya channel, which initiated a period of channel widening and bank erosion upstream of Markuli. Channel instability has continued to occur as a result of progressive meander migration, with ongoing erosion along the outer (concave) river banks. This erosion is currently threatening Markuli town on the left bank. Channel breaches are common in the pre–monsoon season at the outer (concave) banks of meander bends. The breaches erode sediment from the banks and deposit the materials as splays in near by beels and haors.

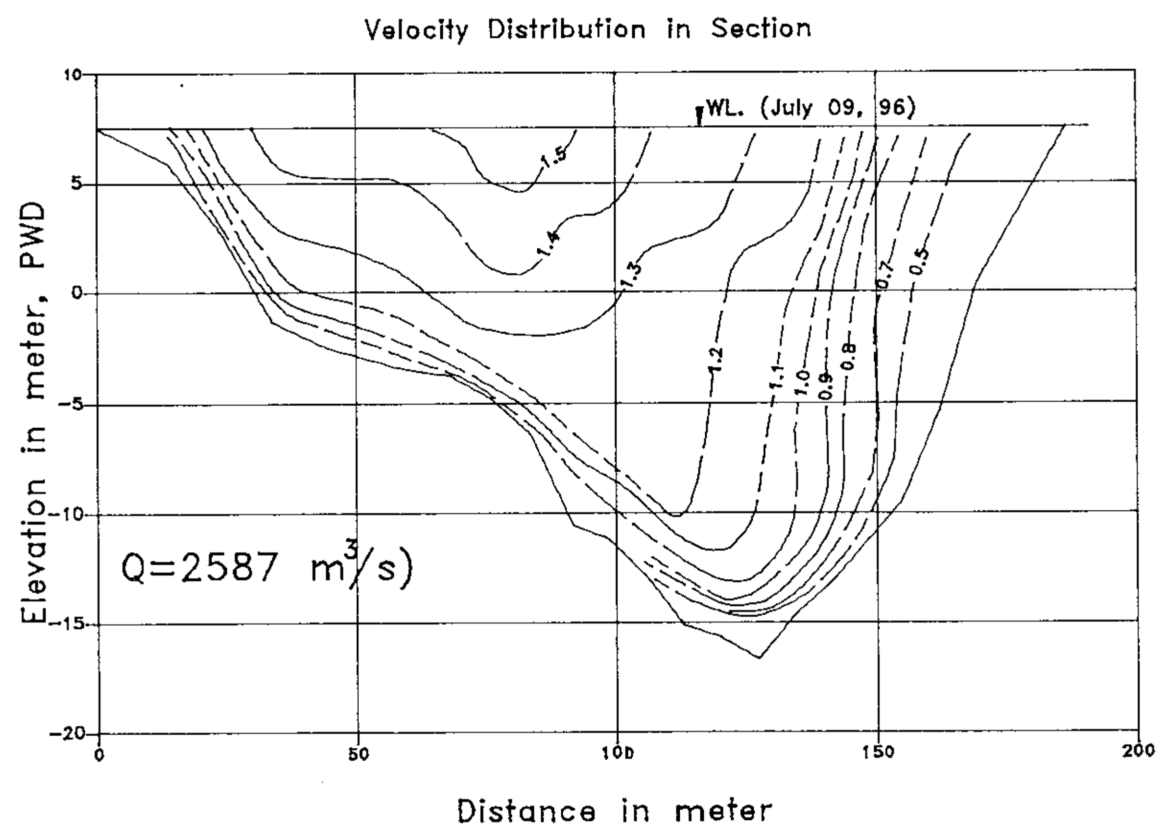
Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Kalni River at Markuli	
Prepared by: DGM/Tarek; Computer Drafting by: Mamun	December 1997

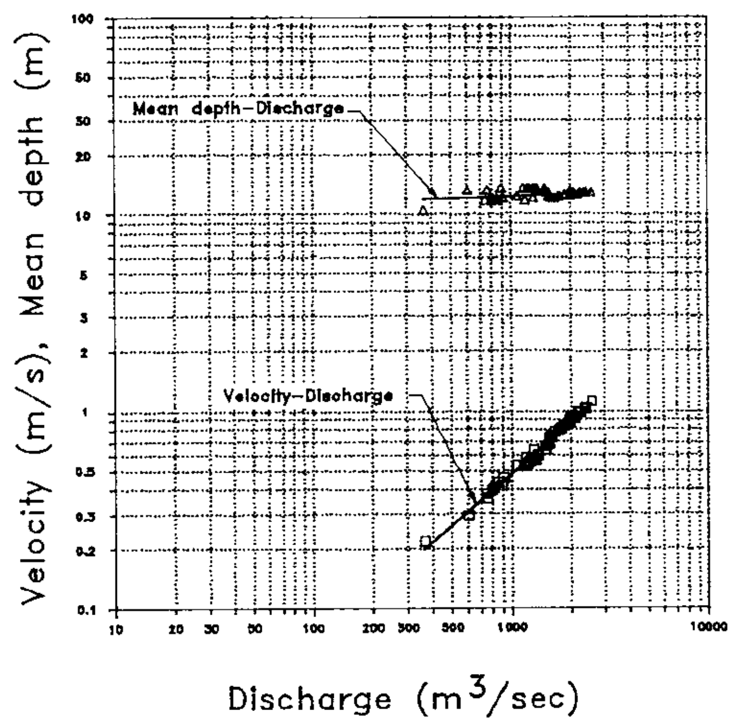
FILE: SED–07L.DWG

Figure A.22









COMMENTS

1. Temporary station 1995-96
   Opereted by SWMC 1988-92 & NERP1995

2. Hydraulic Geometry Relations
   $A = 832.3\,Q^{0.132}$
   $W = 90.5\,Q^{0.091}$
   $d = 9.20\,Q^{0.041}$
   $v = 0.0012\,Q^{0.868}$

Condition	Q	A	W	d	v
Avg. monthly March	226	1704	149	11.5	0.13
Avg. monthly April	663	1965	164	12.0	0.34
Avg. monthly May	1438	2177	176	12.4	0.66
Pre-monsoon 2 Year	1630	2213	178	12.4	0.74
Pre-monsoon 5 Year	2330	2320	184	12.6	1.00
Pre-monsoon 10 Year	2700	2366	186	12.7	1.14
Annual 2 Year					
Annul 5 Year					
Annual 10 Year					
Bankfull (existing)	1965	2268	181	12.5	0.87
April 6/96	1350	2158	175	12.3	0.63

Q= Discharge (m^3/s)
A= Area (m^2)
W= Top Width (m)
d= Mean Depth (m)
v= Velocity (m/s)

Northeast Regional Project

Kalni-Kushiyara River Management Project

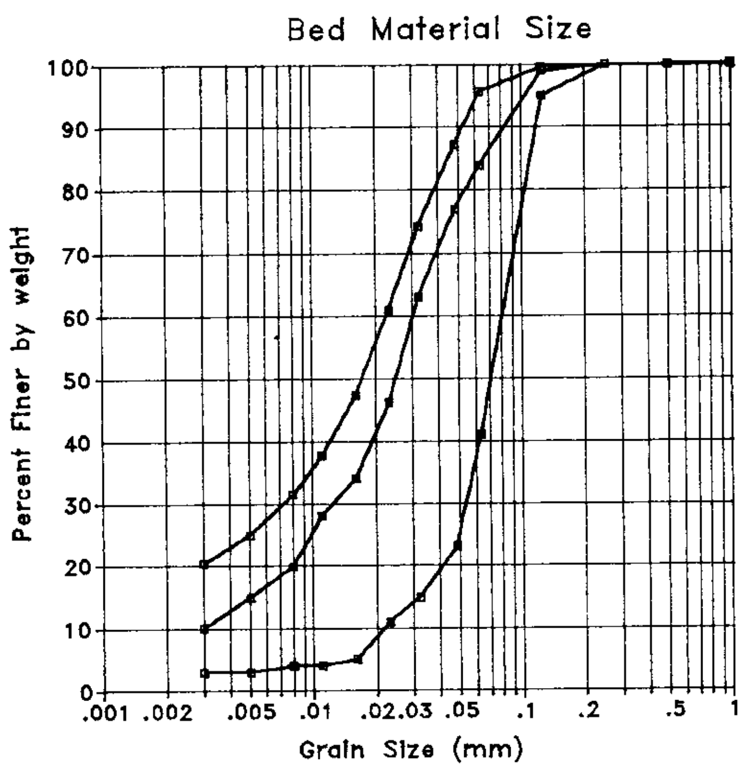
Kalni River
at Markuli

Prepared by: Tarek
Computer Drafting by: Mamun

December 1997

FILE: SED-038.DWG

326



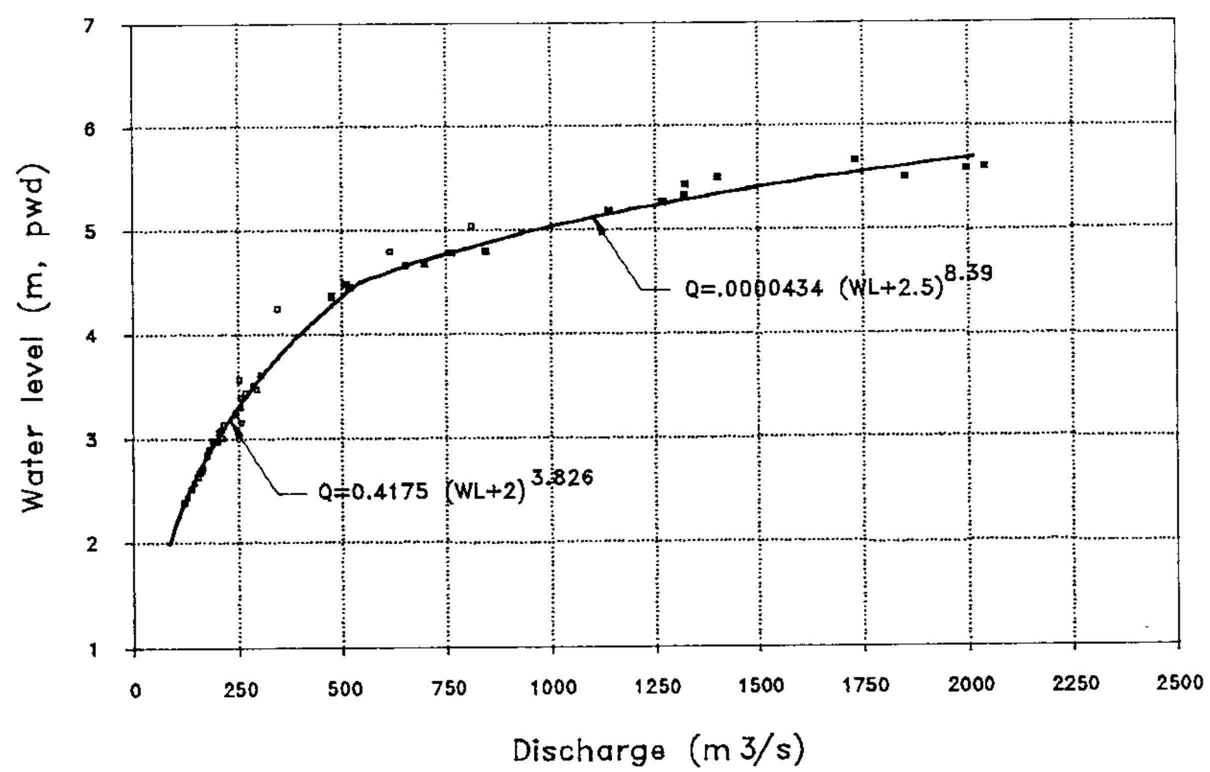
River Characteristics

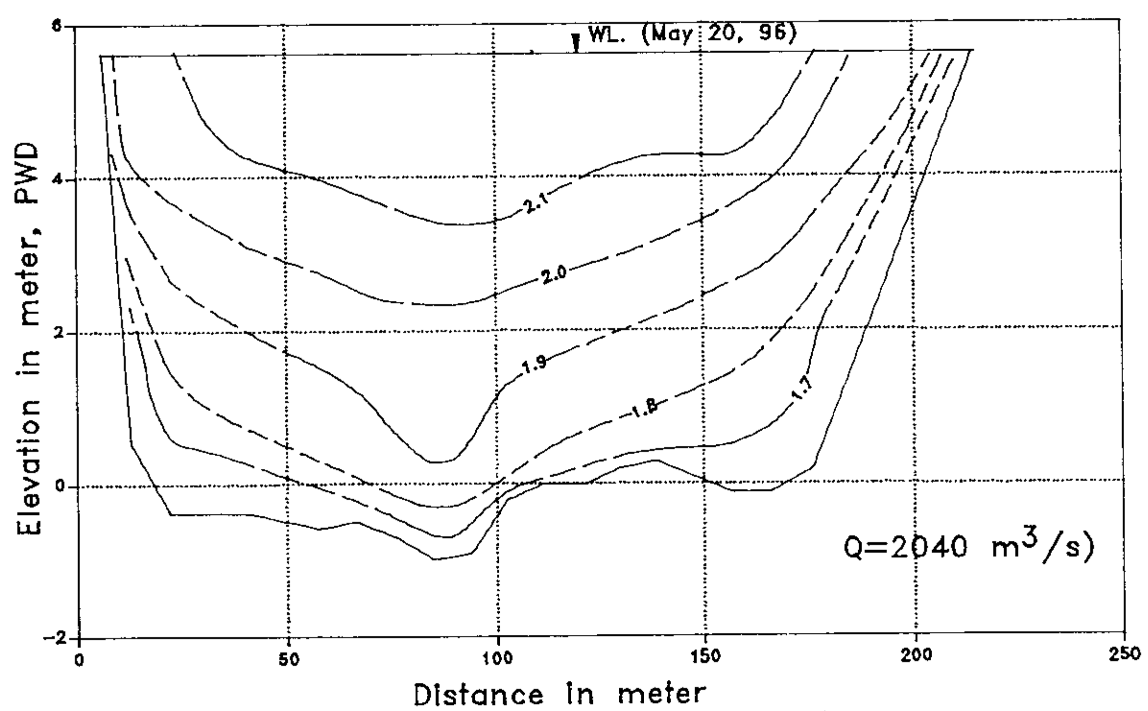
1. Gauge Number: 271
2. Location: Km 106.5
   - Lat. 24°32'31" N
   - Long. 91°13'40" E
3. Available Data
   - Water Level: 1964–1996
4. Physical Setting
   - Physiographic Unit: Sylhet Basin Lowlands
   - Features: Unconfined alluvial floodplain sloping into low-lying floodbasins and haors areas.
5. Channel Pattern
   - Channel: Single, sinuous channel, occasionally split by distributaries
   - Bars: Mid–channel shoals
   - Sinuosity: 1.13
6. Sedimentology
   - Channel: Highly variable mixture of very fine sand, silty sand and sandy silt.
   - Banks: Mainly silt and silty clay
7. Pattern of Instability: Considerable aggradation has occurred at Ajmiriganj over the last 30 years. The channel has remained stable laterally.

Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Kalni River at Ajmiriganj	
Prepared by: DGM/Tarek Computer Drafting by: Mamun	December 1997

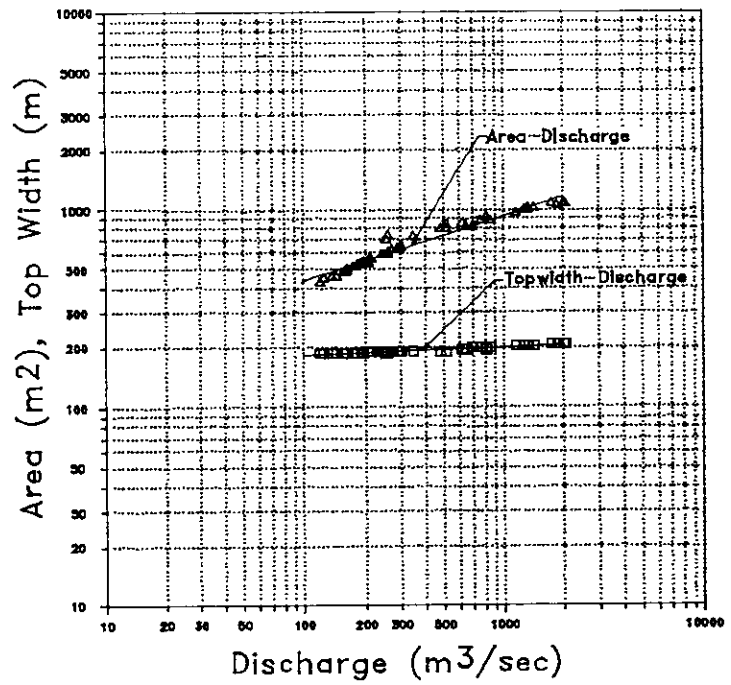
FILE: SED-072.DWG

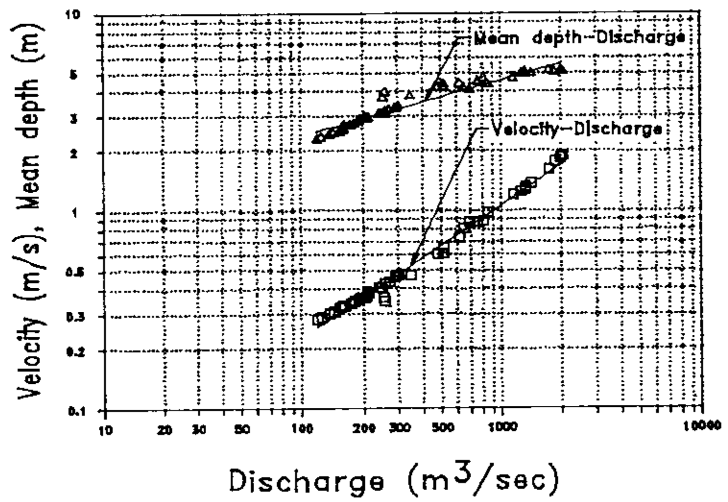
228





Hydraulic Geometry





Discharge (m 3/s)

COMMENTS

1. At BWDB gauge 271
2. Rating curve not valid in Monsoon season.
3. Hydraulic Geometry Relations

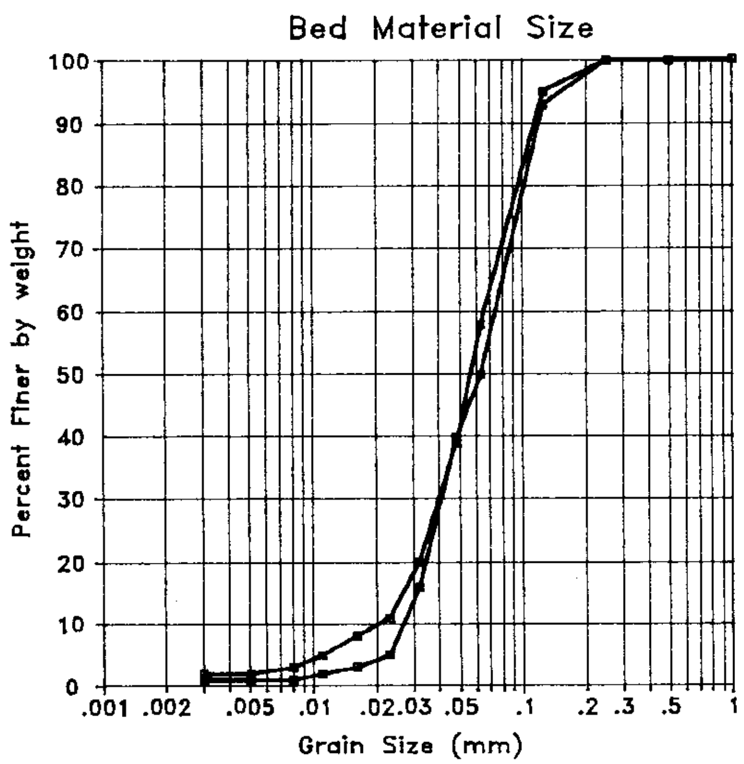
$A = 97.975 Q^{0.326}$
$W = 152.173 Q^{0.0401}$
$d = 0.644 Q^{0.286}$
$v = 0.0102 Q^{0.674}$

Condition	Q	A	W	d	v
Avg. monthly March	226	573	189	3.04	0.39
Avg. monthly April	663	814	197	4.13	0.81
Avg. monthly May	1438	1048	203	5.15	1.37
Pre-monsoon 2 Year	1630	1092	204	5.34	1.49
Pre-monsoon 5 Year	2330	1227	207	5.91	1.90
Pre-monsoon 10 Year	2700				
Annual 2 Year					
Annul 5 Year					
Annual 10 Year					
Bankfull (existing)	1750	1118	205	5.45	1.57
April 6/96	1485	1059	204	5.20	1.40

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	
Kalni-Kushiyara River Management Project	
Kalni River at Ajmiriganj	
Prepared by: TAREK	December 1997
Computer Drafting by: Jalal	

FILE: SED-038.DWG



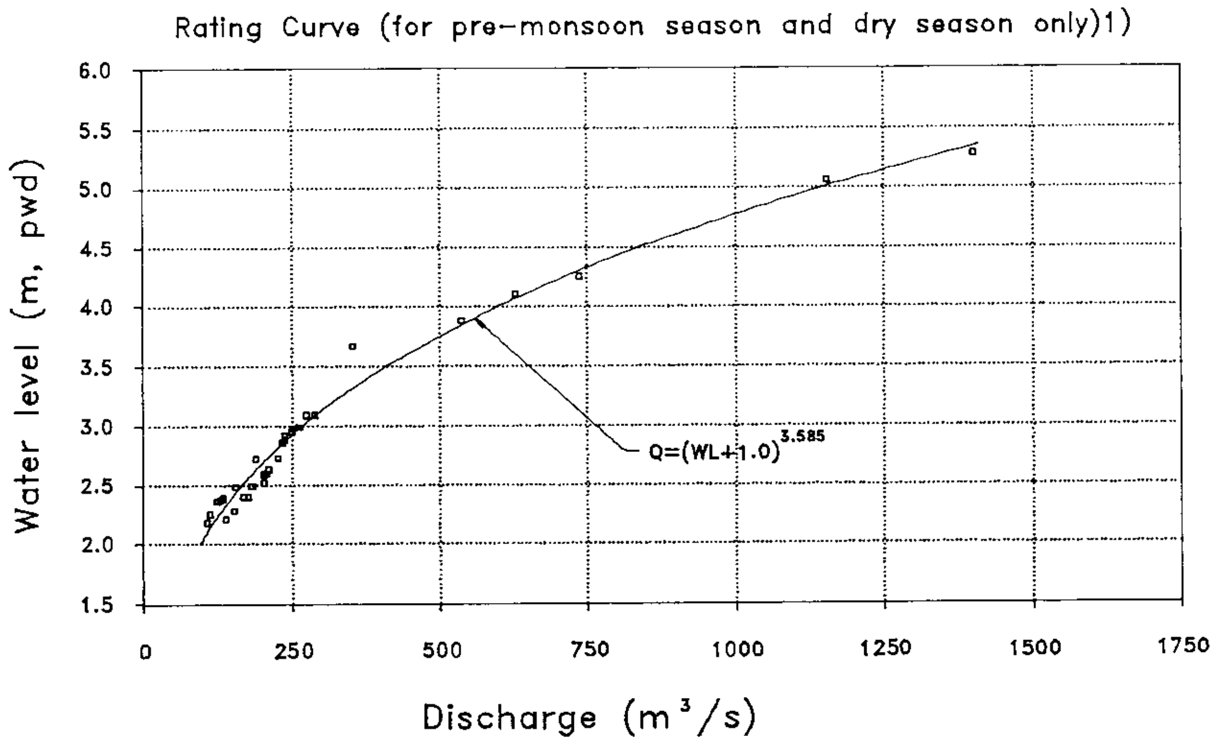
River Characteristics

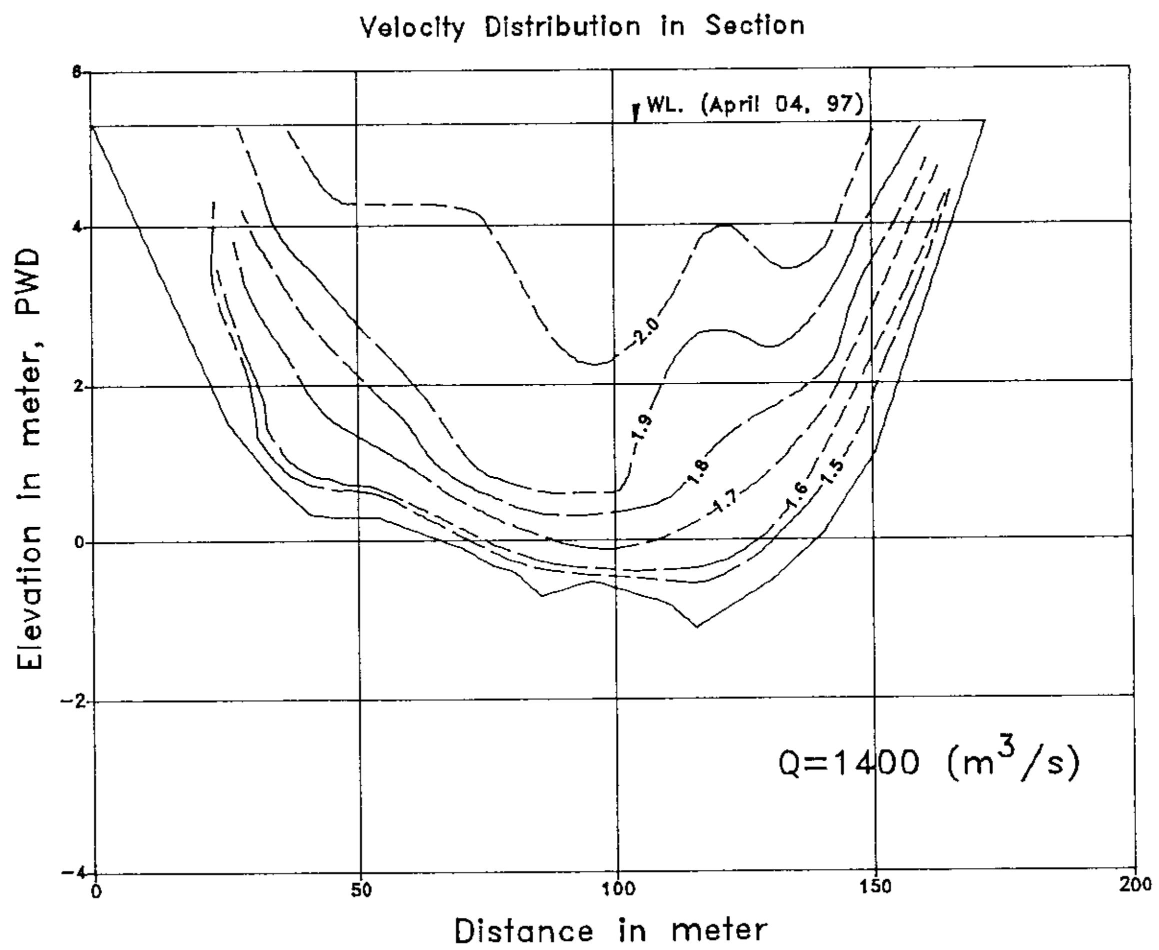
1. **Gauge Number:** Temporary Gauge
2. **Location:** Km 95.4
   - Lat. 24°28'49" N
   - Long. 91°11'20" E
3. **Available Data**
   - Water Level: 1995–1996
4. **Physical Setting**
   - Physiographic Unit: Sylhet Basin
   - Features: Unconfined alluvial floodplain sloping into low-lying floodbasins and haor areas.
5. **Channel Pattern**
   - Channel: Split Channel with irregular meanders.
   - Bars: none
   - Sinuosity: 1.35
6. **Sedimentology**
   - Channel: Highly variable mixture of very fine sand, silty sand and sandy silt.
   - Banks: Mainly silt and silty clay
7. **Pattern of Instability:** Up until the 1970's the river flowed in the western branch, while the eastern channel was a minor khal. The east branch has enlarged and is now capturing virtually all of the flow. The channel has undergone considerable widening and rapid bank erosion. In 1993 the meander near Katkhal village made a natural cutoff, causing the destruction of Shahibnagar Village.

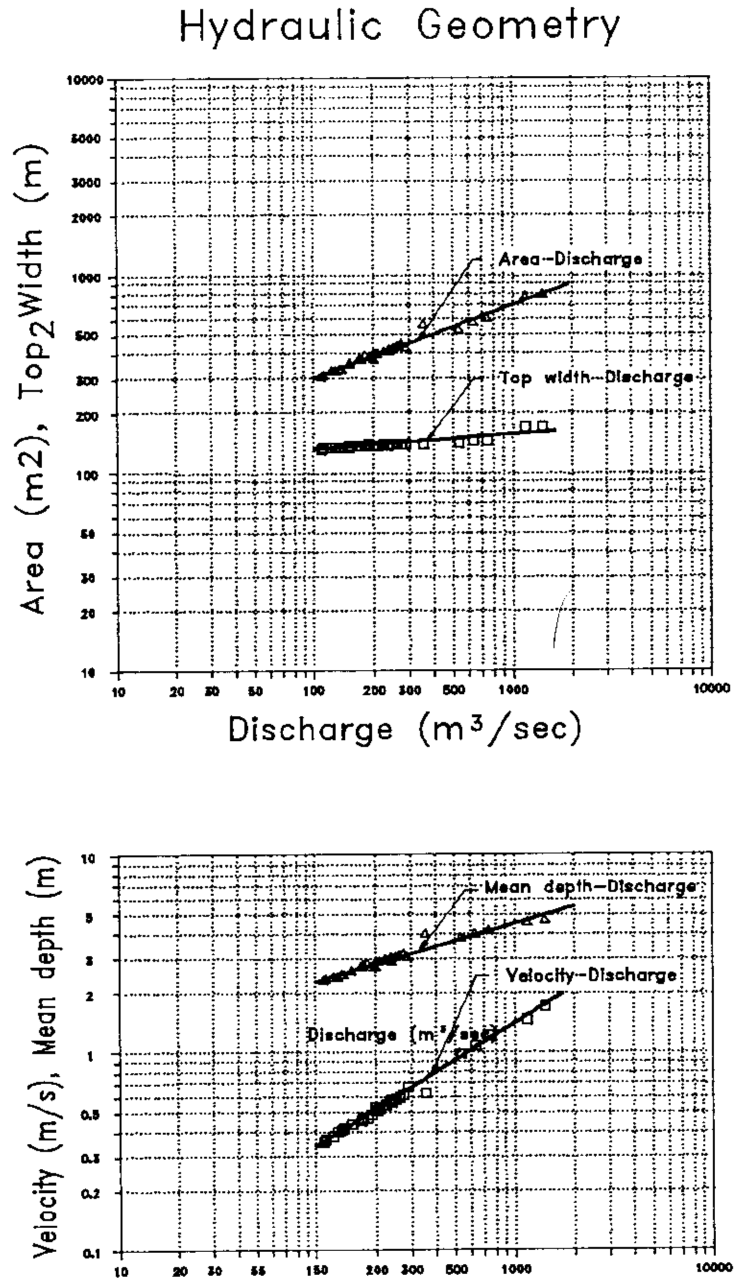
Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Kalni River at Shantipur	
Prepared by: TAREK	December 1997
Computer Drafting by: Jalal	

FILE: SED-073.DWG

Figure A.26







COMMENTS

1. Temporary gauge 1995-96
2. Rating curve not valid in Monsoon season.
3. Hydraulic Geometry Relations

$A = 54.033 Q^{0.372}$
$W = 92.82 \ Q^{0.0752}$
$d = 0.5821 Q^{0.2972}$
$v = 0.0185 Q^{0.626}$

Condition	Q	A	W	d	v
Avg. monthly March	226	406	140	2.91	0.56
Avg. monthly April	663	606	151	4.01	1.10
Avg. monthly May	1438	809	160	5.04	1.78
Pre-monsoon 2 Year	1630	847	162	5.23	1.93
Pre-monsoon 5 Year					
Pre-monsoon 10 Year					
Annual 2 Year					
Annul 5 Year					
Annual 10 Year					
Bankfull (existing)	1500	821	161	5.11	1.83
April 6/96	1337	787	159	4.94	1.70

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
Kalni-Kushiyara River Management Project

Kalni River at Shantipur

Prepared by: Tarek
Computer Drafting by: Jalal
December 1997

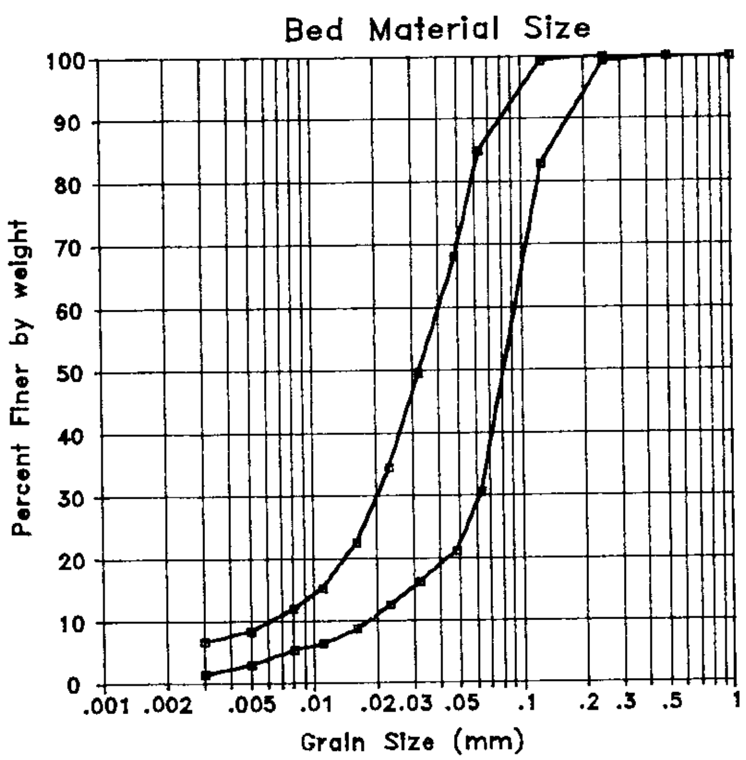
FILE: SED-040.DWG

Figure A.27

229

River Characteristics

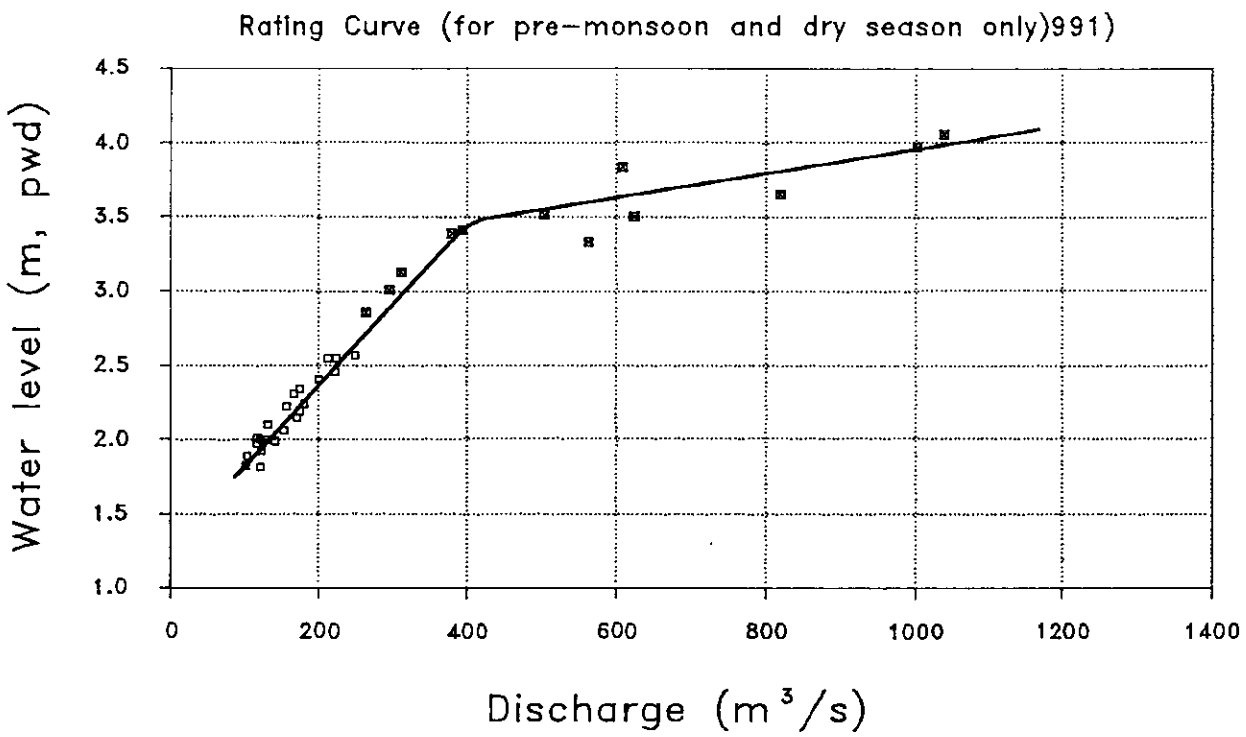
1. Gauge Number: Temporary Gauge
2. Location: Km 48.7
   - Lat. 24°25'42" N
   - Long. 91°12'12" E
3. Available Data
   - Water Level: 1995–1996
4. Physical Setting
   - Physiographic Unit: Central Basin Lowlands
   - Features: Unconfined alluvial floodplain sloping into low-lying floodbasins and haor areas.
5. Channel Pattern
   - Channel: Meandering split channel upstream. Single, sinuous unconfined channel downstream
   - Bars: Point bar growth on right bank has encroached into channel
   - Sinuosity: 1.16
6. Sedimentology
   - Channel: Very fine sand and silty sand
   - Banks: Mainly silt and silty clay
7. Pattern of Instability: Progressive deposition on the large right bank point downstream of Kadamchal has encroached into the Channel causing bank erosion on the left bank. In 1993 the natural cutoff near Katkhal re-directed flow into Cherapur Khal (4 km upstream of Kadamchal) causing this distributary to undergo rapid bank erosion and widening. This enlargement of the khal has been accomanied by reduced flows in the lower Kalni River.

