Flood Action Plan
FAP 3
North Central Regional Study

Supporting Report II.1
Hydrometeorology

WATER RESOURCES

February 1993

Financed by: Commission of the European Communities and
Caisse Française de Développement
Project ALA/90/03

Consortium:
BCEOM, Compagnie Nationale du Rhone
Euroconsult, Mott MacDonald International,
Satec Développement

***in association with*:**
Desh Upodesh Ltd.
BETS Ltd.

Flood Action Plan

FAP 3

North Central Regional Study

Supporting Report II

Water Resources

Hydrometeorology II.1

River and Drainage System II.2

River Morphology II.3

Groundwater II.4

Hydraulic Model II.5

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SR II.1
Hydrometeorology

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The Regional Water Resources Development Plan - Final Report consists of the following:-

Main Volume REGIONAL WATER RESOURCES DEVELOPMENT PLAN

Supporting Reports:-

SR I	LAND RESOURCES AND AGRICULTURE
SR II	WATER RESOURCES
SR III	FISHERIES
SR IV	HUMAN RESOURCES SOCIO-ECONOMICS AND INSTITUTIONS
SR V	ENVIRONMENT
SR VI	INFRASTRUCTURE AND EXISTING SCHEMES
SR VII	ENGINEERING
SR VIII	DEVELOPMENT OPTIONS
SR IX	PLANNING UNITS AND REGIONAL SCHEMES
SR X	ECONOMIC, AND MULTICRITERIA IMPACT ASSESSMENT

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NORTH CENTRAL REGIONAL WATER RESOURCES DEVELOPMENT PLAN

FAP-3

SUPPORTING REPORT II.1 - HYDROMETEOROLOGY

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
BADC	Bangladesh Agricultural Development Corp.
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BB	Bangladesh Bank
BBS	Bangladesh Bureau of Statistics
BCAL	Bangladesh Census Agricultural Livestock
BCAS	Bangladesh Centre for Advanced Studies
FDC	Bangladesh Fisheries Development Corp.
BIDS	Bangladesh Institute of Development Studies
BIWTA	Bangladesh Inland Water Transport Auth.
BJRI	Bangladesh Jute Research Institute
BKB	Bangladesh Krishi Bank
BNPP	Bangladesh National Physical Plan. Board
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engg.Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CAS	Catch Assessment Survey
CAT	Coordination Advisory Team
CCCE	Caisse Centrale de Coopération Economique
CEC	Commission of European Communities
CPM	Coarse Pilot Model
CS	Consultants' Studies
DA	Development Area
DAE	Department of Agricultural Extension
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DDT	Dichlorodiphenyl-trichloroethane
DHI	Danish Hydraulics Institute
DOE	Department of Environment
DOF	Department of Fisheries
DOS	Disk Operating System
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
DUL	Desh Upodesh Ltd.
EEC	European Economic Community
EIA	Environmental Impact Assessment
EIP	Early Implementation Programme
FAO	Food & Agricul.Organ.of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control,Drainage & Irrigation Project
FFYP	Fourth Five Year Plan
FHS	Flood Hydrology Study
FMM	Flood Management Modelling
FPCO	Flood Plan Co-ordination Organisation
FRI	Fisheries Research Institute
FRSS	Fisheries Resources Survey System
FSR	Farming Research System
FWP	Food for Work Programme
FY	Financial Year
GOB	Government of Bangladesh
GW	Groundwater
HTW	Hand Tubewell
HYV	High Yielding Variety
IDA	International Development Agency
IPM	Integrated Pest Management Programme
IRRI	International Rice Research Institute
JFP	Jamuna Flood Plain
JPPS	Jamalpur Priority Project Study
LGEB	Local Government Engineering Bureau
MCA	Multicriteria Analysis
ME	Ministry of Education
MF	Ministry of Finance
MIWDFC	Minist.of Irrig., Water Dev.& Flood Control
ML	Ministry of Land
MLGRDC	Minist.of Local Govt.,Rural Dev.& Coop.
MOA	Ministry of Agriculture
MOEF	Ministry of Environment and Forestry
MOFL	Ministry of Fisheries & Livestock
MOSTI	Manually Operated Shallow T/W for Irrig.
MP	Ministry of Planning
MPO	Master Plan Organisation
MTN	Madhupur Tract North
MTS	Madhupur Tract South
NCA	Net Cultivable Area
NCR	North Central Region
NCRM	North Central Regional Model
NCRMG	North Central Regional Model Group
NCRS	North Central Regional Study
NFMP	New Fisheries Management Policy
NGO	Non Government Organisation
NGR	Natural Growth Rate
NWP	National Water Plan
OBFP	Old Brahmaputra Flood Plain
O&M	Operation and Maintenance
ODA	Overseas Development Administration (UK)
PA	Planning Area
PFDS	Public Foodgrain Distribution System
POE	Panel of Experts
PU	Planning Unit
PWD	Public Works Datum
RARS	Regional Agricultural Research Station
RHD	Roads and Highways Department
RS	Regional Scheme
SES	Socio-Economic Survey
SOB	Survey of Bangladesh
SPARRSO	Space Research & Remote Sensing Organ.
SR	Supporting Report
SRP	Systems Rehabilitation Project
SRTI	Sugarcane Research and Training Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
TOR	Terms of Reference
Tk	Taka
UNDP	United Nations Development Programme
UNHCR	United Nations H.Commission for Refugees
WFP	World Food Programme

CHAPTER 1
CLIMATE

1.1 General

The North Central Regional's climate is dominated by the monsoon and falls into four seasons:-

Winter Season

During winter months (November to February) the northeast monsoon comes from the Siberian anticyclones and results in generally dry and cool weather.

Pre-Monsoon Season

The winter is followed by a pre-monsoon season (March to May) when significant generally convective, rainfall occurs (some 20 to 25% of the annual total) and both temperature and humidity rise considerably. Temperature rises to maximums of over 40°C and the weather is unstable, with successions of sunny and rainy days. Wind velocities are high and occasionally cyclonic.

Monsoon Season

The south-west monsoon usually begins in June and lasts until October. Heavy rainfall occurs over the whole region, Mainly remains very high (80 to 90%) and temperature remains stable with a diurnal range typically between 25°C and 31°C.

Post Monsoon Season

There is a short transitional period (generally in October to early November), between the wet monsoon season and the dry, cooler winter season.

Within these general features spatial variations can be observed and these are described below along with details of specific meteorological data.

1.2 Source of Data

The meteorological data for Bangladesh is collected by a number of agencies. Rainfall, temperature, evaporation, cloudiness, and sunshine are collected by the Meteorological Department (MD) and the Bangladesh Water Development Board (BWDB).

The Master Plan Organisation (MPO) has had the co-ordinating role of compiling climatic and hydrologic data on a national basis and has presented it in the form of reports and computerised data. MPO data is available upto 1987 (MPO 1987a and MPO 1987b).

Other sources of climatic data have been obtained from FAP-25 (FAP 25 1991 and 1992) and the Surface Water Modelling Centre.

There are 22 reliable rainfall stations distributed throughout the North Central Region Study area (see Figure II.1.1). Most of these rainfall stations were initiated in 1962, but some as early as 1900, and observations have been recorded regularly since then. All the rainfall stations are equipped with standard 125mm rain gauges but only two recording rain gauges are functioning reliably.

The only comprehensive analyses of rainfall and other climatic parameters available is that of the Agro-Climatic Survey of Bangladesh (BRRI 1976). Although the analyses were made in 1974 the long-term climatic parameters are comparable with more recent MPO average values for rainfall. The 1974 data have therefore been used to describe the climatic condition in the NCR.

1.3 Rainfall

The mean monthly rainfall data for the 21 stations in the NCR are listed in Table II.1.1. The monthly variability of rainfall is also listed in Table II.1.2 and the dispersion in Table II.1.3.

The mean rainfall for the NCR is usually less than 50 mm per month in the winter season and increases during the pre-monsoon season of April/May into the wet monsoon season of June to October (with monthly rainfall in the order of 300 to 450 mm in June to August, see Figure II.1.2). The seasonal totals are given in the right hand columns of Table II.1.1.

The NCR area lies between the higher northeastern rainfall region of the Assam Hill Region and the drier southwest region toward Rajshahi. The distribution of annual rainfall in the NCR is also one of higher precipitation in the Northeast (exceeds 2000mm) less in the south (some 1900 mm) and less than 1800mm in the west of the region, see Figure II.1.1.

Return periods for annual rainfall experienced in the years 1981 to 1989 is given in Table II.1.4.

Figure : II.1.1

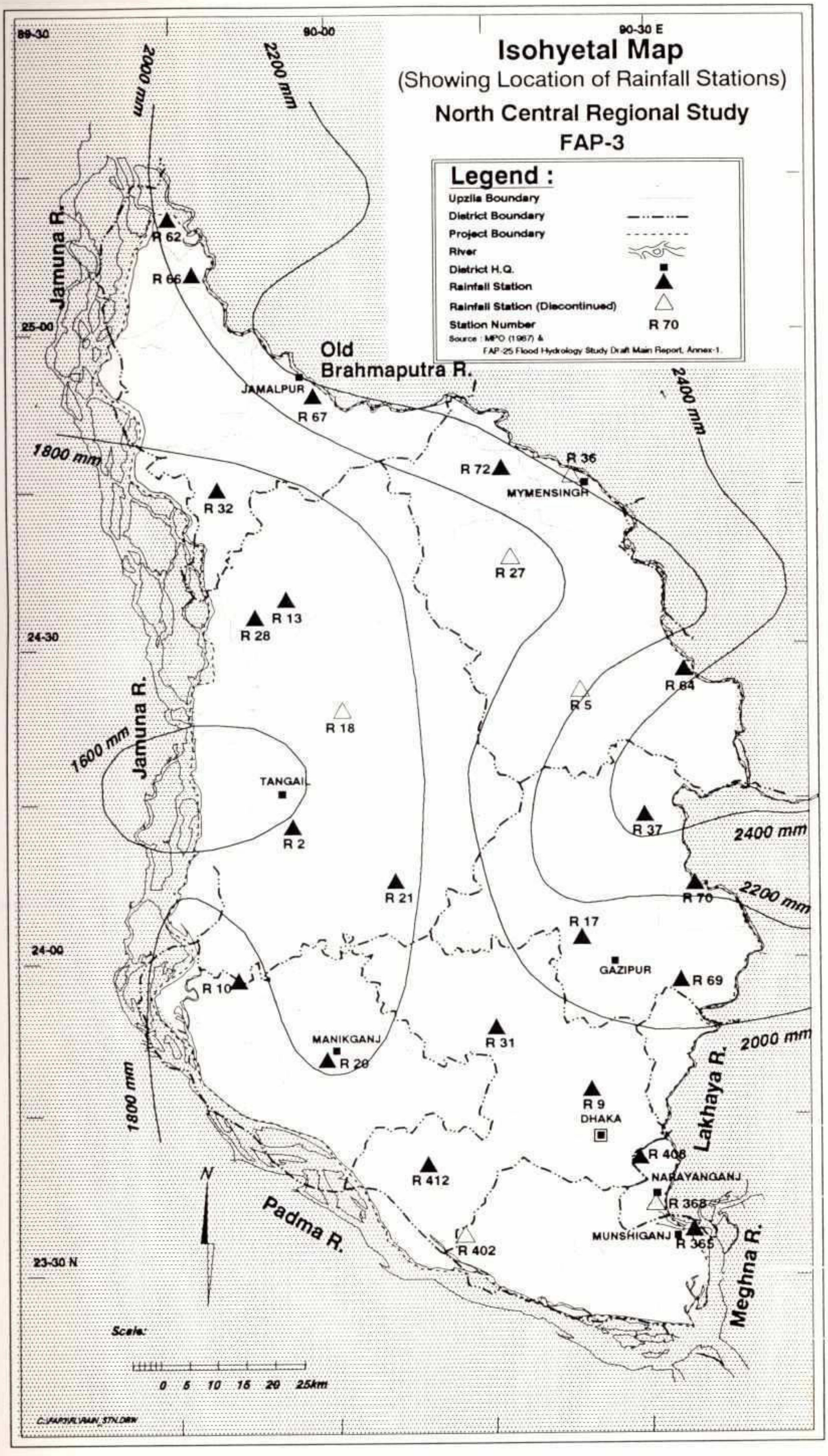
Isohyetal Map
(Showing Location of Rainfall Stations)
North Central Regional Study
FAP-3
Legend :
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Rainfall Station
Rainfall Station (Discontinued)
Station Number
R 70
Source : MPO (1967) &
FAP-25 Flood Hydrology Study Draft Main Report, Annex-1.
89-30
90-00
90-30 E
25-00
24-30
24-00
23-30 N
2000 mm
2200 mm
2400 mm
1800 mm
1600 mm
Jamuna R.
Old
Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
R 62
R 66
R 67
R 72
R 36
R 32
R 27
R 13
R 28
R 64
R 5
R 18
R 37
R 2
R 70
R 21
R 17
R 69
R 10
R 31
R 20
R 9
R 406
R 412
R 368
R 365
R 402
N
Scale:
0 5 10 15 20 25km

Figure : II.1.2
Mean Monthly Rainfall

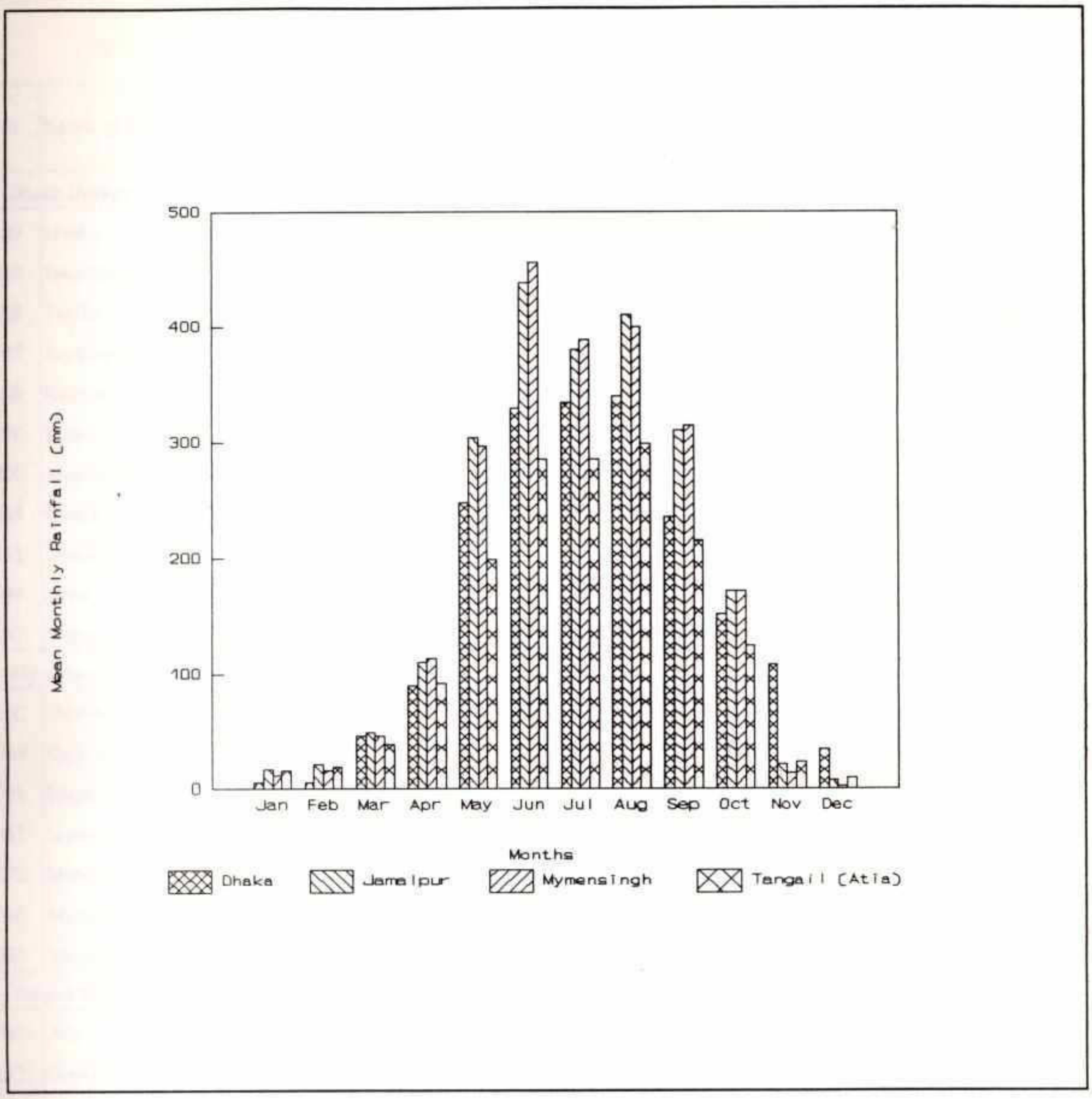

TABLE II.1.1
Mean Monthly and Mean Annual Rainfall for the NCR

No.	Name of Station	Rainfall (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
a) Dhaka District														
009	Dhaka	5.6	5.3	46.5	89.9	247.9	328.6	334.0	339.8	235.1	152.3	108.8	34.4	1928.2
010	Daulatpur	5.0	22.9	40.0	142.2	262.4	269.6	293.1	348.6	231.2	164.9	13.9	13.8	1807.6
408	Fatulla	11.5	15.6	57.4	188.5	269.9	409.3	419.8	413.1	303.8	158.1	46.5	22.3	2315.8
017	Joydebpur	18.5	28.2	60.3	149.8	234.7	368.2	353.3	387.1	266.7	148.7	40.2	13.6	2069.3
069	Kaliganj	7.1	12.7	43.4	126.3	307.2	336.5	378.2	300.4	307.7	151.2	40.0	9.9	2020.6
070	Kapasia	12.7	23.6	47.0	132.7	239.3	351.6	363.3	344.8	265.4	143.1	33.5	15.9	1972.9
020	Manikganj	12.1	27.5	43.8	120.1	208.3	297.9	288.9	298.8	228.2	128.2	33.3	15.0	1702.1
365	Munshiganj	18.2	37.9	59.2	175.4	277.7	369.0	381.1	383.7	287.3	174.0	34.5	21.3	2219.3
412	Nawabganj	16.6	30.6	67.8	145.9	210.2	332.8	319.6	314.4	217.3	128.3	46.3	19.4	1849.2
031	Savar	6.0	13.2	31.3	117.7	218.6	312.9	345.9	386.9	286.1	162.3	37.8	12.3	1931.0
037	Sripur	13.0	21.0	51.6	133.2	293.3	452.0	460.9	525.7	283.5	168.2	67.4	8.6	2478.4
b) Mymensingh District														
062	Dewabganj	13.9	17.2	44.2	113.4	277.6	402.3	437.4	364.2	327.1	167.3	26.3	7.2	2198.1
064	Gafforgaon	11.7	17.5	59.0	136.2	255.4	414.7	404.2	380.1	319.8	141.4	30.2	4.2	2174.4
066	Islampur	7.1	13.1	47.5	111.1	245.5	392.6	467.9	350.3	283.8	135.7	15.2	4.2	2074.0
067	Jamalpur	16.7	20.7	48.7	110.7	303.9	438.6	379.8	410.8	310.7	171.9	20.8	7.7	2241.0
072	Mutagacha	11.9	15.3	32.2	139.7	222.1	488.8	472.8	361.2	361.3	127.6	20.7	12.8	2266.4
036	Mymensingh	11.7	16.3	46.5	113.3	296.7	456.4	388.4	399.8	314.7	172.0	13.7	2.0	2231.5
032	Sarishabari	14.9	18.8	30.7	90.7	212.1	346.0	321.8	334.2	252.1	153.9	33.3	12.3	1820.8
d) Tangail District														
002	Atia	15.9	18.9	38.4	91.7	198.7	285.2	285.4	299.1	215.1	124.8	23.1	9.8	1606.1
013	Gopalpur	12.6	16.4	17.6	126.3	195.5	343.5	332.4	306.4	192.1	176.6	12.3	0.7	1732.4
021	Mirzapur	10.8	18.7	34.9	95.1	201.1	363.1	306.1	434.6	238.8	164.4	16.7	8.0	1892.3
028	Pingna	15.6	22.2	42.1	97.7	214.8	329.5	309.3	307.2	250.8	146.9	28.5	6.4	1771.0

Source Agro-Climate Survey of Bangladesh,
Bangladesh Rice Research Institute (BRR)

C:\123\COLES\HYDMET1.WK1

TABLE II.1.2

Mean Monthly Rainfall Variability

Station No.	Name of Station	Variability (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dhaka District														
009	Dhaka	5.9	6.9	29.3	52.3	110.2	115.1	61.2	132.9	94.5	93.9	93.6	43.5	219.1
010	Daulatpur	6.7	24.7	44.0	114.6	94.9	65.1	117.0	158.9	97.6	101.3	13.4	23.7	339.8
408	Fatulla	13.9	15.2	36.2	65.9	133.1	114.9	131.3	165.6	112.6	78.3	35.2	31.0	442.6
017	Joydebpur	20.1	23.2	44.4	74.0	93.8	118.5	96.6	133.3	92.7	93.1	29.9	13.2	295.0
069	Kaliganj	8.0	14.8	23.3	63.9	56.5	100.4	94.9	119.9	91.3	90.4	31.1	14.3	223.0
070	Kapasia	12.1	21.3	34.5	32.1	104.9	107.7	120.4	135.4	90.6	74.9	26.2	16.9	282.6
020	Manikganj	10.2	24.4	31.4	68.0	74.6	93.0	82.5	102.2	94.5	75.5	27.1	15.3	294.7
365	Munshiganj	15.3	31.3	40.1	87.9	123.6	138.0	130.3	122.8	115.6	103.0	27.8	21.4	383.6
412	Nawabganj	14.0	22.7	51.8	70.5	97.1	109.9	99.0	120.6	81.4	78.3	44.6	20.4	230.0
031	Savar	7.4	13.4	23.8	54.3	47.5	114.3	97.9	136.2	81.5	89.5	28.3	19.2	278.3
037	Sripur	13.2	23.4	33.1	54.2	143.5	72.0	103.2	203.4	98.4	107.5	75.9	13.4	397.8
Mymensingh District														
062	Dewabganj	9.6	15.3	34.8	66.1	118.3	143.9	160.5	140.6	152.1	108.7	24.5	6.9	435.2
064	Gafforgaon	11.7	16.8	58.9	57.0	90.4	66.2	76.6	174.2	124.0	83.9	25.3	6.5	262.8
066	Islampur	8.1	17.1	37.0	59.2	65.9	132.1	118.0	124.2	139.5	117.0	12.2	7.5	323.4
067	Jamalpur	13.7	14.8	32.8	81.9	147.0	178.8	119.8	141.5	101.1	118.9	20.2	8.2	569.2
072	Mutagacha	9.7	17.8	21.3	63.5	92.1	109.2	107.4	156.5	118.4	79.1	18.5	19.4	266.7
036	Mymensingh						Not Available							
032	Sarishabari	12.2	16.2	20.3	46.7	87.3	99.7	93.8	126.0	86.8	97.0	32.7	14.9	231.2
	Sherpur	12.7	15.7	30.7	63.6	118.6	140.3	123.6	166.7	102.4	93.2	22.9	7.7	360.6
Tangail District														
002	Atia	14.1	15.8	26.6	46.6	90.0	99.0	85.4	93.0	96.2	84.1	19.2	9.2	229.0
013	Gopalpur	11.6	19.4	19.3	75.5	81.1	77.2	54.0	144.9	78.6	153.5	13.7	1.3	264.0
021	Mirzapur	12.2	25.7	26.8	30.9	89.9	91.6	85.1	131.3	87.2	118.9	12.9	12.1	303.7
028	Pingna	12.6	18.9	31.3	61.2	87.5	104.8	112.5	120.8	114.3	103.8	23.7	7.5	333.5

Source BRRI

C:\123\COLES\HYDMET2.WK1

TABLE II.1.3

Mean Monthly & Annual Rainfall Dispersion for Selected Stations in the NCR.

Name of Station	Para-meter	Rainfall dispersion (mm)												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dhaka District														
Joydebpur	Mn	0.0	0.0	0.0	2.5	34.0	122.6	11.4	69.8	40.1	4.8	0.0	0.0	1098.5
	LQ	0.7	4.8	14.0	74.0	147.4	254.1	271.3	273.8	187.7	60.9	10.6	0.2	1717.5
	Md	7.6	17.1	47.6	141.8	215.6	348.7	347.2	352.4	256.6	112.3	27.9	8.2	1883.0
	UQ	21.5	41.6	82.5	217.4	316.6	483.4	416.6	487.6	350.5	218.4	55.8	21.3	2254.0
	Mx	205.2	116.8	364.4	474.9	546.6	843.2	879.8	1755.1	579.8	457.4	184.1	71.1	2703.0
Kapacia	Mn	0.0	0.0	1.2	19.0	27.6	123.6	108.4	67.3	106.6	2.5	0.0	0.0	sorry
	LQ	2.0	2.5	8.1	68.0	149.3	247.2	253.2	226.1	182.1	70.3	6.3	0.0	1676.0
	Md	5.3	12.8	34.9	126.2	220.9	343.2	335.1	317.8	236.8	110.9	22.8	5.4	1772.2
	UQ	20.3	38.0	68.5	180.0	328.4	443.7	432.4	464.4	359.9	185.1	48.2	18.7	2112.2
	Mx	90.6	96.5	231.6	323.8	565.9	699.7	720.8	786.1	518.1	378.4	145.2	77.4	3008.6
Manikganj	Mn	0.0	0.0	0.0	8.8	7.8	68.8	75.9	103.3	27.9	6.8	0.0	0.0	sorry
	LQ	1.5	3.5	17.0	63.2	136.5	205.8	200.9	201.4	143.0	54.6	4.0	0.0	1365.2
	Md	7.1	19.0	27.9	99.1	198.3	283.4	264.1	281.0	188.9	99.5	19.3	3.8	1491.4
	UQ	17.7	43.4	68.8	158.7	253.2	358.3	346.4	374.7	281.1	195.5	40.6	22.0	sorry
	Mx	62.9	110.9	179.8	460.7	556.7	464.9	536.7	662.9	558.2	482.8	230.8	74.6	sorry
Munshiganj District														
	Mn	0.0	0.0	0.0	10.6	10.1	91.1	124.7	108.4	65.2	6.8	0.0	0.0	1375.6
	LQ	3.5	6	13.9	91.1	160.1	233.1	251.9	278.6	164.3	64.6	3.8	0	1728.9
	Md	12.4	22	46.7	151.3	264.7	371	357.1	334	247.6	146.5	22.6	5.5	sorry
	UQ	24.1	63.5	85.8	228.5	322.1	485.9	466.3	439.4	339.0	247.1	43.6	30.2	sorry
	Mx	133.0	172.7	242.8	643.1	1038.0	918.7	1148.5	985.5	878.8	594.8	150.8	141.9	sorry
Dewabganj	Mn	0.0	0.0	0.0	0.5	0.0	46.4	112.7	12.7	101.6	3.8	0.0	0.0	1064.7
	LQ	3	1.7	11.3	55.2	146.0	268.4	285.2	237.8	168.9	58.4	2.5	0.0	1737.8
	Md	10.1	9.7	28.3	93.5	244.6	370.0	382.1	333.6	260.0	122.6	13.7	4.5	1872.7
	UQ	20.3	30.2	58.8	139.0	318.7	506.9	536.1	475.1	400.0	230.8	29.4	11.5	2430.5
	Mx	43.1	74.6	272.0	574.0	696.4	1045.2	1158.2	887.4	1145.5	769.3	150.8	29.2	4225.2
Jamalpur	Mn	0.0	0.0	3.3	0.0	39.6	51.3	100.8	66.0	116.5	3.3	1.2	0.0	1162.5
	LQ	3.3	6.0	16.5	33.0	175.2	273.0	252.7	295.4	225.8	59.6	3.0	0.0	1639.8
	Md	10.7	15.4	34.5	84.8	252.4	386.5	345.7	406.3	283.7	123.5	9.6	4.0	1958.1
	UQ	21.4	35.3	82.0	137.6	372.1	548.6	475.9	529.3	360.1	218.5	22.0	16.0	2232.6
	Mx	89.4	96.5	170.1	631.6	961.6	1238.7	782.5	857.7	789.9	805.4	112.2	41.9	4987.0
Sarishabari	Mn	0.0	0.0	0.0	3.8	12.1	79.7	137.1	90.1	55.3	13.9	0	0.0	1205.7
	LQ	5.0	2.9	8.8	51.5	129.0	259.5	240.2	210.0	150.6	60.9	5.3	0.0	1501.9
	Md	8.1	10.1	21.8	68.9	183.7	334.6	285.4	287.9	233.1	122.0	13.9	1.7	1571.2
	UQ	24.8	26.6	42.6	109.9	277.3	456.1	410.4	411.2	292.3	184.1	67.6	19.1	1951.2
	Mx	84.8	81.5	126.7	360.4	508.0	655.5	540.7	975.1	524.7	572.7	189.9	78.7	2333.7
Tangail District														
	Mn	0.0	0.0	0.0	0.0	21.8	101.0	103.6	87.6	14.9	4.3	0.0	0.0	814.8
	LQ	1.7	3.4	7.6	46.7	117.8	171.8	194.5	226.0	119.3	41.9	2.7	0.0	1377.4
Atia	Md	9.3	11.9	28.4	84.3	183.8	270.7	265.4	271.2	205.7	93.9	12.7	5.9	1443.2
	UQ	24.3	31.6	54.6	127.2	271.2	378.0	323.3	397.0	313.6	189.2	30.7	11.3	1681.2
	Mx	75.1	70.8	163.0	328.9	484.8	573.2	681.4	595.8	474.9	466.3	95.2	82.2	2393.4

Source: BRRI

TABLE II.1.4

Return Periods for Dhaka and Mymensigh Annual Rainfall 1961 to 1989

Mymensingh			Dhaka		
Year	Annual Rainfall (mm)	Return Period	Year	Annual Rainfall (mm)	Return Period
1961	1645	1.03	1961	2000	1.76
1962	2209	1.43	1962	1841	1.43
1963	2038	1.20	1963	1908	1.58
1964	2938	7.50	1964	2434	7.50
1965	2654	3.75	1965	2102	2.14
1966	1919	1.11	1966	2025	1.88
1967	2121	1.30	1967	1730	1.15
1968	2296	1.67	1968	1731	1.20
1969	2191	1.36	1969	1556	1.03
1970	2276	1.58	1970	1869	1.50
1971	2273	1.50	1971	2294	4.30
1972	1783	1.07	1972	1825	1.30
1973	2804	5.00	1973	2192	3.75
1974	3134	15.00	1974	1953	1.67
1975	2406	2.30	1975	2130	2.50
1976	2602	3.00	1976	2123	2.30
1977	2714	4.30	1977	2166	2.70
1978	2381	1.88	1978	2356	5.00
1979	2514	2.70	1979	1841	1.36
1980	2332	1.76	1980	2183	3.00
1981	2383	2.00	1981	1630	1.11
1982	2023	1.15	1982	1743	1.25
1983	3102	10.00	1983	2433	6.00
1984	2654	3.30	1984	3028	30.00
1985	2071	1.25	1985	2065	2.00
1986	2810	6.00	1986	2479	10.00
1987	2384	2.14	1987	2186	3.30
1988	3374	30.00	1988	2525	15.00
1989	2451	2.50	1989	1622	1.07

Source: FAP-25 data files

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1.4 Temperature

Temperature data is available from the Meteorological Department for only a limited number of stations in the NCR, see Table II.1.5 showing the maximum, minimum and the range.

The temperatures start to rise from March, increasing to a maximum in May, decrease slightly during the monsoon, and start to recede from November to February. There is a general decrease in temperatures from south to north. Minimum temperatures can be as low as 5.6°C in January in Dhaka and 4.4°C in Mymensingh. Maximum March temperatures in Dhaka and Mymensingh reach 42°C and during the monsoon they average 36°C.

Temperature is one of the most important meteorological parameters that influences the growth of rice, and other crops. Assimilation nearly ceases as the temperature approaches 0°, the optimum temperature for photosynthesis is 17/18°C. Panicle initiation and development is very sensitive to temperature extremes. On the other hand, lower temperatures of 15/21°C can delay heading and reduced grain yields by inhibiting fertilization. Temperatures higher than 37°C can cause pollen grain desiccation thus reducing yields. Plant species have to be adapted, by breeding and selection, to suit the temperature regime of a locality.

1.5 Evapotranspiration

The evaporation regime over the area is fairly consistent with the maximum over March, April, and May when the temperature is high, dropping slightly during the wet season and decreasing during the dry winter season.

Potential evapotranspiration and open water evaporation values are presented in Table II.1.6.

A comparison of Tables II.1.6 and II.1.1. shows that rainfall is in excess of potential evapotranspiration for the months of May to October, but there is a net deficit of rainfall compared to evapotranspiration from November to April.

1.6 Other Meteorological Factors

The relative humidity over the NCR is fairly homogenous the data for two stations in the NCR are given for the morning and evening observations, in Table II.1.7.

The wind speed, see Table II.1.8, for the Dhaka sub-region is significantly greater than for the northern sub-region around Mymensingh, though the winds are generally calm for 43% of the time. However this does not preclude occasional cyclonic gale force winds that cause great damage to property and crops.

There is only one sunshine recording station in the NCR, at Dhaka, see Table II.1.9. This shows that despite longer day length in June to September the sunshine hours are reduced, due to cloud cover. Comparing the measured bright sunshine with the day length for Dhaka, the difference for December is 2.0 hours and for June is 8.6 hours.

TABLE II.1.5
Mean Monthly Maximum and Minimum Temperatures & Diurnal Range

Name of Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka District													
	Max	25.3	28.3	32.8	34.4	33.5	31.5	30.1	30.9	31.3	30.7	28.7	25.9
	Min	11.9	14.1	19.3	23.3	25.1	25.8	26.1	26.2	25.8	23.6	17.7	12.8
	Range	13.4	14.2	13.5	11.3	8.4	5.7	4	4.7	5.5	7.1	11	13.1
Mymensingh District													
	Max	25.2	27.6	32	33.8	32.4	31.2	31.3	31.3	31.5	30.7	28.7	26.4
	Min	11.6	13.8	18.2	22	23.5	24.9	25.7	25.6	25.4	23.8	18.2	13.6
	Range	13.6	13.8	13.8	11.8	8.9	6.3	5.6	5.7	6.1	6.9	10.5	12.8

Source : BRRI

TABLE II.1.6
Evapotranspiration in the NCR

Name of Station	Mean Monthly Value (mm)												Annual (mm)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
a) A-pan Evapotranspiration													
Dhaka	64.2	82.9	137.1	143.6	154.1	103.2	98.9	87.4	91.0	81.3	67.6	55.2	1166.5
Fatullah	77.3	93.2	140.3	153.2	151.6	116.9	126.3	126.2	132.0	94.2	82.7	68.7	1362.6
Jamalpur	83.4	90.2	131.5	157.5	144.8	109.2	98.8	93.6	106.0	107.5	81.2	81.1	1284.8
Mymensingh	60.1	74.8	117.0	132.9	124.5	96.1	99.8	83.2	94.5	93.0	73.2	60.7	1109.8
b) Ep - Potential Evapotranspiration													
Dhaka	89.0	109.2	168.6	187.5	187.9	137.6	144.5	140.1	128.4	112.0	99.3	93.6	1597.7
Faridpur	84.6	95.8	145.7	174.3	182.6	121.8	137.0	136.7	126.9	124.9	129.3	81.2	1540.8
Mymensingh	80.0	97.7	138.6	154.8	163.1	119.7	130.2	126.2	119.7	112.8	95.1	77.8	1415.7
Narayanganj	89.0	107.2	170.8	170.7	181.7	131.7	178.7	142.6	127.5	130.8	103.2	88.4	1622.3

Source a) BRRI, b) MPO

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TABLE II.1.7

Monthly Relative Humidity at 9 A.M. & 6 P.M. for Stations in or adjacent to the NCR

Name of Station	Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka	9 AM	74	65	64	70	78	84	87	86	84	78	73	78
	6 PM	61	48	44	54	75	81	82	83	79	71	70	
Narayanganj	9 AM	80	76	76	78	79	86	87	87	84	80	78	82
	6 PM							Not Available					
Faridpur	9 AM	80	74	68	73	77	85	87	86	83	79	77	80
	6 PM	65	60	49	58	75	84	85	84	83	81	76	75
Mymensingh	9 AM	62	77	73	76	82	87	87	88	85	85	81	84
	6 PM	62	54	49	56	74	82	81	81	82	79	73	67

Source : Agro-climatic Survey of Bangladesh, BRRI

TABLE II.1.8

Average Monthly Wind Speed in Kilometres per Hour for Stations in the NCR

Name of Station	Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka	Km/hr	5.2	6	9.3	13.2	15.9	13.5	13.9	11.9	12	8.9	5.2	5.6
Faridpur	Km/hr	2.8	3.7	6.3	10.4	11.9	10.4	9.8	10.6	7	3.9	2.6	2.6
Mymensingh	Km/hr	2.3	2.8	3.9	5.2	5	5	6	4.6	3.7	3	2.3	1.9

Source : Agro-climatic Survey of Bangladesh, BRRI

TABLE II.1.9

Bright Sunshine Recorded at Dhaka

Name of Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dhaka	8.8	8.8	8.6	8.4	8.7	5.0	5.4	5.6	5.9	7.3	9.2	9.1

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CHAPTER 2
HYDROLOGICAL DATA

2.1 General

The river and drainage system of the North Central Region is described in SR II.2. This chapter presents the source of hydrological data and the main characteristics. Further data is to be found in Appendices II.A, II.B and II.C.

2.2 Source of Data

The main agent responsible for the collection of hydrological data is the Bangladesh Water Development Board (BWDB), but there are also water level and discharge stations in the NCR operated by the Bangladesh Inland Water Transport Authority (BIWTA) and the Bangladesh Meteorological Department (BMD).

Some records data back to more than 50 years, but MPO document records go back as far as 1940. The network of stations was extended in the 1960's by BWDB and the most useful available data is for the period from 1965 onwards.

Daily water level and streamflow records are available on a computer data base kept at the Surface Water Modelling Centre (SWMC). Data for a selected numbers of station are also published in Master Plan Organisation (MPO) Technical Reports - Nr. 10. Surface Water Authority (MPO 1987a) and Nr.11, Floods and Storms (MPO 1987b).

The MPO processed the data for the National Water Resources Plan (MPO 1991). FAP 25 has recently carried out further hydrological studies, and calculated return periods for the major recording stations (FAP-25, 1992).

Additional water level and discharge gauging stations (15 Nrs.) were established in the NCR during 1990 to gather data for the hydromodelling activities of this study (NCRS 1991). Further data is being collected during the 1992 monsoon season.

The BWDB has also carried out suspended sediment sampling in the region. The sampling procedure allows for concentration and grain size distribution to be measured.

2.3 Water Level Data

The location of the water level and stage gauging stations are shown on Figure II.1.3 and detailed in Table II.1.10. The additional gauging stations installed by the Bridging Study are listed in Table II.1.11. Only one auto-recording station operates in the NCR (at Mill Barak, Dhaka) and the rest are manually recorded.

2.4 Discharge Data

The discharge of the river and drainage system are measured at 25 locations throughout the NCR. The stations are listed in Table II.1.12 and shown on Figure II.1.3.

Figure : II.1.3

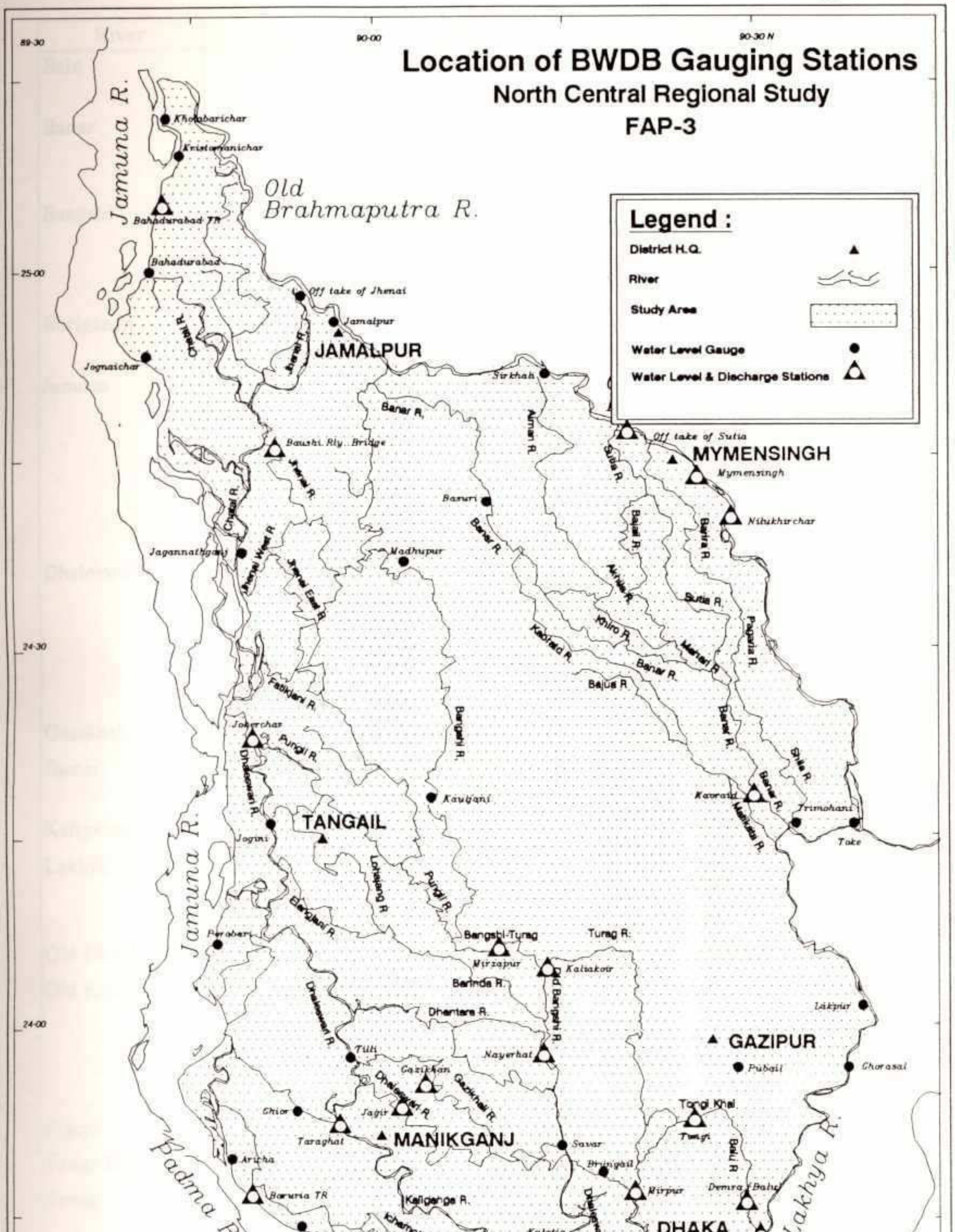
Location of BWDB Gauging Stations
North Central Regional Study
FAP-3
Legend :
District H.Q.
River
Study Area
Water Level Gauge
Water Level & Discharge Stations
89-30
90-00
90-30 N
25-00
24-30
24-00
23-30 E
Jamuna R.
Old Brahmaputra R.
Kholabarichar
Kristomanichar
Bahadurabad TR
Bahadurabad
Off take of Jhenai
Jamalpur
JAMALPUR
Jognaichar
Sirkhali
Banar R.
Aymon R.
Off take of Sutia
MYMENSINGH
Mymensingh
Nilukhirchar
Baushi Rly. Bridge
Jhenai R.
Chatal R.
Baruri
Banar R.
Sutia R.
Bajali R.
Baria R.
Jagannathganj
Madhupur
Jhenai West R.
Jhenai East R.
Sutia R.
Kaoraid R.
Khiro R.
Banar R.
Bajua R.
Pagaria R.
Fatikjani R.
Bangshi R.
Jokerchar
Pungli R.
Dhaleswari R.
Kaoraid
Banar R.
Shila R.
Trimohani
Toke
Kaulijani
TANGAIL
Jogini
Lohajang R.
Pungli R.
Bangshi R.
Jamuna R.
Porabari
Bangshi-Turag
Turag R.
Mirzapur
Kaliakoir
Old Bangshi R.
Barinda R.
Dhantara R.
Lakpur
GAZIPUR
Pubail
Ghorasal
Dhaleswari R.
Tilli
Nayerhat
Gazikhali
Gazikhali R.
Ghior
Jagir
Taraghat
MANIKGANJ
Savar
Tongi Khal
Tongi
Balu R.
Padma R.
Aricha
Baruria TR
Kaliganga R.
Mirpur
Demra (Balu)
Lakhya R.
Kadamtala
Ichamoti R.
Kalatia
DHAKA
Demra (Lakhya)
Mill Barrak
Buriganga R.
Narayanganj
Kusumhati
Horharpur
NARAYANGANJ
Ichamoti R.
Bhagyakul
Rekabibazar
Katpatti
MUNSHIGANJ
Meghna R.
N
Mawa
Nari
Tarpasha
Padma R.
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\GAUGE_ST.DRW

TABLE II.1.10
Water Level Stations in North Central Region

River	No	Location	Year
Balu	7.5	Demra	1962-89
	7	Pubail	1945-89
Banar	8	Basuri	1976-89
	9	Koraid	1964-89
	9.5	Trimohini	1968-89
Bangshi	12	Madhupur	1957-89
	13	Kawaljani	1959-89
	14	Mirzapur Bangshi Br.	1945-89
	14.5	Nayarhat	1968-89
Buriganga	42	Dhaka (Mill Barak)	1909-89
	43	Hariharpara	1945-89
Jamuna	46.7 L	Kholabarichar	1964-89
	46.9 L	Bahadurabad	1949-89
	46.7 R	Kristomanichar	1964-84
	47.3 L	Jognaichar	1965-84
	48	Jagannathganj	1962-89
	49	Serajganj	1945-89
	50	Porabari	1940-89
Dhaleswari	68	Tilli	1949-89
	68.5	Jagir (Dswari Br.)	1964-89
	69	Savar	1945-89
	70	Kalatia	1968-89
	71 A	Rekabi Bazar	1968-89
	71	Kalagachia	1945-87
Gazikhali	304	Gazikhali	1965-76
Jhenai	134 B	Offtake of Jhenai	1966-89
	134 A	Baushi Bridge	1965-89
Kaliganga	137 A	Taraghat	1964-89
Lakhya	177	Lakhpur	1968-89
	179	Demra	1952-89
	180	Narayanganj	1947-82
Old Dhaleswari	186	Jugini	1945-89
Old Brahmaputra	225	Jamalpur	1945-89
	226	Sirkhali	1959-84
	228	Mymensingh	1944-85
	228.5	Nilukhirchar	1959-88
	229	Toke	1948-89
Pungli	134	Jokerchar	1958-89
Tongi Khal	299	Tongi	1960-89
Turag	301	Kaliakair	1949-89
	302	Mirpur	1952-89
Padma	50.6	Aricha	1964-89
	91.9 L	Baruria Tr.	1964-89
	93.4 L	Bhagyakul	1968-89
	93.5 L	Mawa	1968-89
	93.6 L	Wari	1968-77
	94	Tarapasha	1928-89
	93	Kushumhati	1945-84
	92.3 L	Kadamtala	1964-78
Ghior	98	Ghior	1952-79
Karnafuli	303	Brungail	1965-75

Source: FAP-25 Flood Hydrology Study Draft Main Report, Annex-1

TABLE II.1.11
Special Water Level Gauge Stations for the Bridging Period

River	No.	Location
Chatal	SG-1	Madarganj
Jhenai	SG-2	Dhanbari
Jhenai East	SG-4	Gopalpur
Fatikjani	SG-3	Gopalpur
	SG-5	Gopalpur
Pungli	SG-6	Bhuapur
	SG-7	Kalihati
Elongjani	SG-8	Surooj
Lauhajang	SG-9	Kagmari
Dhantara	SG-10	Hinganagar
Khiro	SG-11	Benupur
Banar	SG-12	Phulbaria
Sutia	SG-13	Narayanpur
Tongi Khal	SG-14	Trisal
	SG-15	Tongi

Source : Bridging Study, FAP-3

TABLE II.1.12
Discharge Measuring Stations in North Central Region

River	No.	Location	Year
Balu	7.5	Demra	1965
Banar	9	Kaoraid	1965
Bangshi	14	Mirzapur Bangshi Bridge	1965
	14.5	Nayarhat	1964
Jamuna	46.9 L	Bahadurabad Tr.	1956
Dhaleswari	68.5	Jagir (Dswari Bridge)	1964
Ganges	91.9 L	Baruria Transit	1966
	93.5 L	Mawa	1965
Jhenai	134 A	Baushi Bridge	1964
Pungli	134	Jukerchar	1965
Kaliganga	137 A	Taraghat	1964
Lakhya	179	Demra	1952
Old Brahmaputra	228	Memensingh	1964
	228.5	Nilukhirchar	1964
Tongi Khal	299	Tongi	1964
Turag	301	Kaliakoir	1965
	302	Mirpur	1964
Gazikhali	304	Gazikhali	1965
Sutia	227	Old Brahmaputra	1964

Source : Bridging Study, FAP-3

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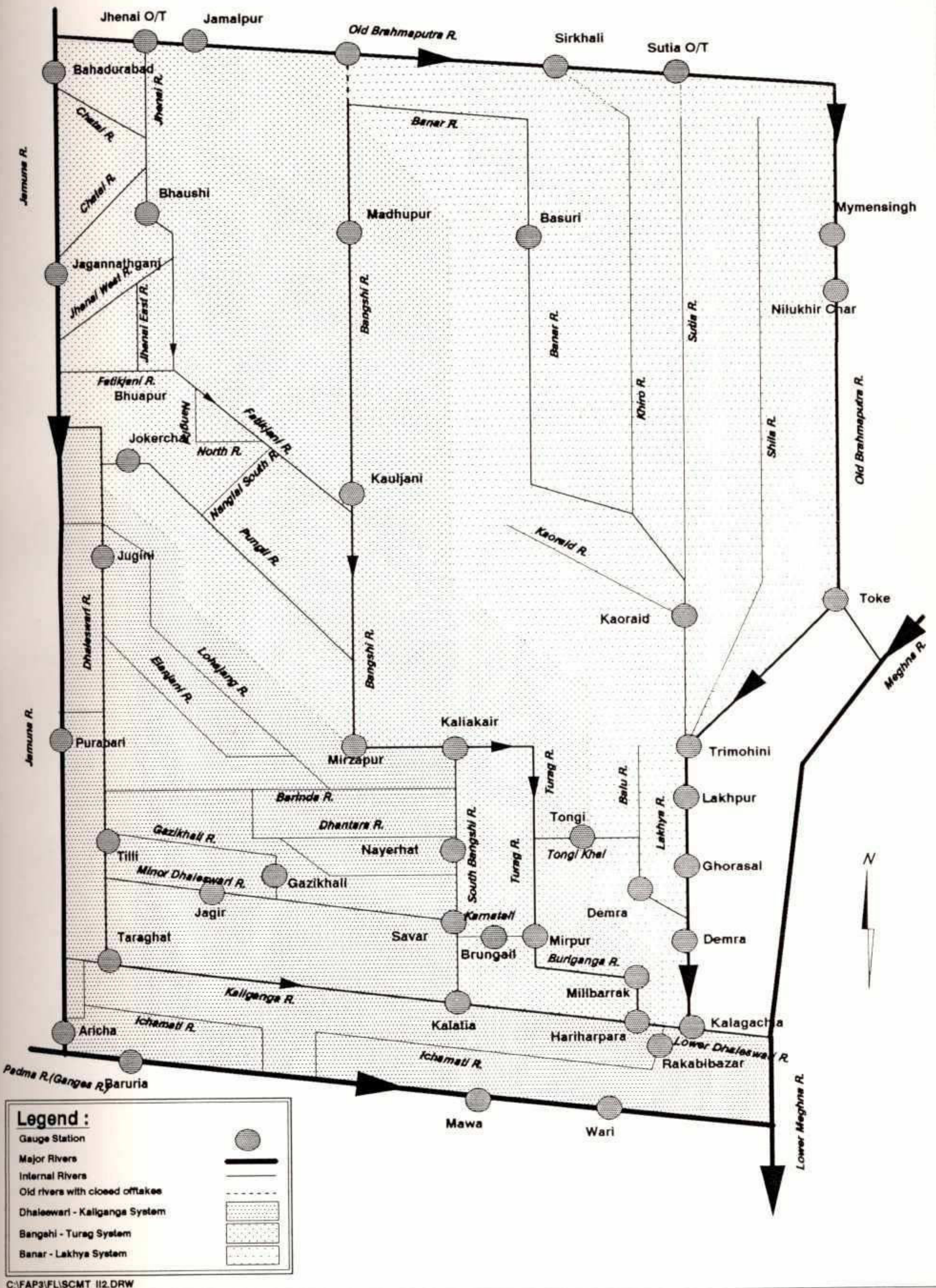
Figure : II.1.4

Schematic Map of the Rivers & Drainage System of the North Central Region



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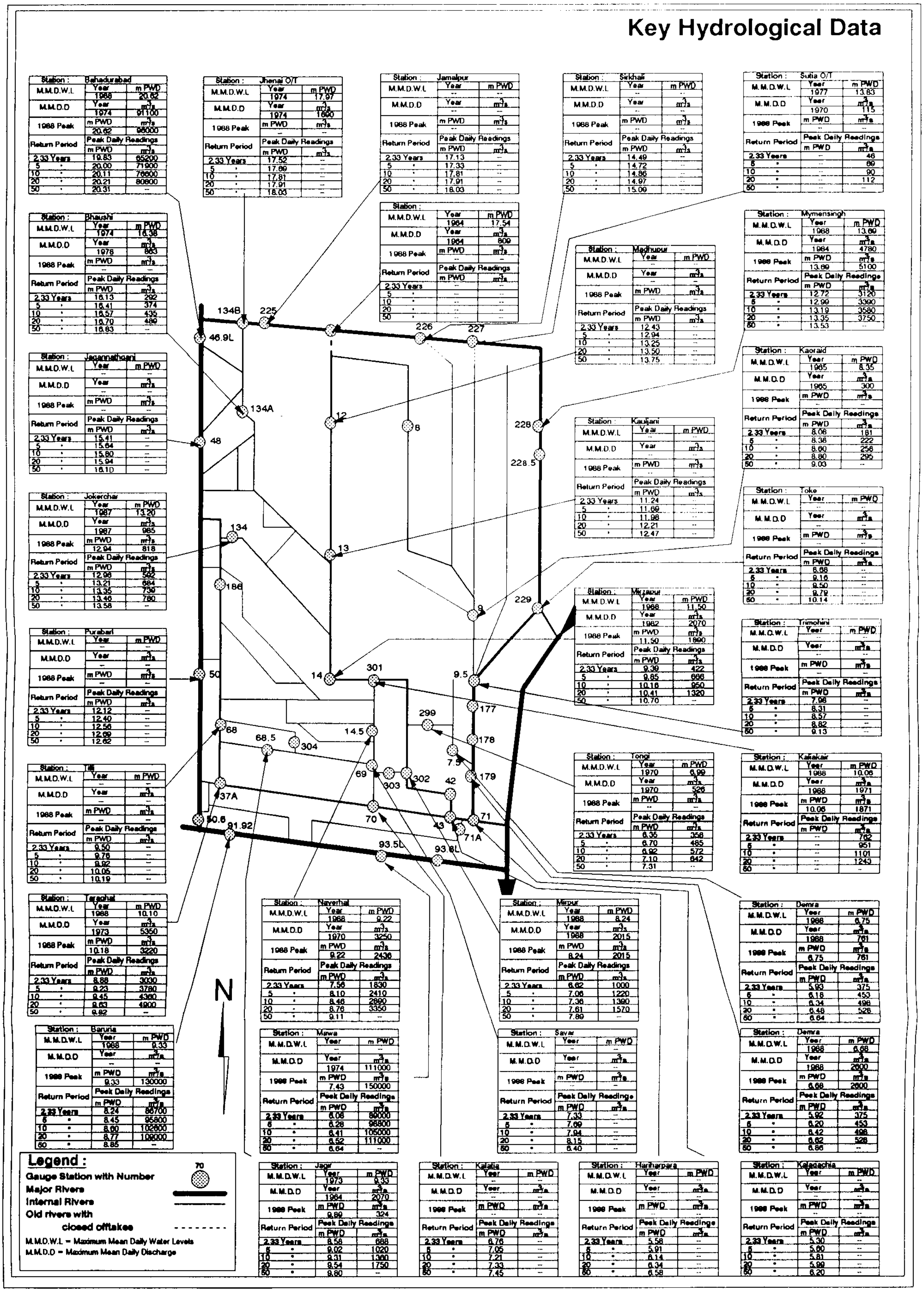

Figure : II.1.5
Key Hydrological Data

Stage-discharge rating curves for the rivers of this region are subject to variations arising from the degradation and aggradation of the channel sections, (see CBJET 1991). Such variations were noted earlier in the Dhaka South West Project Report (DSWP 1971). Similar variations in stage-discharge relationships occur on most of the river channels in the region. Discharge values an only therefore be considered as approximate for stages levels for most of the rivers, except where recent cross-section have been carried out. Stage discharge curves have been calculated by the NCRS and are given as Appendix II.C.

Cross section and longitudinal sections have been surveyed for most of the rivers and connector distributaries of the NCR. Some of the surveying was carried out by the Morphology Section of the BWDB. The approximate location of the cross sections is given in Figure II.1.6.

The precise location of the cross sections is in doubt. The location of the sections in the field is always difficult and in this region, the nature of the landscape and the 1/50 000 BOS topographic maps offer little help locating places on the ground. Use of this information therefore has to be treated with caution. Future surveys should utilise modern locating system such as geodetic positioning system (GPS) to improve the location accuracy. Additional survey work was initiated in March 1990 during the Bridging Period. This work was carried out by Desh Upodesh and was completed for 676 kilometres of internal rivers in April 1991. Further cross section survey work was initiated by the SWMC during 1991 and has continued since. This work was incorporated into the model data base.

Data

Peak discharges and maximum daily water levels for the river systems are shown on Figure II.1.5 and Tables II.1.13 and II.1.14. The maximum one day average flood levels for return periods of 2.33,5,10,20 and 50 years are also shown in Figure II.1.5. Seasonal mean discharge is given in Table II.1.15.

The hydrographs in Appendix II.B show a comparison of water levels for the 1988 and 1989 floods for 28 of the stations (data supplied by the SWMC).

TABLE II.1.13
Observed Peak Discharges and Related Return Periods

Rivers	Jamuna		Padma		Upper Meghna		Old Brahmaputra	
Stations	Bahadurabad		Baruria		Bhairab Bazar		Nilukhirchar	
Years	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.
1965	64200	1.63	-	-	12100	1.26	3200	2.7
1966	73700	3.34	81300	1.44	14400	2.81	3400	3.93
1967	72000	2.9	63600	1.01	12700	1.5	3000	2
1968	62300	1.47	80200	1.38	13300	1.84	2800	1.61
1969	57000	1.16	72700	1.1	11500	1.11	2700	1.55
1970	74400	3.57	84200	1.64	16400	6.27	3200	2.77
1972	68800	2.25	76600	1.22	11500	1.11	-	-
1973	68200	2.15	90900	2.37	12400	1.36	-	-
1974	85400	9.9	113000	11.26	19500	19.57	3800	6.6
1975	54700	1.09	93300	2.75	12700	1.5	3000	2.15
1976	65000	1.72	83500	1.59	16700	7.05	3200	2.62
1977	66800	1.94	81800	1.47	-	-	3500	4.31
1978	56100	1.13	80400	1.39	-	-	2700	1.55
1979	60300	1.32	-	-	-	-	2600	1.36
1980	91200	17.67	109000	8.31	-	-	3300	3.15
1981	66400	1.88	88200	2.02	11200	1.06	2600	1.43
1982	64300	1.64	89600	2.19	13500	1.98	2400	1.21
1983	70900	2.66	101000	4.62	16000	5.36	2300	1.13
1984	76300	4.19	107000	7.15	13600	2.06	4700	31.63
1985	63900	1.6	90200	2.27	14300	2.7	3000	2.18
1986	47600	1.01	81100	1.43	11100	1.05	1900	1.01
1987	70400	2.55	113000	11.26	15200	3.89	3200	2.62
1988	108500	102.47	132000	49.94	19800	21.66	4800	40.31
1989	69800	2.44	79800	1.36	15500	4.38	2100	1.05

Source : FAP-25 Flood Hydrology Study, Draft Main Report, Annex-I

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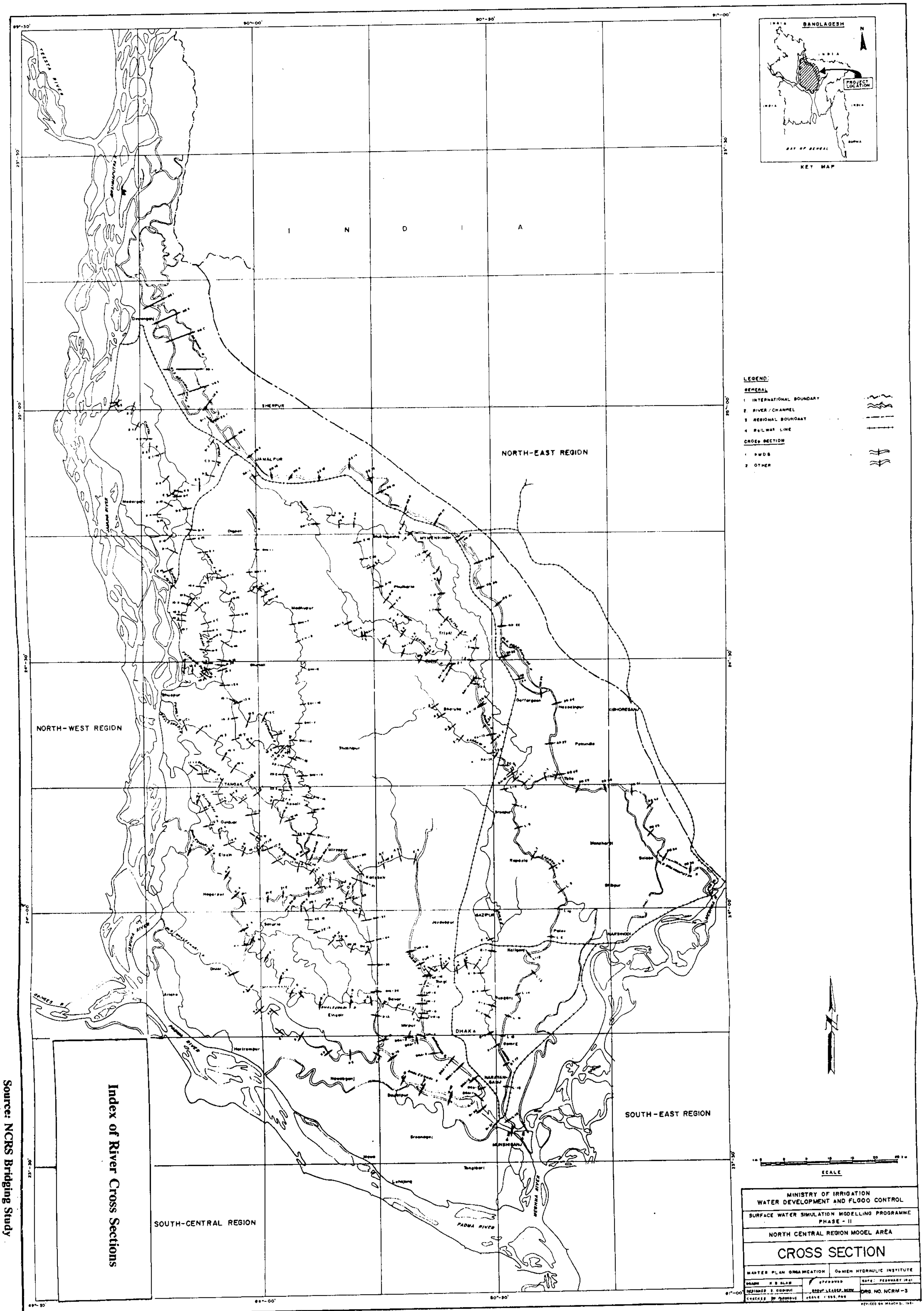


Figure : II.1.6

Index of River Cross Sections

Source: NCRS Bridging Study

TABLE II.1.14

Observed Peak Water Levels and Related Return Periods

Rivers	Jamuna										Padma				Meghna		Old Brahmaputra						Kaliganga		Lakhya	
Stations	Chilmari		Bahadurabad		Kazipur		Serajganj		Porabari		Baruria		Mawa		Bhairab Baza		Jamalpur		Nilukhirchar		Toke		Taraghat		Demra	
Year	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.
1965	23.34	1.01	19.69	1.54	(-)	(-)	13.77	1.49	12.24	1.95	8.11	1.86	5.97	2.37	6.49	1.72	17.07	2.16	-	-	-	-	9.05	2.89	5.80	2.04
1966	23.81	1.46	19.62	1.31	(-)	(-)	13.87	1.84	12.49	3.50	8.46	4.41	6.38	8.24	6.91	4.37	17.04	2.04	-	-	-	-	9.30	4.54	6.23	5.61
1967	23.97	1.98	19.50	1.09	15.46	1.56	13.64	1.20	12.19	1.79	7.87	1.22	5.73	1.28	6.25	1.23	16.83	1.46	12.06	1.37	-	-	8.73	1.82	5.42	1.19
1968	24.04	2.32	19.80	2.10	15.62	2.14	13.94	2.16	12.40	2.76	8.43	4.07	6.20	4.75	6.77	3.07	16.98	1.82	12.08	1.39	8.44	1.82	9.19	3.67	6.06	3.62
1969	23.79	1.42	19.84	2.39	15.52	1.74	13.82	1.65	12.31	2.25	8.19	2.23	6.30	6.45	6.71	2.67	17.09	2.26	12.04	1.34	8.23	1.48	8.82	2.04	5.83	2.17
1970	24.19	3.45	20.20	9.73	16.20	11.49	14.22	4.45	12.61	5.05	8.41	3.86	-	-	7.10	7.43	17.38	4.99	12.62	3.20	8.84	3.21	9.33	4.83	6.23	5.61
1972	24.09	2.63	19.98	3.97	15.65	2.28	13.90	1.97	12.12	1.60	7.74	1.07	5.75	1.33	6.09	1.09	17.28	3.65	12.42	2.20	-	-	8.56	1.51	5.38	1.15
1973	23.88	1.65	19.88	2.74	15.77	3.06	14.22	4.45	12.30	2.20	8.27	2.70	6.12	3.71	6.48	1.69	17.29	3.65	12.85	5.38	8.87	3.38	9.19	3.67	5.86	2.30
1974	24.46	8.26	20.26	12.60	15.90	4.39	14.24	4.69	12.54	4.05	8.61	6.65	6.47	10.81	7.65	43.35	17.56	9.84	12.29	18.44	9.68	21.22	9.47	6.58	6.57	15.05
1975	23.78	1.40	19.60	1.26	15.07	1.05	13.60	1.14	12.06	1.47	8.18	2.18	5.87	1.79	6.48	1.69	16.90	1.61	12.31	1.85	-	-	8.28	1.21	5.58	1.42
1976	23.90	1.71	19.87	2.65	15.35	1.33	13.46	1.02	11.68	1.09	7.91	1.29	5.61	1.06	7.02	5.90	17.22	3.08	12.49	2.49	-	-	-	-	5.45	1.22
1977	24.11	2.77	19.99	4.12	15.42	1.47	13.90	1.97	12.28	2.11	8.12	1.90	5.89	1.89	6.57	1.99	17.28	3.65	12.81	4.88	9.09	5.11	8.63	1.62	5.90	2.50
1978	23.68	1.23	19.63	1.34	14.91	1.01	13.52	1.06	11.55	1.04	7.83	1.16	5.72	1.25	5.99	1.04	16.81	1.42	12.19	1.58	8.35	1.65	7.96	1.06	5.48	1.26
1979	(-)	(-)	19.78	1.98	15.25	1.19	13.67	1.26	11.74	1.12	7.68	1.03	5.59	1.04	6.33	1.35	16.74	1.32	12.16	1.52	8.35	1.65	8.02	1.08	5.56	1.39
1980	24.25	4.12	20.10	6.40	15.99	5.76	14.50	9.64	12.81	10.58	8.65	7.43	6.33	7.07	6.41	1.51	17.40	5.34	12.80	4.77	8.83	3.16	9.40	5.65	6.21	5.32
1981	(-)	(-)	19.48	1.07	15.41	1.44	13.87	1.84	11.83	1.18	7.96	1.40	5.84	1.65	6.46	1.63	16.68	1.25	11.78	1.12	7.79	1.13	8.31	1.23	5.72	1.77
1982	(-)	(-)	19.42	1.03	15.43	1.49	13.73	1.39	12.00	1.37	7.99	1.47	5.64	1.10	6.43	1.56	16.62	1.19	12.00	1.29	8.01	1.26	8.16	1.14	5.47	1.25
1983	24.04	2.32	19.92	3.17	15.61	2.09	14.19	4.10	12.41	2.83	8.48	4.65	5.91	2.00	6.79	3.22	16.52	1.12	11.97	1.26	7.98	1.24	8.92	2.35	-	-
1984	24.25	4.12	20.10	6.40	15.87	4.03	14.62	13.47	12.77	9.00	8.37	3.47	6.15	4.07	6.89	4.15	17.30	3.87	12.82	5.00	8.96	3.97	9.22	3.92	6.30	6.80
1985	23.92	1.78	19.61	1.29	15.69	2.51	14.14	3.59	12.44	3.06	8.06	1.68	5.94	2.17	6.38	1.45	17.50	7.72	12.50	2.53	-	-	8.72	1.80	5.68	1.65
1986	23.44	1.04	19.15	1.00	15.39	1.40	13.66	1.24	11.90	1.24	7.88	1.24	5.76	1.36	5.90	1.02	15.96	1.01	11.36	1.01	7.38	1.03	8.38	1.29	5.12	1.02
1987	24.69	19.67	19.68	1.50	16.18	10.73	14.57	11.72	12.88	14.24	9.04	22.55	-	-	6.90	4.26	17.20	2.93	12.72	3.96	8.92	3.69	9.70	11.24	6.38	8.54
1988	25.04	85.87	20.61	59.52	16.76	94.84	15.11	51.65	13.14	51.20	9.35	54.44	7.06	58.01	7.65	43.35	17.81	32.71	13.70	72.93	9.81	30.74	10.37	74.09	6.92	45.96
1989	23.58	1.12	19.57	1.20	15.54	1.81	13.65	1.22	11.53	1.04	7.74	1.07	5.69	1.19	6.41	1.51	16.28	1.04	11.84	1.15	-	-	7.87	1.04	5.32	1.10

Notes: (A Log-Normal distribution is used for all the stations except Hardinge Bridge
For Hardinge Bridge, Gumbel distribution with left censoring has been applied
Therefore a return period can be define for peaks higher than 14.80 m

Source : FAP-25 Flood Hydrology Study, Draft Main Report, Annex-1

C:\123\COLES\TABII-14.WK1

TABLE II.1.15

Seasonal (May-October) Mean Discharges and Related Return Periods

Rivers	Jamuna		Padma		Upper Meghna		Old Brahmaputra	
Stations	Bahadurabad		Baruria		Bhairab Bazar		Nilukhirchar	
Years	Peak	R.P.	Peak	R.P.	Peak	R.P.	Peak	R.P.
1965	31500	1.54	-	-	7600	1.78	1400	3.72
1966	37800	6.77	40400	1.13	9100	4.16	1700	18.16
1967	31200	1.47	37100	1.03	6500	1.15	1200	1.8
1968	31900	1.65	40600	1.14	7200	1.5	1400	2.95
1969	28000	1.09	40600	1.13	6500	1.16	1200	1.84
1970	36600	4.7	46500	1.89	8500	2.81	1500	4.59
1972	29800	1.25	39700	1.1	6300	1.11	-	-
1973	29700	1.24	49200	2.91	9100	4	-	-
1974	39100	10.07	56700	19.82	10600	10.34	1700	15.32
1975	29800	1.25	50900	4.13	-	-	1300	2.1
1976	29000	1.15	42500	1.26	-	-	1200	1.84
1977	38300	7.9	49000	2.78	-	-	1900	39.4
1978	30000	1.27	48400	2.51	-	-	1200	1.69
1979	34900	3.06	-	-	-	-	1200	1.77
1980	38000	7.16	53300	7.18	-	-	1400	2.67
1981	32500	1.83	44400	1.48	-	-	1100	1.25
1982	29500	1.2	44300	1.47	-	-	1000	1.11
1983	31900	1.65	48600	2.63	-	-	1000	1.17
1984	35100	3.18	53500	7.76	-	-	-	-
1985	33000	2	52400	5.78	-	-	-	-
1986	26300	1.02	41600	1.2	6400	1.12	800	1.03
1987	36400	4.43	51000	4.19	8700	3.28	1300	1.92
1988	39800	12.63	57200	23.3	12000	25.39	1400	2.66
1989	42700	35.33	48900	2.76	-	-	900	1.06