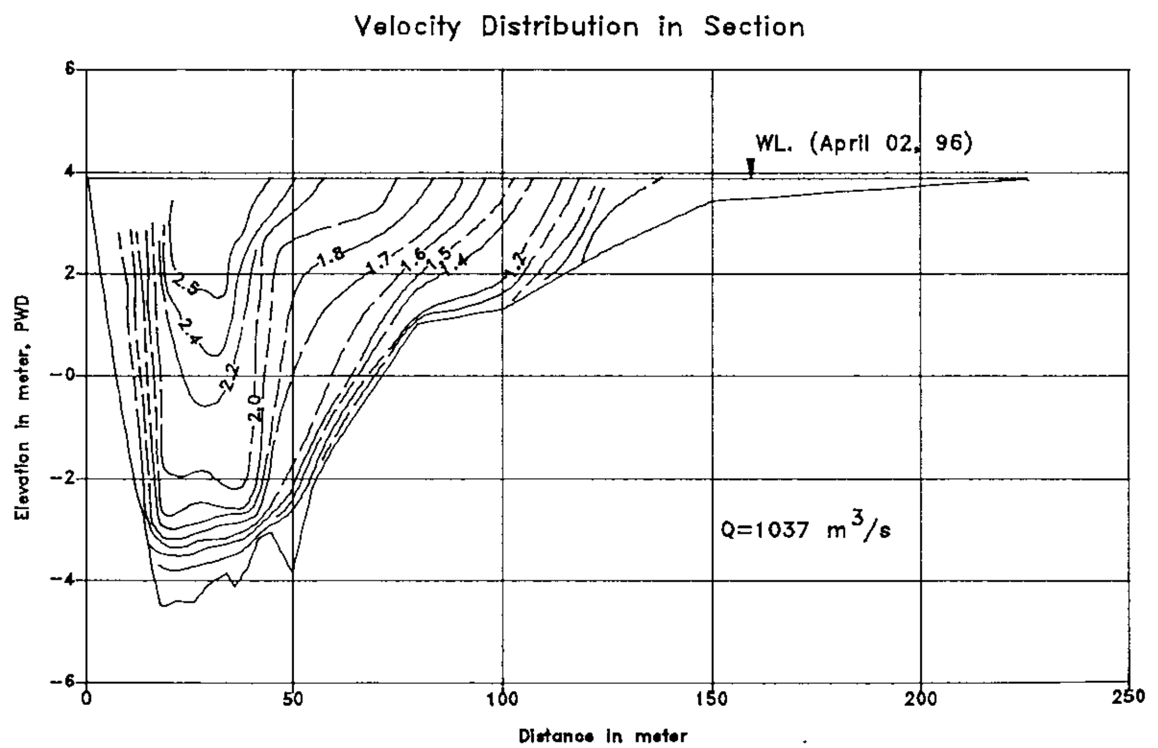


Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Kalni River at Kadamchal	
Prepared by: TAREK	December 1997
Computer Drafting by: Jalal	

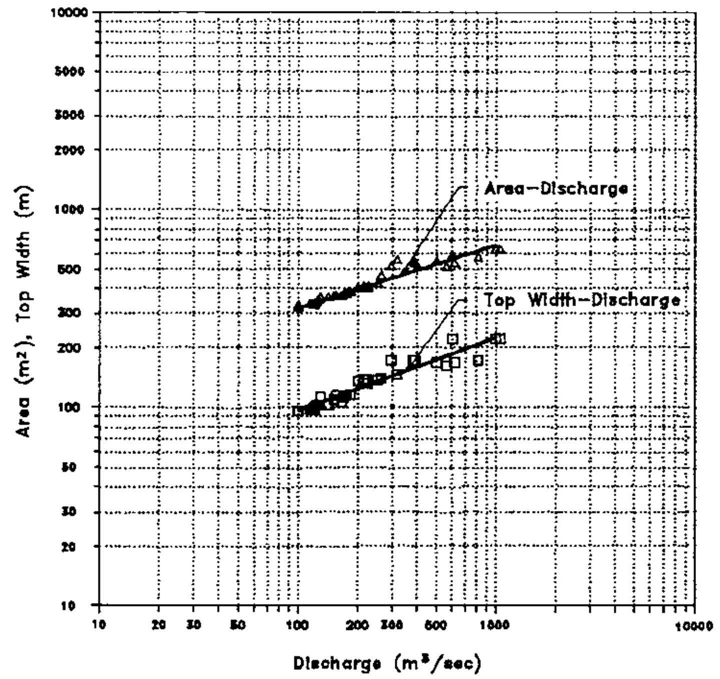
FILE: SED-074.DWG

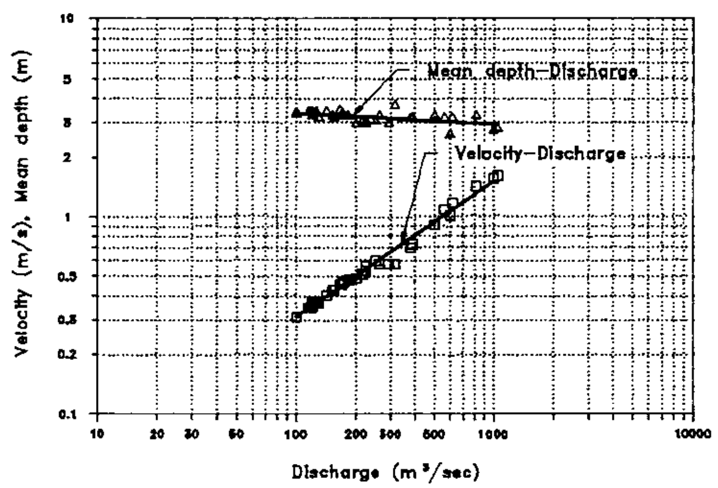
Figure A.28





Hydraulic Geometry





COMMENTS

1. Temporary gauge 1995-96
2. Rating curve not valid in Monsoon season.
3. Hydraulic Geometry Relations

$A = 76.06 \; Q^{0.313}$
$W = 17.506 \; Q^{0.37}$
$d = 4.34 \; Q^{-0.057}$
$v = 0.01315 Q^{0.687}$

Condition	Q	A	W	d	v
Avg. monthly March	170	379	117	3.24	0.45
Avg. monthly April	497	531	174	3.54	0.94
Avg. monthly May	1079	677	232	4.51	1.59
Pre-monsoon 2 Year	1223	704	243	4.69	1.74
Pre-monsoon 5 Year					
Pre-monsoon 10 Year					
Annual 2 Year					
Annul 5 Year					
Annual 10 Year					
Bankfull (existing)	1350	726	252	4.84	1.86
April 6/96	1100	681	234	4.54	1.62

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)

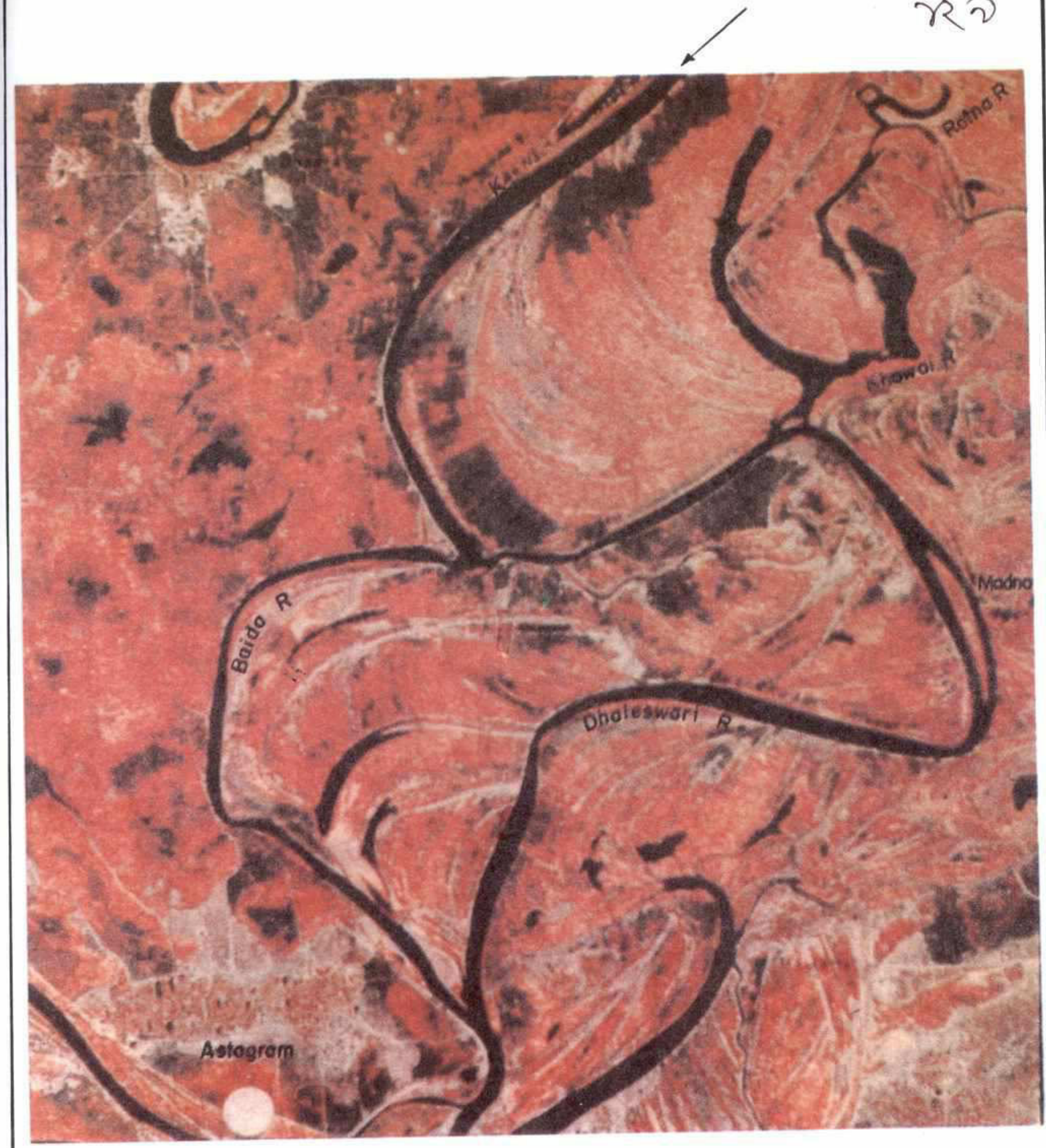
Northeast Regional Project

Kalni-Kushiyara River Management Project

Kalni River at Kadamchal

Prepared by: TAREK | Computer Drafting by: Jalal | December 1987

FILE: SED-041.DWG



Scale

1 0 1 2 km

Northeast Regional Project

Kalni-Kushiyara River Management Project

Dhaleswari/Khowai River Junction

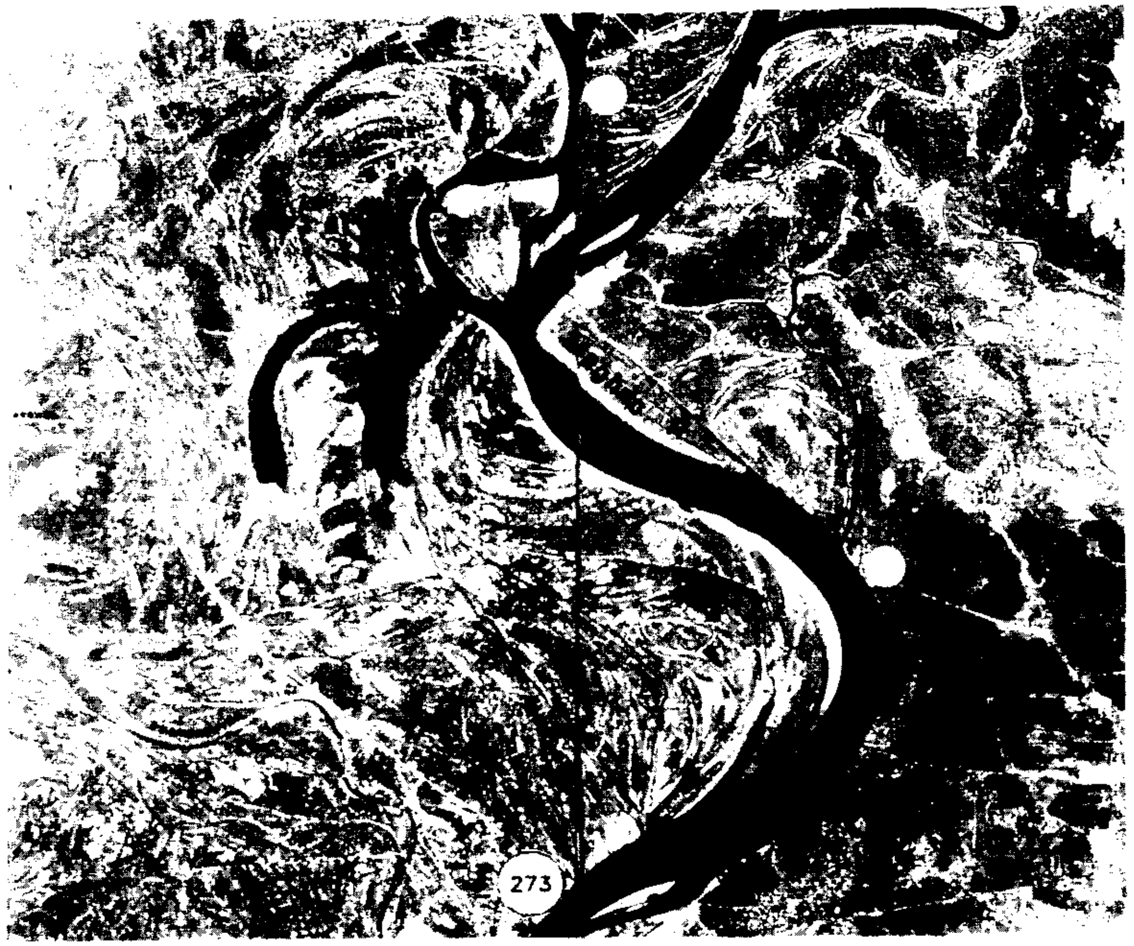
Prepared by: Tarek

Computer Drafting by: Mamun

December 1997

FILE: SED-A11.DWG

Figure A.30



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

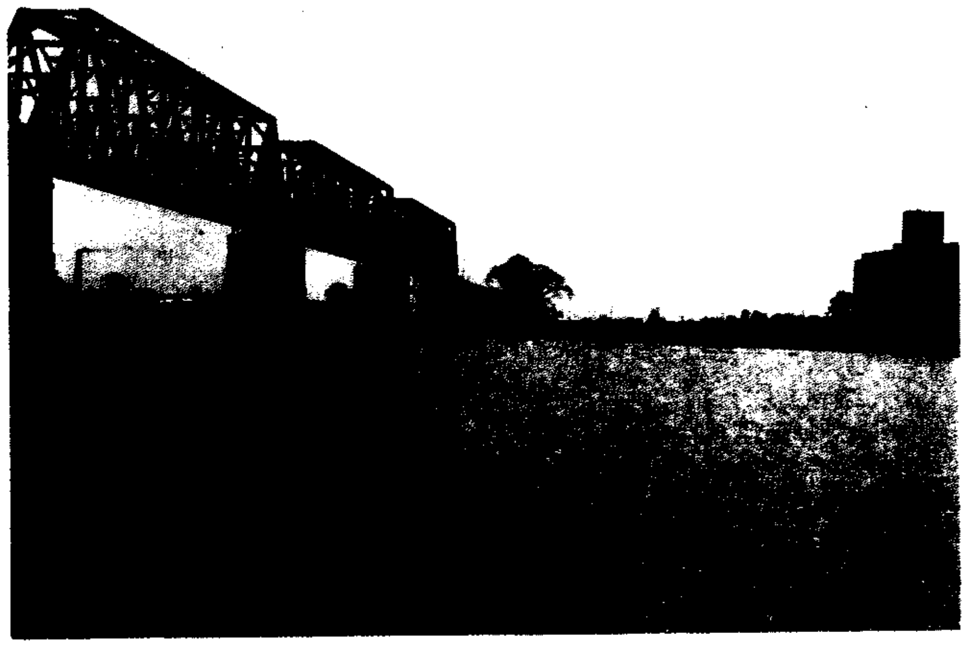
4. Physical Setting:
   Physiographic Unit: Lowland Floodplain
   Agro-ecologic Zone: Middle Meghna River Floodplain
   Features: The Meghna River is the main outlet for the NE Region. Below Bhairab, the river occupies the former channel of the Brahmaputra R., which shifted westwards into its present 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

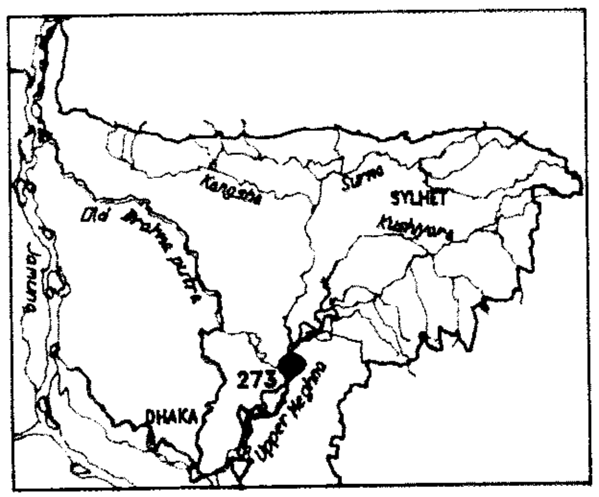
6. Sedimentology
   Channel: Mainly fine sand.

   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.



View to left bank, downstream of gauge

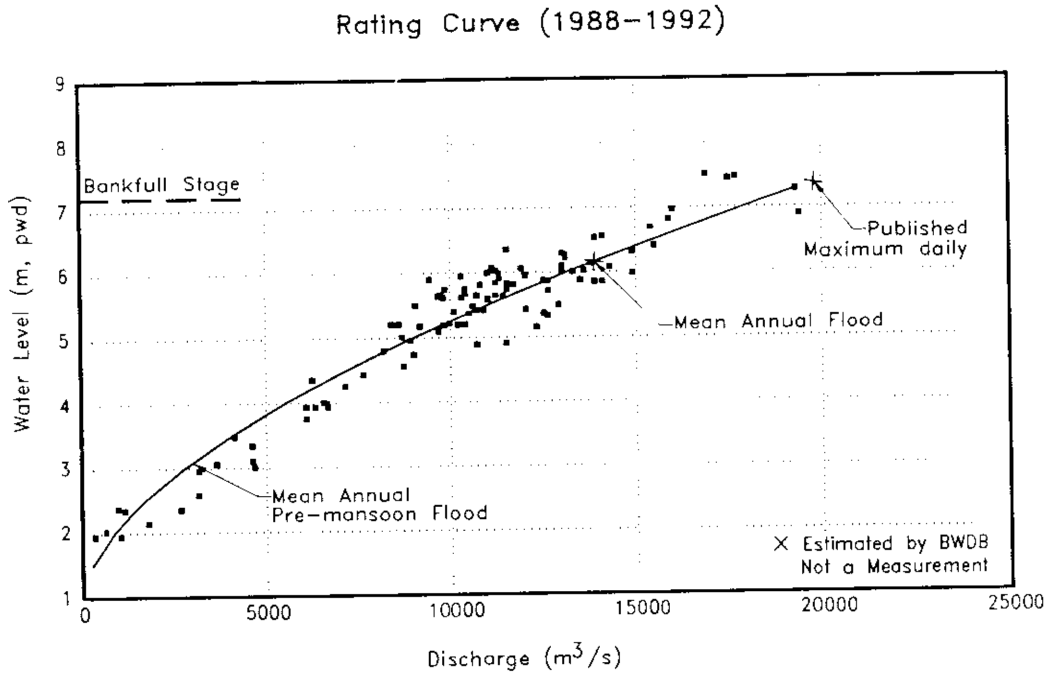


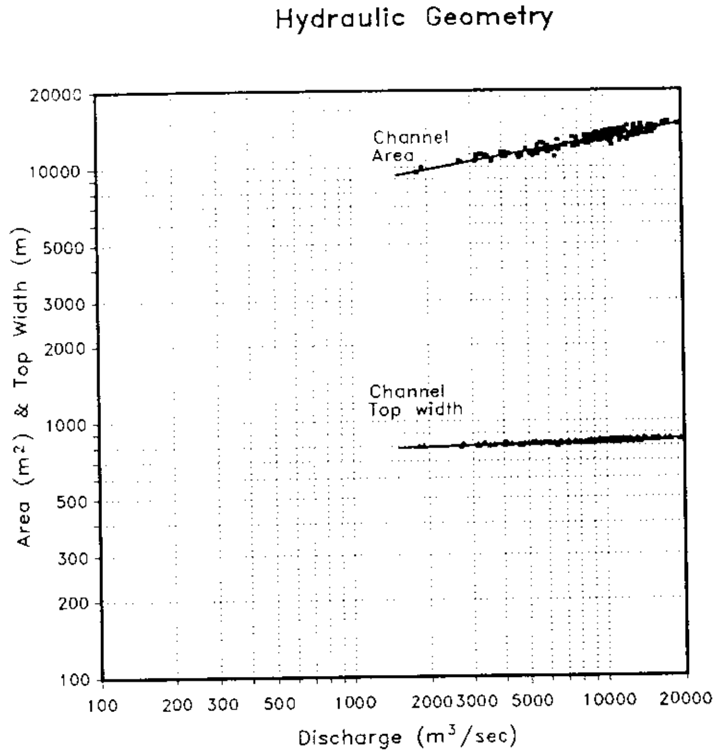
Site Location:

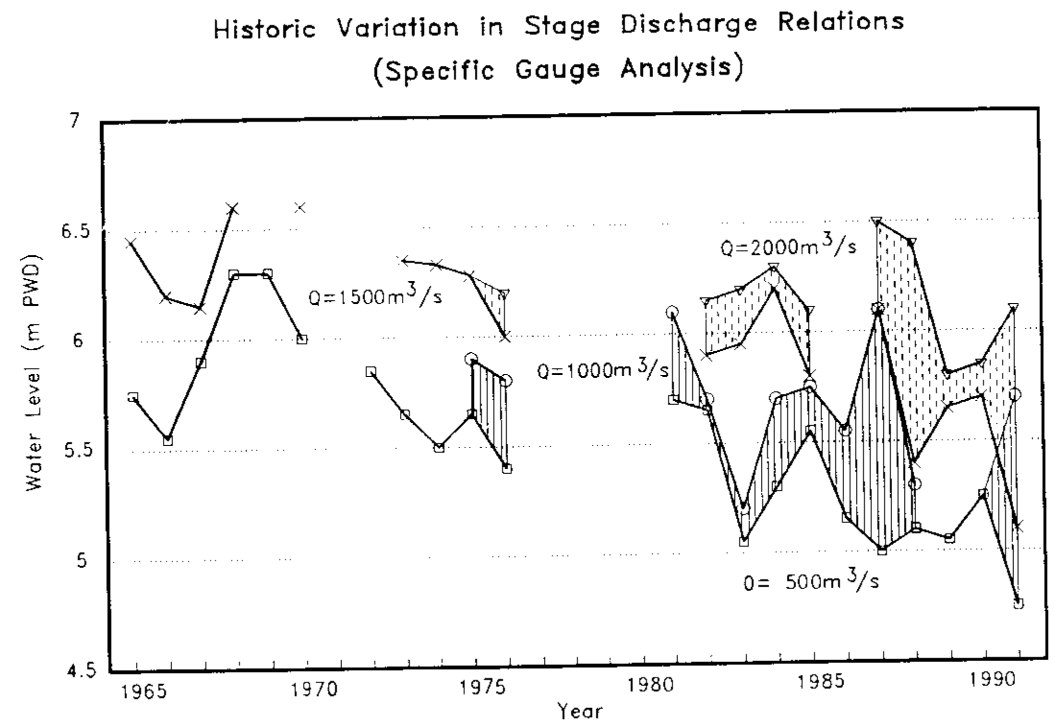
Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Meghna River at Bhairab Bazar	
Prepared by: TAREK	December 1997
Computer Drafting by: Jalal	

FILE: SED-078.DWG

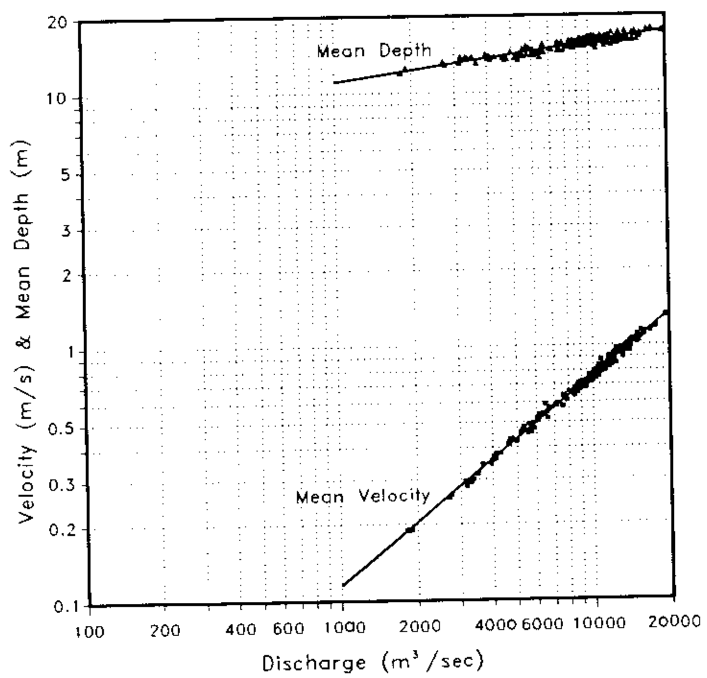
Figure A.31







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

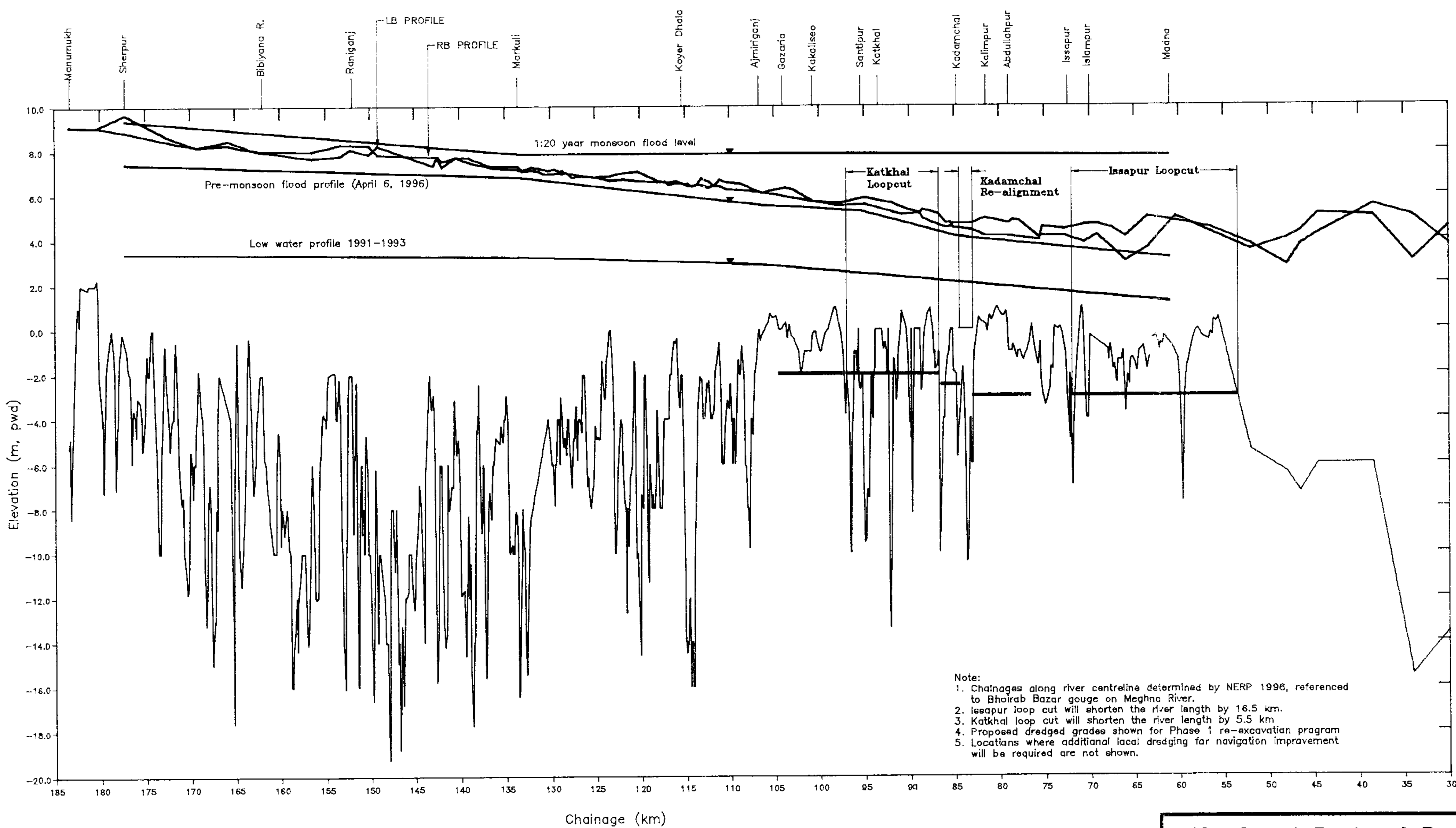
Kalni-Kushiyara River Management Project

Meghna River at Bhairab Bazar

Prepared by: TAREK	December 1997
Computer Drafting by: Jalal	

FILE: SED-077.DWG

Figure A.32



Northeast Regional Project

Kalni-Kushiyara River Management Project

Longitudinal Profile of Kalni-Kushiyara River

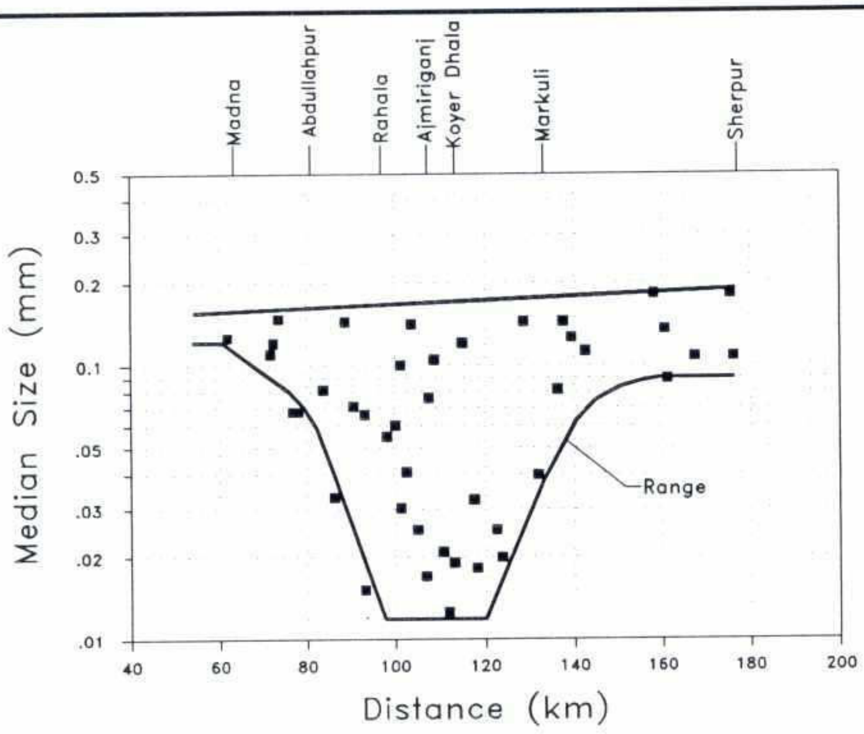
Prepared by: D.G.M.

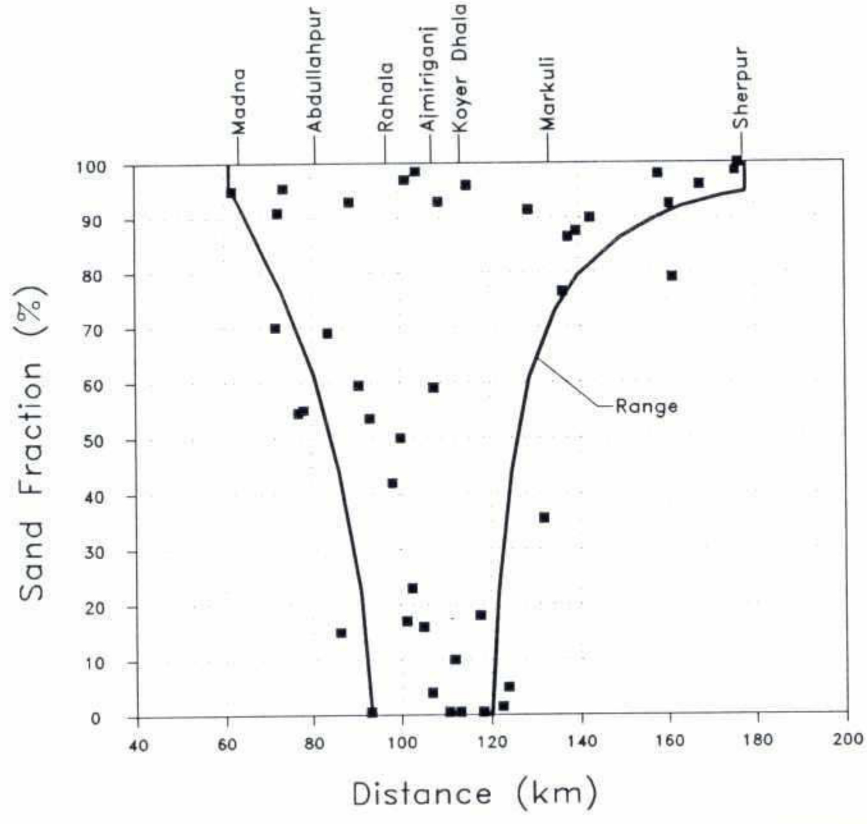
Computer Drafting by: Jalal

December 1997

FILE: SED-012.DWG

Figure A.33

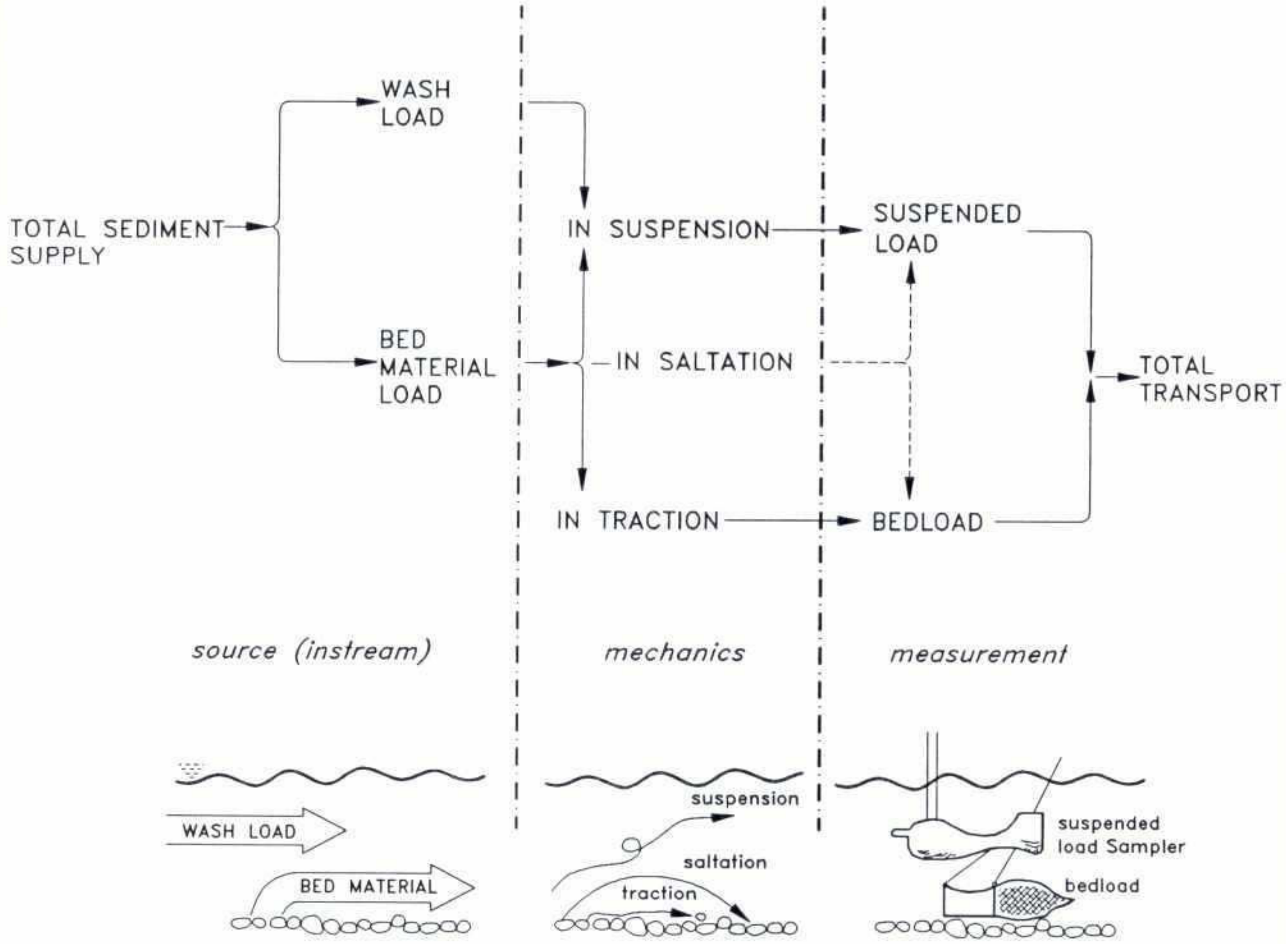




Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Bed Material Characteristics Along Kalni-Kushiyara River	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-013.DWG

268



Northeast Regional Project

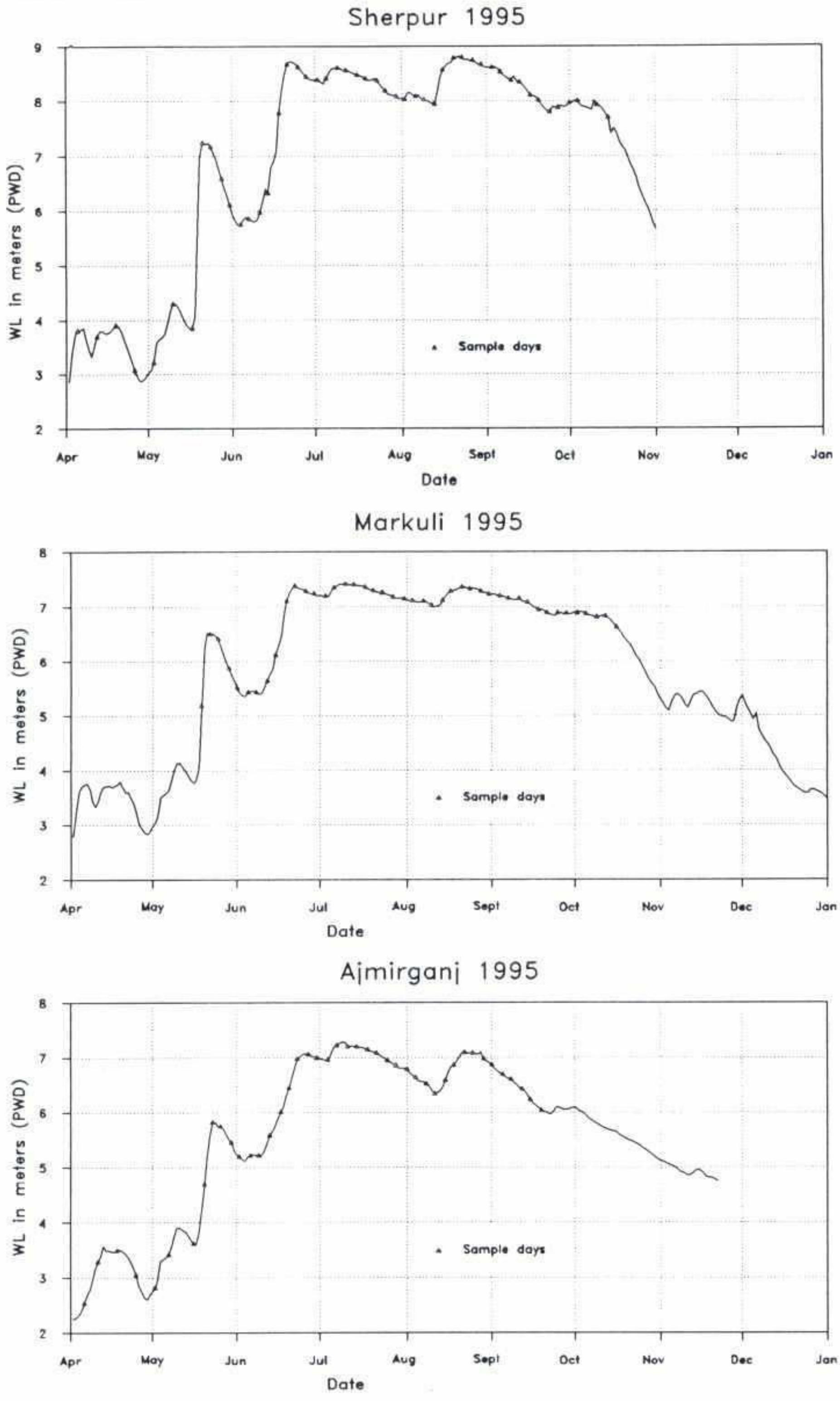
Kalni-Kushiyara River Management Project

Classification of Sediment Transport in Rivers

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

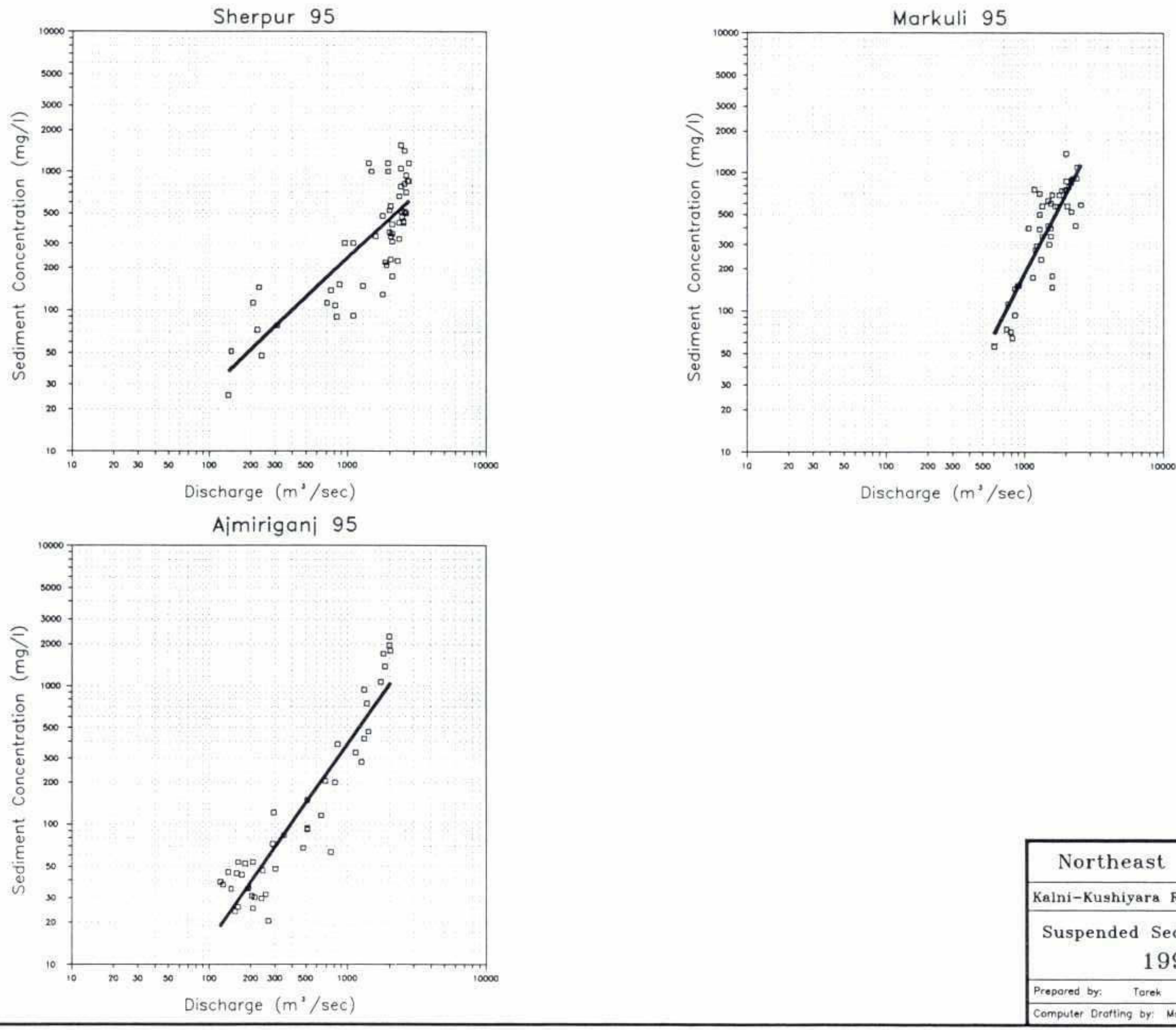
FILE: SED-014.DWG

Figure A.35



Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Sampling Days at Sherpur, Markuli and Ajmiriganj	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-078.DWG

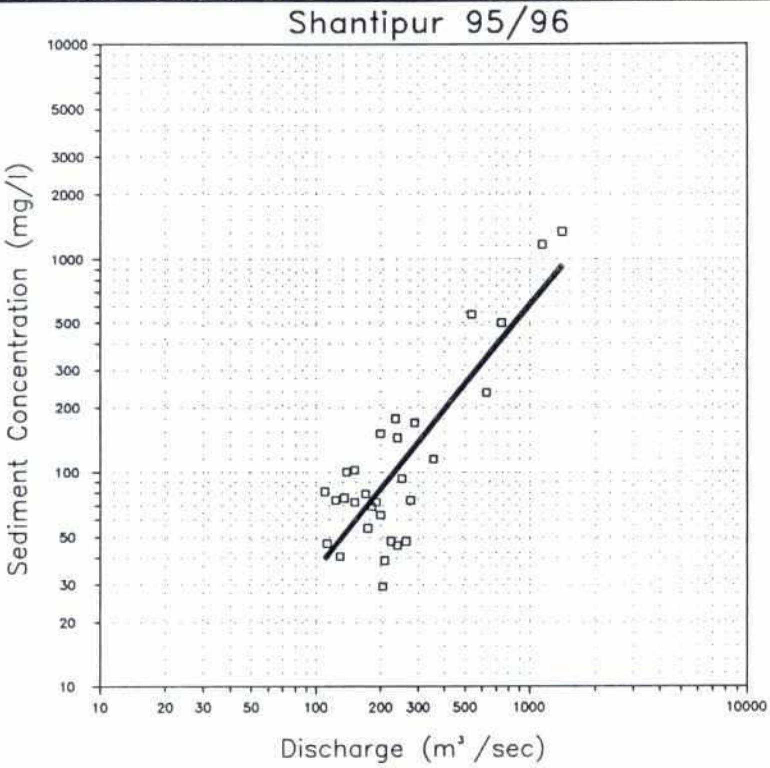


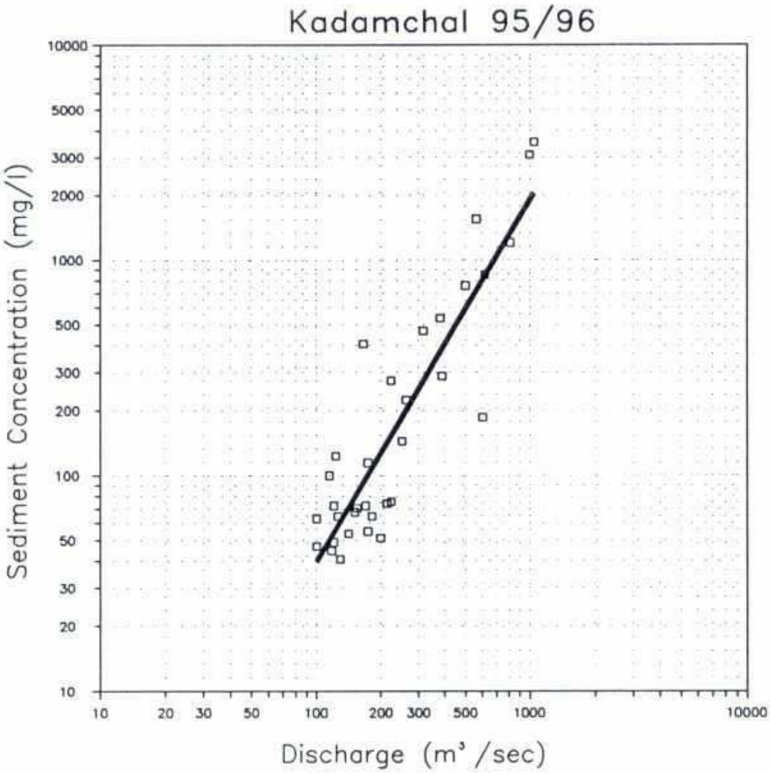
FILE: SED-015.DWG

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Suspended Sediment Rating Curves 1995–1996	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

Figure A.36

Figure A.37





Northeast Regional Project

Kalni-Kushiyara River Management Project

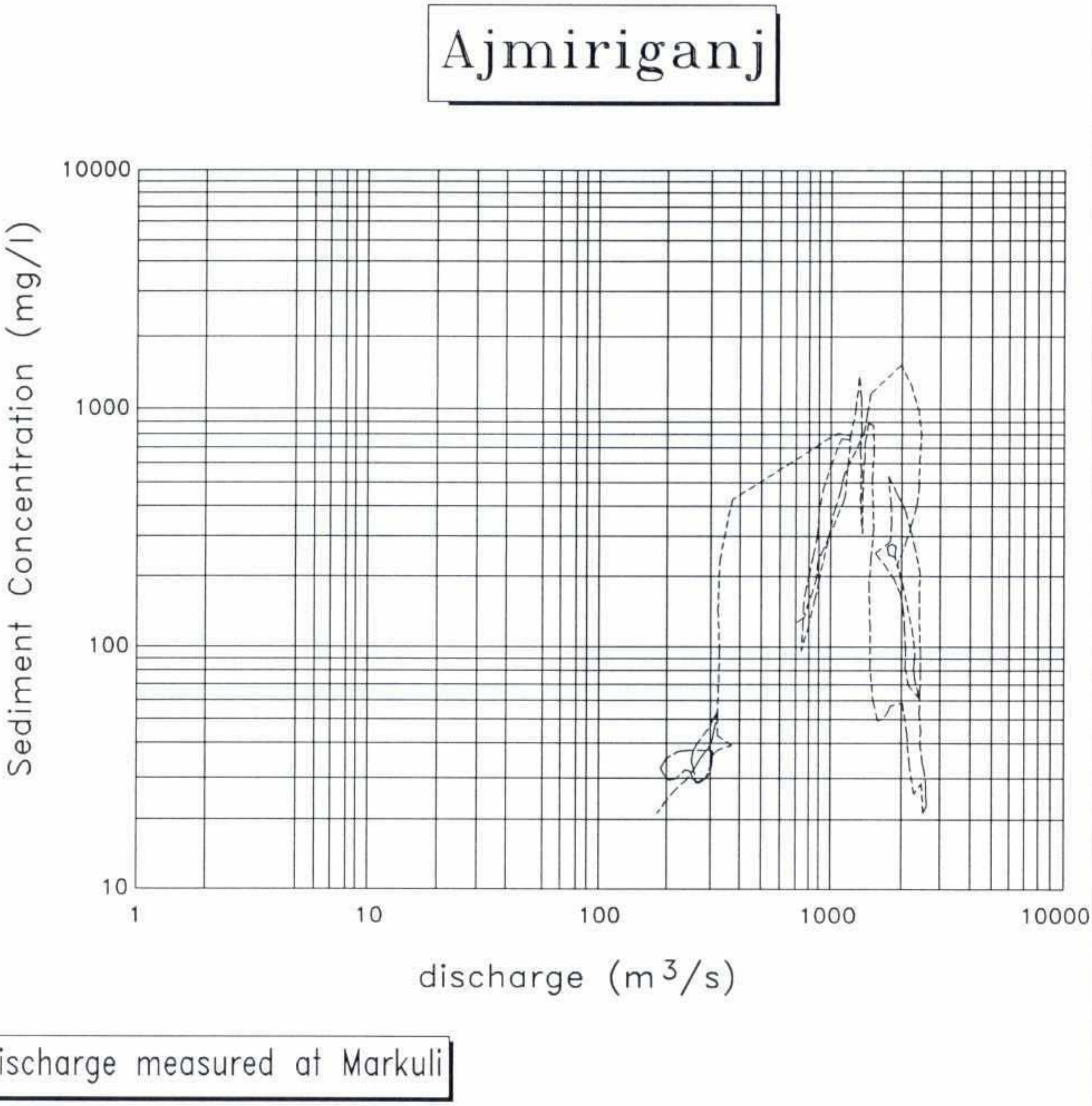
Suspended Sediment Rating Curves 1995-1996

Prepared by: Tarek

Computer Drafting by: Mamun

December 1997

FILE: SED-016.DWG



Northeast Regional Project

Kalni–Kushiyara River Management Project

Seasonal Hysteresis at Ajmiriganj

Prepared by: D.G.M.

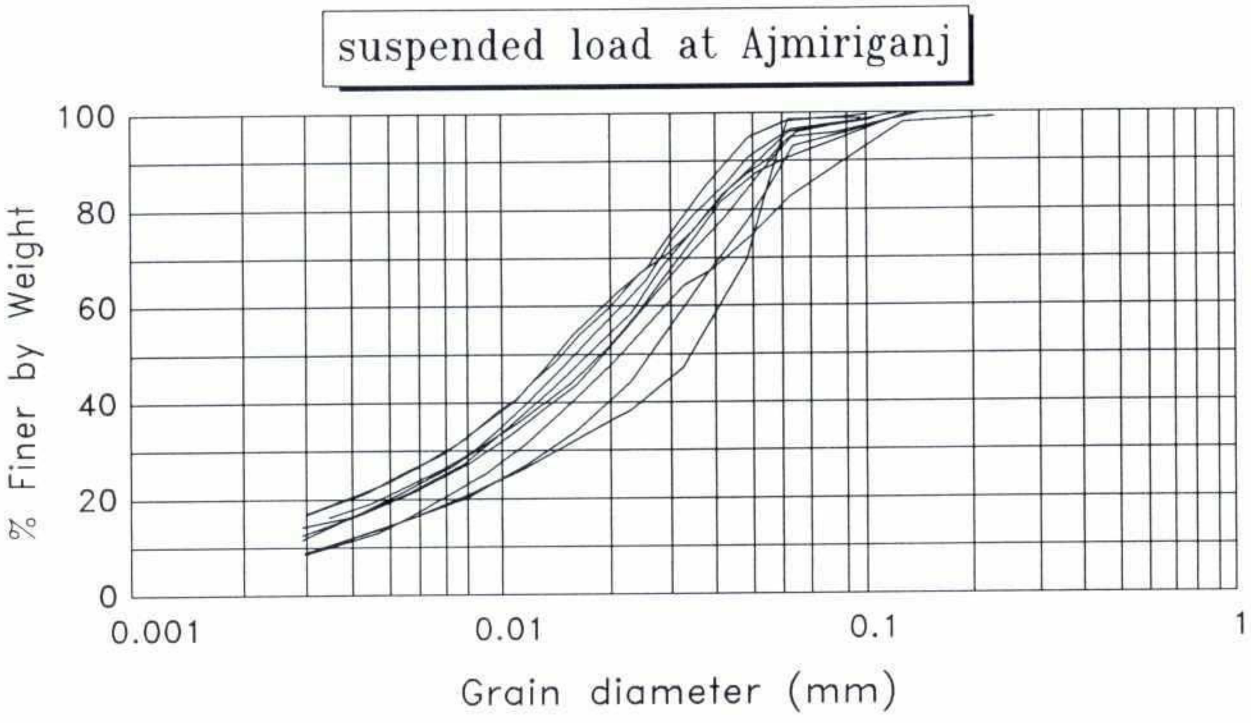
Computer Drafting by: Mamun

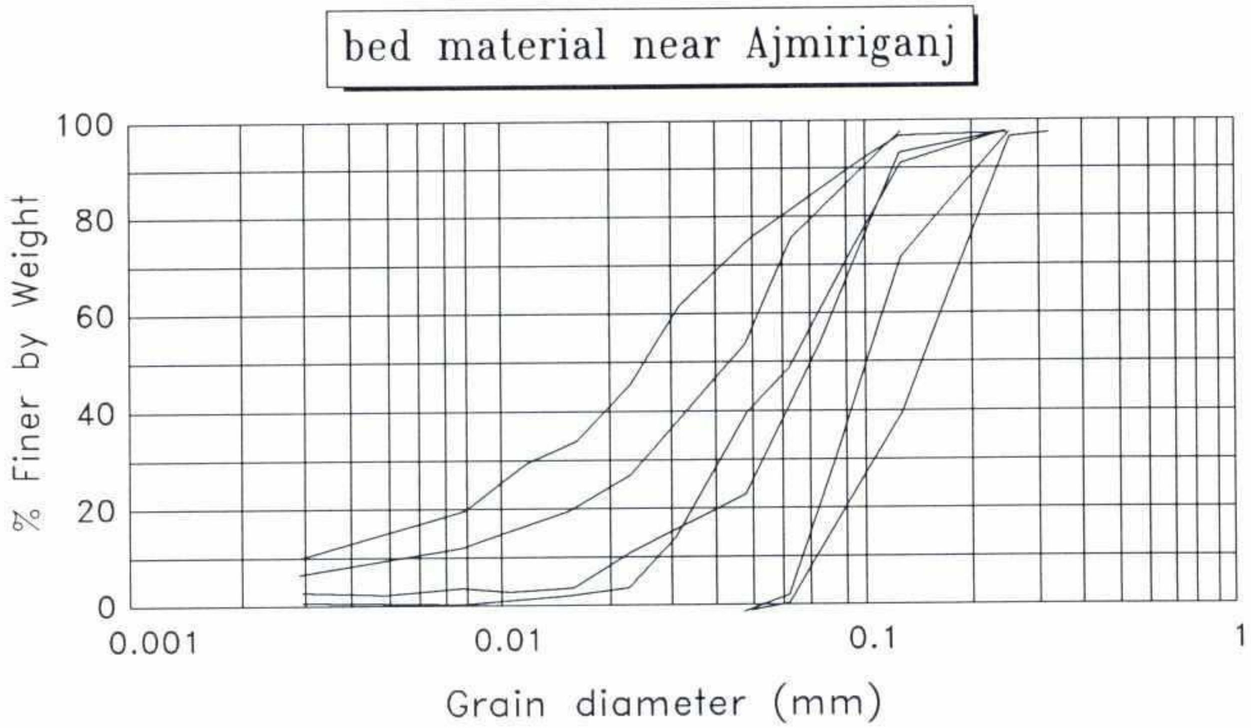
December 1997

FILE: SED-062.DWG

Figure A.39

252

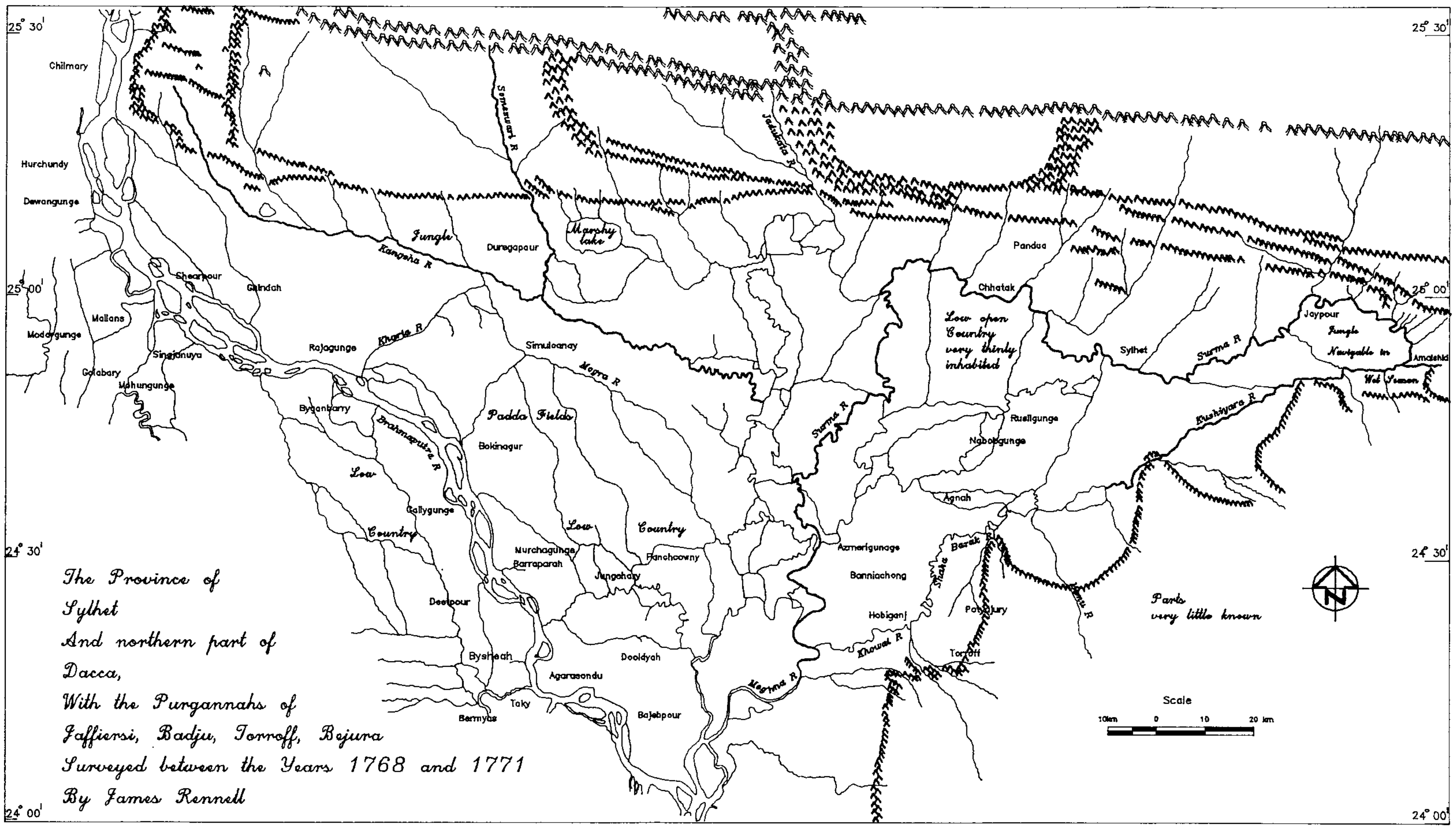




Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Size Distribution of Suspended Sediment Samples	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-063.DWG

280



Northeast Regional Project

Kalni-Kushiyara River Management Project

Rennell's Map of the Northeast Region

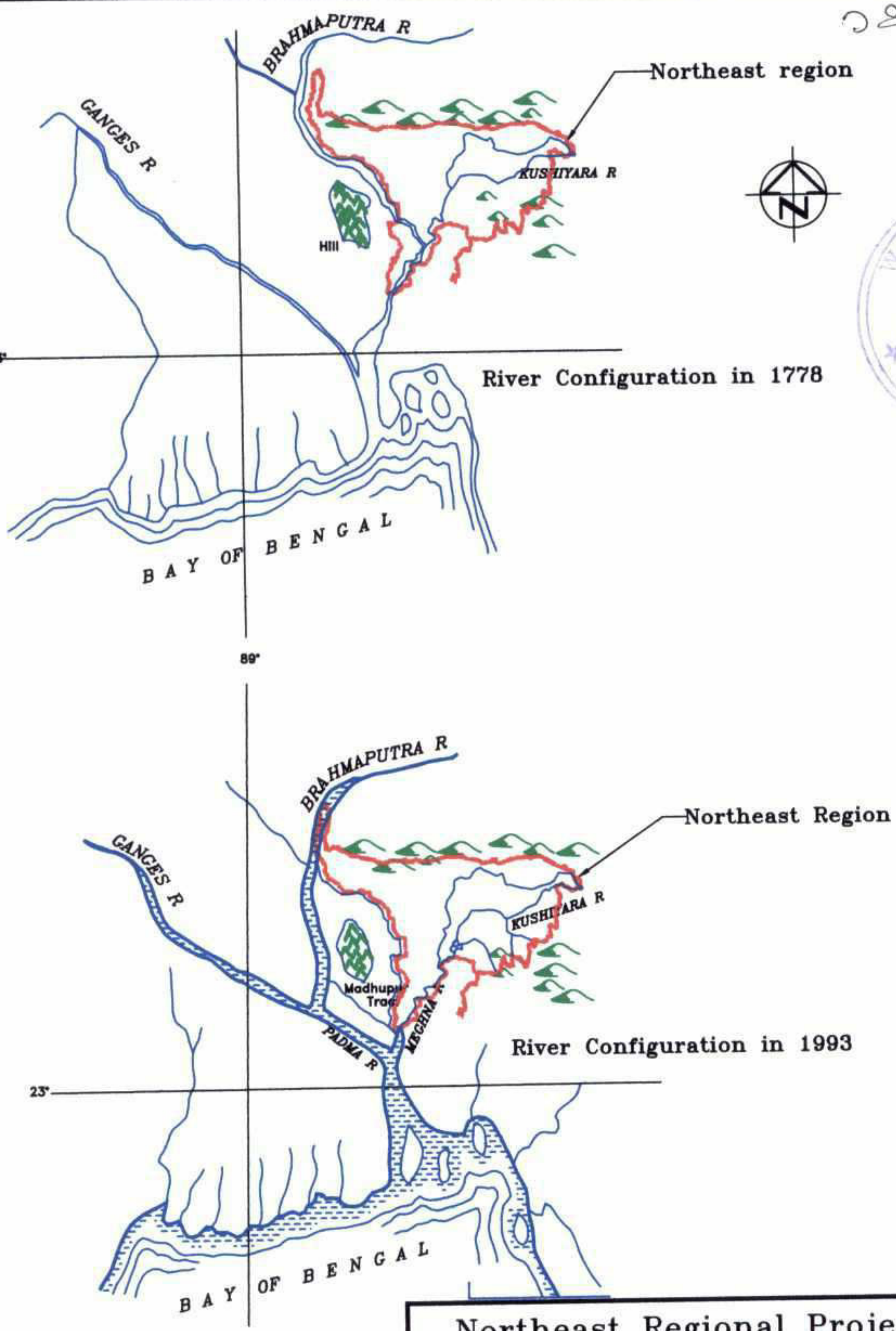
Prepared by: D.G.M.