Note : A Log-Normal distribution is used for all stations

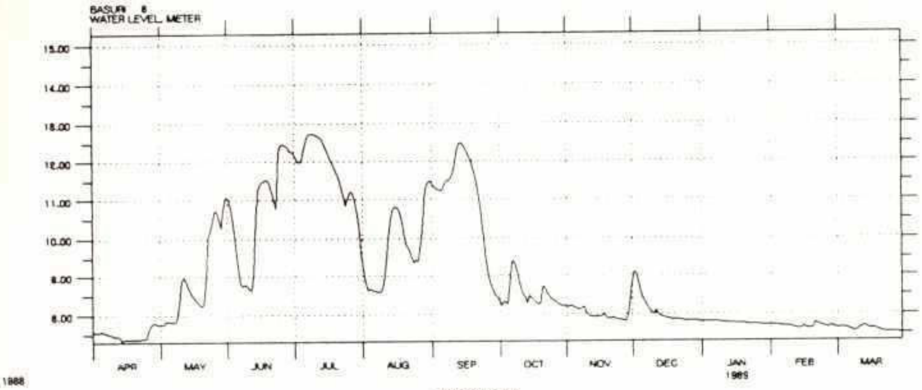
Source: FAP-25 Flood Hydrology, Draft Main Report, Annex-1

C:\123\COLES\TABLE-15.WK1

Supporting Report - II

Appendix II. A
Hydrographs for 28 Water Level Recording Stations

Figure : II.A.1
1988 and 1989 Hydrographs - Bar TR 91.9L and Basuri 8



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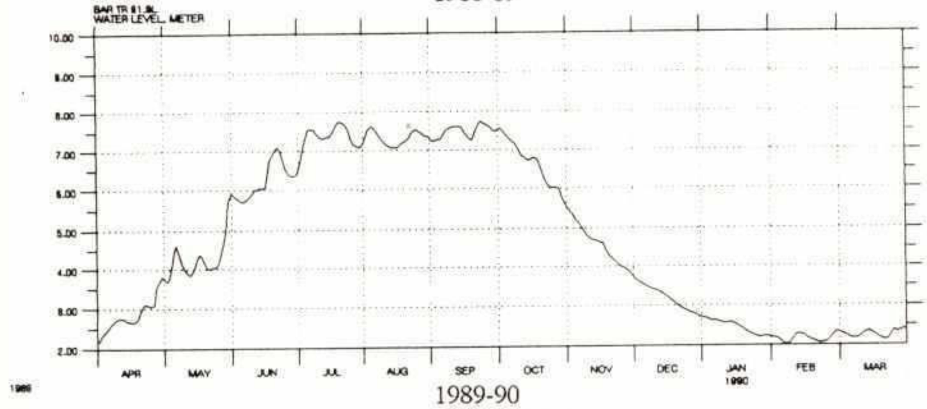
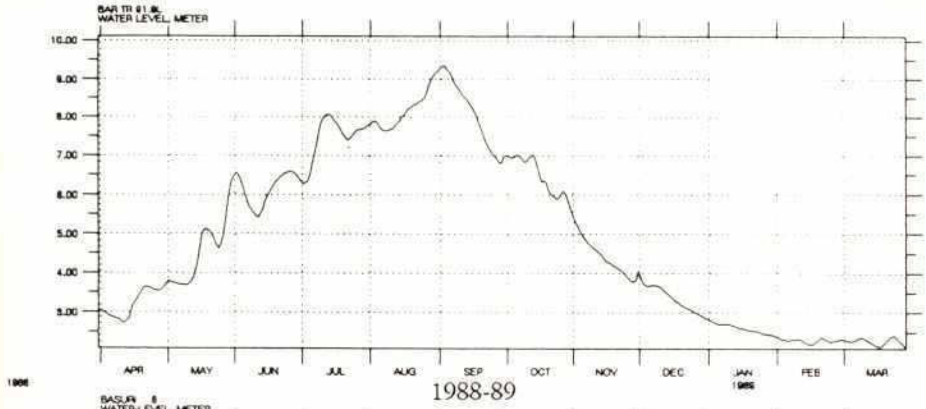


1989-90

Bar TR 91.9L



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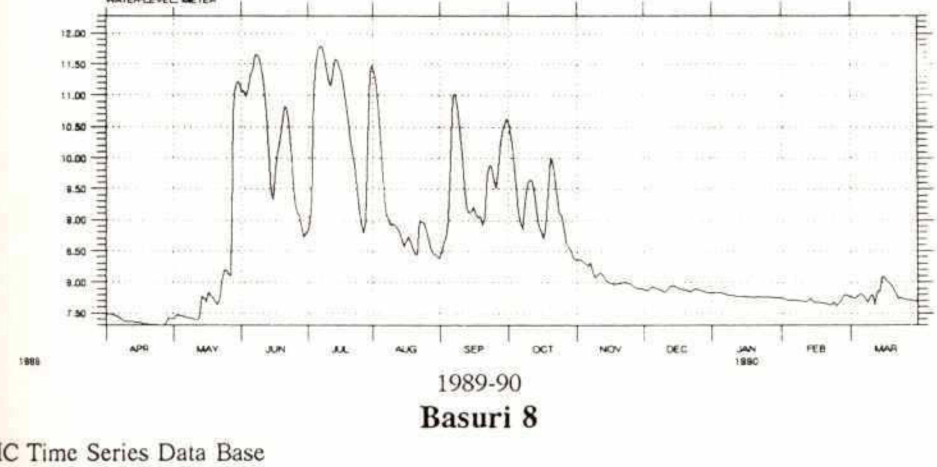


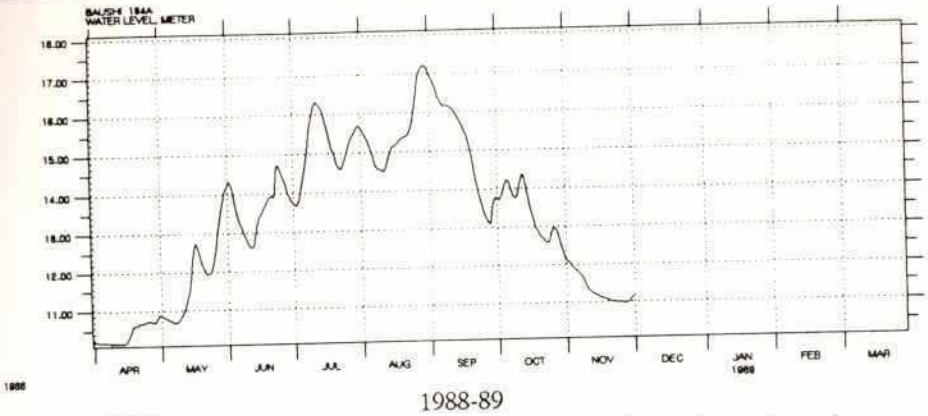
1989-90

Basuri 8

Source:- SWMC Time Series Data Base

Figure : II.A.2

1988 and 1989 Hydrographs - Baushi 184A and BD TR 46.9L



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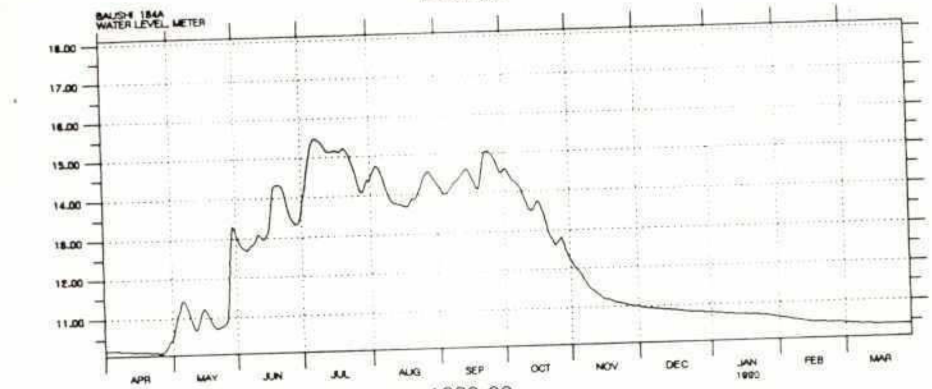
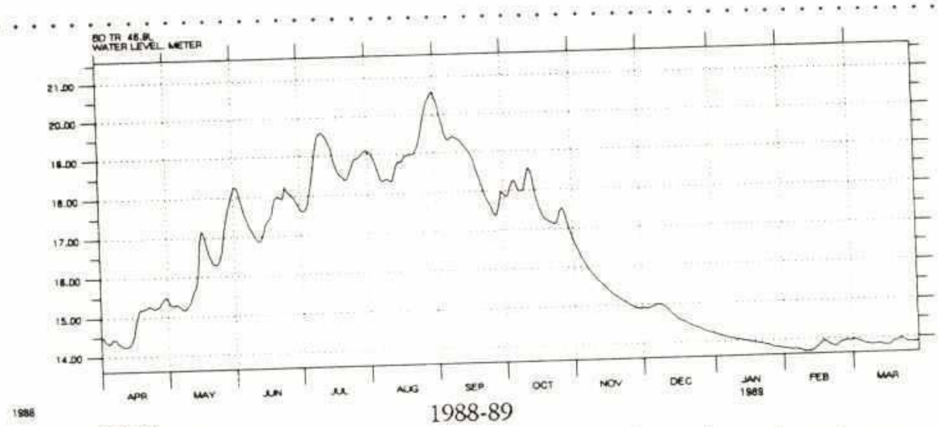
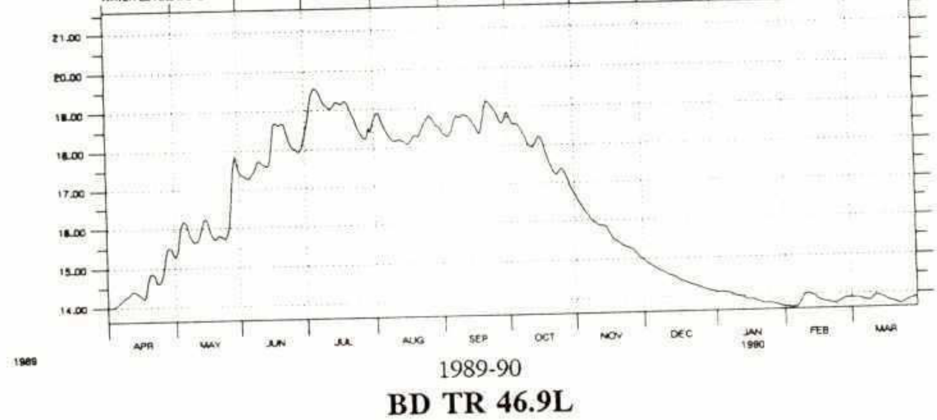


1989-90

Baushi 184A



1988-89



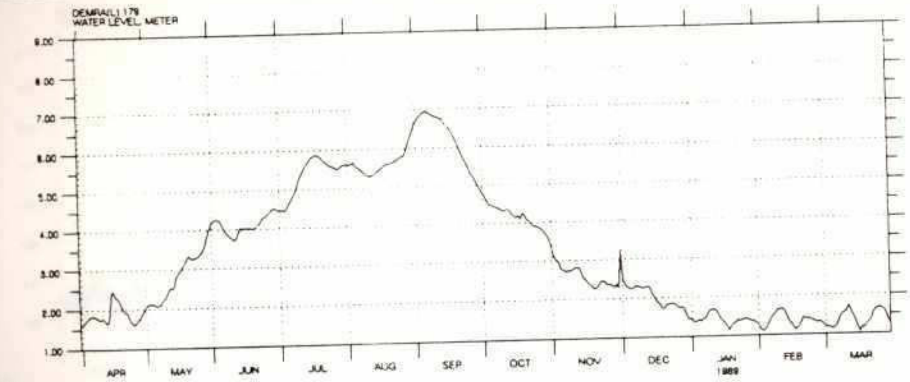
1989-90

BD TR 46.9L

Source:- SWMC Time Series Data Base

Figure : II.A.3

1988 and 1989 Hydrographs - Demra(L)178 and Dhaka 42



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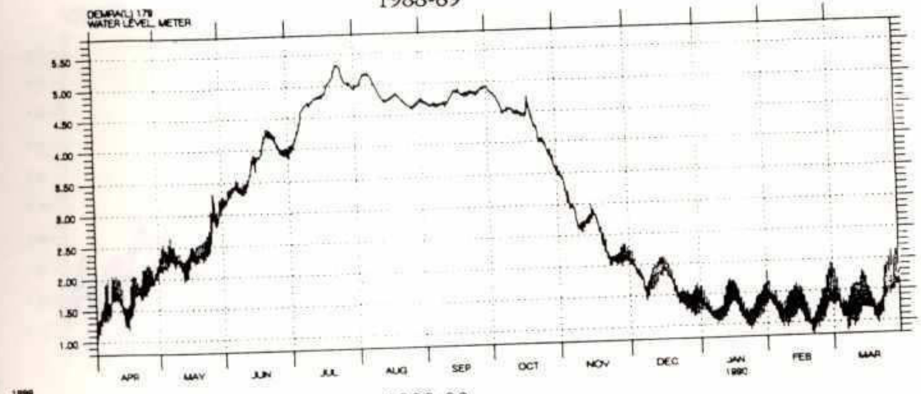

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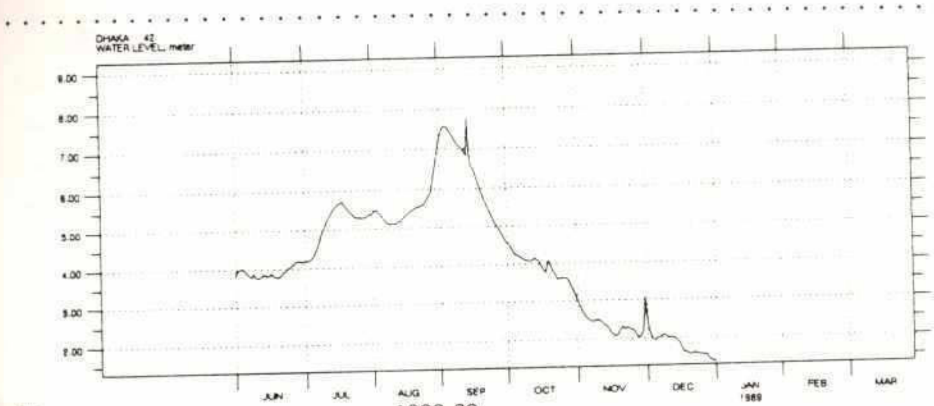
Demra(L)178



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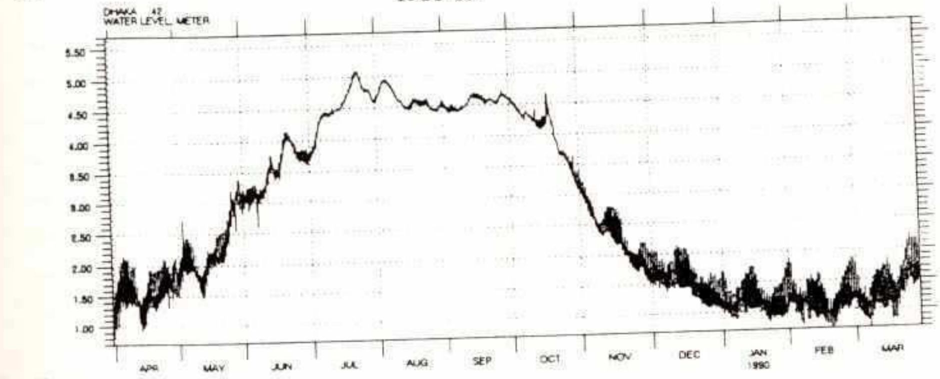


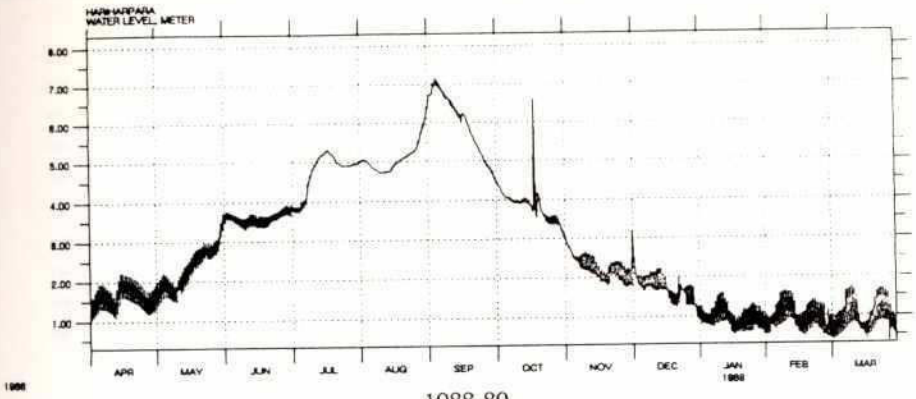
1989-90

Dhaka 42

Source:- SWMC Time Series Data Base

Figure : II.A.4

1988 and 1989 Hydrographs - Hariharpara and Jaganathganj 48



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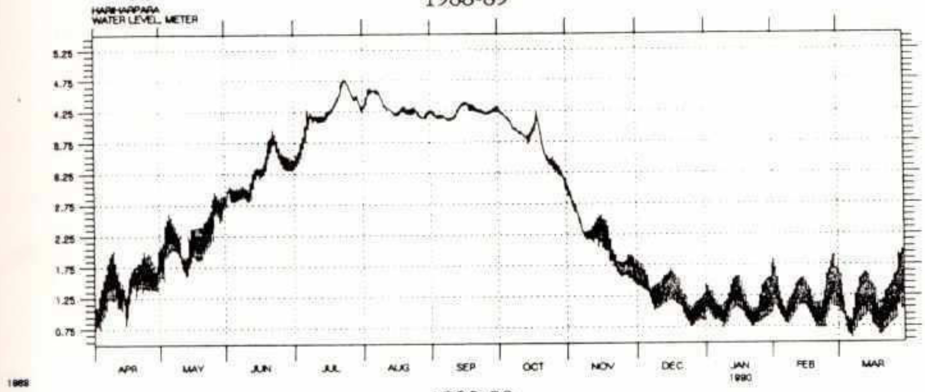

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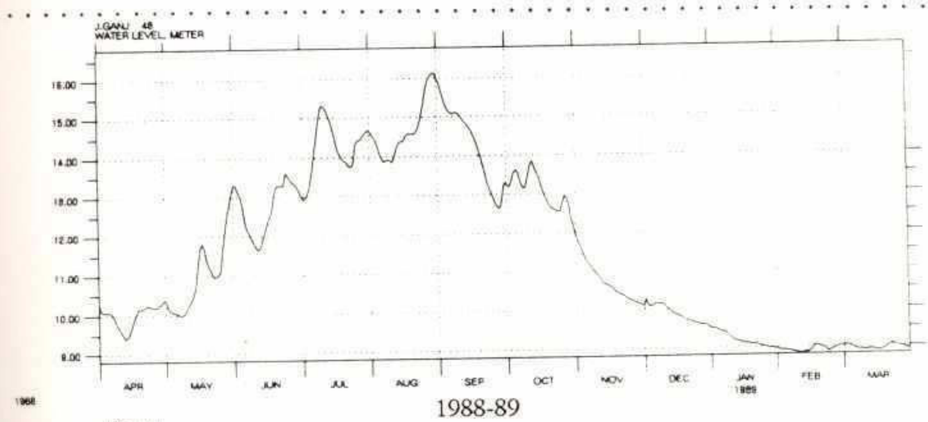
Hariharpara



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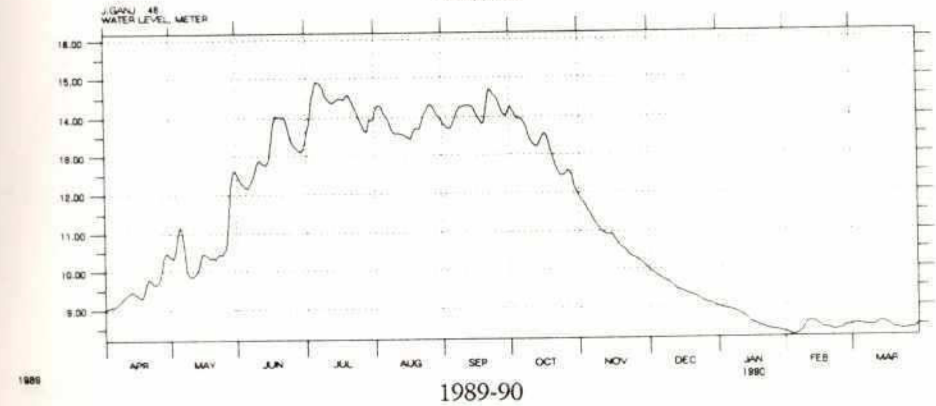


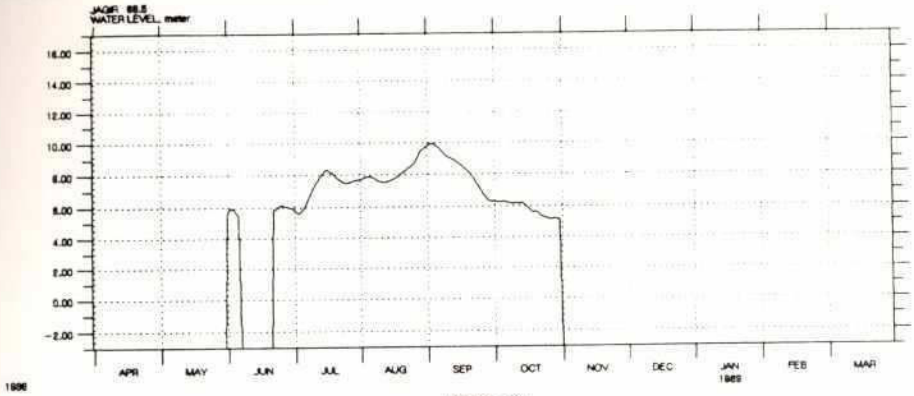
1989-90

Jaganathganj 48

Source:- SWMC Time Series Data Base

Figure : II.A.5

1988 and 1989 Hydrographs - Jagir 68.5 and Jamalpur 225



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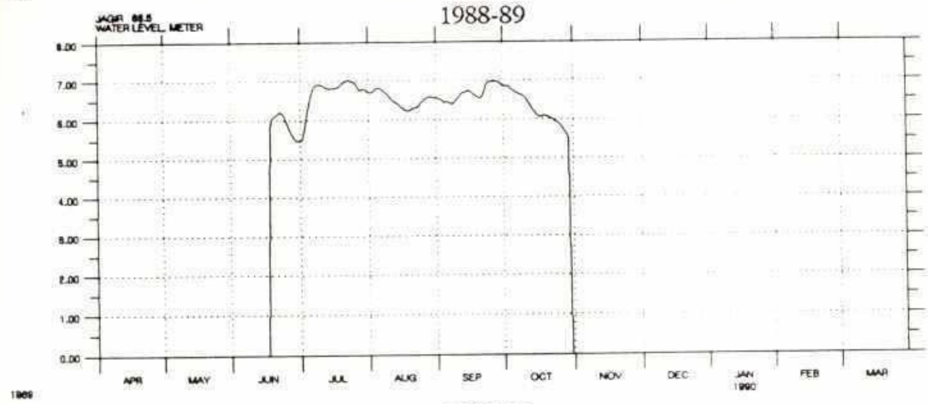
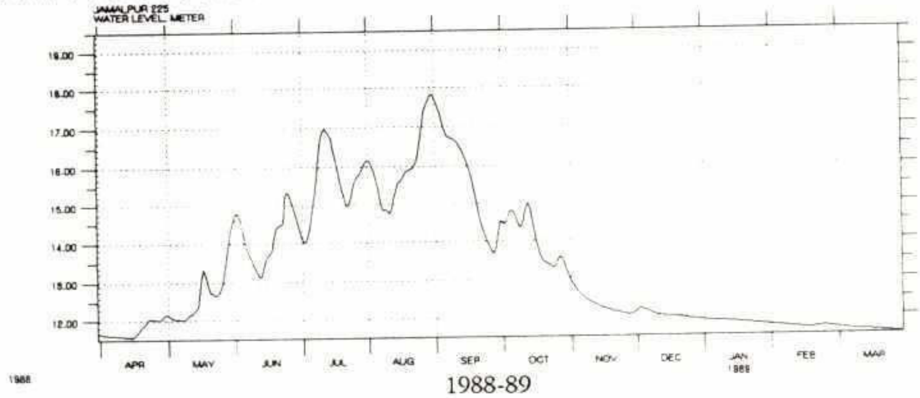


1989-90

Jagir 68.5



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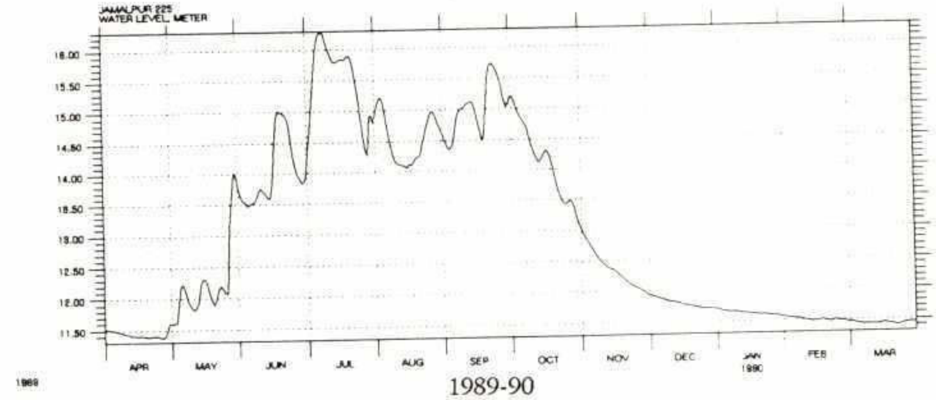


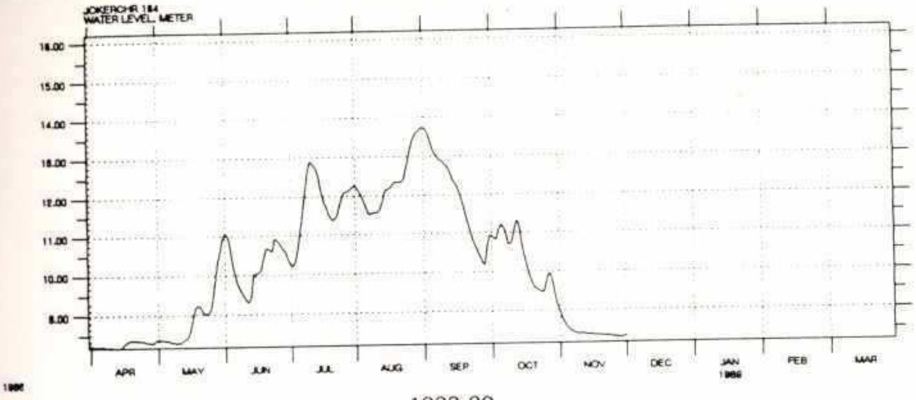
1989-90

Jamalpur 225

Source:- SWMC Time Series Data Base

Figure : II.A.6

1988 and 1989 Hydrographs - Jokerchar 134 and Jugini 186



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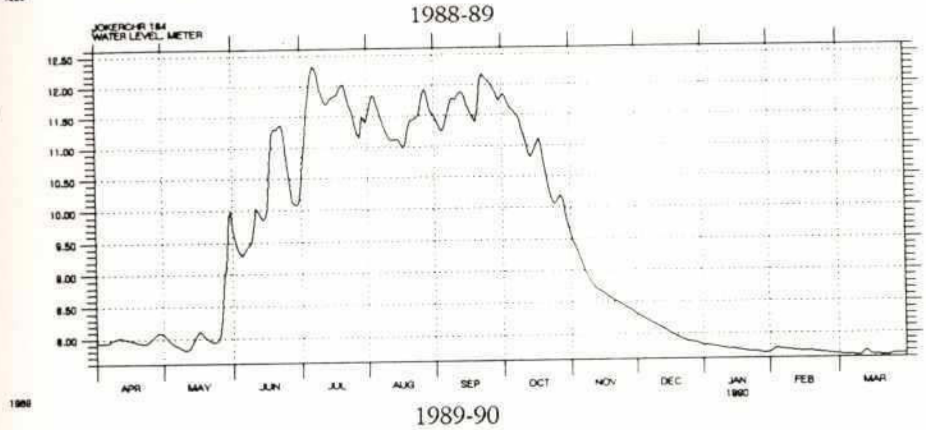
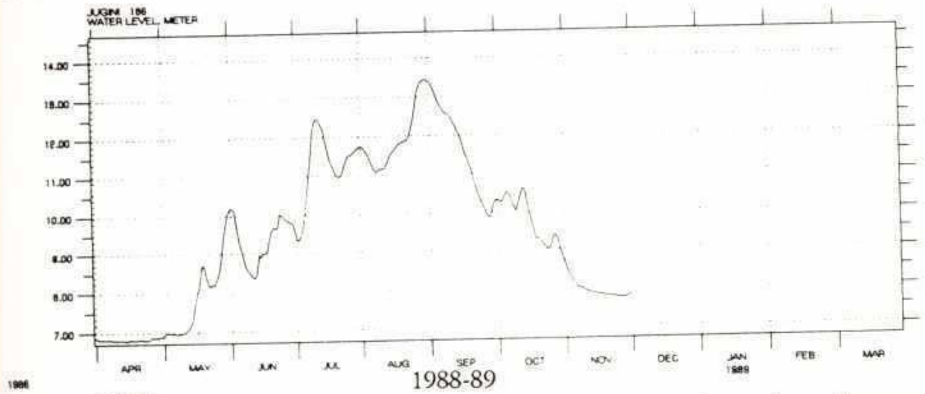


1989-90

Jokerchar 134



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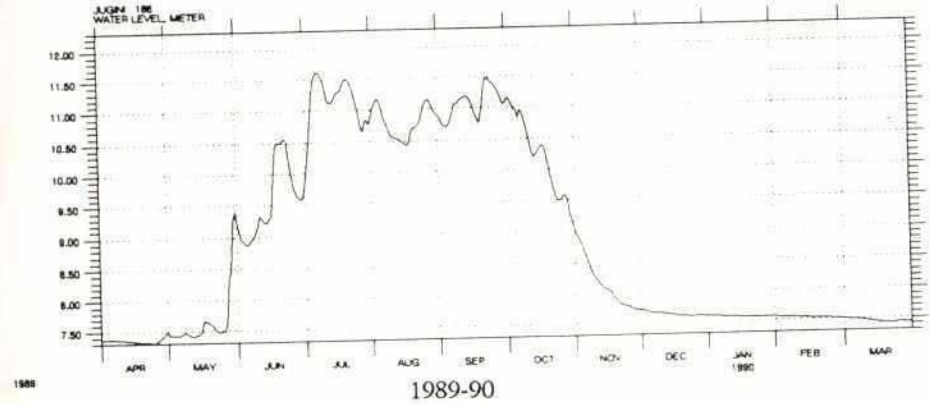


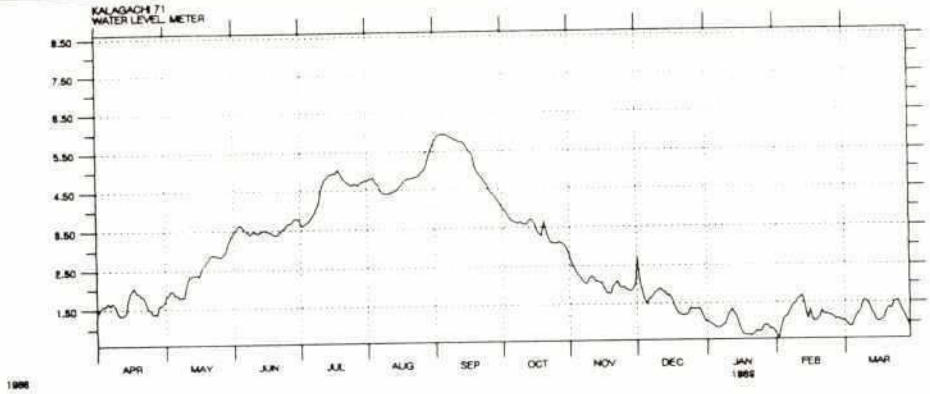
1989-90

Jugini 186

Source:- SWMC Time Series Data Base

Figure : II.A.7

1988 and 1989 Hydrographs - Kalagachi 71 and Kalatia 70



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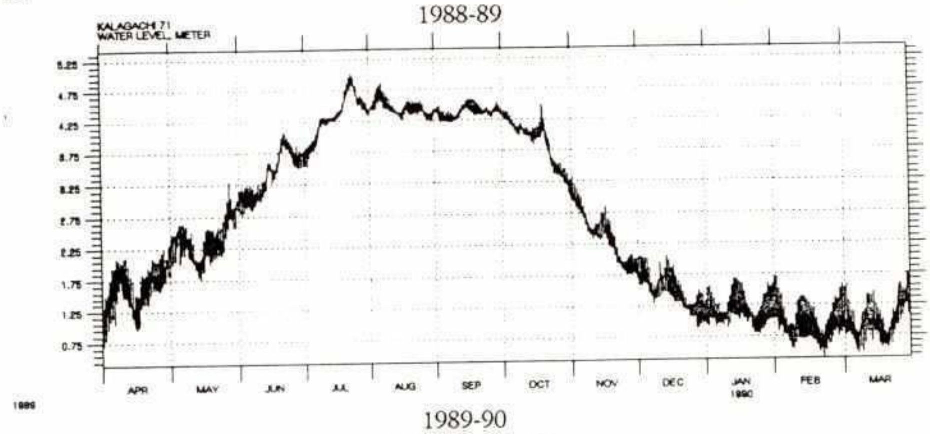

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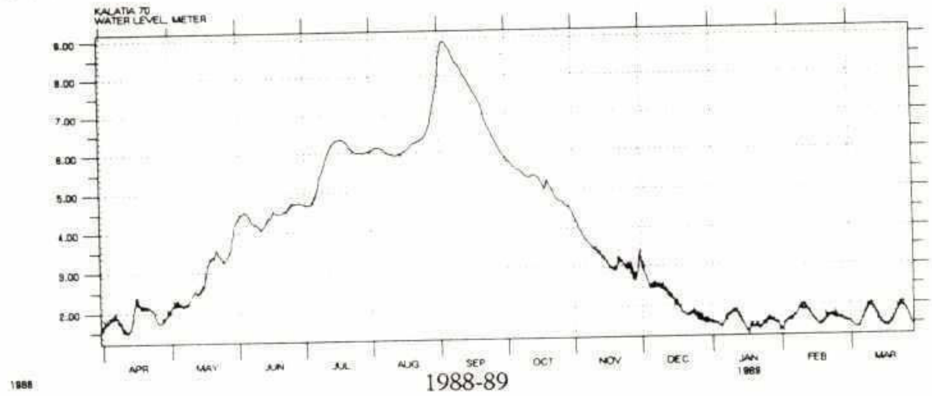
Kalagachi 71



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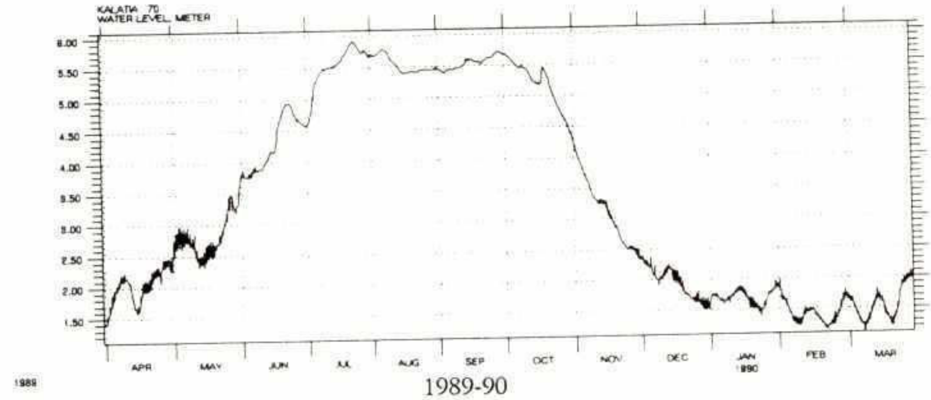


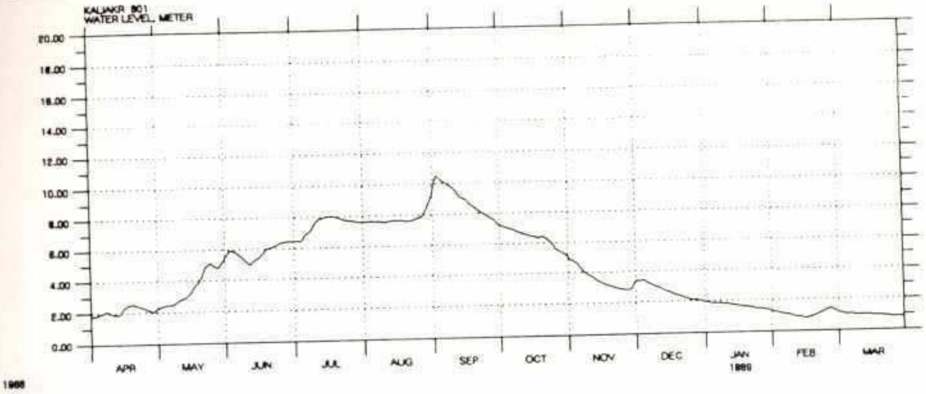
1989-90

Kalatia 70

Source:- SWMC Time Series Data Base

Figure : II.A.8

1988 and 1989 Hydrographs - Kaliaka 301 and Kaoraid 8



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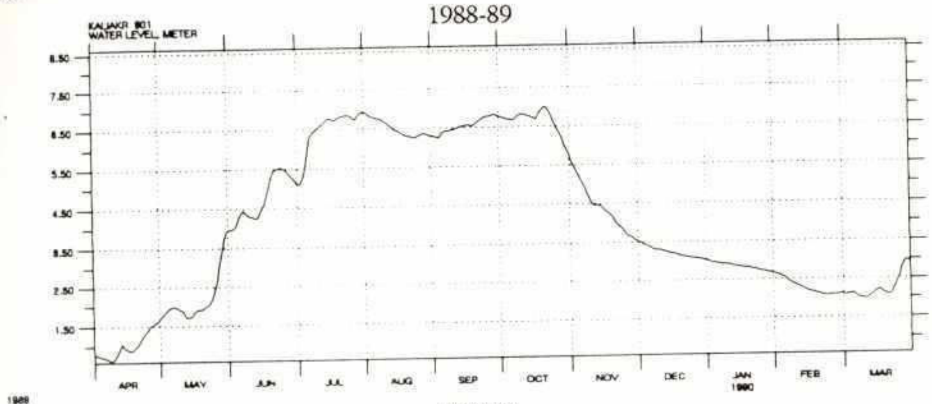
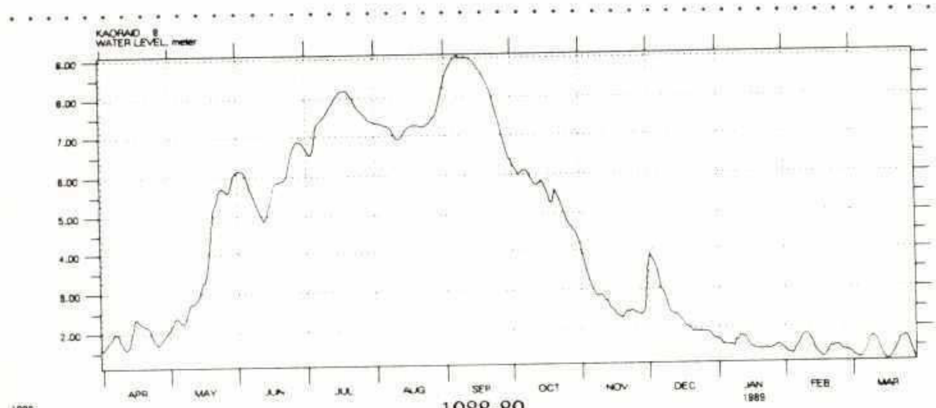


1989-90

Kaliaka 301



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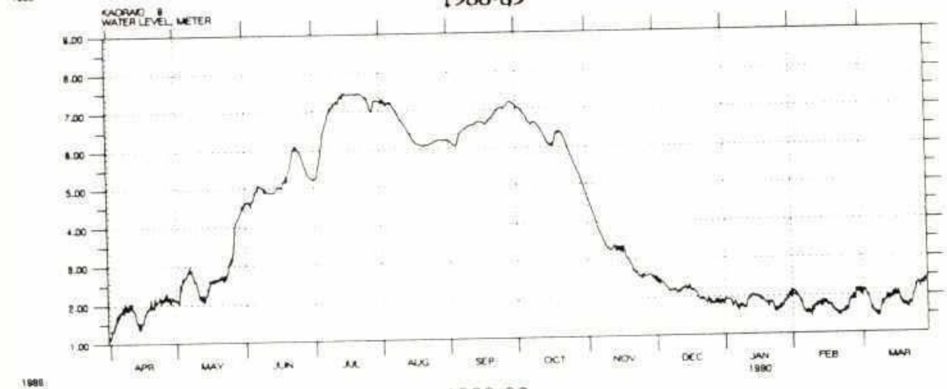


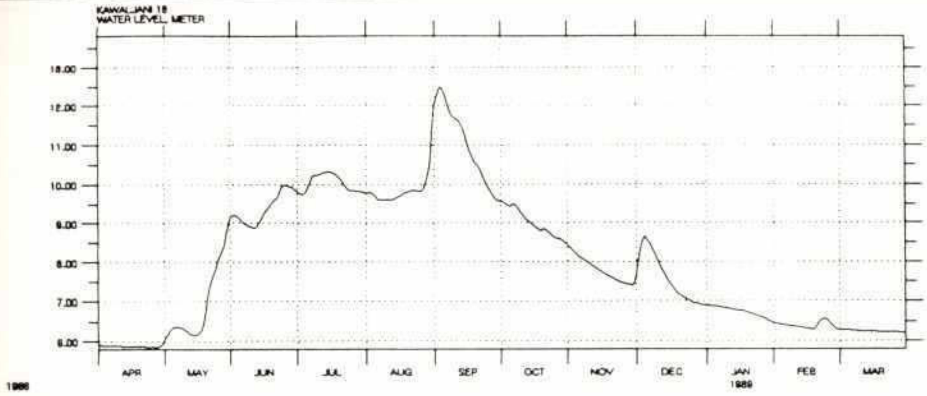
1989-90

Kaoraid 9

Source:- SWMC Time Series Data Base

Figure : II.A.9

1988 and 1989 Hydrographs - Kawaljani 13 and KB CHR 46.7



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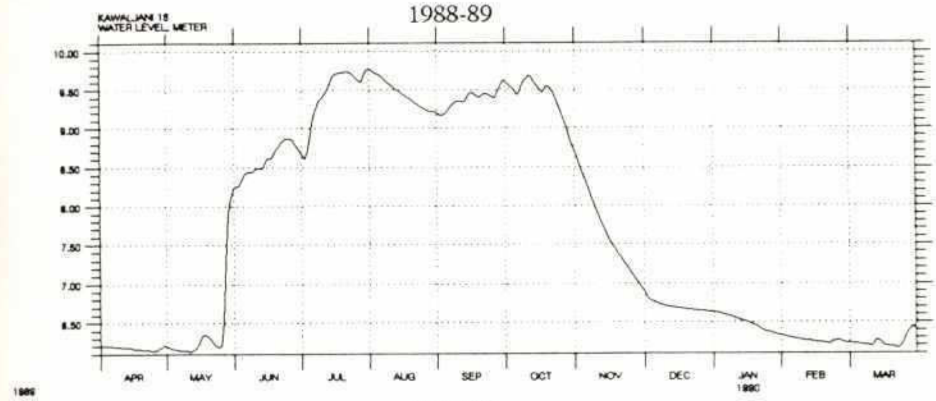
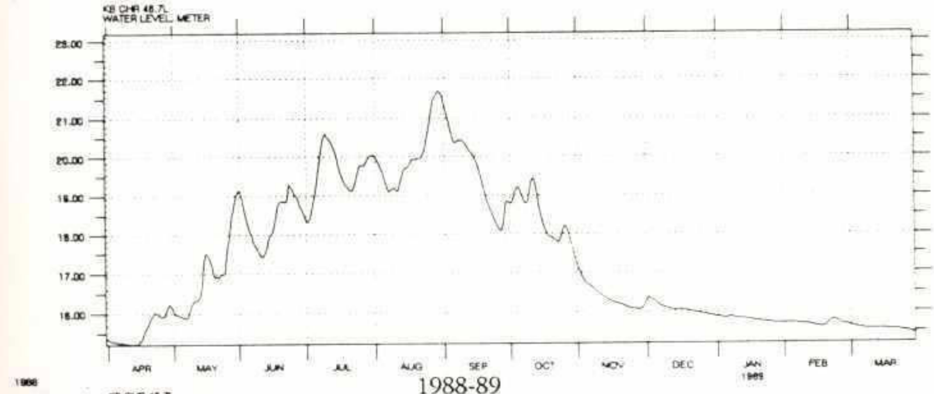


1989-90

Kawaljani 13



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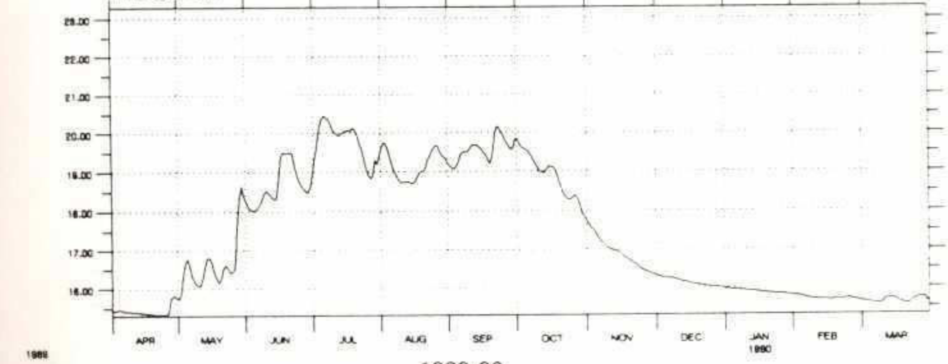