Computer Drafting by: Mamun

December 1997

FILE: SED-017.DWG

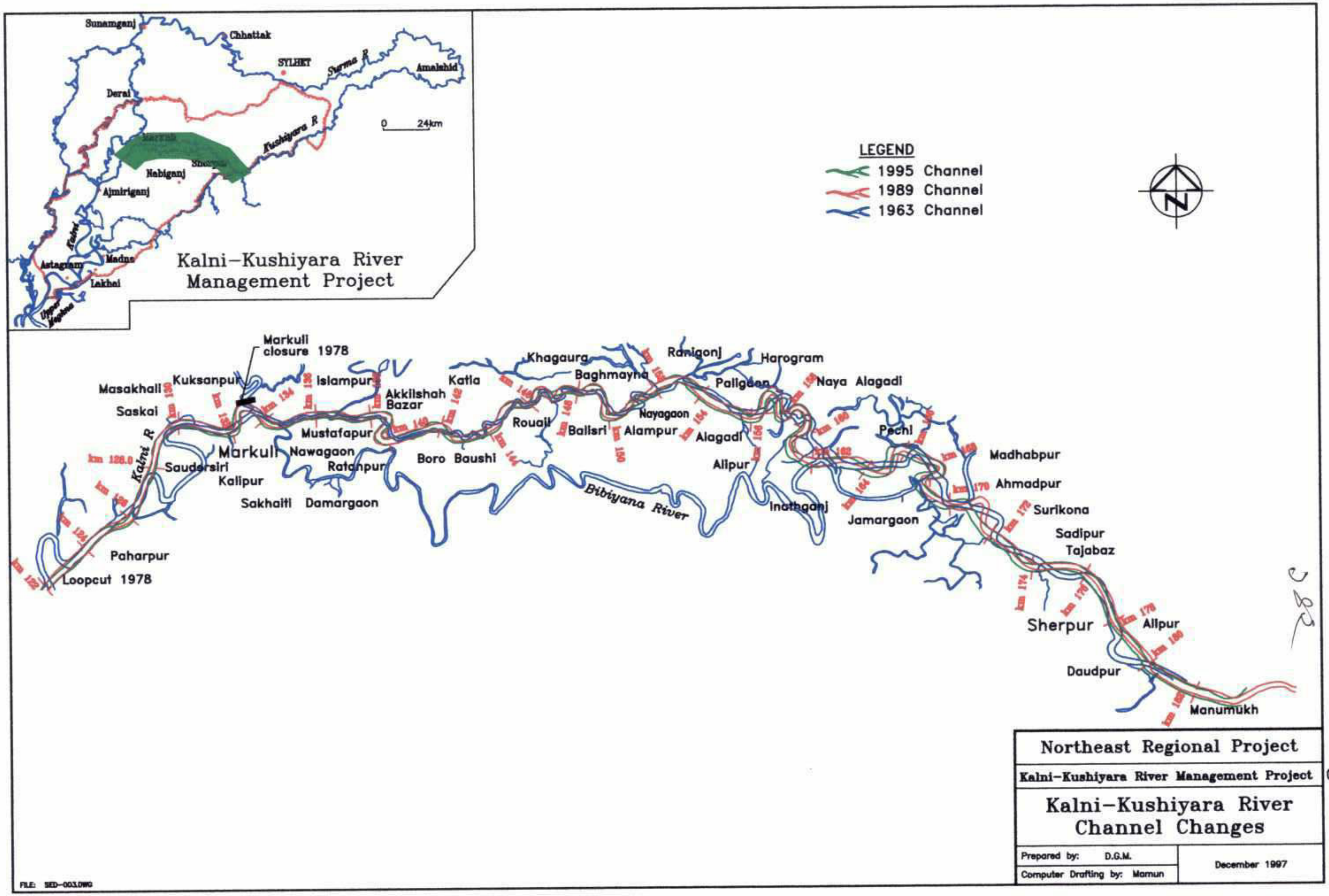
Figure A.41



Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Evolution of River Systems	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

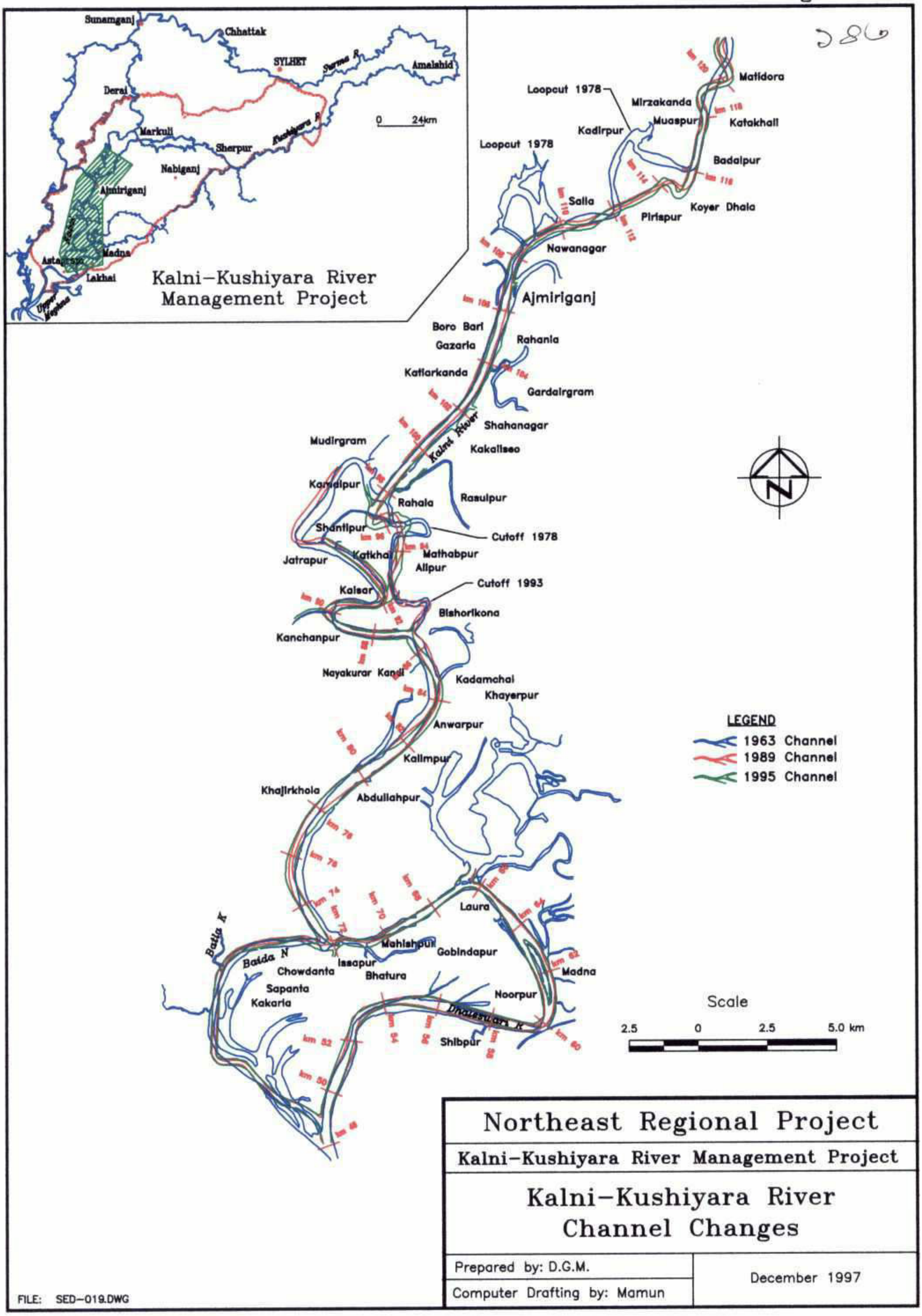
FILE: SED-018.DWG

Figure A.42



Sunamganj
Chhatak
SYLHET
Surma R
Amalshid
Derai
Kushiyara R
0 24km
Nabiganj
Ajmiriganj
Kalni
Astagram
Madna
Lakhai
Kalni-Kushiyara River Management Project
LEGEND
1995 Channel
1989 Channel
1963 Channel
N
Markuli closure 1978
Masakhali
Kuksanpur
Islampur
Akkilshah Bazar
Katla
Khagaurg
Baghmayna
Ranigonj
Harogram
Paligaon
Naya Alagadi
Saskai
Kalni R
Markuli
Mustafapur
Nawagaon
Ratanpur
Boro Baushi
Rouali
Balisri
Nayagaon
Alampur
Alagadi
Alipur
Pechi
Madhabpur
Ahmadpur
Surikona
Sadipur
Tajabaz
Saudersiri
Kalipur
Sakhaiti
Damargaon
Bibiyana River
Inathganj
Jamargaon
Paharpur
Loopcut 1978
Sherpur
Alipur
Daudpur
Manumukh
km 126.0
km 122
km 130
km 134
km 138
km 142
km 144
km 146
km 148
km 150
km 152
km 154
km 156
km 158
km 160
km 162
km 164
km 168
km 170
km 172
km 174
km 176
km 178
km 180
km 182
Northeast Regional Project
Kalni-Kushiyara River Management Project
Kalni-Kushiyara River Channel Changes
Prepared by: D.G.M.
Computer Drafting by: Mamun
December 1997
FILE: SED-003.DWG

Figure A.43



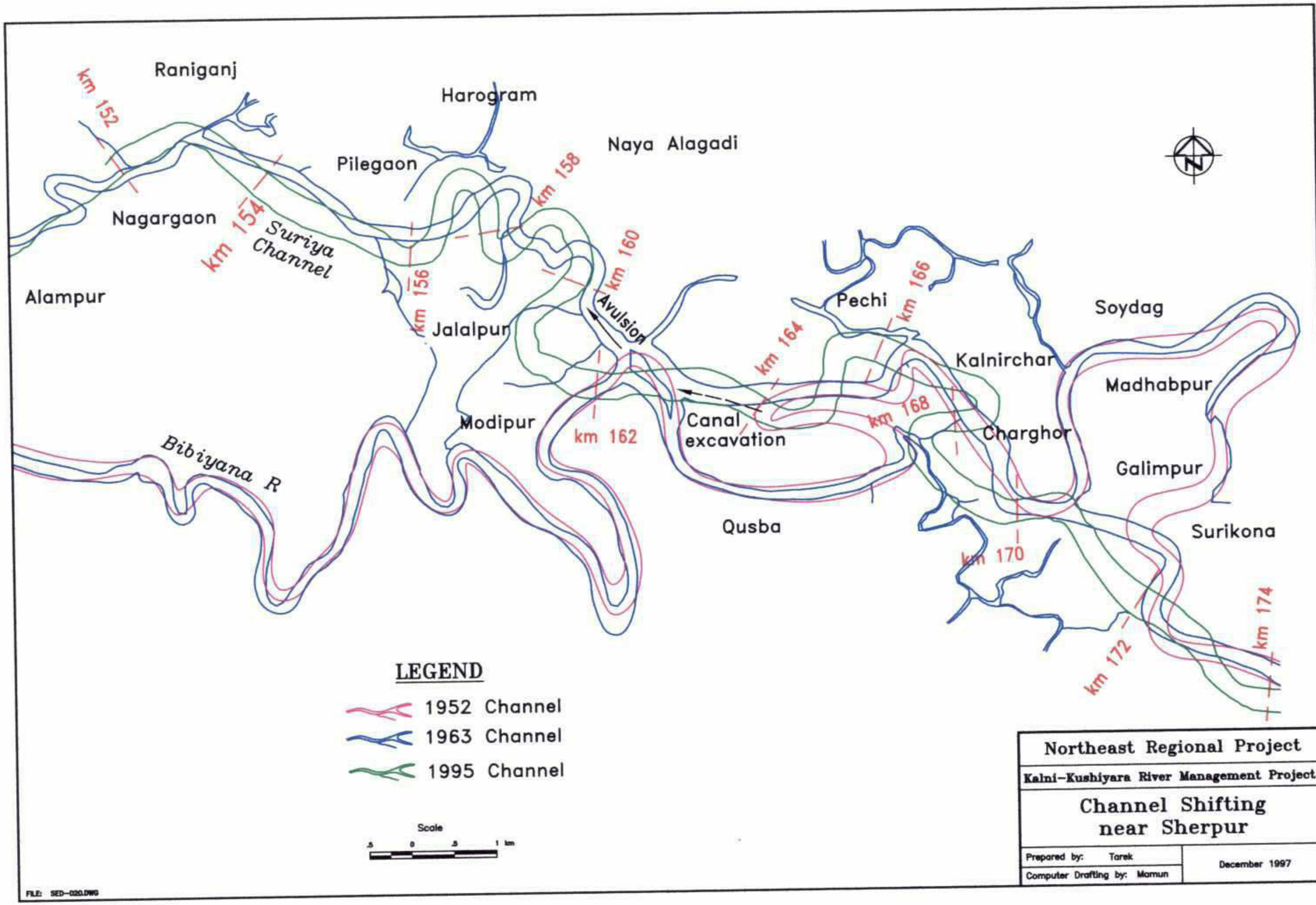
Northeast Regional Project

Kalni-Kushiyara River Management Project

Kalni-Kushiyara River Channel Changes

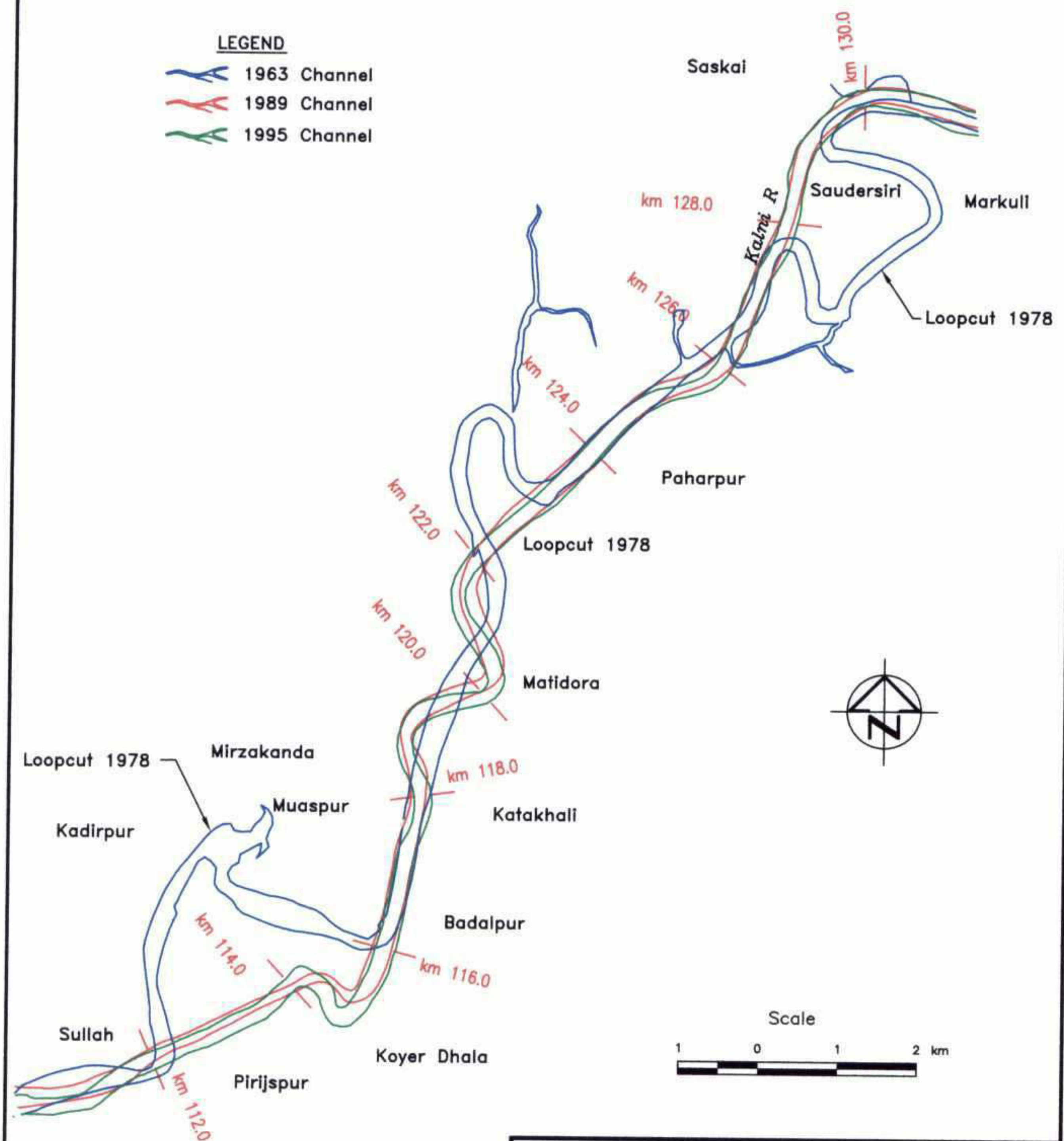
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

Figure A.44



Raniganj
Harogram
Naya Alagadi
Pilegaon
Nagargaon
Suriya Channel
Alampur
Jalalpur
Avulsion
Pechi
Soydag
Kalnirchar
Madhabpur
Modipur
Canal excavation
Charghor
Galimpur
Bibiyana R
Qusba
Surikona
km 152
km 154
km 156
km 158
km 160
km 162
km 164
km 166
km 168
km 170
km 172
km 174
LEGEND
1952 Channel
1963 Channel
1995 Channel
Scale
Northeast Regional Project
Kalni-Kushiyara River Management Project
Channel Shifting near Sherpur
Prepared by: Tarek
Computer Drafting by: Mamun
December 1997
FILE: SED-020.DWG

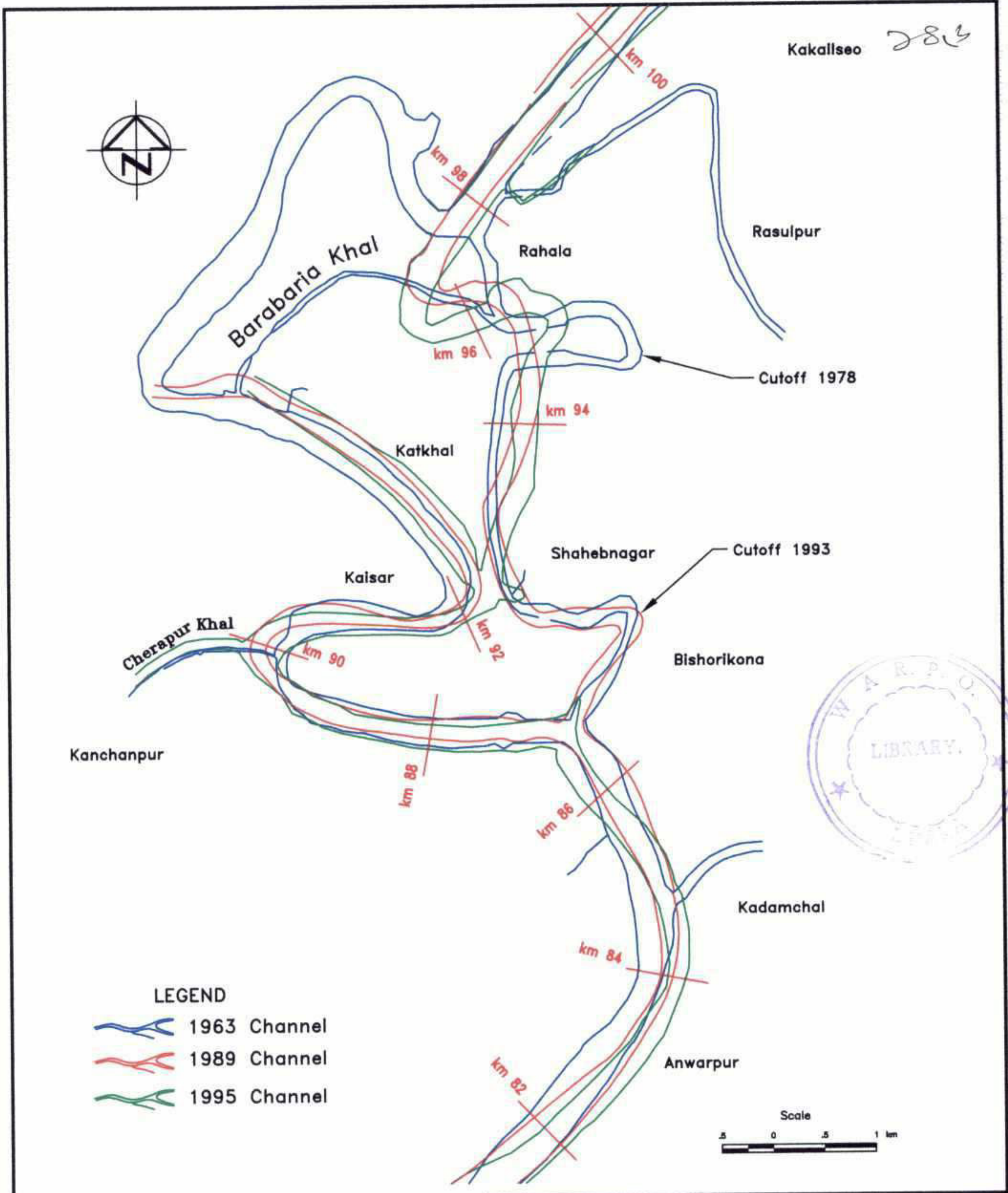
280



Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Channel Shifting near Markuli	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-021.DWG

Figure A.46



Northeast Regional Project

Kalni–Kushiyara River Management Project

Channel Shifting near Katkhal

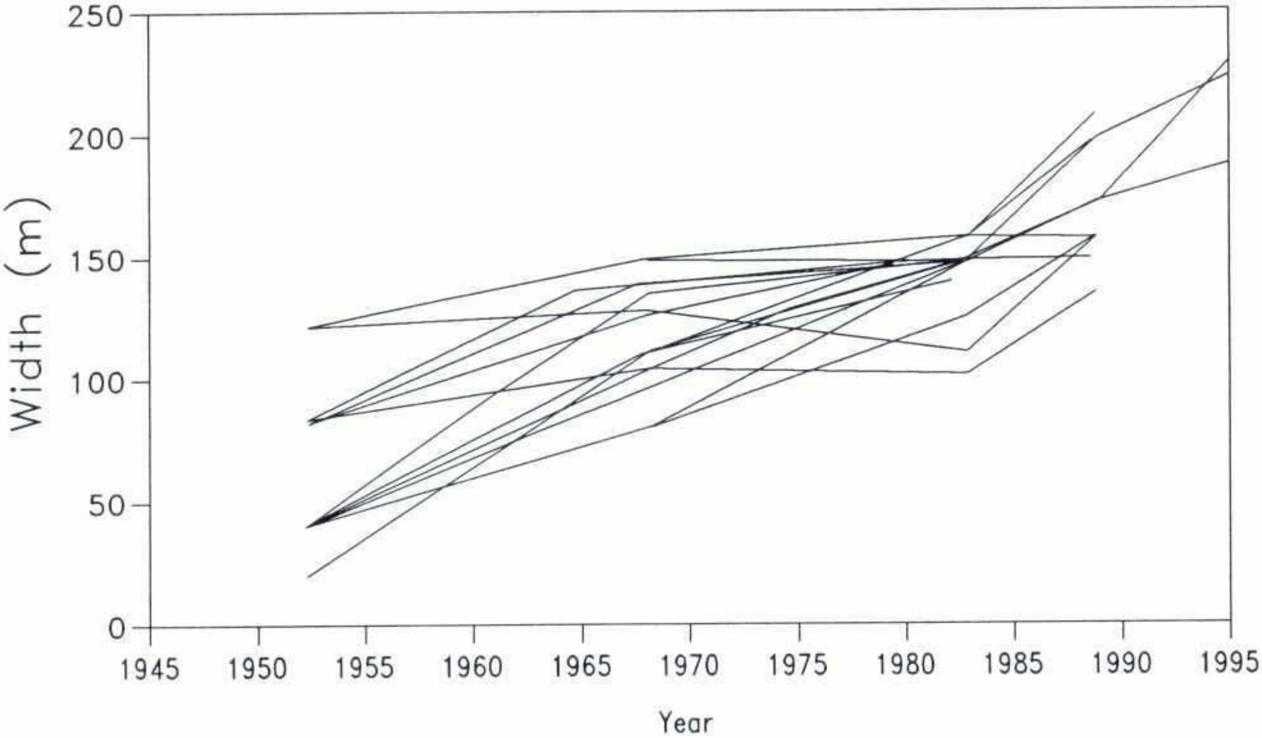
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED–022.DWG

Figure A.47

D 89

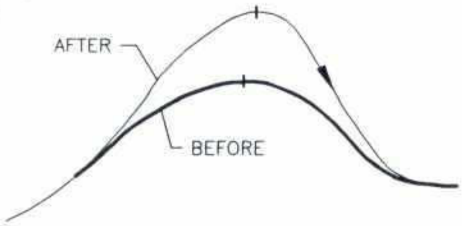
Channel Widening along Kalni-Kushiyara River



channel widths measured from topo maps

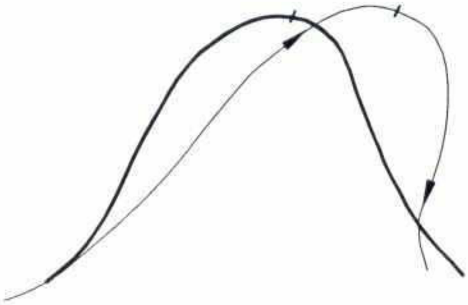
Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Channel Widening on Kalni-Kushiyara River	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-064.DWG



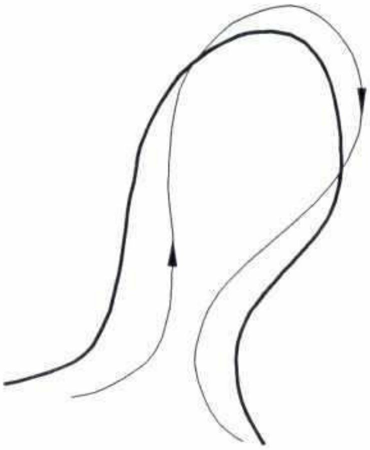
A–EXTENSION

B–TRANSLATION



C–ROTATION

D–CONVERSION TO A
COMPOUND MEANDER



E–NECK CUTOFF

F–CHUTE CUTOFFS
(FROM BRICE, 1974)

Northeast Regional Project

Kalni–Kushiyara River Management Project

Meander Changes

Prepared by: D.G.M.

Computer Drafting by: Mamun

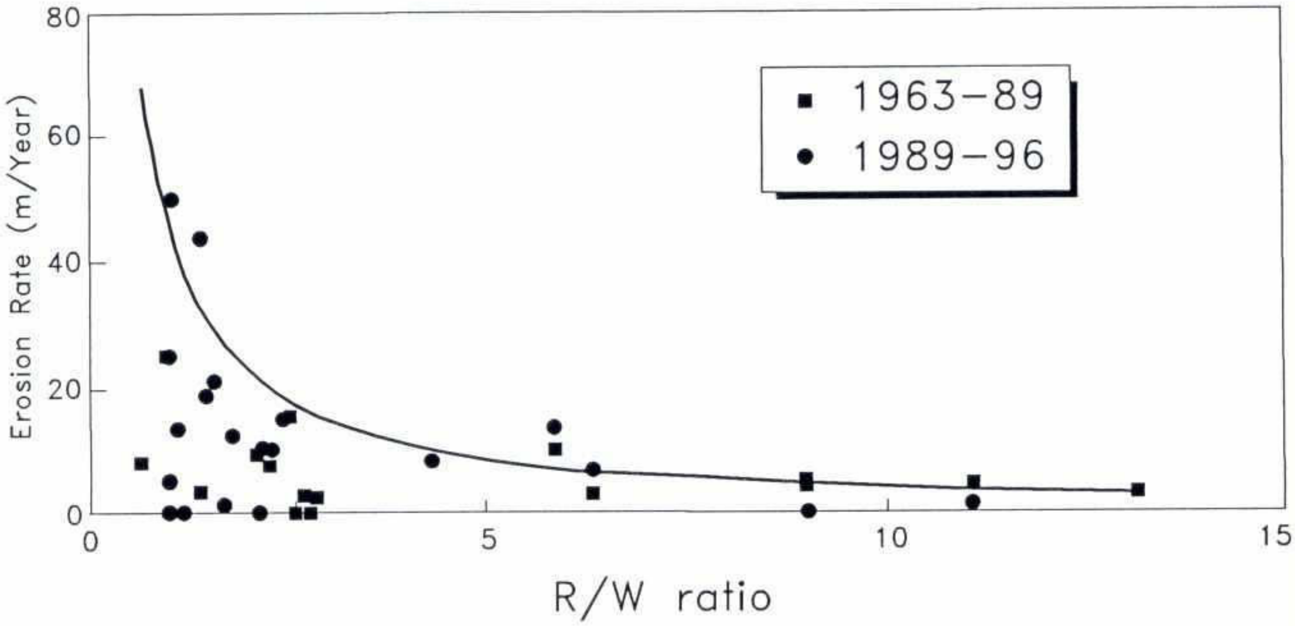
December 1997

FILE: SED–023.DWG

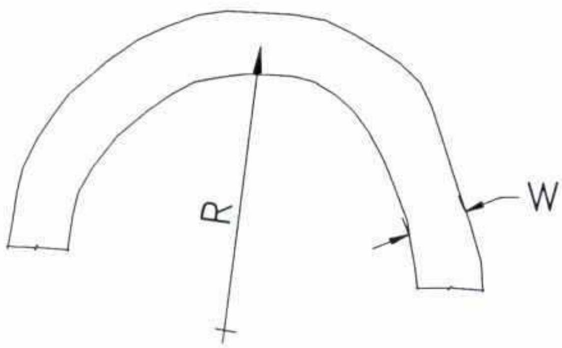
Figure A.49

280

Bank Erosion in Bends



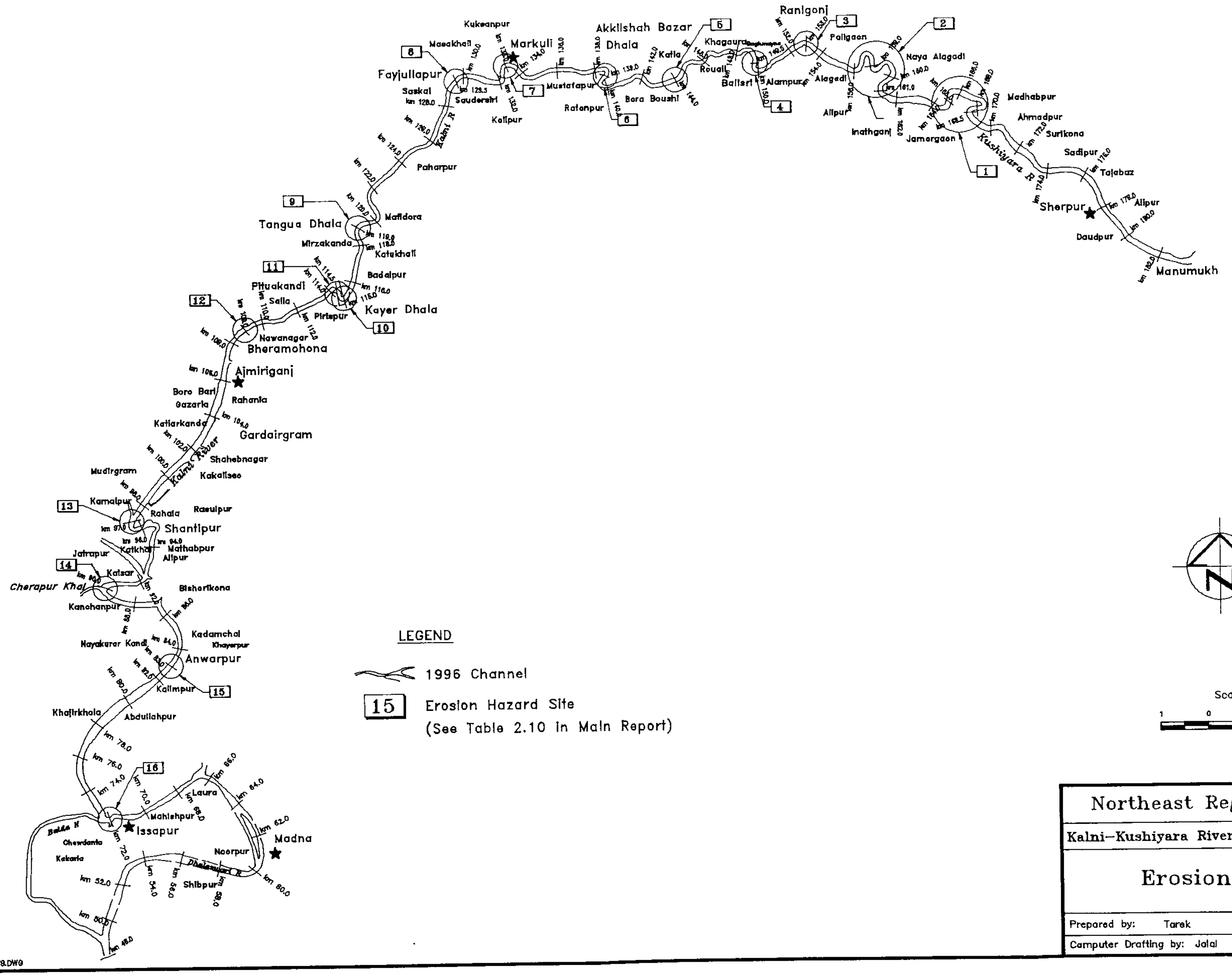
width measured at bend entrance



Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Rates of Erosion on Kalni-Kushiyara River	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-024.DWG