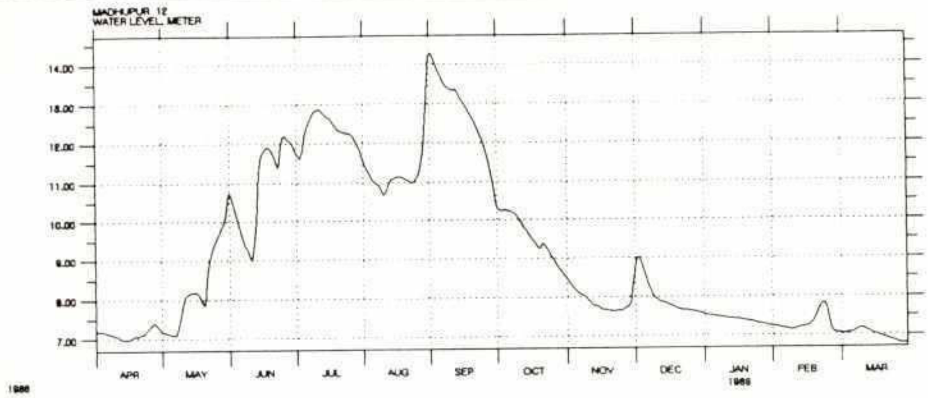
1989-90

KB CHR 46.7L

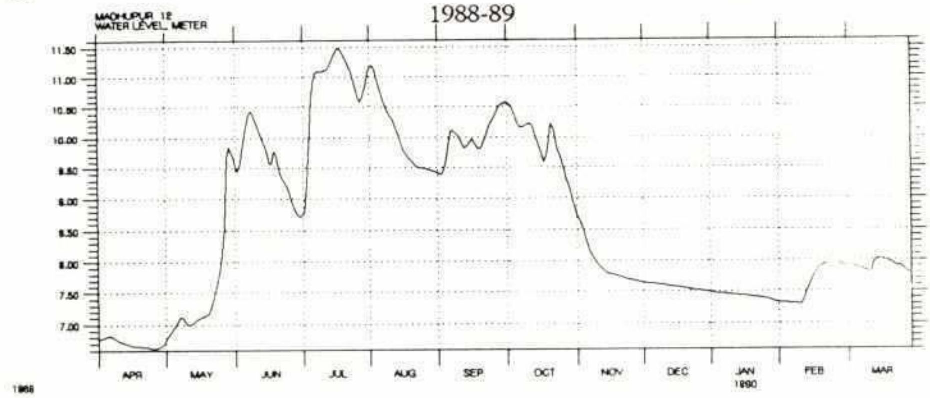
Source:- SWMC Time Series Data Base

[1] SR II.1;Appendix A - Hydrographs

Figure : II.A.10
1988 and 1989 Hydrographs - Madhupur 12 and Mawa 93.5L

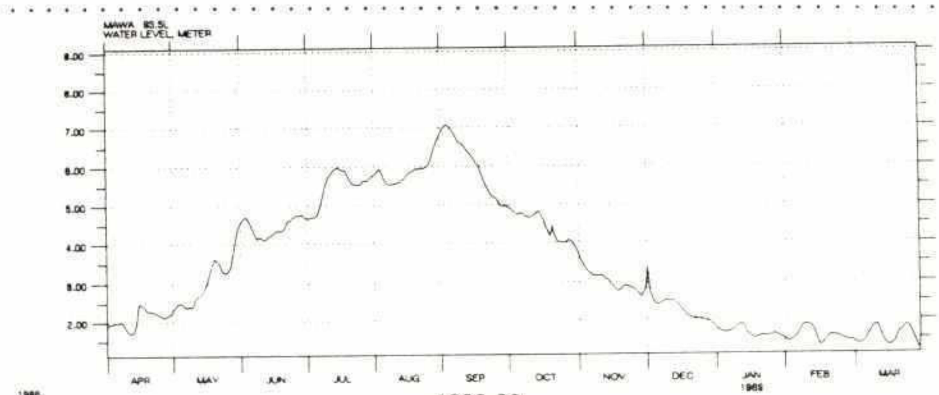


1988-89

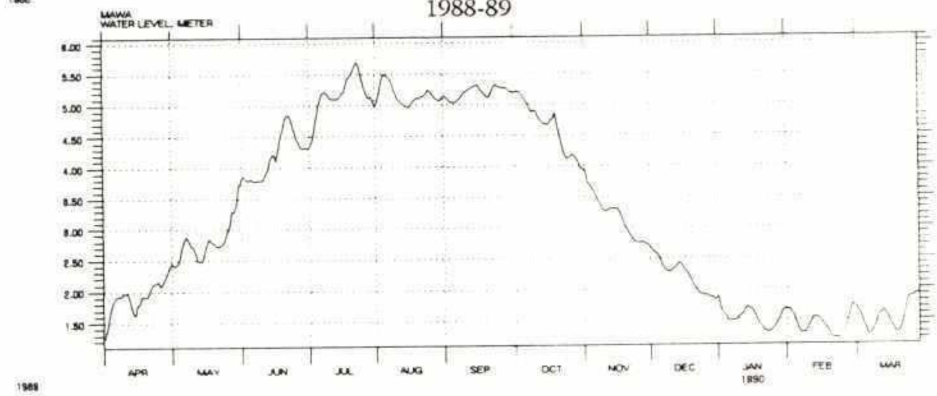


1989-90

Madhupur 12



1988-89



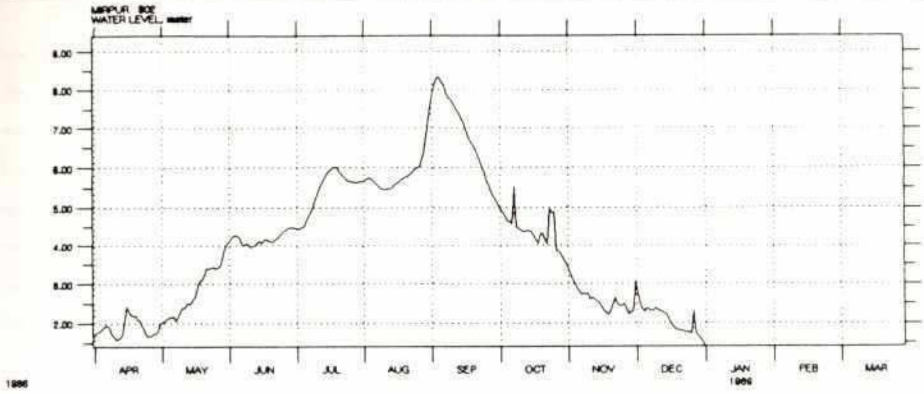
1989-90

Mawa

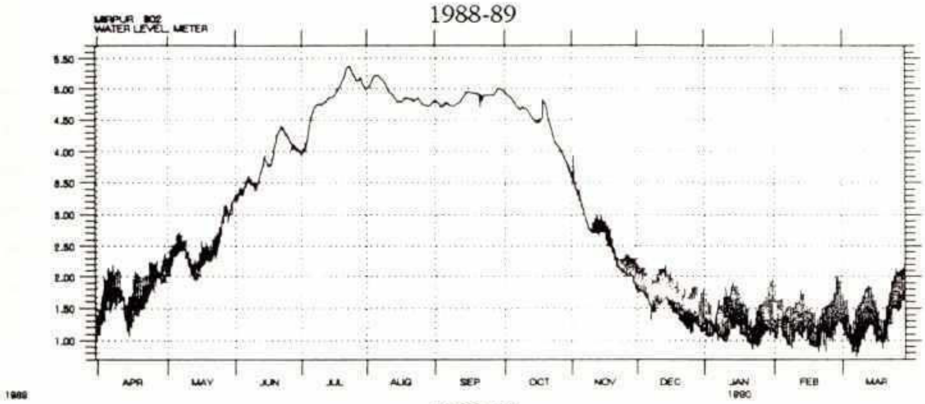
Source:- SWMC Time Series Data Base

Figure : II.A.11

1988 and 1989 Hydrographs - Mirpur 302 and Mirzapur 14

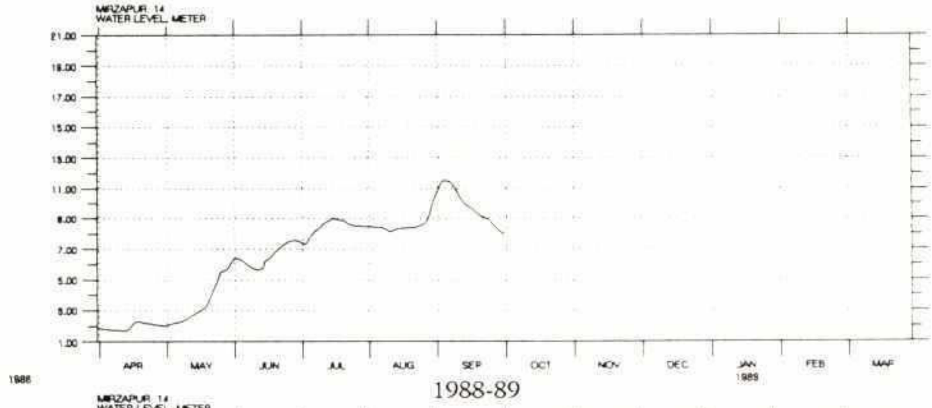


1988-89

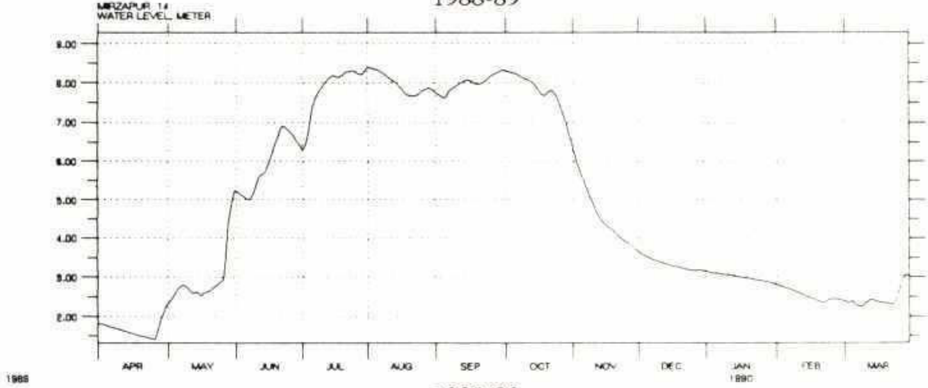


1989-90

Mirpur 302



1988-89

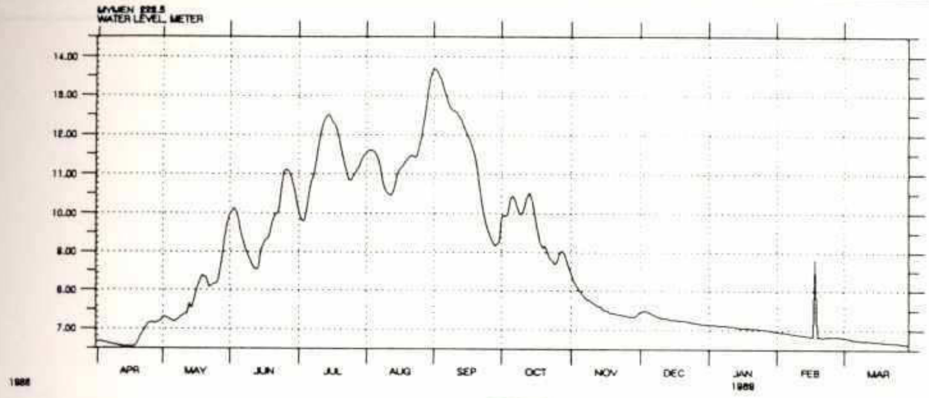


1989-90

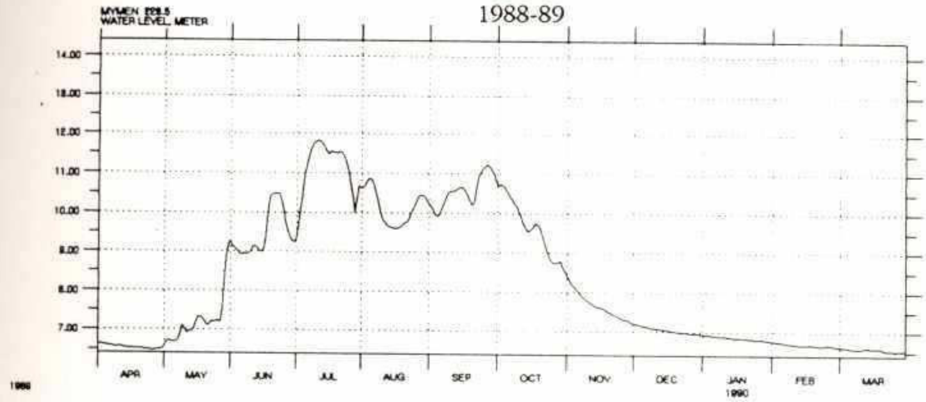
Mirzapur 14

Source:- SWMC Time Series Data Base

Figure : II.A.12
1988 and 1989 Hydrographs - Mymen 228.5 and Nayarht 14.5

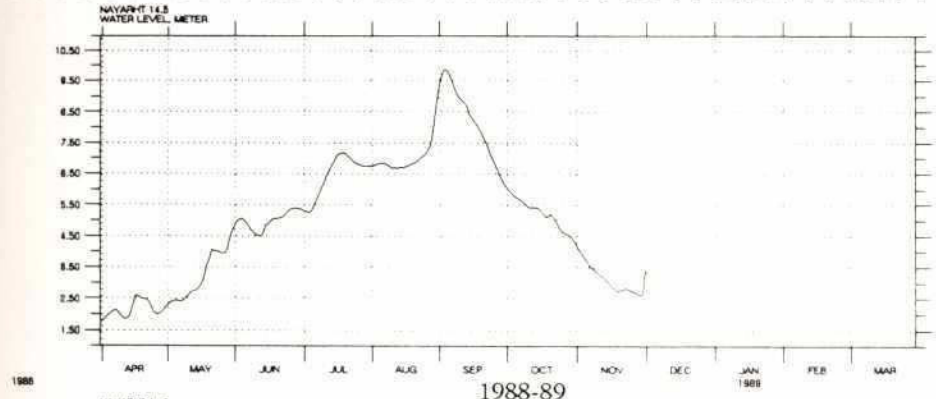


1988-89

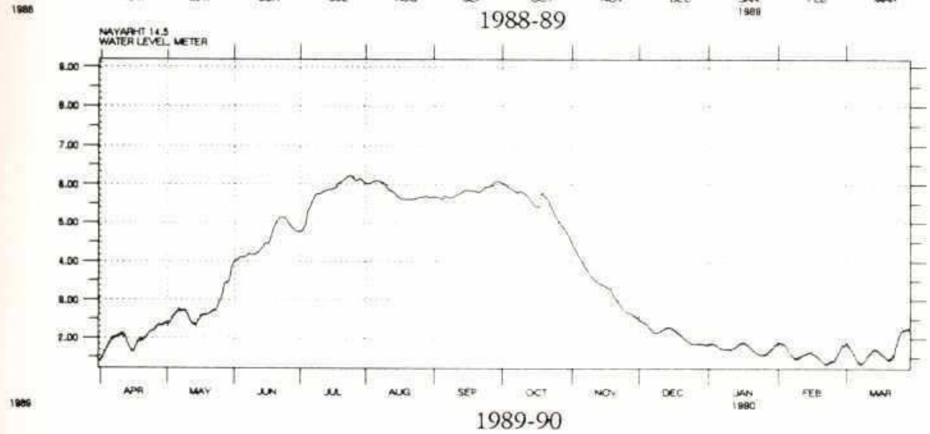


1989-90

Mymen 228.5



1988-89

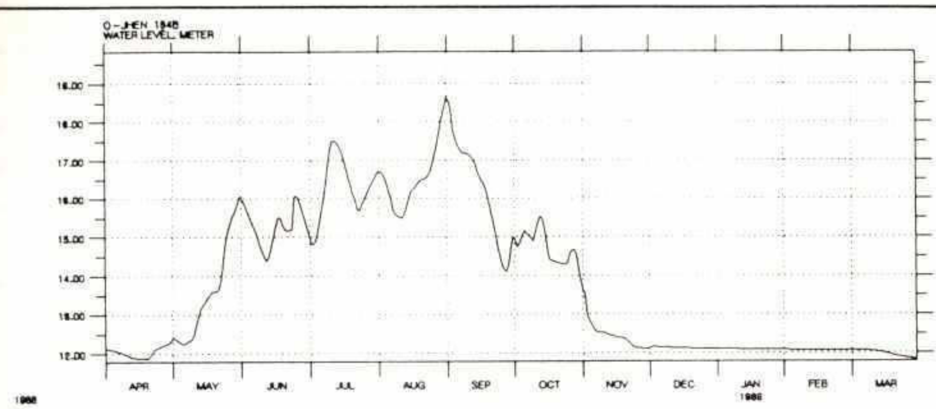


1989-90

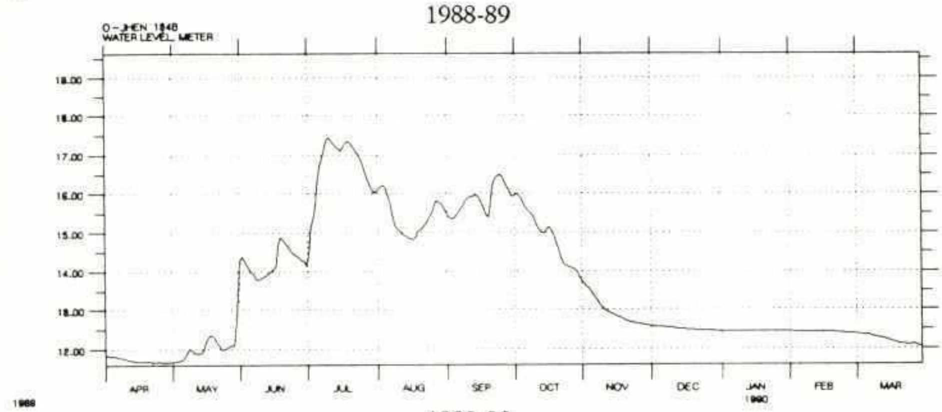
Nayarht 14.5

Source:- SWMC Time Series Data Base

Figure : II.A.13
1988 and 1989 Hydrographs - O-Jhen 134B and O-Sutia 227

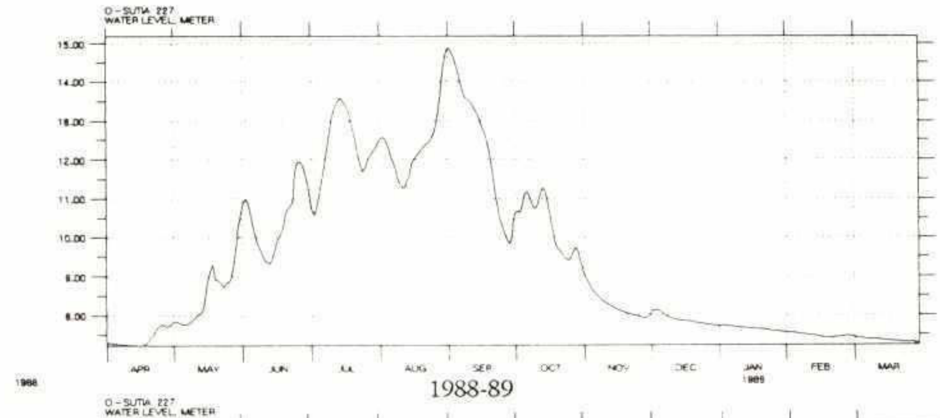


1988-89

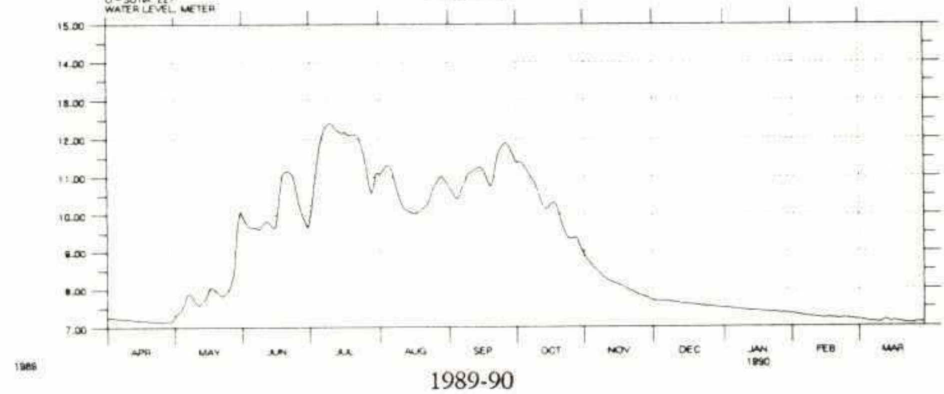


1989-90

O-Jhen 134B



1988-89



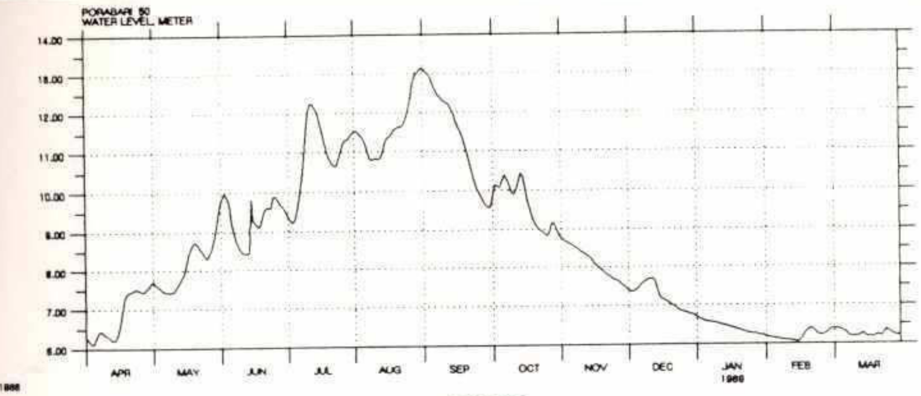
1989-90

O-Sutia 227

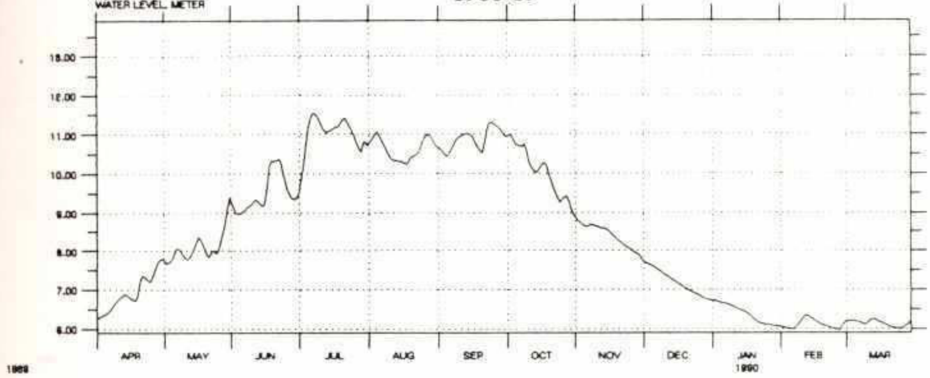
Source:- SWMC Time Series Data Base

Figure : II.A.14

1988 and 1989 Hydrographs - Porabari 50 and Serajganj 49

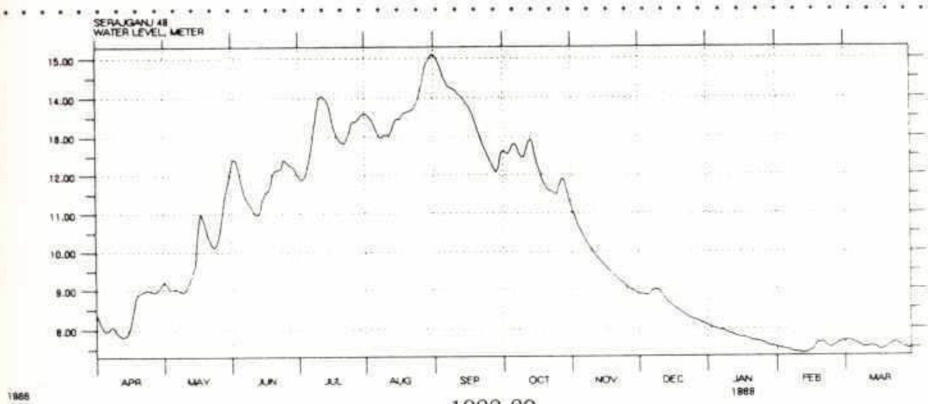


1988-89

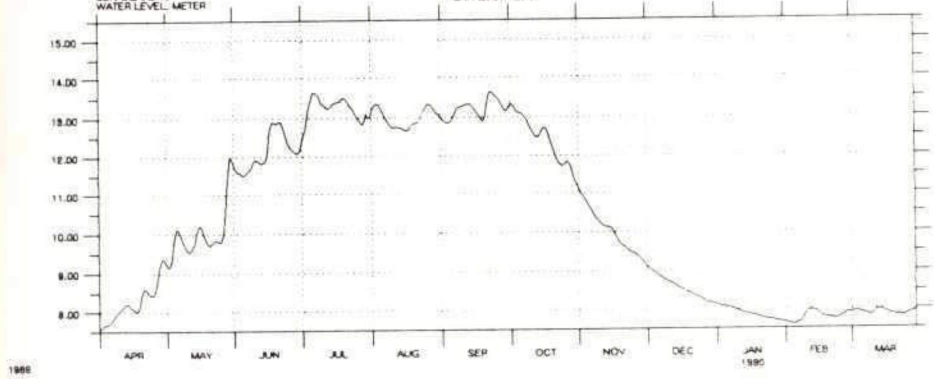


1989-90

Porabari 50



1988-89

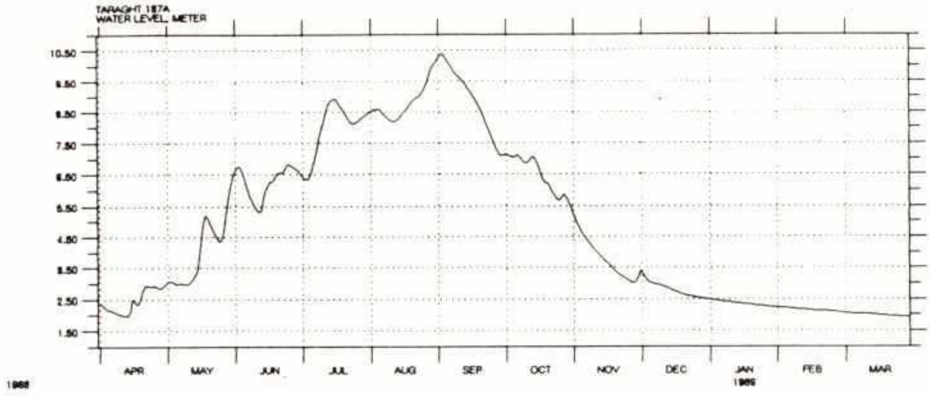


1989-90

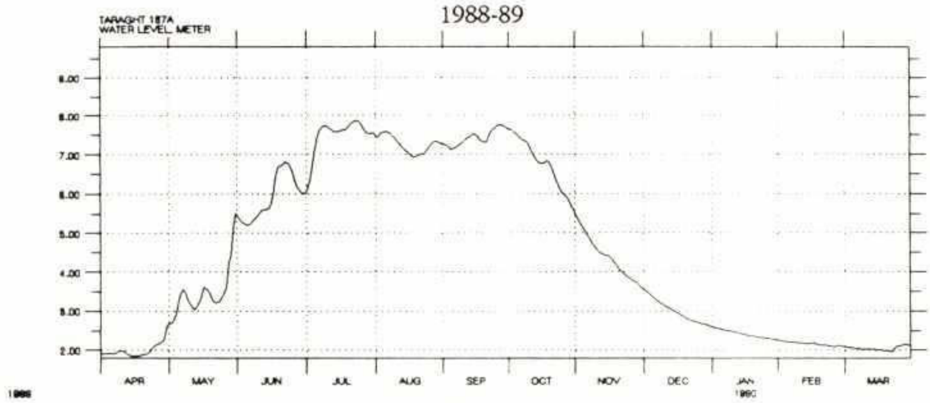
Serajganj 49

Source:- SWMC Time Series Data Base

Figure : II.A.15
1988 and 1989 Hydrographs - Taraght 137A and Tilli 68

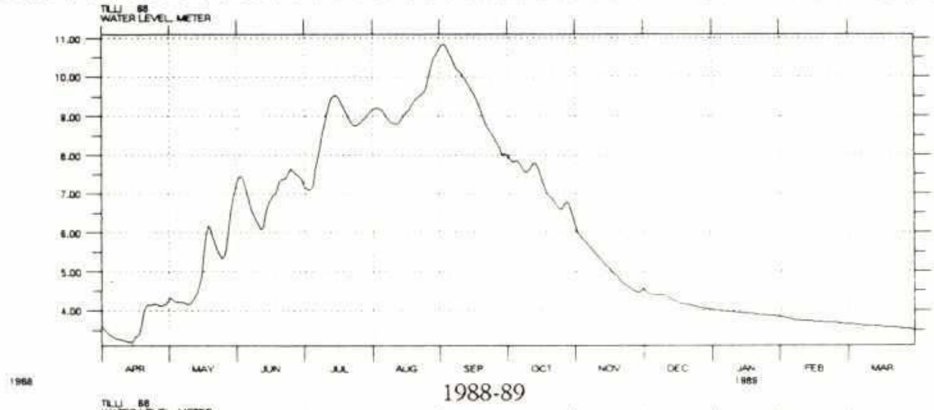


1988-89

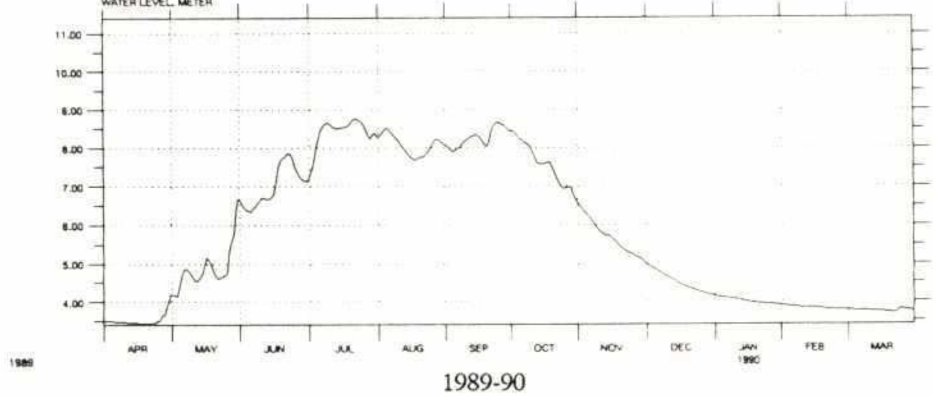


1989-90

Taraght 137A



1988-89



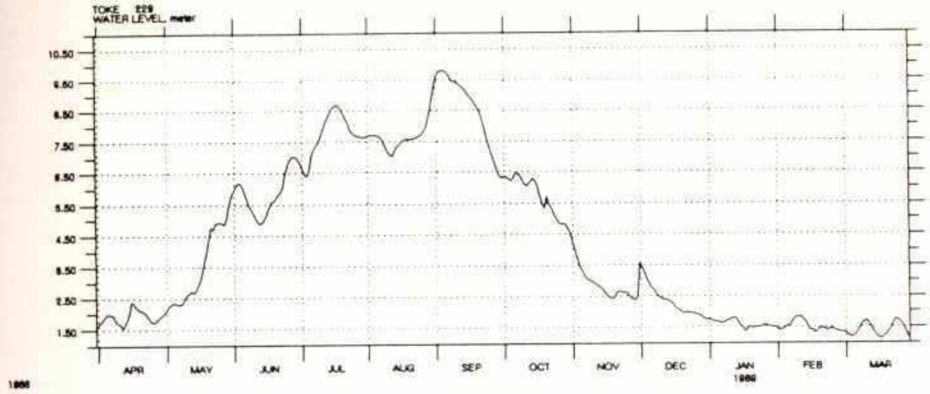
1989-90

Tilli 68

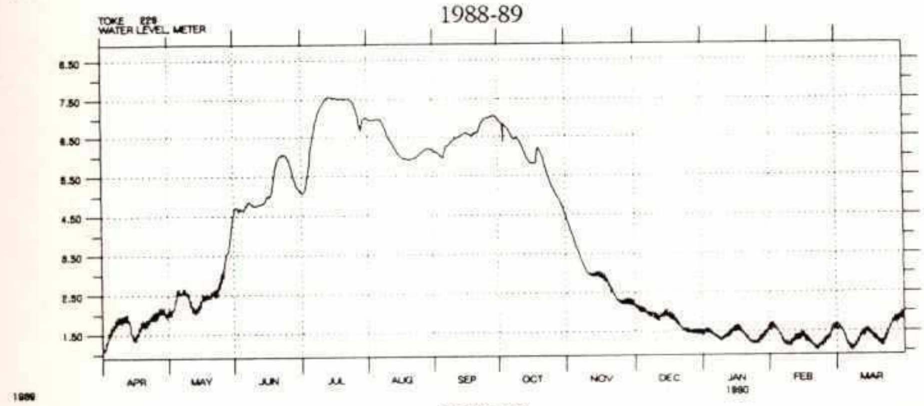
Source:- SWMC Time Series Data Base

Figure : II.A.16

1988 and 1989 Hydrographs - Toke 229 and Trimohoni 9.5

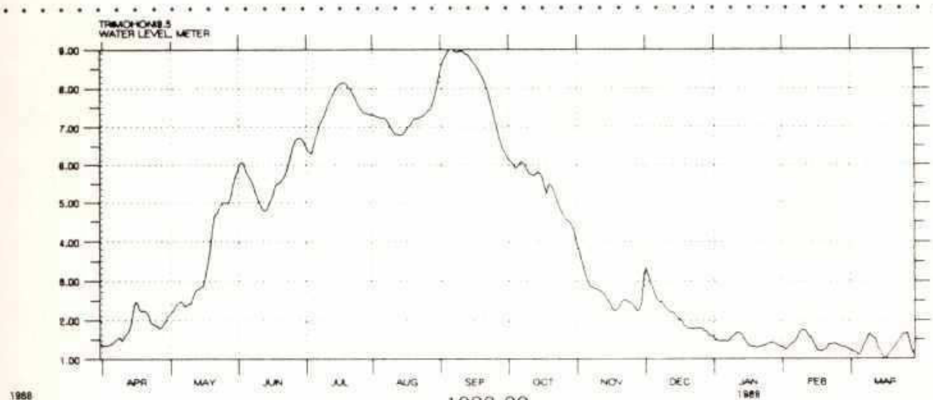


1988-89

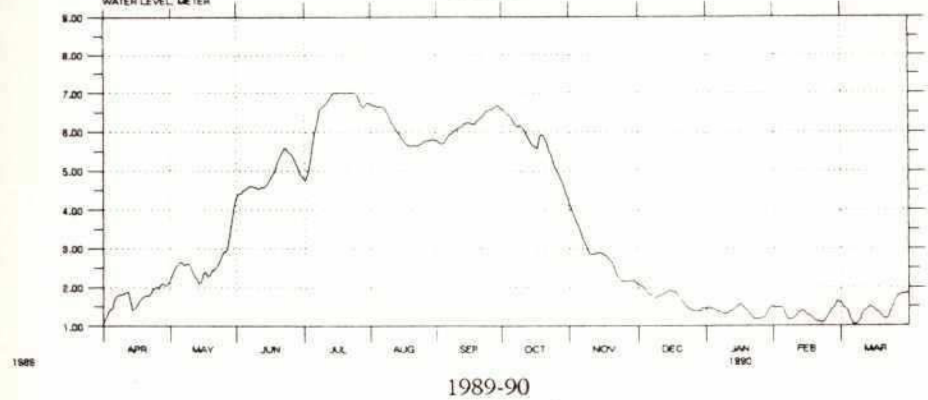


1989-90

Toke 229



1988-89



1989-90

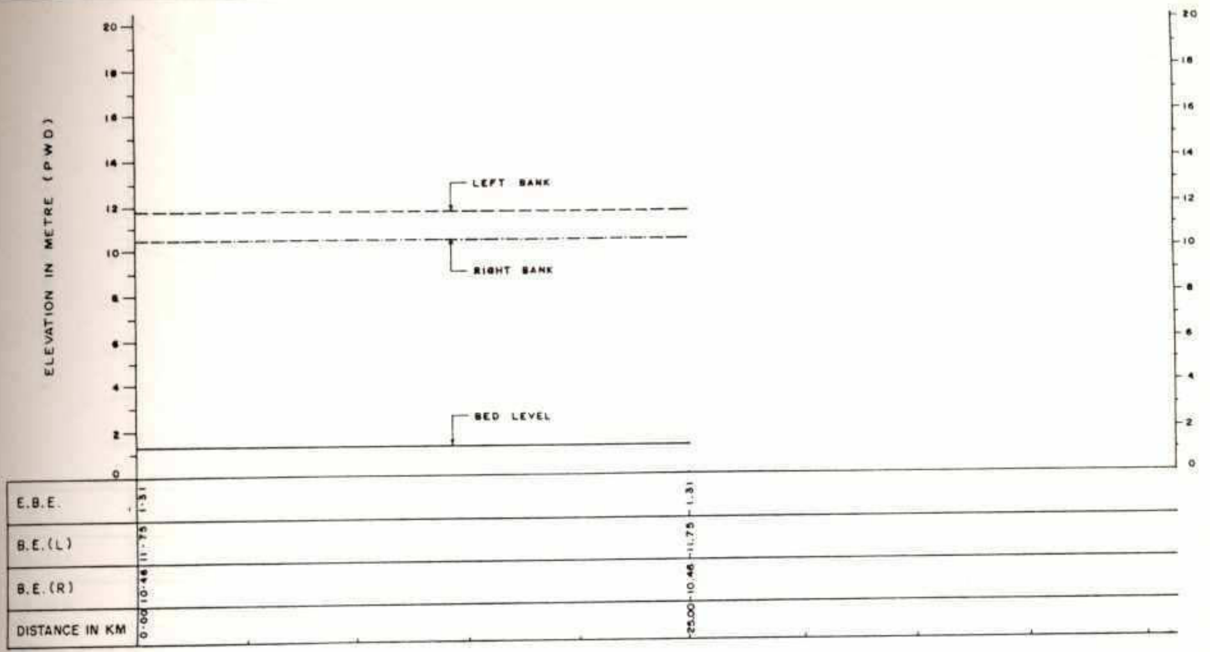
Trimohoni 9.5

Source:- SWMC Time Series Data Base

Supporting Report - II

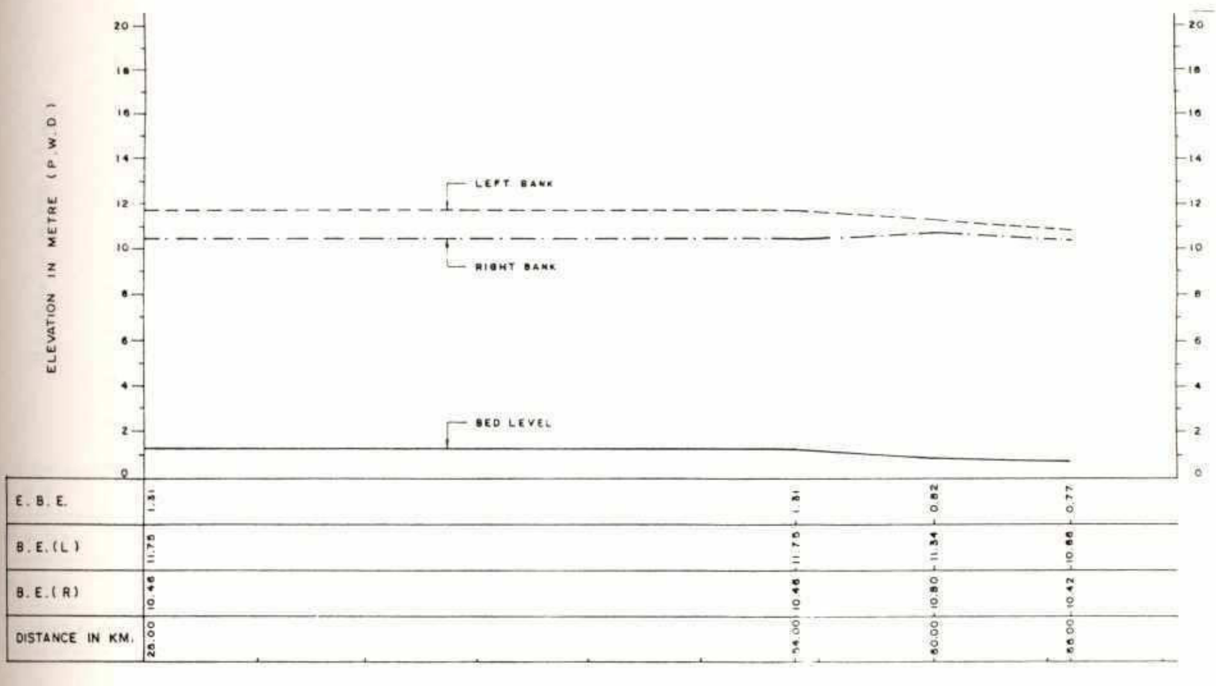
Appendix II. B
Longitudinal Sections

Figure : II.B.1a
Longitudinal Sections; Banar-Lakhya River System



E.B.E = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Banar River

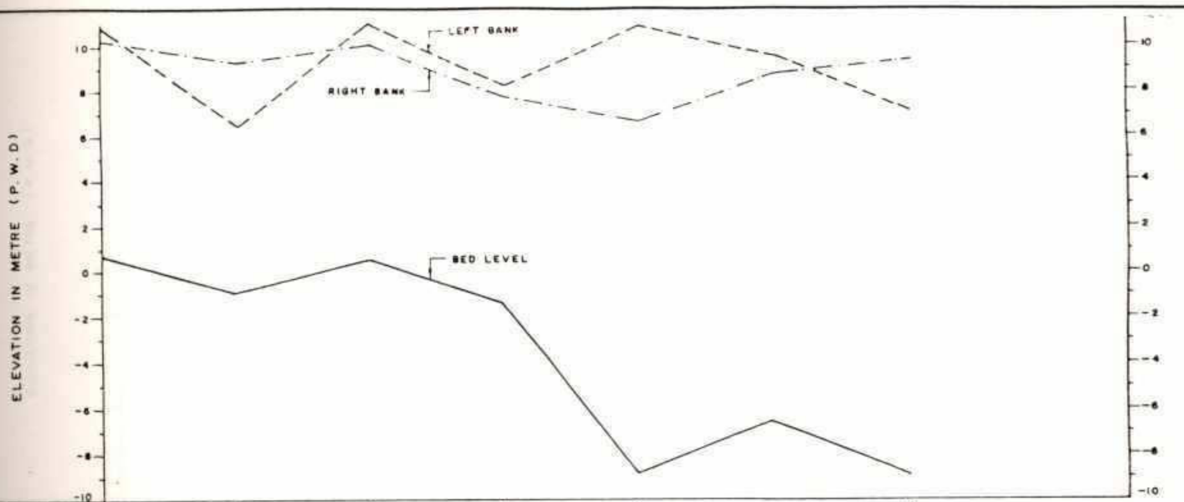


E. B. E = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Banar River

Source:- CS 1992

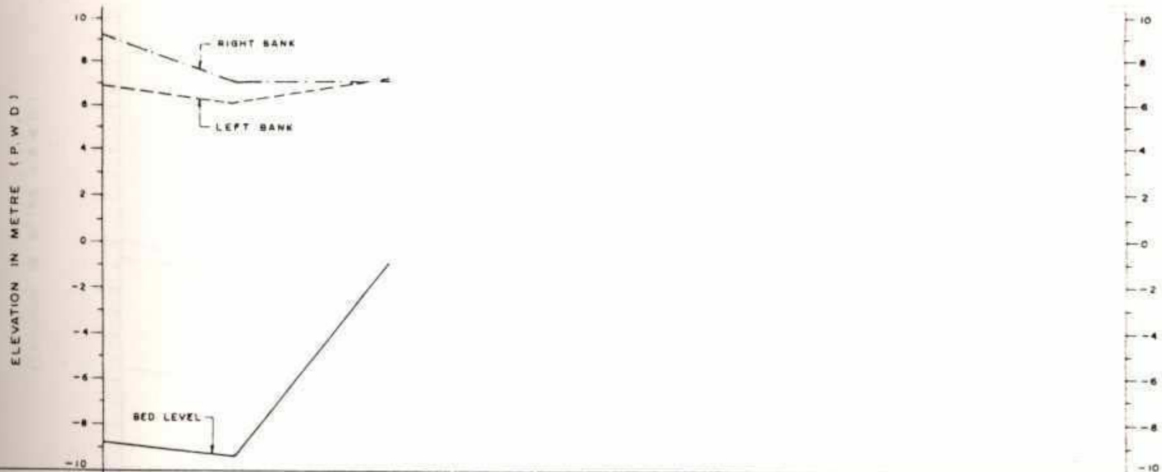
Figure : II.B.1b
Longitudinal Sections; Banar-Lakhya River System



E. B. E.	0.77	-1.07	0.45	-1.54	-8.82	-6.71	-8.64
B. E. (L)	10.86	6.31	11.06	8.31	10.77	9.54	6.97
B. E. (R)	10.42	9.30	10.07	7.88	6.85	8.84	9.35
DISTANCE IN KM	66.00	72.00	78.00	84.00	90.00	96.00	102.00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Banar River



E. B. E.	-8.64	-9.37	-0.97
B. E. (L)	6.97	6.11	7.25
B. E. (R)	9.35	7.15	7.15
DISTANCE IN KM.	102.00	108.00	115.00

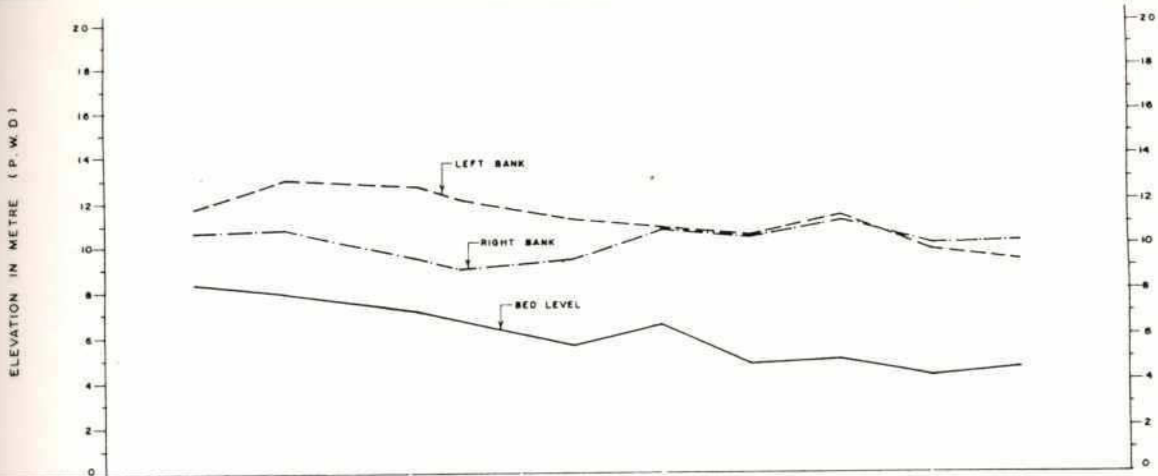
E. B. E = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Banar River

Source:- CS 1992

Figure : II.B.1c

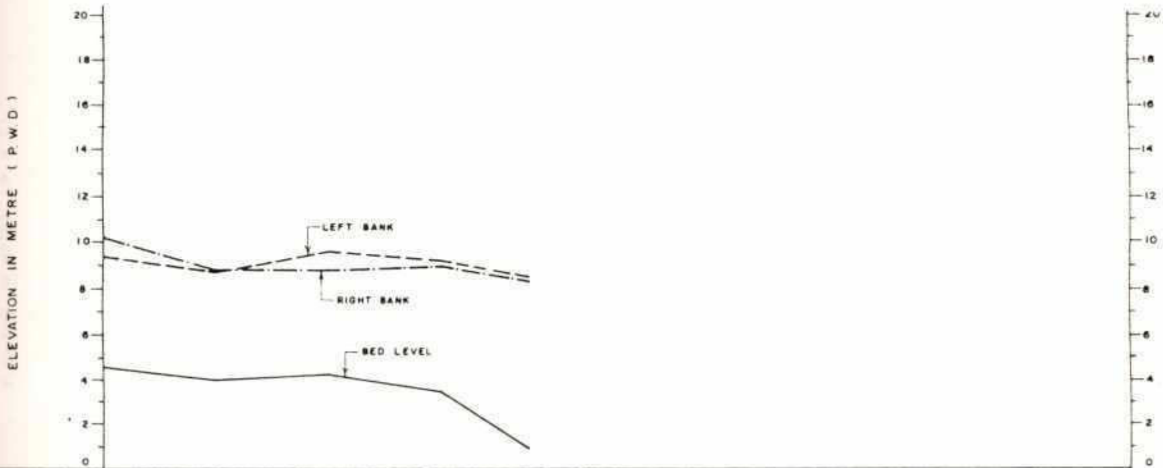
Longitudinal Sections; Banar-Lakhya River System



E. B. E.		8·35	7·93	7·09	6·63	5·51	6·45	4·74	4·95	4·20	4·58
B. E. (L)		11·78	13·04	12·73	12·12	11·22	10·85	10·50	11·41	9·81	9·38
B. E. (R)		10·66	10·80	9·50	8·97	9·40	10·73	10·38	11·07	10·06	10·20
DISTANCE IN KM.	0·00	4·00	8·00	14·00	16·00	21·00	25·00	29·00	33·00	37·00	41·00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Sutia River



E. B. E.	4·58	4·00	4·22	3·43	0·89
B. E. (L)	9·38	8·64	9·61	9·21	8·52
B. E. (R)	10·20	8·80	8·82	8·97	8·36
DISTANCE IN KM.	41·00	46·00	51·00	56·00	60·00

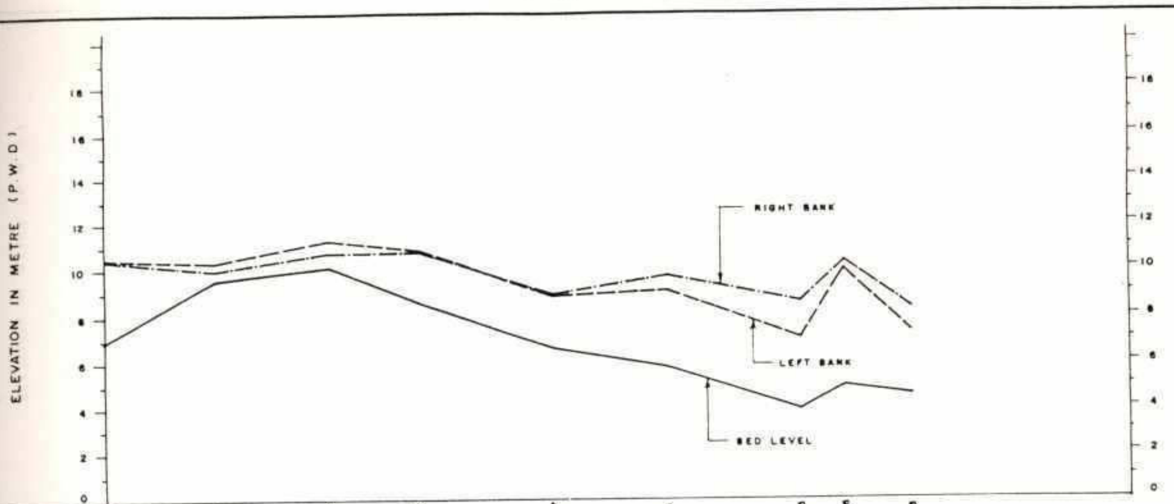
E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Sutia River

Source:- CS 1992

Figure : II.B.1d

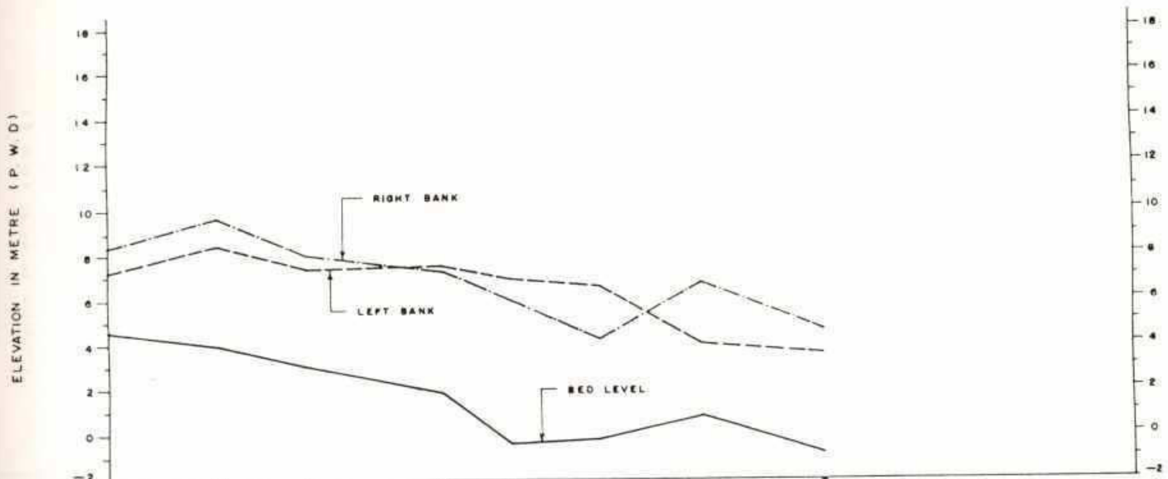
Longitudinal Sections; Banar-Lakhya River System



E.B.E.	6.85	9.49	10.05	8.55	6.57	5.73	3.85	4.86	4.56
B.E.(L)	10.42	10.24	11.22	10.77	8.81	9.07	7.03	9.98	7.23
B.E.(R)	10.40	9.88	10.70	10.70	8.86	9.88	8.59	10.29	8.34
DISTANCE IN KM.	0.00	5.00	10.00	14.00	20.00	25.00	31.00	33.00	36.00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Khiro River



E.B.E.	4.56	3.90	3.05	1.80	-0.45	-0.24	0.70	-0.95
B.E.(L)	7.23	8.57	7.27	7.47	6.91	6.58	3.94	3.46
B.E.(R)	8.34	9.63	7.96	7.20	6.00	4.17	6.68	4.65
DISTANCE IN KM.	36.00	41.00	45.00	51.00	54.00	58.00	62.50	66.00

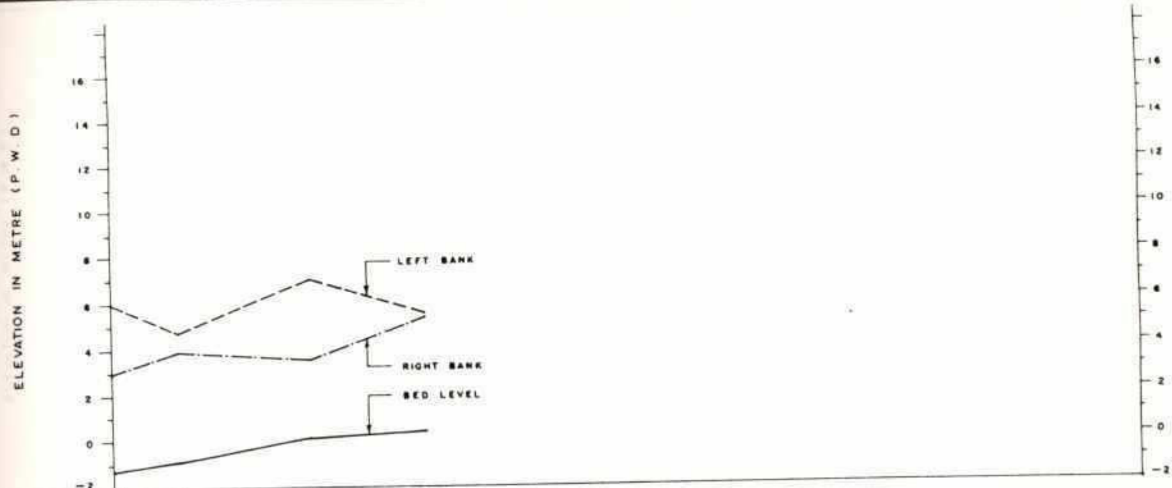
E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Khiro River

Source:- CS 1992

Figure : II.B.1e

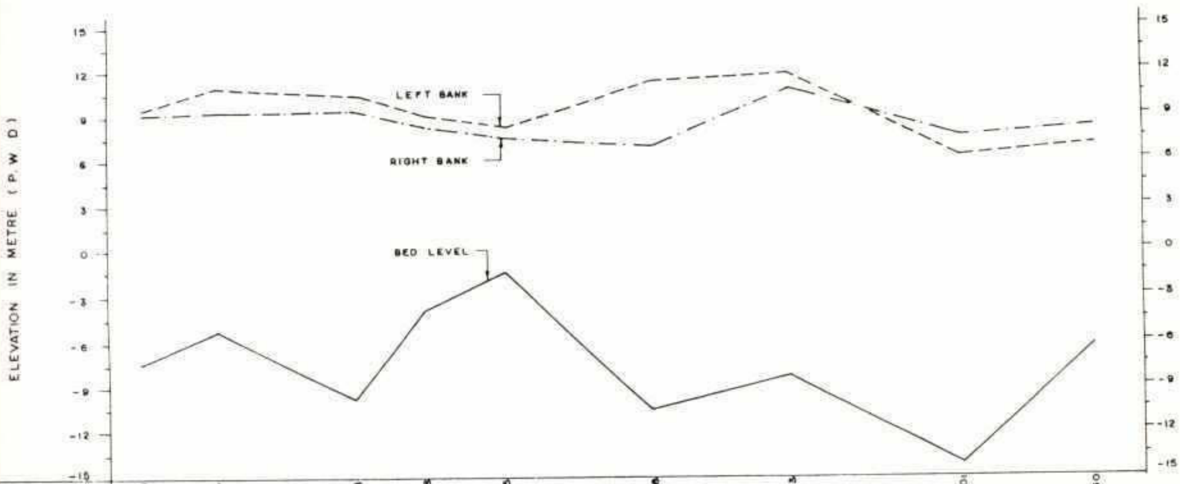
Longitudinal Sections; Banar-Lakhya River System



DISTANCE IN KM	0·00	3·00	9·00	14·00
E. B. E	-1·28	-0·90	0·12	0·27
B. E. (L)	6·00	4·66	7·05	5·44
B. E. (R)	2·95	3·87	3·48	5·32

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Kaoraid River



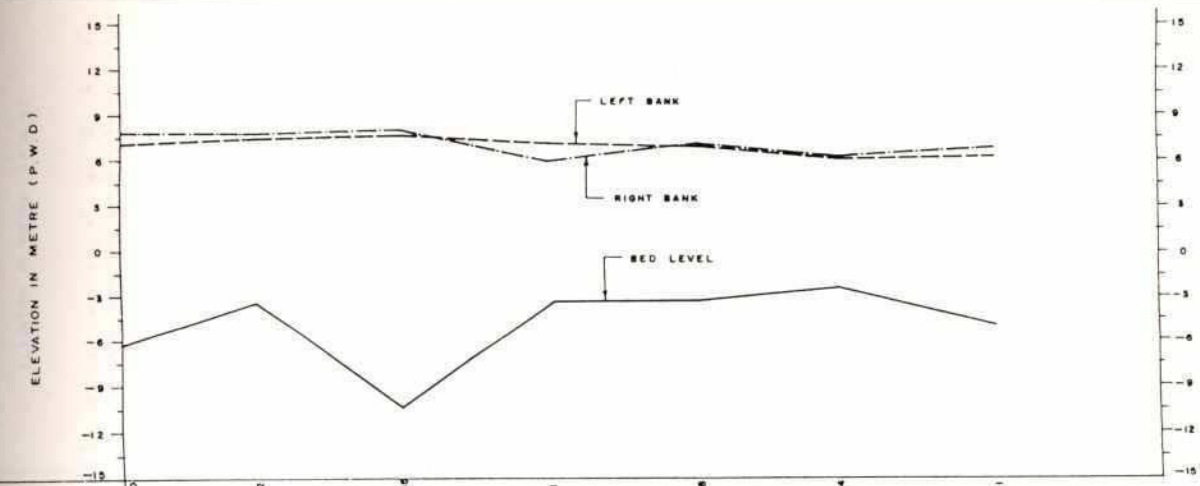
DISTANCE IN KM.	0.00	1.50	5.00	11.00	14.00	17.50	24.00	30.00	37.50	43.50
E. B. E.		-7.50	-4.77	-9.95	-4.08	-1.55	-10.56	-8.33	-14.01	-6.30
B. E. (L)		9.62	10.94	10.40	9.00	8.55	11.42	11.83	6.33	7.04
B. E. (R)		9.25	9.60	9.34	8.32	7.86	6.94	10.95	7.53	7.75

E. B. E = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Lakhya River

Source:- CS 1992

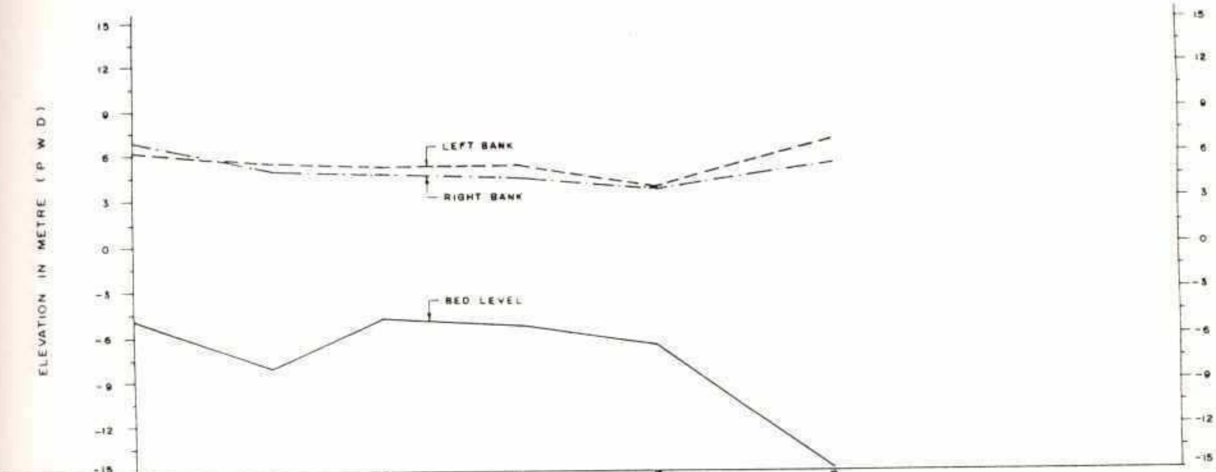
Figure : II.B.1f
Longitudinal Sections; Banar-Lakhya River System



E. B. E.	-6.50	-3.52	-10.85	-3.41	-3.28	-2.44	-5.01
B. E (L)	7.04	7.50	7.68	7.14	6.89	6.15	6.24
B. E. (R)	7.75	7.76	7.99	6.05	7.09	6.28	6.82
DISTANCE IN KM.	43.50	49.50	56.00	62.50	69.00	75.00	82.00

E.B.E = EXISTING BED ELEVATION
B.E (L) = BANK ELEVATION (LEFT)
B.E (R) = BANK ELEVATION (RIGHT)

Lakhya River



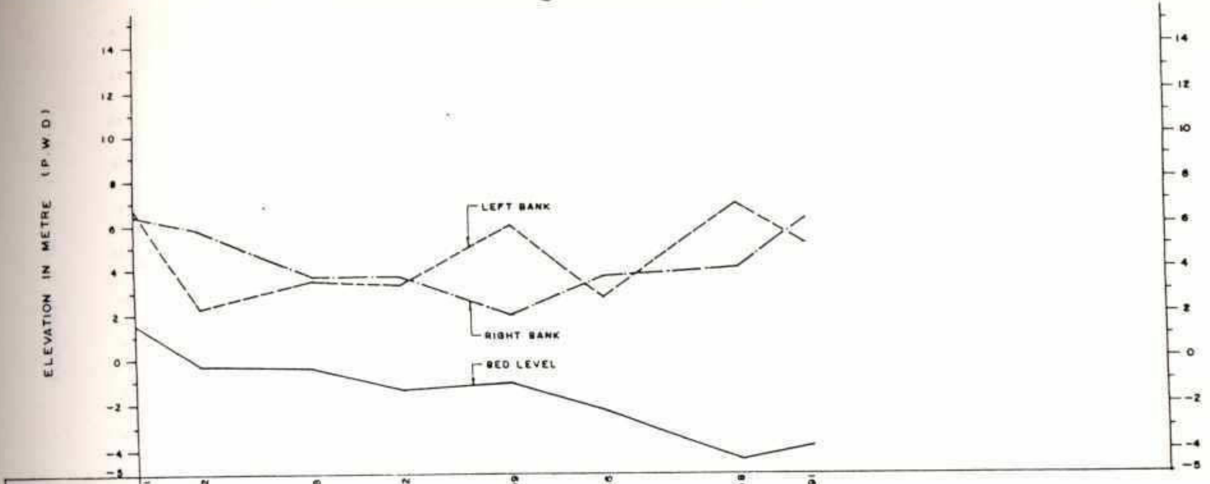
E. B. E.	-5.01	-8.07	-4.88	-5.89	-6.63	-14.88
B. E. (L)	6.24	5.81	5.63	5.58	4.02	6.94
B. E. (R)	6.82	5.49	5.27	4.61	3.96	5.32
DISTANCE IN KM.	82.00	86.00	93.00	99.00	105.00	112.50

E.B.E = EXISTING BED ELEVATION
B.E (L) = BANK ELEVATION (LEFT)
B.E (R) = BANK ELEVATION (RIGHT)

Lakhya River

Source:- CS 1992

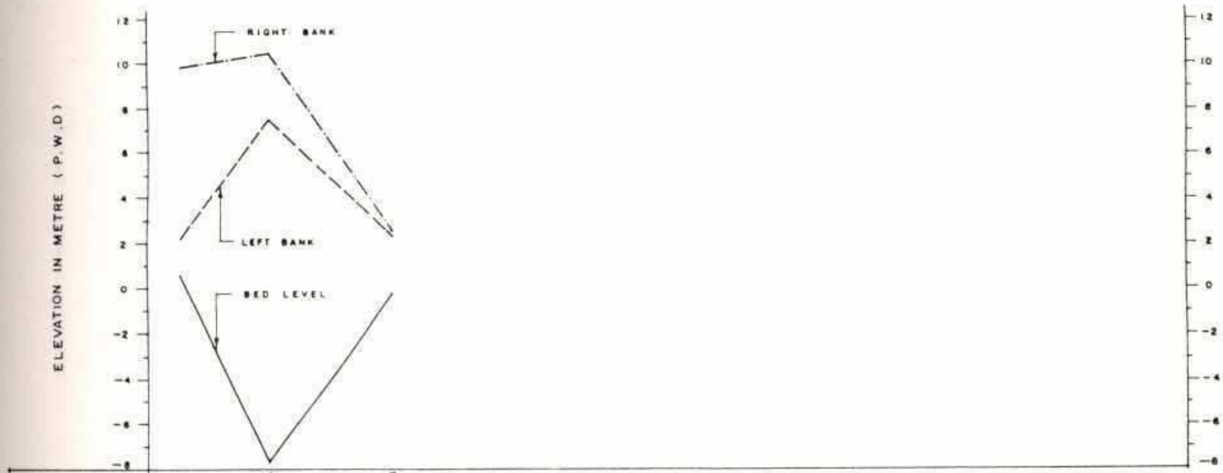
Figure : II.B.1g
Longitudinal Sections; Banar-Lakhya River System



E.B.E.	0.51	-0.32	-0.38	-1.42	-1.09	-2.35	-4.48	-3.91
B.E.(L)	6.70	2.21	3.52	3.35	6.01	2.84	6.97	5.00
B.E.(R)	6.40	5.89	3.79	3.75	1.99	3.72	4.05	6.24
DISTANCE IN KM	0.00	3.00	8.00	12.00	17.00	21.00	27.00	30.00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Balu River



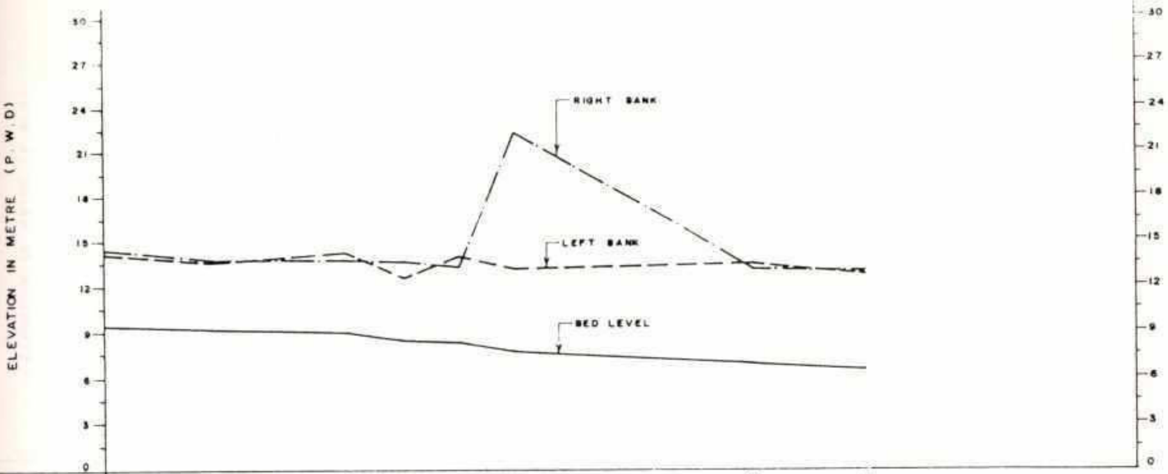
E.B.E.		0.57	-7.76	-0.23
B.E.(L)		2.19	7.49	2.35
B.E.(R)		9.84	10.48	2.49
DISTANCE IN KM.	0.00	1.50	5.50	11.00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Tongi River

Source:- CS 1992

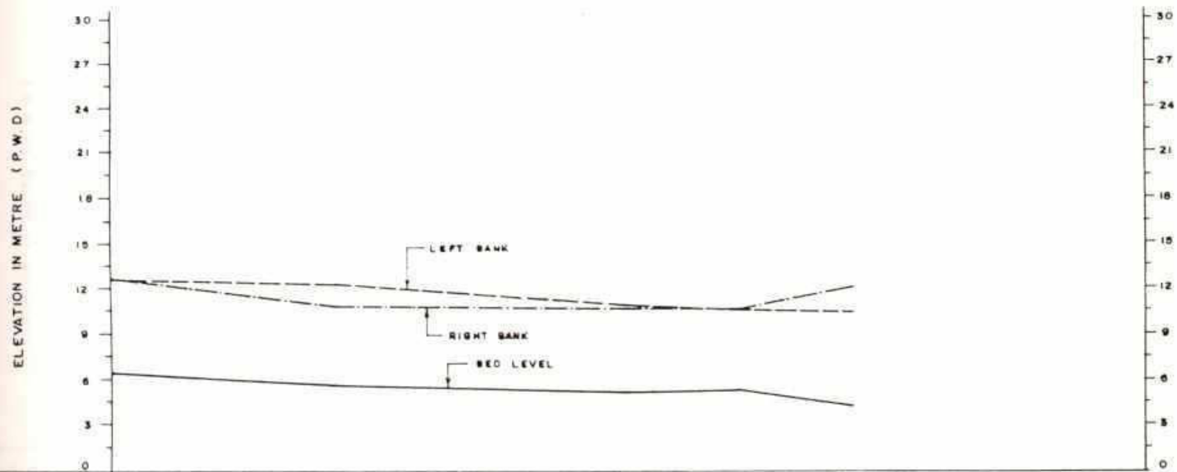
Figure : II.B.2a
Longitudinal Sections; Bangshi-Turag River System



E. B. E.	9·58	9·16	8·93	8·59	8·22	7·11	6·89	6·48
B. E. (L)	14·16	13·59	14·23	12·55	13·92	13·10	13·49	12·63
B. E. (R)	14·42	13·63	13·78	13·64	13·20	22·84	13·04	12·67
DISTANCE IN KM.	0·00	5·00	11·00	13·50	16·00	18·50	29·00	34·00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Bangshi River



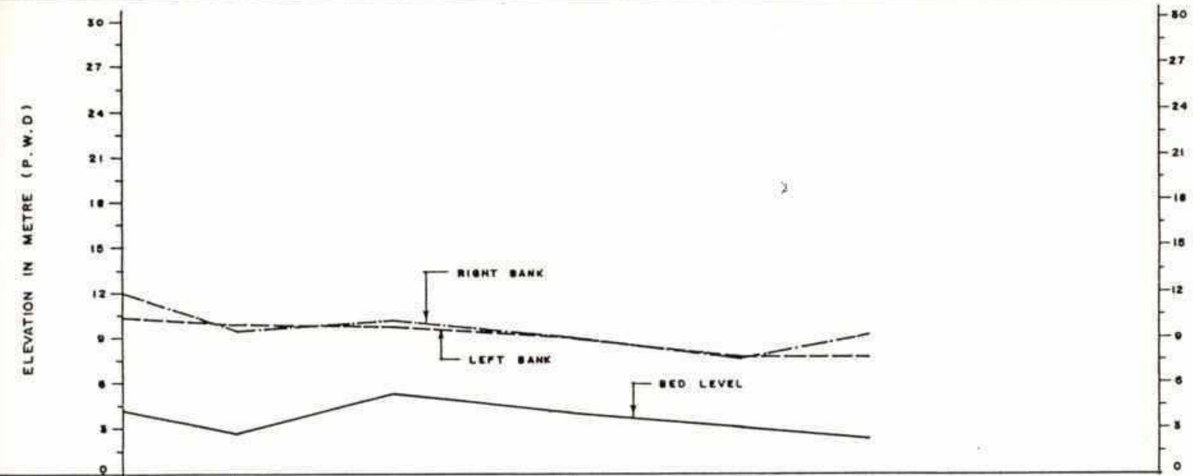
E. B. E.	6·48	5·60	5·12	5·26	4·16
B. E. (L)	12·63	12·24	10·91	10·66	10·43
B. E. (R)	12·67	10·65	10·70	10·67	12·03
DISTANCE IN KM	34·00	44·00	57·00	62·00	67·00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Bangshi River

Source:- CS 1992

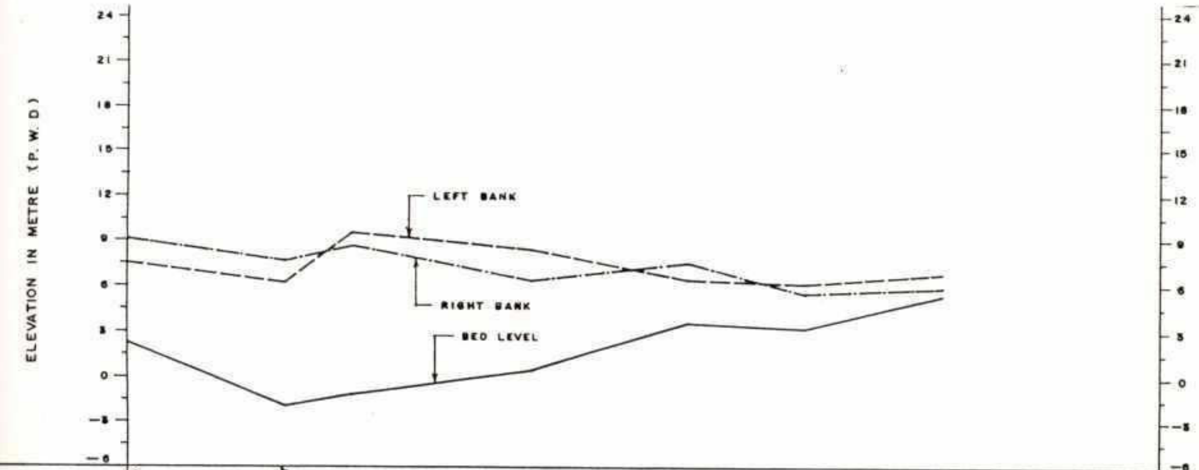
Figure : II.B.2b
Longitudinal Sections; Bangshi-Turag River System



E. B. E.	4.16	2.60	5.29	3.92	2.99	2.23
B. E. (L)	10.43	9.96	9.60	8.60	7.64	7.57
B. E. (R)	12.08	9.46	10.10	8.86	7.61	9.17
DISTANCE IN KM.	67.00	72.00	79.00	87.00	94.50	100.00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Bangshi River



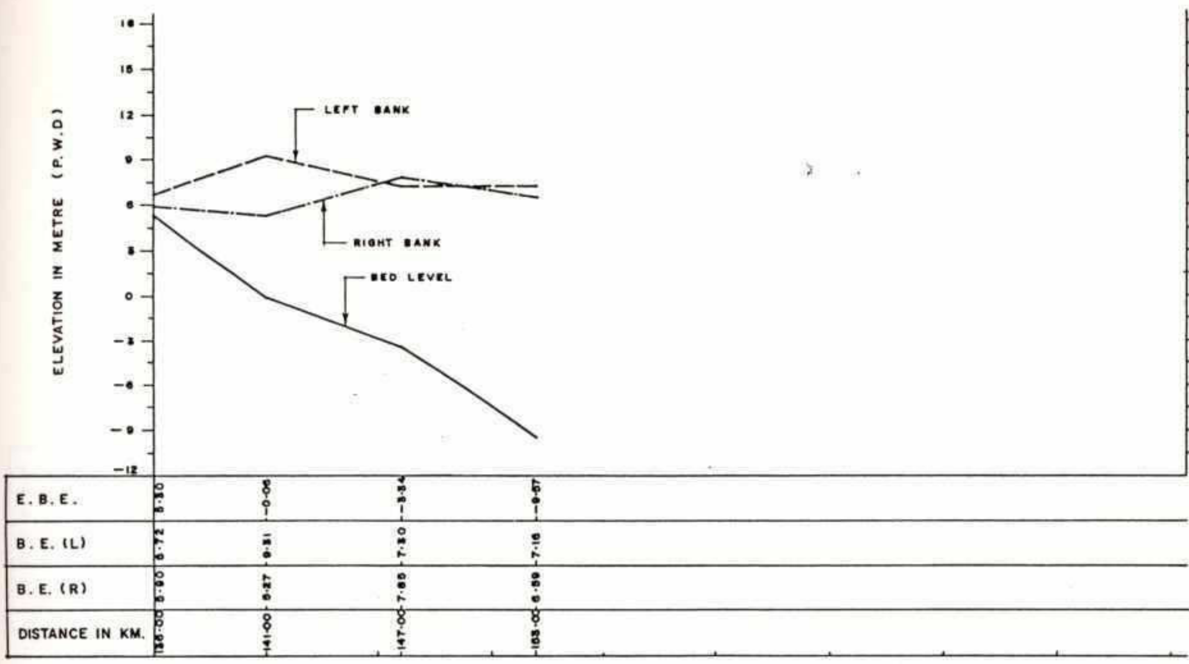
E. B. E.	2.23	-1.87	-1.11	0.49	3.62	3.12	5.30
B. E. (L)	7.57	6.28	9.59	8.45	6.42	6.22	6.72
B. E. (R)	9.17	7.75	8.69	6.39	7.56	5.54	5.90
DISTANCE IN KM.	100.00	107.00	110.00	118.00	128.00	130.00	136.00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Bangshi River

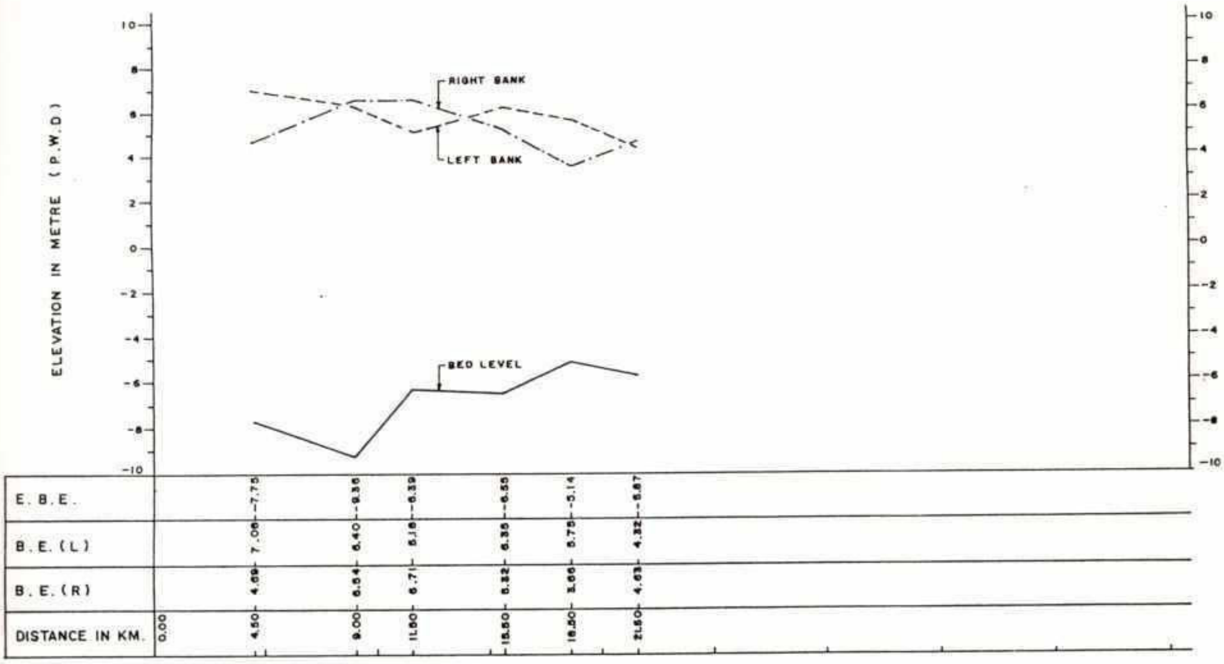
Source:- CS 1992

Figure : II.B.2c
Longitudinal Sections; Bangshi-Turag River System



E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Bangshi River

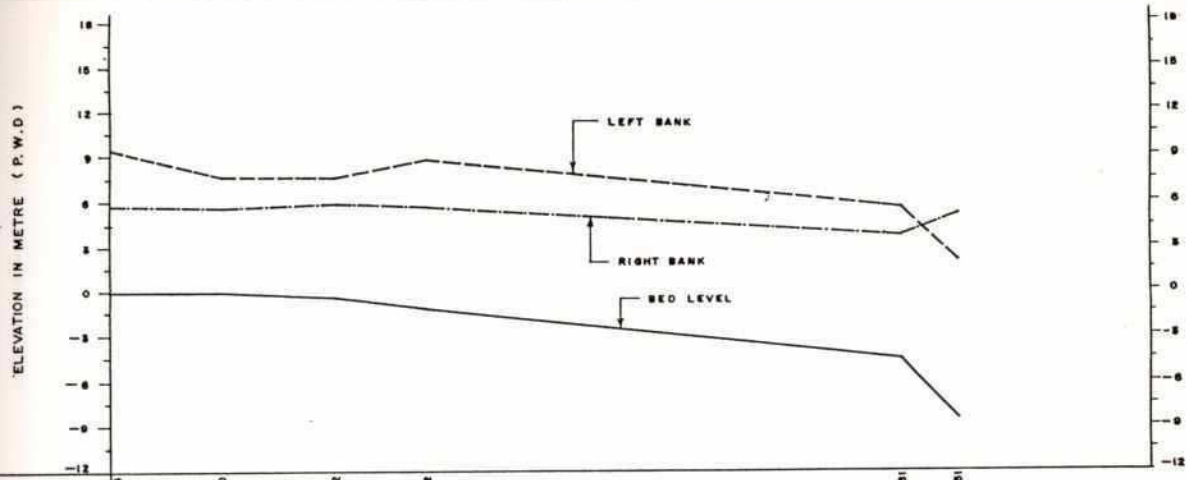


E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Buriganga River

Source:- CS 1992

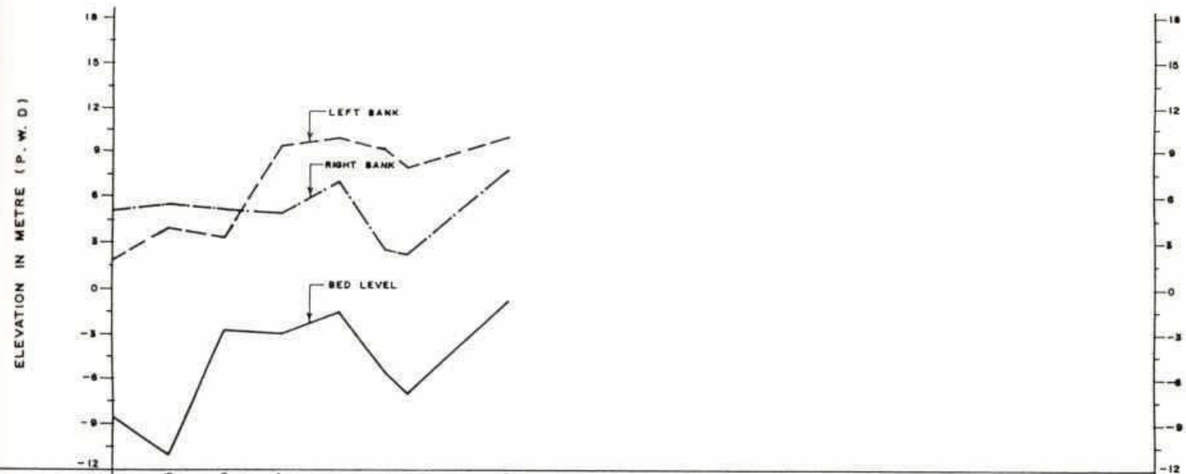
Figure : II.B.2d
Longitudinal Sections; Bangshi-Turag River System



E. B. E.	-0.04	-0.10	-0.62	-1.22	-4.61	-8.51
B. E. (L)	9.46	7.65	7.62	8.80	5.60	2.06
B. E. (R)	5.75	5.60	5.82	5.72	3.78	5.11
DISTANCE IN KM.	0.00	5.00	10.00	14.00	35.00	37.50

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Turag River



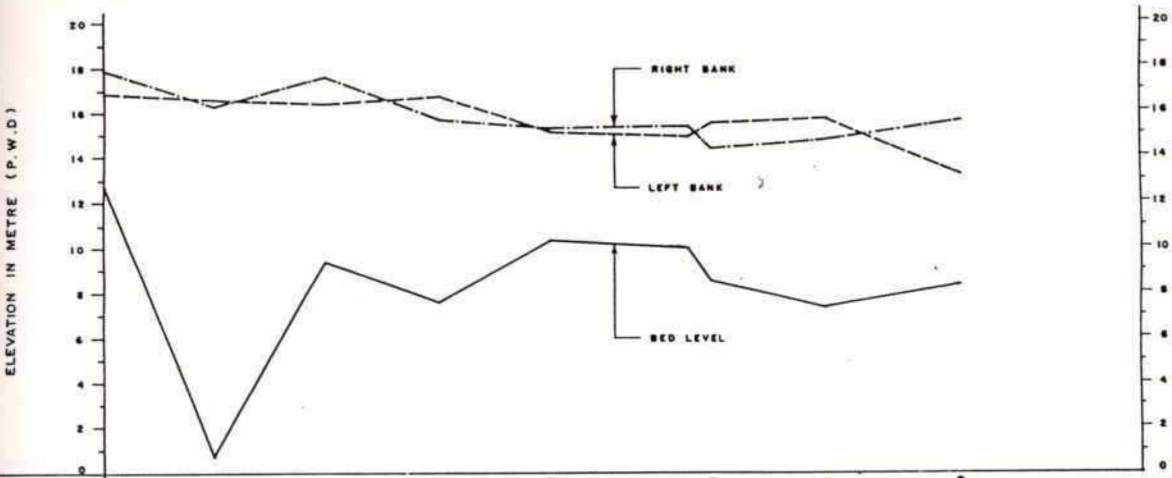
E. B. E.	-8.51	-10.95	-2.70	-2.97	-1.59	-5.62	-7.06	-0.80
B. E. (L)	2.06	4.04	3.33	9.50	10.05	9.28	8.07	10.06
B. E. (R)	5.11	5.51	5.27	5.03	6.96	2.60	2.28	7.85
DISTANCE IN KM.	37.50	40.00	42.50	45.00	47.50	49.00	50.00	54.50

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Turag River

Source:- CS 1992

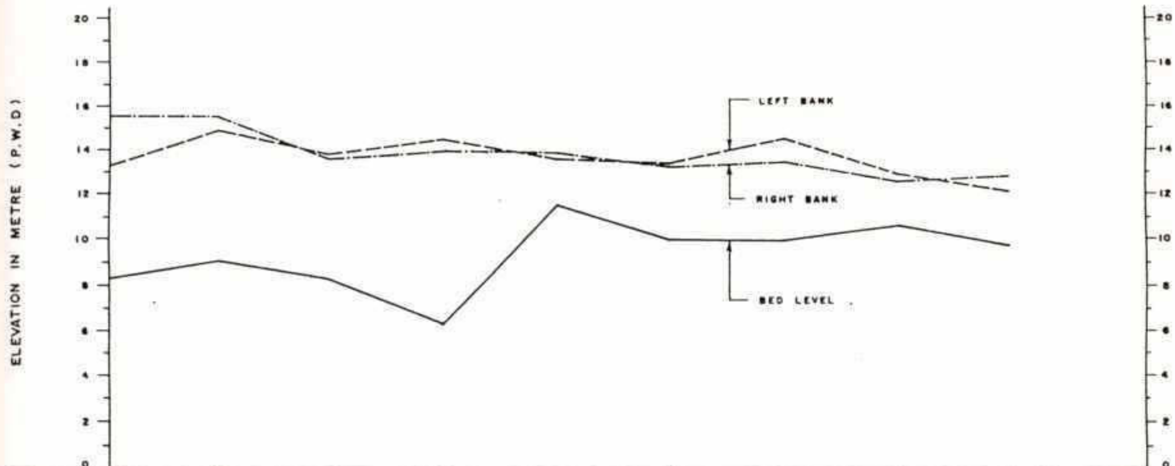
Figure : II.B.2e
Longitudinal Sections; Bangshi-Turag River System



E. B. E.	12·77	0·71	9·31	7·47	10·32	9·98	8·48	7·32	8·29
B. E. (L)	16·86	16·58	16·37	16·74	15·12	14·92	15·47	15·69	13·26
B. E. (R)	17·87	16·24	17·58	15·72	15·23	15·34	14·39	14·75	15·58
DISTANCE IN KM.	0·00	5·00	10·00	15·00	20·00	26·00	27·00	32·00	38·00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Jhenai River



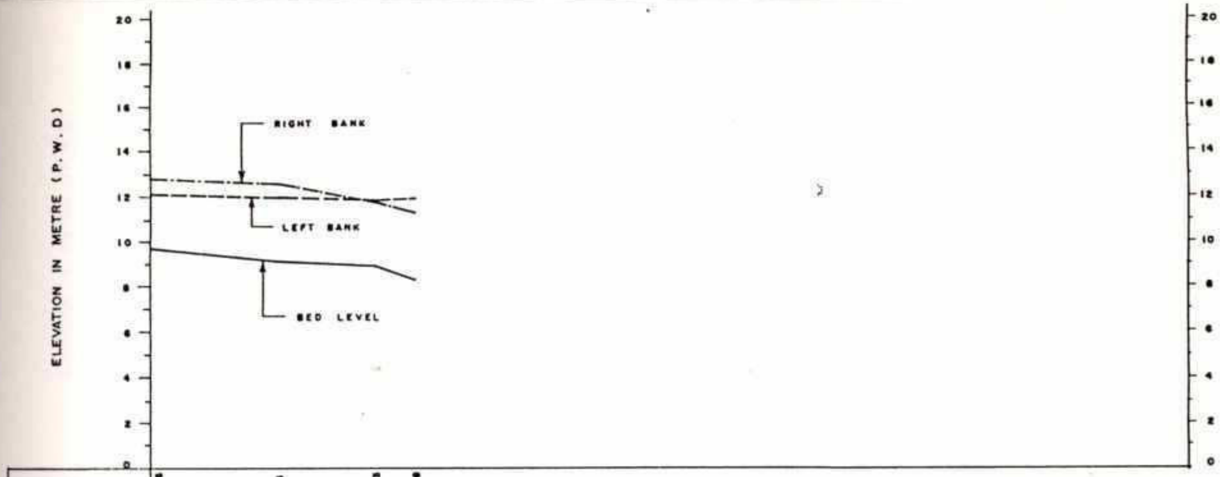
E. B. E.	8·29	9·08	8·24	6·29	11·45	9·99	9·97	10·60	9·78
B. E. (L)	13·26	14·88	13·64	14·46	13·54	13·41	14·54	12·87	12·11
B. E. (R)	15·58	15·55	13·61	13·92	13·83	13·24	13·45	12·52	12·83
DISTANCE IN KM.	38·00	43·00	48·00	53·00	58·00	63·00	68·00	73·00	78·00

E. B. E. = EXISTING BED ELEVATION
B. E. (L) = BANK ELEVATION (LEFT)
B. E. (R) = BANK ELEVATION (RIGHT)

Jhenai River

Source:- CS 1992

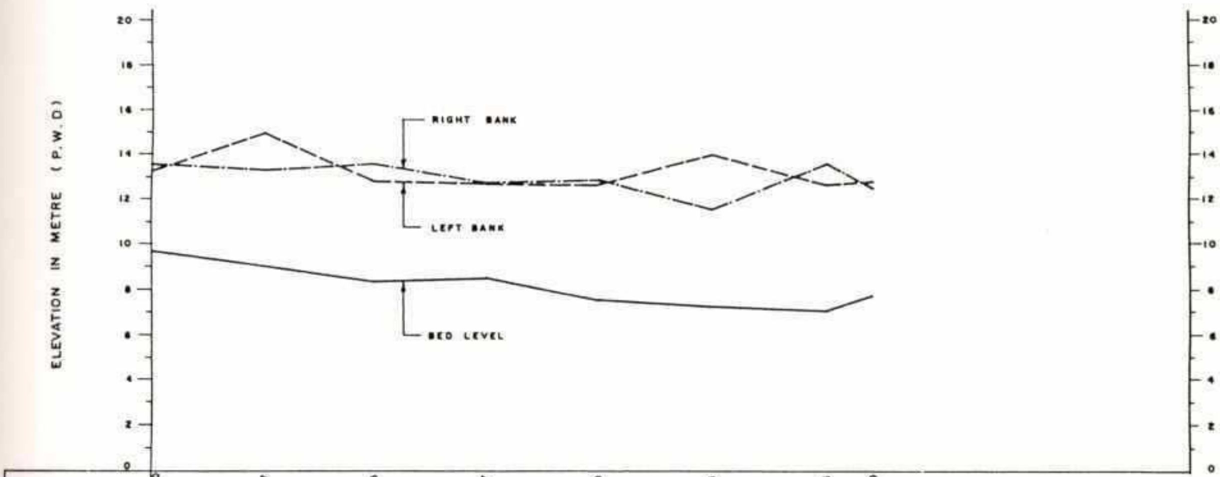
Figure : II.B.2f
Longitudinal Sections; Bangshi-Turag River System



E.B.E.	9·76	9·15	8·93	8·29
B.E.(L)	12·11	12·02	11·87	11·95
B.E.(R)	12·83	12·61	11·90	11·31
DISTANCE IN KM.	78·00	83·70	88·00	89·80

E.B.E = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Jhenai River



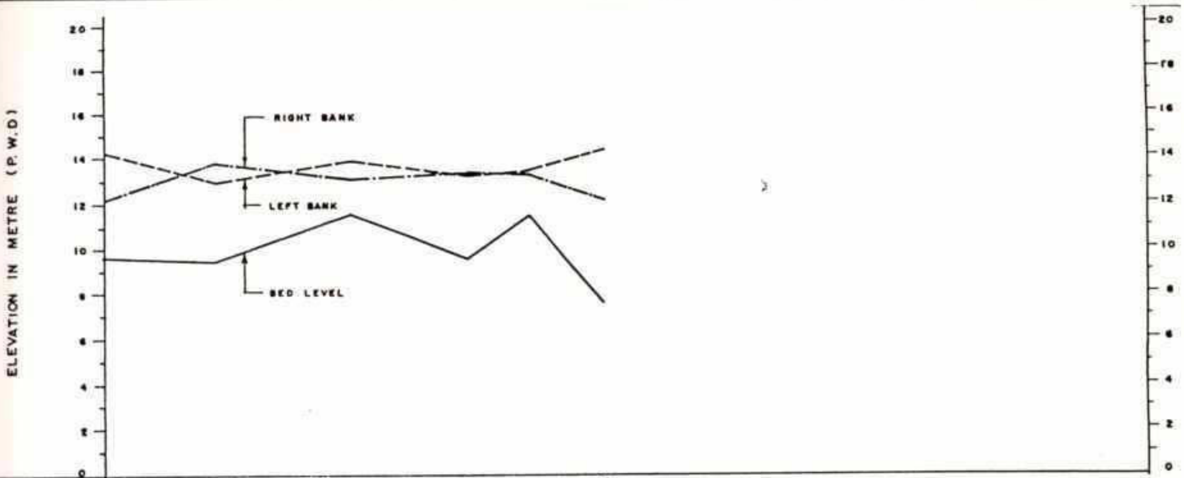
E.B.E.	9·70	9·07	8·35	8·47	7·49	7·25	7·03	7·70
B.E.(L)	13·33	14·97	12·80	12·71	12·65	13·98	12·58	12·81
B.E.(R)	13·62	13·37	13·60	12·76	12·91	11·53	13·59	12·54
DISTANCE IN KM.	0·00	5·00	10·00	15·00	20·00	25·00	30·00	32·00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Jhenai (East) River

Source:- CS 1992

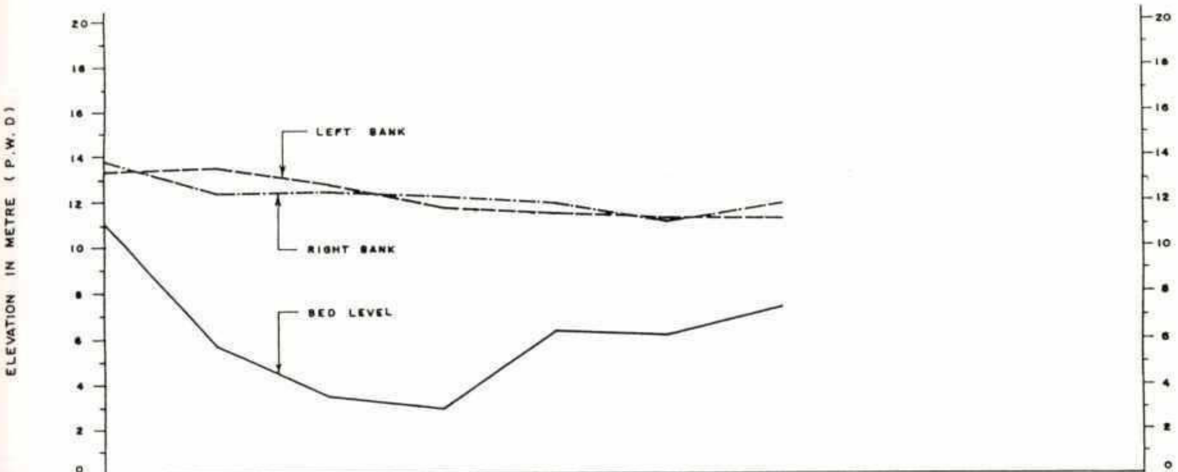
Figure : II.B.2g
Longitudinal Sections; Bangshi-Turag River System



E.B.E.	9.62	9.41	11.54	9.03	11.51	7.55
B.E.(L)	14.27	12.96	13.85	13.31	13.48	14.36
B.E.(R)	12.19	13.80	13.14	13.37	13.22	12.18
DISTANCE IN KM.	0.00	4.85	10.90	16.05	19.75	22.25

E.B.E = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Jhenai (West) River



E.B.E.	11.06	5.66	3.47	2.95	6.33	6.10	7.36
B.E.(L)	13.37	13.56	12.79	11.77	11.55	11.26	11.24
B.E.(R)	13.66	12.40	12.46	12.28	11.97	11.13	11.94
DISTANCE IN KM.	0.00	5.00	10.00	15.00	20.00	25.00	30.00

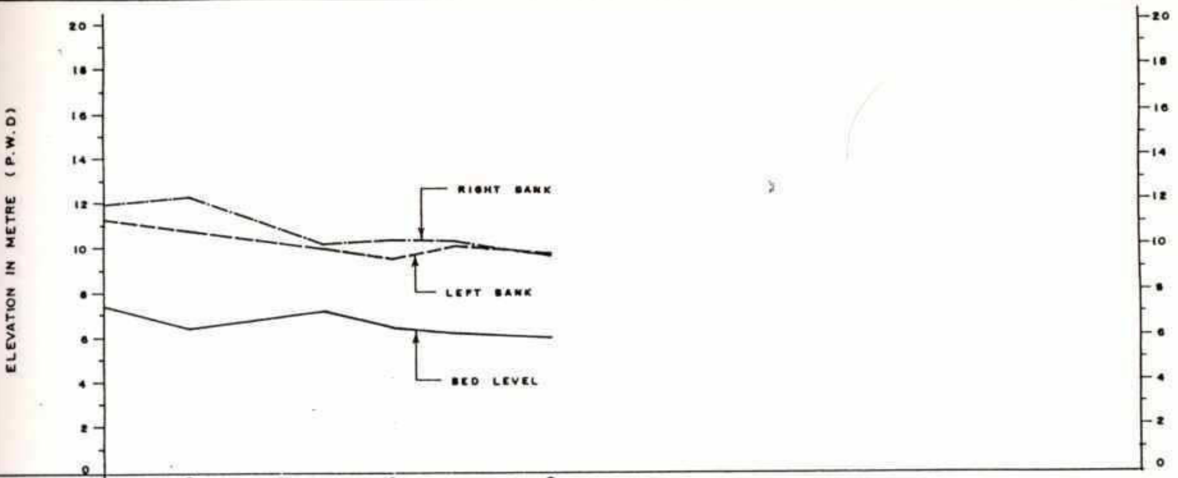
E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Fatikjani River

Source:- CS 1992

Figure : II.B.2h

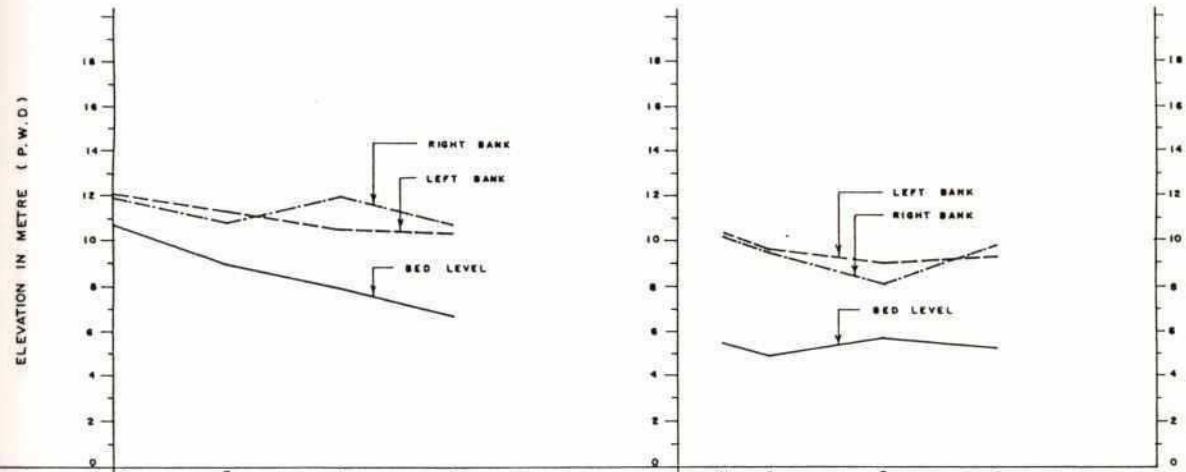
Longitudinal Sections; Bangshi-Turag River System



E.B.E.	7·36	6·38	7·11	6·30	6·11	5·89
B.E.(L)	11·24	10·76	9·92	9·44	9·99	9·72
B.E.(R)	11·94	12·25	10·11	10·30	10·21	9·67
DISTANCE IN KM	30·00	35·90	40·00	43·00	45·65	50·00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Fatikjani River



NANGLAI (N)

E.B.E.	10·75	8·98	7·95	6·68
B.E.(L)	12·05	11·34	10·50	10·36
B.E.(R)	11·93	10·82	12·00	10·73
DISTANCE IN KM	0·00	5·00	10·00	15·00

NANGLAI (S)

E.B.E.		5·42	4·84	5·69	5·25
B.E.(L)		10·36	9·59	9·01	9·33
B.E.(R)		10·16	9·46	8·12	9·77
DISTANCE IN KM	0·00	2·00	4·00	9·00	14·00

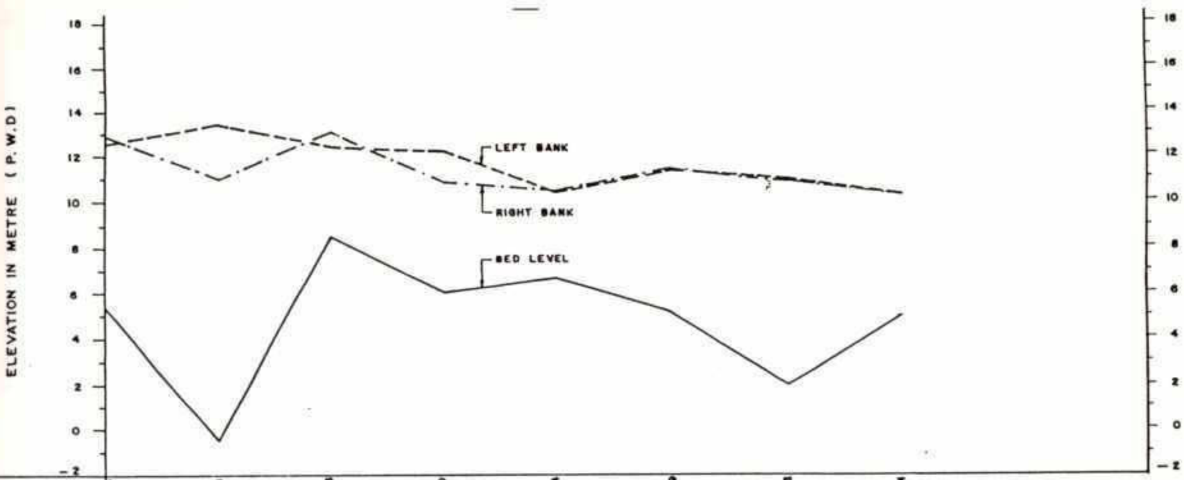
E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Nanglai (N & S) River

Source:- CS 1992

Figure : II.B.2i

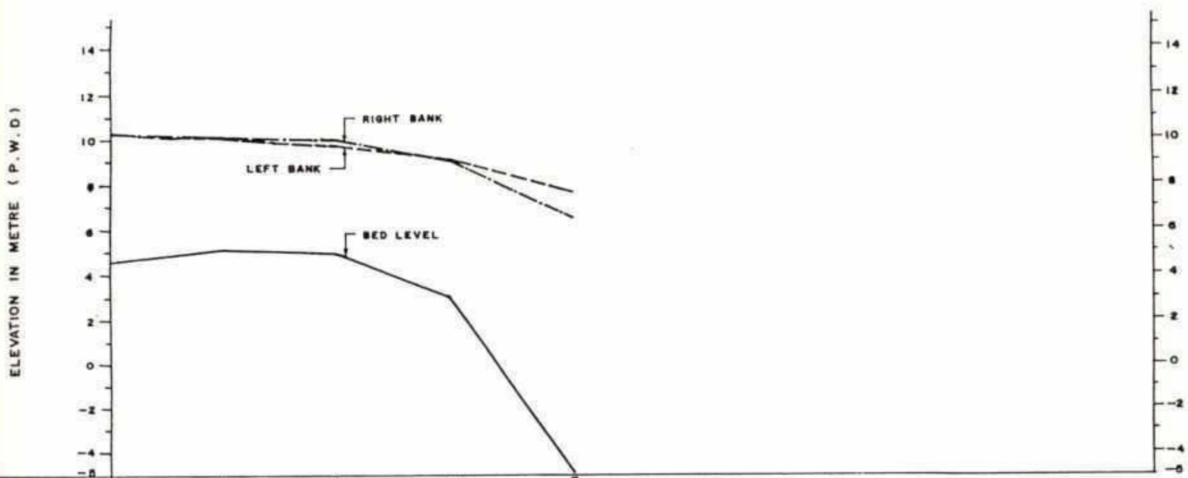
Longitudinal Sections; Bangshi-Turag River System



E. B. E.	5.27	-0.84	8.46	6.00	6.64	5.09	1.93	4.54
B. E. (L)	12.54	13.54	12.45	12.34	10.50	11.64	10.91	10.31
B. E. (R)	12.80	11.12	13.10	10.98	10.58	11.65	10.88	10.30
DISTANCE IN KM.	0.00	5.00	10.00	15.00	20.00	25.00	30.00	35.00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Pungli River



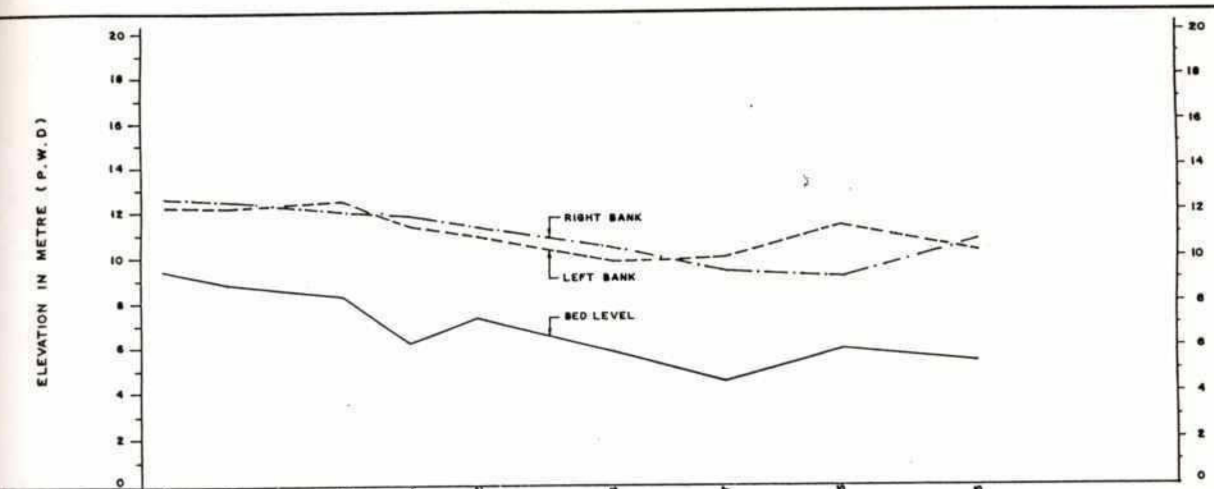
E. B. E.	4.54	5.02	4.93	2.98	-4.88
B. E. (L)	10.31	10.12	9.86	9.14	7.67
B. E. (R)	10.30	10.15	10.13	9.04	6.44
DISTANCE IN KM.	35.00	40.00	45.00	50.00	55.50

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Pungli River

Source:- CS 1992

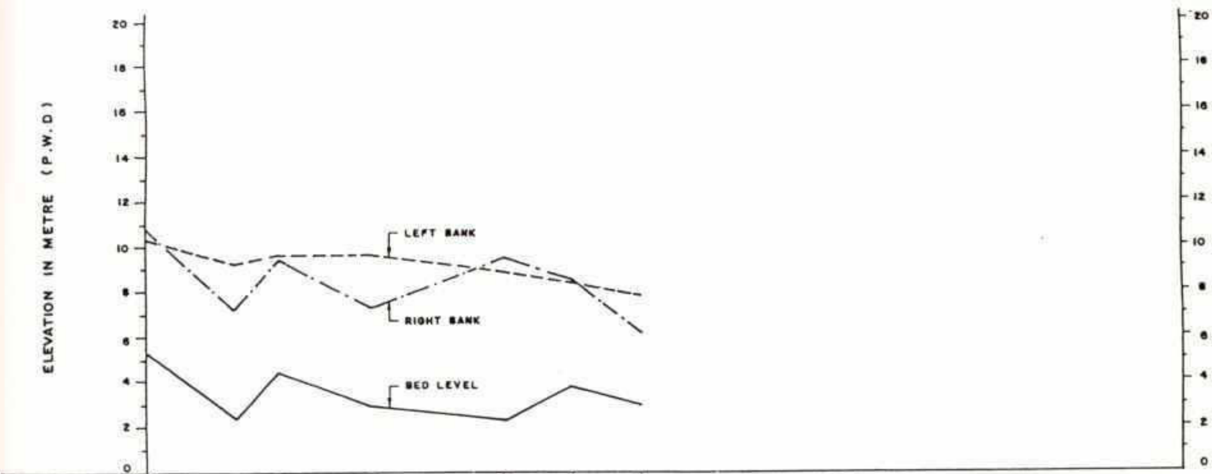
Figure : II.B.3a
Longitudinal Sections; Dhaleswari-Kaliganga River System



E.B.E.		9.42	8.88	8.34	6.23	7.42	5.83	4.47	5.95	5.35
B.E.(L)		12.30	12.32	12.50	11.52	11.05	9.94	10.03	11.41	10.58
B.E.(R)		12.64	12.61	12.12	11.92	11.44	10.55	9.50	9.34	10.80
DISTANCE IN KM	0.00	1.00	4.00	9.00	12.00	15.00	21.00	26.00	31.00	37.00

E.B.E = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Lauhajang River



E.B.E.	5.35	2.39	4.34	2.81	2.34	3.74	2.94
B.E.(L)	10.38	9.26	9.69	9.59	8.84	8.32	7.80
B.E.(R)	10.80	7.19	9.41	7.27	9.50	8.57	6.16
DISTANCE IN KM	37.00	41.00	43.00	47.00	53.00	56.00	59.80

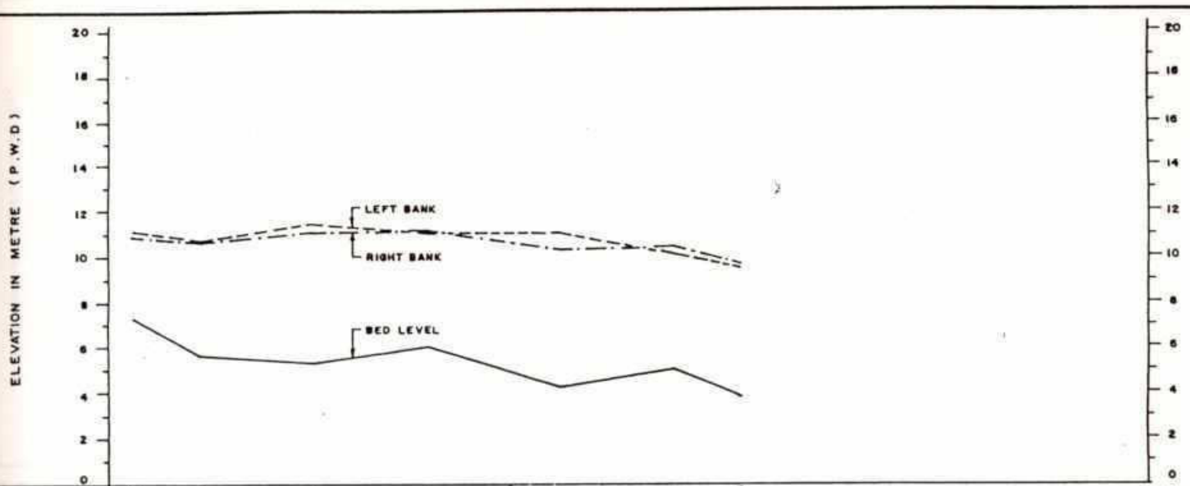
E.B.E = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Lauhajang River

Source:- CS 1992

Figure : II.B.3b

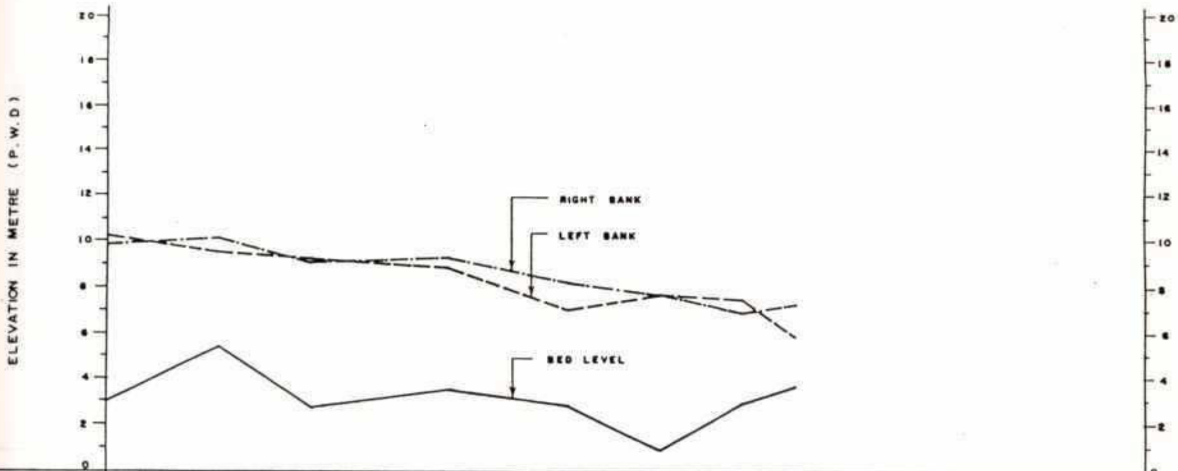
Longitudinal Sections; Dhaleswari-Kaliganga River System



E.B.E	7.32	5.60	5.24	5.99	4.17	4.99	3.75
B.E. (L)	11.15	10.66	11.57	11.14	11.04	10.09	9.45
B.E. (R)	10.96	10.67	11.17	11.22	10.27	10.42	9.72
DISTANCE IN KM.	0.00 1.00	4.00	9.00	14.00	20.00	25.00	28.00

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Elangjani River



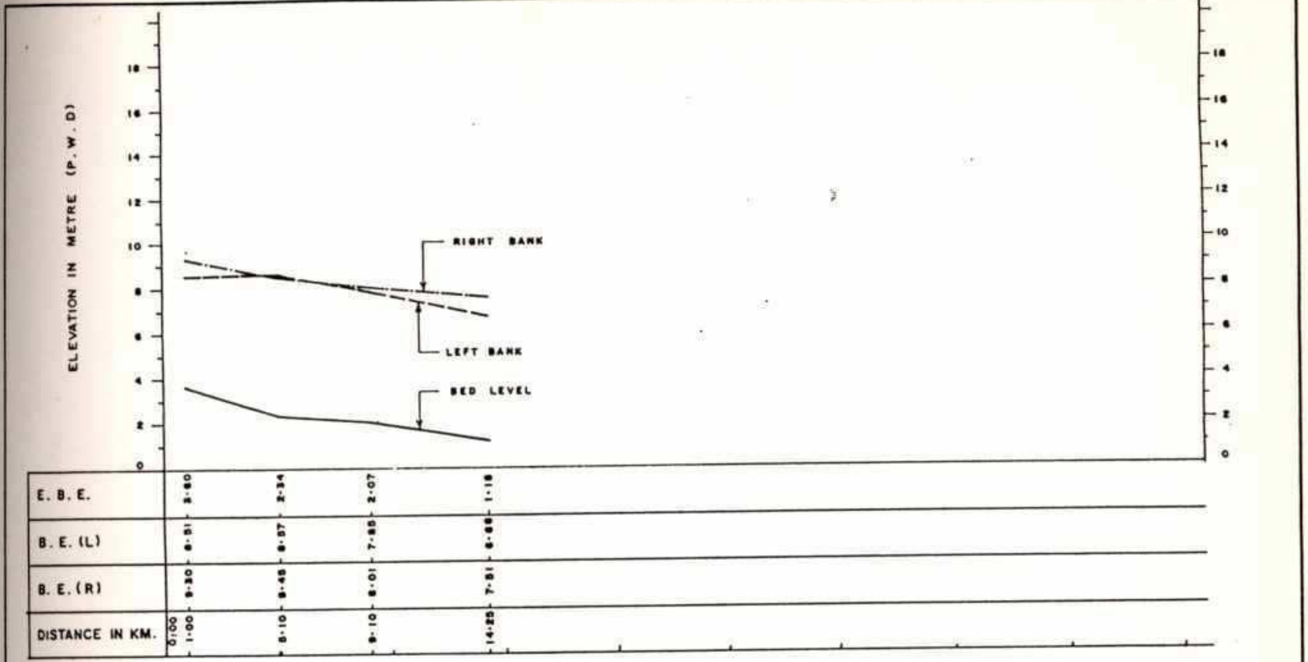
E. B. E.	2·99	5·41	2·73	3·48	2·84	0·86	2·88	3·65
B.E.(L)	10·21	9·52	9·21	8·87	7·07	7·70	7·50	5·84
B.E.(R)	9·82	10·14	9·16	9·27	8·23	7·70	6·88	7·23
DISTANCE IN KM.	0·00	5·00	9·10	15·17	20·60	24·70	28·40	30·70

E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Barinda River

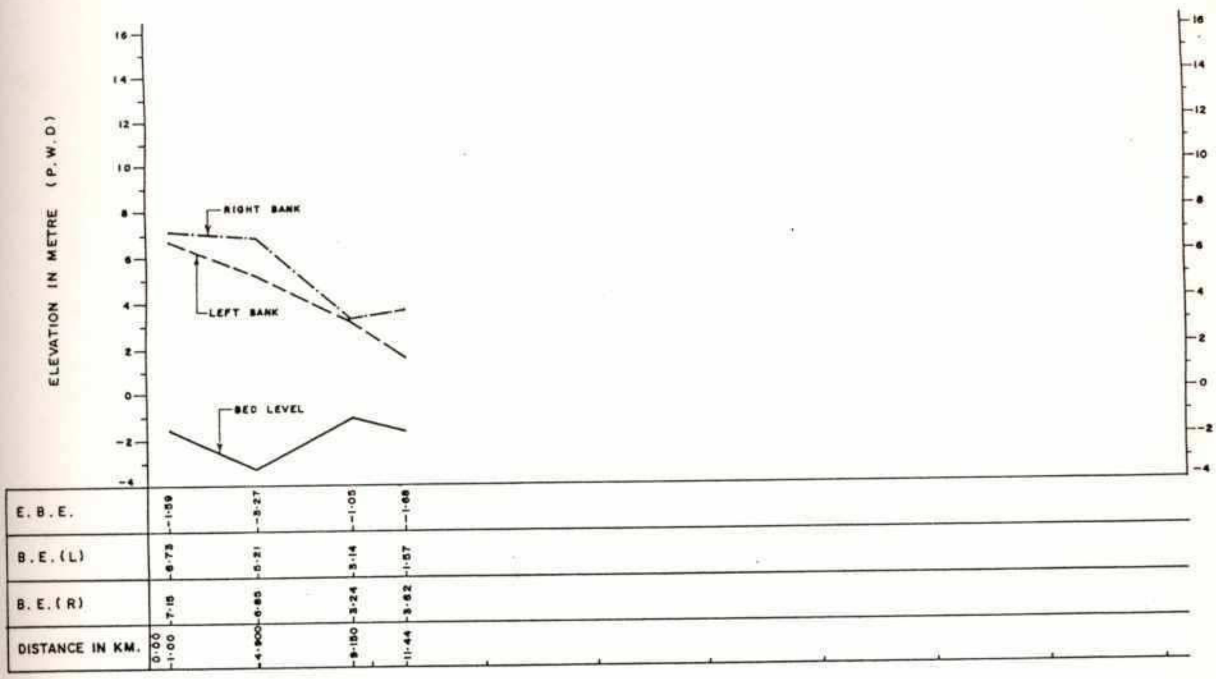
Source:- CS 1992

Figure : II.B.3c
Longitudinal Sections; Dhaleswari-Kaliganga River System



E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

Dhantara Khal



E.B.E. = EXISTING BED ELEVATION
B.E.(L) = BANK ELEVATION (LEFT)
B.E.(R) = BANK ELEVATION (RIGHT)

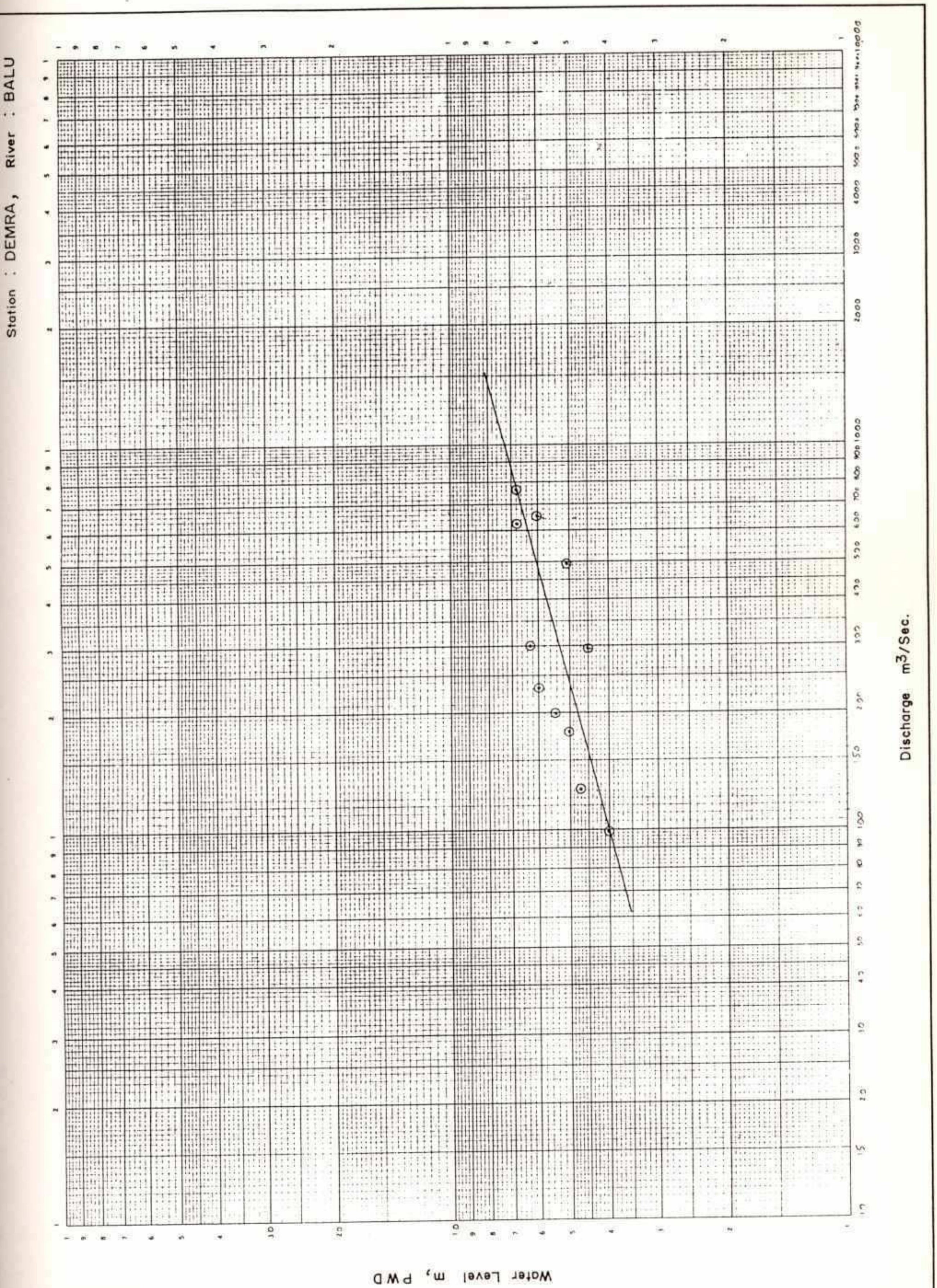
Karnatali River

Source:- CS 1992

Supporting Report - II

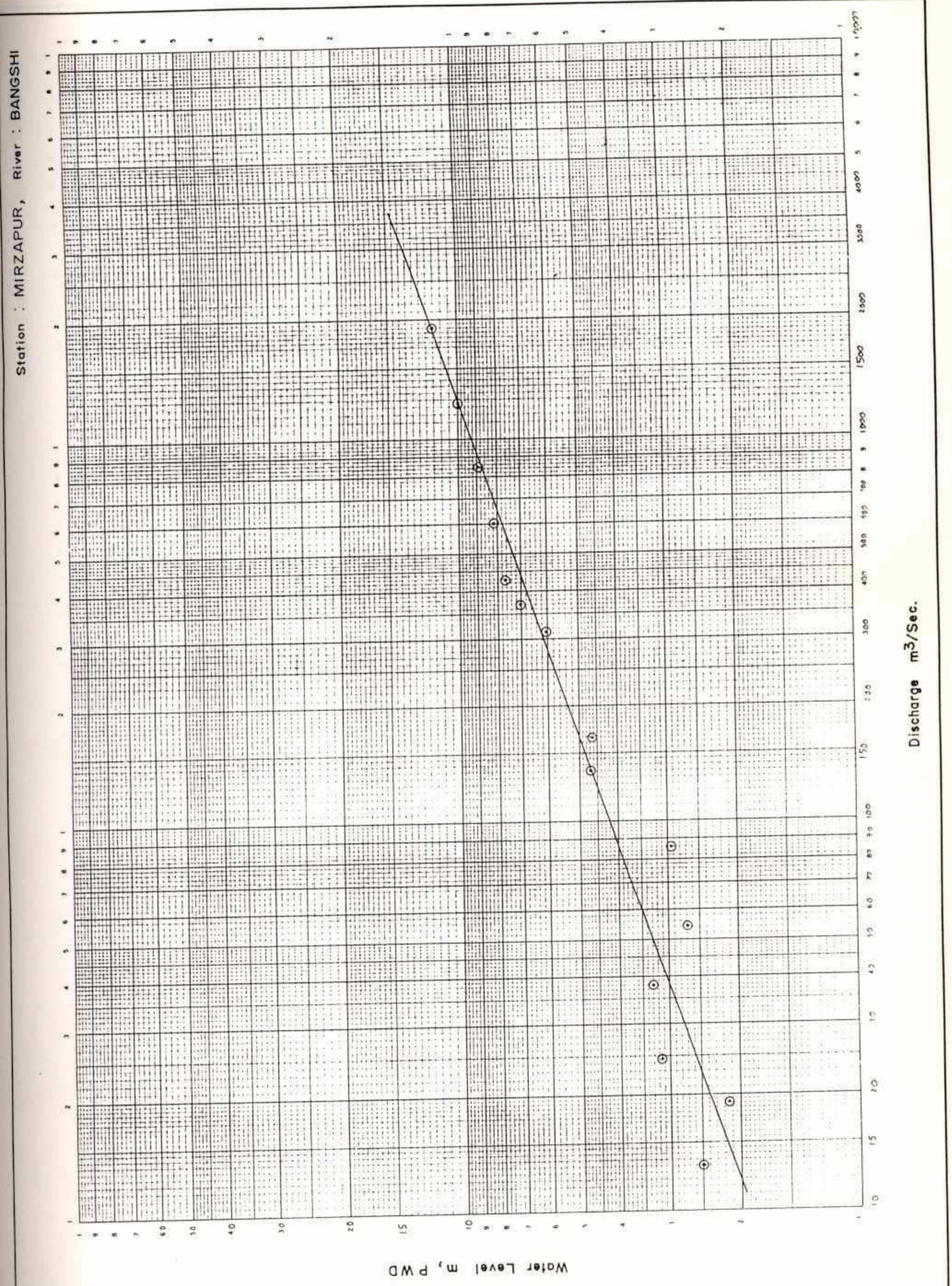
Appendix II. C
Stage-discharge Curves

Figure : II.C.1
Stage-Discharge Curves - Demra Station, Balu River



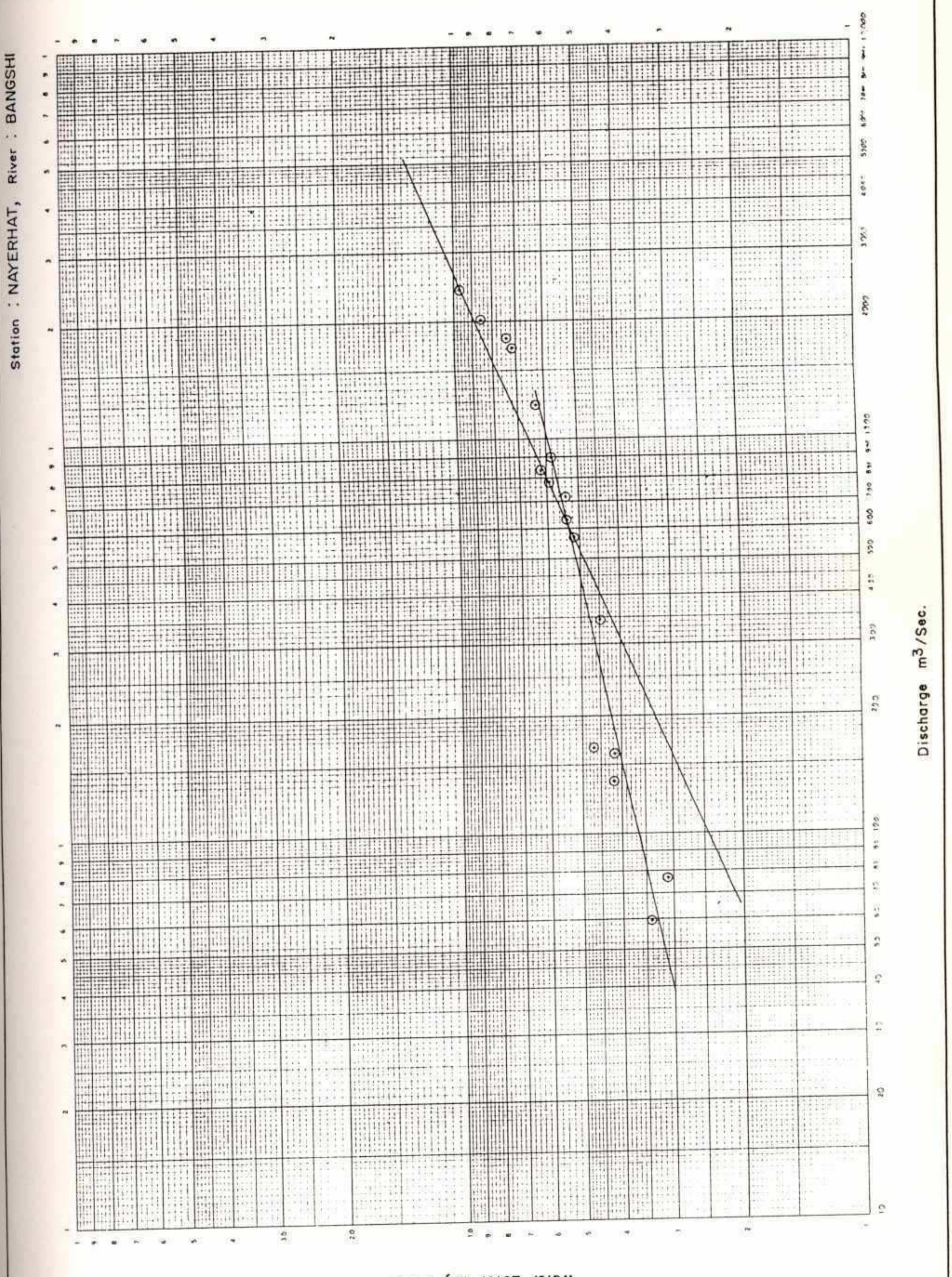
Source:- CS 1992

Figure : II.C.2
Stage-Discharge Curves - Mirzapur Station, Bangshi River



Source:- CS 1992

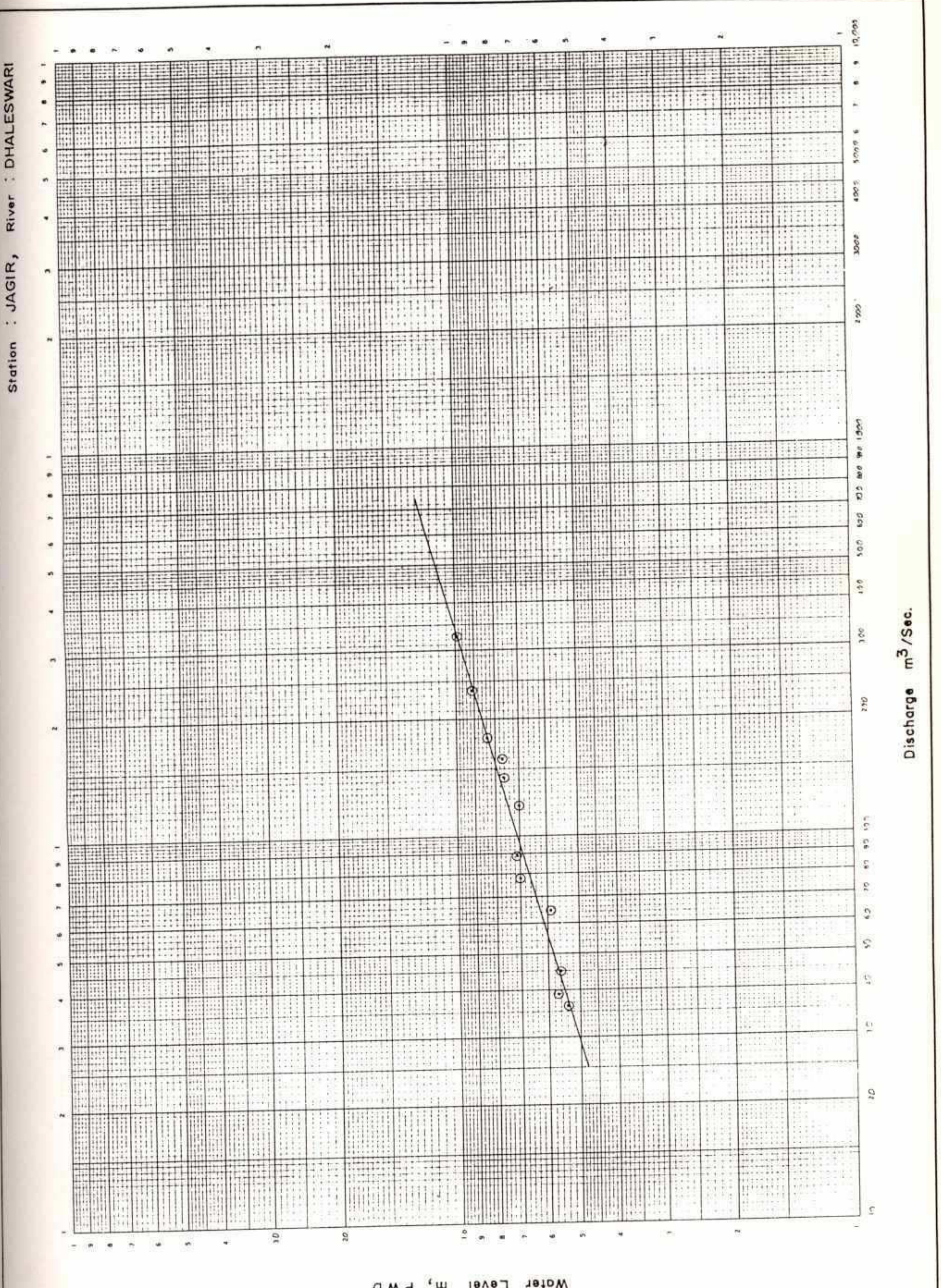
Figure : II.C.3
Stage-Discharge Curves - Nayerhat Station, Banghsi River



Source:- CS 1992

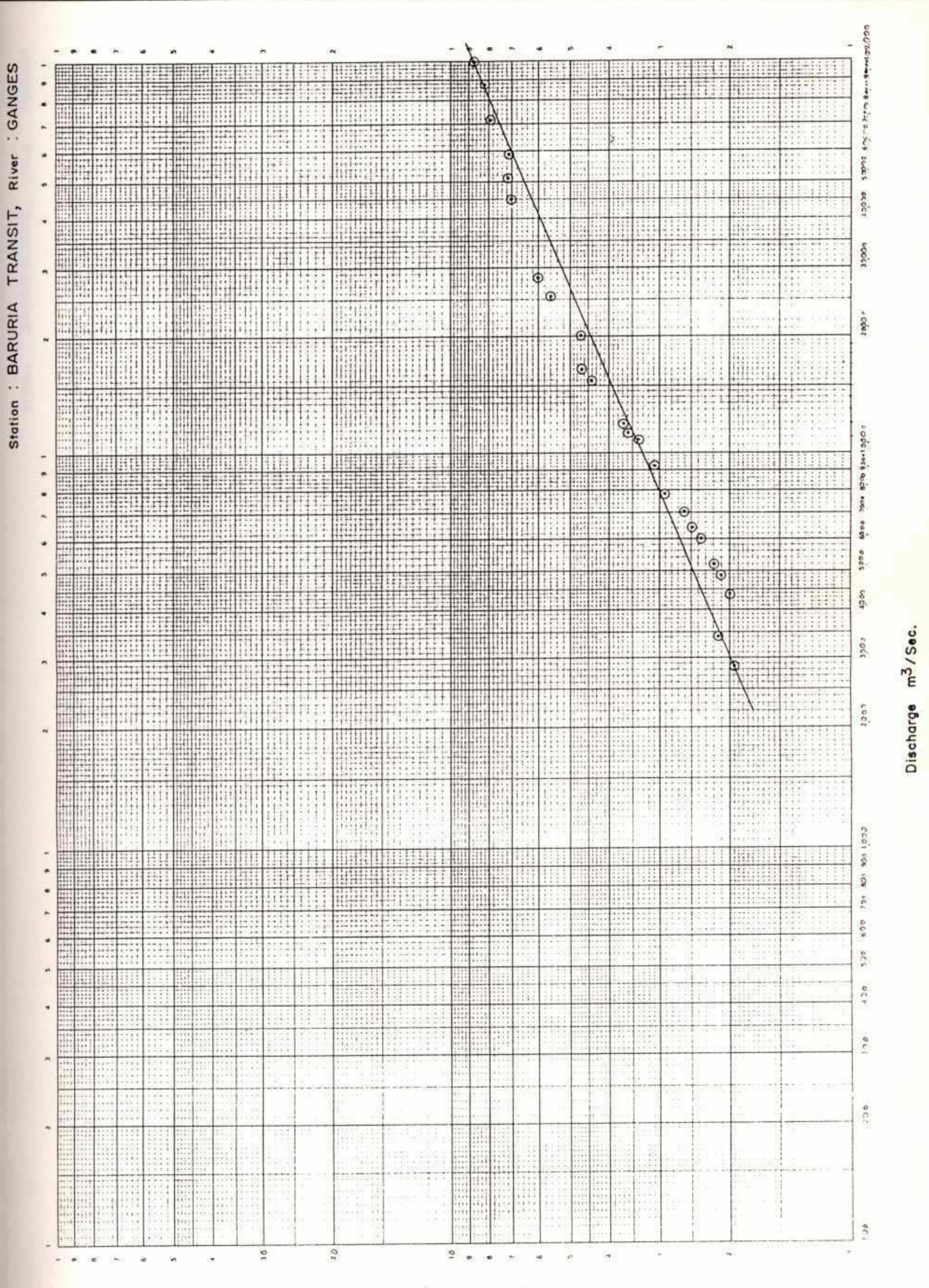
Figure : II.C.4

Stage-Discharge Curves - Jagir Station, Dhaleswari River



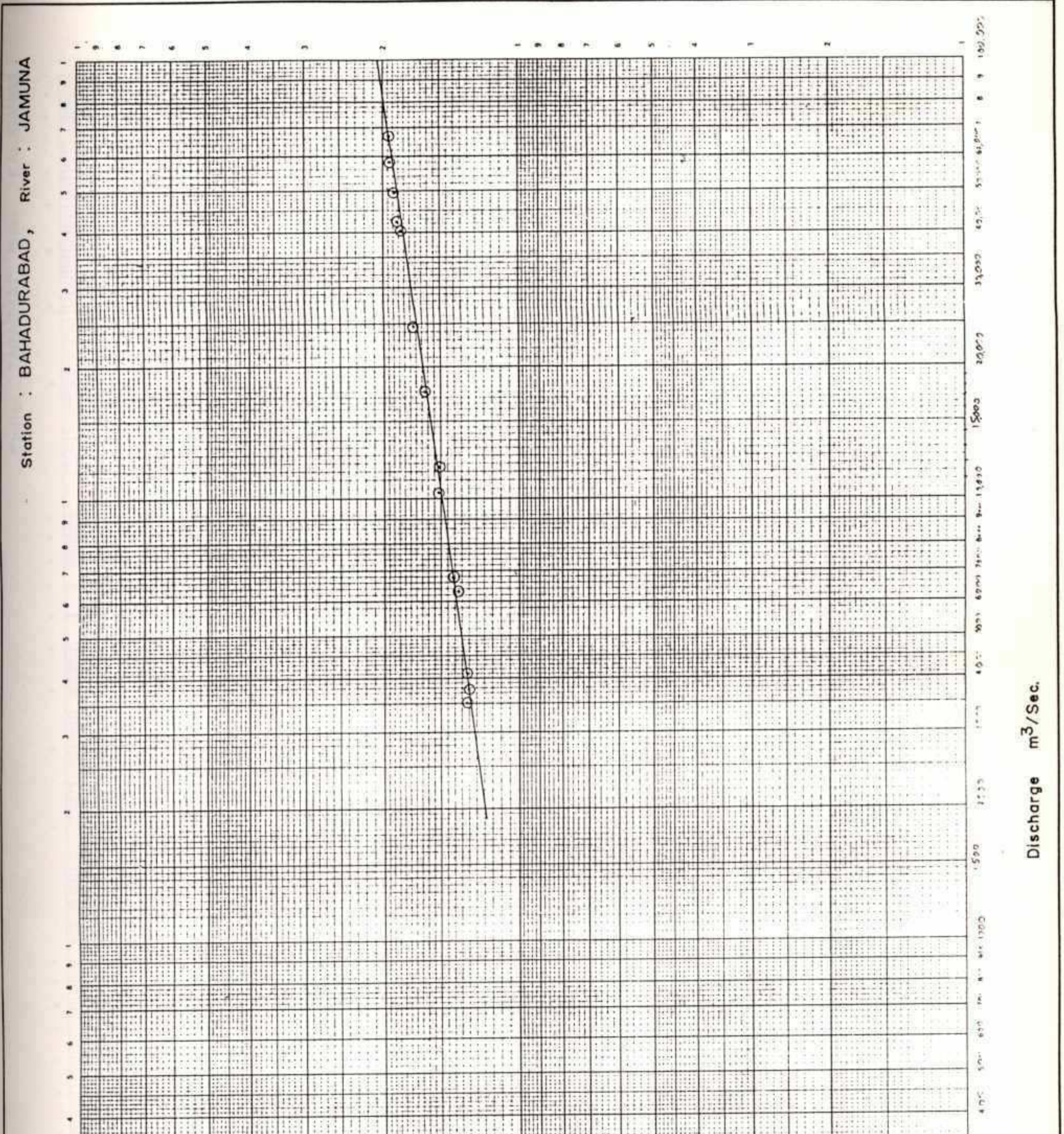
Source:- CS 1992

Stage-Discharge Curves - Baruria Station, Ganges(Padma) River



Source:- CS 1992

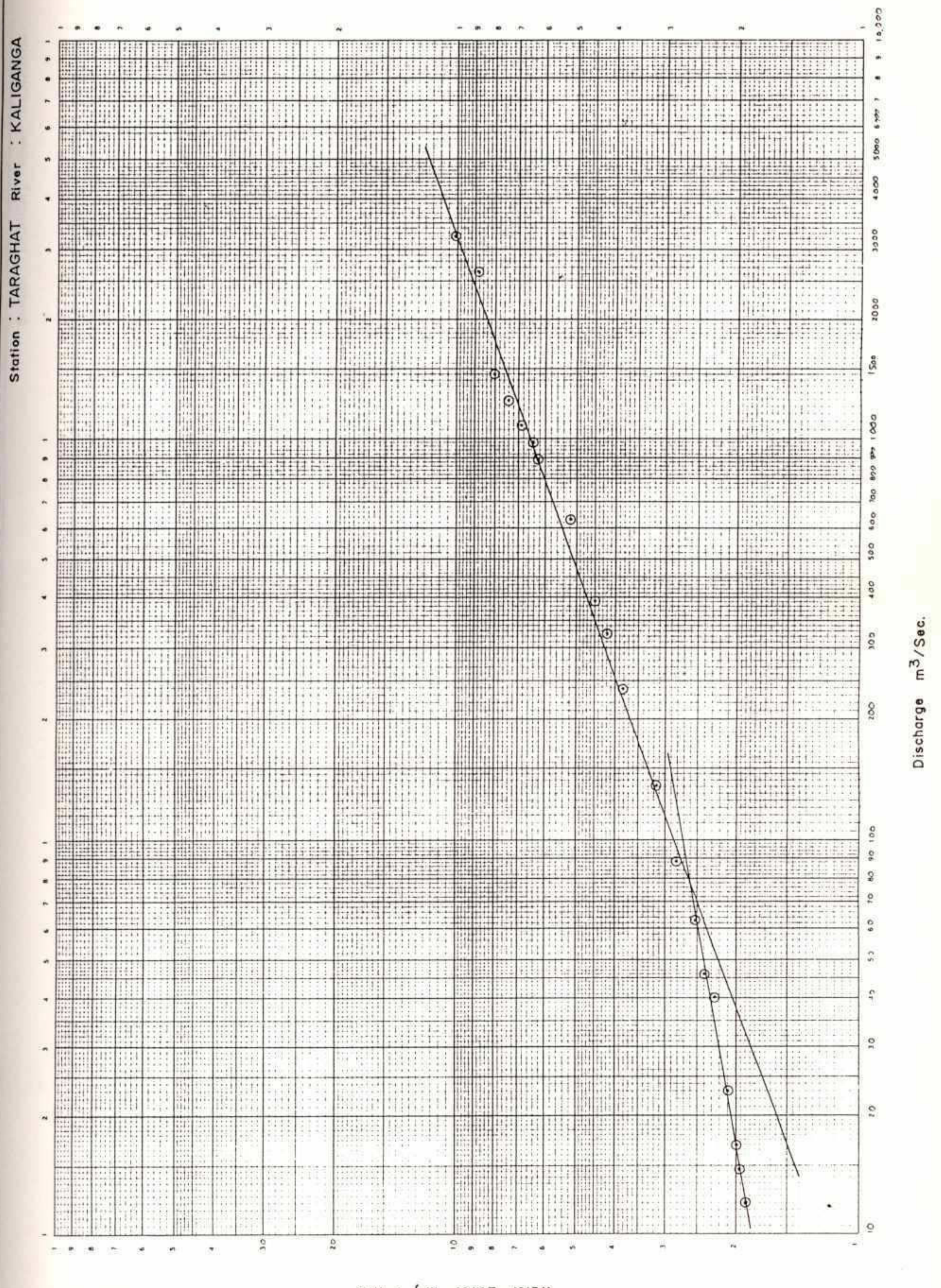
Figure : II.C.6
Stage-Discharge Curves - Bahadurabad Station, Jamuna River



Source:- CS 1992

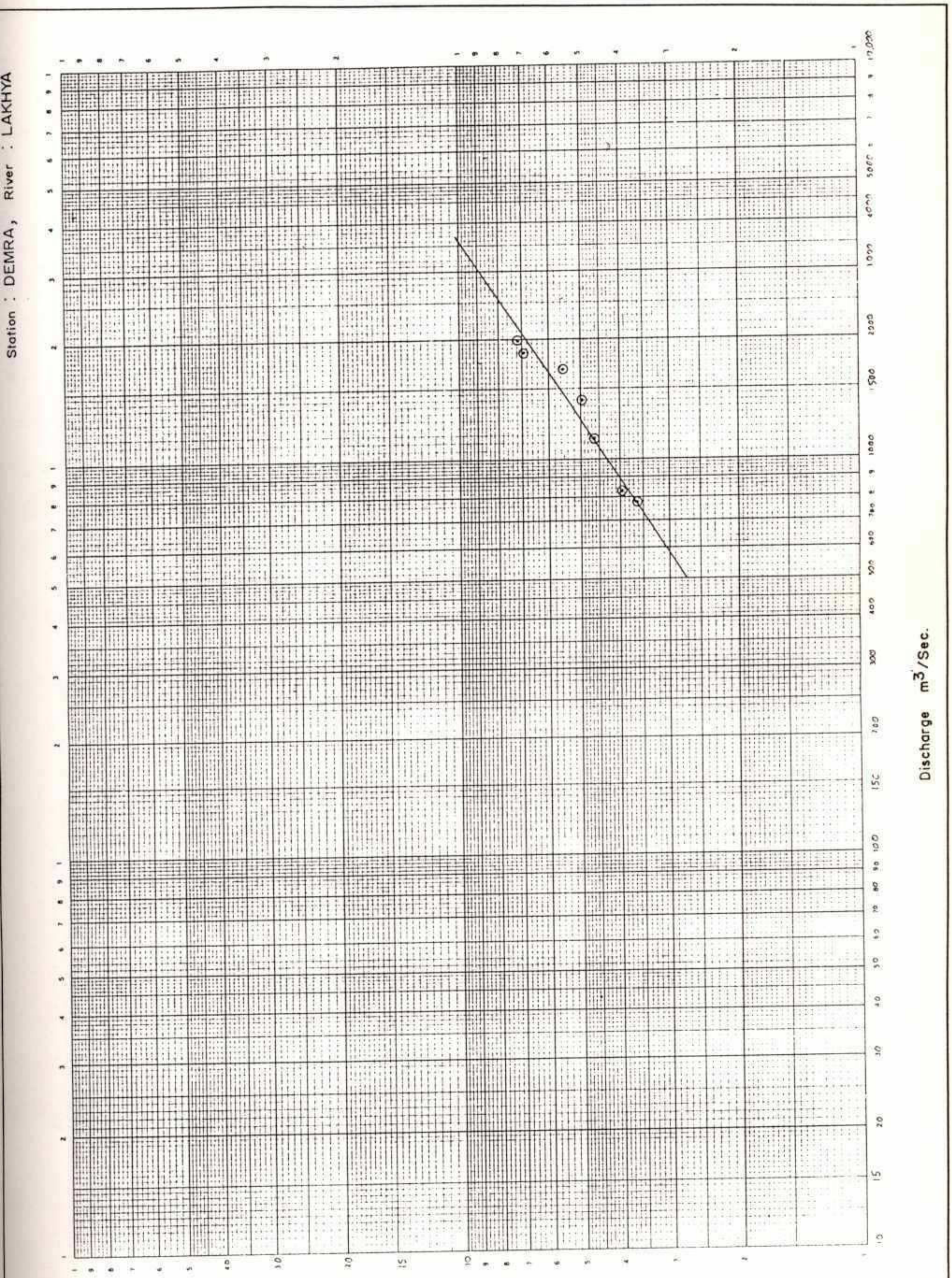
Figure : II.C.7

Stage-Discharge Curves -Taraghat Station, Kaliganga River



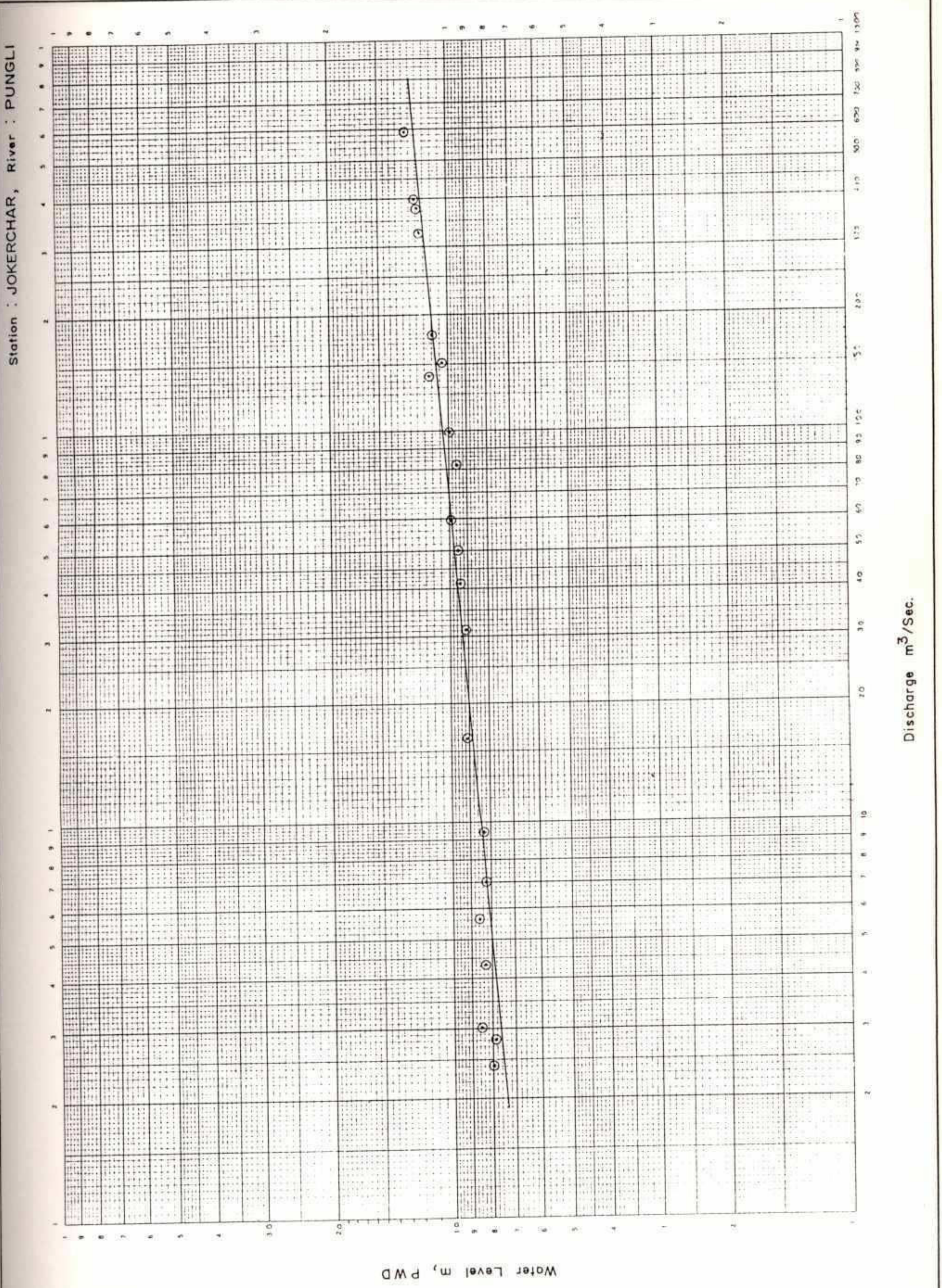
Source:- CS 1992

Figure : II.C.8
Stage-Discharge Curves - Demra Station, Lakhya River



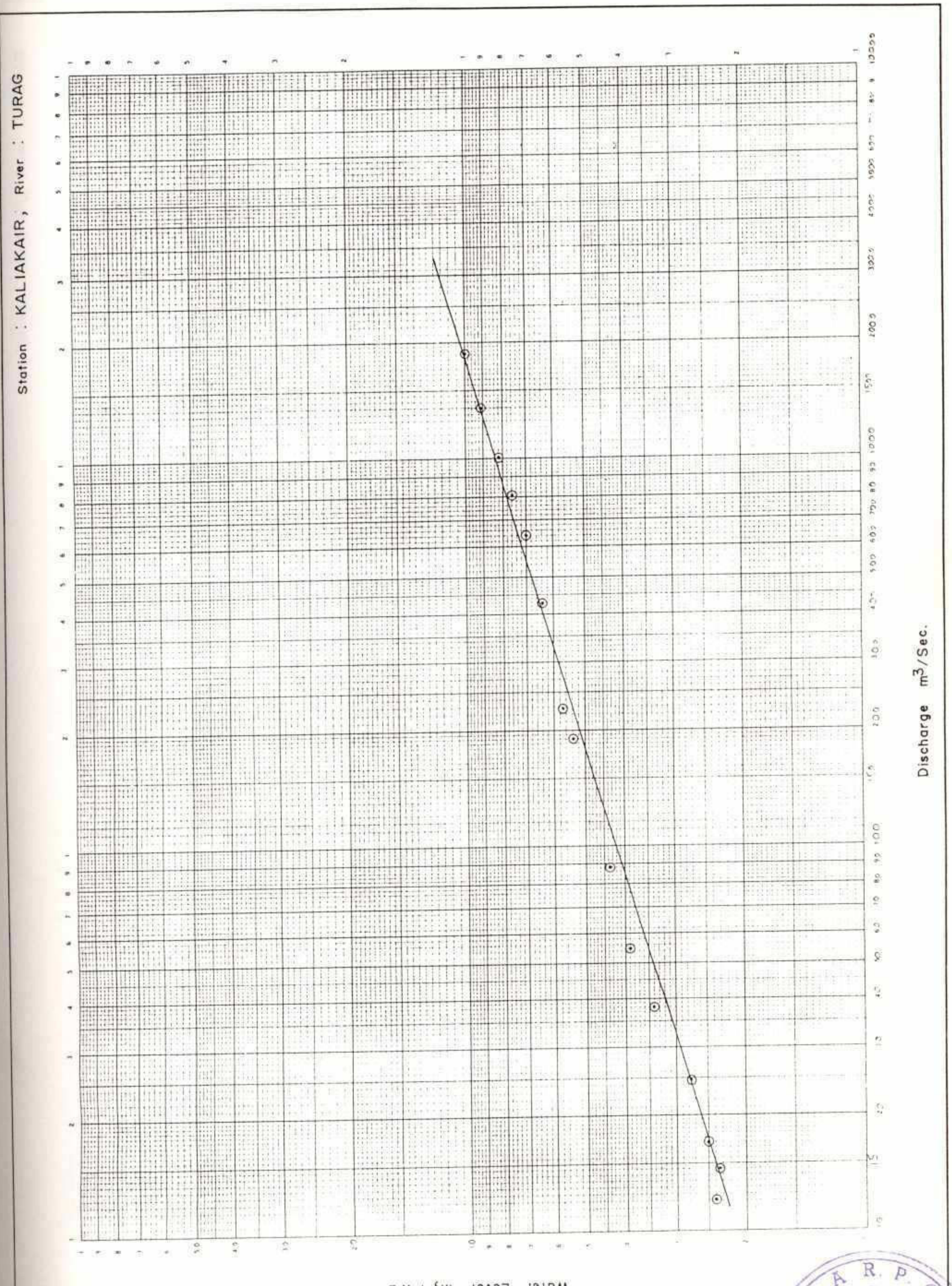
Source:- CS 1992

Figure : II.C.9
Stage-Discharge Curves - Jokerchar Station, Pungli River



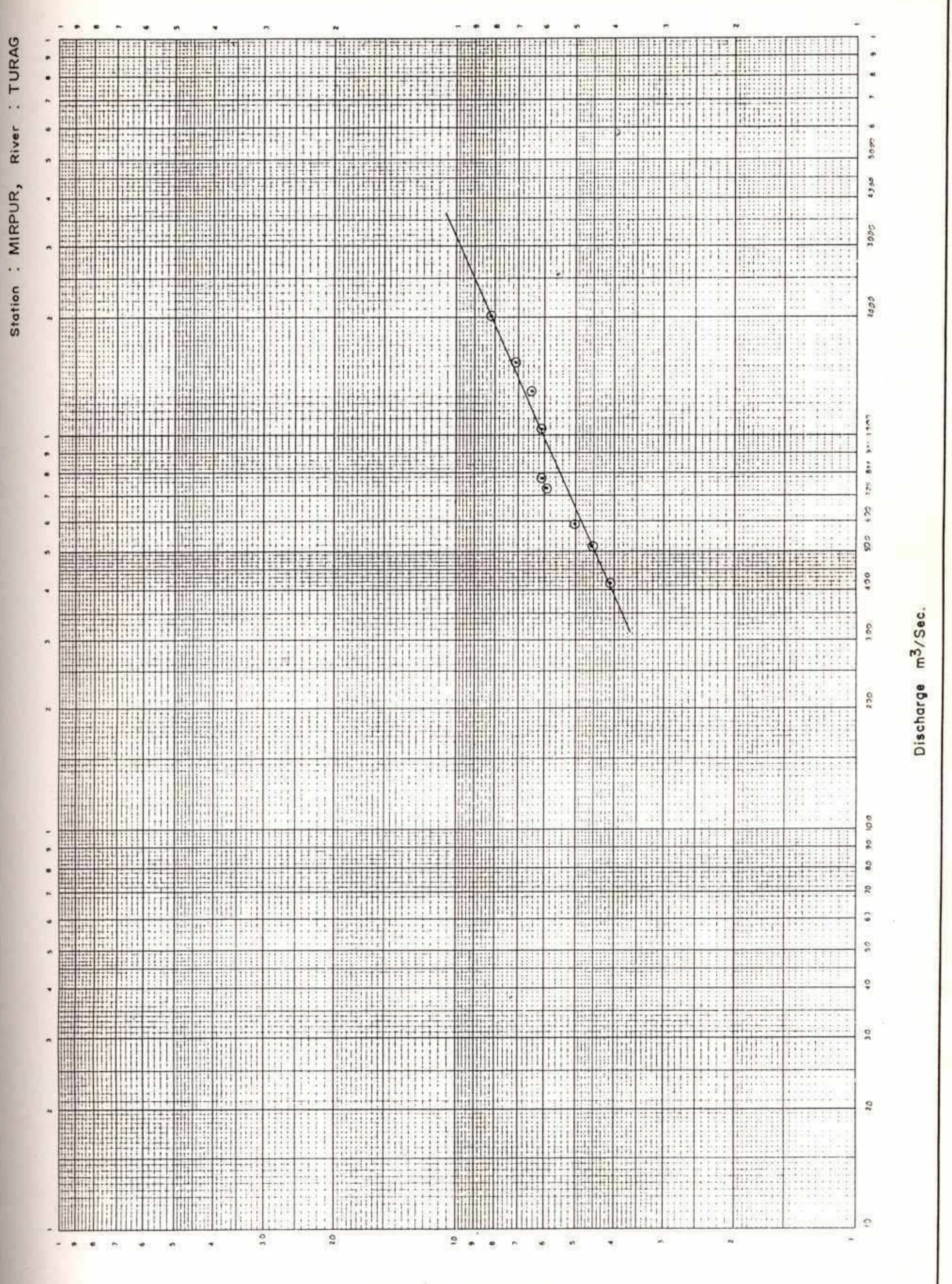
Source:- CS 1992

Figure : II.C.10
Stage-Discharge Curves -Kaliakair Station, Turag River



Source:- CS 1992

Figure : II.C.11
Stage-Discharge Curves - Mirpur Station, Turag River



Source:- CS 1992

SR II.2
River and Drainage System

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Flood Action Plan
FAP 3
North Central Regional Study

Supporting Report II.2
River and Drainage System

February 1993

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BETS Ltd.