200



LEGEND

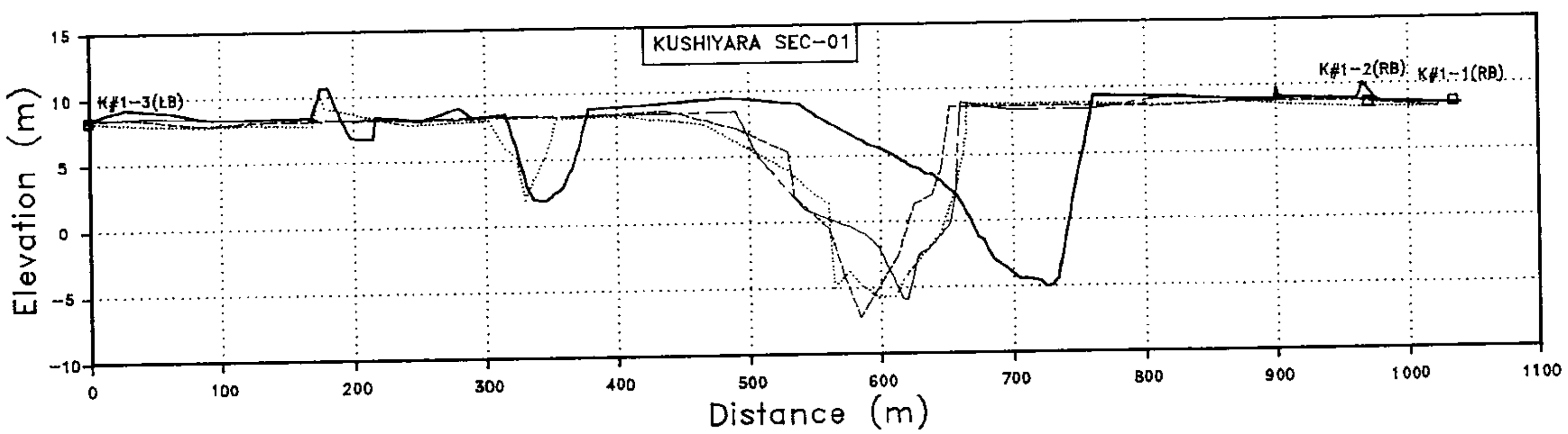
1996 Channel

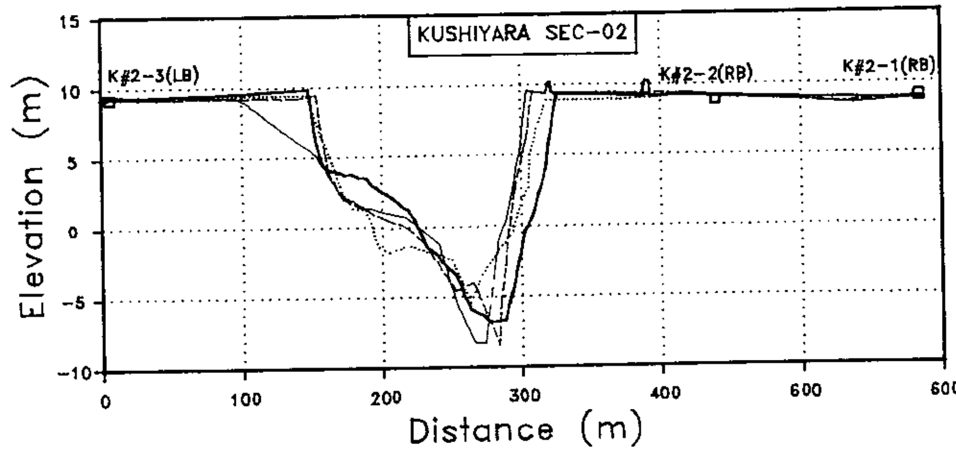
15 Erosion Hazard Site
(See Table 2.10 in Main Report)

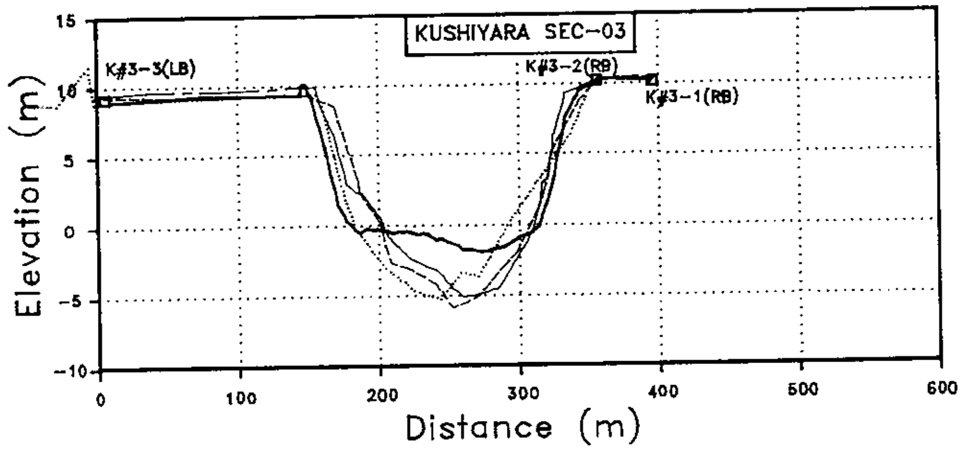
Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Erosion Hazard	
Prepared by: Tarek Computer Drafting by: Jalal	December 1997

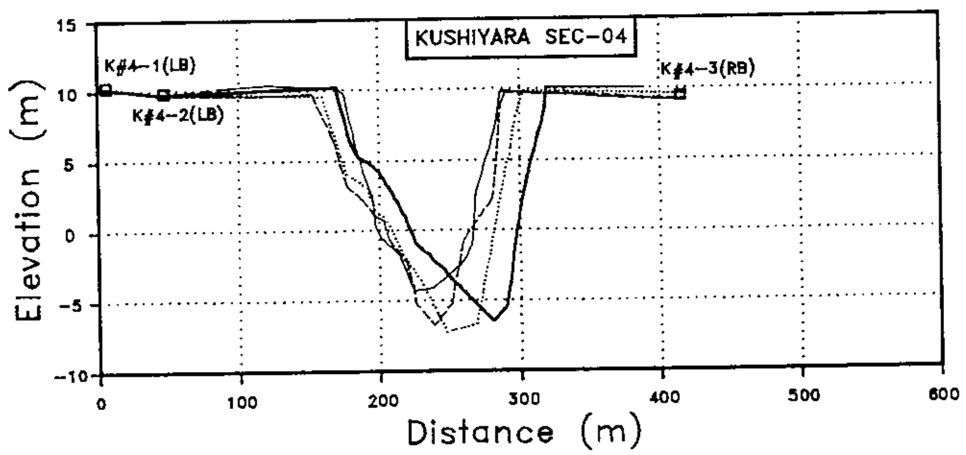
FILE: SED-078.DWG

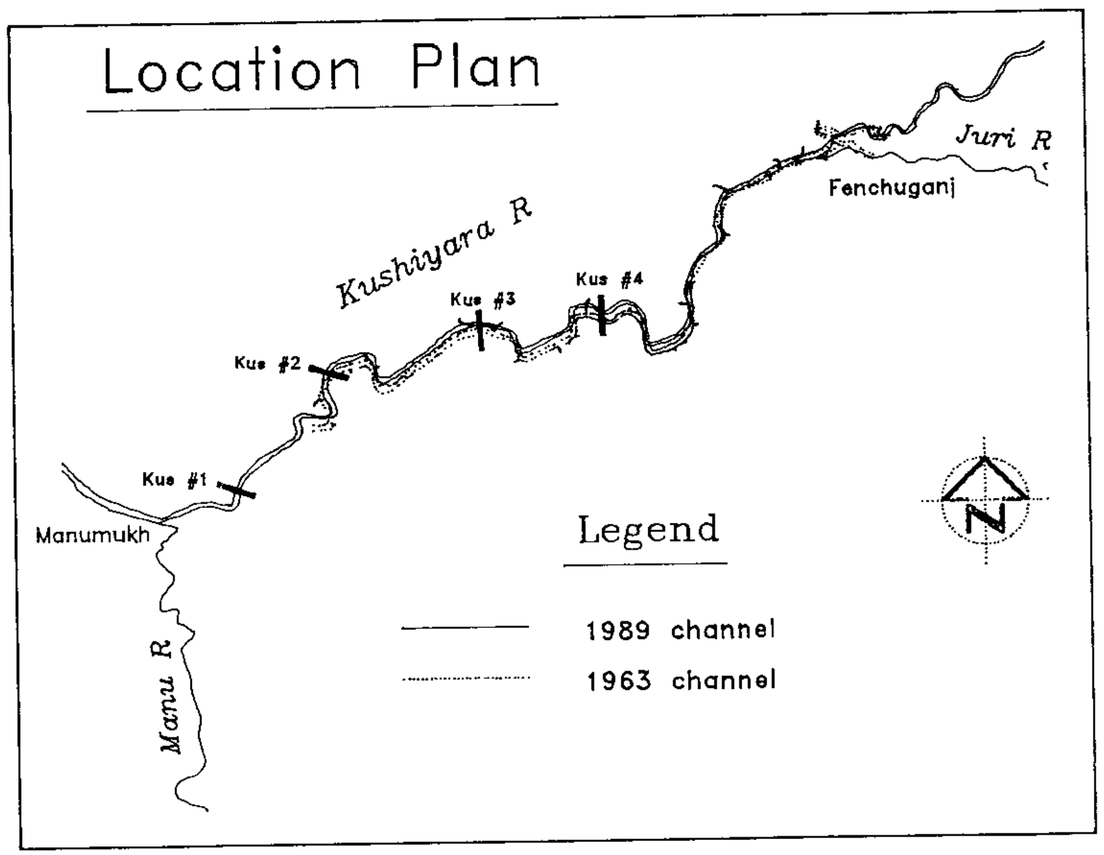
Figure A.51











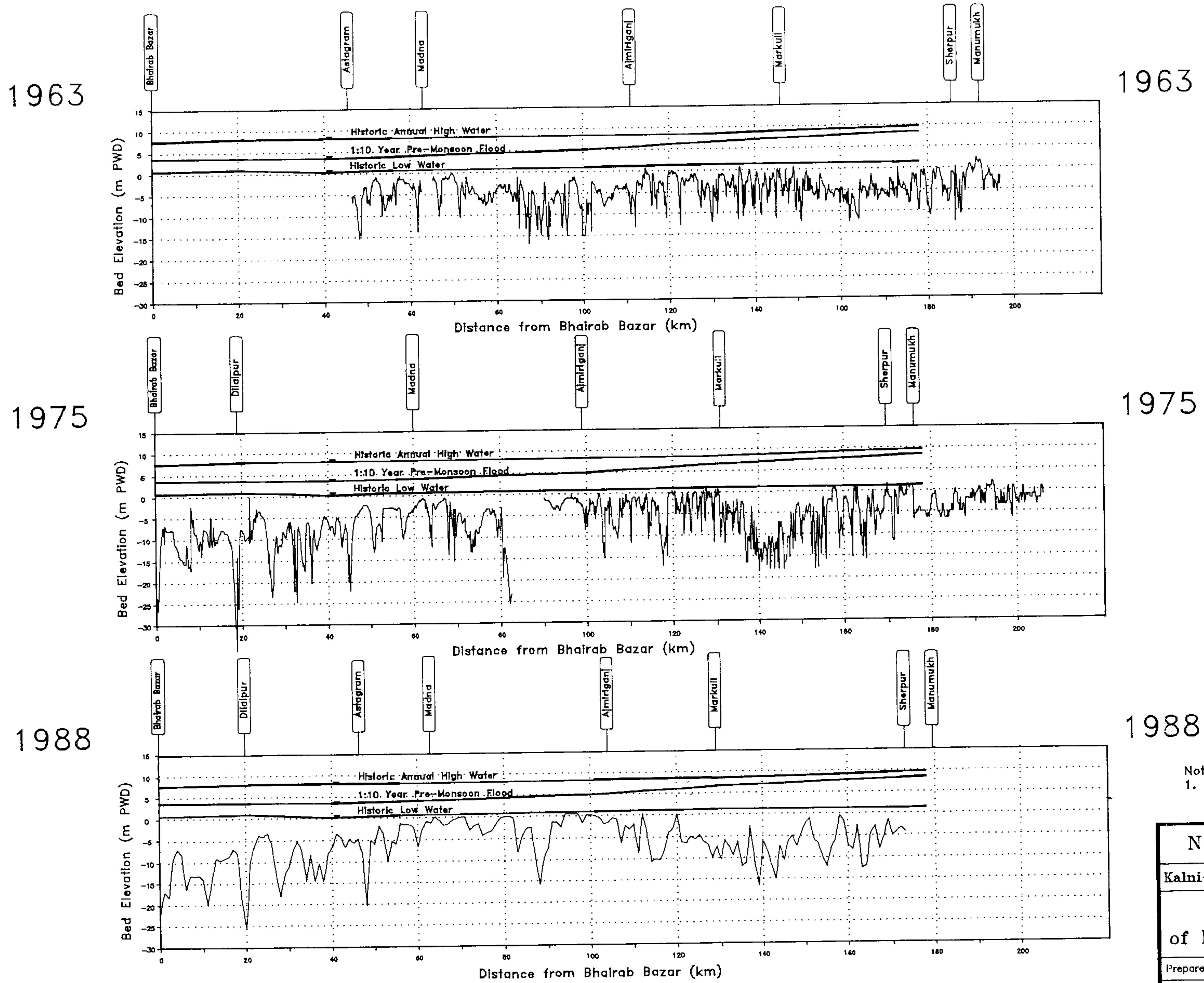
Legend

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

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Upper Kushiyara River Cross Section Comparisons	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Jalal	

FILE: SED-025.DWG

Figure A.52

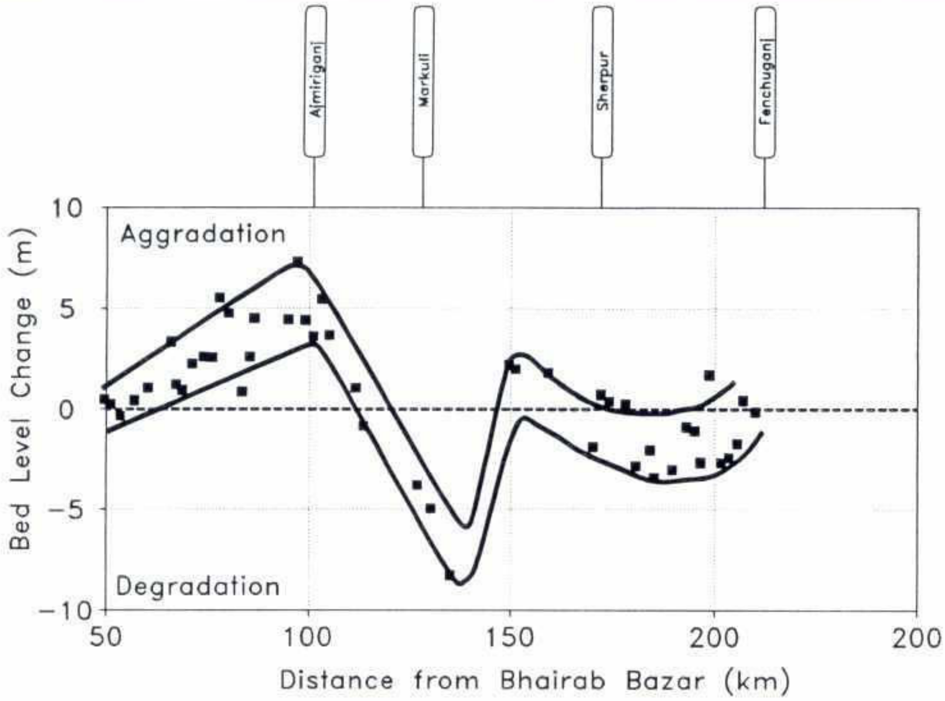


Note:
1. Bed levels from BIWTA navigation charts

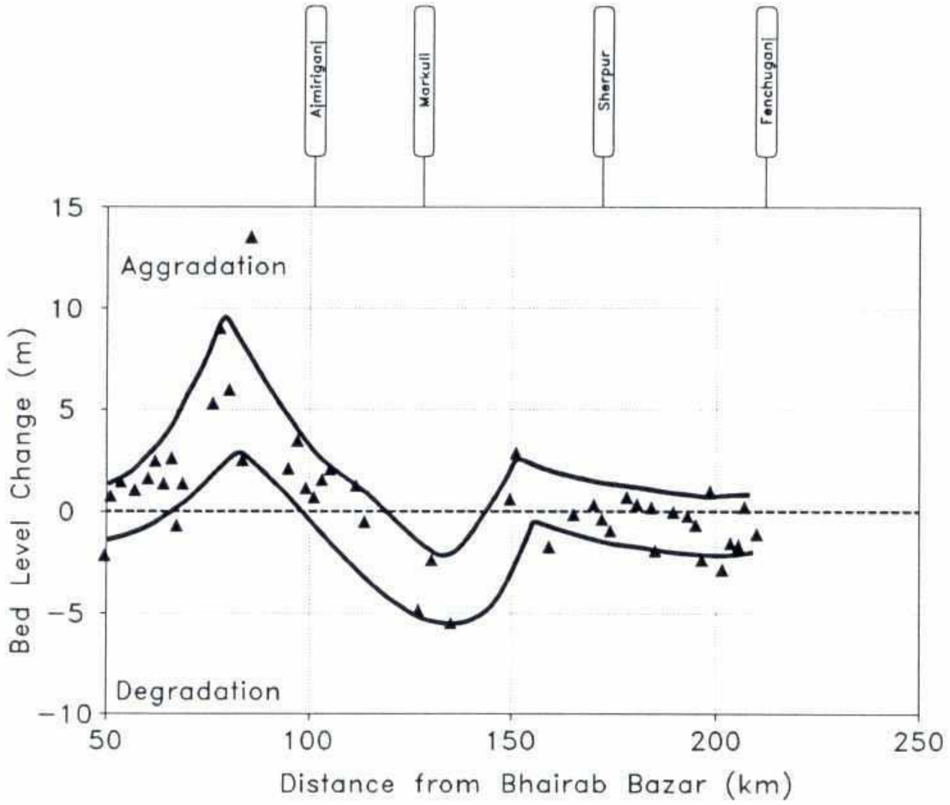
Northeast Regional Project
Kalni-Kushiyara River Management Project
Longitudinal Profile of Kushiyara River (1963-1988)
Prepared by: Tarek / Computer Drafting by: Jalal — December 1997

FILE: SED-026.DWG

Figure A.53



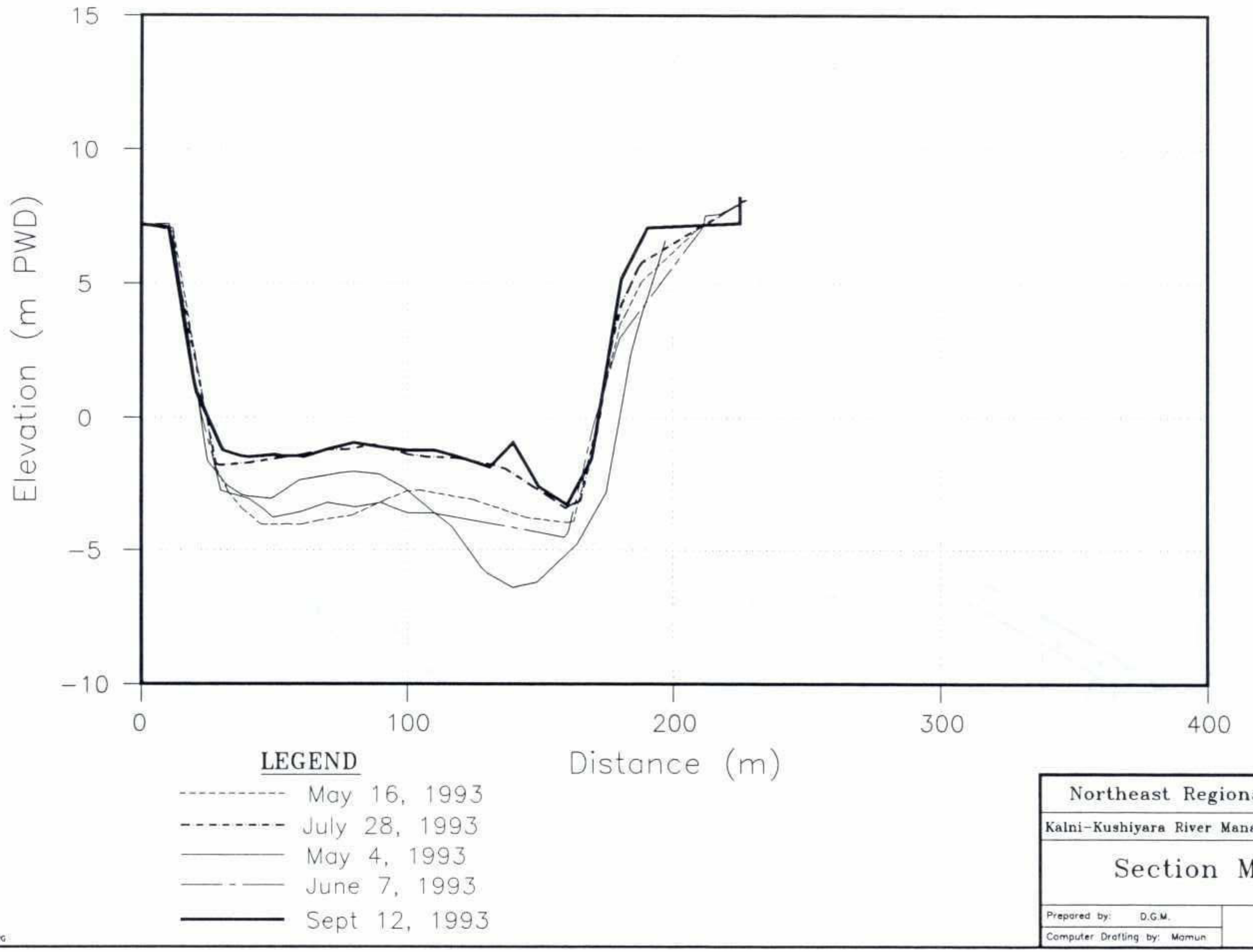
1963–1988



1975–1988

Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Bed Level Changes Kushiyara River	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-027.DWG



FILE: SED-028.DWG

Northeast Regional Project

Kalni-Kushiyara River Management Project

Section M-38

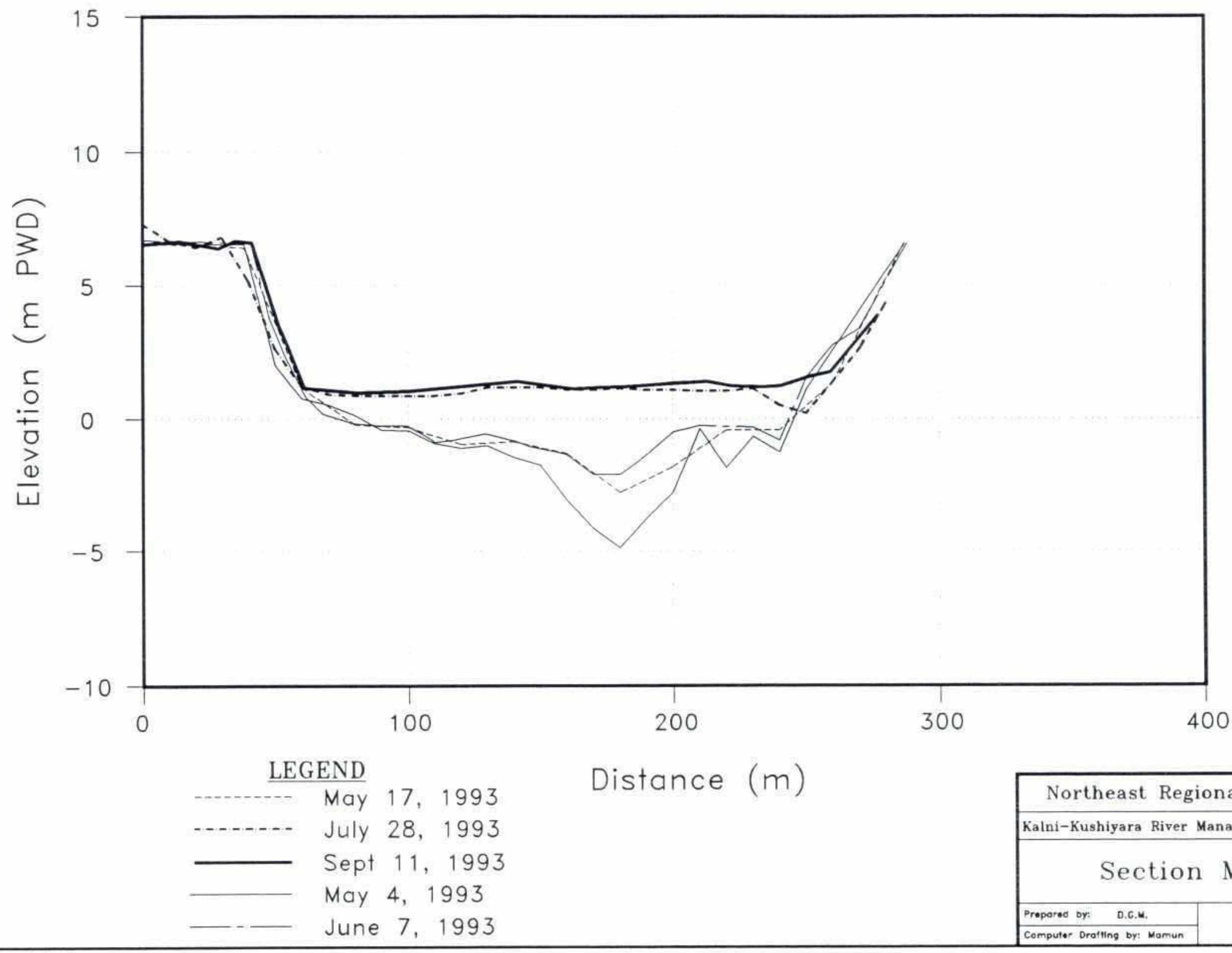
Prepared by: D.G.M.

Computer Drafting by: Mamun

December 1997

Figure A.54

Figure A.55



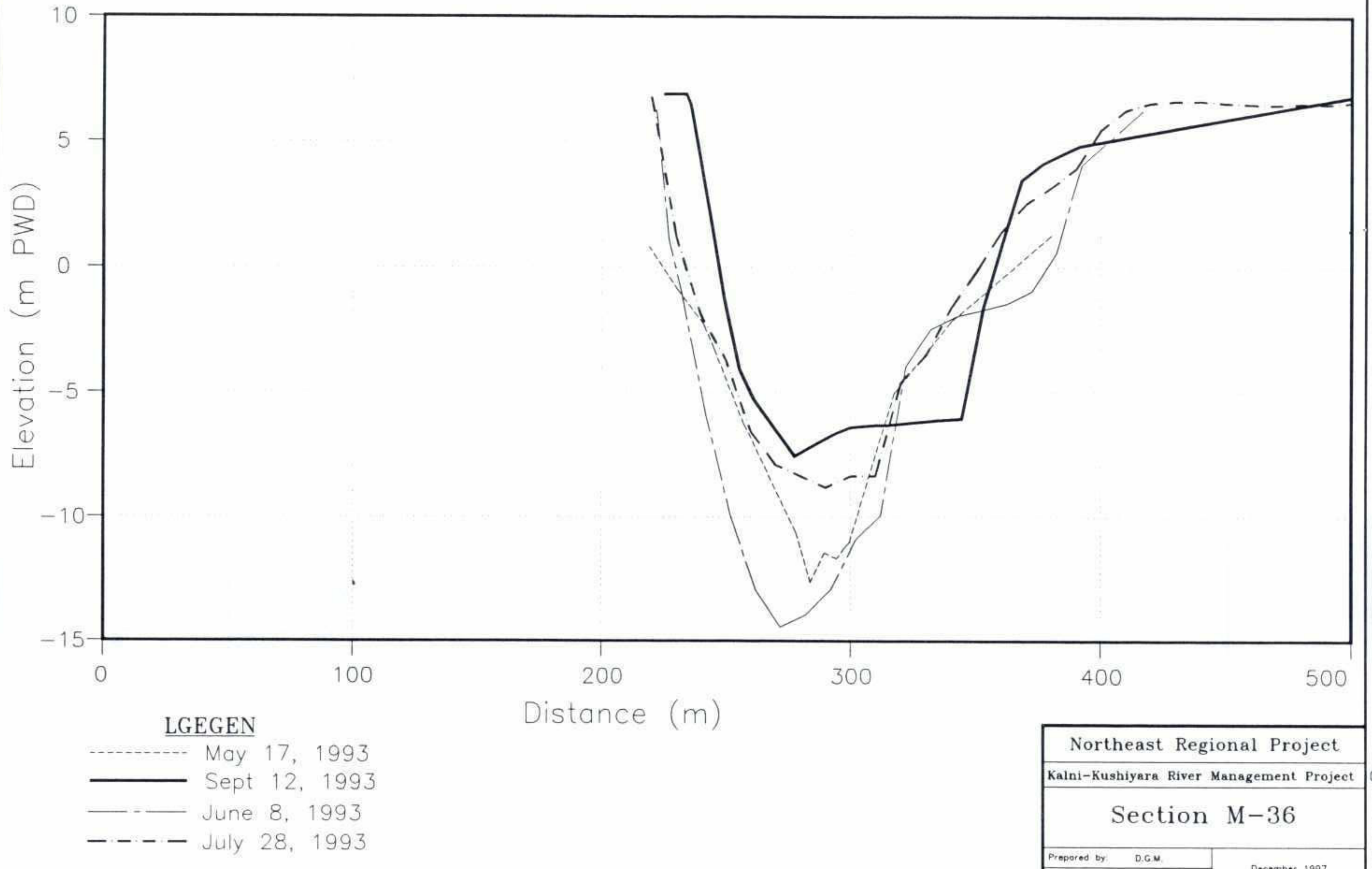
Northeast Regional Project

Kalni-Kushiyara River Management Project

Section M-37

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-029.DWG



Northeast Regional Project

Kalni-Kushiyara River Management Project

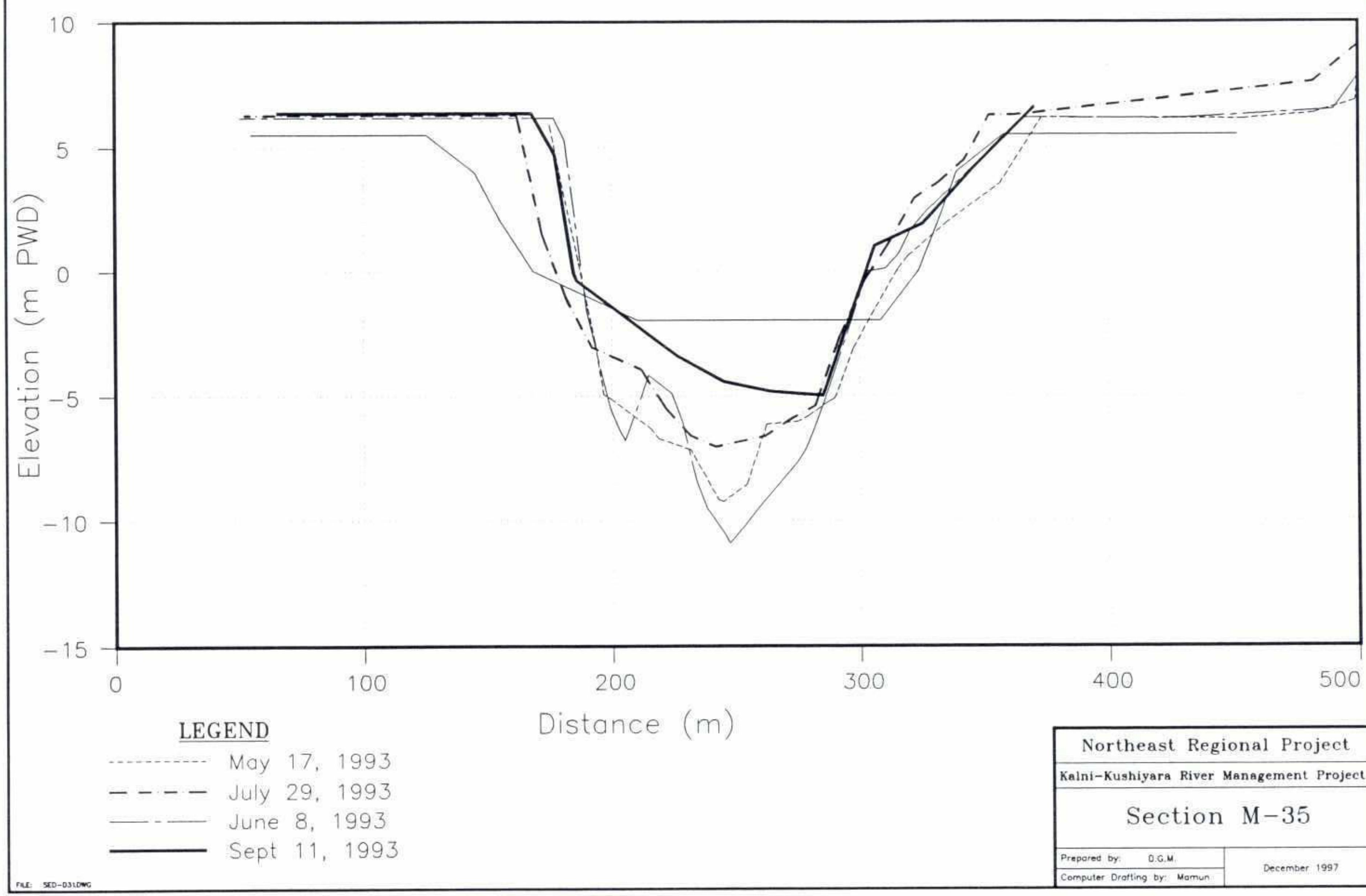
Section M-36

Prepared by: D.G.M.

Computer Drafting by: Mamun

December 1997

Figure A.56



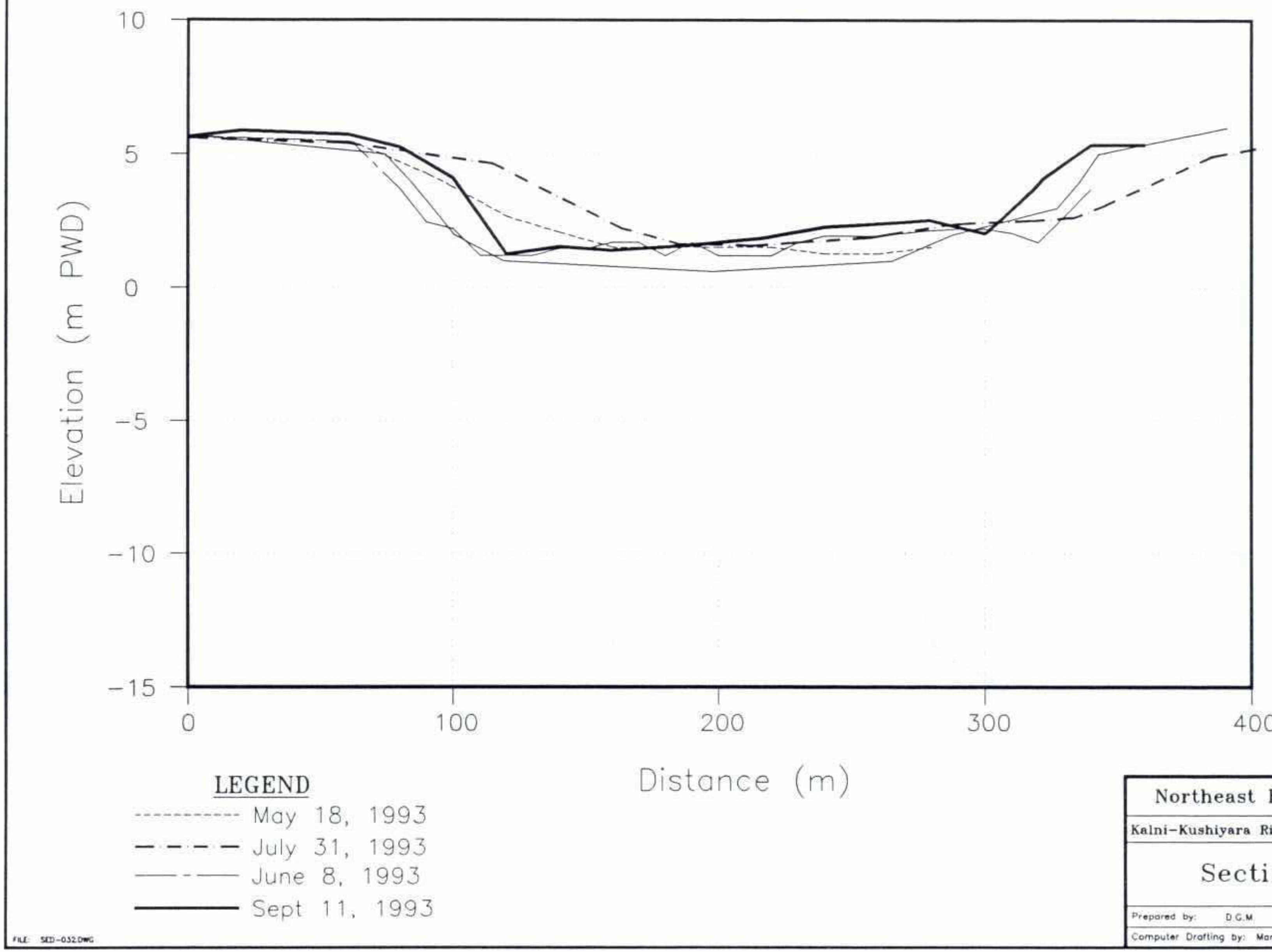
Northeast Regional Project

Kalni-Kushiyara River Management Project

Section M-35

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

Figure A.57



Northeast Regional Project

Kalni-Kushiyara River Management Project

Section M−34

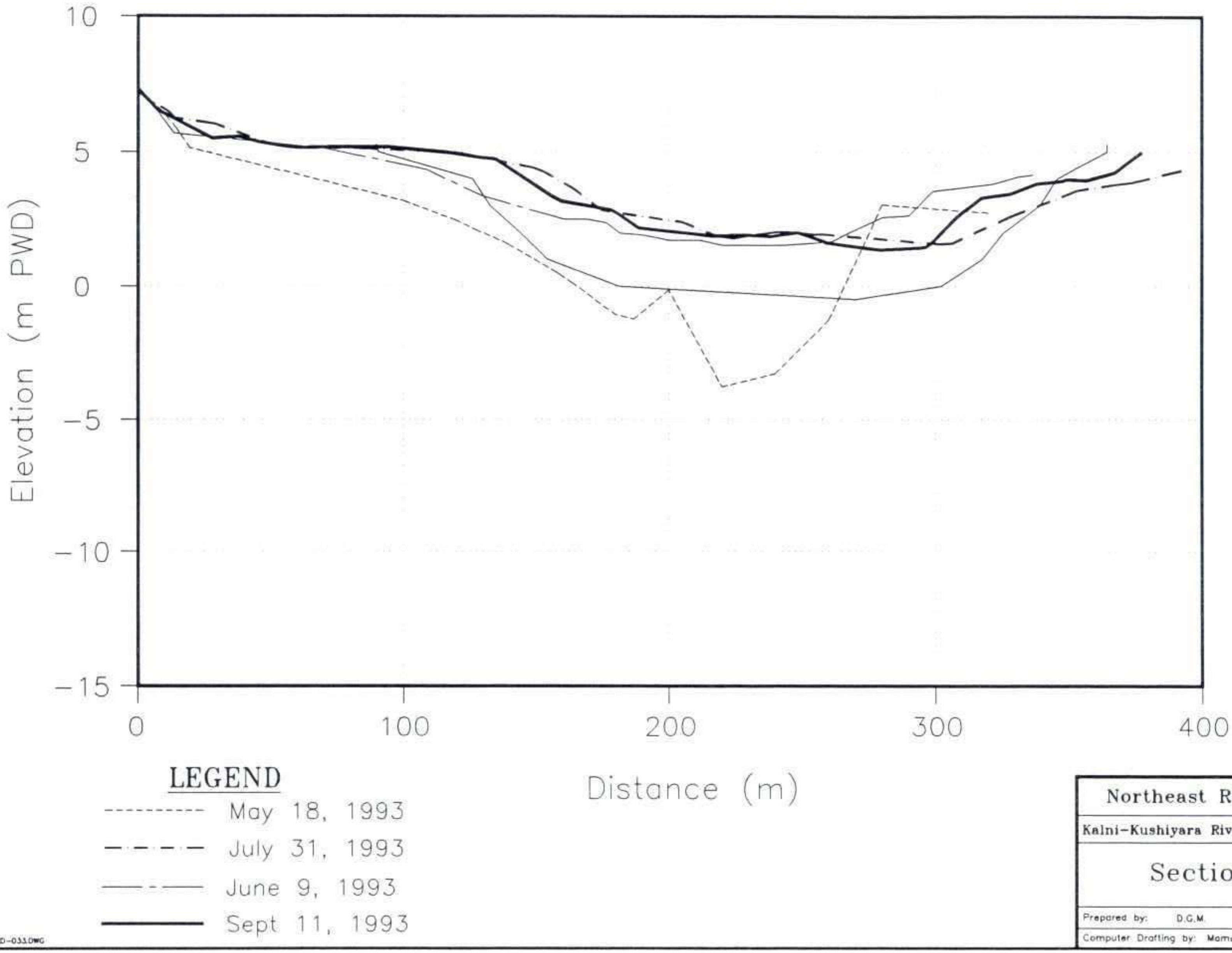
Prepared by: D.G.M

Computer Drafting by: Mamun

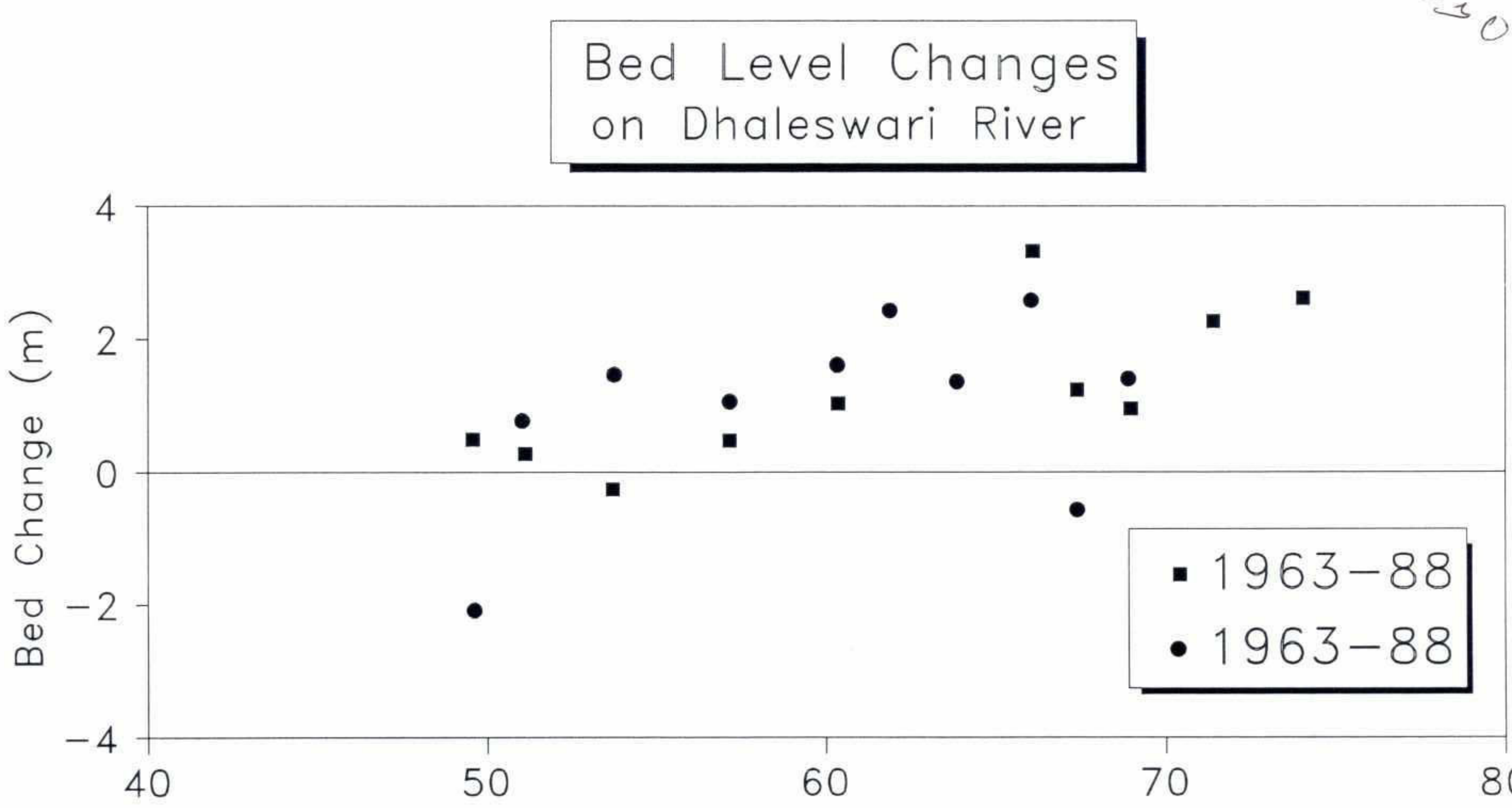
December 1997

Figure A.58

Figure A.59



Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Section M-33	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	



Northeast Regional Project

Kalni–Kushiyara River Management Project

Bed Level Changes on Dhaleswari River

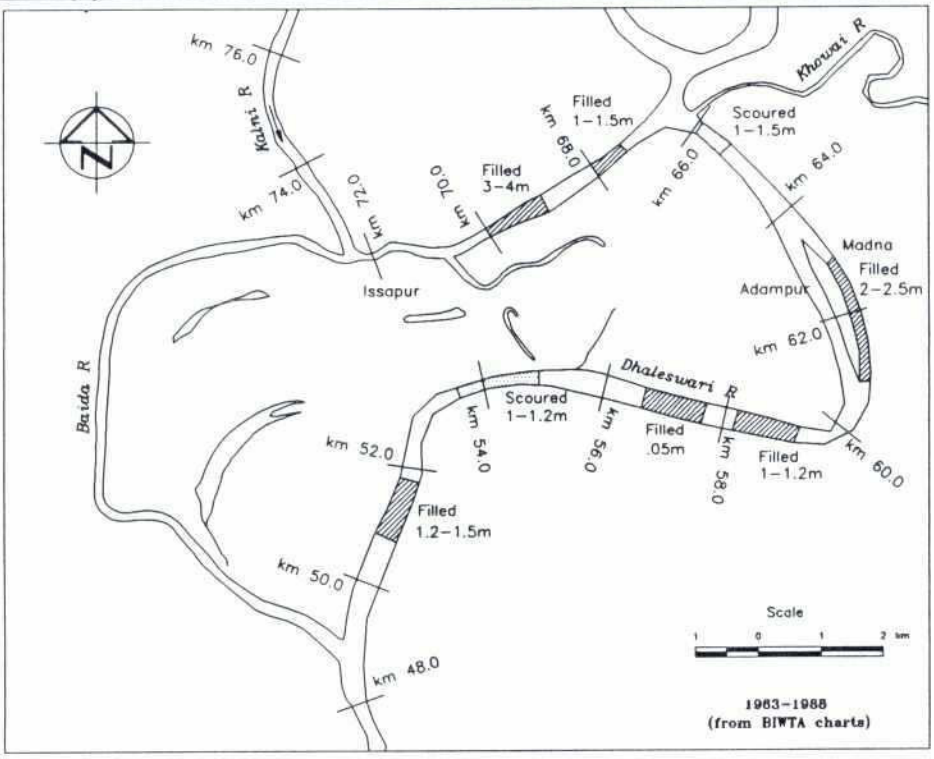
Prepared by: Tarek

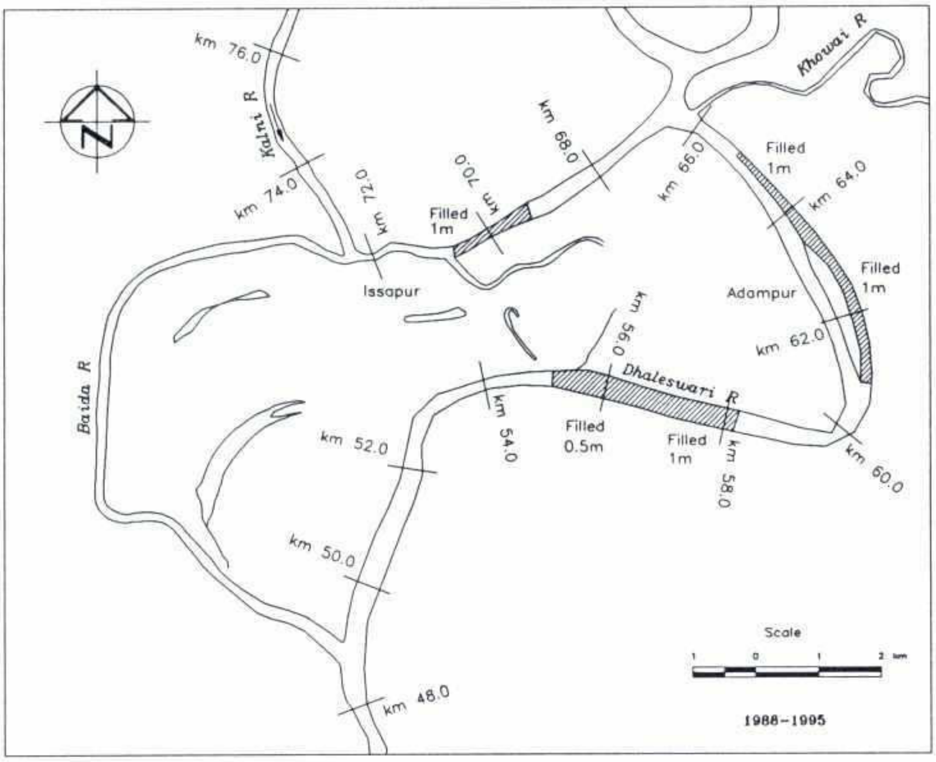
Computer Drafting by: Mamun

December 1997

FILE: SED-065.DWG

Figure A.60





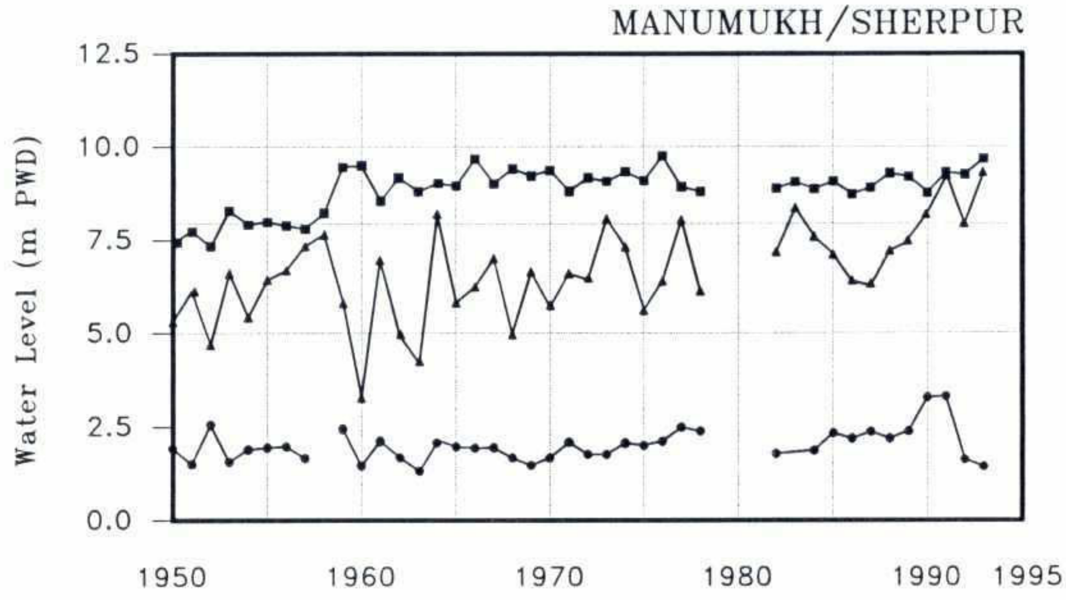
Northeast Regional Project

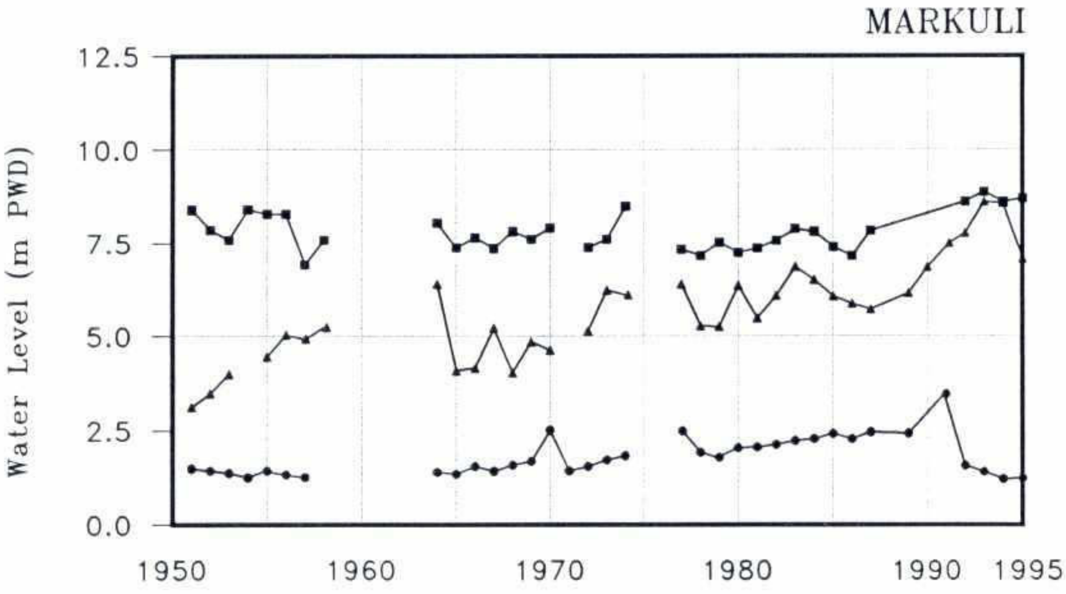
Kalni–Kushiyara River Management Project

General Pattern of Deposition on Dhaleswari River

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED–034.DWG





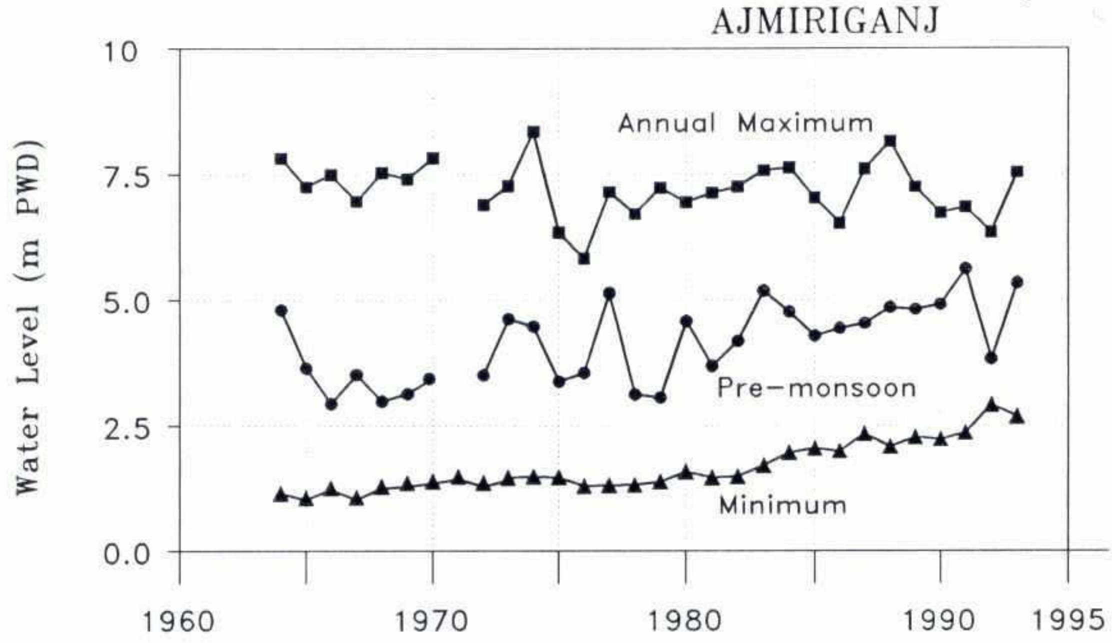
LEGEND

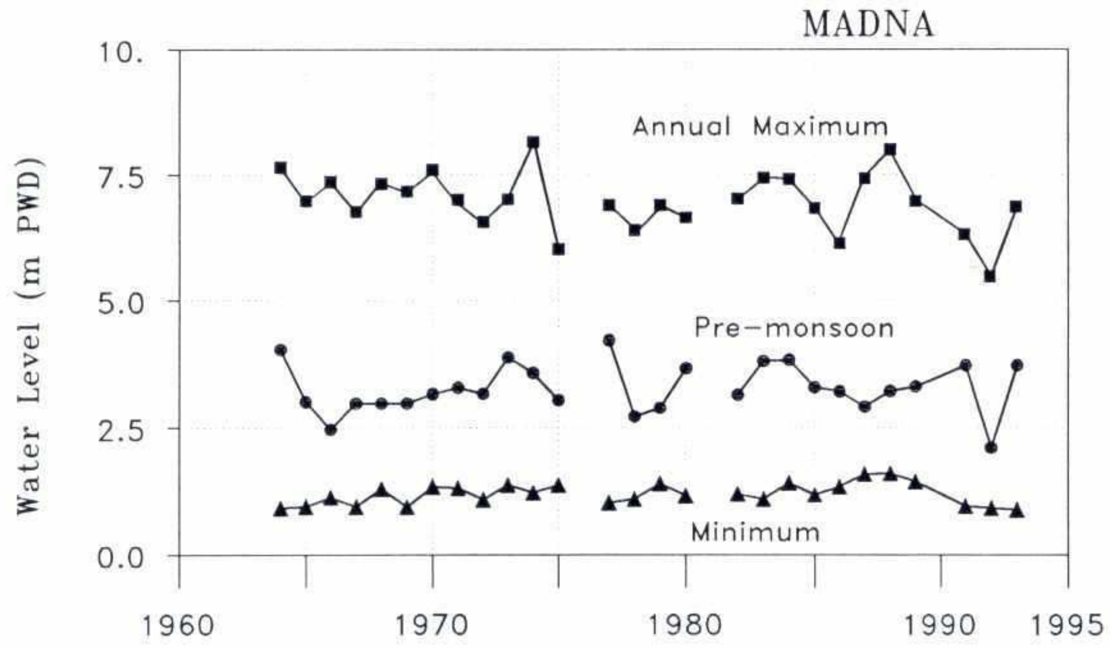
- ▪ Annual Maximum
- ▴ Pre-Monsoon
- • Minimum

FILE: SED-056.DWG

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Annual Water Levels Kushiyara River	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

Figure A.63



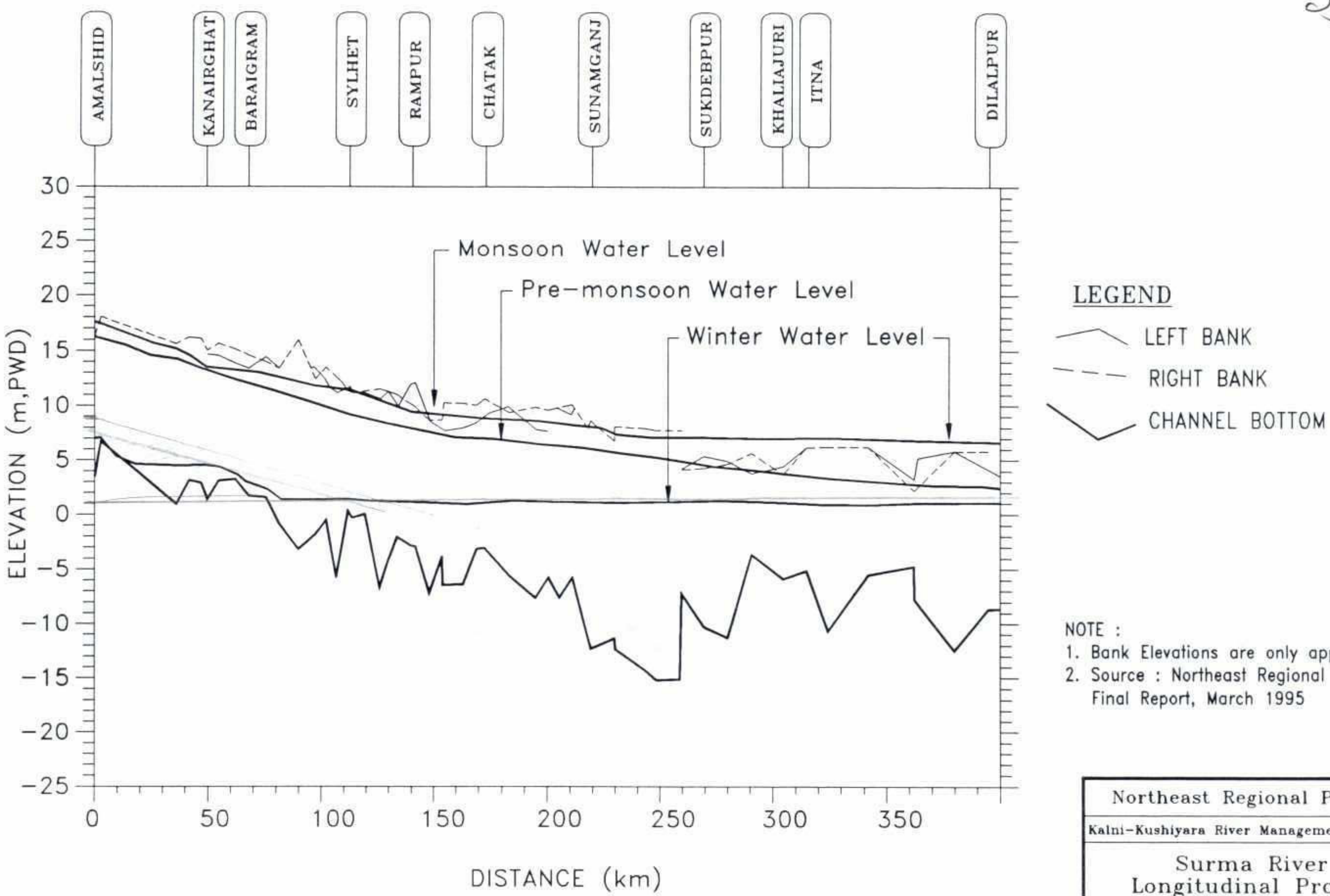


LEGEND
- ■ Annual Maximum
- ● Pre-monsoon
- ▲ Minimum

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Annual Water Levels Kalni River	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-057.DWG

Figure A.64



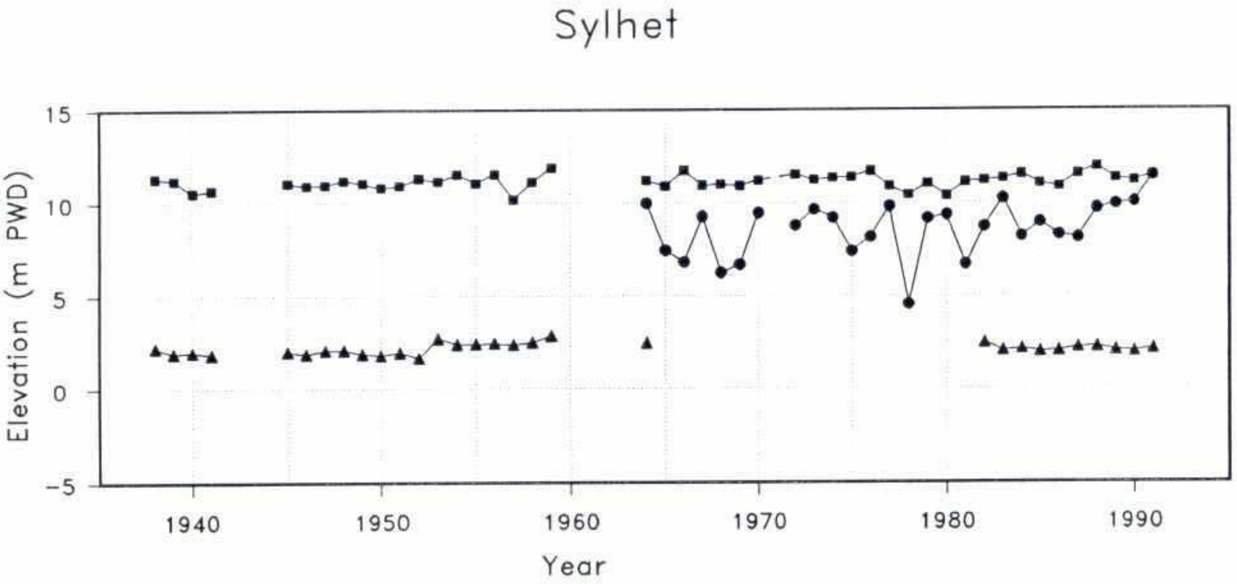
NOTE :

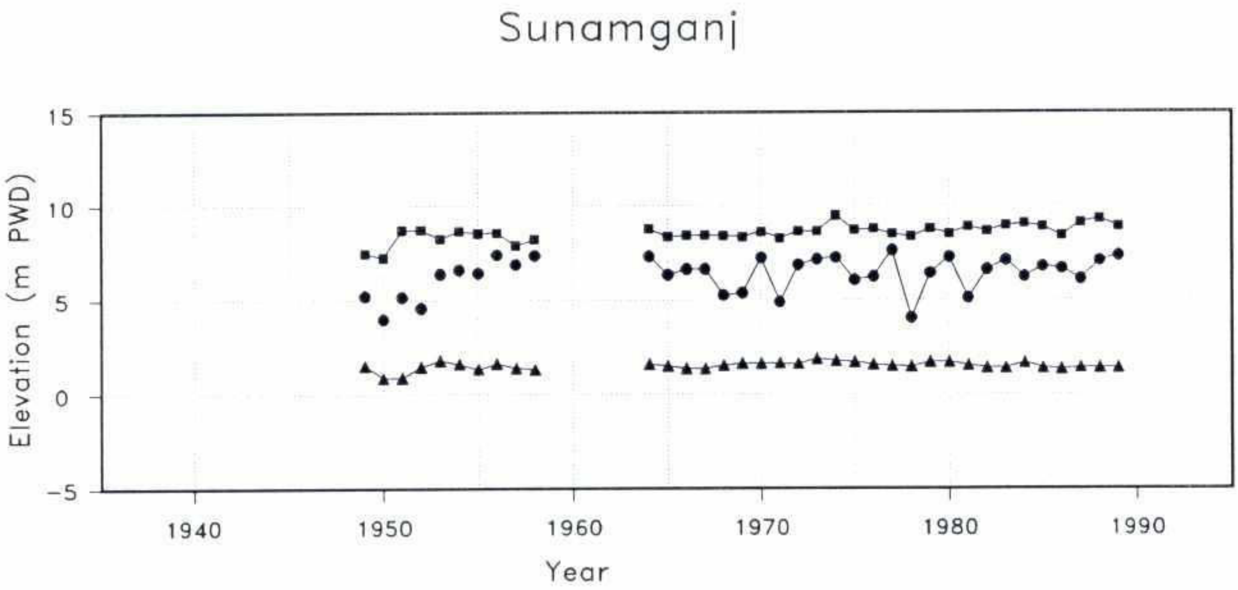
1. Bank Elevations are only approximate
2. Source : Northeast Regional Model, Final Report, March 1995

Northeast Regional Project
Kalni-Kushiyara River Management Project
Surma River Longitudinal Profile
Prepared by: / Computer Drafting by: Mamun — December 1997