NORTH CENTRAL REGIONAL WATER RESOURCES DEVELOPMENT PLAN
FAP-3
SUPPORTING REPORT II.2 - RIVER AND DRAINAGE SYSTEM

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
BADC	Bangladesh Agricultural Development Corp.
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BB	Bangladesh Bank
BBS	Bangladesh Bureau of Statistics
BCAL	Bangladesh Census of Agricultural Livestock
BCAS	Bangladesh Centre for Advanced Studies
FDC	Bangladesh Fisheries Development Corp.
BIDS	Bangladesh Institute of Development Studies
BIWTA	Bangladesh Inland Water Transport Auth.
BJRI	Bangladesh Jute Research Institute
BKB	Bangladesh Krishi Bank
BNPP	Bangladesh National Physical Plan. Board
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engg.Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CAS	Catch Assessment Survey
CAT	Coordination Advisory Team
CCCE	Caisse Centrale de Coopération Economique
CEC	Commission of European Communities
CPM	Coarse Pilot Model
CS	Consultants' Studies
DA	Development Area
DAE	Department of Agricultural Extension
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DDT	Dichlorodiphenyl-trichloroethane
DHI	Danish Hydraulics Institute
DOE	Department of Environment
DOF	Department of Fisheries
DOS	Disk Operating System
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
DUL	Desh Upodesh Ltd.
EEC	European Economic Community
EIA	Environmental Impact Assessment
EIP	Early Implementation Programme
FAO	Food & Agricul.Organ.of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control,Drainage & Irrigation Project
FFYP	Fourth Five Year Plan
FHS	Flood Hydrology Study
FMM	Flood Management Modelling
FPCO	Flood Plan Co-ordination Organisation
FRI	Fisheries Research Institute
FRSS	Fisheries Resources Survey System
FSR	Farming Research System
FWP	Food for Work Programme
FY	Financial Year
GOB	Government of Bangladesh
GW	Groundwater
HTW	Hand Tubewell
HYV	High Yielding Variety
IDA	International Development Agency
IPM	Integrated Pest Management Programme
IRRI	International Rice Research Institute
JFP	Jamuna Flood Plain
JPPS	Jamalpur Priority Project Study
LGEB	Local Government Engineering Bureau
MCA	Multicriteria Analysis
ME	Ministry of Education
MF	Ministry of Finance
MIWDFC	Minist.of Irrig., Water Dev.& Flood Control
ML	Ministry of Land
MLGRDC	Minist.of Local Govt.,Rural Dev.& Coop.
MOA	Ministry of Agriculture
MOEF	Ministry of Environment and Forestry
MOFL	Ministry of Fisheries & Livestock
MOSTI	Manually Operated Shallow T/W for Irrig.
MP	Ministry of Planning
MPO	Master Plan Organisation
MTN	Madhupur Tract North
MTS	Madhupur Tract South
NCA	Net Cultivable Area
NCR	North Central Region
NCRM	North Central Regional Model
NCRMG	North Central Regional Model Group
NCRS	North Central Regional Study
NFMP	New Fisheries Management Policy
NGO	Non Government Organisation
NGR	Natural Growth Rate
NWP	National Water Plan
OBFP	Old Brahmaputra Flood Plain
O&M	Operation and Maintenance
ODA	Overseas Development Administration (UK)
PA	Planning Area
PFDS	Public Foodgrain Distribution System
POE	Panel of Experts
PSR	Preliminary Supporting Report
PU	Planning Unit
PWD	Public Works Datum
RARS	Regional Agricultural Research Station
RHD	Roads and Highways Department
RS	Regional Scheme
SES	Socio-Economic Survey
SOB	Survey of Bangladesh
SPARRSO	Space Research & Remote Sensing Organ.
SRP	Systems Rehabilitation Project
SRTI	Sugarcane Research and Training Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
TOR	Terms of Reference
Tk	Taka
UNDP	United Nations Development Programme
UNHCR	United Nations H.Commission for Refugees
WFP	World Food Programme

CHAPTER 1
MAJOR RIVERS

1.1 Introduction

The river and drainage (see Figure II.2.1) system of the North Central Region is characterised and influenced by the 3 major rivers forming its boundary:- the Jamuna, Padma and the Old Brahmaputra-Lakhya-Meghna system.

These rivers form both a source of flooding from overbank spillage during periods of high discharges, see Chapter 2 and a restriction to the outflows of drainage water, see Chapter 3.

The hydrological data and river morphological characteristics of the rivers are described in SR II.1 and II.3 respectively. They are also described in the Main Report of FAP-25 (FAP-25 1992).

1.2 Jamuna River

The Jamuna River to the west of the project area carries runoff from the Himalayan mountain chain, passing through Nepal, Bhutan and Tibet before flowing into Bangladesh. The river has a broad braided bed with large sand shoals and islands (chars). It is very unstable morphologically, with severe bank erosion, resulting in recorded shifts in bank alignment of over 1 kilometre in a single year. Some 200 years ago the Jamuna was a small regional river but the Brahmaputra changed its course leaving the Old Brahmaputra as a dying smaller distributary and choosing the Jamuna as its main course. The mean annual peak discharge of the Jamuna, calculated from measurements made at Bahadurabad, is approximately 67,000 cumecs, with the 1 in 100 year flood discharge estimated at 108,000 cumecs, (FAP-2, 1992). The Jamuna is from 5 to 15 km in width.

Once the river water levels rise there is little opportunity for rainwater accumulating on the land surface from draining away and this is the principal cause of the inundation of the agricultural land and settlements.

Within Bangladesh the "Brahmaputra" keeps its name until it bifurcates into the "Jamuna" river and the "Old Brahmaputra" (upstream of Bahadurabad)[1]. Downstream the Jamuna merges with the Ganges, near to Aricha to form the Padma and flows down to join with the Meghna and on to the sea.

1.3 Padma River

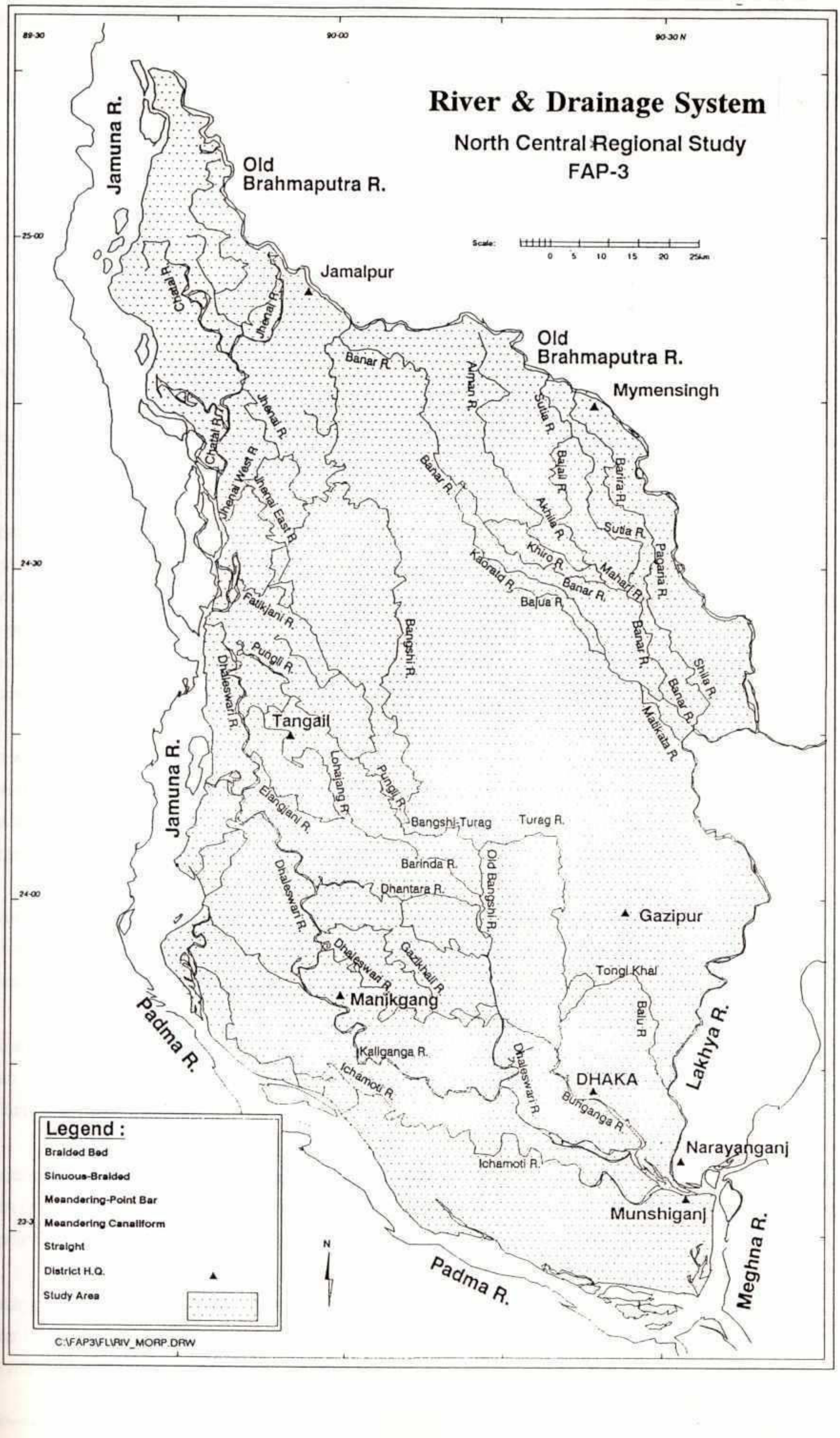
The Padma river forms the southern boundary of the Region and carries the combined discharge of the Jamuna and the Ganges rivers and is a more stable river than the Jamuna river.

It has a mean annual peak discharge of 88,000 cumecs but it is subject to the timing of the peak discharge flows of both the Ganges and the Jamuna. When these two peak flows coincide (as was the case in 1988) then very large flows occur. 1988 was estimated as a 1 in 50 years event (FAP-25 1992) with a peak flow of 132000 cumecs.

---

1 Up until the end of the 18th century the Brahmaputra flowed though the centre of the Mymensingh district joining the Meghna river near Bhairab Bazar. From about 1780 the river began to alternate between the Brahmaputra channel and the Jamuna Channel, the older river eventually became filled with sediment and the Jamuna channel became the principle river flowing directly south offering a more direct route to the sea.

Figure : II.2.1


River & Drainage System
North Central Regional Study
FAP-3
Scale: 0 5 10 15 20 25km
Jamuna R.
Old Brahmaputra R.
Jamalpur
Chatal R.
Jhenai R.
Banar R.
Aman R.
Old Brahmaputra R.
Mymensingh
Sutia R.
Bajali R.
Barira R.
Akhila R.
Sutia R.
Khiro R.
Kaoraid R.
Banar R.
Mahari R.
Pagaria R.
Bajua R.
Jhenai West R.
Jhenai East R.
Fatikjani R.
Pungli R.
Bangshi R.
Banar R.
Shila R.
Dhaleswari R.
Tangail
Malikata R.
Lohajang R.
Pungli R.
Elangjani R.
Bangshi-Turag
Turag R.
Jamuna R.
Barinda R.
Old Bangshi R.
Dhantara R.
Dhaleswari R.
Gazipur
Gazikhali R.
Tongi Khal
Manikganj
Balu R.
Lakhya R.
Padma R.
Kaliganga R.
Ichamoti R.
Dhaleswari R.
DHAKA
Buriganga R.
Narayanganj
Ichamoti R.
Munshiganj
Meghna R.
Padma R.
N
Legend :
Braided Bed
Sinuous-Braided
Meandering-Point Bar
Meandering Canaliform
Straight
District H.Q.
Study Area
C:\FAP3\FL\RIV_MORP.DRW

At the south-east corner of the study area, the Padma combines with the Meghna to drain an area of some 1.55 million square kilometres in total, only a small percentage of which lies in Bangladesh.

1.4 The Old Brahmaputra-Lakhya-Meghna-System

The Old Brahmaputra follows the course of a once larger river, which changed its course during the period 1720 to 1830 so that the majority of the annual flow subsequently flowed down the Jamuna river with only a portion of flows at higher discharges, continuing to flow from the Brahmaputra into the Old Brahmaputra. According to some sources (CBJET 1991) the original river course changed dramatically in 1987 when a catastrophic event formed the new course of the river.

The present course of the Old Brahmaputra begins as a minor river, the Jinjaram river, north of Karkhana. The Jinjiram flows south for about 300km before reaching the present course of the Old Brahmaputra. It flows between the main course of the Brahmaputra and the western spurs of the Assam hills. The Jinjiram splits off into a small channel, near Chullar Char, flowing closer to the hills and is joined by a number of smaller rivers from the adjacent hills (the larger channel is also called the Sunabari).

The mouth of this river has been steadily silting over the year since the river changed its course and the flows down this branch are a fraction of the original. This has significant impact on dry season flows. The mean annual peak flood, calculated from discharge measurements made at Mymensingh, is 3,120 cumecs, which is 4.8% of the mean annual peak flood of the Jamuna at Bahadurabad. The remainder of the eastern boundary of the study area is delineated by the Lakhya River, a right bank distributary of the Old Brahmaputra River. Due to heavy silting of the Old Brahmaputra downstream of this bifurcation, the majority of the flow passes down the Lakhya River.

The present connection between the Old Brahmaputra and the Jamuna is unstable and there is no clear channel between the two rivers. The Jinjiram constitutes the main source of discharge into the Old Brahmaputra during the dry season but during the high flood season over bank spillage from the Brahmaputra/Jamuna accounts, for significant discharges from the main river into the Old Brahmaputra.

The mean annual peak discharge of the Old Brahmaputra (at Nilukhirchar, close to Mymensingh) is 3120 cumecs which is 4.8% of the mean annual peak discharge of the Jamuna. The 1988 peak flood discharge was 4800 cumecs and is calculated to have a return period of 40 years (FAP-25 1992).

Significant flows divert back to the Jamuna via the Jhenai river which bifurcates from the Old Brahmaputra just upstream of Jamalpur. In 1988 approximately 25% of the total Old Brahmaputra discharge flowed down the Jhenai to the Jamuna.

Downstream of Jamalpur the Old Brahmaputra is well confined on its right bank by the railway embankment. At Toke the river bifurcates with the majority of the river flowing down the Lakhya. The remaining section of the Old Brahmaputra from Toke to Bhairab Bazar is now largely silted up and only carries small flows.

The Lakhya flows from Toke down to Dhaka, forming the eastern boundary of the NCRS area. At Dhaka it joins the lower Dhaleswari and the Meghna before also joining with the Padma to form the lower Meghna at the south-east (downstream) corner of the study area.

CHAPTER 2
THE REGIONAL RIVERS

2.1 General

The interior rivers may be categorised as falling into 3 distinct systems (see Figure II.1.4)

- the Dhaleswari-Kaliganga system in the south-west
- the Bangshi-Turag system in the central part
- the Banar-Lakhya system in the eastern part

The Dhaleswari-Kaliganga system comprises the major distributaries of the left bank of the Jamuna (Old Dhaleswari, Dhaleswari, and a number of un-named but significant spill channels). together with their distributaries, (Louhajang, Elangjani, Barinda). At a point some 48 kilometres downstream from its offtake from the Jamuna, the Dhaleswari bifurcates, the major channel now called the Kaliganga to the south of the diminished Dhaleswari. The two channels reunite at Kalatia, the Dhaleswari at this point having "captured" the Bangshi river.

The Bangshi-Turag system provides the central spine drainage of the region. It is fed partly by spill from the Jamuna through the northern Dhaleswari intake via the Pungli river, partly by the accumulated runoff from the north-west of the region, (Jhenai river, Futikjani river), and partly from the direct runoff into the Bangshi from the western slopes of the Madhupur Tract. Over recent years, the rainfall/runoff contribution from the Madhupur Tract may have increase significantly due to the extensive denudation of the Madhupur Forest.

The Banar-Lakhya system to the east of the Madhupur Tract is mainly rainfall fed, with direct contribution form the Old Brahmaputra through the Lakhya River. Downstream of Toke,the Lakhya River is the main branch of the Old Brahmaputra. This system is unaffected by flows in the Jamuna, although extreme levels in the Old Brahmaputra can result in spillage at certain locations.

2.2 Dhaleswari/Kaliganga/Lower Dhaleswari System

The Dhaleswari/Kaliganga/Lower Dhaleswari System acts both as a main relief or collector channel for the Jamuna and as a drainage system from local rainfall. From the northern most offtake at Bhuapur south to the second and largest offtake, the Dhaleswari runs almost parallel to the Jamuna, from this second offtake the river swings southeast to Manikganj continuing on eventually to Munshiganj where it joins the Meghna river. There is a third offtake from the Jamuna but that presently discharges water only at very high water levels in the Jamuna. The Dhaleswari Kaliganga system carries peak discharges in the order of 3000 to 5400 cumecs (at Taraghat during August 1965 flow was measured at 3230 cumecs, 5350 cumecs in August 1973 and 3220 cumecs in August 1988).

The Dhaleswari/Kaliganga river system conveys upto 13% of the Jamuna flow as overbank spillage together with the discharge through the two main offtakes to the Dhaleswari. Some of this overbank spillage, possibly upto 20% returns to the Padma below Aricha (FAO-SF Water Balance Study, 1965/68 and Dhaka Southwest Project 1971).

The longitudinal sections of the two rivers are shown in Appendix II.B.3. The Dhaleswari river is about 150km and the Kaliganga 60km in length.

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The FAP-8A study have estimated that during the peak period of 1988 the discharge through Lower Dhaleswari into the Meghna river was as much as 20 000 cumecs (FAP-8A Main Report, 1991). This accounts for almost all of the drainage of the North Central Region. The annual peak discharge into the Meghna has been estimated to be from 12 000 to 14 000 cumecs (CS 1991/92).

Dhaleswari River and Kaliganga River

The Upper Dhaleswari begins at on offtake close to Bhuapur just above the proposed site of the Jamuna Bridge, see Figures II.2.1 & II.2.2. The approach road to the bridge is under construction and an embankment from the approach road to the Bhuapur/Tarakandi embankment is also being constructed.

Downstream of the main offtake (see Figure II.2.3) the Dhaleswari flows into a complex floodplain area with connections into the Barinda, Gazikati and Main Dhaleswari. The direction of flows is generally eastward out of the Dhaleswari but at high flood periods particularly with heavy local rainfall, the flows direction can be reversed. Downstream of Tilli, the main Dhaleswari flow is known as the Kaliganga.

The Kaliganga flows across older floodplain material and has a more stable morphology (see SR II.3) than the Dhaleswari. At Kalatia the Kaliganga joins with the lower Bangshi (which collects water from the Barinda, Gazikhali and Minor Dhaleswari) and is renamed as the 'Lower Dhaleswri'. The lower Dhaleswari joins with the Buriganga at Fatullah and thereby forms a river (still called the lower Dhaleswari) which effectively acts as the lower section of a central drainage system for the North Central Region.

The **southwest area** below the Dhaleswari/Kaliganga has only one recognisable river, the **Ichamati** which is perched for most of its course up to its confluence with the Dhaleswari. There are a number of minor channels and khals that drain floodgate out of this south western area. The large Arial beel was once an important fishery area but owing to sedimentation, drainage, and paddy cultivation it has diminished in size.

The Louhajang River

The Louhajang river takes off from the Dhaleswari river and flows through Tangail town. The river floods the town periodically although embankments to divert the river around the main town centre has averted some of the flood hazard. The river is about 60km in length and joins the Elangjani river before meeting the Barinda to the southeast of Mirzapur.

The Louhajang river drains most of the region south of the Pungli with an average slope of 0.1084m/km. The drainage of the area around Tangail is being investigated by FAP-20 as part of a pilot compartmentalisation project. The river long section is given as Figure II.B.3a.

The Elangjani River

The Elangjani river takes off the Dhaleswari downstream of the Louhajang river and follows along the edge of the flood plain almost parallel to the Dhaleswari for a third of its length, then turns eastward and joins the Louhajang 28km below the offtake. An embankment extends down from the Louhajang and continues along the Elangjani.

Figure : II.2.2
Aerial Photograph (Dec 1990) - Jamuna Bridge,N.Dhaleswari Offtake & Pungli River

Figure : II.2.3
Aerial Photograph (Dec 1990) - Main Dhaleswari Offtake & Elanjani Offtake

Cross sections were surveyed along the river and the longitudinal section is shown in Figure II.8.3b. There are few hydrometric measurement on this river but the discharge capacity is of the order of 70 to 90 cumecs with a bed slope of 0.1275m/km.

The Barinda River

The Barinda river is a relatively large channel taking off from the Dhaleswari in the vicinity of Nagarpur and flowing eastward, near Kandapara the river branches with the northern branch being joined by the Louhajang to the south of Mirzapur. The river continues on to join the South Bangshi above Nayerhat.

The Barinda river can flow in either direction serving to convey water from the South Bangshi or in the opposite direction depending on water levels at either end. The channel is 30km long and the longitudinal section is shown in Figure II.B.3b.

A western bypass channel from the Bangshi/Turag river joins the Barinda about 4km upstream of Nayerhat, and the Barinda meanders across the flood plain with a second river called the Dhantara offtakes. This small channel joins the South Bangshi south of Nayerhat. The main Barinda channel flows on to the southeast and is sometimes called the Dhamrai and joins the South Bangshi at Dhamrai.

Gazikali River

The Gazikali river is a minor channel taking off from the Upper Dhaleswari close to Saturia. The discharge of the Gazikali is estimated as 256 cumecs for 1/2.33 years return period and 428 cumecs for a 1/20 year return period.

Minor Dhaleswri River

The minor Dhaleswari was formerly a continuation of the Upper Dhaleswari but the main flow takes a southerly course down the Kaliganga. The present minor Dhaleswari river channel meanders across the old riverine plain and splits into two channels before joining the South Bangshi river just south of Savar.

The discharge measured at Jagir was 2070 cumecs during 1964 but such discharges are no longer encountered. The average peak flood discharge is estimated of 688 cumecs (1/2.33 years) and the 1/20 year at 1750 cumecs.

2.3 Bangshi/Turag/Buriganga System

The western floodplains of the NCR are drained by the Bangshi/Turag/Buriganga river system. Although the river network is complex with channels bifurcating and joining as it flows downstream this central system allows for drainage flow down to the south-east corner of the region. However during the monsoon season high water levels in the Meghna/Padma crete a back-up effect and inhibits flow out of the Buriganga/Lower Dhaleswari rivers, see Chapter 4.

Bangshi River

The Bangshi River formerly took off water from the Old Brahmaputra, downstream of Jamalpur. That offtake was closed in the early 1970's and now the Bangshi acts almost entirely as a drain for runoff form the Madhupur Tract.

It is a relatively well formed river as far as Deopari where it is joined by the Fatikjani river. Downstream of the junction the river has low bed slopes and meanders considerably. Close downstream the Bangshi flows into a complex area with considerable cross-flows between the Pungli and a distributary of the Bangshi called the Nanglai. The triangular area between these rivers are deeply inundated annually (up to 6m is places). The area acts as a flood water storage area.

Downstream the majority of the Bangshi flows into the Turag river to the east with smaller flows into the Old Bangshi. It is considered that there is potential for improving flow out of this area by increasing the capacity of the Old Bangshi through Regional Scheme 4 (see Main Volume, Chapter 5). There are two existing channels into the Old Bangshi; the eastern one has a present capacity of some 400 to 500 cumecs whilst the western one carries some 200 to 300 cumecs.

Turag River

The Turag river follows as apparent 'fault line' from the Bangshi river past Kaliakoir through the Madhupur Tract in an easterly direction.

The Turag joins with Iubundhu khal and turns due south toward the western perimeter of Dhaka city. The river meanders through a fairly narrow defile between the higher lying Madhupur country. Both banks are densely populated and cultivated and the area on either side of the river is deeply inundated during the annual flood season.

Near Qasimpur the Turag straightens and widens. The Tongi Khal takes off from the Turag just to the north of Zia Airport flowing east to join the Balu river. The Tongi Khal appears to serve as a bypass to the Balu when water levels in the Turag are high and reverse flow also occurs. Regulation of the flow between the two rivers may be desirable to present surplus water flowing from the Balu into the Buriganga which would raise water levels along the city perimeter.

At Mirpur, a small river called the Karnatali links the South-Bangshi to the Turag, which then becomes the Buriganga river. The Karnatali river has a discharge capacity of about 600 cumecs.

The **Buriganga** river is about 30km in length from Mirpur to the junction with the Dhaleswari at Fatullah. The peak discharge in the Turag at Kaliakoir was 1490 cumecs during 1987 and at Mirpur was 1600 cumecs in 1974.

The **Chatal** offtake channel is located along the active flood plain running parallel with the main Jamuna river some 12km south of Bahadurabad.

Figure : II.2.4
Aerial Photograph (Dec 1990) - Fatikjani Offtake and Bhuapur Ghat

The Chatal is a fairly mature channel that conveys water from the upper reaches of the Jamuna at high flood flows to the lower reach close to Dyalpur, at the fertilizer factory. It also serves to drain the accumulated rainwater that inundates the area during the monsoon period.

The **Jhenai river** offtake, from the Old Brahmaputra river about 10km to the northwest of Jamalpur town. The river passes through the railway bridge on the Jamalpur/Dewanganj railway line and flows to join the Chatal, the two rivers meander across the lower flood plain and then form a single channel at Sarishabari flowing south into the Jamuna. Below the junction of the Jhenai and the Chatal a small channel off takes from the main river to flow through the railway line at the Bhausi Bridge and continues as a smaller Jhenai river. Downstream of Baushi bridge minor channels referred to as the East and West Jhenai split off from the main Jhenai channel.

Cross sections and longitudinal sections of the Jhenai and Futikjani and minor rivers were surveyed during the Bridging period and are shown in Figure II.B.3. The peak discharge measured at the Jhenai railway bridge was 1690 cumecs during 1974 and at Bhaushi bridge was 863 cumecs during 1978 (MPO Tech. Report No.11). However, these discharges do not seem to have been exceeded during the 1988 flood season. The FOA-SF Water Balance Study of 1963/68 estimated that no more than 3% to 4% of the Jamuna discharge, measured at Bahadurabad, overspilled into the area between Bahadurabad and Bhuapur. Since the embankment was constructed the overbank spillage has been reduced to manageable proportions.

The Futikjani

The Jhenai joins the Futikjani about 5km from the Jamuna off-take, the rivers follow a southeasterly course and join the Bangshi south of Doepara. A minor channel, the Nanglai, loops around an area of higher land and serves as a bypass along the Futikjani.

This system of rivers formerly carried the overspillage from the Jamuna (from the west) (see Figure II.2.3) and from the Old Brahmaputra (from the north). The significant feature of the rivers is that the banks are perched and therefore do not drain water away from surface accumulations until the water levels rise above the perched bank level.

The Pungli River

The Pungli river offtake is located on the Dhaleswari about 8km below the upper (northern) offtake of the Dhaleswari river from the Jamuna (see Figure II.2.2). The Pungli has high bed levels close to the offtake with the Dhaleswari with the bed 2.00m above the bed level of the Dhaleswari at the offtake. Water does not flow into the Pungli until the Jamuna reaches high flood levels.

It is apparent that the Pungli river has carried heavy sediment loads in the past as there are extensive deposits of sand along the course of the river bed. The Pungli flows on a southeasterly course, just north of Tangail town, joining the Bangshi close to the town of Mirzapur. The peak discharge measured at the Jokerchar (134) gauging station was 985 cumecs during 1987 and the average annual (1/2.33 year) discharge is 592 cumecs.

The South Bangshi

The South Bangshi river appears to have formerly been the main channel from the northern Bangshi river which now flows mainly into the Turag river.

Presently the South Bangshi river acts as a collector for the minor rivers located between the Pungli in the north and the Dhaleswri/Kaliganga to the south, these rivers all originate from the north/south upper Dhaleswari river. The area thereby drained is about 180 000 ha in extent, and most of it is inundated for the monsoon period. The South Banghsi flows from the north, close to Kaliakoir, along the western extremity of the Madhupur Tract and then joins the Kaliganga at Kalatia.

The river continues on to the Nayerhat bridge where the maximum peak discharge measured at the bridge was 3250 cumecs during 1968, the 1/2.33 year discharge is 1830 cumecs and the 1/20 year discharge 3350 cumecs. The channel has the capacity to carry these volumes of water but bed slope is quite flat and the velocities are low. The river is subject to backwater effects from high water levels downstream in the Lower Dhaleswari/Meghna.

2.4 The Banar/Lakhya System

The Banar/Lakhya System forms the main drainage system for the region that lies between the Old Brahmaputra on the east and the Madhupur Tract. This sub-region is seldom inundated from overbank spillage from the primary rivers, even during the peak floods of 1988, most of the area was not flooded from the Old Brahmaputra river. However, substantial lower lying areas are inundated by rainwater, with the water being unable to drain away through the extensive network of rivers and khals near to Trimohini and due to the limited capacity of the outlet channel of the Lakhya.

Later in the season high water levels in the Old Brahmaputra/Lakhya back the water up into the system preventing a rapid outflow from the region.

The Banar River

The origin of the Banar river was formerly from the Bangshi offtake from the Old Brahmaputra (O/B), but this was closed in the 1970's and although still connected to the Bangshi little water now flows along that section.

The main function of the Banar is now as a drain for the eastern catchment of the Madhupur Tract. The river is connected to the Kaoraid (longitudinal sections are given in Appendix II.B.1).

The Sirkali River

The Sirkali river is a small river some 15km long, which drains the area in the vicinity of Narundi and joins the Banar. The old course of the Old Brahmaputra river traverses this area and many beels occur around Narundi and southeast of Muktagacha. The whole of the Eastern region is inundated solely from rainfall and it is only toward the end of September that this water starts to drain out once the water levels in the primary rivers recede.

The extensive beel system and the water retained in the river channels after the water levels have receded provides water for irrigation by low-lift pumping and sustains a diminishing fishery industry. From 30,000 to 40,000 ha of land can be irrigated form this source for two to three months over the cooler part of the dry season, the Kharif season. As far as can be ascertained no water is drawn from the O/B for irrigation purposes.

The Sirkali river and Aiman river originate close to the Old Brahmaputra but the actual channels are not clearly defined nor confirmed in the field. The Aiman flows south for some way and then turns southeast to flow close to the town of Muktagacha, the name change to Akhila at Phulbari, then Mahari at Trisal, then joins the Khiro, and eventually the Banar near Gopalpur, on the road to Goffargaon.

The Sutia River

The Sutia river is another important drainage channel, the offtake on the Old Brahmaputra has a regulating structure built across the inlet channel but the invert level appears to be at a much higher than the average Old Brahmaputra flood level. The structure presently acts to allow flow with the Old Brahmaputra at times of high local rainfall.

The Sutia river rises to the northwest of Mymensingh on the right bank of the O/B and flows in a southerly direction for about 60km, joining the Banar river close to Raona. The longitudinal section of the river is shown in Figure II.B.1. The river has a fairly consistent bed slope over 56km of about 0.0879m/km but then the slope decreases sharply. Back water effects from the primary rivers do not extend this far up into the area, but at the downstream end daily fluctuations of about 0.30 to 0.50m occur.

The Shila River

The Shila river begins as the Barira river close to Mymensingh town. This river flows between the Sutia and the Old Brahmaputra, joining the Banar at Trimohini.

The Balu and Tongi Khal

The Balu river is about 30 to 40km in length and the catchment lies entirely in the Madhupur tract north of Dhaka, the headwaters of the river continue to Rajendrapur, close to Sripur. The peak discharge at Demra (7.5) was 476 cumecs in 1968, during September 1988 it was 760 cumecs. It is possible that some proportion of the discharge originates from the Tongi khal, during 1970 the discharge was 524 cumecs - no records are available for more recent discharges since the station was discontinued in 1981. The longitudinal section is shown in Figure II.B.1.

The Lakhya River

The Lakhya river forms the lower eastern boundary of the North Central Region study area.

The course of the Lakhya river begins at the bifurcation of the O/B at Toke. The present course of the O/B is a considerably smaller channel flowing in the old bed. It appears that the old channel has been settled and cultivated for some time.

At Toke the course of the river swings away to the west, flowing through typical Madhupur Tract country, at Trimohini the Banar and the Shila converge and flow into the Lakhya river. At this point the course is almost due south traversing the rough dendritic type countryside. At Kapasia the river emerges into the lower flood plain of either the Old Brahmaputra or of the Meghna (this area is not covered by the SPOT images). The course follows along the western edge of the Madhupur Tract in a southeastly direction and continues on to the confluence with the Dhaleswari downstream of Narayanganj.

The Lakhya river is a well defined channel that courses through the erosion resistant soils of the Madhupur Tract, without meanders and braiding. The length of the river from Toke to the confluence with the Dhaleswari is 112.5km. The peak discharge of the river during the 1988 was 2600 cumecs and the average maximum daily discharge was 2540 cumecs in 1966.

CHAPTER 3
FLOODING AND DRAINAGE

3.1 Flooding

3.1.1 General

Flooding in the North Central Region can occur from 3 sources: direct rainfall, direct overbank spillage from the major boundary rivers and overbank spillage from the internal regional rivers (see section 3). It is possible for each phenomenon to occur separately or in combination obtain with any other, see Figure II.2.5. The pattern of river levels generally experienced in the region shows a 2-peaked responses, the first peak being generated by internal regional rainfall excess, normally in June/July, and the second peak resulting from high cross-boundary flows in the major rivers, normally in early September (detailed hydrographs are given in SR II.1 Appendix A). The flood of 1988 was caused by the unusual coincidence of peak floods in both Jamuna and the Ganges rivers whereas the floods of 1987 were caused primarily by the unusually high regional rainfall, see Figure II.2.6.

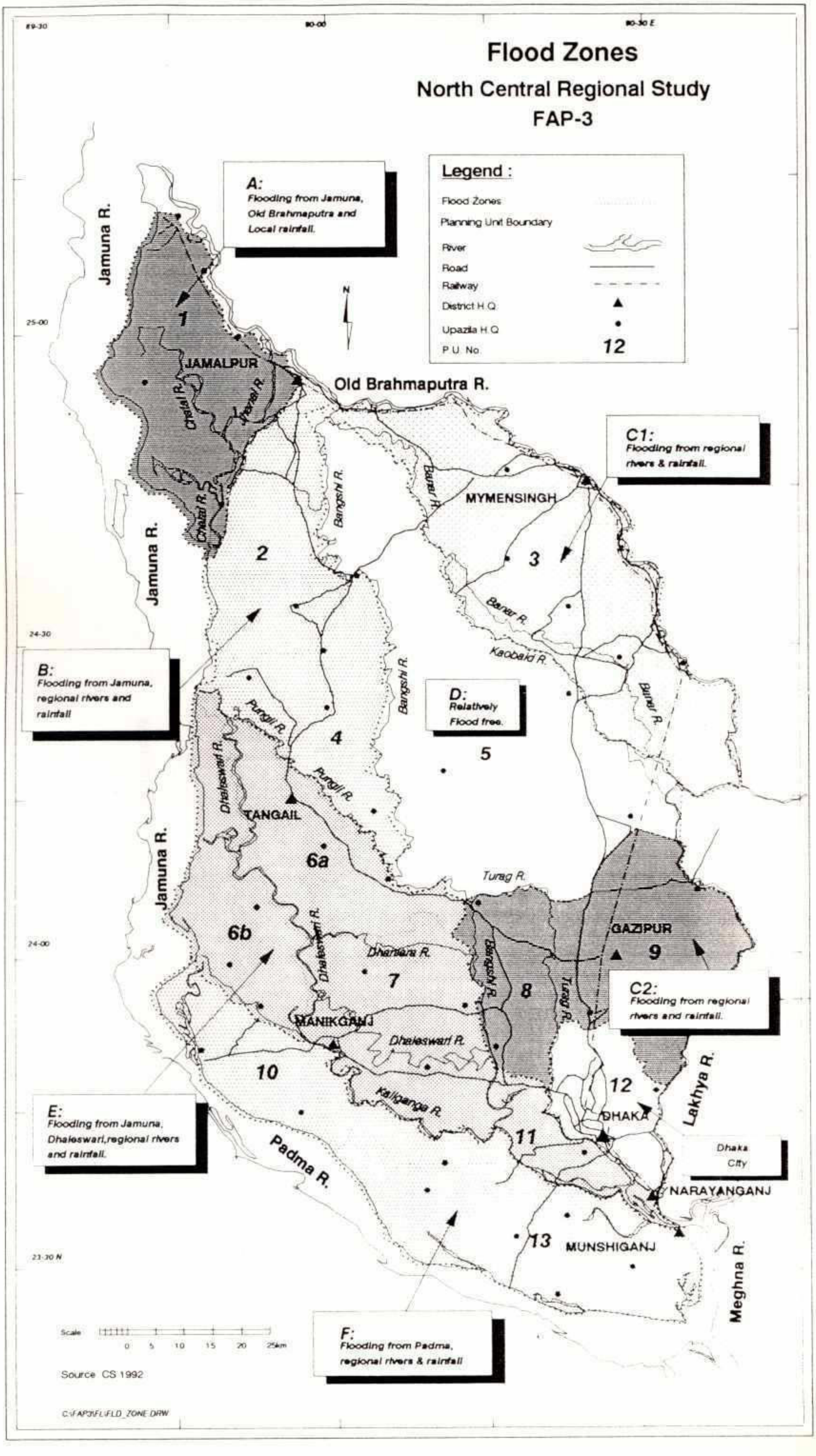
The rainfall experienced within the region amounts to some 2000 mm per annum (decreasing from north-east to south-west), generally occurring over a 5-6 month period (see PAR II.1). In consequence of this, large volumes of excess rainwater accumulate in the depressions and low-lying areas. During the pre-monsoon and monsoon seasons, (from May to October), the predominantly high water levels in the major boundary rivers coupled with the high water levels in the regional rivers conveying spills from the Jamuna, prevent the withdrawal of excess rainfall from the internal flood plains. As long as the commanding water levels in the boundary rivers remain high, the levels in the regional rivers also remain high and the removal of water from, (or transfer through), the region is severely inhibited. The Meghna-Padma at the south-east corner is tidal influenced, (see Figure II.2.7 and II.2.8) and this causes further reduction of drainage in the Region, thus keeping flood levels high.

Ingress of floodwater from the Jamuna River can occur via direct overbank spillage, the precise location of which can vary from year to year, or through well-defined existing river channels which offtake from the Jamuna. Most of the direct overbank spill occurs between the northern intake of the Dhaleswari and the Dhaleswri offtake from the Jamuna some 30 kilometres to the south.

As a result of the inter-connection between the Jamuna River and the western rivers of the region, these regional rivers perform a dual function. During the monsoon season, when the water levels in the boundary rivers are high, they act as"conduits", transferring water from the Jamuna to the Meghna, with little or no spar capacity to accommodate accumulated floodwater resulting from rainfall excess. Indeed, the incapacity of some of the regional rivers to carry the required volume of overflow from the Jamuna serves only to exacerbate an already major flooding situation.

The drainage of accumulated rain water is prevented from flow out of the region by the backwater reaching up as far as Trimohini and with exceptionally high levels even further up the Shila, Kaoraid, and the Banar. The railway embankment was close to being overtopped to the south during the 1988 peak period.

Figure : II.2.5



Flood Zones
North Central Regional Study
FAP-3
Legend :
Flood Zones
Planning Unit Boundary
River
Road
Railway
District H.Q
Upazila H.Q
P.U. No.
12
A: Flooding from Jamuna, Old Brahmaputra and Local rainfall.
B: Flooding from Jamuna, regional rivers and rainfall
C1: Flooding from regional rivers & rainfall.
C2: Flooding from regional rivers and rainfall.
D: Relatively Flood free.
E: Flooding from Jamuna, Dhaleswari, regional rivers and rainfall.
F: Flooding from Padma, regional rivers & rainfall
Dhaka City
Jamuna R.
Old Brahmaputra R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Padma R.
Lakhya R.
Meghna R.
Turag R.
Dhaleswari R.
Kaliganga R.
Bangshi R.
Pungli R.
Banar R.
Kaobald R.
Dhaleswari R.
1
2
3
4
5
6a
6b
7
8
9
10
11
12
13
Scale
0 5 10 15 20 25km
Source CS 1992
C:\FAP3\FL\FLD_ZONE.DRW

Figure : II.2.6

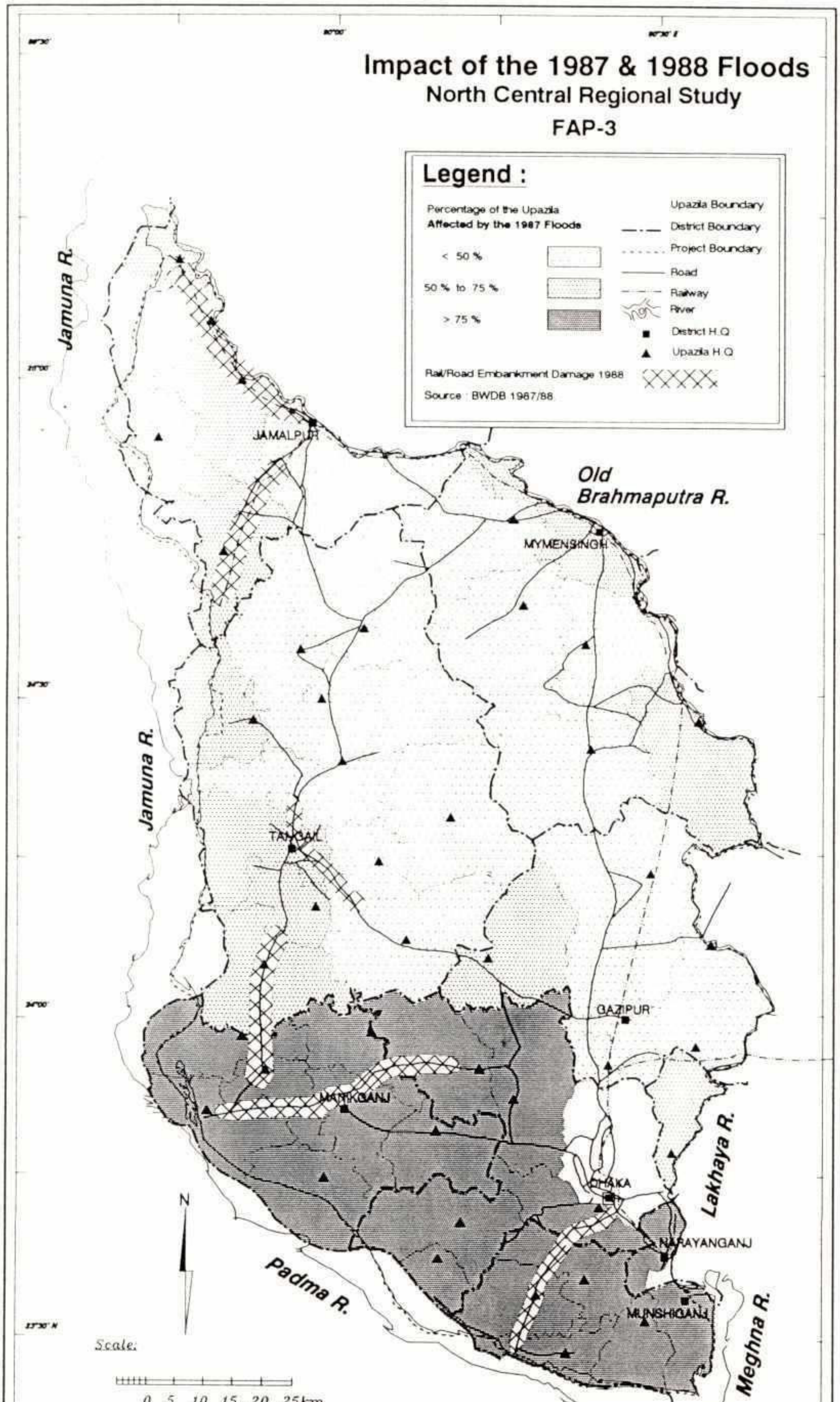
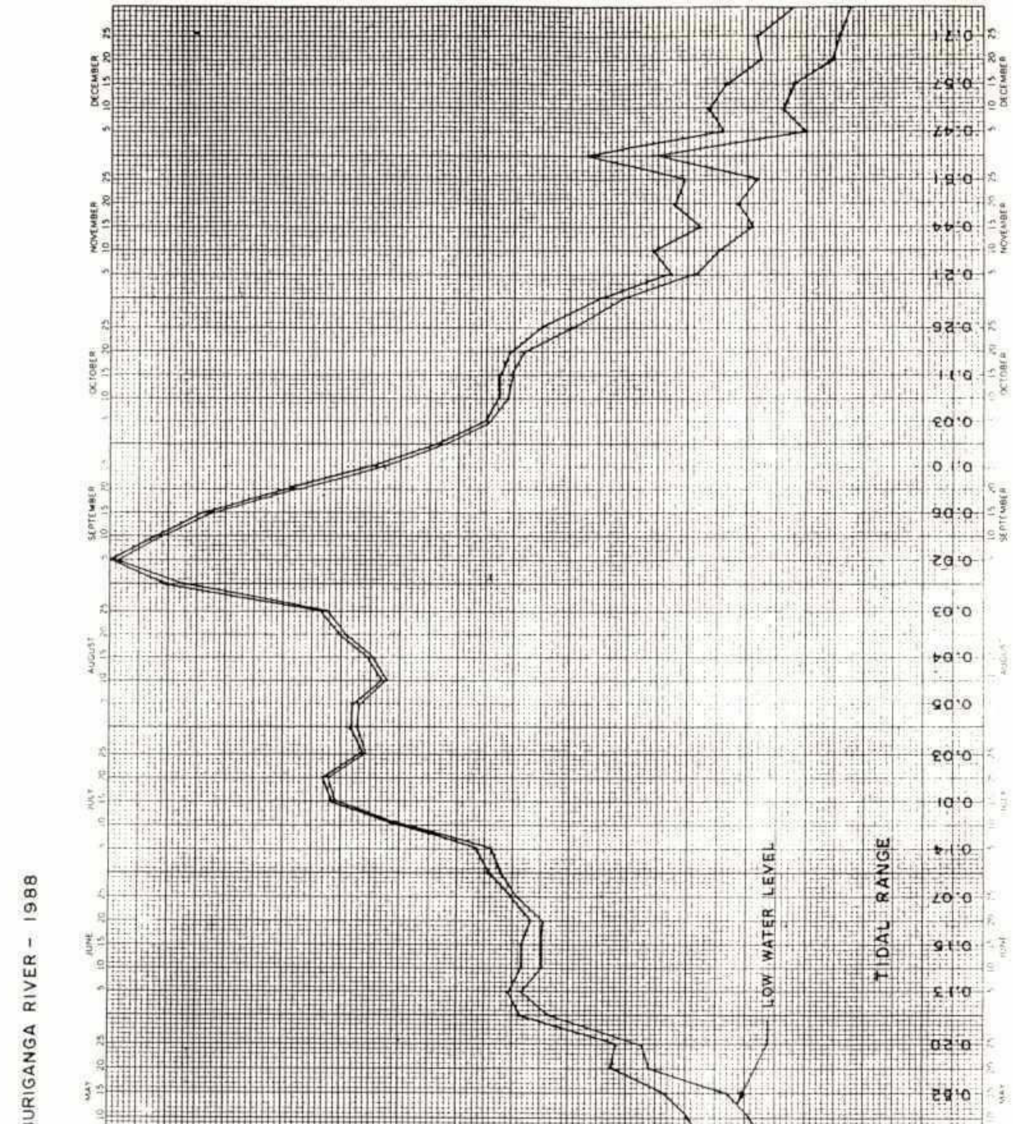

Impact of the 1987 & 1988 Floods
North Central Regional Study
FAP-3
Legend :
Percentage of the Upazila Affected by the 1987 Floods
< 50 %
50 % to 75 %
> 75 %
Rail/Road Embankment Damage 1988
Source : BWDB 1987/88
Upazila Boundary
District Boundary
Project Boundary
Road
Railway
River
District H.Q
Upazila H.Q
Jamuna R.
JAMALPUR
Old Brahmaputra R.
MYMENSINGH
Jamuna R.
TANGAIL
GAZIPUR
MANIKGANJ
Lakhaya R.
DHAKA
NARAYANGANJ
Padma R.
MUNSHIGANJ
Meghna R.
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\IMPACTFD.DRW

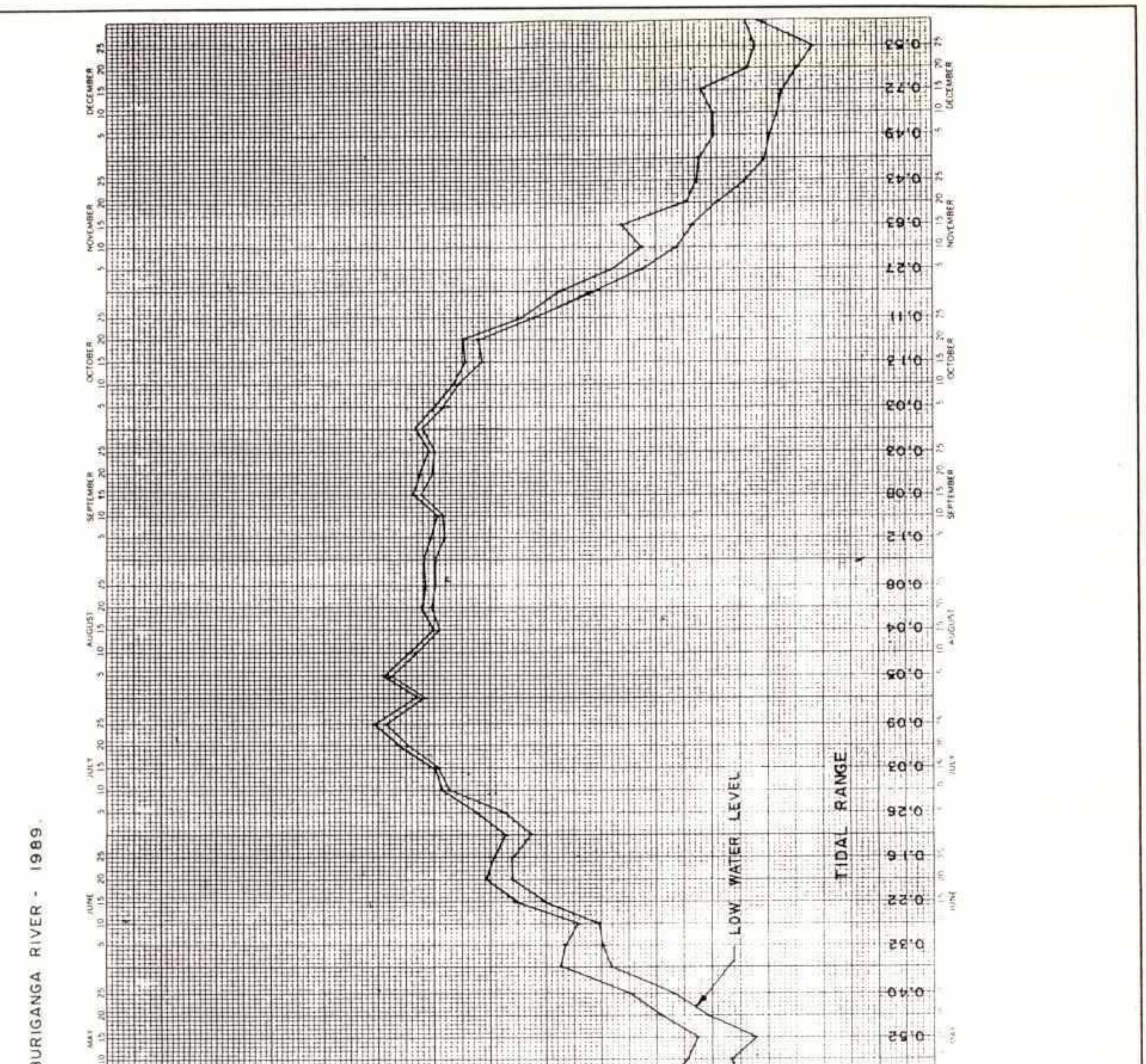
Figure : II.2.7
Tidal Water Level,Mill Barrak(Dhaka),Buriganga River-1988



Source:- CS 1992

Figure : II.2.8

Tidal Water Level,Mill Barrak(Dhaka),Buriganga River-1989



Source:- CS 1992

The water levels in the river system are controlled by the discharge through the Lakhya river. Three rivers converge at Trimohini; the Banar/Kaoraid, the Shila and the Lakhya (a distributary of the Old Brahmaputra starting at Toke), the water levels in the Lakhya are controlled by the levels in the Meghna below the confluence of the Lakhya and the Lower Dhaleswri at Kalagachia.

The land slopes from about 14/15m (PWD) in the north near the Old Brahmaputra and 9/10m near the confluence of the Banar and Kaoraid rives. The distance is a from 75 to 80 km and the approximate slope 0.05m to 0.07m per km, (these levels are generally above the 1/50 year return period levels). An examination of the NOAHA satallite imagery to the 24th of September 1988 shows that the greater part of the eastern region was not inundated though the Banar and the Koaradi was flooded.

3.1.2 Flooding from Main Rivers

The danger level of the **Jamuna** at Bahadurabad is 19.25 m (CBJET 1991) and in an average year the river flows above this level for source 21 days. The longest continuous period recorded was 44 days during 1974/75 (total of 38 days), 32 days in both 1965/66 and 1970-71 and 26 days in 1977/78. During the 1988 flood the Jamuna reached a level of 20.62 m at Bahadurabad, with an estimated flow of 96,000 cumecs.

Water levels for location along the Jamuna and other rivers are given in Figure II.1.5.

The **Old Brahmaputra** river did not flood over the railway embankment south of Jamalpur during the high 1988 flood. However the embankments upstream of Jamalpur was overtopped, see SR VI

3.1.3 Flooding from Internal Rivers

The water levels for **Dhaleswari-Kaliganga** internal river system in the south-west is mainly governed by levels in the Jamuna. During a normal year some 16% of the Jamuna peak flow discharges into the Dhaleswari-Kaliganga and associated rivers. The adjacent land is thereby inundated by a combination of this overbank spillage and local rainfall (to an average depth of 1.5 to 2.m).

The northern section of the **Bangshi-Turag** system receives most of its water form rainfall runoff but it is joined by the Pungli and Fatikjani close to Mirzapur. These rivers are mainly controlled by Jamuna river levels and thus downstream of this confluence flow in the Bangshi-Turag is also related to Jamuna level.

The **Jhenai** river are dependent on the Old Brahmaputra with most of its water flowing out the Jamuna south of Sarishabari. However at high flows some 20 to 30% of the Jhenai flows though Baushi bridge into the lower Jhenai and eventually joins the Bangshi, close to Kauljani. This water contributes significantly to flooding in the floodplain of PU2 and PU4.

The eastern **Banar-Lakhya** system receives nearly all its water from rainfall. However drainage from the area is restricted see, section 3.2 and leads to flooding caused by backwater effects.

The Shila River Project (World Bank/BWDB, 1985/86) reported that about 46% of the area was above normal food level and 11% flooded to a depth of 1.0m, with the remainder flooded to a depth greater than 1.0m. The area adjacent to the Madhupur tract may be subjected to flooding due to excessive runoff from the steeper, denuded area of highly impervious heavy soils. It has been reported that flash floods are prevalent in the Madhupur tract area. Generally flooding in the Madhupur tract region would occur in the low lying detritic alley bottoms from runoff occurring on the higher, sloping, land surfaces. The runoff is rapid and causes serious erosion silting up the shallow valleys. There is little or no information regarding the hydrology of this region.

3.2 Drainage

The regional rivers in the west of the North Central Region are predominantly characterised by having river banks (levels) which are elevated above the surrounding flood plain. This is a result of either man-made intervention, in the form of embankments, or a natural phenomenon of built-up levees, typically exhibited by rivers subject to regular flooding of sediment-laden waters. The consequence of this physical characteristic serves to determine the system response to rainfall and river flooding.

Drainage of the North Central Region takes places at 4 levels: the boundary river system (primary), the regional river system (secondary), the khal system (tertiary), and the beel system (quaternary). The mechanism by which the region drain relates directly to this hierarchical system and its interconnections.

Excess rainwater accumulates first in the depressions (beels), until these have reached their capacity. Gradually the extent of inundation increases until the small khals, which link the depressions, begin to flow. These khals form an interlinking network within the internal drainage system and they are also the means by which the transfer of water between the regional rivers and the flood plain takes places.

In the western part of the study area, the regional rivers are connected to the adjacent flood plain by means of the khal system. There are a limited number of theses connections and interchange of water takes place at specific points along the regional river length, rather than being uniformly distributed, as in the case of a typical drainage section. This configuration results in a restricted interchange of water between the river and flood plain which is exacerbated by the already "embanked" nature of the regional rivers. Hence, the regional rivers do not have to be even near their bankfull capacity to preclude effective drainage from the adjacent flood plain. During the monsoon season, some of the regional rivers have a limited drainage function and the accumulated rainfall excess, together with overspill from the boundary and regional rivers, remains on the flood plain.

On recession of the boundary rivers the regional rivers can begin to discharge more effectively and, on their recession, the internal drainage begins to function but only at the limited locations of the khal/regional river interconnections. Hence, the key to the drainage of the North Central Region lies in the prolonged influence of the high river levels in the boundary rivers over the regional river levels. Unless the levels of the lower Meghna can be reduced at times of high flow, the drainage outlet from the North Central Region will remain congested. Limited improvements can be made to local drainage conditions within the region, but these will ultimately be at the expense of the downstream reaches, however restricting the inflow from the main rivers into the distributaries would decrease flooding by limiting the water entering the regional drainage network.

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Coleman	1969	Brahmaputra River channel processes and sedimentation; J.M.Coleman; Sediment. Geol.,8 (1969)
ECI	1961	Old-Brahmaputra Multipurpose Project Phase I Feasibility Report; ECI Intern.-LWB-ACE (November, 1961)
FEC	1989	Prefeasibility Study for Flood Control in Bangladesh; French Engineering Consortium (May, 1989)
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SR II.3
River Morphology

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Flood Action Plan
FAP 3
North Central Regional Study

Supporting Report II.3
River Morphology

February 1993

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Desh Upodesh Ltd.
BETS Ltd.

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NORTH CENTRAL REGIONAL WATER RESOURCES DEVELOPMENT PLAN

FAP-3

SUPPORTING REPORT II.3 - RIVER MORPHOLOGY

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
BADC	Bangladesh Agricultural Development Corp.
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BB	Bangladesh Bank
BBS	Bangladesh Bureau of Statistics
BCAL	Bangladesh Census of Agricultural Livestock
BCAS	Bangladesh Centre for Advanced Studies
FDC	Bangladesh Fisheries Development Corp.
BIDS	Bangladesh Institute of Development Studies
BIWTA	Bangladesh Inland Water Transport Auth.
BJRI	Bangladesh Jute Research Institute
BKB	Bangladesh Krishi Bank
BNPP	Bangladesh National Physical Plan. Board
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engg.Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CAS	Catch Assessment Survey
CAT	Coordination Advisory Team
CCCE	Caisse Centrale de Coopération Economique
CEC	Commission of European Communities
CPM	Coarse Pilot Model
CS	Consultants' Studies
DA	Development Area
DAE	Department of Agricultural Extension
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DDT	Dichlorodiphenyl-trichloroethane
DHI	Danish Hydraulics Institute
DOE	Department of Environment
DOF	Department of Fisheries
DOS	Disk Operating System
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
DUL	Desh Upodesh Ltd.
EEC	European Economic Community
EIA	Environmental Impact Assessment
EIP	Early Implementation Programme
FAO	Food & Agricul.Organ.of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control,Drainage & Irrigation Project
FFYP	Fourth Five Year Plan
FHS	Flood Hydrology Study
FMM	Flood Management Modelling
FPCO	Flood Plan Co-ordination Organisation
FRI	Fisheries Research Institute
FRSS	Fisheries Resources Survey System
FSR	Farming Research System
FWP	Food for Work Programme
FY	Financial Year
GOB	Government of Bangladesh
GW	Groundwater
HTW	Hand Tubewell
HYV	High Yielding Variety
IDA	International Development Agency
IPM	Integrated Pest Management Programme
IRRI	International Rice Research Institute
JFP	Jamuna Flood Plain
JPPS	Jamalpur Priority Project Study
LGEB	Local Government Engineering Bureau
MCA	Multicriteria Analysis
ME	Ministry of Education
MF	Ministry of Finance
MIWDFC	Minist.of Irrig., Water Dev.& Flood Control
ML	Ministry of Land
MLGRDC	Minist.of Local Govt.,Rural Dev.& Coop.
MOA	Ministry of Agriculture
MOEF	Ministry of Environment and Forestry
MOFL	Ministry of Fisheries & Livestock
MOSTI	Manually Operated Shallow T/W for Irrig.
MP	Ministry of Planning
MPO	Master Plan Organisation
MTN	Madhupur Tract North
MTS	Madhupur Tract South
NCA	Net Cultivable Area
NCR	North Central Region
NCRM	North Central Regional Model
NCRMG	North Central Regional Model Group
NCRS	North Central Regional Study
NFMP	New Fisheries Management Policy
NGO	Non Government Organisation
NGR	Natural Growth Rate
NWP	National Water Plan
OBFP	Old Brahmaputra Flood Plain
O&M	Operation and Maintenance
ODA	Overseas Development Administration (UK)
PA	Planning Area
PFDS	Public Foodgrain Distribution System
POE	Panel of Experts
PSR	Preliminary Supporting Report
PU	Planning Unit
PWD	Public Works Datum
RARS	Regional Agricultural Research Station
RHD	Roads and Highways Department
RS	Regional Scheme
SES	Socio-Economic Survey
SOB	Survey of Bangladesh
SPARRSO	Space Research & Remote Sensing Organ.
SRP	Systems Rehabilitation Project
SRTI	Sugarcane Research and Training Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
TOR	Terms of Reference
Tk	Taka
UNDP	United Nations Development Programme
UNHCR	United Nations H.Commission for Refugees
WFP	World Food Programme

SUMMARY

The Jamuna is a broad braided river which experiences high rates of bank migration. Whereas the major part of right bank tends to shift westward, there is no discernible trend of shifting on the left bank.

Allowing for the erratic character of the bank erosion pattern on the left bank, it is unrealistic to define a constant safe distance between the bank and the alignment of the embankment.

The critical sections, which have undergone sustained erosion since 1983 and which should be protected by priority works, are localized (Bahadurabad and Madarganj).

The objective of complete control of the Jamuna seems unrealistic. A long term bank stabilisation scheme could, however, be envisaged to limit the set-back distance of embankments on the left side.

Embanking the left side of the Jamuna should not induce significant changes of the active channel if the main offtakes are maintained open. Complementary runs of the general model and of morphological models are required to confirm this assertion.

A constant set-back distance of 1 km for the left-side embankment of the Padma is tentatively proposed. This suggestion is justified by the apparently more stable character of the river. In-depth morphological studies of the Padma are required to confirm this proposal.

The Dhaleswari river system is a complex network of left bank distributaries of the Jamuna, some of which are rather unstable. Major development scenarios in some portion of this system, with sand-silt river bed and high sediment load, must be carefully designed, as they could induce significant adjustments on the whole course of the concerned channel and/or considerable maintenance requirement.

As far as possible, the repartition of discharges in the system should be kept as close as possible to the natural conditions up to the bankfull stage. Dredging in such rivers will probably not be cost effective.

Presently, the Old-Brahmaputra has lost its previous role of major waterway as significant deposition takes place at its mouth. The program of a pre-feasibility study aimed at assessing the possibilities of resuscitation of the river is outlined but the objectives of such an initiative should be clarified beforehand.

CHAPTER 1
INTRODUCTION

1.1 Introduction

This river morphology supporting report should be read in conjunction with SRs.II.1 and II.2 which present the hydrometeorology and a description of the river and drainage system of the North Central Region.

After a brief summary of the river systems this report presents a morphological description of the region. The analysis is based on reviewing work previously carried out by others, together with the use of aerial photographs and satellite imagery.

1.2 Overview of the River System in the Region

The North Central Region is bordered by :

- the Jamuna on the western side
- the Padma on the southern side
- the Old Brahmaputra on the northern side
- the Lakhya on the eastern side.

The Old-Brahmaputra is the former course of the Brahmaputra river. At the end of the 18th century, a major event led to the original river course being abandoned, in favour of the present course which was gradually enlarged to form the Jamuna river.

The interior rivers can be categorised as falling into three systems (see Figure II.2.1):

- the Dhaleswari-Kaliganga system in the South-western part
- the Pungli-Bangshi-Turag system in the Central part
- the Banar-Lakhya system in the eastern part.

The **Dhaleswari-Kaliganga** system is made up with distributaries, offtaking in the southern half of the Jamuna's left bank.

The **Pungli-Bangshi-Turag** system is a mixed system, supplied by local rainfall (Madhupur Tracts) and overspilling, along the northern half of the Jamuna's left bank and along the right bank of the Old-Brahmaputra.

The **Banar-Lakhya** system is mainly supplied by local rainfall and by water coming from the Old-Brahmaputra. Downstream of Toke, the Lakhya river is the main branch of the Old-Brahmaputra. In practice, the two former systems are largely connected by secondary branches and spill channels during flood flows. Under medium and low water-stages, no flow is able to get into most of the distributaries.

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CHAPTER 2
CLASSIFICATION OF RIVER PATTERNS

2.1 Methods

The qualitative classification of the regional rivers is based on four major planform properties observed on aerial photographs and satellite imageries: sinuosity, point-bars, braiding and anabranches.

A quantitative index used to describe the channel planform is the sinuosity, defined as the ratio of channel length to valley length : a meandering river has a sinuosity greater than 1.5. As usual, the bankfull discharge is used as the channel forming discharge. The channel geometry at bankfull stage is estimated from aerial photographs, satellite maps and available cross-sections.

Many researchers believe that geometric properties of river channels are not continuous because there exists several thresholds between pattern states. Near a critical value of the slope, a small adjustment may lead to a large change in channel pattern.

H.H. Chang's diagram (Chang, 1988) is used to compare the observed values with the critical values and to assess the possible geometric adjustments of the regional rivers (Figure II.3.1).

The considerations about the main rivers are based on previous studies (in particular Coleman 1989, FEC 1989, CBJET 1991 and Halcrow 1991).

2.2 Main Rivers

2.2.1 Jamuna

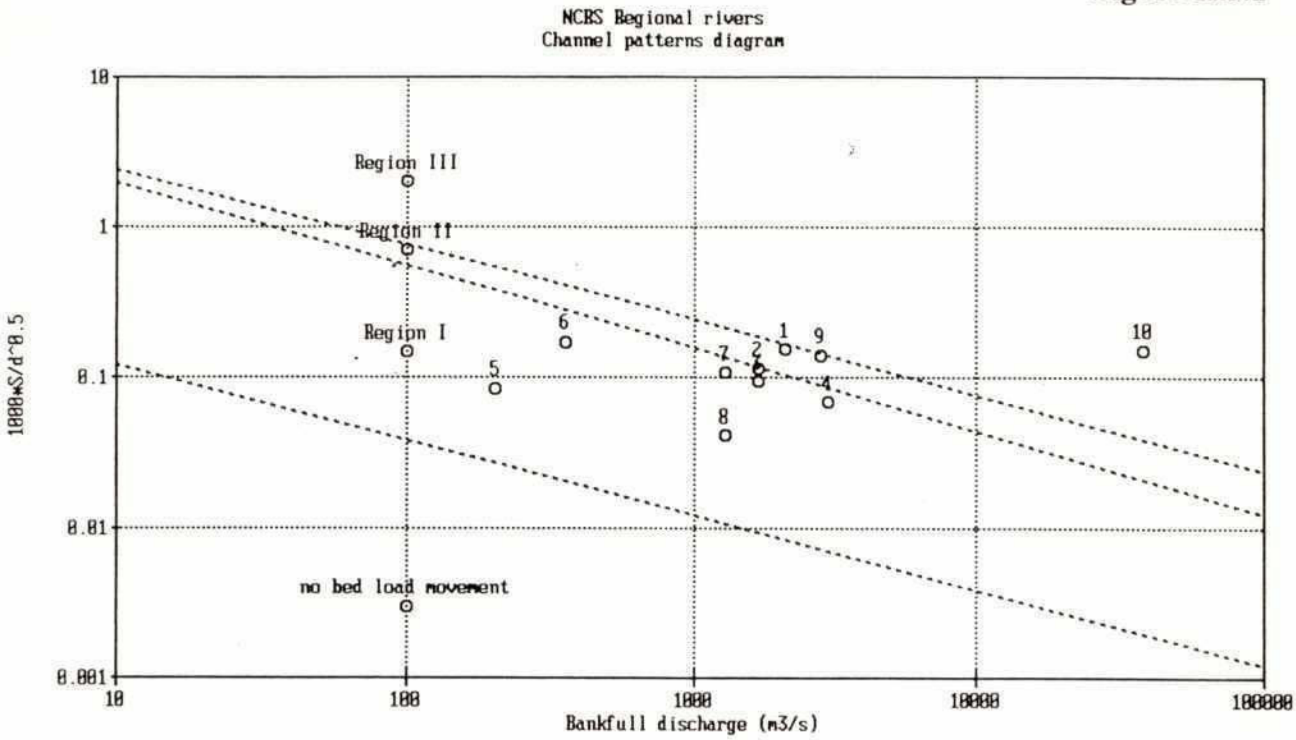
The Jamuna is a broad braided river with large sand shoals and islands (chars), side-channels and anabranches. High rates of lateral migrations take place : average rates of approximately 300 m/yr and maximum values of 800 to 1000 m/yr are reported.

Its main features are the following:

• Dominant discharge	:	38,000 m3/s
• Slope (at dominant discharge)	:	6 to 8 cm/k
• Median size (50) of bed material	:	0.17 to 0.26 mm
• Mean water surface width (bankfull)	:	4.5 km
• Mean surface width of a branch(bankfull)	:	$16.1*Qb^{0.53}$
• Mean depth at bankfull stage	:	$0.23*Qb^{0.32}$
• Mean annual sediment load	:	$0.5\ 10^9$ tons
• Mean total sediment concentration (at dominant discharge)	:	500 ppm

According to FAP-1 studies (Halcrow 1991) the Jamuna is in the braiding-meandering transition, as it shows, at macro-scale, characters of both patterns. The fluvial processes of the Jamuna are described in Section 3.3.

Figure II.3.1



LEGEND

1. Upper Dhaleswari (upstream of Barinda Offtake)
2. Middle Dhaleswari
3. Kaliganga
4. Lower Dhaleswari
5. Minor Dhaleswari
6. Pungli
7. Bangshi-Turag
8. Buriganga
9. Old Brahmaputra (upstream of Jhenai Offtake)
10. Jamuna

Region I	:	Equiwidth point-bars streams and stable canals
Region II	:	Transition
Region III	:	Braided point-bars streams and wide-bend point-bars streams

Source : C.S. 1991

2.2.2 Padma

The Padma is a stable braided channel, which also shows a meandering character at macro-scale. Its banks are reported as consisting of more cohesive soil than the Jamuna's.

Though some significant rates of bank-line migration are reported, the erosion process seems less unpredictable than along the Jamuna (Figure II.3.2), as the braiding character is far less developed than in the Jamuna river.

Its main features are the following:

• Bankfull discharge	:	55,000 m3/s(approx.)
• Slope (at dominant discharge)	:	2 to 4 cm/km
• Median size (d50) of bed material	:	0.13 mm
• Mean water surface width (bankfull)	:	4.3 km
• Mean annual sediment load	:	0.6 10^9 tons

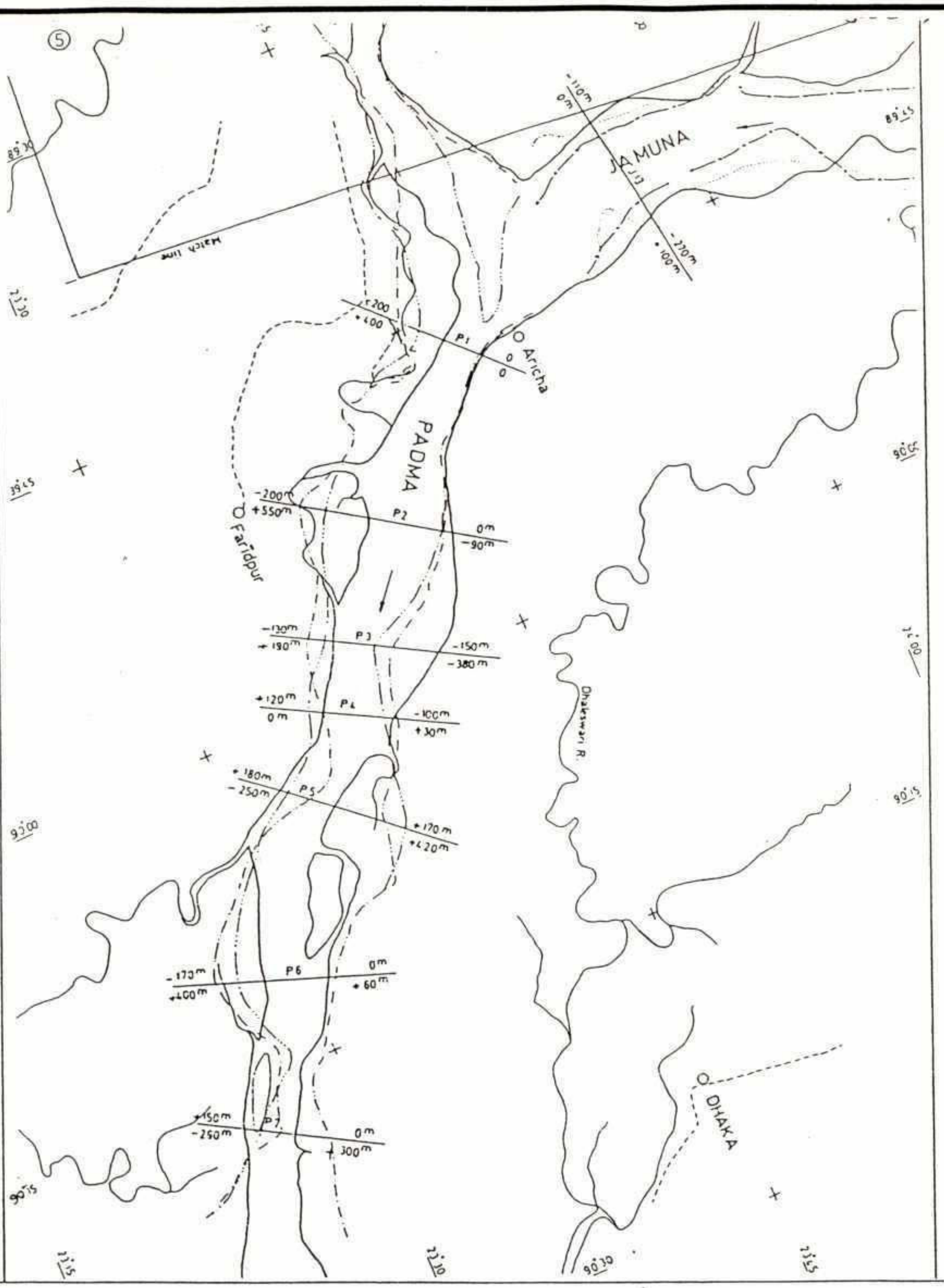
The braiding intensity decreases largely at the downstream end. On the basis of a preliminary analysis of 1/50,000 SPOT imagery, bank-erosion seems to occur on a large-scale when the movement of a large char creates a side-channel impinging on the bank. The eroded bend would then migrate downstream and be gradually replaced by accretion when the bend curvature increases the flow path and reduces the water surface slope.

In this hypothesis, it could be assumed that erosion never persists on the same point during a long time and that accretion and erosion occur alternately in the same cross-section. Figure II.3.2 confirms this assumption.

The Chinese report on Flood-control and River Training (CBJET,1991) indicates that a 100 years-old tree has been found on the flood plain near Baruria, which also show the global stability of the channel.

Two rather stable sections exist at Aricha and Mawa and contribute also to stabilize the banks along the whole course of the river. The maximum bend radius of curvature appears larger than on the Jamuna.

Detailed geomorphological studies are required to confirm this assumption of global stability and to predict the maximum radius of curvature and the migration rate of a bend.



PADMA RIVER Sheet 5

LEGEND:

BANK LINE 1966 —·—

BANK LINE 1976 —··—

BANK LINE Feb 87 ——

-30^m/year : EROSION

$+100^m$/year : ACCRETION

$+60^m$ / -30^m — -50^m période 1966/1976

$+10^m$ période 1976/1987

Scale : 1/500 000 approx.

réf : BWDB Survey

SOURCE :- FEC 1989

2.3 Regional Rivers

Table II.3.1 indicates some observed characteristics pertaining to the geomorphology of the main regional rivers.

Figure II.2.1 delineates the three river systems and locates the main regional rivers. Figure II.3.3 indicates the river patterns.

Table II.3.2 indicates calculated characteristics of some regional rivers derived from theoretical relations assuming that most of the morphological features arise from an initial single straight bed under the "regime theory" (M. Ramette; La Houille Blanche n°1-1990). The calculated features are in fair agreement with the observed ones. This simplified process can be used to assume the long term overall adjustments induced by development scenarios.

Observations (cross-sections, sediment discharge measurements, sediment size analysis) and mathematical morphological models are required to deal more precisely which these problems.

2.3.1 Dhaleswari-Kaliganga System

The Dhaleswari (Figure II.3.4) is the main left bank distributary of the Jamuna river and the main channel of a complex river system.

The Offtake System

The Dhaleswari offtakes in two major locations : the first offtake, near Bhuapur, is decaying while the second one, just upstream of Porabari is presently the most active and is showing signs of rapid development.

Recently,the upper intake has shown little shifting of location while, in contrast , the southern one has shown significant movement.

At present, these two offtakes only flow during the higher discharge levels of the Jamuna : from late May to early November for the upper one and from early April to early January for the lower one.

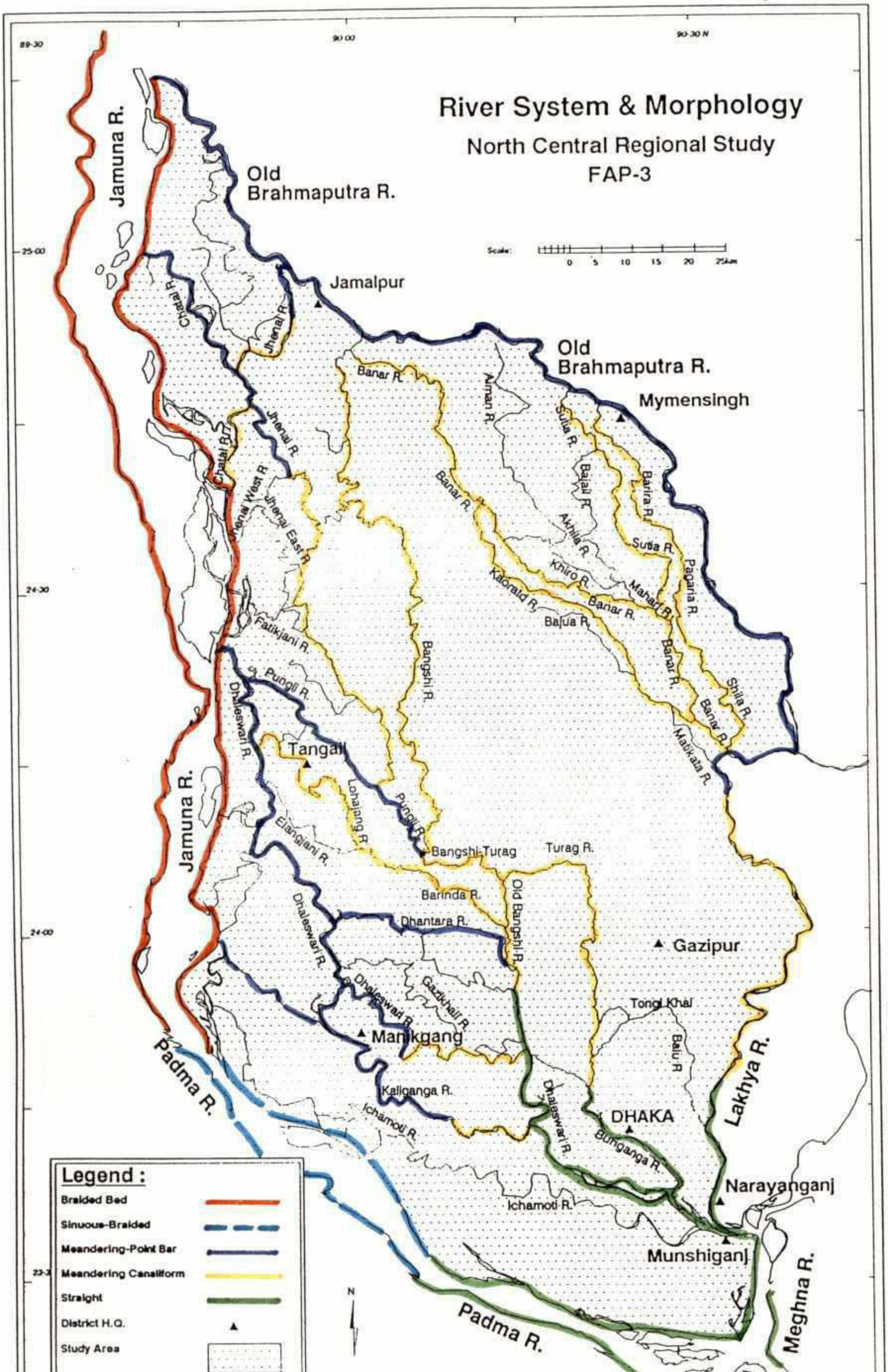
In addition to the major intakes, there are several minor spill-channels which can become significant at higher discharge levels, particularly when differences in levels develop between the Jamuna and Dhaleswari channels.

In the long term, the relative importance of each offtake is a transient feature, owing to the character of the Jamuna river.

Old maps of 1956 show that much of the area between the Jamuna and the present channel of the Upper Dhaleswari was predominantly char land and the 1830 bank line seems to indicate that the present left bank of the Dhaleswari was the boundary of the Jamuna.

As the left bank retreat has started again south of Bhuapur since 1989, the reactivation of one of the minor offtakes cannot be excluded.

Figure : II.3.3



Source:CS 1992, SR II.3

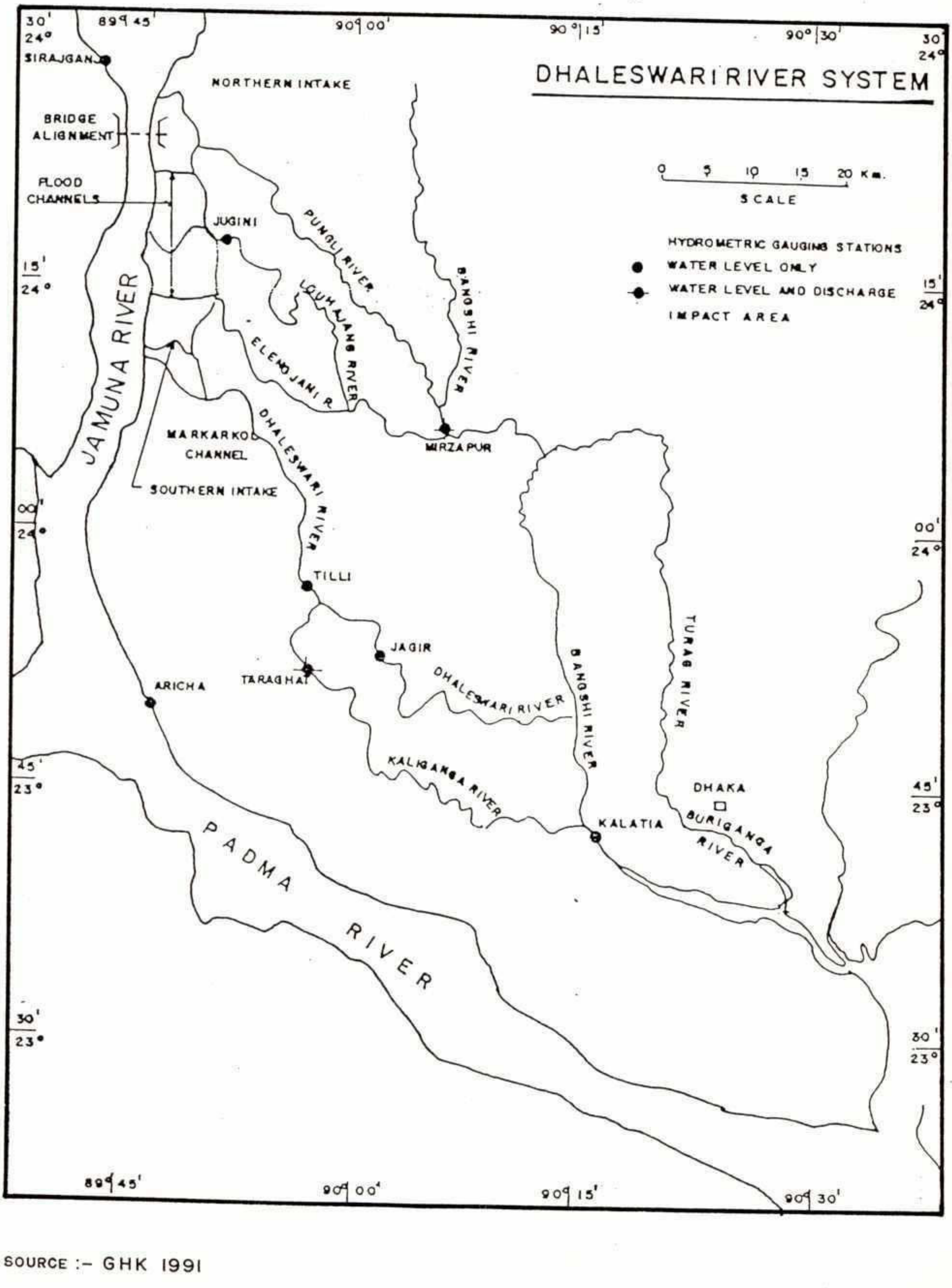
TABLE II.3.1
Regional Rivers - Observed Morphological Characteristics

River	Qbank m3/s	Slope cm/km	Depth m	width m	Length channel	Length valley	Sinuousity	River Pattern
Upper Dhaleswari	2100	6.0	7.0	300	40 km	25 km	1.60	sinuous point-bar
Middle Dhaleswari	1700	4.5	7.0	250	29 km	12 km	1.66	sinuous point-bar
Kaliganga	1700	3.7	9.5	200	49 km	34 km	1.44	sinuous point-bar
Lower Dhaleswari	3000	2.7	10/11	250/300	26 km	21 km	1.25	straight
Old Dhaleswari	200	3.3	3.0	60	62 km	30 km	1.90	meandering
Barinda	400	5.8	2.0	100	52 km	33 km	1.57	meandering
Bangshi South	1300	3.1	10/15	150	25 km	21 km	1.20	sinuous canaliform
Upper Jhenai	300	3.7	5.0	120	37 km	30 km	1.23	sinuous point-bar
Lower Jhenai	?	5.6	3/4	40/50	85 km	61 km	1.40	meandering
Upper Bangshi	?	4.2	4.0	50	32 km	18 km	1.80	meandering
Pungli	350	6.7	4/5	80	53 km	38 km	1.40	sinuous point-bar
Bangshi-Pungli-Turag	1300	3.9	7.0	100	78 km	60 km	1.30	meandering
Buriganga	1300	1.2	10/14	150/200	39 km	38 km	1.0	straight
Lakhya	1700	3.0	10.0	200/250	65 km	53 km	1.20	sinuous canaliform
Old Brahmaputra								
• Jamalpur	2800	8.4	6.0	500	48 km	40 km	1.20	sinuous point-bar
• Mymensingh	2800	7.4	6.0	200/300	62 km	49 km	1.24	sinuous point-bar
• Toke	2800	5.8	8.0	200/300	80 km	61 km	1.30	sinuous point-bar

TABLE II.3.2
Regional Rivers - Calculated Morphological Characteristics

River	Qbank m3/s	Slope cm/km	D50 est m	Width m	Depth m	Qsedim. m3/s	Concentra. ppm	River Pattern
Upper Dhaleswari	2100	6.0	0.18	214	6.6	0.18	140	sinuous point-bar
Middle Dhaleswari	1700	4.5	0.15	175	7.5	0.11	102	sinuous point-bar
Kaliganga	1700	3.7	0.15	171	8.4	0.08	73	sinuous point-bar
Lower Dhaleswari	3000	2.7	0.13	243	9.5	0.11	60	straight
Min. Dhaleswari	200	3.3	0.15	49	6.2	0.003	24	meandering
Pungli	350	6.7	0.18	78	4.7	0.02	87	sinuous point-bar
Bangshi-Pungli-Turag	1300	3.9	0.15	149	7.8	0.06	71	meandering
Buriganga	1300	1.5	0.13	126	13.1	0.01	16	straight
Lakhya	1700	3.7	0.15	163	9.6	0.05	50	sinuous canaliform

Figure II.3.4



SOURCE :- GHK 1991

The Channels

The downstream channels of the Dhaleswari system are relatively old and appear to have reached a mature regime whilst the upstream ones are unstable and still in course of development.

The upper courses of the Dhaleswari, from the upper and lower offtakes to the offtake of the Barinda river, shows a meandering point-bar pattern.

The process of meander bend migration is very active. Lateral migration of 2 km with simultaneous down valley translation are observed on aerial photographs, from 1983 to 1989.

Old meander loops can be seen at a large distance from the present course. The middle course, from the Barinda offtake to the Kaliganga, displays also a meandering point-bar pattern, but the meander migration is less active.

Downstream of the confluence with the Old Dhaleswari, which comes from the southernmost offtake, the Dhaleswari becomes the Kaliganga, a meandering point-bar then meandering canaliform river where the process of erosion is less and less active.

The lower course of the main Dhaleswari, after the confluence with the Bangshi-South river, is a straight, stable and deep channel which flows into the confluence of the Padma and the Meghna rivers.

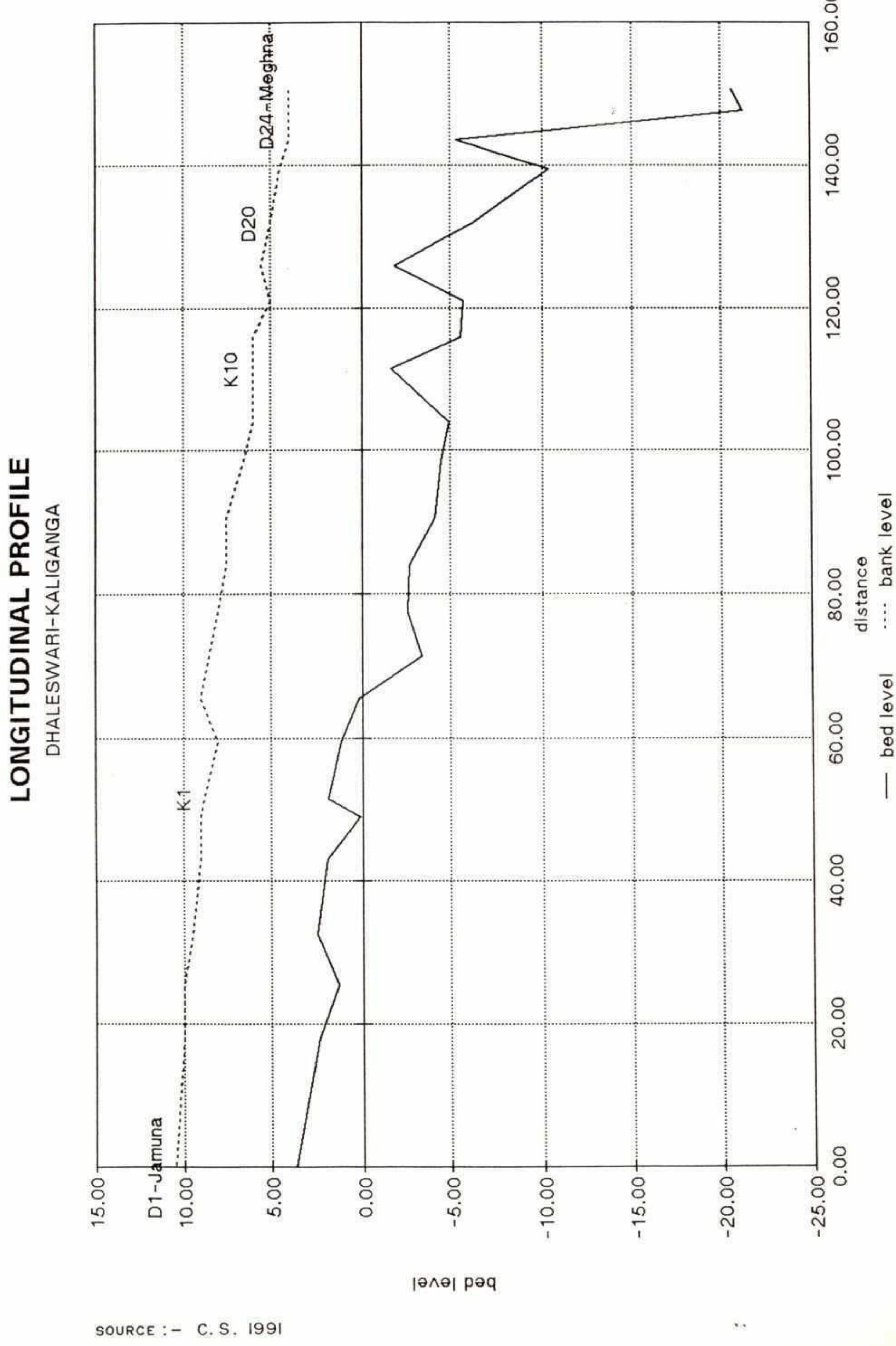
The Minor Dhaleswari, the Barinda, the Elanganj and the Louhaganj rivers which offtake from the main channel upstream of the Kaliganga confluence, are stable highly meandering channels which flow into the South-Bangshi river, a stable sinuous canaliform stream.

Table II.3.1 and Figure II.3.5 show that, as usual in a river system, the slopes gradually decrease (from 6 cm/km to 2.7 cm/km) in the downstream direction, as the width decreases and the water depth increases.

It is assumed that the mean diameter of the bed material decreases from the offtakes to the confluence with the Meghna. It should not, however, be very different from that of the Jamuna and the Padma. The sediment load, controlled by the relatively high bed level at offtake, is lower than the Jamuna's. Table II.3.2 indicates that it decreases probably from the usptream part of the system to the downstream part. Sediment concentration seems still rather high in the Lower Dhaleswari: this is in line with visual observations of the Dhaleswri-Meghna confluence on satellite imagery, at the end of the wet season.

The upper and middle course of the Dhaleswari are near the threshold between wide-bend point-bar streams, very sensitive to slight changes, and width meandering and stable streams (Figure II.3.1). The other rivers are in the stable region of the diagram.

Figure II.3.5



SOURCE :- C. S. 1991

2.3.2 Pungli-Bangshi-Turag System

The Jhenai and the Bangshi rivers are rather stable, old meandering channels. The Pungli, a distributary of the Upper Dhaleswari, is a meandering point-bar river with some evidences of erosive activity. These three streams flow into the Turag river, a sinuous canaliform, then straight channel, which becomes the Buriganga.

The slope gradually decreases from 6.7 cm/km to 1.5 cm/km in the downstream direction, as the width decreases and the water depth increases (see Table II.3.1).

2.3.3 Banar-Lakhya System

All this system is composed of stable meandering canaliform rivers. At its downstream end, the Lakhya becomes less and less sinuous, which gives evidence that the water and sediment discharges are in balance with the channel's capacity for transport (like the downstream ends of the Turag, the Dhaleswari and the South-Bangshi).

2.3.4 The Old-Brahmaputra

The Old-Brahmaputra, which follows the old course of the Brahmaputra river, offtakes at the northern end of the North Central Region. Its mouth is presently heavily silted up and practically no water flows into the river from the Jamuna at medium and low stages. In the wet-season, the Jamuna river overspills into the Old-Brahmaputra.

The estimation of the bankfull discharge is 2800 m3/s.

The slope gradually decreases in the downstream direction, from 8.4 cm/km to 5.8 cm/km at the offtake of the Lakhya river.

The channel pattern is sinuous point-bar. This river is in the region of the Chang diagram (Figure II.3.1) where the geometry of channels is very sensitive to small changes in the slope.

The process of meander bend migration is active in the upper course but decreases with the slope, downstream of Jamalpur. Like the Dhaleswari,the sediment load, controlled by the relatively high bed level at offtake, is probably lower than the Jamuna's.

This river is liable to experience significant adjustments if any variation of the dominant discharge or the sediment load occurs.

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CHAPTER 3
JAMUNA FLUVIAL PROCESSES

3.1 General

Owing to the character of the river, many research and engineering studies have been performed about the geomorphology of the Jamuna. One of these studies, FAP-1, is on-going (Halcrow 1991).

This chapter of the report summarises the main findings (especially the recent ones) pertaining to major development scenarios on the left bank of the Jamuna (especially major embankments).

3.2 Macro-scale Geomorphology

There is a considerable amount of data related to historical bank line migration of the river from 1830 up to now, but most cannot be used with a high level of confidence.

Though the oldest bank maps (1830, 1867, 1875, 1930 , 1944, 1952), are not precise enough and too intermittent to understand (and naturally forecast) the shifting of the channel, they give evidence of the magnitude and the chaotic character of these changes on the long term (see Figure II.3.6) related to the left bank.

According to FAP-1 First Draft Report (Halcrow 1991), the recent comparison of the 1:50,000 series of maps produced by the Survey of Bangladesh and 1989 SPOT imagery clearly shows that during the past 30 years there has been substantially more erosion of the right bank than the left bank and that this erosion is mainly located between Sirajganj and Sariakandi (see Figure II.3.7).

This finding is in line with Professor Coleman's paper (Coleman 1969) and the Chinese Study Report on the Brahmaputra river (CBJET, 1991) On the contrary, the Jamuna Bridge Study (RPT 1990) concluded that shifting was randomly distributed between left and right banks with no systematic trend in the last fifteen years.

In the Chinese Study, comparisons have been made of the banklines in 1830, 1952 and 1989 and the average annual rate of erosion/deposition have been calculated (Table II.3.3).

TABLE II.3.3
Jamuna River-Annual Erosion/Deposition Rates

Period	Right bank m/Yr	Let bank m/Yr
1830 - 1952	- 44.5	+ 5.8
1952 - 1989	- 67.3	+ 2.4

Source : CBJET 1991

Figure : II.3.6

Bank Migration from 1830 to 1990

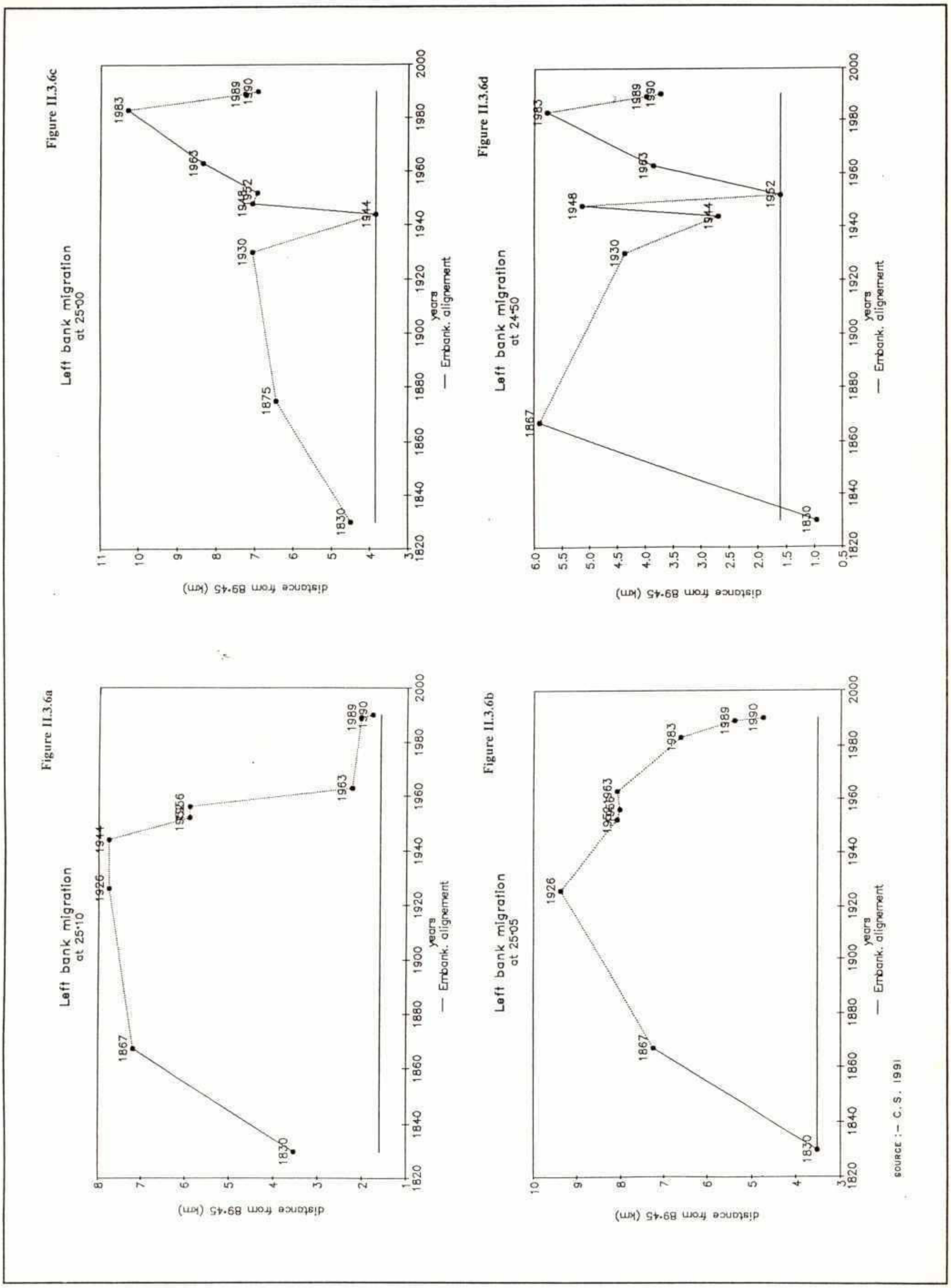


Figure : II.3.6(Contd.)

Bank Migration from 1830 to 1990

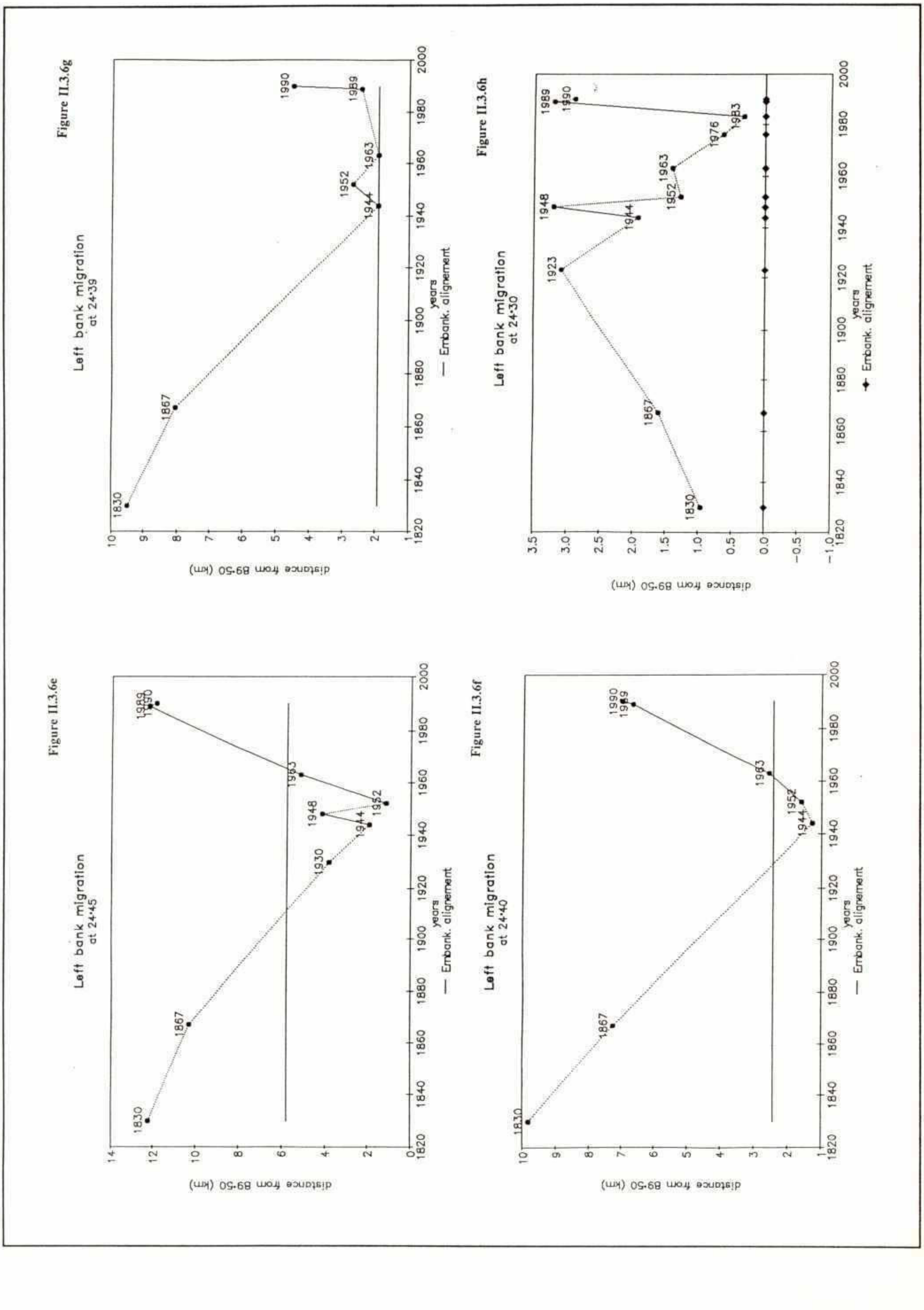


Figure : II.3.6(Contd.)
Bank Migration from 1830 to 1990

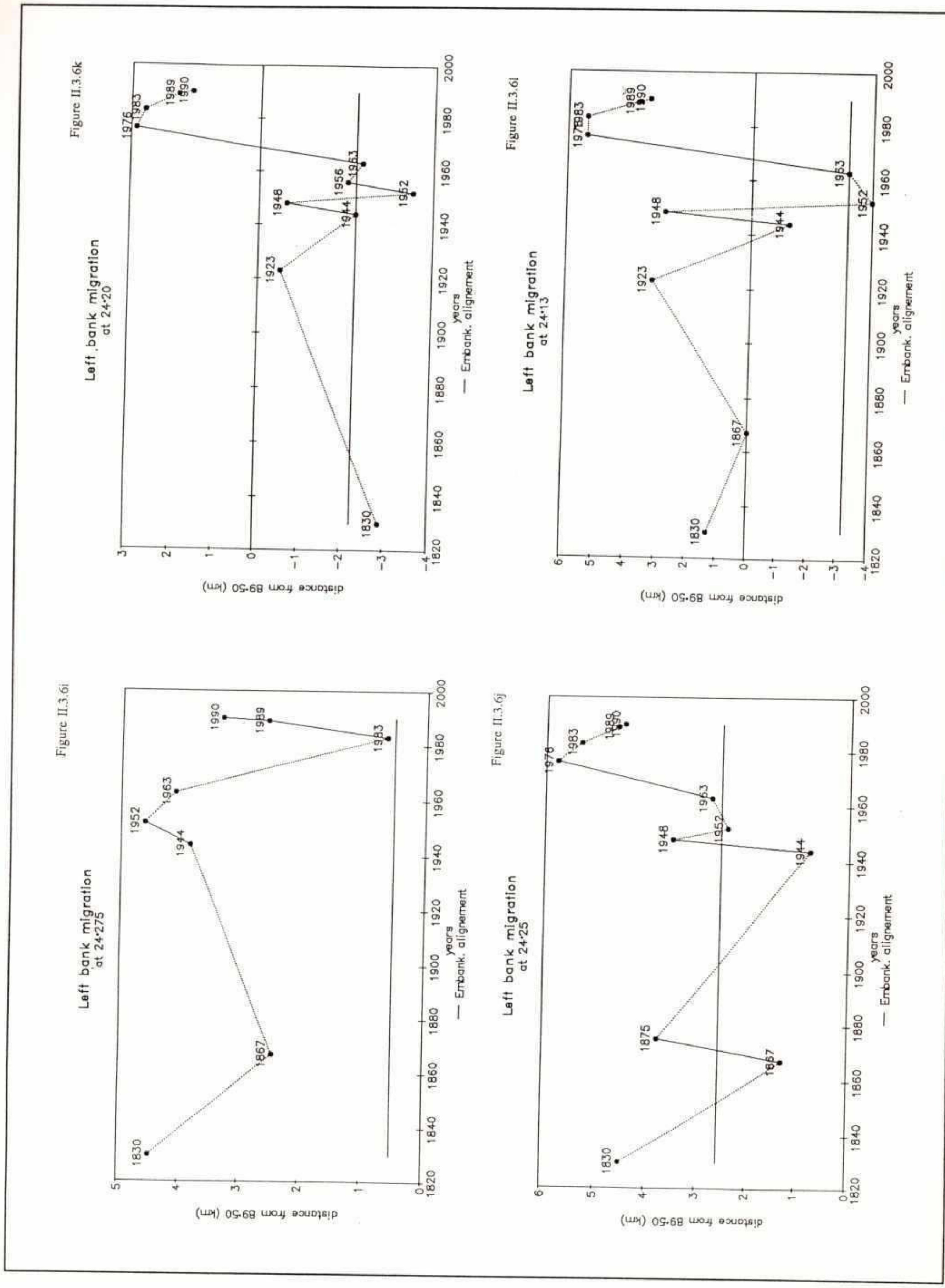


Figure : II.3.6(Contd.)

Bank Migration from 1830 to 1990

Figure II.3.6m

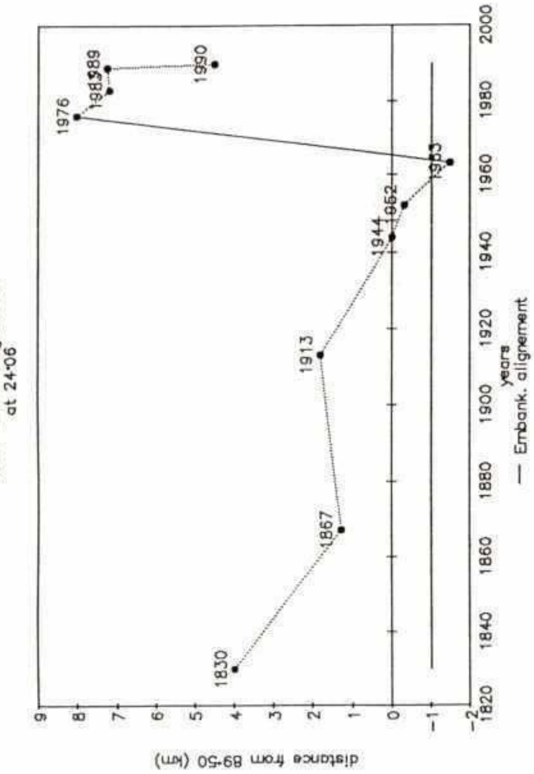


Figure II.3.6n

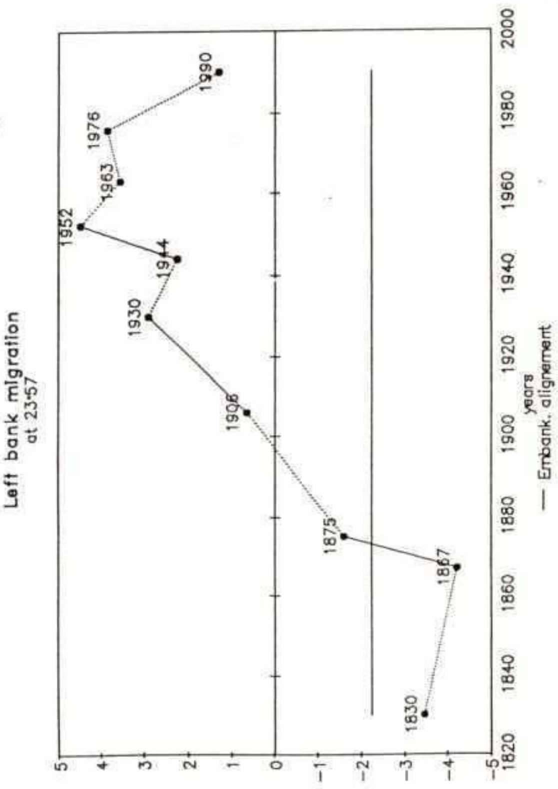
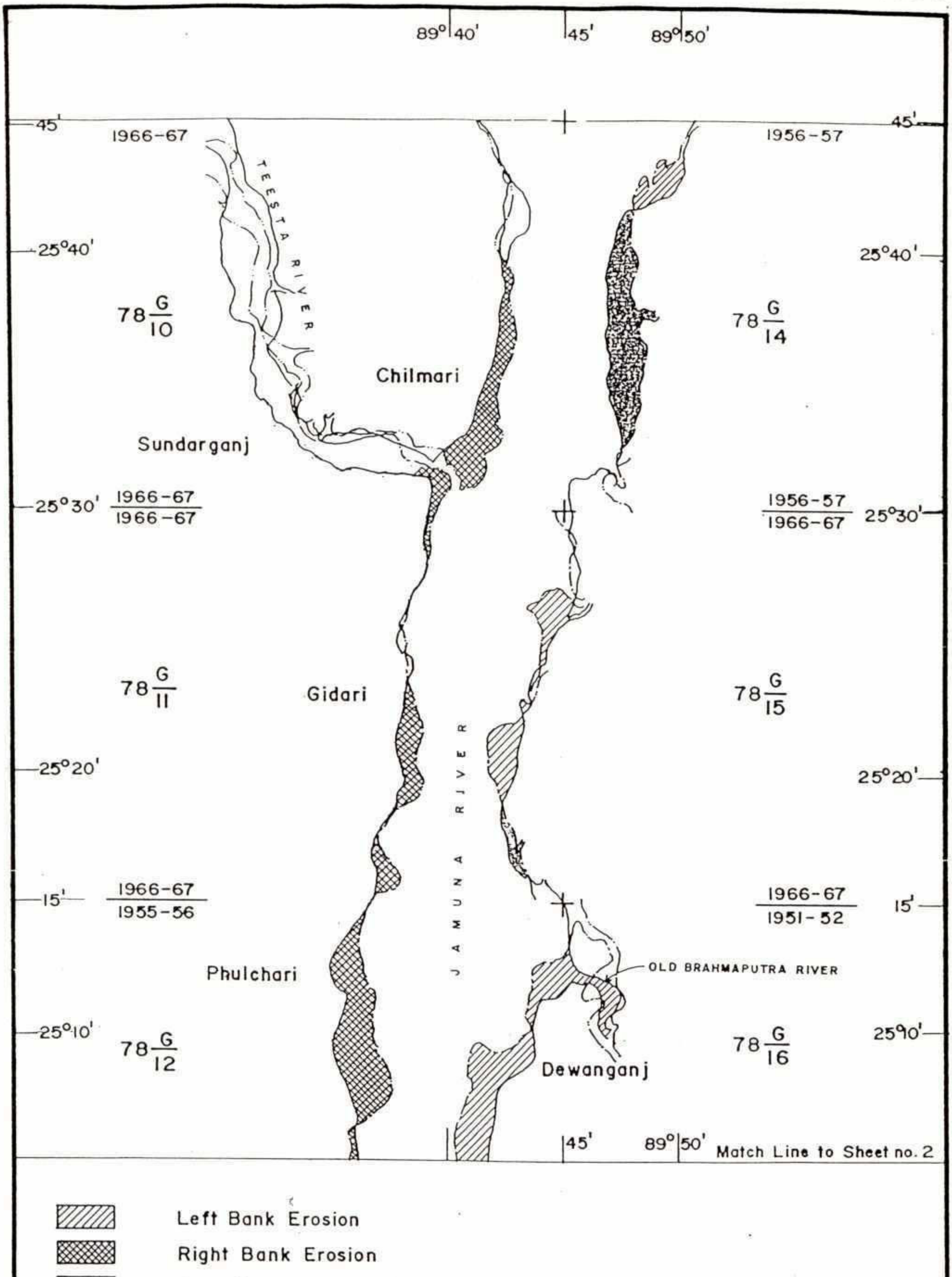


Figure II.3.7a

BANK MOVEMENT FROM ABOUT 1956



SOURCE :– HALCROW 1991.

Figure II.3.7b

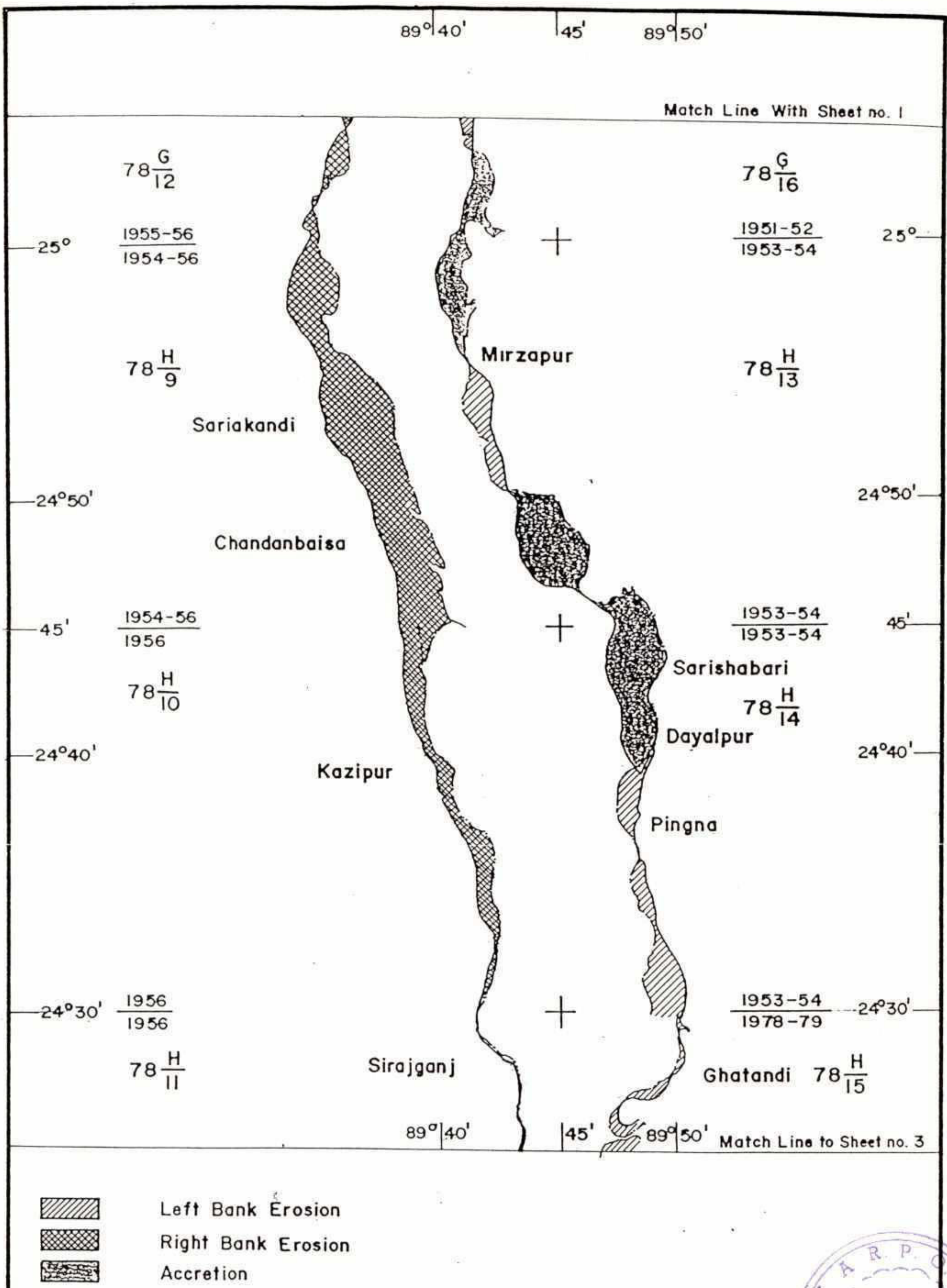
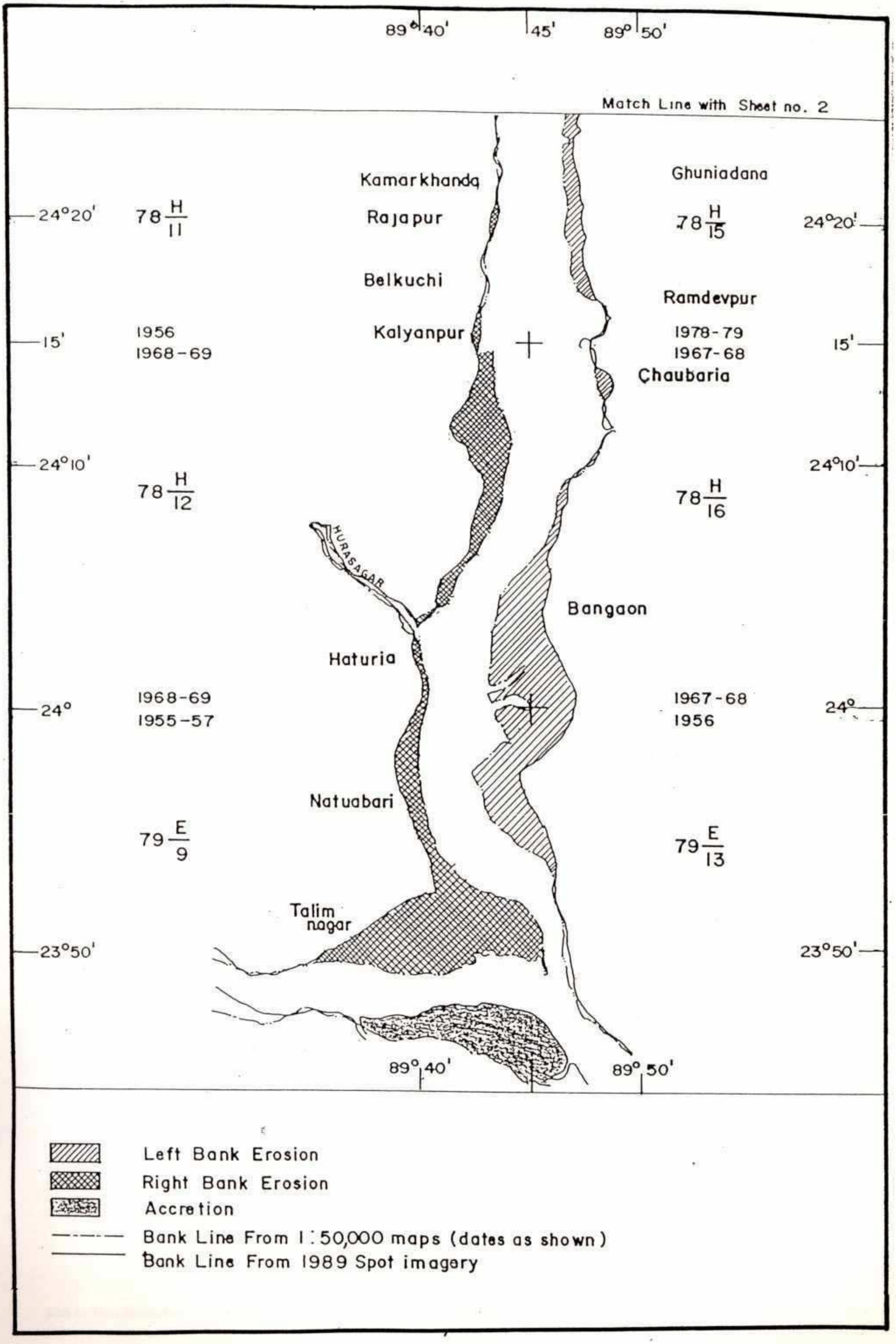


Figure II.3.7c



These results do not mean that the river moves bodily westward but show that, on the right bank, erosion does not compensate for accretion, as more or less the case on the left bank (allowing for the precision of these exercises). The net result of this mean that the overall Jamuna channel widens steadily.

That could mean tht the channel widens steadily. At this stage, however, FAP-1 conclude that the data available are not sufficiently accurate to reject or sustain that the chnnel width is stable or tends towards increase.

Figure II.3.8 (CBJET 1991) seem to give some some evidence that erosion and deposition areas alternate regularly along the left bank.

FAP-1 Report (Halcrow 1991) suggests that the reason for the westward shifting of the right bank is that it is mainly located in the concave part of two macro-scale meanders of the whole braid belt (Figure II.3.9).

This tentative explanation is attractive, especially for the first macro-meander, which could be a consequence of the sudden change of direction of the Brahmaputra at the entrance of Bangladesh. Yet, it does not fit well in the observations of similar concave bend on the left bank which does not shift steadily eastward where the FAP-1 explanation suggests it would do, i.e. between Gaffargaon and the Dhaleswari.

The comparison of bank lines in 1952 and 1989 (Figure II.3.7) and in 1956 and 1989 (Figure II.3.8) show little erosion on this left bank section.

FAP-1 Report (Halcrow 1991) suggests that more consolidated sediments associated with the Madhupur plateau constrain the otherwise free migration of the left bank north of Bhuapur.

3.3 Longitudinal Variations

The analysis of stage-discharge relations and of the evolution of cross-sections do not show any significant trend of channel deposition or erosion. Therefore, the Jamuna is in a state of longitudinal equilibrium.

3.4 Chars and Islands

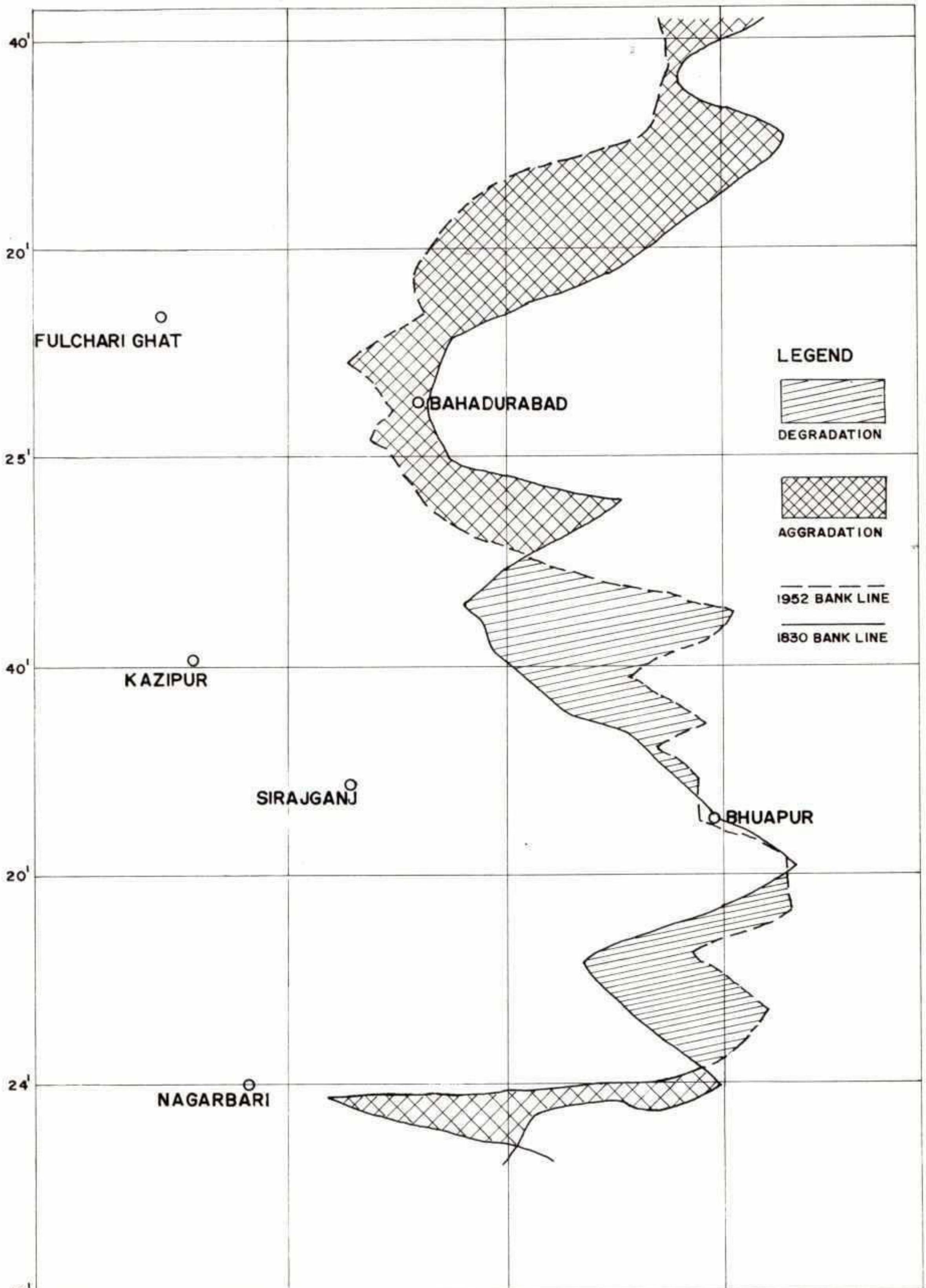
Although a general agreement exists upon the important role played by chars and islands in fluvial processes of the Jamuna, few data and finding are available.

Studies of historical changes are difficult to perform because previous observations and comparisons have focused on the right and left banks.

According to the Chinese Report (CBJET 1991) comparisons of satellite imegery since 1973 underline that six large islands, controlled by nodes of the river, are relatively stable (only the part at lower elevation, changes greatly by erosions).

Figure II.3.8

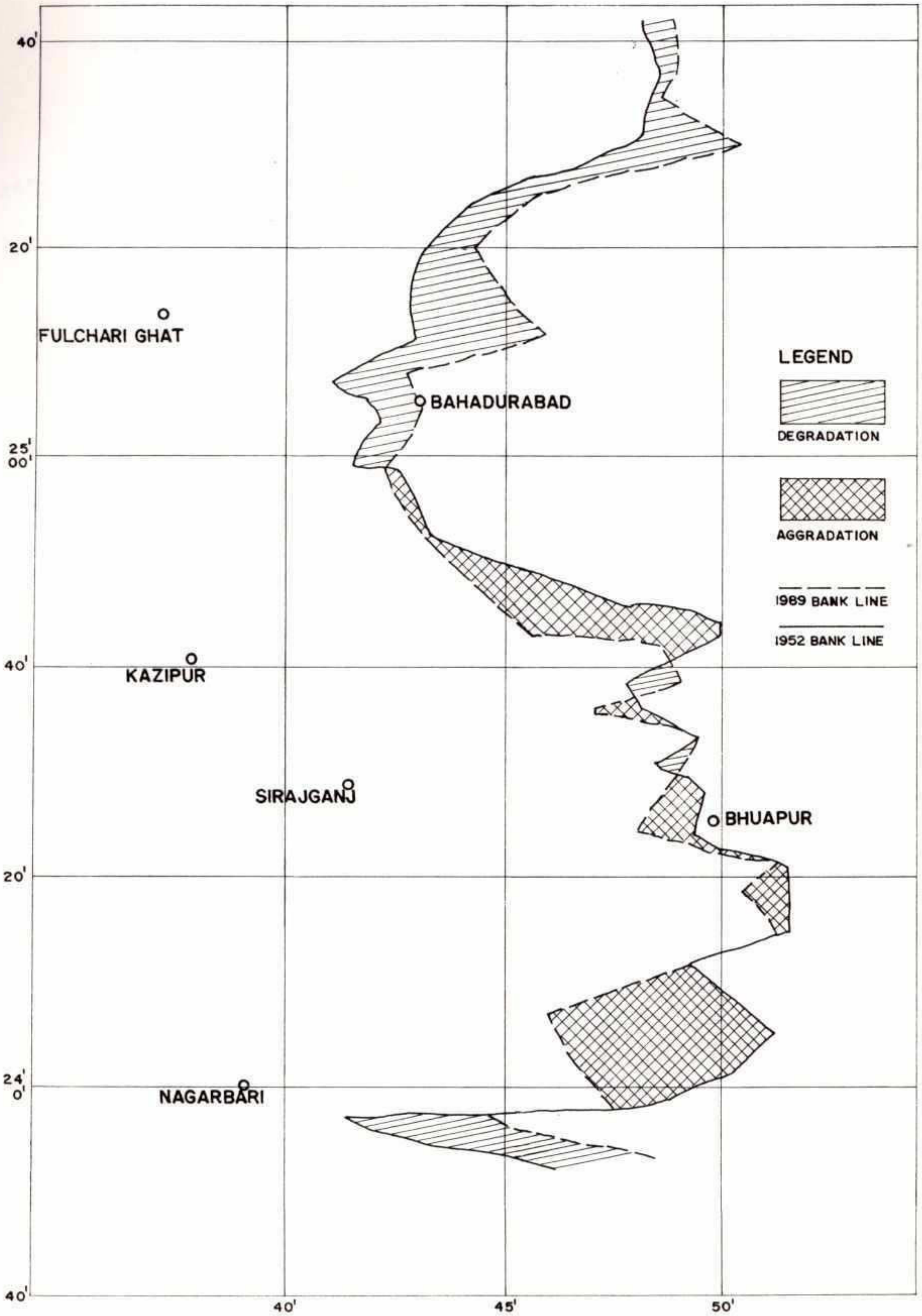
COMPARISON OF LEFT BANK LINES IN 1830 AND 1952 OF BRAHMAPUTRA RIVER



SOURCE : CS 1991

Figure II.3.8(cont.)

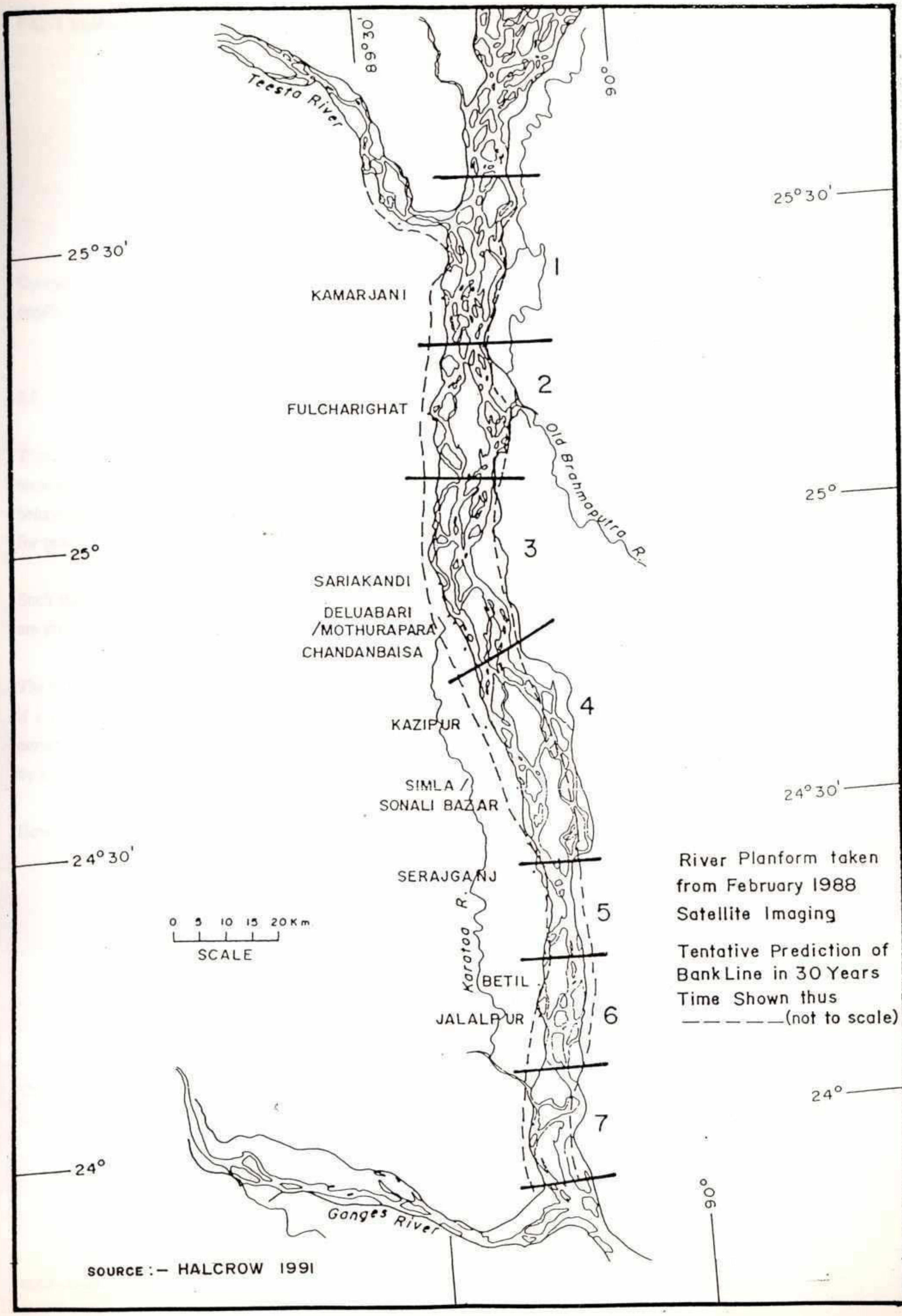
COMPARISON OF LEFT BANK LINES IN 1952 AND 1989 OF BRAHMAPUTRA RIVER



SOURCE : CS 1991

Figure II.3.9

MACRO - MEANDERING OF THE JAMUNA



FAP-1 studies lead to two interesting findings:

- the water surface level at the dominant discharge is typically 0.28 m above the char level, which support the thesis that the sediment transport capacity of the river just above the barfull stage should be substantially greater than just below barfull stage.

- in a particular reach, amounts of sand sediment involved in bank erosion and net chr deposition are similar, which suggests and intimate link between bank erosion and char growth.

Complementary in-depth studies, including nortably time-consuming analysis of cross-sections, are required to confirm what are at this stage only preliminary results and tentative proposals.

3.5 Migration of Anabranch Meanders

There is some evidence that the dominant anabranch waveform is associated with a major proportion of serious erosion features on the right bank. There is no reason why it should be different on the left bank. Thus, if the behaviour of individual anabranch bends can be described by morphological relationships, this could form the basis for predicting the rate of erosion of a particular bend in the short term.

Such studies are presently being undertaken at FAP-1. Curves giving the bend migration versus the bend curvature are proposed.

The better understanding of band propagation, supported by some particular cases, such as Sirajganj, suggests that if a growing loop is stopped by a hard point, then the loop backs out of the embankment when the radious of curvature becomes too small. If this interpretation, proposed by FAP-1, is correct, an anabranch can be controlled by a scheme of hard points.

However, at least two other phenomena introduce great uncertainty in the forecasting of bank erosion :

- the existence of chute channels across point bars which, though carrying a small proportion of the total discharge, have the potential to trigger channel avulsion by providing pilot channels for re-location of the deep water talweg,

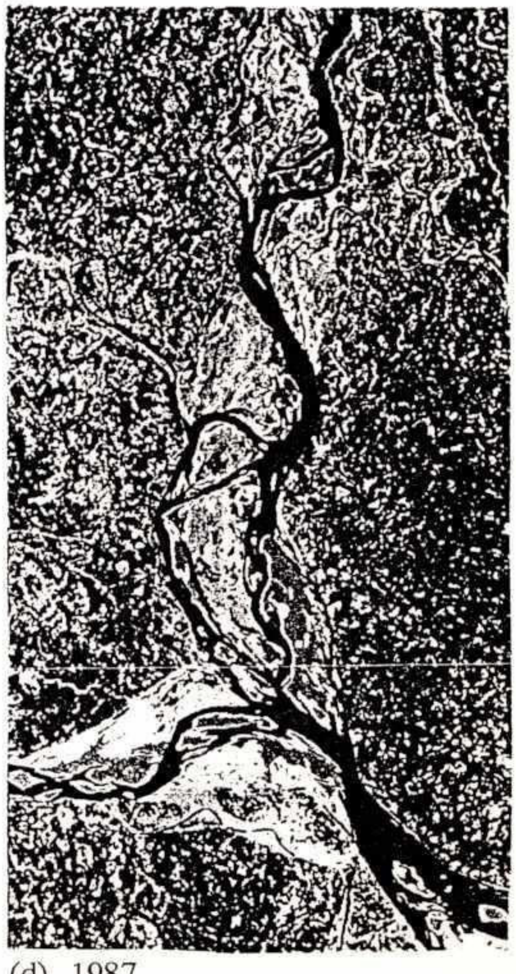
- the periodic switching of the locus of maximum flow between left and right bank anabranch, at the upstream end of a char.

These "bifurcations" give a stochastic character in the bank line shifting, which explain its somewhat erratic appearance (Figure II.3.6), and gives little hope of predicting the behaviour of an anabranch beyond 2 or 3 years.

(a) 1978

(b) 1984

(c) 1986



(d) 1987

Images of changes in channel pattern in the Jamuna River

Source : RPT 1990

3.6 Confluence of Jamuna and Ganges

The comparison of the confluence configuration between 1976 and 1988, performed in the Chinese report (CBJET 1991), indicates that the channel width was narrowed by 50 percent. This observation is supported, by information the Jamuna Bridge Design Report (RPT 1990), see Figure II.3.10.

However, the analysis of the evolution of the stage against the discharge at Baruria does not give any evidence of long term changes of the local water-surface base. The decrease of the channel width is probably mitigated by the increase of the channel depth caused by intense confluence scouring.

On the other hand, when the discharge at Bahadurabad is used, the long term changes of the water surface at Baruria has the tendency after 1975 of raising : it could imply that the downstream base of the Jamuna rises due to the increase of incoming discharge from the Ganges and the increase of the probability of simultaneous peaking of the Jamuna and the Ganges. This assumption should be confirmed by in-depth hydrological studies.

The assumption of a recent increase of backwater effect allowing for more escape flood flow into the main offtake of the Dhaleswari system cannot be rejected at this stage.

3.7 Influence of Bank Material

The recent finding of FAP-1 (Halcrow 1991) is that no correlation exists between the nature of the bank material and the erosion rate. Although in general this conclusion also applies to the left bank, the more consolidated sediment associated with the Madhupur Tract soils (occurring at some locations on the left bank) may decrease erosion rate.

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CHAPTER 4
MORPHOLOGICAL EFFECTS OF DEVELOPMENT SCENARIOS

4.1 Main Rivers

4.1.1. Major Embankments

In order to assess the impacts of embankments along the Jamuna and the Padma,the main issues are :

- to evaluate the increase of discharge and levels in the main channels caused by the confining effect of embankments on the flood plain flow
- to assess the adjustments of the Jamuna channel geometry liable to follow any change of water discharge &
- to evaluate the morphological impacts on the Dhaleswari system.

a. Impact of Confinement

FAP 25 (FAP 25 1992) have carried out runs of the General Model (GM) to assess the effect of an embankment running from the offtake of the Old Brahmaputra down to the Dhaleswari offtake and along the left bank of Dhalesari-Kaligana until Kalatia. The right embankment of Jamuna was already included in the existing situation.

It can be seen (see Figure II.3.11) that the main increase in water level is observed along the Dhaleswari and the Jamuna itself. This increase is mainly explained by the increase in the discharge due to the closure of the Jamuna left bank spillage channels. The increase reaches 1.2 m in the Dhaleswari located downstream of the embankment and 0.60 m at Serajganj. At Bahadurabad, the increase is only 0.08 m, although the rating curve at this location is directly under the influence of the embankment. In the Padma, the increase is in the range of 20 to 30 cm and at Chandpur in the lower Meghna it is only 7 cm.

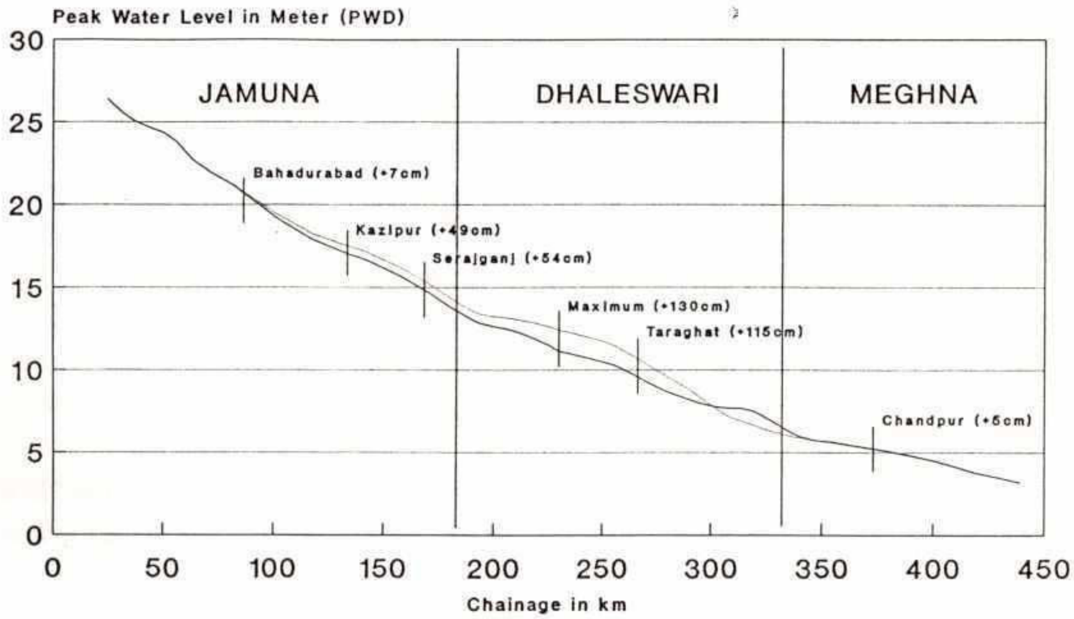
Further complementary runs of the GM are to be performed. These should take into account different set-back distances of the left major embankment and different escape flows in the distributaries, to evaluate the impact of confinement on peak discharges and levels of the Jamuna. A good calibration of the flood plain conveyance is required, in order to obtain reliable results.

b. Adjustments of the Jamuna

River channel formation is a result of the constantly changing discharge of the river. In river morphology, the bankfull discharge is usually used as the channel-forming discharge (or dominant discharge) for downstream changes in channel geometry.