FILE: SED-067.DWG

২৬৭





Legend

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

Northeast Regional Project

Kalni-Kushiyara River Management Project

Water Levels
Surma River

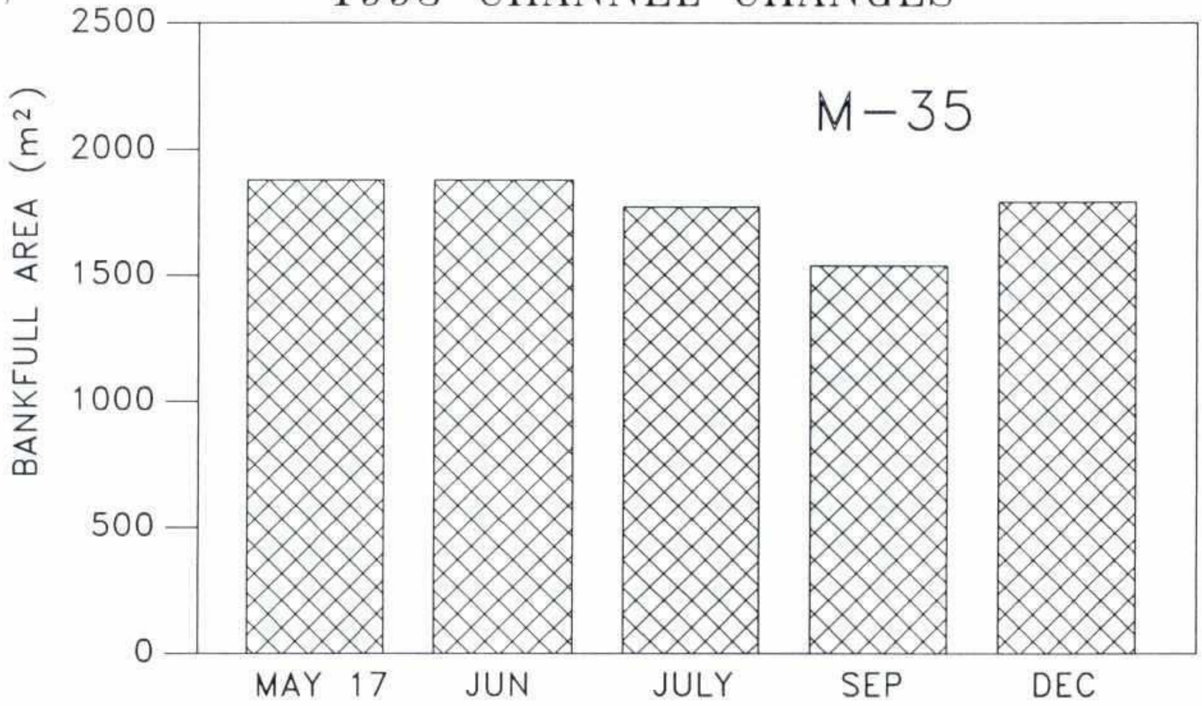
Prepared by: CHW

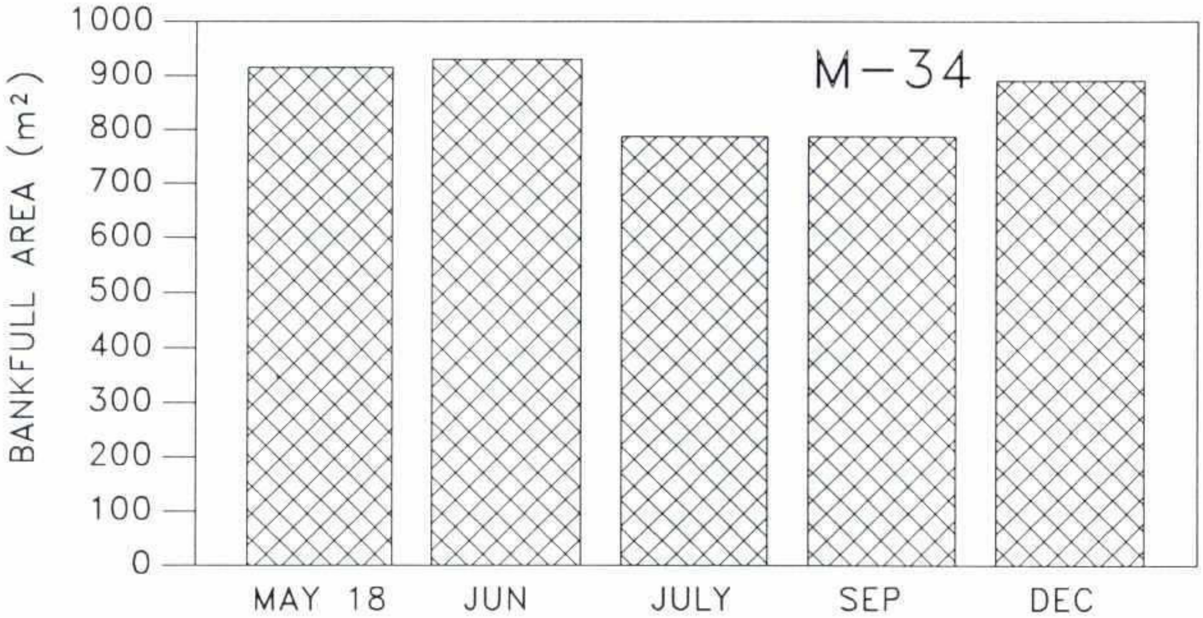
Computer Drafting by: Mamun

December 1997

FILE: SED-058.DWG

1993 CHANNEL CHANGES

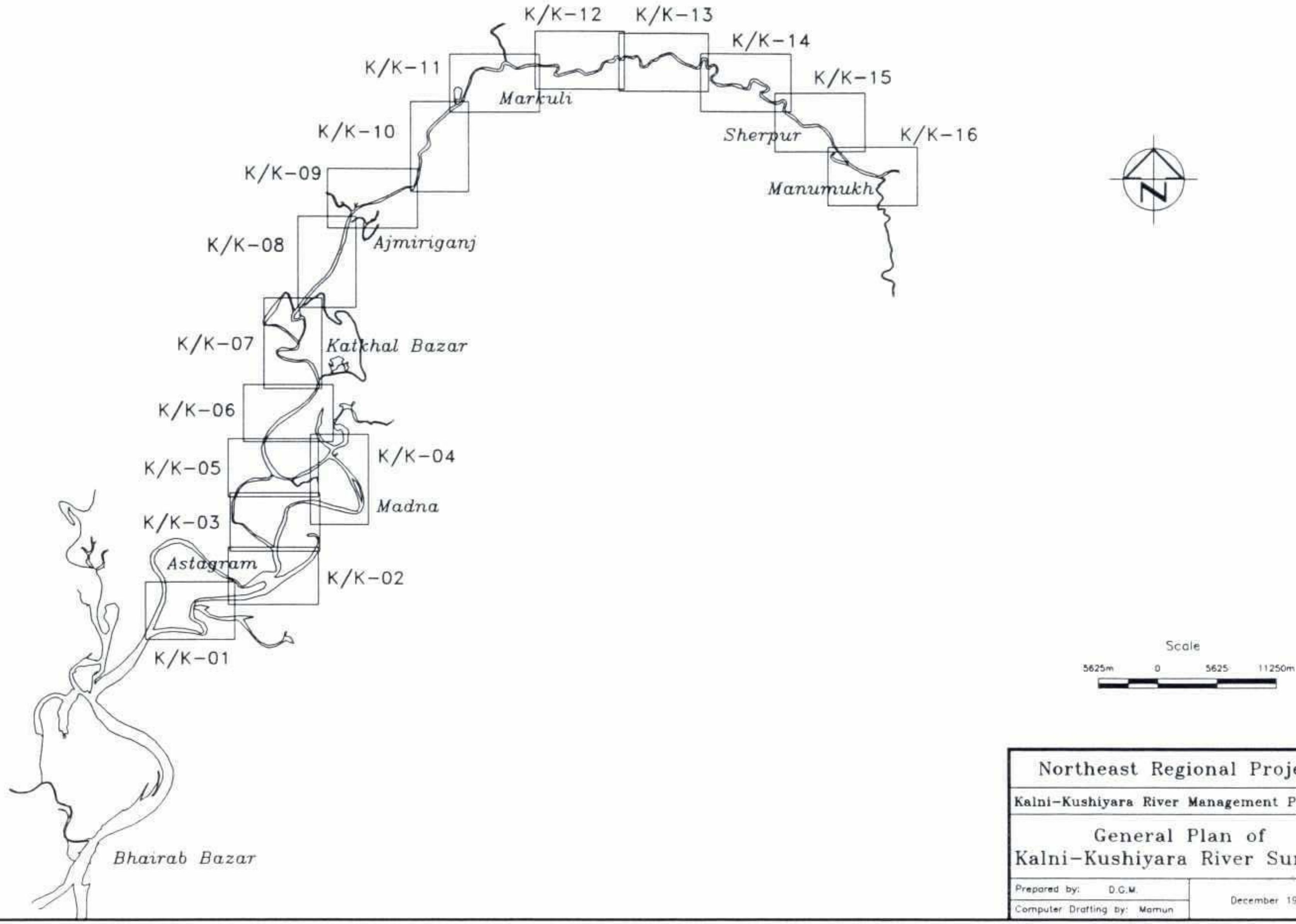




Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Seasonal Variations in Bankfull Area	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

FILE: SED-066.DWG

Figure A.67

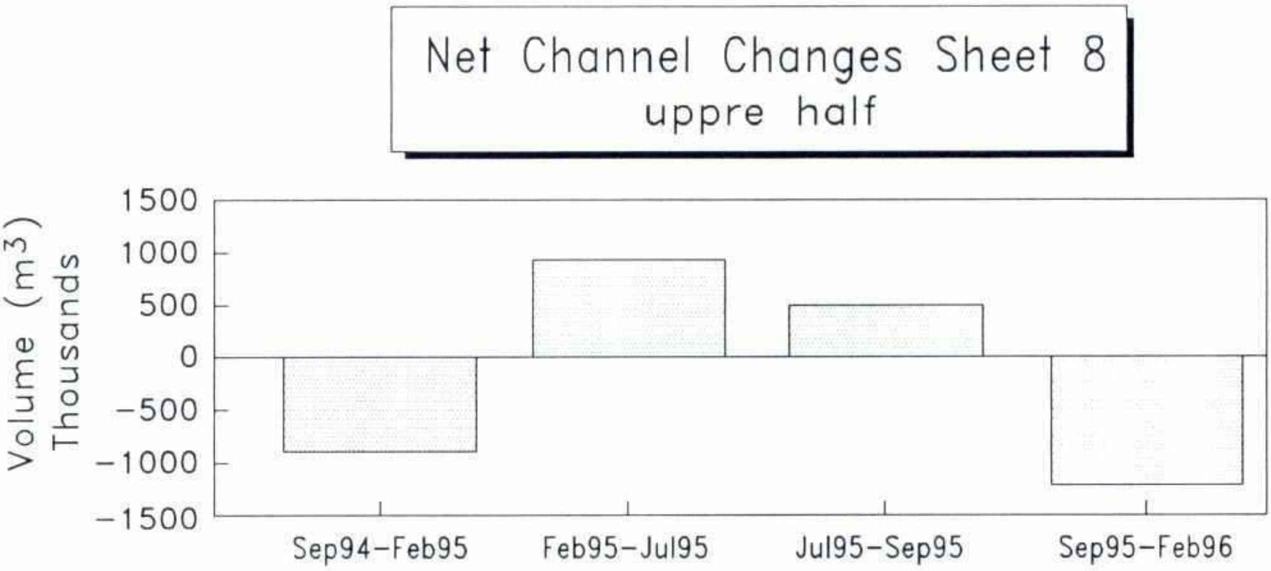


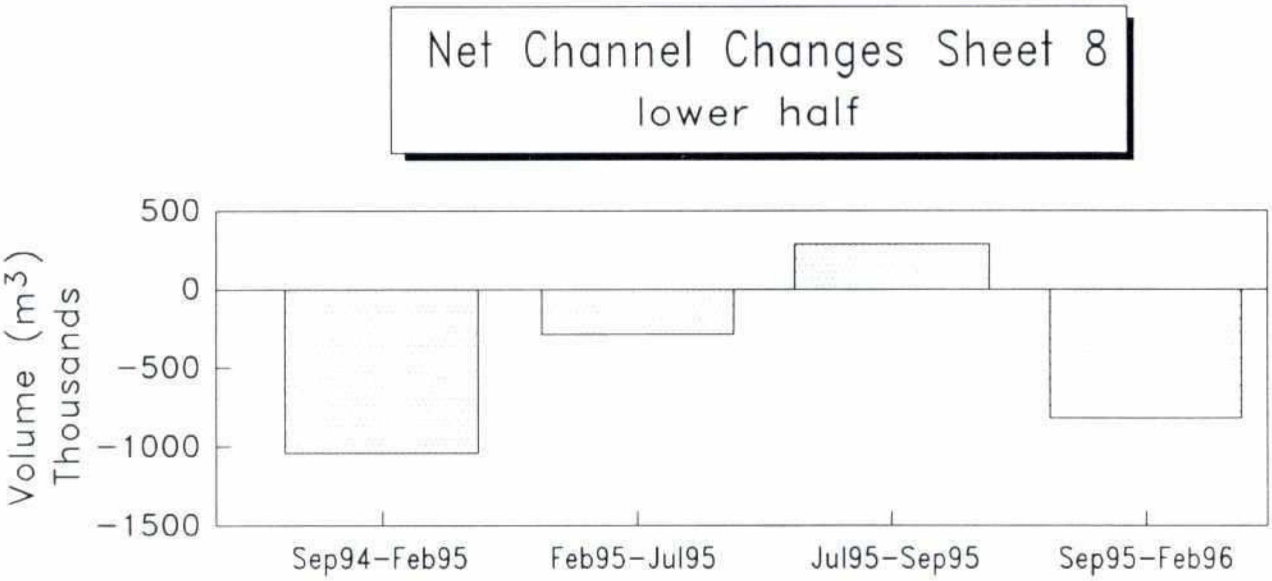
Northeast Regional Project

Kalni-Kushiyara River Management Project

General Plan of
Kalni-Kushiyara River Surveys

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	





Northeast Regional Project

Kalni-Kushiyara River Management Project

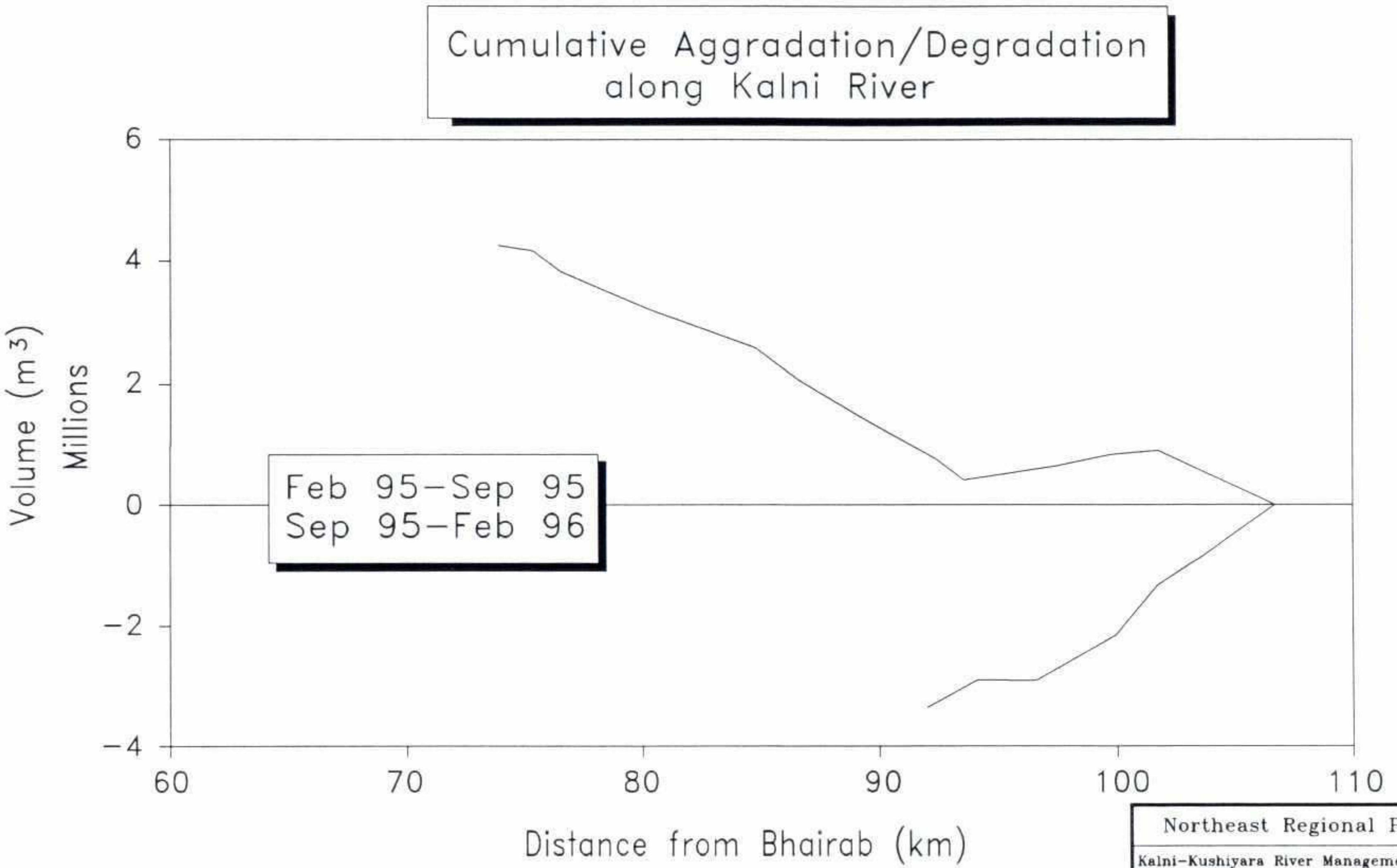
Scour and Fill near Ajmiriganj

Prepared by: Tarek

Computer Drafting by: Mamun

December 1997

FILE: SED-060.DWG



Northeast Regional Project

Kalni–Kushiyara River Management Project

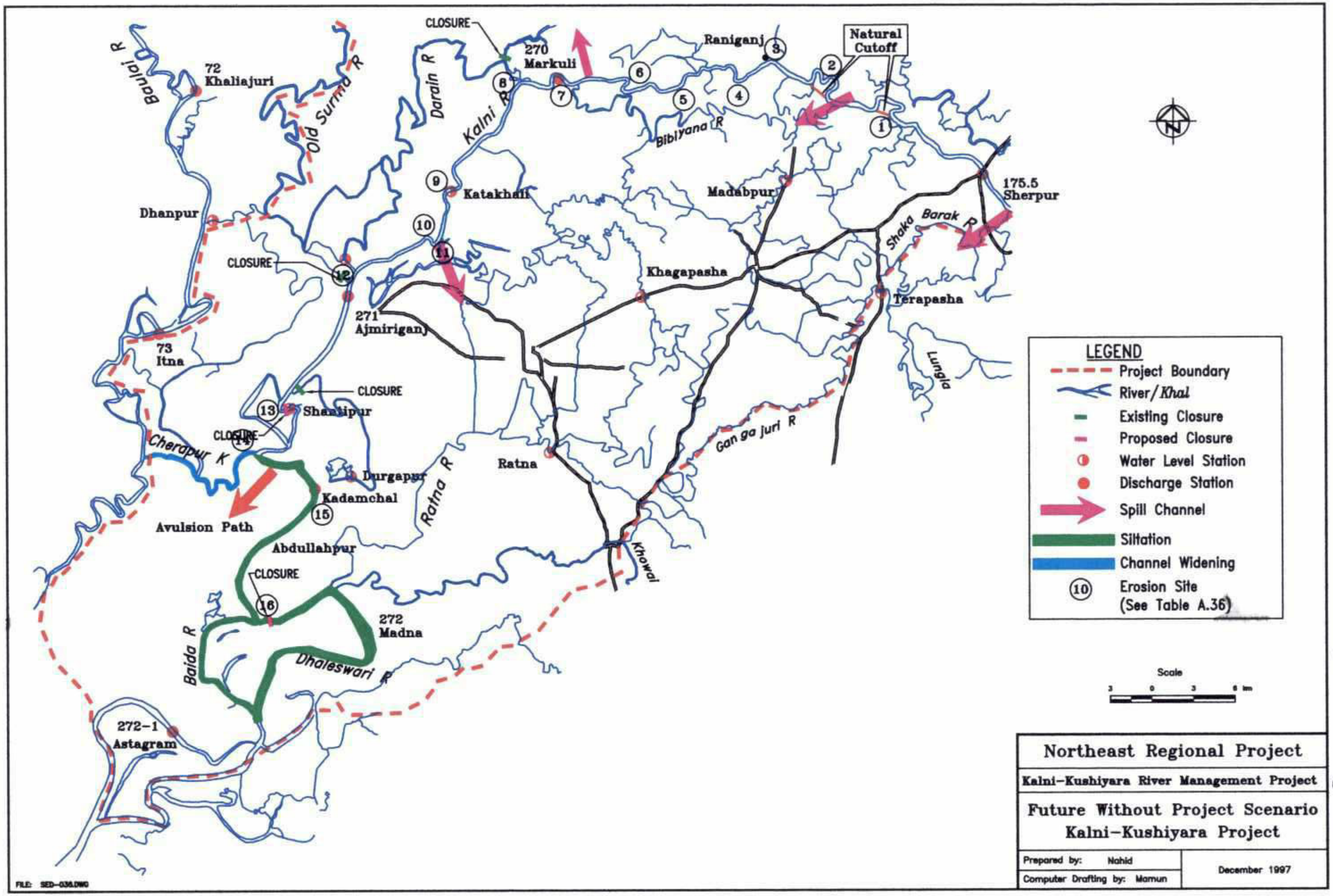
Cumulative Bed Level Changes Downstream of Ajmiriganj

Prepared by: Tarek | Computer Drafting by: Mamun | December 1997

FILE: SED-059.DWG

Figure A.69

Figure A.70



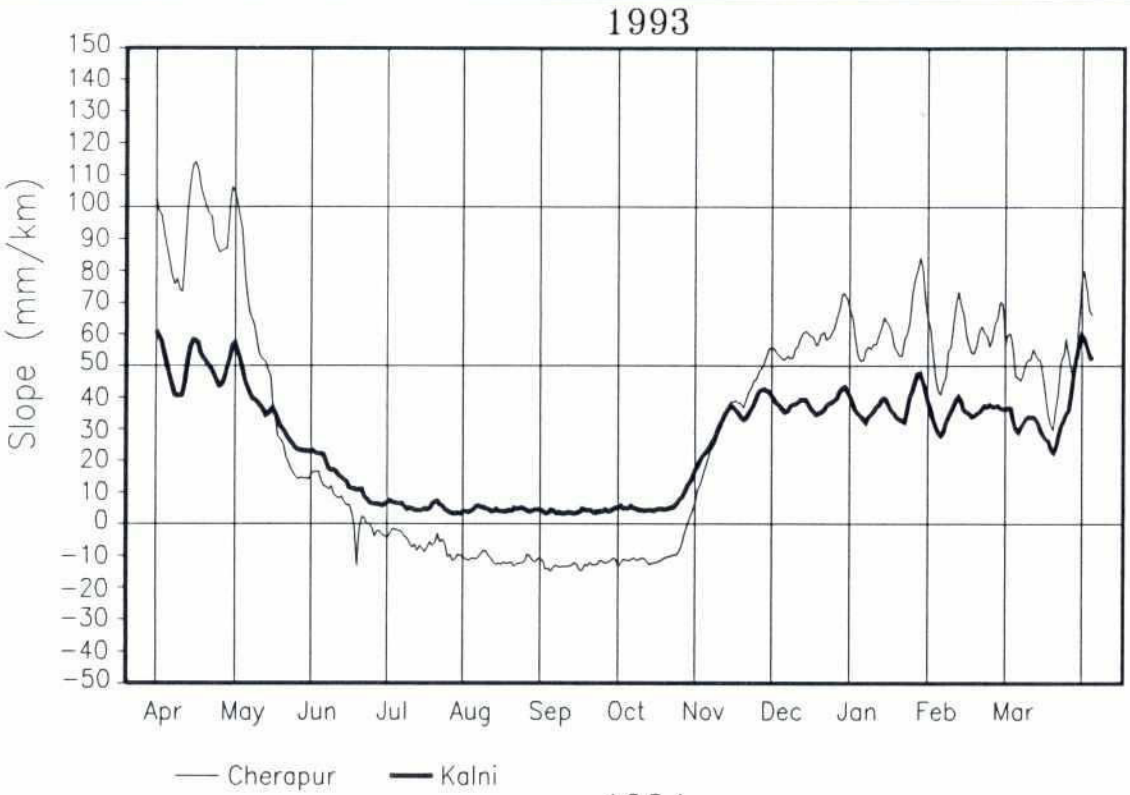
Northeast Regional Project

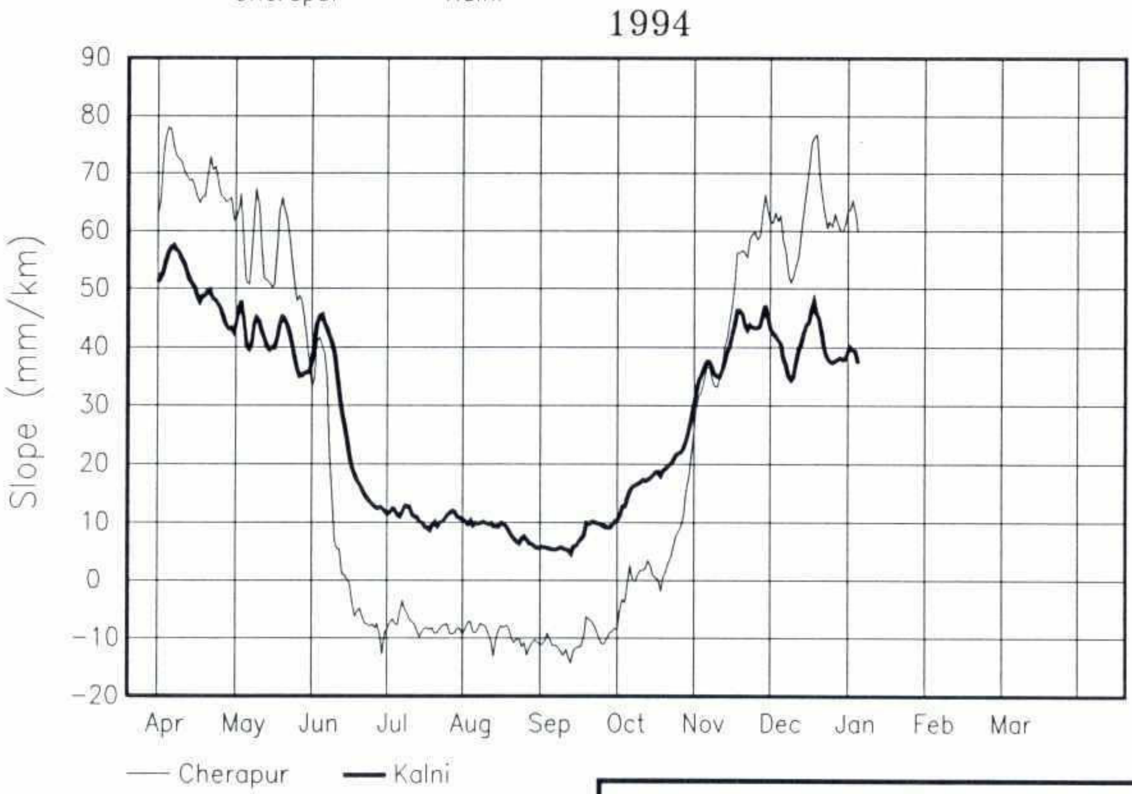
Kalni-Kushiyara River Management Project

Future Without Project Scenario
Kalni-Kushiyara Project

Prepared by: Nahid
Computer Drafting by: Mamun
December 1997

Figure A.71





Northeast Regional Project

Kalni-Kushiyara River Management Project

Comparison of Slope on Kalni River & Cherapur Khal

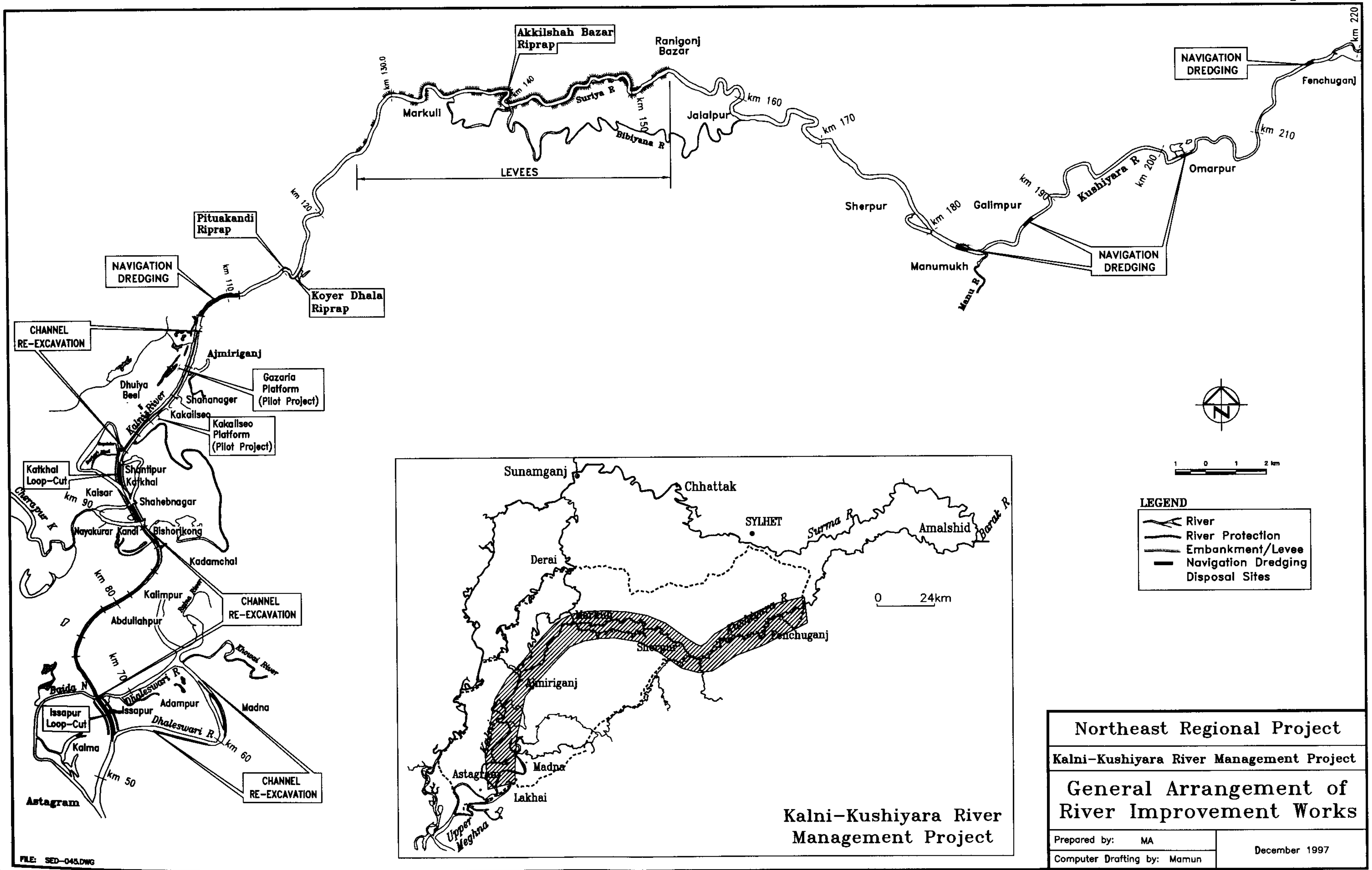
Prepared by: Tarek

Computer Drafting by: Mamun

December 1997

FILE: SED-042.DWG

Figure A.72


Akkilshah Bazar Riprap
Ranigonj Bazar
NAVIGATION DREDGING
Fenchuganj
Markuli
Suriya R
Jalalpur
Bibiyana R
LEVEES
km 130.0
km 140
km 150
km 160
km 170
km 180
km 190
km 200
km 210
km 220
km 120
km 110
Omarpur
Kushiyara R
Sherpur
Galimpur
Manumukh
Manu R
NAVIGATION DREDGING
Pituakandi Riprap
NAVIGATION DREDGING
Koyer Dhala Riprap
CHANNEL RE-EXCAVATION
Ajmiriganj
Gazaria Platform (Pilot Project)
Dhulya Beel
Kalni River
Shahanager
Kakailseo
Kakailseo Platform (Pilot Project)
Katkhal Loop-Cut
Shantipur
Katkhal
Kaisar
km 90
Shahebnagar
Cherapur K
Nayakurar
Kandi
Bishorikong
Kadamchal
km 80
Kalimpur
Abdullahpur
CHANNEL RE-EXCAVATION
Khowai River
km 70
Baida N
Dhaleswari R
Issapur Loop-Cut
Issapur
Adampur
Madna
Kalma
km 60
km 50
Astagram
CHANNEL RE-EXCAVATION
FILE: SED-045.DWG
Sunamganj
Chhattak
SYLHET
Surma R
Amalshid
Barak R
Derai
0 24km
Markuli
Kushiyara R
Sherpur
Fenchuganj
Ajmiriganj
Madna
Astagram
Lakhai
Upper Meghna
Kalni–Kushiyara River Management Project
N
1 0 1 2 km
LEGEND
River
River Protection
Embankment/Levee
Navigation Dredging Disposal Sites
Northeast Regional Project
Kalni–Kushiyara River Management Project
General Arrangement of River Improvement Works
Prepared by: MA
Computer Drafting by: Mamun
December 1997