FAP-1 has more precisely computed the dominant discharge of the river, defined as the flow which, over a long period, does the most work in transporting sediment. This discharge of 38,000 m3/s is a little less than the bankfull discharge (44,000 m3/s) and has a return period of a little less than a year. The corresponding water surface level is topically 0.28 m above the char level. The cumulative contribution of all flows greater than 70,000 m3/s (return period : 3 years) on sediment transport is less than 2%.

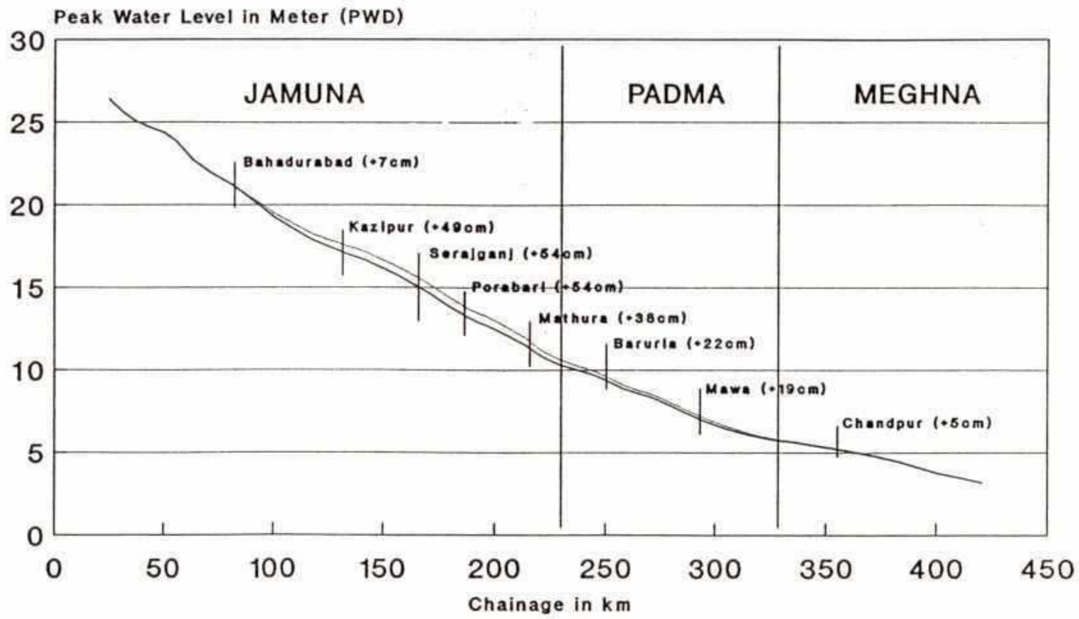
Figure : II.3.11
Comparison of Peak Water Level Profile - 1988



¨ EMBANKED SITUATION

— PRESENT SITUATION

Jamuna-Dhaleswari-Meghna System in 1988



Jamuna-Padma-Lower Meghna System in 1988

Source:- FAP-25 1992

According to these findings, embankments along the Jamuna and the Padma, which should not modify the discharges and levels below the bankfull stage, would induce few changes in the channel geometry. Nevertheless, some large rivers in the world have experienced significant adjustments of their longitudinal profile (downstream aggradation) as a result of major embanking of the flood plain.

Tight embankments are liable to increase the hydraulic efficiency of overbank flows on the active channel and, thus, to increase the relative contribution of low-frequency flows to channel formation.

Consequently, other river morphology experts, like M. Ramette (F.E.C. Report Appendix A.4.1.4. 1989) advise to limit the increase of discharge in the main channels at no more than a ratio of 10 %, or at the very maximum 20 % to avoid any drastic change of the river bed (erosion of banks and chars, bed aggradation).

This condition should be respected if the Dhaleswari and the Old-Brahmaputra offtakes are maintained open, as the conveyance of remaining areas of the flood plain is probably limited by the shallow depth of flow and numerous obstacles (minor embankments, roads, vegetation).

More precise indications about teh influence of confinement on river-bed and bank processes could result from specific runs of the 1-D and 2-D morphological models operated by FAP-1.

c. Impact on Morphology of Distribution

Increased levels during a major flood event could induce considerable changes at offtake and, consequently, on the channel pattern of the distributaries.

For instance, an increased differential head between the Jamuna and the Upper Dhaleswari would possibly activate the spill channels, increase scouring in the main offtake and induce substantial aggradation in the lower part of the system (with more drainage congestion) during the transition period.

Throttled opening with revetments would then be required to control the discharge, with the aim of maintaining the present conditions of dominant discharge and sediment yield.

In the case of the youthful, unstable Upper Dhaleswari, a slight decrease of sediment and peak water discharge could cause positive effects on the stability of the channel.

If embankment construction turns out to be possible, one other important issue falling in the field of river morphology is the set-back distance required to limit erosion hazards, see Section 5.4.

4.1.2 Enlargement of the Main Rivers

The possibility of enlarging two particular (relatively narrow) sections of the main rivers, the section of the Meghna just downstream of the Dhaleswari confluence and the section of the Padma at Baruria has been considered:-

- The Meghna; according to the available old maps (1/50,000 Survey of Bangladesh), the Meghna narrow has been very stable for a long period. It is, thus, believed that this section is well adjusted

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to the sediment load, and enlarging this section would, no doubt, increase siltation and imply a long term commitment to maintenance dredging. Further investigation of this option are therefore not recommended at this stage.

- The Padma; although the cross-section of the Padma would theoretically be worth enlarging to increase its conveyance capacity (which could be done by dredging a new channel on the right bank) such an initiative seems impractical. The analysis of satellite imagery included in the Jamuna Bridge Report (CRPT 1990) shows that the confluence of two of the largest rivers in the world results in huge sediment movements every year. The scale of maintenance activity for such an initiative would be immense. Moreover, it is very difficult to predict with any degree of certainty what would be the impact of such works on the rather stable banks of the Padma.

4.2 Regional Rivers

Table II.3.4 summaries the possible channel adjustments and impacts of some development scenarios in the regional rivers and indicates foreseen long term changes.

4.2.1 Embankments Along the Regional Rivers

The impacts of embankments assessed (see Table II.3.4) are also valid for regional rivers, in particular, the Dhaleswari-Kaliganga channel.

The impact of confining the adjacent flood plain is probably not considerable, for its conveyance and its active width are probably small. More significant would be the impact of the increase of discharge due to the possible closure of secondary distributaries in order to mitigate the flood in the compartments.

An increase of water discharge with no related increase of the sediment discharge may lead to a decrease in the slope, an increase of both width and depth and a worsening of the meandering pattern, with adverse effects on bank stability and excessive siltation at the downstream end during the transition period. If these effects are to be avoided, the following principles should be respected :

- to keep the repartition of discharges in the Dhaleswari river system as close as possible to the natural conditions, up to the bankfull stage,

- to limit the increase in peak flow at no more than 10 % or, at the very maximum, 20 % of the natural peak flow,

- to adapt the set-back distance of embankments to a possible worsening bend migration.

TABLE II.3.4

Possible Adjustments and Impacts on River Morphology of Development Scenarios

Location	Project	Possible River Adjustments				Possible Impacts on the River Bed			
		Depth	Width	Bed slope	Sinuosity	Bank Erosion	Naviga -tion	Fish habitat (river bed)	Mainte- nance
Dhaleswari-Kaliganga	Embankment	+	+	-	+	-	=	=	-
Lower-Dhaleswari	Dredging	+/-	+	-	+/-	-	+	--	--
Dhaleswari-Kaliganga	Cutoffs	-	+	-	+	-	-	=	-
Minor Dhaleswri, Pungli, Barinda Offtakes	Controlled Structures	+/-	+/-	-	+	=/-	=/-	=	=/-
Dhaleswari Offtake	Throttled Opening	+	-	-	+	-	+	=	+
Kaliganga	Diversion Canals	+/-	+/-	+	-	=	=/-	=	-

4.2.2 Dredging in the Lower-Dhaleswari

At the bankfull discharge of 2100 m3/s ,the cross-section area of the Lower-Dhaleswari is very large (about 2500 m2) and the water-surface slope is small (about 2.7 cm/km). Considering the straight channel pattern, the present geometric characteristics of the channel seem well adjusted to the sediment yield.

Large volumes of dredging (may be more than 5 million m3 for a 30 km-long reach) would be required to increase significantly the flood-discharge. The bed-material yield during the high-flow season, evaluated with the Engelund-Hansen bed-load formula, could be roughly as large as 1 million m3 (assuming an average flood-flow of 1500 m3/s during 4 months).

As dredging would reduce the sediment transport capability of the reach, a significant part of this sediment yield would depose in the dredged channel and a considerable maintenance requirement can be anticipated. Thus, dredging will probably not be cost-effective. Similar conclusions can probably be drawn as regards dredging for most of the river-system in the North-Central Region, where the sediment load is generally high.

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4.2.3 Kaliganga Cutoffs

The Kaliganga river shows some sharp meander-loops. Artificial cutoffs could straighten the channel and increase the flood-discharge.

These cutoffs would increase the channel-slope and alter the quasi-equilibrium of the meandering Kaliganga river, the channel of which is rather stable in the downstream reach. Without design precautions, works in a sand-silt river-bed could be accompanied by significant adjustments of the channel :

- the decrease of the slope of the new channel toward the natural slope
- a meandering tendency

To reduce these drawbacks, the cutoff should be adjusted, taking into account the regime conditions related to the new slope, i.e. a new channel, wider and shallower than the natural one.

Some river training works (revetments or bottom panels) could be required to maintain the cross-section.

4.2.4 Controlled Structures at Offtakes

These structures are aimed at controlling the flood-flow introduced in the distributaries of the Jamuna river. If these structures stop the bed-load transport, degradation of the channel or increased meandering tendency (with adverse effects on bank erosion process) could occur downstream of the structure. If the discharge decreases too much, siltation could take place.

As far as possible, these structures should be designed and operated to keep almost unchanged the sediment and water discharges in the river channel, up to the annual flood flow. The mitigation of higher flood flows should not induce adverse adjustment of the channels.

4.2.5 Excavation of New Canals Linking the Kaliganga and the Padma

These canals are aimed at diverting part of the flood flow of the Dhaleswari-Kaliganga in the post-monsoon period, provided that the differential head between the Padma and the Kaliganga is large enough.

Considering the high sediment discharge in this river-system, the canal geometry should be adjusted to the regime conditions, so as to limit siltation.

As the slope should probably be small, a controlled structure is required at the intake in order to avoid siltation by limiting the sediment yield towards the canal:

- a weir at the intake could limit the bed load
- the water should preferably be taken near the surface, where the concentration of the wash load is the lowest, with suitable gates.

The intake should also be carefully located to avoid siltation at the entrance, for instance in the concave part of a stable bend. Provided that these precautions be taken, the maintenance of such a canal could be tolerable. Bottom panels are liable to limit the maintenance activity.

CHAPTER 5
LEFT BANK PROTECTION

5.1 General

On the right bank of the Jamuna river, a 220 km long embankment has been constructed to protect the assets and the lands against the ravages of the flood. Every year, this embankment has to be retired at several places due to bank erosion: a total length of 140 km of retired embankments has been constructed over the past 20 years.

Since river erosion is also causing serious problems at specific locations such as ferry crossings, river stabilisation works, like revetments or groynes, have been constructed with limited success.

The FAP-1 study should elaborate a long term strategy for the protection of the Brahmaputra Right Embankment (Halcrow 1991). In the past years, no significant stabilisation work has been constructed on the left bank.

The main questions to be addressed regarding possible major embankments on the left bank are :

- erosion processes : is there any similarity between the right and the left bank in the short term and the long term ?
- is there any discernible pattern of bank erosion on the left side of the river ?
- is there any discernible consequence of the anticipated right bank protection scheme on the left bank erosion process ?
- is there any safe set-back distance for the embankment alignment ?
- what are the priority locations of bank stabilisation works ?
- given that some form of stabilisation is desirable, then, what is the best form for it to take and what is the order of magnitude of costs involved ?

Most of these questions would be answered more precisely at the end of the FAP-1 studies. Yet, some guidelines can be already elaborated at the prefeasibility stage, as discussed below.

5.2 The Erosion Pattern of the Left Bank

The long term erosion pattern of the left bank is different from that of the right bank. There is no discernible trend of overall aggradation or erosion with a sustained shifting towards the west or the east direction.

Periods of aggradation and erosion appear to take place alternatively in a given section. Moreover, eroding and aggrading stretches seem to alternate more or less regularly along the left bank.

These conclusions are supported by the foregoing studies quoted in Section 2.1 and Figure II.3.5. The bank alignment is plotted against the year of observation in several sections.

Thus, the active recession occurring in the some sections of the east side of the Jamuna is certainly a transient feature. Yet, it seems very difficult to predict with any degree of certainty the duration of the process.

Regarding local morphology, there is no reason why the process of migration of anabranch meanders, which reportedly rule the major erosion features of the right bank, should be different on the left one. Thus, all the findings of FAP-1 studies pertaining to predicting the bend migration can apply to the left bank.

5.3 The Consequences of Right Bank Protection

Some foregoing studies conclude that the Jamuna braided belt widens steadily, due to the westward shifting of the right bank. FAP-1 (Halcrow 1991) puts forward a selection of short term works, liable to stop the recessing trend of the right bank.

The consequence on the width of the braided belt is not evident and only a tentative prediction could be proposed. In the scope of the "macro-scale meandering" model (Section 3.1), the river should not compensate on the left bank for the non eroded right bank. The main channels should gradually slide towards the concave side of the "macro-bend" and increase their depth, as they do in all meandering patterns.

5.4 Assessment of the Safe Set-back Distance

Allowing for the erratic character of the bank erosion pattern on the left side, it appears impossible to define a constant safe distance between the bank and the alignment of the embankment. This distance depends on the present location of the channel, compared to the past locations. In other words, where the river flowed in the past, it could come back in the future.

Figure II.3.12 shows a tentative prediction of the envisaged maximum excursion of the Jamuna on the left side, within 20 years and without any training works.

The proposed alignment of the embankment is indicated on each graph of Figure II.3.6. In some cases, the anticipated migration rates are low enough to allow for a nearer location than the furthest past bankline. The set-back distance varies approximately between 0.75 km and 6.5 km. The largest distances are obtained along two convex bends located between Bahadurabad and Sarishabari, between the two offtakes of the Dhaleswari and at the convex bend just upstream of Aricha. The wide convex bends are ancient chars which gradually combined with the bank. These low lying areas are proned to erosion, for instance by the development of a cutoff channel across the bar. The upper area of the Dhaleswari catchment is composed of relatively young mobile alluvial deposits.

5.5 Location of Critical Sections and Priority Works

The comparison of 1/50,000 aerial photographs (1983), 1/50,000 SPOT imagery (Jan,1989) and 1/20,000 FINNMAP aerial photographs (Dec, 1990) allows for locating the currently most eroded areas (see Figure II.3.12).

The following points have undergone sustained erosion since 1983:

- Bahadurabad Ghat and a 15 km-long stretch downstream of this point (approximately down to the offtake of the Chatal)
- the 10 km-long embankment around Madarganj
- a 10 km-long stretch, downstream of the designed location of the Jamuna Bridge;

In these points, the left bank migration reached 3 km between 1983 and 1990 and almost 1 km in one year, in the more exposed points between 1989 and 1990. These points are all exposed to the flow of a main anabranch of the river.

Figure II.3.6 shows the left bank migration against time at a selection of sections and indicates that the most recessing parts of the left bank have previously shifted further eastward. Thus, the erosion process is likely to go on. Yet, the Madarganj bend has a rather small radius of curvature; the maximum erosion point could migrate gradually down the valley.

5.6 Tentative Bank Stabilisation Scheme

The objective of this scheme is not the complete control of the river. Such an active strategy would necessarily concern both banks of the river and, possibly, the main islands.

Owing to the limited number of assets threatened by the river on the left side, it would probably involve a very large cost for a relatively minor benefit.

Moreover, it is not proven that this strategy would be actually practicable for the Jamuna and would not induce considerable morphological adjustment of the river bed, notably an unbearable aggradation at the downstream end.

A strategy based on the establishment of hard points seem more practicable, as is the case for the right bank. (see Figures II.3.12 and II.3.13). Some hard points would primarily be implemented where assets and infrastructure are directly threatened by sustained erosion processes. Presently, Bahadurabad Ghat and Madarganj are identified as suitable sites for priority works. The other potential site of Jagannathganj Ghat is at present protected from direct attacks by a newly deposited char.

It should be noted that river morphology processes are so rapid along the Jamuna that the situation could changed before proposals for work can be implemented.

Other hard points should progressively be constructed to limit the erosion process along the stretches where a large safe set-back distance is foreseen without river training works. These stretches are localized between Bahadurabad and Madarganj and south of Bhuapur.

The Jamuna Bridge guide bund could be part of the scheme. Two hard points would be required at the main offtake of the Dhaleswari, which is very unstable.

NORTH CENTRAL REGIONAL STUDY

JAMUNA RIVER

TENTATIVE PREDICTIONS OF LEFT BANK LINES

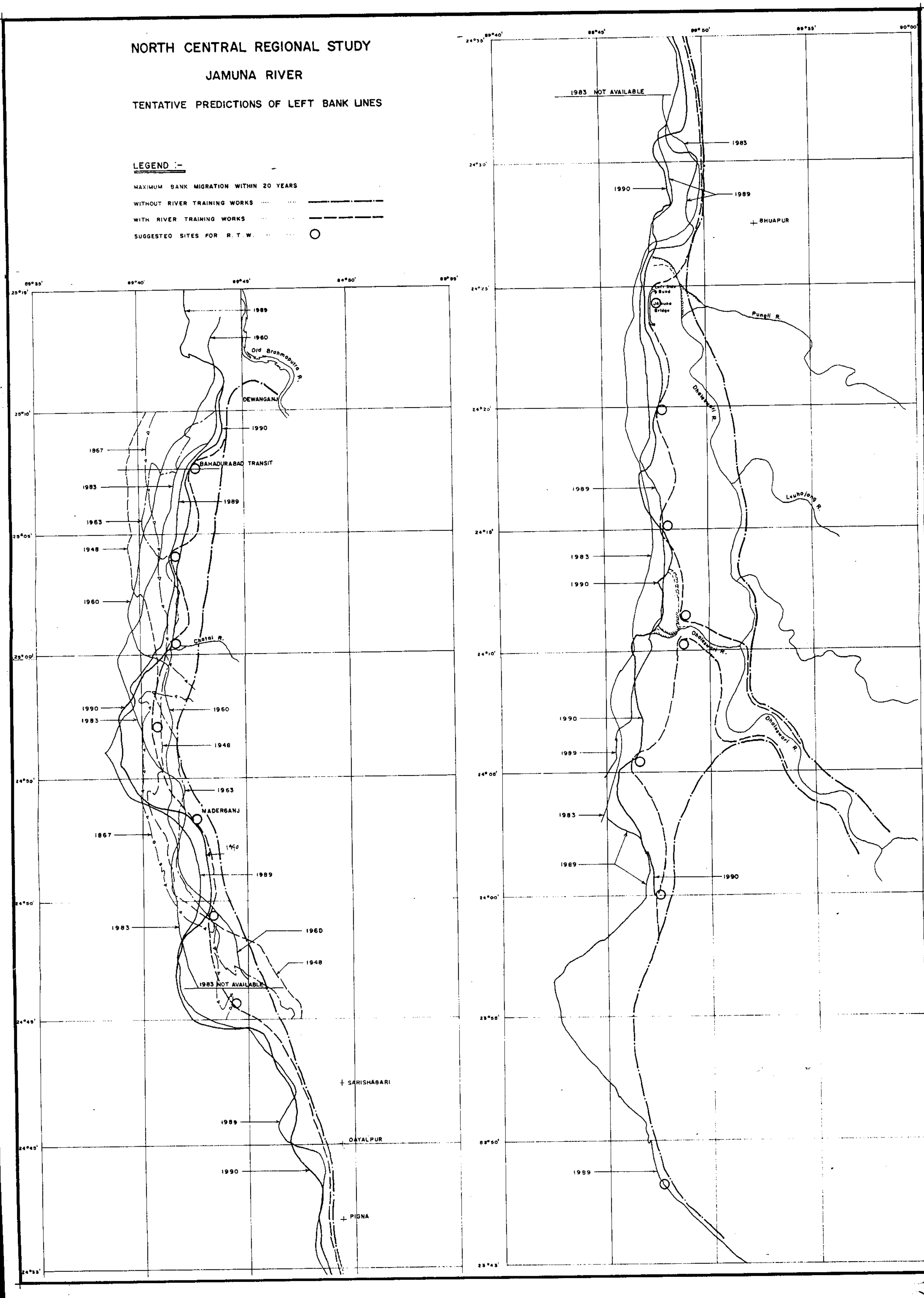

Figure II.3.12

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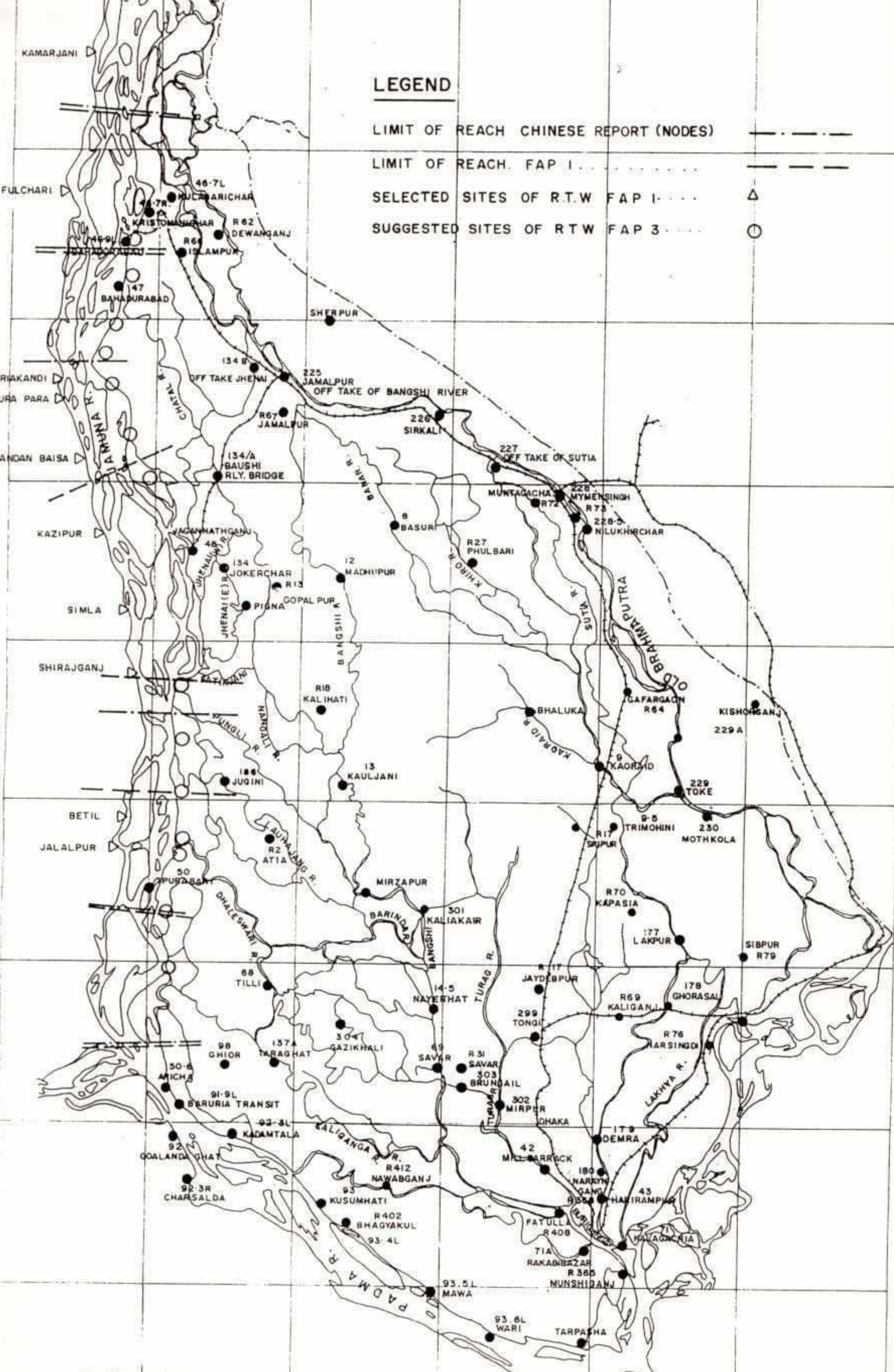
NORTH CENTRAL REGIONAL STUDY

FAP-3

JAMUNA RIVER

TENTATIVE RIVER TRAINING SCHEME



According to FAP-1 findings, a "wavy" bankline could thus be obtained. Figure II.3.12 shows also a very indicative alignment of the future left bank with protective measures. Bankline migration at the most threatened spots would be tentatively estimated as half that without stabilisation works but would not be stopped, except at the very location of the works.

The bend migration studies and the geomorphology studies, presently in hand at FAP-1, could help to determine the spacing of hard points required to obtain a given maximum bend erosion.

5.7 Types of Protection and Design Procedure

In the course of FAP-1 studies, it has been demonstrated that revetment in the river bed will be the most effective bank protection measure to be adopted at priority sites, where no set-back distance exists between the present bank and the assets or infrastuctures to be protected.

The construction of active river training works in the river bed (like groynes), impinging on the current direction, is, no doubt very costly.

The conclusion could be different in the case of large groynes built in the flood plain (like Jamuna Bridge guide bunds), in a waiting position, supposing that a certain bank recession is bearable.

In some cases, series of groynes could prove effective, to prevent one hard point from outflanking. For the purpose of this tentative protection scheme, the conclusions of FAP-1 for the design of priority works are adopted.

Figure II.3.14 shows a typical bank revetment section. Its main features are :

- side slope : 4/1
- maximum scour depth : 28 m under 1:100 yrs level
- gunny bags or geotextile bags fill
- hand placed block protection above LWL
- dumped block protection below LWL
- falling apron wherever the present scour depth is lower than the maximum scour depth.

A geotextile filter layer must be provided everywhere between the river bed and the block protection. Figure II.3.15 shows a typical layout of a groyne to be constructed in the flood plain.

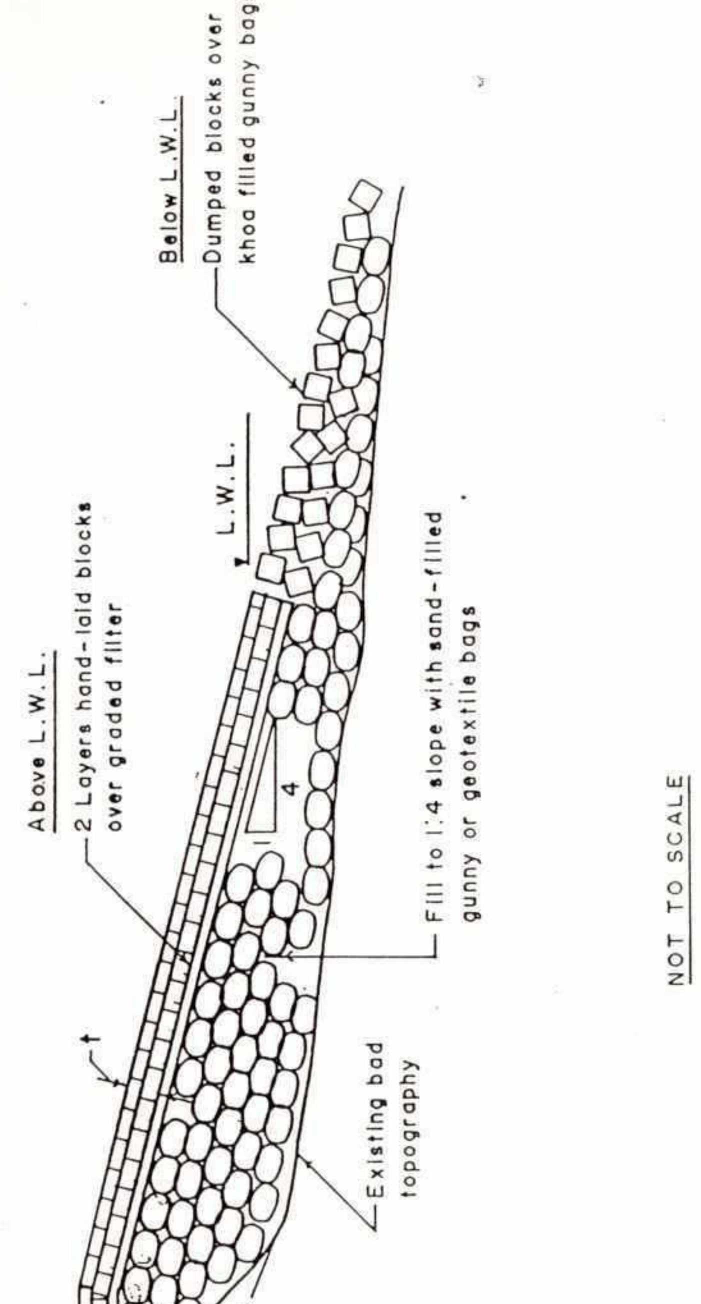
Figure II.3.16 shows a typical layout of bank protection work. In the case of long term protective works, the hard points could probably be constructed at a cheaper cost in the flood plain, in a waiting position.

At feasibility study, stage specific conditions at every proposed site should be carefully analysed to determine the bank protection measures : length, location related to the threatened site, complementary works to prevent outflanking etc.

At this stage, an average revetment length of 1.5 km is assumed to be required at each hard point (including the prevention of outflanking). This is supported by FAP-1 layout for several specific sites of the right bank (Kazipur: 1.2 km, Phulchari Ghat: 1.7 km, Sariakandi: 2.0 km).

Figure II.3.14

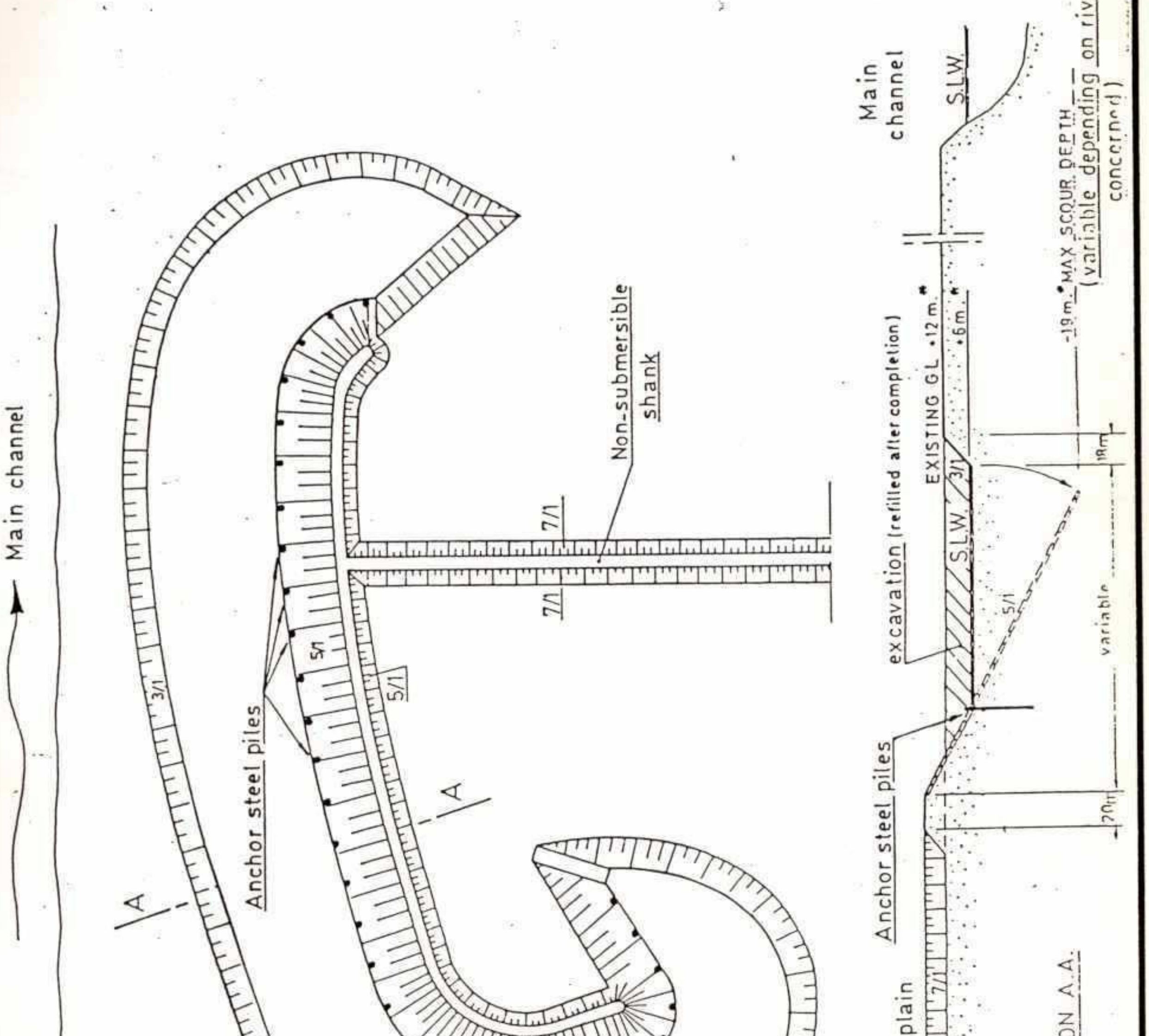
TYPICAL BANK REVETMENT SECTION



SOURCE :- HALCROW 1991

Figure II.3.15

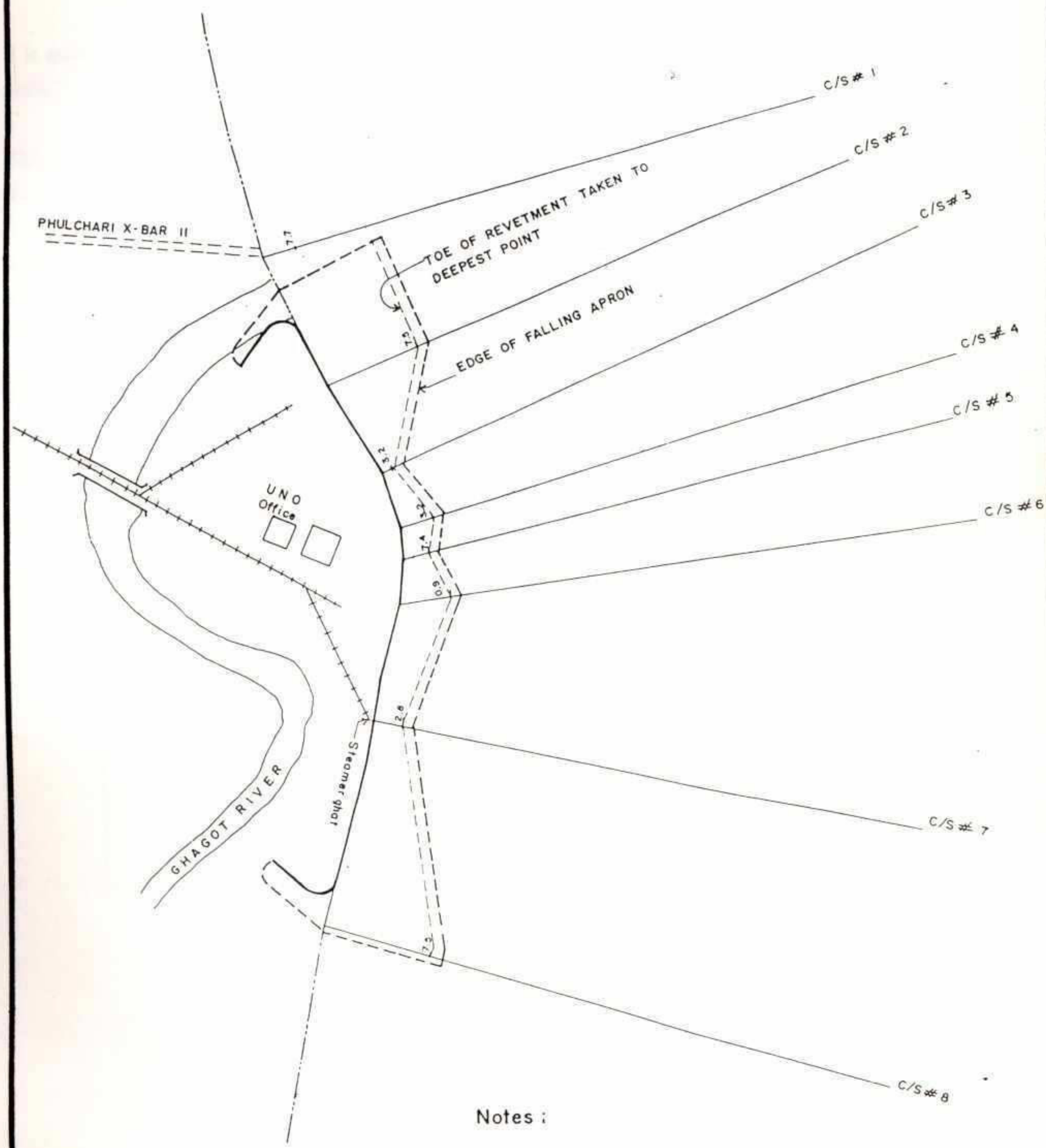
TYPICAL NON SUBMERSIBLE T - HEAD GROYNE FALLING APRON PRINCIPLE



SOURCE :— F E C 1989

Figure II.3.16

TYPICAL LAYOUT OF BANK STABILISATION WORKS



Notes :

1. Upstream limit of revetment is 250m upstream from cross-section # 2
2. Downstream limit of revetment is at cross-section # 8
3. Overall length of revetment along the bank is 1450 m.
4. Falling apron is 24m wide from upstream and to cross-section # 3 and from cross-section # 7 to downstream end. It is 17m wide between cross-section # 3 and # 7.
5. Lowest near bank bed level, and its position, is shown on each cross-section line.

0 100 200 300 400 500 m

SCALE

SOURCE :- HALCROW 1991

5.8 Assessment of Costs

5.8.1 Investment Costs

It is assumed that some 14 hard points are required on the left bank, half of which to be constructed in the flood plain. Two of the hard points are priority works (Bahadurabad and Madarganj).

FAP-1 First Interim Report performed a first assessment of revetment cost for priority works, which is 100,000 TK per meter. According to FAP-1, this estimation is probably far too low and will be increased up to approximately 250,000 Tk per meter. As a comparison, the estimation of the F.E.C. Report (May,1989) was around 450,000 TK/m (with 30% for contingencies and 15% for engineering), taking into account higher unit rates than in BWDB schedules of rates. The cost of hard points constructed in the flood plain could be approximately half the figure of that at the river bank.

The estimation (including contingencies and engineering costs) of the investment cost of bank stabilisation measures for the full left bank length jamuna is detailed in Table II.3.5.

TABLE II.3.5
Estimated Cost of Bank Stabilisation Works

Designation	Quant. km	Rate (Tk.1,000)	Amount (Tk.1000)	Amount (US $ 1,000)
Priority works	3.0	250,000	750,000	19,737
Long Term Works				
- in the river bed	7.5	250,000	1,875,000	49,342
- in the flood plain	10.5	125,000	1,312,500	34,540
Grand Total	**21.0**		**3,937,500**	**103,619**

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5.8.2 Operation and Maintenance Costs

According to the Guidelines for Project Assessment (FPCO 1992) the Operation and Maintenance costs for river bank protection and training is given as 10 % of the investment costs.

Presently, the performances of existing bank protection and river training works are generally judged as poor for two main reasons:

- Insufficient data on which to base the design, leading to inadequate scour protection, under-size revetment material, or deficient filters.
- Insufficient quality control during construction.

The lack of proper maintenance methods, including notably regular topographical and river surveys, is perhaps another important reason.

It is anticipated that the on-going studies will lead to more correct design, supervision and maintenance procedures. For instance regular river surveys and extensive use of satellite imagery could allow for deciding limited preventive works before stabilisation works suffer significant damages. In France, the Operation and Maintenance costs of a 300 km-long full-developed river, with embankments and bank protection works are no more than 4 to 5 % of the investment costs. Accordingly, it is proposed to reduce to 5% the percentage for O&M applied to high standard bank protection works.

5.9 Left Bank Protection on the Padma

Presently, steady bank recession is reported since 1983 along a 10km-long stretch of the left bank, at Maniknagar. Owing to the river morphology processes on the Padma adressed in (see Section 4.1) it is reasonable to believe that the bend will gradually migrate in the downstream direction.

Construction of bank protection works along such a mighty river (observed scour depths can reach 40 m) would involve colossal costs for relatively minor benefits, since bank migration rates are far lower than on the Jamuna (apparently no more than 500m since 1983 at the threatened stretch).

Accordingly, a constant set-back distance of 1 km is proposed along the left bank of the Padma without any protective measure. This proposal seems in line with the layout of the South-West Dhaka project.

CHAPTER 6
RESUSCITATION OF THE OLD-BRAHMAPUTRA

6.1 Present Conditions

6.1.1. Overview

In previous years, the mouth of the Old-Brahmaputra has been the most important offtake located on the left bank of the Jamuna. At present, serious deposition has taken place at the mouth, induced by intense char movement and, more precisely, the full connection of a large char to the previous left bank. This is supported, for instance, by the alignment of 1963-bankline indicated on Figure II.3.17. If this mouth is resuscitated, it could be an important intake for irrigation, water supply, sanitation, fisheries or any other uses.

The decrease of the Old-Brahmaputra in its role as a major waterway has had various effects on its area of influence. Before a study of the possibilities of resuscitation and/or maintenance of the Old-Brahmaputra is investigated, the objectives of such an initiative should be clarified. At this stage, only the subject areas are given, the priorities would have to be addressed at a later stage, if a pre-feasibility is undertaken, see Section 6.4.

The level of the chars which close the offtake is probably not very different from the average bankfull level underlined by FAP-1, that is approximately 0.30 m below the average flood level.
This means that no flow is able to get into the mouth under medium and low flow.

This situation could be compared to the situation of the northern offtake of the Dhaleswari, where gradual siltation has limited the period of overspilling from late May to early November. The analysis of 1/50,000 SPOT imagery shows that,presently, the flow into the Old Brahmaputra comes exclusively from the Jinjiram catchment area, during the dry season (see Figure II.3.17). During the higher discharge levels in the Jamuna, overbank flow comes directly into the Old-Brahmaputra mouth, and, also into several spill channels towards the lower Jinjiram channels. These channels are located on Figure II.3.18.

The present network of channels between the Jamuna and the Jinjiram river represent a complex fairly unstable river system, which is still in the course of development. Part of this system is located in India.

6.1.2 The Spill Channels

There are four spill channels which link active branches of the Jamuna to the lower Jinjiram channel.

- channel n°1 connects a secondary channel of the Jamuna to the Sonabari river at the location of the previous confluence of this river.
- channel n°2 connects the lower channel of the Sonabari river (an old branch of the Jamuna) to the Jinjiram river.
- channel n°3 connects the present Sonabari river confluence to a silted channel flowing into the Old-Brahmaputra at its very upstream end.
- channel n°4 links a main branch of the Jamuna to the same silted channel.

Figure II.3.17

RESTORATION OF OLD-BRAHMAPUTRA OFF TAKE- LOCATION MAP

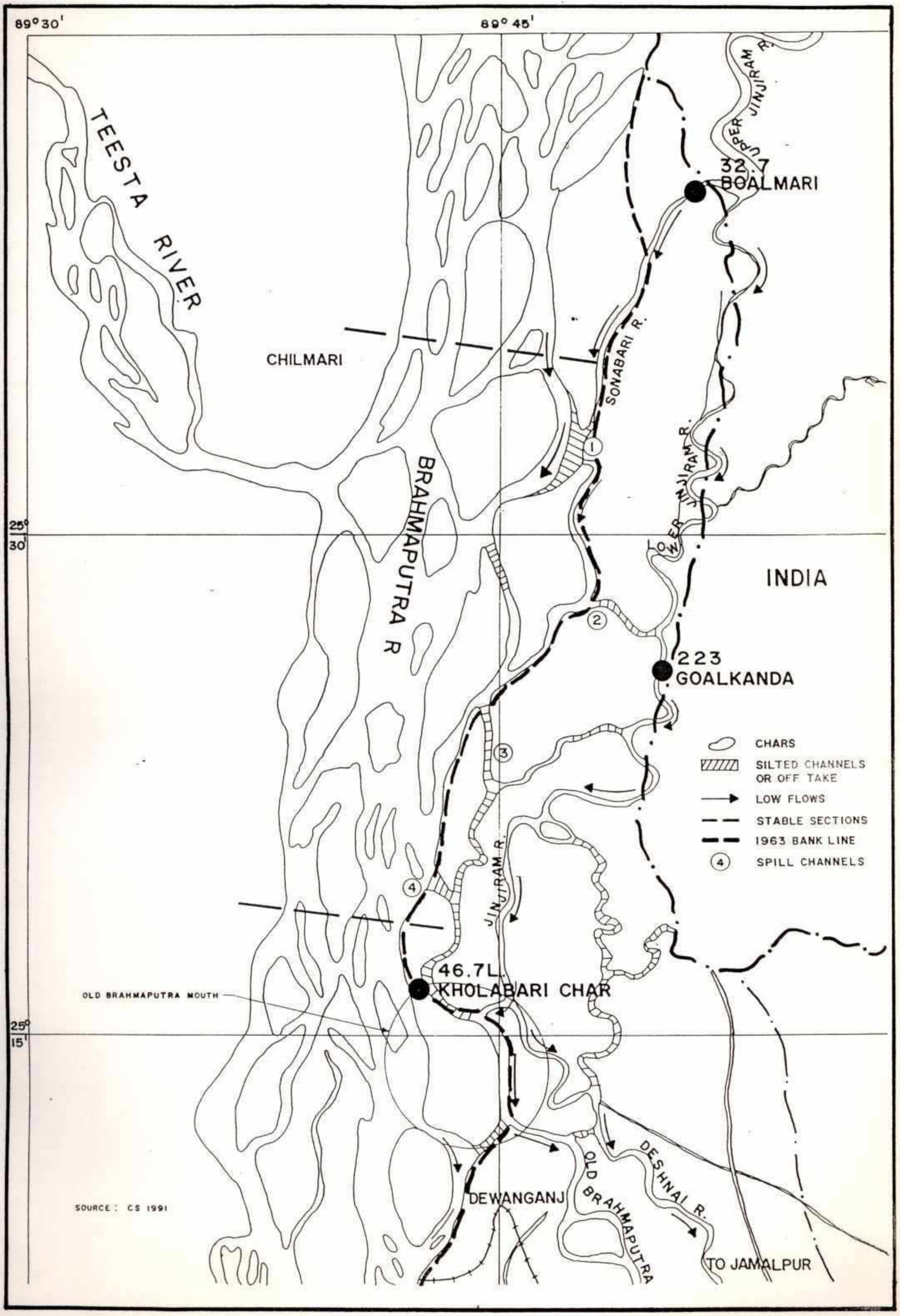
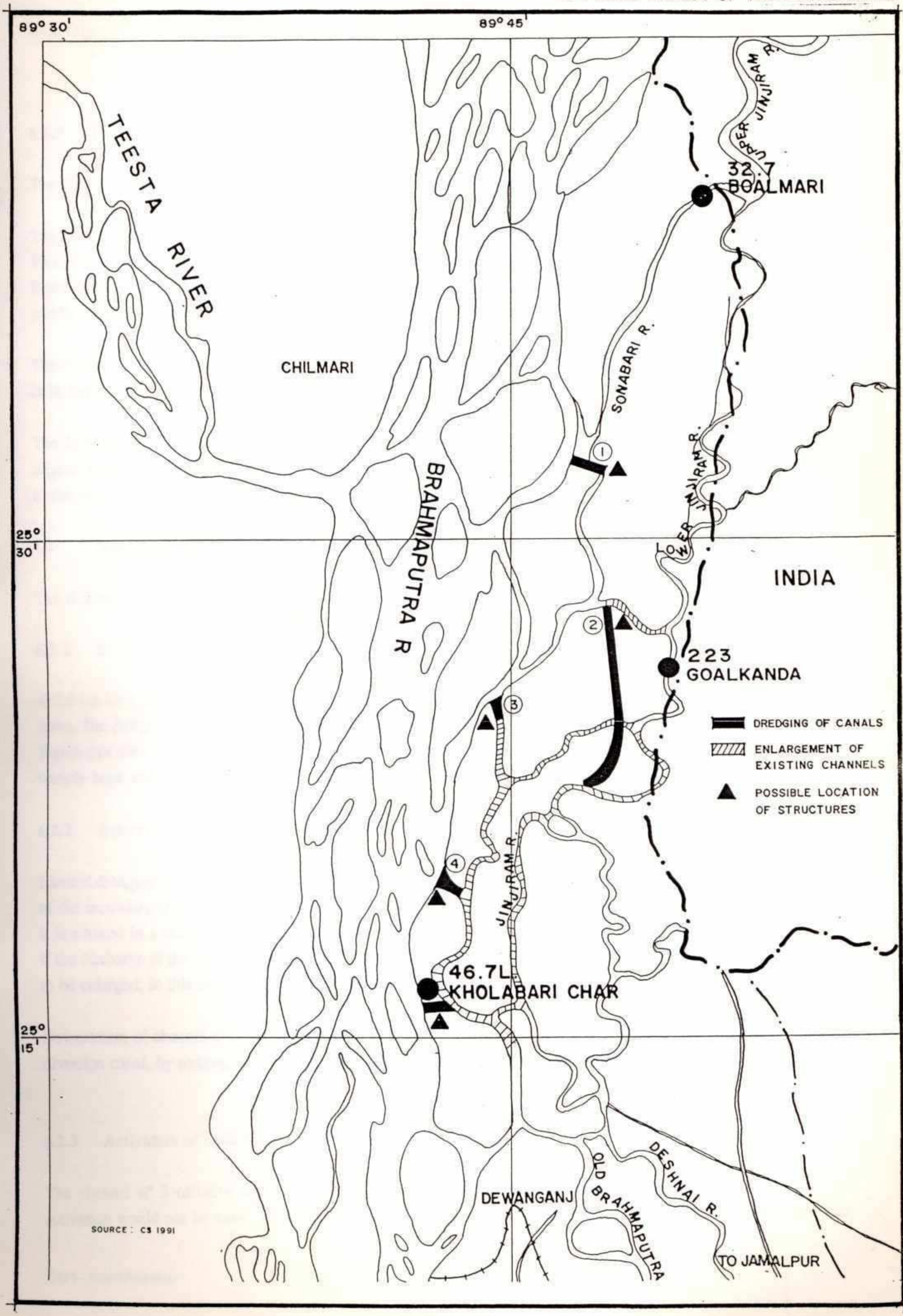


Figure II.3.18

RESTORATION OF OLD BRAHMAPUTRA OFF TAKE-LAYOUT OF THE POSSIBILITIES



Referring to the old bankline maps of 1830 to 1963, two sections located on Figure II.3.17, appear to be fairly stable:

- the northern one is located at the offtake of the secondary branch of the Jamuna.
- the southern one is located at the offtake of channel n°4.

6.1.3 The River System

The Old-Brahmaputra shows a rather unstable sinuous point-bar pattern (see Section 2.3.4).

The Jinjiram river rises in the northwest portion of the Assam Range in India. It has a catchment area of more than 1000 km2. It flows around the western end of the foothills to join the Jamuna through the Sonabari river and the Old-Brahmaputra through the lower Jinjiram and the Deshnai. This latter river, which is a minor distributary, flows quite parallel to the Old-Brahmaputra down to Jamalpur.

The Sonabari river conveys presently the major part of the flow coming from the Jinjiram catchment area. Its offtake is in India.

The Jinjiram and the Sonabari are unstable sinuous point bar rivers, with some anabranches. The process of bend migration is very active. The satellite maps show numerous old meander loops in the flood plain. Some bends seem to alternate from one side of the border to the other.

6.2 Assessment of the Possibilities of Resuscitation

The different possibilities for resuscitation are located on Figure II.3.18, and described below.

6.2.1. Dredging of the Mouth

A 2.5 km-long canal could connect the Jamuna main channel to the Old-Brahmaputra's through relatively low-lying areas. The design of the channel and the intake should take into account the intense sediment movement in this area. Significant river training works would be required to stabilize the intake and, if possible, limit maintenance activity: namely bank stabilisation works at entrance and bottom panels increasing the scouring in the canal.

6.2.2 Activation of Spill Channels N°1 and 2

Limited dredging of a 5-km channel is required to activate these offtakes, which are still partially open. The stability of the secondary channel of the Jamuna, in which spill channel n° 1 offtakes, has to be assessed in the long term. It is situated in a fairly stable reach of the Jamuna.
If the discharge of the Sonabari river is large enough to cope with the water demand, only the spill channel n°2 needs to be enlarged; in this case, less morphological problems are anticipated.

Downstream of channel n°2, the Jinjiram river follows the border. To avoid this potential difficulty, a new 10-km diversion canal, by-passing the international course of the river, could be considered.

6.2.3 Activation of Spill Channels N°3 and 4

The channel n° 3 offtakes in the confluence area of the Sonabari river where intense siltation takes place. Its activation would not be easy. The channel n° 4 offtakes in a rather stable main branch of the Jamuna where less siltation is foreseen. It could be linked to the Old-Brahmaputra either by enlarging a natural channel parallel to the left bank of the Jamuna or by digging a canal towards the lower Jinjiram river.

6.2.4 Pumping Station

A fixed or floating pumping station could also be implemented; offtake n°4 is apparently an appropriate location, with lettle sedimentation.

In each scenario, several alternatives should be considered :

- implementation of controlled intakes, with or without gates,
- bottom panels to limit yearly maintenance activities,
- implementation of navigation locks and fish ladders.

All these possibilities could also be combined to ensure the required water supply, whatever the water level of the Jamuna and the aggradation at intakes.

6.3 Constraints

The main constraints are :

- the water levels of the Jamuna river at each intake
- the water levels of the Jinjiram river system and the available natural discharges
- the topography of the flood plain and of the river beds (including the Old-Brahmaputra river bed downstream of the Jinjiram confluence).
- the geotechnical conditions
- the dynamic fluvial processes in the Jamuna and the Jinjiram river system.
- the environmental and socio-economic constraints. The proximity of the international border should notably be kept in mind.

6.4. Proposed Surveys and Studies

All these constraints would have to be addressed in a prefeasibility study, which should include the following phases:

- collection of the relevant data : water levels and water discharges, satellite imagery, topographical maps, geological data
- topographical survey of the area between the Jamuna and the border, including cross-sections of selected channels.
- assessment of the water demand
- analysis of hydrological data (water levels, discharges) for available stations on the Jamuna, the Jinjiram, the Old-Brahmaputra
- hydromodelling activity dealing with the Lower Jinjiram river system, part of the Old-Brahmaputra and the new canals. Simple computations taking into account steady gradually varied flows are only required for dimensioning new channels.
- geomorphological study of the Upper Jamuna, the Old- Brahmaputra and the Jinjiram river system
- river engineering, including the dimensionment of new canals, channels and structures, and the prefeasibility design of river training works,
- multi-criteria or cost-benefit analysis.

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Flood Action Plan
FAP 3
North Central Regional Study

Supporting Report II.4
Groundwater

February 1993

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NORTH CENTRAL REGIONAL WATER RESOURCES DEVELOPMENT PLAN
FAP-3
SUPPORTING REPORT II.4 - GROUNDWATER

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
BADC	Bangladesh Agricultural Development Corp.
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BB	Bangladesh Bank
BBS	Bangladesh Bureau of Statistics
BCAL	Bangladesh Census of Agricultural Livestock
BCAS	Bangladesh Centre for Advanced Studies
FDC	Bangladesh Fisheries Development Corp.
BIDS	Bangladesh Institute of Development Studies
BIWTA	Bangladesh Inland Water Transport Auth.
BJRI	Bangladesh Jute Research Institute
BKB	Bangladesh Krishi Bank
BNPP	Bangladesh National Physical Plan. Board
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engg.Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CAS	Catch Assessment Survey
CAT	Coordination Advisory Team
CCCE	Caisse Centrale de Coopération Economique
CEC	Commission of European Communities
CPM	Coarse Pilot Model
CS	Consultants' Studies
DA	Development Area
DAE	Department of Agricultural Extension
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DDT	Dichlorodiphenyl-trichloroethane
DHI	Danish Hydraulics Institute
DOE	Department of Environment
DOF	Department of Fisheries
DOS	Disk Operating System
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
DUL	Desh Upodesh Ltd.
EEC	European Economic Community
EIA	Environmental Impact Assessment
EIP	Early Implementation Programme
FAO	Food & Agricul.Organ.of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control,Drainage & Irrigation Project
FFYP	Fourth Five Year Plan
FHS	Flood Hydrology Study
FMM	Flood Management Modelling
FPCO	Flood Plan Co-ordination Organisation
FRI	Fisheries Research Institute
FRSS	Fisheries Resources Survey System
FSR	Farming Research System
FWP	Food for Work Programme
FY	Financial Year
GOB	Government of Bangladesh
GW	Groundwater
HTW	Hand Tubewell
HYV	High Yielding Variety
IDA	International Development Agency
IPM	Integrated Pest Management Programme
IRRI	International Rice Research Institute
JFP	Jamuna Flood Plain
JPPS	Jamalpur Priority Project Study
LGEB	Local Government Engineering Bureau
MCA	Multicriteria Analysis
ME	Ministry of Education
MF	Ministry of Finance
MIWDFC	Minist.of Irrig., Water Dev.& Flood Control
ML	Ministry of Land
MLGRDC	Minist.of Local Govt.,Rural Dev.& Coop.
MOA	Ministry of Agriculture
MOEF	Ministry of Environment and Forestry
MOFL	Ministry of Fisheries & Livestock
MOSTI	Manually Operated Shallow T/W for Irrig.
MP	Ministry of Planning
MPO	Master Plan Organisation
MTN	Madhupur Tract North
MTS	Madhupur Tract South
NCA	Net Cultivable Area
NCR	North Central Region
NCRM	North Central Regional Model
NCRMG	North Central Regional Model Group
NCRS	North Central Regional Study
NFMP	New Fisheries Management Policy
NGO	Non Government Organisation
NGR	Natural Growth Rate
NWP	National Water Plan
OBFP	Old Brahmaputra Flood Plain
O&M	Operation and Maintenance
ODA	Overseas Development Administration (UK)
PA	Planning Area
PFDS	Public Foodgrain Distribution System
POE	Panel of Experts
PSR	Preliminary Supporting Report
PU	Planning Unit
PWD	Public Works Datum
RARS	Regional Agricultural Research Station
RHD	Roads and Highways Department
RS	Regional Scheme
SES	Socio-Economic Survey
SOB	Survey of Bangladesh
SPARRSO	Space Research & Remote Sensing Organ.
SRP	Systems Rehabilitation Project
SRTI	Sugarcane Research and Training Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
TOR	Terms of Reference
Tk	Taka
UNDP	United Nations Development Programme
UNHCR	United Nations H.Commission for Refugees
WFP	World Food Programme

CHAPTER 1
INTRODUCTION

1.1 Introduction

The hydrogeology and physiography of the North Central Region has been extensively described in previous studies and reports. The entire area is covered by weakly consolidated alluvial sediments of the Meghna, Ganges and Brahmaputra river system forming an aquifer system several hundred metres thick. The main physiographic units consist of flood plains of the Old Brahmaputra, Jamuna and Meghna rivers surrounding the central elevated Madhupur Tract. Over most of the area, a four layer multi-aquifer system is recognized which consists broadly of:

Layer 1 :	Upper clay or silty clay layer
Layer 2 :	Intermediate fine sand aquifer
Layer 3 :	Lower semi-confining clay layer
Layer 4 :	Main medium to coarse grained aquifer

The clay layers may be thin or absent in the Jamuna and Brahmaputra flood plain areas, and are particularly thick on the Madhupur Tract.

Technical Report 5 of the MPO National Water Plan Phase-I provides a detailed description and analysis of the hydrogeology of the area.

The aquifers of the study area have been extensively developed for irrigation by shallow tubewells (STW) and deep tubewells (DTW) over a period of some 20 years. Deep tubewells are concentrated in the Madhupur Tract, while shallow tubewells predominate elsewhere. Most of the deep tubewells have been installed by BADC; The IDA Deep Tubewell Project has recently completed the sinking of 4000, two cusec deep tubewells in the Mymensingh, Dhaka, Gazipur and Manikganj districts.

The groundwater related study objectives require an assessment of the impact of flood control on groundwater resources and the preparation of a groundwater development plan which is integrated with new flood control and drainage measures proposed for the North Central Region.

Special conditions apply to the urbanised areas of Dhaka and Tongi where groundwater recharge is reduced and intensive abstractions for public and industrial water supplies are occurring. Detailed studies and groundwater modelling have been conducted in this region for Dhaka WASA. These areas have been excluded from the present assessment which considers mainly the agricultural potential of groundwater resources in the remainder of the study area.

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CHAPTER 2
PRESENT GROUNDWATER DEVELOPMENT

2.1 Data Sources

Data on present levels of groundwater development were obtained from the AST/CIDA national census of minor irrigation for 1989, and from BADC for deep tubewells. A new and greatly expanded census has been conducted in 1991 and preliminary (unpublished) results have been incorporated. From the preliminary 1991 figures, which include details of irrigated areas, estimates of national average areas irrigated by different type of minor irrigation equipment were made as follows:

- Shallow tubewells (STW) : 4.5 ha
- Deep tubewells (DTW) : 20.0 ha
- Low lift pumps (LLP)(1 cusec equivalent) : 7.5 ha

The above values were used to assess thana-wise total irrigation by various equipment types. For planning purposes, an average water duty of 160 ha/Mm3 (625 mm equivalent) was then used to estimate current abstractions for irrigation. This is based on average net crop water requirements in the study area for winter irrigation, and assumes that all field and conveyance seepage losses return to groundwater storage.

2.2 Patterns of Development

Details of estimated unit numbers, irrigated areas and abstractions for the 1991 irrigation season for 47 thanas in the study area are summarized in Table II.2.1. The distribution of equipment is shown in Figures II.2.1-2.5.

Low Lift Pumps

There is limited potential for low lift pumps (LLP) in most of the Region. The details of numbers for the 1991 irrigation seasons is given in Figure II.2.1.

Shallow Tubewells

The distribution of shallow tubewells (STW) is shown in Figure II.2.2. Highest concentrations occur in Tangail, Jamalpur, Dhaka and Manikganj districts where groundwater levels are shallow and aquifer conditions are favourable. Numbers are limited in the Madhupur Tract. Unlike northwest Bangladesh, deep setting of shallow tubewells (DSSTWs), has never been significant in the North Central region.

Deep Tubewells

Highest concentrations of deep tubewells (DTW) occur in the Madhupur Tract (see Figure II.2.3) and peripheral areas where conditions are not generally suitable for shallow tubewells due to deep water levels and poorer aquifers.

Deep and shallow tubewells are very much the dominant mode of irrigation everywhere in the study area except Munshiganj, where low lift pumps are the primary method.