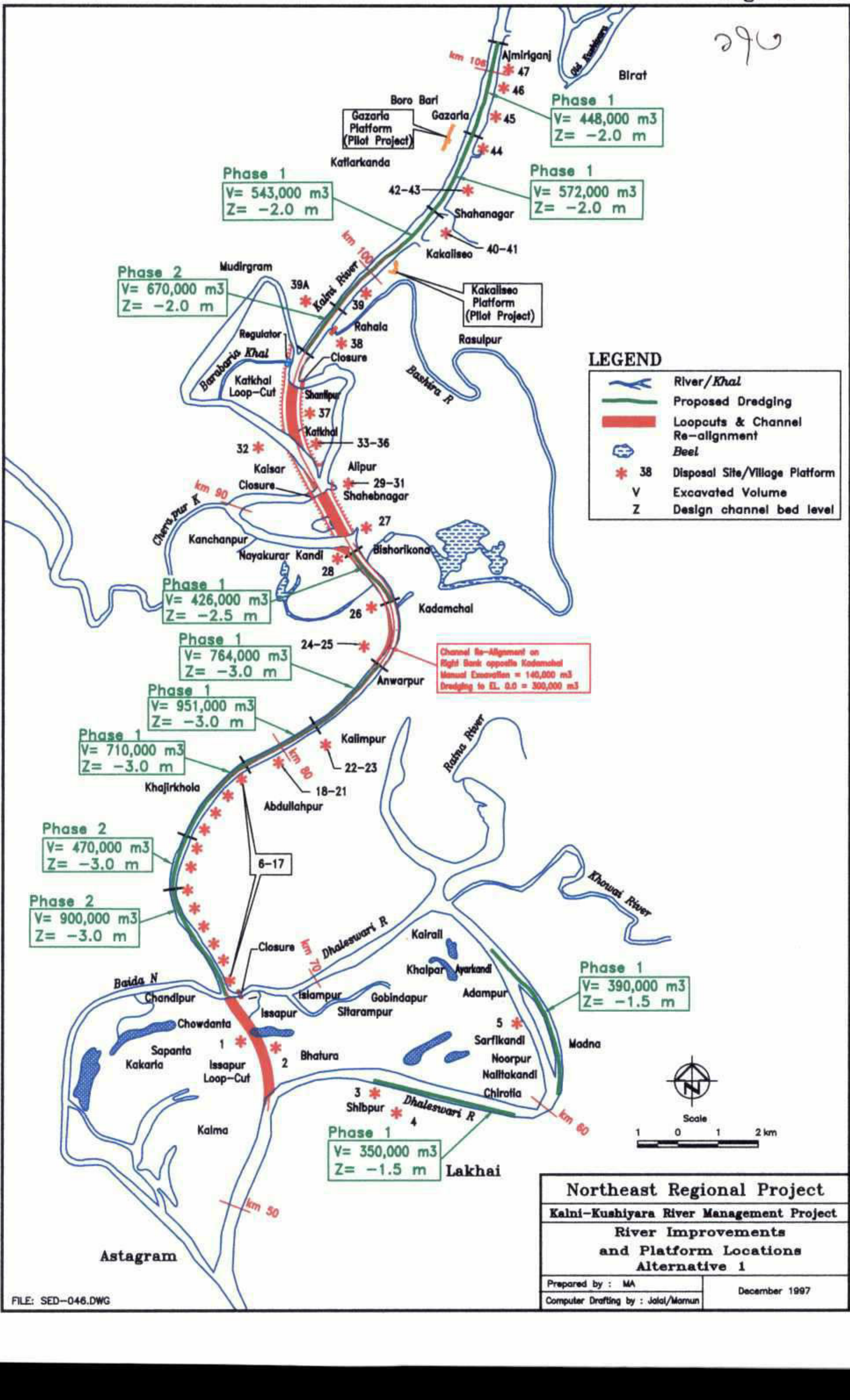
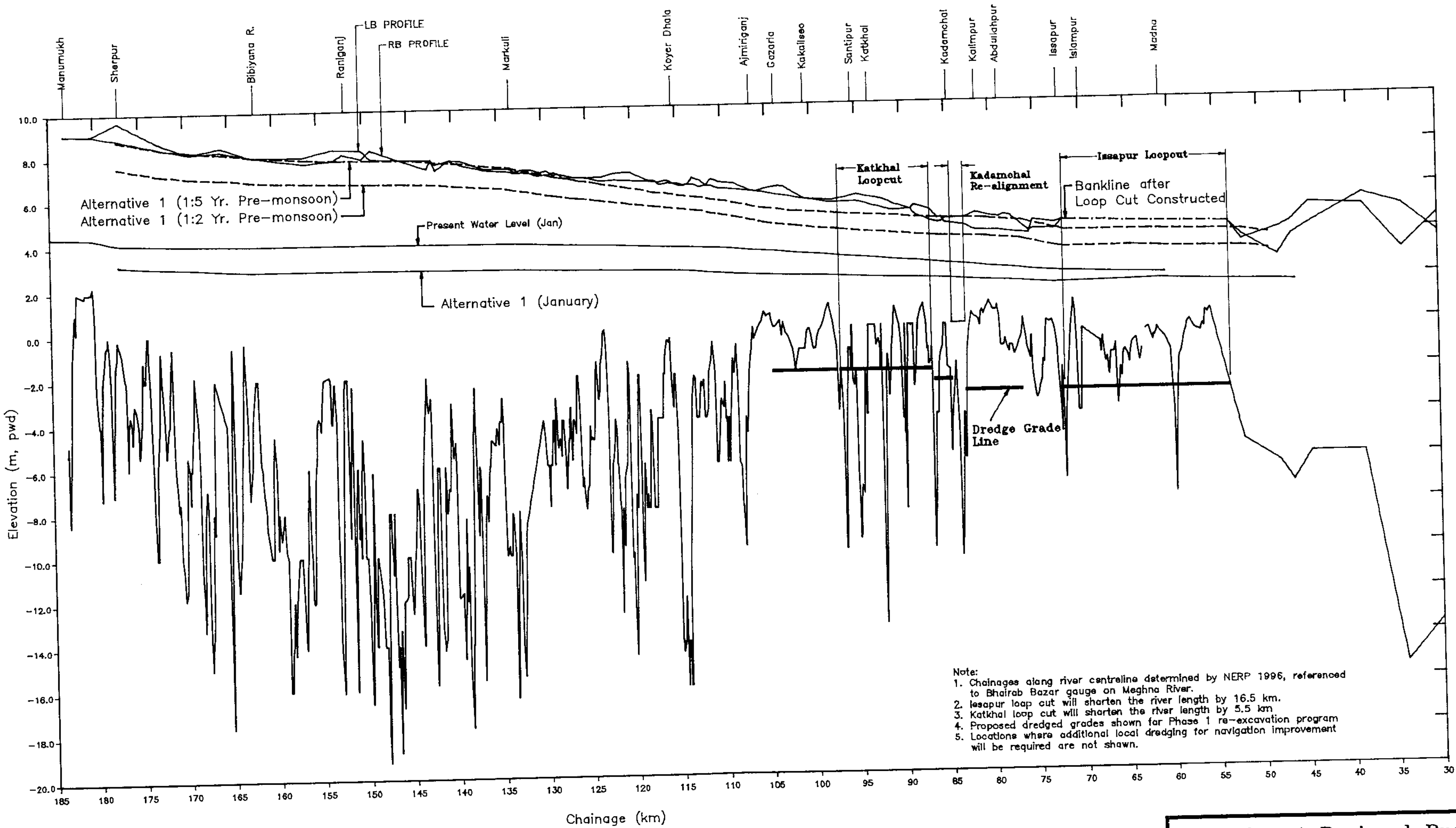

Ajmiriganj
km 106
47
46
45
44
Birat
Old Kushiyara
Boro Bari
Gazaria
Gazaria Platform (Pilot Project)
Phase 1
V= 448,000 m3
Z= -2.0 m
Katlarkanda
Phase 1
V= 543,000 m3
Z= -2.0 m
42-43
Phase 1
V= 572,000 m3
Z= -2.0 m
Shahanagar
Kakaliseo
40-41
km 100
Kalni River
Phase 2
V= 670,000 m3
Z= -2.0 m
Mudirgram
39A
39
Rahala
38
Kakaliseo Platform (Pilot Project)
Rasulpur
Regulator
Closure
Barabaria Khal
Katkhal Loop-Cut
Shantipur
37
Katkhal
33-36
32
Bashira R
Kalsar
Closure
Alipur
29-31
Shahebnagar
km 90
Cherapur K
Kanchanpur
27
Nayakurar Kandi
Bishorikona
28
Phase 1
V= 426,000 m3
Z= -2.5 m
26
Kadamchal
Phase 1
V= 764,000 m3
Z= -3.0 m
24-25
Channel Re-Alignment on Right Bank opposite Kadamchal
Manual Excavation = 140,000 m3
Dredging to EL. 0.0 = 300,000 m3
Anwarpur
Phase 1
V= 951,000 m3
Z= -3.0 m
Kalimpur
22-23
Ratna River
km 80
Phase 1
V= 710,000 m3
Z= -3.0 m
Khajirkhola
18-21
Abdullahpur
Phase 2
V= 470,000 m3
Z= -3.0 m
6-17
Phase 2
V= 900,000 m3
Z= -3.0 m
Khowai River
Closure
km 70
Dhaleswari R
Kairail
Khalpar
Ayarkandi
Adampur
Phase 1
V= 390,000 m3
Z= -1.5 m
Baida N
Chandipur
Islampur
Gobindapur
Sitarampur
Issapur
Chowdanta
5
Sarfikandi
Madna
Sapanta
Kakaria
1
Issapur Loop-Cut
2
Bhatura
Noorpur
Nalitakandi
Chirotia
3
Shibpur
4
Dhaleswari R
km 60
Phase 1
V= 350,000 m3
Z= -1.5 m
Lakhai
Kalma
km 50
Astagram
LEGEND
River/Khal
Proposed Dredging
Loopcuts & Channel Re-alignment
Beel
38 Disposal Site/Village Platform
V Excavated Volume
Z Design channel bed level
N
Scale
1 0 1 2 km
Northeast Regional Project
Kalni-Kushiyara River Management Project
River Improvements and Platform Locations Alternative 1
Prepared by : MA
Computer Drafting by : Jalal/Mamun
December 1997
FILE: SED-046.DWG

Figure A.74

298

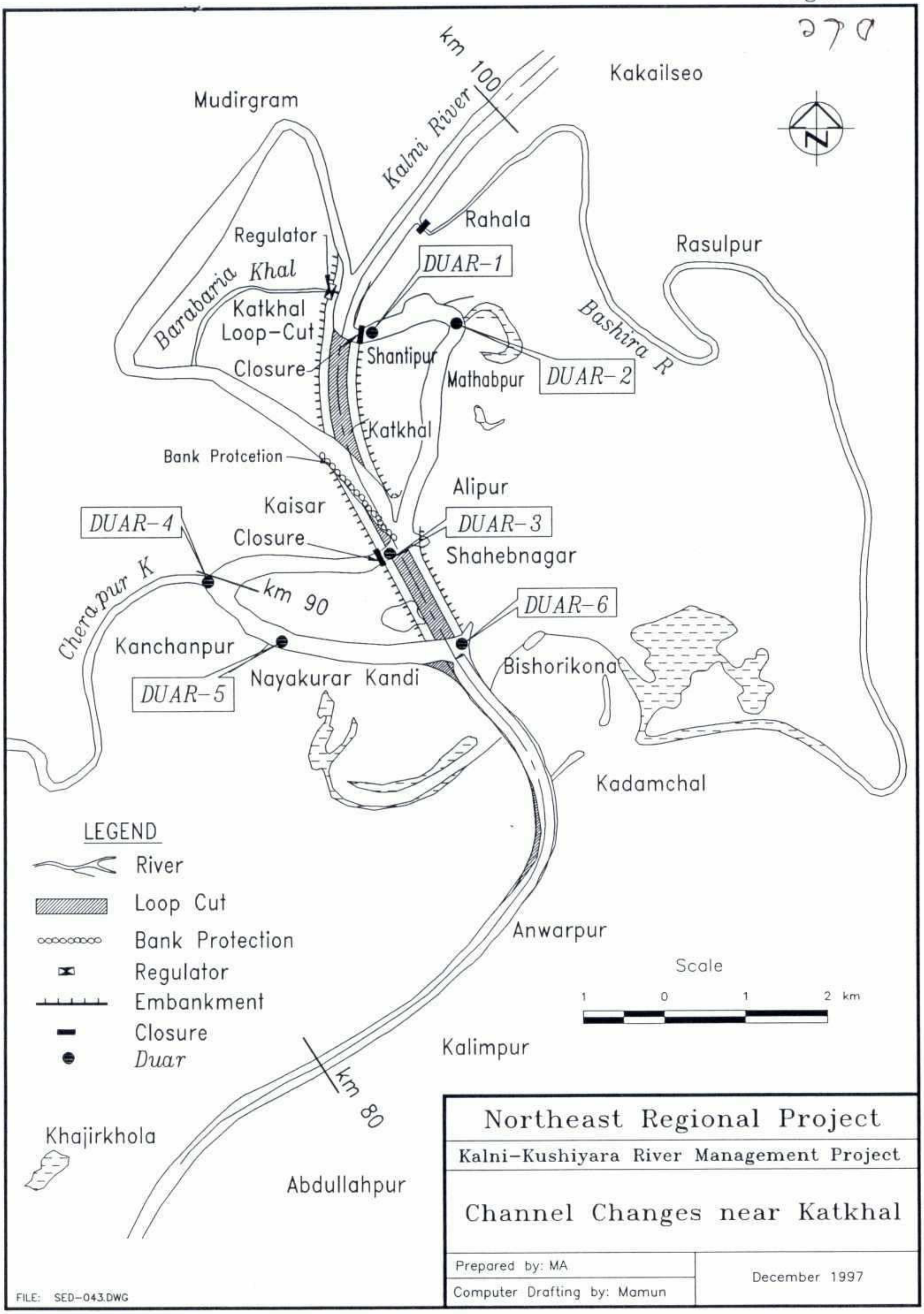


Note:
1. Chainages along river centreline determined by NERP 1996, referenced to Bhairab Bazar gauge on Meghna River.
2. Issapur loop cut will shorten the river length by 16.5 km.
3. Katkhal loop cut will shorten the river length by 5.5 km
4. Proposed dredged grades shown for Phase 1 re-excavation program
5. Locations where additional local dredging for navigation improvement will be required are not shown.

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Water Surface Profile (1:5yr Flood) Alternative 1	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Jalal	

FILE: SED-047.DWG

Figure A.75



Northeast Regional Project

Kalni-Kushiyara River Management Project

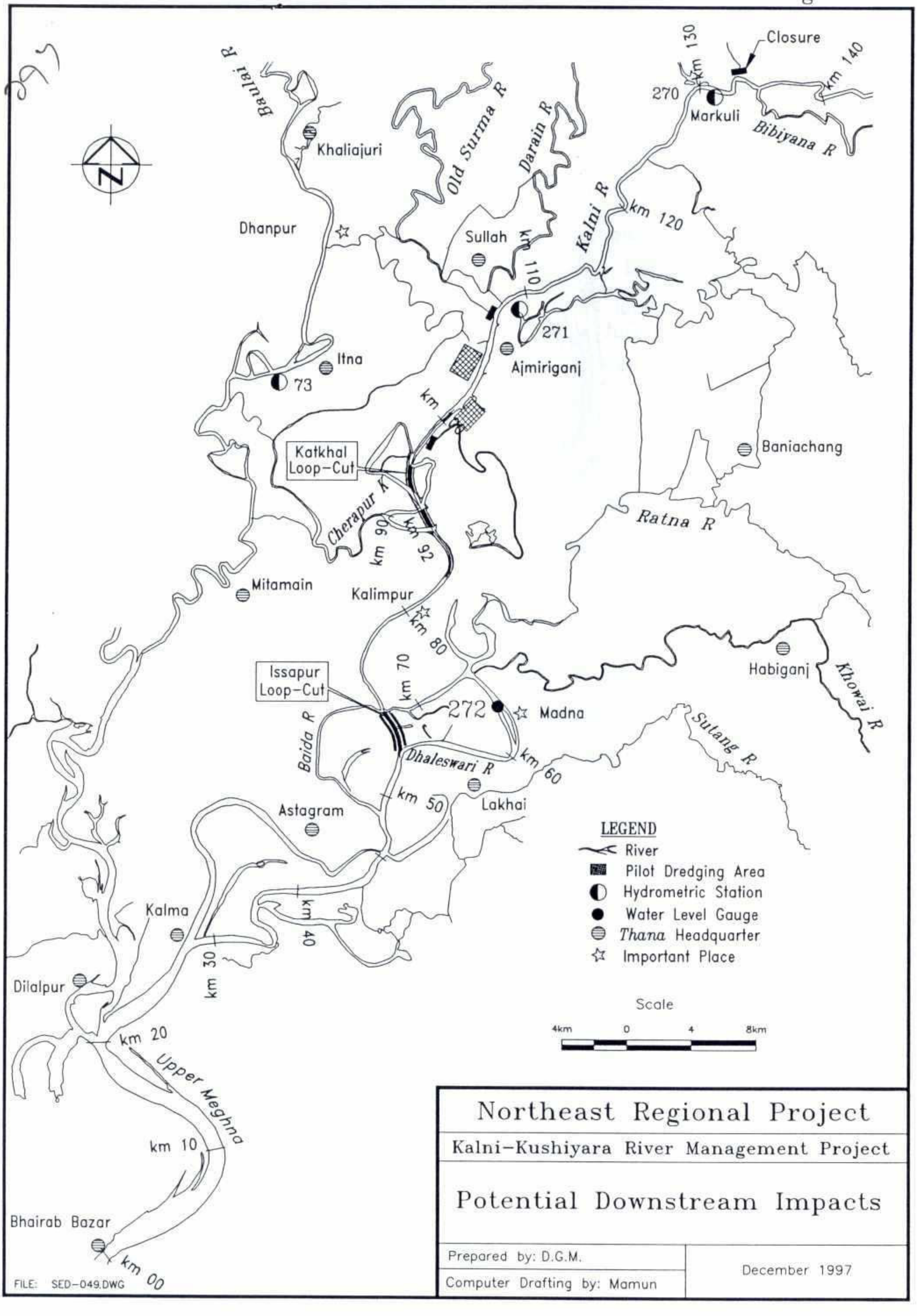
Channel Changes near Katkhal

Prepared by: MA

Computer Drafting by: Mamun

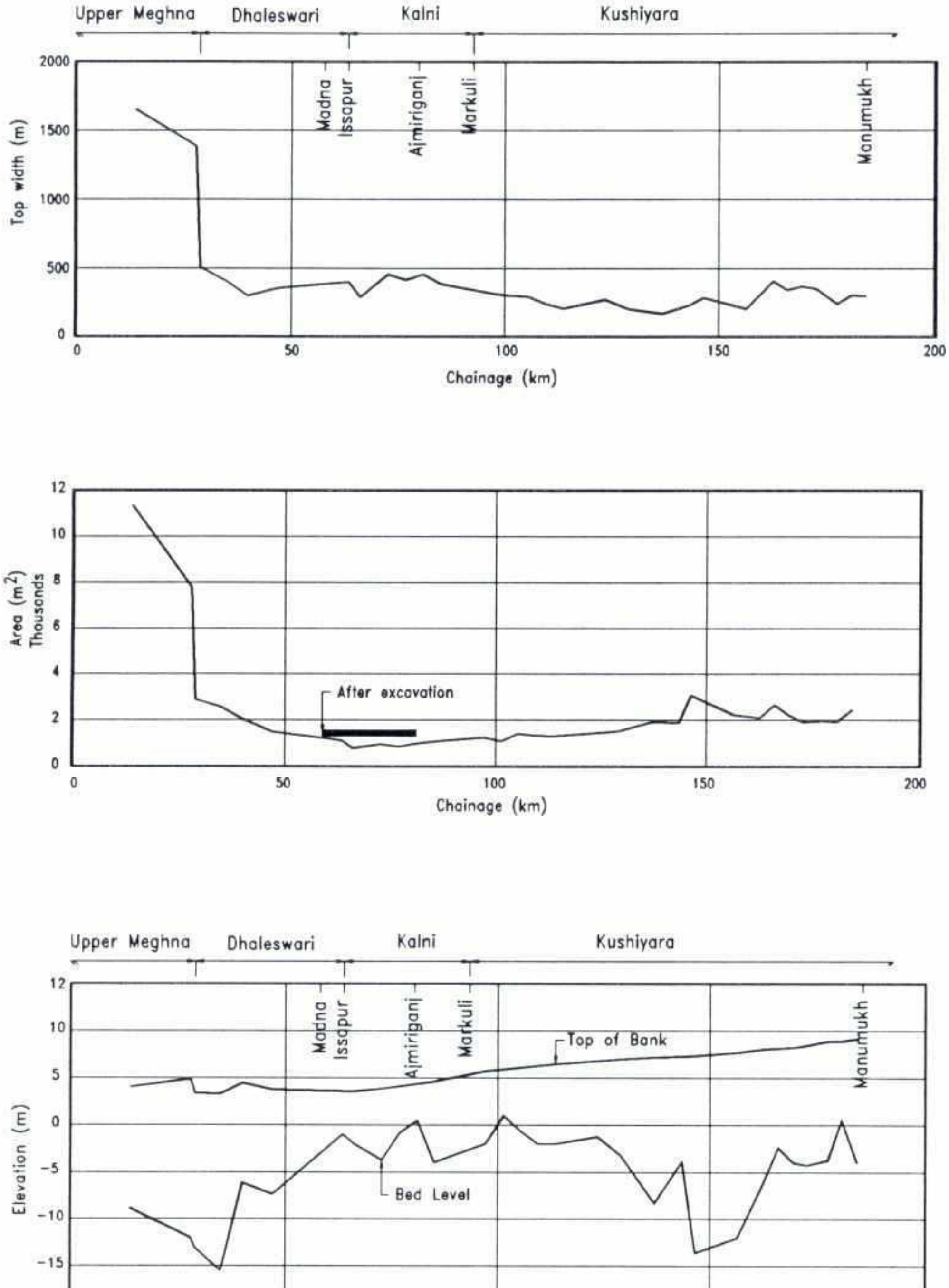
December 1997

Figure A.76



Baulai R
Khaliajuri
Old Surma R
Darain R
Closure
km 130
km 140
270
Markuli
Bibiyana R
Kalni R
km 120
Dhanpur
Sullah
km 110
271
Itna
73
Ajmiriganj
km
Katkhal Loop-Cut
Baniachang
Cherapur R
km 90
km 95
Ratna R
Mitamain
Kalimpur
km 80
Issapur Loop-Cut
km 70
272
Madna
Habiganj
Khowai R
Baida R
Dhaleswari R
km 60
Sutang R
km 50
Lakhai
Astagram
LEGEND
River
Pilot Dredging Area
Hydrometric Station
Water Level Gauge
Thana Headquarter
Important Place
Kalma
km 40
km 30
Dilalpur
Scale
4km 0 4 8km
km 20
Upper Meghna
km 10
Bhairab Bazar
km 00
FILE: SED-049.DWG
Northeast Regional Project
Kalni-Kushiyara River Management Project
Potential Downstream Impacts
Prepared by: D.G.M.
Computer Drafting by: Mamun
December 1997

Figure A.77



FILE: SED-048.DWG

Northeast Regional Project

Kalni–Kushiyara River Management Project

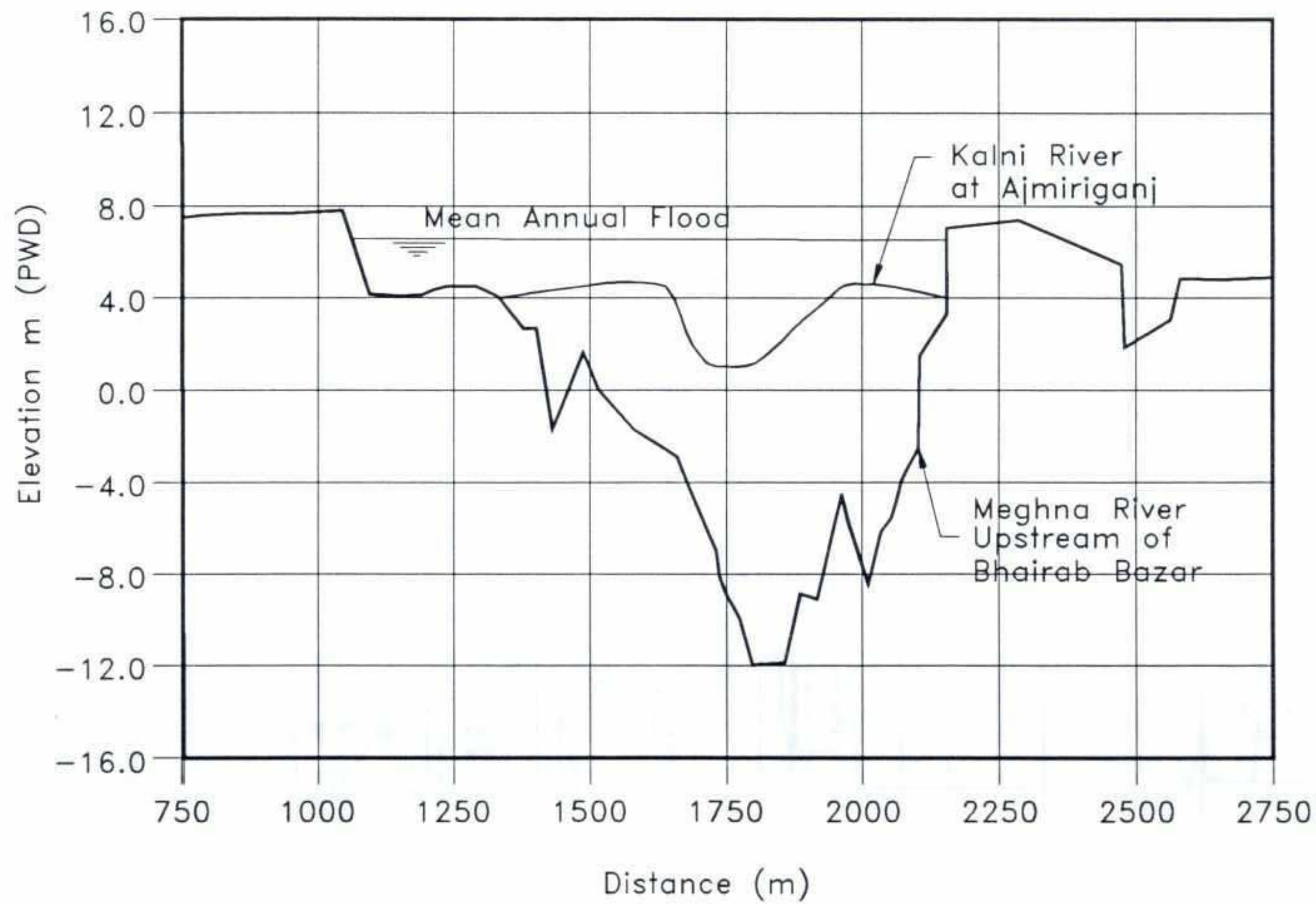
Kalni–Kushiyara River Bankfull Properties

Prepared by: D.G.M.

Computer Drafting by: Mamun

December 1997

Figure A.78



Northeast Regional Project

Kalni-Kushiyara River Management Project

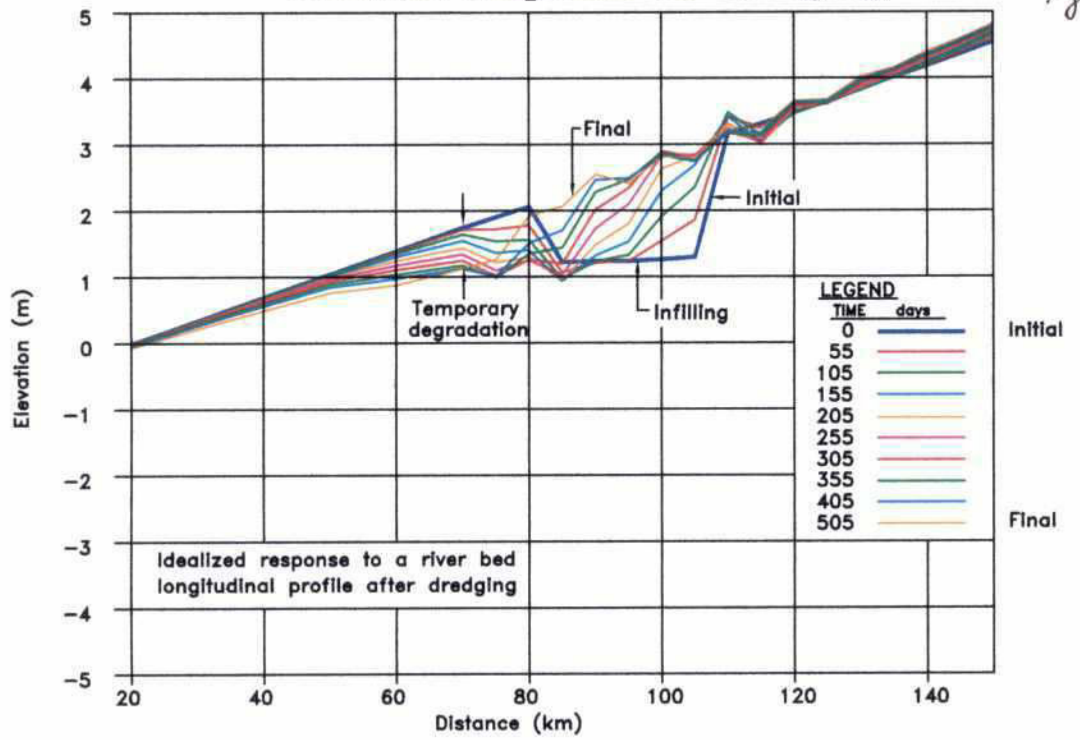
Comparision of Channels
Meghna River and Kalni River

Prepared by: D.C.M.
Computer Drafting by: Mamun
December 1997

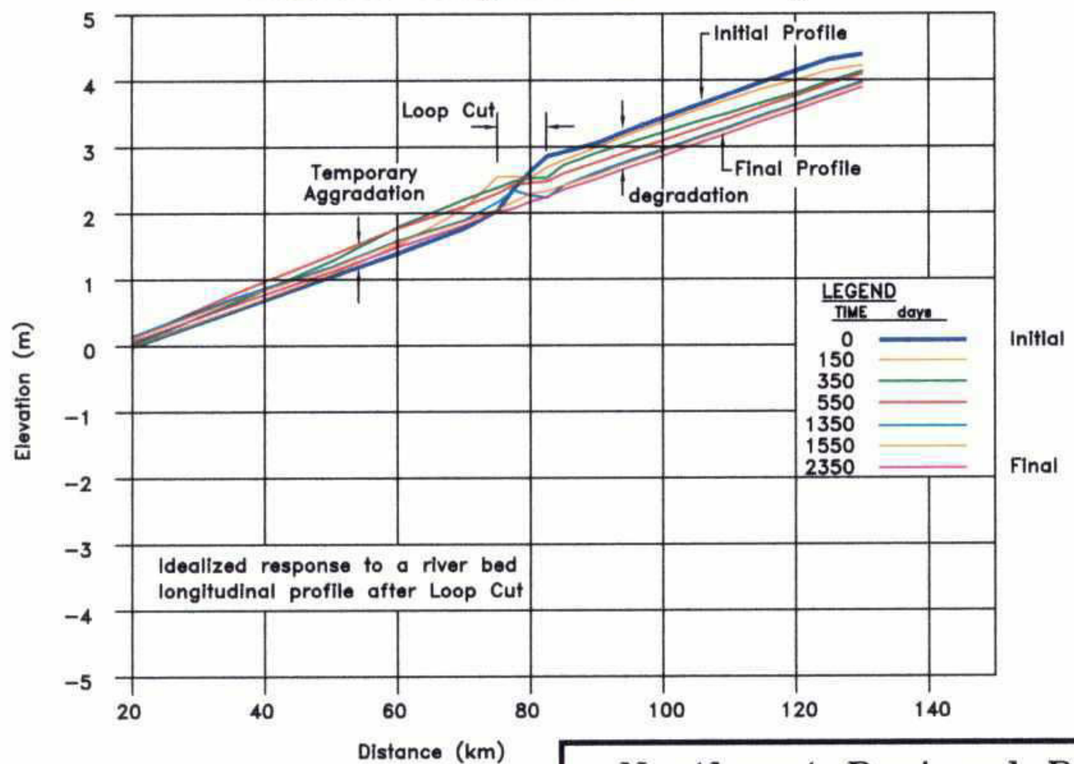
FILE: SED-053.DWG

Figure A.79

Channel response to dredging



Channel response after loop cut



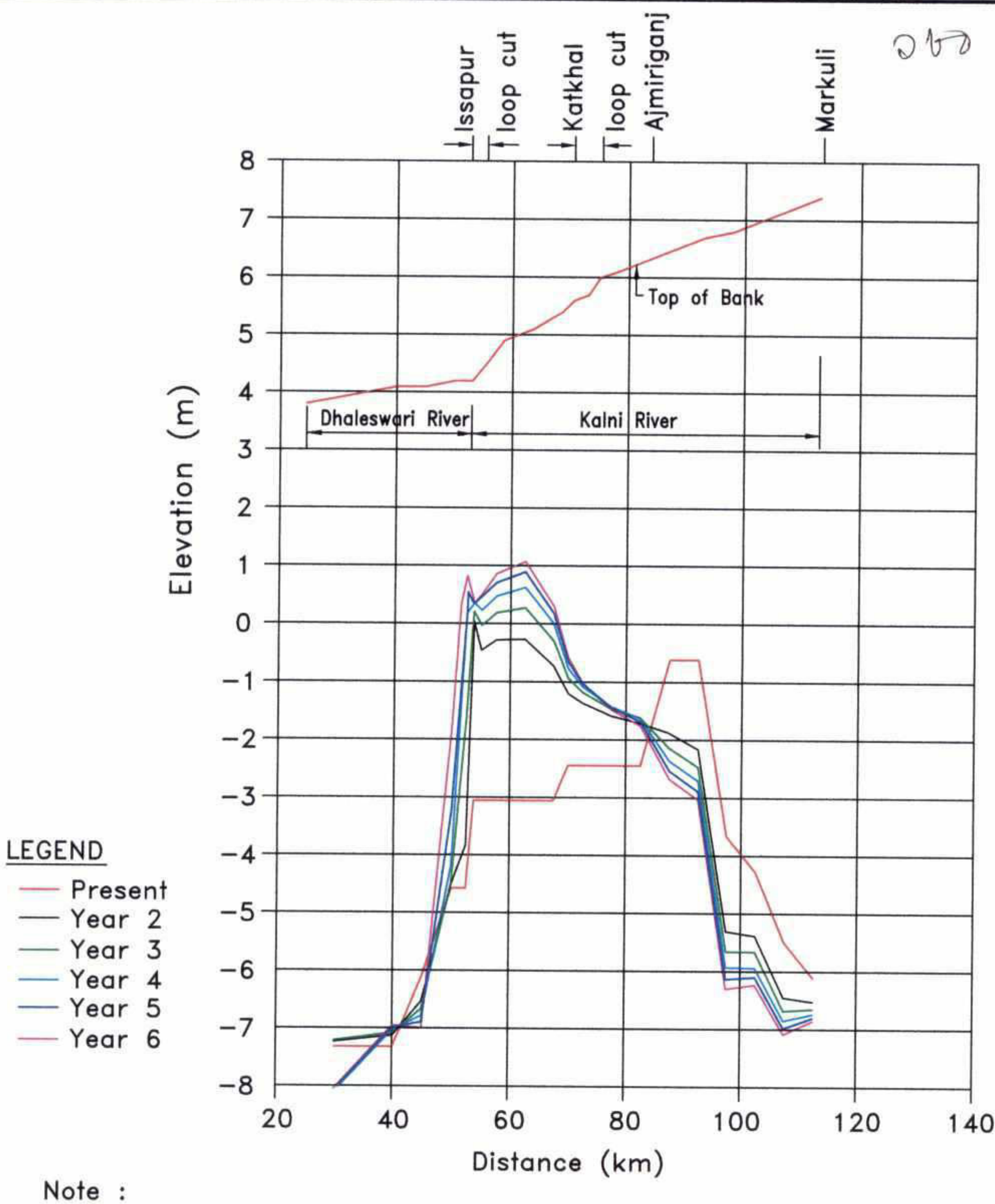
Northeast Regional Project

Kalni-Kushiyara River Management Project

Channel Response to Dredging and Loop Cutting

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-050.DWG



Note :

1. Simulated bed level response with Alternative 1, under a worst-case scenario of no maintenance excavation.
2. Bed profile shows mean bed levels along the channel.
3. Chainages have been adjusted to account for loop cuts.

Northeast Regional Project

Kalni–Kushiyara River Management Project

Long term Bed Profile Response–Alternative 1

Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: SED-055.DWG

F
G
A

S