TABLE II.2.1
Existing Minor Irrigation - 1991

Nr	Upazila	District	STW	DSSTW	DTW Units	LLP-1	STW	DSSTW	DTW Ha*1000	LLP	Total Gwater	Total All	STW	DSSTW	DTW mm	LLP	Total Gwater	Total All
1	Dhamrai	Dhaka	1339	8	199	131	6.0	0.0	4.0	1.0	10.0	11.0	123	1	81	20	204	224
2	Dohar	Dhaka	384	0	1	29	1.7	0.0	0.0	0.2	1.7	2.0	71	0	1	9	72	81
3	Keraniganj	Dhaka	448	0	16	137	2.0	0.0	0.3	1.0	2.3	3.4	76	0	12	38	87	126
4	Nawabganj	Dhaka	1159	0	2	118	5.2	0.0	0.0	0.9	5.3	6.1	133	0	1	23	134	157
5	Savar	Dhaka	199	13	223	312	0.9	0.1	4.5	2.3	5.4	7.8	20	1	100	52	121	173
6	Joydebpur	Gazipur	172	5	250	413	0.8	0.0	5.0	3.1	5.8	8.9	14	0	90	56	104	160
7	Kaliakoir	Gazipur	283	1	264	230	1.3	0.0	5.3	1.7	6.6	8.3	26	0	106	35	132	166
8	Kaliganj	Gazipur	22	5	118	368	0.1	0.0	2.4	2.8	2.5	5.2	3	1	75	87	79	166
9	Kapasia	Gazipur	1542	4	58	471	6.9	0.0	1.2	3.5	8.1	11.6	123	0	21	63	144	206
10	Sreepur	Gazipur	132	0	240	331	0.6	0.0	4.8	2.5	5.4	7.9	8	0	65	34	73	107
11	Dewanganj	Jamalpur	611	0	10	1	2.7	0.0	0.2	0.0	2.9	3.0	41	0	3	0	44	44
12	Islampur	Jamalpur	1885	0	50	12	8.5	0.0	1.0	0.1	9.5	9.6	155	0	18	2	173	174
13	Jamalpur	Jamalpur	1889	24	397	57	8.5	0.1	7.9	0.4	16.5	17.0	110	1	103	6	215	220
14	Madarganj	Jamalpur	1998	0	10	0	9.0	0.0	0.2	0.0	9.2	9.2	244	0	5	0	250	250
15	Melandaha	Jamalpur	3143	0	88	34	14.1	0.0	1.8	0.3	15.9	16.2	369	0	46	7	415	421
16	Sharishabari	Jamalpur	1783	0	60	32	8.0	0.0	1.2	0.2	9.2	9.5	194	0	29	6	223	229
17	Daulatpur	Manikganj	704	0	22	14	3.2	0.0	0.4	0.1	3.6	3.7	93	0	13	3	106	110
18	Ghior	Manikganj	363	0	61	3	1.6	0.0	1.2	0.0	2.9	2.9	71	0	53	1	123	124
19	Harirampur	Manikganj	302	0	34	36	1.4	0.0	0.7	0.3	2.0	2.3	35	0	17	7	52	59
20	Manikganj	Manikganj	467	0	108	57	2.1	0.0	2.2	0.4	4.3	4.7	68	0	70	14	138	152
21	Saturia	Manikganj	518	0	63	5	2.3	0.0	1.3	0.0	3.6	3.6	94	0	51	2	145	147
22	Shivalaya	Manikganj	358	0	44	20	1.6	0.0	0.9	0.2	2.5	2.6	56	0	30	5	86	91
23	Singair	Manikganj	884	0	67	36	4.0	0.0	1.3	0.3	5.3	5.6	119	0	40	8	159	166
24	Lohajang	Munshiganj	419	0	3	70	1.9	0.0	0.1	0.5	1.9	2.5	91	0	3	25	94	120
25	Munshiganj	Munshiganj	15	0	1	143	0.1	0.0	0.0	1.1	0.1	1.2	3	0	1	43	4	47
26	Serajdikhan	Munshiganj	427	0	0	170	1.9	0.0	0.0	1.3	1.9	3.2	67	0	0	45	67	112
27	Sreenagar	Munshiganj	522	0	14	264	2.3	0.0	0.3	2.0	2.6	4.6	74	0	9	63	83	146
28	Tongibari	Munshiganj	137	0	0	103	0.6	0.0	0.0	0.8	0.6	1.4	26	0	0	33	26	59
29	Bhaluka	Mymensingh	151	6	170	259	0.7	0.0	3.4	1.9	4.1	6.0	10	0	48	27	58	85
30	Fulbaria	Mymensingh	90	0	305	75	0.4	0.0	6.1	0.6	6.5	7.1	5	0	79	7	84	91
31	Gaffargaon	Mymensingh	154	3	297	356	0.7	0.0	5.9	2.7	6.6	9.3	11	0	95	43	106	149
32	Muktagacha	Mymensingh	100	1	332	10	0.5	0.0	6.6	0.1	7.1	7.2	9	0	132	1	142	143
33	Mymensingh	Mymensingh	894	0	230	39	4.0	0.0	4.6	0.3	8.6	8.9	67	0	77	5	144	149
34	Trishal	Mymensingh	41	1	364	114	0.2	0.0	7.3	0.9	7.5	8.3	5	0	183	21	187	209
35	Narayanganj	Narayanganj	96	0	2	98	0.4	0.0	0.0	0.7	0.5	1.2	31	0	3	54	34	88
36	Rupganj	Narayanganj	135	0	53	365	0.6	0.0	1.1	2.7	1.7	4.4	16	0	28	72	44	117
37	Basail	Tangail	1539	0	74	79	6.9	0.0	1.5	0.6	8.4	9.0	246	0	53	21	299	320
38	Bhuapur	Tangail	776	0	37	2	3.5	0.0	0.7	0.0	4.2	4.2	98	0	21	0	118	119
39	Delduar	Tangail	973	0	110	1	4.4	0.0	2.2	0.0	6.6	6.6	161	0	81	0	241	242
40	Ghatail	Tangail	2851	0	173	57	12.8	0.0	3.5	0.4	16.3	16.7	178	0	48	6	226	232
41	Gopalpur	Tangail	2689	0	124	6	12.1	0.0	2.5	0.0	14.6	14.6	350	0	72	1	422	423
42	Kalihati	Tangail	2602	0	110	25	11.7	0.0	2.2	0.2	13.9	14.1	251	0	47	4	298	302
43	Madhupur	Tangail	2500	10	225	42	11.3	0.0	4.5	0.3	15.8	16.1	147	1	59	4	207	211
44	Mirzapur	Tangail	1869	1	274	86	8.4	0.0	5.5	0.6	13.9	14.5	144	0	94	11	237	248
45	Nagarpur	Tangail	1850	0	34	523	8.3	0.0	0.7	3.9	9.0	12.9	180	0	15	85	195	280
46	Shakhipur	Tangail	505	0	226	99	2.3	0.0	4.5	0.7	6.8	7.5	33	0	65	11	98	108
47	Tangail	Tangail	1168	0	97	9	5.3	0.0	1.9	0.1	7.2	7.3	125	0	46	2	171	172
		Total	43088	82	5640	5835	194	0	113	44	307	351						
		Average											97	0	49	23	146	169

B:\TAB221.WK1

Figure : II-2.1

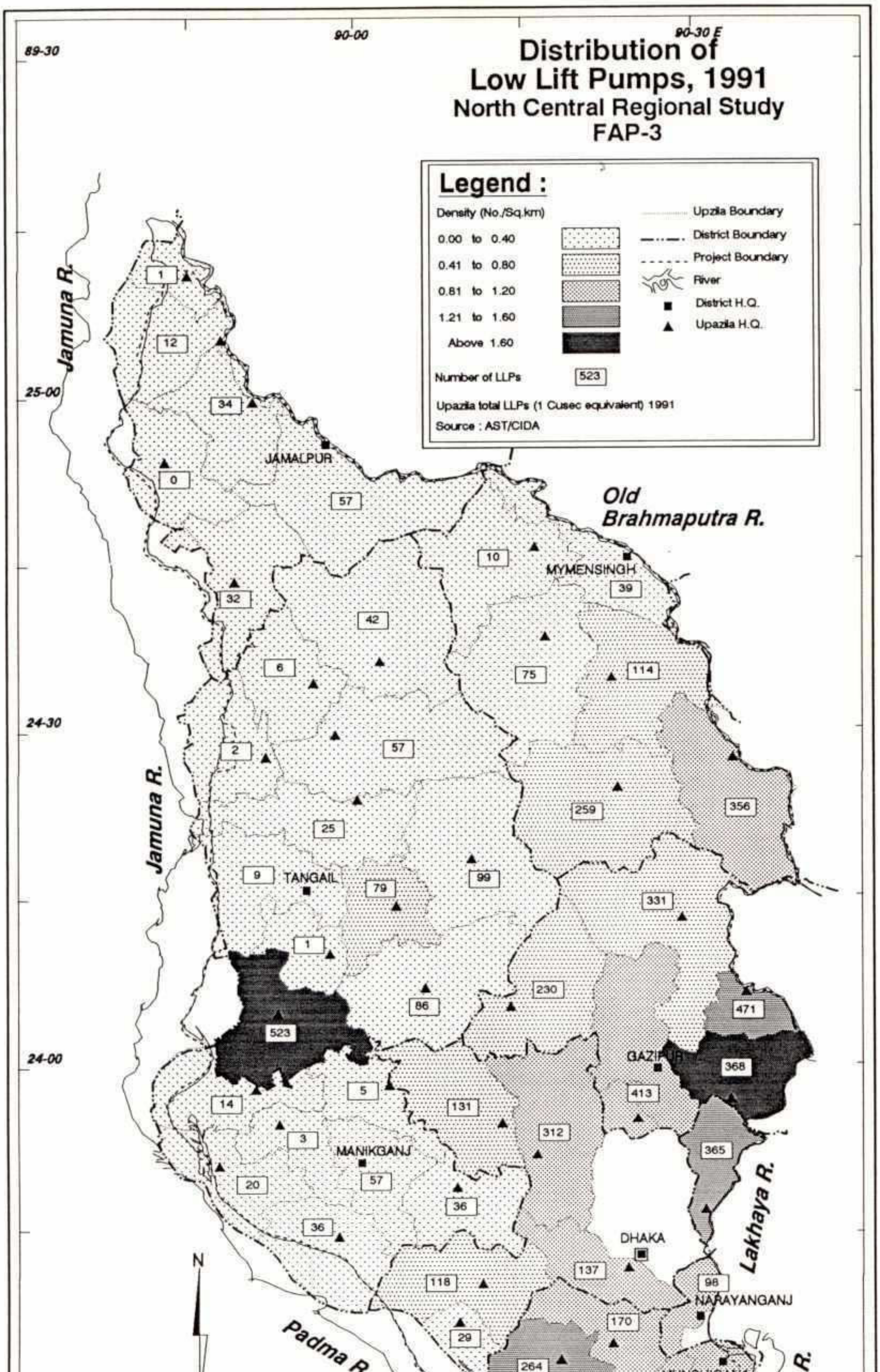

Distribution of
Low Lift Pumps, 1991
North Central Regional Study
FAP-3
Legend :
Density (No./Sq.km)
0.00 to 0.40
0.41 to 0.80
0.81 to 1.20
1.21 to 1.60
Above 1.60
Number of LLPs
523
Upzila total LLPs (1 Cusec equivalent) 1991
Source : AST/CIDA
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
89-30
90-00
90-30 E
25-00
24-30
24-00
23-30 N
Jamuna R.
Old Brahmaputra R.
Lakhaya R.
Padma R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
1
12
34
0
57
10
39
32
42
6
75
114
2
57
259
356
25
9
79
99
331
1
230
471
86
523
368
5
14
131
413
3
312
365
57
20
36
36
137
98
118
170
29
264
143
70
143
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\LLP_91.DRW

Figure : II.2.2

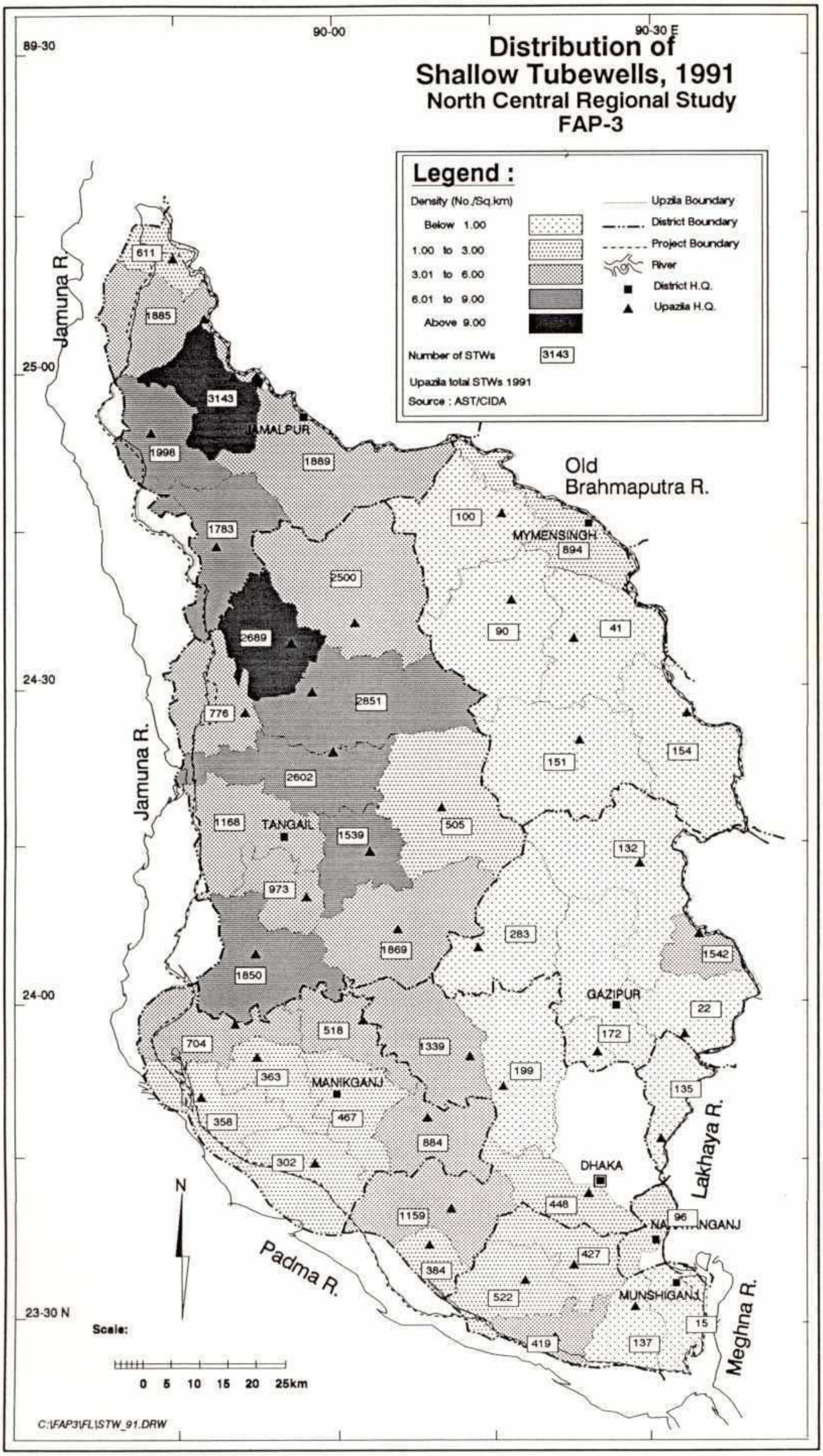
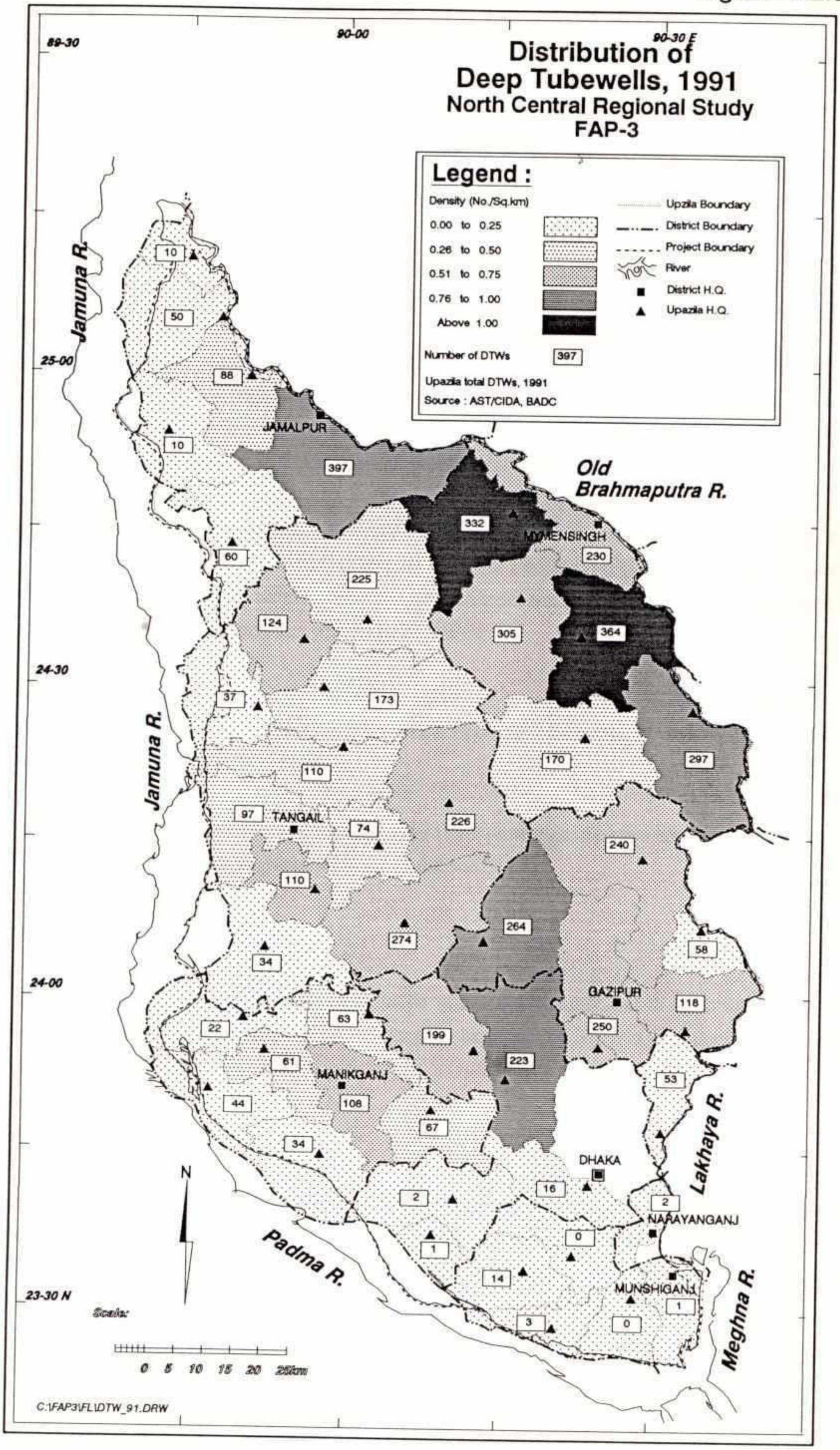

Distribution of
Shallow Tubewells, 1991
North Central Regional Study
FAP-3
Legend :
Density (No./Sq.km)
Below 1.00
1.00 to 3.00
3.01 to 6.00
6.01 to 9.00
Above 9.00
Number of STWs
3143
Upazila total STWs 1991
Source : AST/CIDA
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
89-30
90-00
90-30 E
25-00
24-30
24-00
23-30 N
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
MUNSHIGANJ
611
1885
3143
1998
1889
100
894
1783
2500
2689
90
41
2851
776
151
154
2602
1168
1539
505
132
973
283
1869
1542
1850
22
704
518
1339
172
363
199
358
467
135
884
302
448
96
1159
384
427
522
419
137
15
Scale:
0 5 10 15 20 25km
N
C:\FAP3\FL\STW_91.DRW

Figure : II.2.3



Distribution of Deep Tubewells, 1991
North Central Regional Study
FAP-3
Legend :
Density (No./Sq.km)
0.00 to 0.25
0.26 to 0.50
0.51 to 0.75
0.76 to 1.00
Above 1.00
Number of DTWs
397
Upazila total DTWs, 1991
Source : AST/CIDA, BADC
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
89-30
90-00
90-30 E
25-00
24-30
24-00
23-30 N
Jamuna R.
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
MANIKGANJ
GAZIPUR
DHAKA
NARAYANGANJ
MUNSHIGANJ
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\DTW_91.DRW

CHAPTER 3
GROUNDWATER RECHARGE

3.1 Methodology

One of the primary study requirements is to assess the effects of flood control measures on groundwater recharge. For this purpose, computer simulation of groundwater recharge based on software developed for the MPO was used.

MPO Groundwater Recharge Model

The recharge model is fully described in MPO Technical Report 5 of the National Water Plan Phase-I. Salient principles only are repeated here. The recharge model computes recharge to the aquifer system with an infinite storage capacity (that is no recharge is rejected from the system due to aquifer-full conditions). The recharge model simulates potential recharge for third monthly time steps from an analysis of the water balance of the root zone for a 17 year period of historical data.

A large number of parameters which influence potential recharge are simulated in the model, of which the main factors are rainfall, soil permeability and the degree of flooding. MPO parameters for deep percolation in the medium category (2-10 mm/day depending on soil type) were adopted, based on the results of detailed groundwater modelling calibrations conducted by MPO.

The extend, duration and depth of flooding is simulated in the MPO model, using a synthesized flood hydrograph which is based on long term average flood characteristics as defined by the flood phase classification (F0,F1,F2,F3,F4) of the land.

For the reassessment of groundwater recharge after flood protection, the simulation model was run with the MPO synthesized flood hydrograph modified as follows :

Full Flood Protection (FFP)

This is an extreme case which is unlikely to be practically feasible, but is indicative of the potential maximum impact on groundwater recharge under any circumstances. For this case, flooding was completely removed on all flood phases.

Partial Flood Protection (PFP)

This case represents the impact on groundwater recharge for the flood protection scenario which is most likely to be implemented; no changes in average flood levels, but reduction in the duration flooding. For this case, flood durations were reduced by 20 days at the beginning and 20 days at the end of the normal flood period, but average flood levels on each flood phase were retained.

Details of the synthesized flood hydrographs for unprotected, partially protected and fully flood protected cases are given in Table II.3.3 and the flood phase distribution in the study area is shown in Table II.3.4. It should be noted that the flood depths and durations indicated by the hydrographs are generalised, and cannot be related to the detailed surface water modelling results.

The MPO model simulates the recharge from rivers only as vertical flow through the river bed. Horizontal recharge components affect a narrow bankside strip 2-3 km wide. However, this component is quantitatively small relative to other recharge factors on an thana planning scale. This edge effect would yield an additional unquantified resource in the vicinity of rivers. Details of hydrographs for regional rivers have been plotted and are available on project files.

3.2 Effects of Flood Protection

The results of the recharge modelling for each of the three flood protection cases are summarized in Table II.3.1 and Figures II.3.1, II.3.2 and II.3.3.

Potential recharge with no flood protection ranges from a minimum of 500-600mm per annum in the Madhupur Tract to over 2000mm in areas south and west of Dhaka which are subject to prolonged deep flooding.

For the full flood protection case, groundwater recharge becomes dependent on infiltration from rainfall and areas of permanent open water. Recharge is substantially reduced in most areas. Large reductions exceeding 50% appear likely in areas which are presently subject to prolonged flooding such as Munshiganj. In Madhupur Tract areas where flooding is not normally widespread (except temporary and localised) reductions of typically 10 to 15% are indicated.

For the partial flood protection case, only small reductions in potential recharge are indicated, ranging up to 10% in areas where flooding is currently widespread, and less than 5% in the Madhupur Tract.

3.3 Useable Recharge

In the assessment of resource potential, useable recharge is defined by MPO as 75% of potential recharge. This allows a safety factor of 25% to account for uncertainties in the potential recharge estimate and also provides a reserve for natural baseflows. The same procedure has been followed for the NCR study, and the resulting estimates of useable recharge for partially flood protected and unprotected conditions are given in Table II.3.2.

TABLE II.3.1

North Central Region : Potential Recharge

Nr	Upazila	District	Rainfall	Pot Recharge (mm)			Recharge/Rainfall			Recharge Ratios	
			mm	NFP	PFP	FFP	NFP	PFP	FFP	PFP/NFP	FFP/NFP
1	Dhamrai	Dhaka	1886	880	818	494	47	43	26	93	56
2	Dohar	Dhaka	1776	850	803	586	48	45	33	94	69
3	Keraniganj	Dhaka	2005	1147	1094	757	57	55	38	95	66
4	Nawabganj	Dhaka	1801	880	824	562	49	46	31	94	64
5	Savar	Dhaka	1968	769	738	576	39	38	29	96	75
6	Joydebpur	Gazipur	2111	640	632	579	30	30	27	99	90
7	Kaliakoir	Gazipur	1967	758	744	665	39	38	34	98	88
8	Kaliganj	Gazipur	2246	762	732	586	34	33	26	96	77
9	Kapasia	Gazipur	2214	762	747	686	34	34	31	98	90
10	Sreepur	Gazipur	1947	690	687	666	35	35	34	100	97
11	Dewanganj	Jamalpur	2212	972	902	703	44	41	32	93	72
12	Islampur	Jamalpur	2185	1054	991	806	48	45	37	94	76
13	Jamalpur	Jamalpur	2249	694	675	618	31	30	27	97	89
14	Madarganj	Jamalpur	2087	1034	960	752	50	46	36	93	73
15	Melandaha	Jamalpur	2197	747	722	640	34	33	29	97	86
16	Sharishabari	Jamalpur	2039	699	681	630	34	33	31	97	90
17	Daulatpur	Manikganj	1890	1177	1068	596	62	57	32	91	51
18	Ghior	Manikganj	1976	1280	1122	529	65	57	27	88	41
19	Harirampur	Manikganj	1851	1151	1070	734	62	58	40	93	64
20	Manikganj	Manikganj	1852	863	806	551	47	44	30	93	64
21	Saturia	Manikganj	1920	1006	924	526	52	48	27	92	52
22	Shivalaya	Manikganj	1901	1555	1415	875	82	74	46	91	56
23	Singair	Manikganj	1961	909	845	538	46	43	27	93	59
24	Lohajang	Munshiganj	2023	3381	3272	2659	167	162	131	97	79
25	Munshiganj	Munshiganj	2314	1202	1144	846	52	49	37	95	70
26	Serajdikhan	Munshiganj	2024	2298	2207	1784	114	109	88	96	78
27	Sreenagar	Munshiganj	1947	1271	1202	782	65	62	40	95	62
28	Tongibari	Munshiganj	2218	1698	1605	952	77	72	43	95	56
29	Bhaluka	Mymensingh	2128	583	575	574	27	27	27	99	98
30	Fulbaria	Mymensingh	2192	550	550	537	25	25	24	100	98
31	Gaffargaon	Mymensingh	2206	785	755	649	36	34	29	96	83
32	Muktagacha	Mymensingh	2174	642	633	600	30	29	28	99	93
33	Mymensingh	Mymensingh	2214	622	614	574	28	28	26	99	92
34	Trishal	Mymensingh	2277	675	660	611	30	29	27	98	91
35	Narayanganj	Narayanganj	2195	1206	1121	710	55	51	32	93	59
36	Rupganj	Narayanganj	2190	1029	922	776	47	42	35	90	75
37	Basail	Tangail	1835	785	717	451	43	39	25	91	57
38	Bhuapur	Tangail	1835	953	882	585	52	48	32	93	61
39	Delduar	Tangail	1874	819	760	559	44	41	30	93	68
40	Ghatail	Tangail	1893	632	609	537	33	32	28	96	85
41	Gopalpur	Tangail	1928	765	712	550	40	37	29	93	72
42	Kalihati	Tangail	1967	824	750	495	42	38	25	91	60
43	Madhupur	Tangail	2086	682	674	644	33	32	31	99	94
44	Mirzapur	Tangail	1910	811	738	484	42	39	25	91	60
45	Nagarpur	Tangail	1848	795	750	601	43	41	33	94	76
46	Shakhipur	Tangail	1923	561	555	533	29	29	28	99	95
47	Tangail	Tangail	1820	844	769	517	46	42	28	91	61
		AVERAGE	2027	972	919	695	48	46	34	94	74

Figure : II.3.1

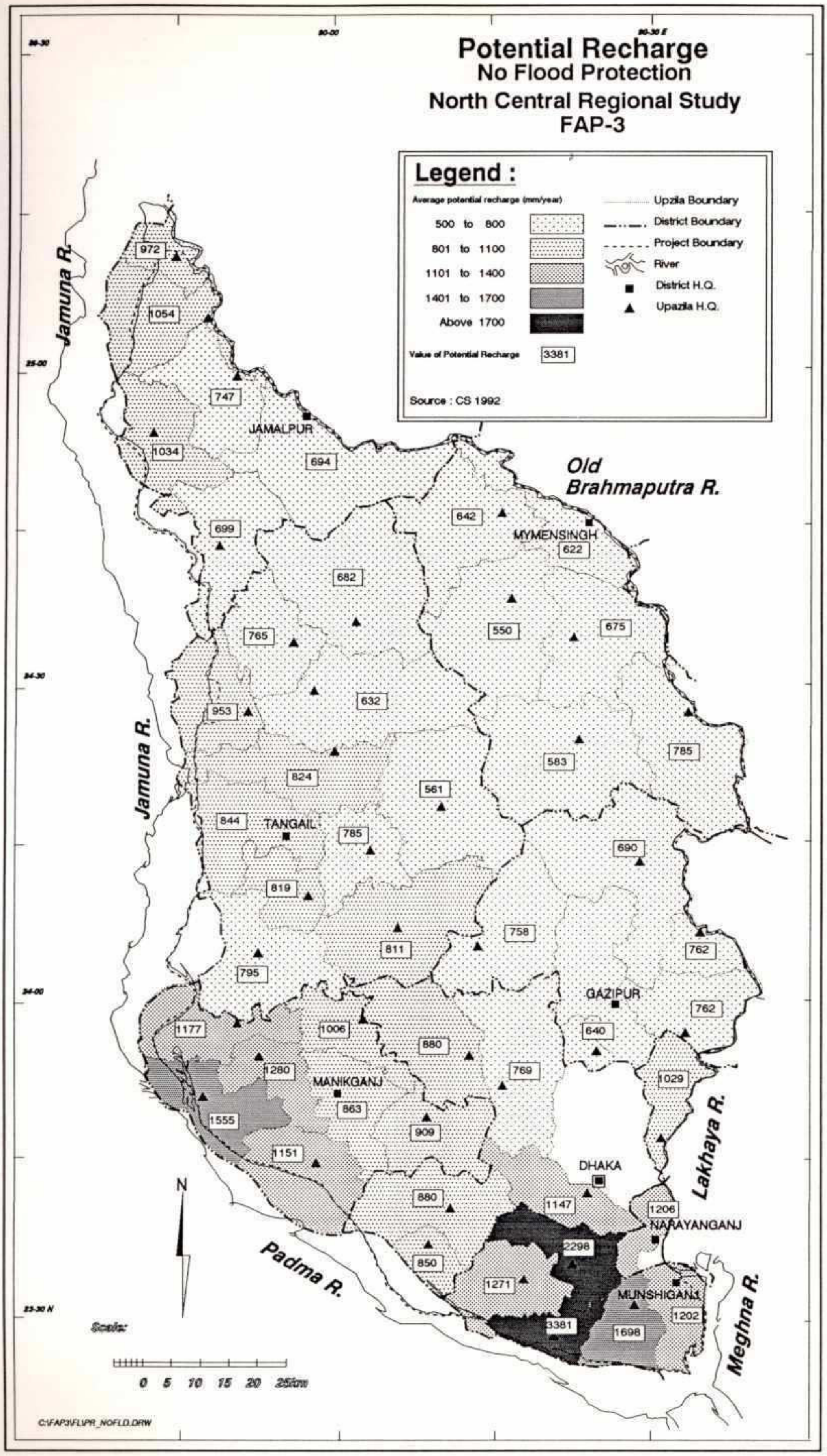

Potential Recharge
No Flood Protection
North Central Regional Study
FAP-3
Legend :
Average potential recharge (mm/year)
500 to 800
801 to 1100
1101 to 1400
1401 to 1700
Above 1700
Value of Potential Recharge
3381
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : CS 1992
Jamuna R.
Old Brahmaputra R.
Lakhaya R.
Padma R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
972
1054
747
1034
694
699
642
622
682
765
550
675
953
632
583
785
824
561
844
785
690
819
758
811
762
795
762
1177
1006
880
640
1280
769
1029
1555
863
909
1151
880
1147
1206
2298
850
1271
1202
3381
1698
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FLIPR_NOFLD.DRW

Figure : II.3.2

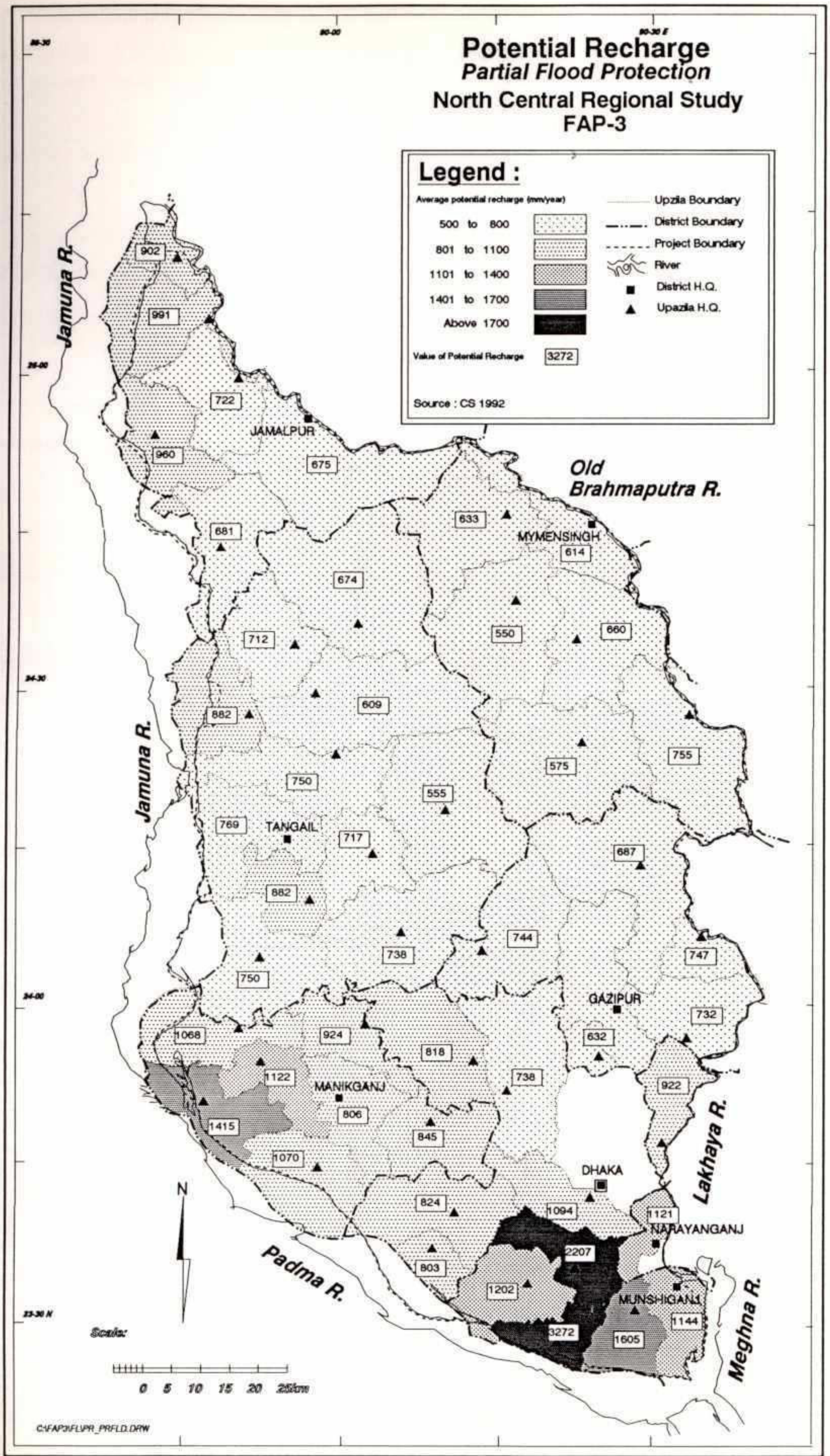

Potential Recharge
Partial Flood Protection
North Central Regional Study
FAP-3
Legend :
Average potential recharge (mm/year)
500 to 800
801 to 1100
1101 to 1400
1401 to 1700
Above 1700
Value of Potential Recharge
3272
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : CS 1992
Jamuna R.
Old Brahmaputra R.
Lakhaya R.
Padma R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
902
991
722
960
675
681
633
614
674
712
550
660
882
609
755
575
750
555
769
717
687
882
744
738
747
750
1068
924
732
818
632
1122
738
922
806
1415
845
1070
824
1094
1121
2207
803
1202
1144
3272
1605
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FLUPR_PRFLD.DRW

Figure : II.3.3

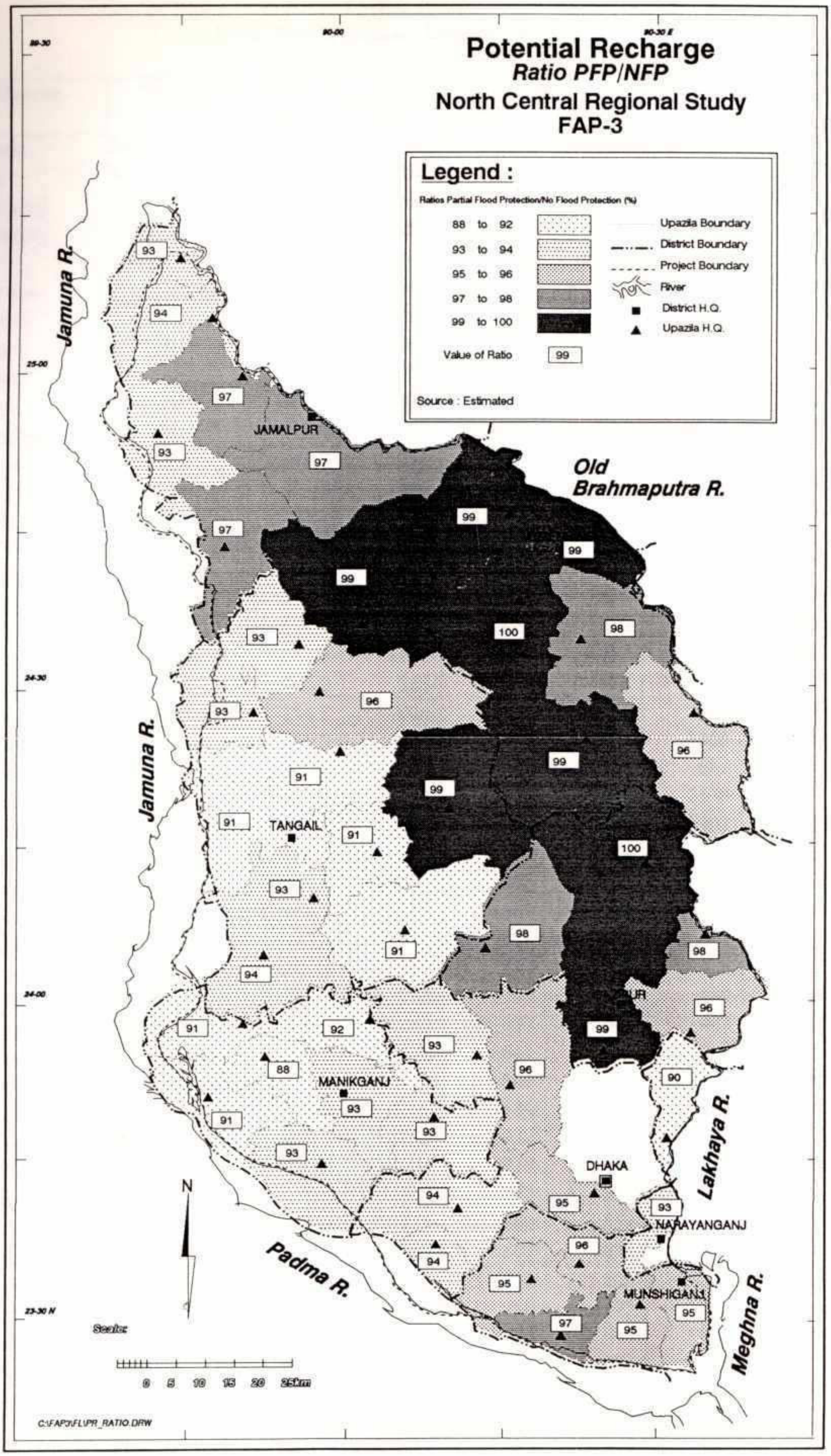

Potential Recharge
Ratio PFP/NFP
North Central Regional Study
FAP-3
Legend :
Ratios Partial Flood Protection/No Flood Protection (%)
88 to 92
93 to 94
95 to 96
97 to 98
99 to 100
Value of Ratio
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : Estimated
Jamuna R.
Old Brahmaputra R.
JAMALPUR
TANGAIL
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Padma R.
Meghna R.
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\PR_RATIO.DRW

TABLE II.3.2

North Central Region : Useable Recharge

Nr	Upazila	District	Area	Pot Recharge (mm)			Useable Recharge (mm)		
			km2	NFP	PFP	FFP	NFP	PFP	FFP
1	Dhamrai	Dhaka	307.4	880	818	494	660	614	371
2	Dohar	Dhaka	151.8	850	803	586	638	602	440
3	Keraniganj	Dhaka	166.9	1147	1094	757	860	821	568
4	Nawabganj	Dhaka	244.8	880	824	562	660	618	422
5	Savar	Dhaka	280.1	769	738	576	577	554	432
6	Joydebpur	Gazipur	347.2	640	632	579	480	474	434
7	Kaliakoir	Gazipur	311.5	758	744	665	569	558	499
8	Kaliganj	Gazipur	197.2	762	732	586	572	549	440
9	Kapasia	Gazipur	352.8	762	747	686	572	560	515
10	Sreepur	Gazipur	461.9	690	687	666	518	515	500
11	Dewanganj	Jamalpur	416.0	972	902	703	729	677	527
12	Islampur	Jamalpur	343.0	1054	991	806	791	743	605
13	Jamalpur	Jamalpur	481.2	694	675	618	521	506	464
14	Madarganj	Jamalpur	230.2	1034	960	752	776	720	564
15	Melandaha	Jamalpur	239.6	747	722	640	560	542	480
16	Sharishabari	Jamalpur	258.3	699	681	630	524	511	473
17	Daulatpur	Manikganj	211.8	1177	1068	596	883	801	447
18	Ghior	Manikganj	144.7	1280	1122	529	960	842	397
19	Harirampur	Manikganj	244.3	1151	1070	734	863	803	551
20	Manikganj	Manikganj	193.0	863	806	551	647	605	413
21	Saturia	Manikganj	154.3	1006	924	526	755	693	395
22	Shivalaya	Manikganj	181.3	1555	1415	875	1166	1061	656
23	Singair	Manikganj	209.6	909	845	538	682	634	404
24	Lohajang	Munshiganj	128.9	3381	3272	2659	2536	2454	1994
25	Munshiganj	Munshiganj	155.3	1202	1144	846	902	858	635
26	Serajdikhan	Munshiganj	178.4	2298	2207	1784	1724	1655	1338
27	Sreenagar	Munshiganj	197.1	1271	1202	782	953	902	587
28	Tongibari	Munshiganj	146.3	1698	1605	952	1274	1204	714
29	Bhaluka	Mymensingh	442.9	583	575	574	437	431	431
30	Fulbaria	Mymensingh	485.4	550	550	537	413	413	403
31	Gaffargaon	Mymensingh	391.7	785	755	649	589	566	487
32	Muktagacha	Mymensingh	313.3	642	633	600	482	475	450
33	Mymensingh	Mymensingh	374.2	622	614	574	467	461	431
34	Trishal	Mymensingh	249.3	675	660	611	506	495	458
35	Narayanganj	Narayanganj	85.8	1206	1121	710	905	841	533
36	Rupganj	Narayanganj	236.1	1029	922	776	772	692	582
37	Basail	Tangail	175.7	785	717	451	589	538	338
38	Bhuapur	Tangail	223.6	953	882	585	715	662	439
39	Delduar	Tangail	170.3	819	760	559	614	570	419
40	Ghatail	Tangail	450.6	632	609	537	474	457	403
41	Gopalpur	Tangail	215.9	765	712	550	574	534	413
42	Kalihati	Tangaif	291.9	824	750	495	618	563	371
43	Madhupur	Tangail	477.7	682	674	644	512	506	483
44	Mirzapur	Tangail	366.1	811	738	484	608	554	363
45	Nagarpur	Tangail	288.9	795	750	601	596	563	451
46	Shakhipur	Tangail	435.2	561	555	533	421	416	400
47	Tangail	Tangail	263.2	844	769	517	633	577	388
		AVERAGE		972	919	695	729	689	521

B:\TAB232.WK1

TABLE II.3.3
Synthetic Flood Hydrographs

Land Type	No Flood Protection 10 Day Flood Levels Commencing March 1st (M)												Partial Flood Protection 10 Day Flood Levels Commencing March 1st (M)												Full Flood Protection 10 Day Flood Levels Commencing March 1st (M)											
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0.5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	1	1	1	1	1	1	1	0.75	0.5	0.25	0	0	1	1	1	1	1	1	1	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0.5	1	1.5	2	0	0	0	0	0	0	0	0	0	0	1.5	2	0	0	0	0	0	0	0	0	0	0	0	0
F3	2	2	2	2	2	2	2	1.75	1.5	1.25	1	0.75	2	2	2	2	2	2	2	1.75	1.5	1.25	1	0.75	0	0	0	0	0	0	0	0	0	0	0	0
	0.5	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0.5	1.5	2	2.5	2.5	0	0	0	0	0	0	0	0	0	2	2.5	2.5	0	0	0	0	0	0	0	0	0	0	0	0
F4	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.25	2	1.75	1.5	1.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.25	2	1.75	1.5	1.25	0	0	0	0	0	0	0	0	0	0	0	0
	1	0.75	0.5	0.25	0	0	0	0	0	0	0	0	1	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1.5	2.5	3	3.5	3.5	1	1	1	1	1	1	1	1.5	2.5	3	3.5	3.5	1	1	1	1	1	1	1	1.5	2.5	3	3.5	3.5
OW	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.25	3	2.75	2.5	2.25	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.25	3	2.75	2.5	2.25	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.25	3	2.75	2.5	2.25
	2	1.75	1.5	1.25	1	1	1	1	1	1	1	1	2	1.75	1.5	1.25	1	1	1	1	1	1	1	1	2	1.75	1.5	1.25	1	1	1	1	1	1	1	1

B:\TAB233.WK1

TABLE II.3.4
North Central Region : Land Type Distribution

Nr	Upazila	District	Land Area km2	Land Type Percentages F(0) H	F(1) MH	F(2) ML	F(3) L	F(4) B+W	House	Total F0-F2	Total F0-F3	Total F0-F4	Total F0-F4+H
1	Dhamrai	Dhaka	307.42	21.33	38.00	11.32	22.75	3.00	3.60	70.65	93.40	96.40	100.00
2	Dohar	Dhaka	151.82	10.90	34.03	28.95	12.18	10.31	3.63	73.88	86.06	96.37	100.00
3	Keraniganj	Dhaka	166.88	8.00	17.22	15.96	37.82	13.18	7.82	41.18	79.00	92.18	100.00
4	Nawabganj	Dhaka	244.81	7.26	17.98	17.87	45.81	6.37	4.71	43.11	88.92	95.29	100.00
5	Savar	Dhaka	280.12	46.19	17.93	9.65	18.03	5.36	2.84	73.77	91.80	97.16	100.00
6	Joydebpur	Gazipur	347.16	53.71	18.55	10.58	9.96	3.53	3.67	82.84	92.80	96.33	100.00
7	Kaliakoir	Gazipur	311.52	51.67	18.60	11.12	11.00	4.28	3.33	81.39	92.39	96.67	100.00
8	Kaliganj	Gazipur	197.19	36.66	11.53	10.80	27.44	8.82	4.75	58.99	86.43	95.25	100.00
9	Kapasia	Gazipur	352.81	50.07	14.18	10.19	12.35	8.03	5.18	74.44	86.79	94.82	100.00
10	Sreepur	Gazipur	461.87	62.05	21.02	4.34	6.41	3.35	2.83	87.41	93.82	97.17	100.00
11	Dewanganj	Jamalpur	415.97	20.94	46.63	24.99	0.00	2.23	5.21	92.56	92.56	94.79	100.00
12	Islampur	Jamalpur	343.01	16.29	47.49	24.32	0.00	8.36	3.54	88.10	88.10	96.46	100.00
13	Jamalpur	Jamalpur	481.17	24.44	49.89	13.82	0.98	4.58	6.29	88.15	89.13	93.71	100.00
14	Madarganj	Jamalpur	230.15	20.07	46.80	26.82	0.18	2.49	3.64	93.69	93.87	96.36	100.00
15	Melandaha	Jamalpur	239.62	20.63	56.63	15.04	0.05	2.65	5.00	92.30	92.35	95.00	100.00
16	Sharishabari	Jamalpur	258.32	23.28	56.34	10.40	0.61	2.37	7.00	90.02	90.63	93.00	100.00
17	Daulatpur	Manikganj	211.78	15.97	29.34	22.63	19.47	9.97	2.62	67.94	87.41	97.38	100.00
18	Ghior	Manikganj	144.67	5.57	14.45	47.88	22.33	5.43	4.34	67.90	90.23	95.66	100.00
19	Harirampur	Manikganj	244.31	0.72	14.28	35.57	25.72	17.53	6.18	50.57	76.29	93.82	100.00
20	Manikganj	Manikganj	192.97	18.82	34.31	21.76	15.16	6.63	3.32	74.89	90.05	96.68	100.00
21	Saturia	Manikganj	154.27	22.76	36.90	14.63	18.80	4.30	2.61	74.29	93.09	97.39	100.00
22	Shivalaya	Manikganj	181.27	5.26	11.06	45.87	14.07	19.96	3.78	62.19	76.26	96.22	100.00
23	Singair	Manikganj	209.63	20.33	37.86	15.36	19.71	4.00	2.74	73.55	93.26	97.26	100.00
24	Lohajang	Munshiganj	128.89	5.00	13.95	20.53	38.01	18.88	3.63	39.48	77.49	96.37	100.00
25	Munshiganj	Munshiganj	155.32	20.70	29.10	14.94	14.59	15.10	5.57	64.74	79.33	94.43	100.00
26	Serajdikhan	Munshiganj	178.36	12.04	18.86	21.63	32.87	10.95	3.65	52.53	85.40	96.35	100.00
27	Sreenagar	Munshiganj	197.14	3.10	7.25	16.77	52.24	16.93	3.71	27.12	79.36	96.29	100.00
28	Tongibari	Munshiganj	146.28	9.25	11.65	17.95	48.07	7.25	5.83	38.85	86.92	94.17	100.00
29	Bhaluka	Mymensingh	442.87	60.23	21.86	8.46	4.16	1.14	4.15	90.55	94.71	95.85	100.00
30	Fulbaria	Mymensingh	485.41	36.39	40.64	16.77	0.41	0.26	5.53	93.80	94.21	94.47	100.00
31	Gaffargaon	Mymensingh	391.70	22.74	47.54	15.21	2.00	3.94	8.57	85.49	87.49	91.43	100.00
32	Muktagacha	Mymensingh	313.31	27.65	49.15	15.37	0.10	0.53	7.20	92.17	92.27	92.80	100.00
33	Mymensingh	Mymensingh	374.15	38.67	35.39	9.10	0.15	7.75	8.94	83.16	83.31	91.06	100.00
34	Trishal	Mymensingh	249.31	25.71	44.74	17.94	1.15	1.96	8.50	88.39	89.54	91.50	100.00
35	Narayanganj	Narayanganj	85.84	11.70	23.04	16.17	11.28	21.77	16.04	50.91	62.19	83.96	100.00
36	Rupganj	Narayanganj	236.12	21.15	9.48	15.33	41.97	7.58	4.49	45.96	87.93	95.51	100.00
37	Basail	Tangail	175.69	0.00	26.25	48.44	16.25	4.58	4.48	74.69	90.94	95.52	100.00
38	Bhuapur	Tangail	223.61	8.96	42.98	17.20	26.02	0.00	4.84	69.14	95.16	95.16	100.00
39	Delduar	Tangail	170.32	16.68	40.07	28.31	7.14	2.64	5.16	85.06	92.20	94.84	100.00
40	Ghatail	Tangail	450.64	42.26	34.43	13.28	3.67	3.25	3.11	89.97	93.64	96.89	100.00
41	Gopalpur	Tangail	215.92	16.74	43.87	24.14	4.57	5.34	5.34	84.75	89.32	94.66	100.00
42	Kalihati	Tangail	291.86	6.87	39.62	32.65	8.64	6.95	5.27	79.14	87.78	94.73	100.00
43	Madhupur	Tangail	477.73	51.04	34.72	7.13	2.34	2.37	2.40	92.89	95.23	97.60	100.00
44	Mirzapur	Tangail	366.14	20.62	31.03	28.07	9.62	5.33	5.33	79.72	89.34	94.67	100.00
45	Nagarpur	Tangail	288.92	12.42	57.80	16.28	1.30	7.43	4.77	86.50	87.80	95.23	100.00
46	Shakhipur	Tangail	435.24	55.85	32.69	5.62	1.90	1.97	1.97	94.16	96.06	98.03	100.00
47	Tangail	Tangail	263.24	9.73	52.19	24.70	2.53	6.23	4.62	86.62	89.15	95.38	100.00
			Average	23.37	31.47	19.19	14.29	6.74	4.93	74.03	88.33	95.07	100.00

NOTES Sources and corrections
1. Figures from MPO recharge model data files re_LTijk.DAT except Delduar,Mymensingh,Muktagacha (missing)
2. Delduar and Muktagacha from DNM data file MPOLT.WK1
3. Mymensingh from NCR Phase 1 report
4. Majority of MPO figures totalled 100% for (f0+f1+f2+f3+f4+housing). Others coorected to 100% by adding/subtracting differences in proportion to percentages
5. Upazilas with 0% housing (eg. Delduar) corrected by average housing percentage for region

B:\TAB234.WK1

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CHAPTER 4
GROUNDWATER RESOURCE POTENTIAL

4.1 MPO Resource Potential Limits

Estimates of groundwater resource potential for the thanas in the study area have been prepared by the MPO using computer simulation techniques which are linked to the recharge model as described in Technical Report 5 of the National Water Plan.

The groundwater resource potential, as distinct from potential recharge, is dependant on the technology employed for groundwater abstraction, which limits the accessible groundwater storage. MPO resource potential limits are given for each of five tubewell technologies, by flood phase for each thana. The potentials are defined in terms of the maximum total thana groundwater abstraction for the specified technology and flood phase. The tubewell technologies are:

- Shallow tubewells (STW) delivering 14 l/s at up to 7.5m water level.
- Deepset shallow tubewells (DSSTW) delivering 14 l/s at up to 10m water level.
- Deep tubewells (DTW) delivering 28 or 56 l/s at up to 20m water level.
- Hand tubewells for water supply (Tara) operating at up to 15m water level.

MPO groundwater resource potentials, as defined for the National Water Plan Phase-II, were obtained and reviewed with regard to currently observed development patterns, and the results are summarized in Table II 4.1.

Shallow tubewells are still capable of operating in parts of all thanas in the study area, and in most locations, numbers are continuing to increase. According to the definition of MPO groundwater potential, total current thana groundwater abstractions should therefore be lower than the MPO resource potential limits for shallow tubewells; Current groundwater abstractions exceed these MPO limits in 44 out of the 47 study thanas. This is due to the conservative approach adopted by MPO in calculating the resources, together with under estimates of certain key parameters including aquifer specific yields and vertical permeability of surface clay layers.
Considering the apparent range and frequency of discrepancies between estimated resources and actual abstractions in the study area, a review of groundwater resource potentials was undertaken.

4.2 Re-assessment of Resource Potential Limits

A revised approach has been adopted to the re-assessment of resource potential taking current groundwater abstractions and observed groundwater levels as a starting point; these two parameters are not considered in the MPO estimates. These parameters have been used to estimate the groundwater reservoir storage capacity and predict development potential limits assuming no changes in aquifer performance with increased future development.

Since aquifer storage properties generally improve with depth in the study area, this is an essentially conservative approach to the assessment. The procedure adopted, based on the aquifer response to groundwater abstractions during the 1989 drought year, is summarised as follows :

a) Thanawise groundwater abstractions during 1989 were estimated from tubewells numbers, and irrigated areas based on a water duty of 160 Ha/Mm3 as described in Chapter 2.

TABLE II.4.1

North Central Region : Comparison Between MPO Potential and Current Irrigation Water use

Nr	MPO Code	Upazila	District	1989 Irrigation Water Use (Mm3)			Total Gwater	NWP II 1991- NO CONSTRAINTS MPO Groundwater Potential (Mm3) USEABLE Recharge, 20m. PWL				NWP II 1991-WITH CONSTRAINT MPO Groundwater Potential (Mm3) AVAILABLE Recharge,20m. PWL				WITHOUT PLANNING CONSTRAINT Ratio 1989 Gwater Abstraction to MPO Useable Recharge Pot.				WITH PLANNING CONSTRAINTS Ratio 1989 Gwater Abstraction to MPO Available Recharge Pot.			
				STW	DSSTW	DTW		STW	DSSTW	DTW-2	DTW-1	STW	DSSTW	DTW-2	DTW-1	STW	DSSTW	DTW-2	DTW-1	STW	DSSTW	DTW-2	DTW-1
1	138	Dhamrai	Dhaka	35.4	0.0	28.1	63.6	4.0	27.6	113.6	113.6	3.4	23.3	96.1	96.1	15.9	2.3	0.6	0.6	18.8	2.7	0.7	0.7
2	145	Dohar	Dhaka	7.9	0.0	0.1	8.1	5.9	10.6	41.2	41.9	4.4	7.8	30.5	30.9	1.4	0.8	0.2	0.2	1.8	1.0	0.3	0.3
3	257	Keraniganj	Dhaka	7.9	0.0	0.9	8.8	1.6	7.7	31.8	48.8	1.3	5.9	24.3	37.3	5.3	1.1	0.3	0.2	7.0	1.5	0.4	0.2
4	364	Nawabganj	Dhaka	23.1	0.0	0.0	23.1	11.7	28.6	74.0	74.0	9.3	22.6	58.6	58.6	2.0	0.8	0.3	0.3	2.5	1.0	0.4	0.4
5	444	Savar	Dhaka	4.0	0.4	38.3	42.6	0.0	1.0	89.3	116.1	0.0	0.9	100.0	100.0	*	42.6	0.5	0.4	*	49.5	0.4	0.4
6	221	Joydebpur	Gazipur	2.2	0.0	28.3	30.5	0.0	0.0	54.3	85.2	0.0	0.0	42.7	67.1	*	*	0.6	0.4	*	*	0.7	0.5
7	236	Kaliakoir	Gazipur	3.8	0.5	34.3	38.6	0.0	0.0	45.8	84.0	0.0	0.0	41.9	76.9	*	*	0.8	0.5	*	*	0.9	0.5
8	237	Kaliganj	Gazipur	0.4	0.0	15.5	15.9	2.8	13.0	53.0	77.6	2.4	11.0	45.0	65.9	5.7	1.2	0.3	0.2	6.7	1.4	0.4	0.2
9	245	Kapasia	Gazipur	13.6	0.1	0.1	13.8	16.5	28.6	85.4	132.3	12.6	21.8	65.2	101.0	0.8	0.5	0.2	0.1	1.1	0.6	0.2	0.1
10	470	Sreepur	Gazipur	1.4	0.1	38.0	39.5	0.0	0.0	51.1	151.7	0.0	0.0	38.9	115.5	*	*	0.8	0.3	*	*	1.0	0.3
11	136	Dewanganj	Jamalpur	15.8	0.0	1.4	17.1	14.4	62.9	110.1	110.1	11.8	51.7	90.6	90.6	1.2	0.3	0.2	0.2	1.4	0.3	0.2	0.2
12	207	Islampur	Jamalpur	41.8	0.0	6.0	47.8	47.4	114.0	166.7	166.7	39.2	94.2	137.7	137.7	1.0	0.4	0.3	0.3	1.2	0.5	0.3	0.3
13	214	Jamalpur	Jamalpur	39.2	1.7	46.4	87.2	44.6	121.6	233.5	233.5	42.7	116.3	223.4	223.4	2.0	0.7	0.4	0.4	2.0	0.7	0.4	0.4
14	300	Madarganj	Jamalpur	49.4	0.0	0.5	49.9	25.6	53.1	88.5	88.5	25.3	52.4	87.3	87.3	1.9	0.9	0.6	0.6	2.0	1.0	0.6	0.6
15	315	Melandaha	Jamalpur	57.5	0.0	12.6	70.2	32.4	65.5	127.6	127.6	31.7	64.1	124.8	124.8	2.2	1.1	0.5	0.5	2.2	1.1	0.6	0.6
16	440	Sharishabari	Jamalpur	42.3	0.0	8.9	51.1	42.0	87.2	97.1	97.1	32.6	67.8	75.5	75.5	1.2	0.6	0.5	0.5	1.6	0.8	0.7	0.7
17	127	Daulatpur	Manikganj	25.0	0.0	1.5	26.5	4.3	17.1	79.3	81.4	2.5	9.9	45.9	47.2	6.2	1.5	0.3	0.3	10.6	2.7	0.6	0.6
18	173	Ghior	Manikganj	11.0	0.0	4.5	15.5	0.0	5.3	47.3	56.4	0.0	4.6	40.7	48.4	*	2.9	0.3	0.3	*	3.4	0.4	0.3
19	199	Harirampur	Manikganj	6.8	0.0	1.1	7.9	2.6	13.8	66.9	99.7	2.0	10.4	50.2	74.8	3.1	0.6	0.1	0.1	4.1	0.8	0.2	0.1
20	309	Manikganj	Manikganj	13.1	0.0	11.4	24.5	0.0	4.0	46.7	85.4	0.0	3.4	39.9	72.9	*	6.1	0.5	0.3	*	7.2	0.6	0.3
21	443	Saturia	Manikganj	17.2	0.0	10.6	27.9	3.6	13.3	57.0	68.9	3.3	12.2	52.3	63.1	7.7	2.1	0.5	0.4	8.4	2.3	0.5	0.4
22	458	Shivalaya	Manikganj	10.5	0.0	1.5	12.0	7.5	16.8	65.1	89.9	5.9	13.2	45.7	70.8	1.6	0.7	0.2	0.1	2.0	0.9	0.3	0.2
23	461	Singair	Manikganj	22.0	0.0	7.0	29.0	4.5	14.6	79.9	93.2	4.1	13.4	73.4	85.6	6.4	2.0	0.4	0.3	7.0	2.2	0.4	0.3
24	298	Lohajang	Munshiganj	10.4	0.0	0.4	10.7	5.9	10.6	39.1	44.7	4.2	7.5	27.7	31.6	1.8	1.0	0.3	0.2	2.6	1.4	0.4	0.3
25	342	Munshiganj	Munshiganj	0.9	0.0	0.1	1.0	1.9	5.0	16.2	21.3	1.5	4.0	13.2	17.3	0.5	0.2	0.1	0.0	0.6	0.2	0.1	0.1
26	446	Serajdikhan	Munshiganj	10.6	0.1	0.0	10.6	6.8	15.0	63.6	71.9	5.5	12.2	51.6	58.3	1.6	0.7	0.2	0.1	1.9	0.9	0.2	0.2
27	469	Sreenagar	Munshiganj	14.0	0.0	0.6	14.6	9.2	19.8	93.2	112.4	6.1	13.0	61.4	74.0	1.6	0.7	0.2	0.1	2.4	1.1	0.2	0.2
28	493	Tongibari	Munshiganj	2.8	0.1	0.0	3.0	5.0	9.8	39.5	52.0	3.9	7.6	30.8	40.6	0.6	0.3	0.1	0.1	0.8	0.4	0.1	0.1
29	66	Bhaluka	Mymensingh	5.0	0.0	22.8	27.8	4.0	17.3	65.5	102.2	3.5	15.2	57.5	89.8	6.9	1.6	0.4	0.3	7.9	1.8	0.5	0.3
30	164	Fulbaria	Mymensingh	3.6	0.3	43.6	47.5	25.1	39.1	118.8	146.2	22.7	35.4	107.6	132.5	1.9	1.2	0.4	0.3	2.1	1.3	0.4	0.4
31	179	Gaffargaon	Mymensingh	3.2	0.0	44.5	47.7	19.7	32.7	98.4	123.0	18.8	31.2	93.8	117.3	2.4	1.5	0.5	0.4	2.5	1.5	0.5	0.4
32	340	Muktagacha	Mymensingh	1.5	0.2	40.0	41.7	19.0	32.4	117.4	139.1	17.4	29.6	107.4	127.2	2.2	1.3	0.4	0.3	2.4	1.4	0.4	0.3
33	276	Mymensingh	Mymensingh	18.2	0.1	29.6	47.9	19.4	35.2	159.9	198.5	17.5	31.7	143.9	178.6	2.5	1.4	0.3	0.2	2.7	1.5	0.3	0.3
34	494	Trishal	Mymensingh	0.5	0.3	32.5	33.3	15.1	26.3	86.6	103.3	13.2	23.0	75.9	90.6	2.2	1.3	0.4	0.3	2.5	1.4	0.4	0.4
35	359	Narayanganj	Narayanganj	0.9	0.0	0.3	1.2	3.5	5.9	17.1	20.4	2.7	4.5	13.0	15.5	0.3	0.2	0.1	0.1	0.4	0.3	0.1	0.1
36	426	Rupganj	Narayanganj	2.3	0.1	11.5	13.9	4.8	12.5	49.0	61.8	2.5	6.4	25.2	31.8	2.9	1.1	0.3	0.2	5.6	2.2	0.6	0.4
37	54	Basail	Tangail	40.2	0.0	10.5	50.7	43.3	86.3	110.6	110.6	43.3	86.3	110.6	110.6	1.2	0.6	0.5	0.5	1.2	0.6	0.5	0.5
38	73	Bhuapur	Tangail	19.3	0.0	5.3	24.5	23.5	59.9	85.1	85.1	12.0	30.6	43.4	43.4	1.0	0.4	0.3	0.3	2.0	0.8	0.6	0.6
39	133	Delduar	Tangail	27.6	0.0	15.6	43.3	17.7	40.2	84.0	84.0	16.8	38.2	80.0	80.0	2.4	1.1	0.5	0.5	2.6	1.1	0.5	0.5
40	172	Ghatail	Tangail	75.1	0.0	27.5	102.6	75.6	137.9	169.1	169.1	69.3	126.5	155.1	155.1	1.4	0.7	0.6	0.6	1.5	0.8	0.7	0.7
41	184	Gopalpur	Tangail	54.3	0.0	20.1	74.4	36.7	60.2	112.4	112.4	36.1	59.2	110.6	110.6	2.0	1.2	0.7	0.7	2.1	1.3	0.7	0.7
42	241	Kalihati	Tangail	71.6	0.0	16.4	88.0	35.1	65.5	162.9	162.9	33.5	62.4	155.3	155.3	2.5	1.3	0.5	0.5	2.6	1.4	0.6	0.6
43	303	Madhupur	Tangail	46.3	0.2	32.0	78.5	0.0	65.0	143.7	143.7	0.0	61.2	135.3	135.3	*	1.2	0.5	0.5	*	1.3	0.6	0.6
44	316	Mirzapur	Tangail	54.3	0.1	31.9	86.2	0.0	0.0	139.5	139.5	0.0	0.0	131.1	131.1	*	*	0.6	0.6	*	*	0.7	0.7
45	348	Nagarpur	Tangail	66.1	0.0	3.8	69.8	23.4	48.3	73.8	73.8	22.7	46.8	71.5	71.5	3.0	1.4	0.9	0.9	3.1	1.5	1.0	1.0
46	448	Shakhipur	Tangail	16.8	0.0	28.4	45.2	0.0	0.0	38.1	96.7	0.0	0.0	38.1	96.7	*	*	1.2	0.5	*	*	1.2	0.5
47	480	Tangail	Tangail	34.2	0.0	13.6	47.8	25.2	62.6	112.5	112.5	24.6	61.0	109.7	109.7	1.9	0.8	0.4	0.4	1.9	0.8	0.4	0.4

B:\TAB241.WK1   * MPO potential = 0

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b) Data on thanawise groundwater levels during 1989 were collected from BWDB, BADC and the Deep Tubewell-II project. Average static water levels were estimated for the beginning and end of the 1989 irrigation season (beginning of January and end of April). The total groundwater abstraction and corresponding water level decline during the irrigation season was used to estimate the effective storage capacity of the aquifer in each thana. Details are given in Tables II.4.2 and II.4.3 and in Figures II.4.1 and II.4.2. Values of storage co-efficient varying between 1-16% are reasonable for the range of geological conditions in the study area.

c) Thanawise average DTW specific capacities (l/s per metre of drawdown) were estimated from pumping test results provided by BADC. The distribution is shown in Figure II.4.3.

d) Maximum pumping levels applicable to deep and shallow tubewells were set considering current practices and likely future performance limits. Field observations indicate that shallow tubewells commonly operate successfully with pumped water levels up to 7.5 m, with typical maximum pit installations around 2-3 m below ground level for deep setting. Deep tubewell pump inlet setting depths currently being installed by BADC, range between 20-25m depending on conditions. Maximum pumped water levels were therefore set at:

- STW : 7.5 m at 14 l/s
- DSSTW : 10 m at 14 l/s
- DTW : 20-25 m at 28-56 l/s depending on conditions

e) Development potential limits were calculated from the effective aquifer storage and average tubewell drawdown at the maximum pumped water level specified for each well type. Corrections to observed static water levels from the reference point of BWDB observation wells were made for estimation of developed potential limits according to flood phase as:

Flood Phase	Deduction form observed Static Water Level (m)
FO	1.0
F1	2.0
F2	3.0
F4	4.0

In the Madhupur Tract, relief differences are greater (up to 7m) and shallow water tables are isolated from deep aquifers by thick clay sequences. Additional adjustments to effective water levels were required in these areas to match current abstractions to the calculated resource potential limits.

f) The resource potential limits were finally adjusted to match maximum useable recharge constraints for no flood protection and partial flood protection cases, as summarised in Table II.4.4.

Present groundwater development in the study area relative to estimated resource potential is shown in Figure II.4.4. Under present conditions (no flood protection), present development ranges from 2-88% of resource potential, and averages 33% for the study area. The introduction of partial flood protection would have no significant effect on this distribution. The RWRDP plan recommends that any developments should be with partial flood protection through controlled flooding schemes. It should be noted that if full flood protection were to be implemented then considerable reductions in recharge would be experienced, see Section 3.2

TABLE II.4.2

Summary of Groundwater Level Data Static Water Levels (m)

Nr	Upazila	District	Minimum			January		Maximum		
			DTW 2 Av	BWDB Av	BWDB Max	BWDB Av	BWDB Max	DTW 2 Av	BWDB Av	BWDB Max
1	Dhamrai	Dhaka	2.1	2.5	2.7	5.0	6.6	6.3	8.2	10.6
2	Dohar	Dhaka		1.9	2.1	4.0	4.6		6.3	7.0
3	Keraniganj	Dhaka	1.5	2.5	2.5	5.3	5.3	5.2	6.2	6.2
4	Nawabganj	Dhaka	1.5	3.0	4.4	4.4	4.9	4.9	7.9	9.9
5	Savar	Dhaka	3.7	3.8	3.8	6.5	6.5	10.0	8.2	8.2
6	Joydebpur	Gazipur	6.9	5.7	8.0	7.2	9.9	14.4	14.3	14.7
7	Kaliakoir	Gazipur	7.0	3.6	7.5	6.3	9.9	12.0	10.8	13.0
8	Kaliganj	Gazipur	3.6	5.3	5.3	6.3	6.3	13.7	9.8	9.8
9	Kapasia	Gazipur	4.3	1.8	1.8	3.2	3.2	7.5	7.2	7.2
10	Sreepur	Gazipur	5.3	2.6	2.7	5.6	7.8	9.8	9.5	11.1
11	Dewanganj	Jamalpur		1.6	1.6	5.0	5.0		6.4	6.4
12	Islampur	Jamalpur		1.8	2.2	5.0	5.8		6.3	6.8
13	Jamalpur	Jamalpur		2.1	3.8	4.2	6.9		6.7	8.7
14	Madarganj	Jamalpur		2.6	2.8	4.6	5.3		5.9	7.0
15	Melandaha	Jamalpur		2.0	2.0	4.6	4.6		7.2	7.2
16	Sharishabari	Jamalpur		1.9	1.9	4.7	4.7		6.7	6.7
17	Daulatpur	Manikganj	1.2	2.5	2.7	4.7	5.5	6.1	6.3	7.2
18	Ghior	Manikganj	1.1	2.6	2.6	6.4	6.4	5.2	7.6	7.6
19	Harirampur	Manikganj	1.2	2.5	2.9	5.3	5.9	4.2	7.4	8.1
20	Manikganj	Manikganj	1.8	2.2	2.5	6.0	6.5	6.0	7.9	8.1
21	Saturia	Manikganj	2.5					5.3		
22	Shivalaya	Manikganj	1.4	2.3	2.5	4.6	4.7	6.1	7.2	7.5
23	Singair	Manikganj	1.6	2.2	2.5	4.7	5.1	5.9	6.4	7.2
24	Lohajang	Munshiganj		1.4	1.4	4.4	4.4		6.4	6.4
25	Munshiganj	Munshiganj								
26	Serajdikhan	Munshiganj		1.8	2.1	4.1	4.2		5.7	5.7
27	Sreenagar	Munshiganj	1.5	2.2	2.2	4.7	4.7		6.5	6.5
28	Tongibari	Munshiganj		3.0	3.0	4.1	4.1		4.3	4.3
29	Bhaluka	Mymensingh	4.1	3.2	4.1	4.7	6.0	9.7	9.4	10.5
30	Fulbaria	Mymensingh	2.4	0.7	0.7	1.7	1.7	13.4	10.5	10.5
31	Gaffargaon	Mymensingh	2.5	2.6	2.6	3.3	4.0	10.3	10.2	11.6
32	Muktagacha	Mymensingh	2.4	2.6	3.2	3.9	4.6	12.4	10.7	15.5
33	Mymensingh	Mymensingh	3.5	2.9	2.9	4.8	4.8	10.9	10.0	10.1
34	Trishal	Mymensingh	2.9	5.4	5.5	5.4	5.5	12.9	13.9	15.0
35	Narayanganj	Narayanganj		0.8	0.8	1.8	1.8		2.3	2.3
36	Rupganj	Narayanganj	2.8	2.3	2.3	4.8	4.8	9.9	6.3	6.3
37	Basail	Tangail		2.1	2.3	4.6	5.1		6.9	7.1
38	Bhuapur	Tangail		1.3	1.3	4.9	4.9		6.3	6.3
39	Delduar	Tangail								
40	Ghatail	Tangail		1.9	2.4	4.5	5.1		6.5	6.8
41	Gopalpur	Tangail		2.1	2.2	3.9	4.2		7.1	7.6
42	Kalihati	Tangail		3.0	5.4	4.7	7.6		7.8	13.1
43	Madhupur	Tangail		2.3	3.5	4.6	6.5		7.7	10.7
44	Mirzapur	Tangail		5.8	7.8	8.0	10.5		10.4	12.6
45	Nagarpur	Tangail		2.2	2.9	5.1	5.7		7.1	7.5
46	Shakhipur	Tangail		2.4	2.4	4.5	4.5		12.4	12.4
47	Tangail	Tangail		1.9	2.6	4.3	5.5		6.6	8.0

TABLE II.4.3

North Central Region : Aquifer Performance in 1989

Nr	MPO Code	Upazila	District	1988/89 Irrigation (units) STW	DSSTW	DTW	LLP 1	1988/89 Irrigation (Ha) STW	DSSTW	DTW	LLP 1	TOTAL G'WATER	AQUIFER PERFORMANCE: 1988/89 Groundwater Levels (m) Average January	Average April	Average Decline	Effective Storage Coeff	Specific Capacity l/s/m
1	138	Dhamrai	Dhaka	1260	0	225	157	35.4	0.0	28.1	7.4	63.6	5.0	8.2	3.2	0.065	9.3
2	145	Dohar	Dhaka	282	0	1	22	7.9	0.0	0.1	1.0	8.1	4.0	6.3	2.3	0.040	7.0
3	257	Keraniganj	Dhaka	280	0	7	161	7.9	0.0	0.9	7.6	8.8	5.3	6.2	0.9	0.058	7.1
4	364	Nawabganj	Dhaka	820	0	0	213	23.1	0.0	0.0	10.0	23.1	4.4	7.9	3.5	0.050	11.6
5	444	Savar	Dhaka	141	15	306	279	4.0	0.4	38.3	13.1	42.6	6.5	10.0	3.5	0.043	6.6
6	221	Joydebpur	Gazipur	78	1	226	269	2.2	0.0	28.3	12.6	30.5	7.2	14.3	7.1	0.012	5.2
7	236	Kaliakoir	Gazipur	136	19	274	184	3.8	0.5	34.3	8.6	38.6	6.3	12.0	5.7	0.022	5.2
8	237	Kaliganj	Gazipur	13	1	124	265	0.4	0.0	15.5	12.4	15.9	6.3	13.7	7.4	0.011	6.3
9	245	Kapasia	Gazipur	485	2	1	246	13.6	0.1	0.1	11.5	13.8	3.2	7.2	4.0	0.010	4.6
10	470	Sreepur	Gazipur	50	5	304	369	1.4	0.1	38.0	17.3	39.5	5.6	9.8	4.2	0.020	6.2
11	136	Dewanganj	Jamalpur	560	0	11	4	15.8	0.0	1.4	0.2	17.1	5.0	6.4	1.4	0.100	17.0
12	207	Islampur	Jamalpur	1487	0	48	18	41.8	0.0	6.0	0.8	47.8	5.0	6.3	1.3	0.107	17.8
13	214	Jamalpur	Jamalpur	1392	60	371	90	39.2	1.7	46.4	4.2	87.2	4.2	6.7	2.5	0.073	10.0
14	300	Madarganj	Jamalpur	1756	0	4	0	49.4	0.0	0.5	0.0	49.9	4.6	5.9	1.3	0.167	20.6
15	315	Melandaha	Jamalpur	2046	0	101	36	57.5	0.0	12.6	1.7	70.2	4.6	7.2	2.6	0.113	15.0
16	440	Sharishabari	Jamalpur	1503	0	71	176	42.3	0.0	8.9	8.3	51.1	4.7	6.7	2.0	0.099	17.8
17	127	Daulatpur	Manikganj	888	0	12	40	25.0	0.0	1.5	1.9	26.5	4.7	6.3	1.6	0.078	15.5
18	173	Ghior	Manikganj	392	0	36	12	11.0	0.0	4.5	0.6	15.5	6.4	7.6	1.2	0.089	11.6
19	199	Harirampur	Manikganj	242	0	9	37	6.8	0.0	1.1	1.7	7.9	6.5	7.4	0.9	0.036	11.6
20	309	Manikganj	Manikganj	464	1	91	72	13.1	0.0	11.4	3.4	24.5	6.0	7.9	1.9	0.067	11.6
21	443	Saturia	Manikganj	613	0	85	7	17.2	0.0	10.6	0.3	27.9	5.0	7.5	2.5	0.072	11.6
22	458	Shivalaya	Manikganj	373	0	12	52	10.5	0.0	1.5	2.4	12.0	6.0	7.2	1.2	0.055	13.3
23	461	Singair	Manikganj	782	0	56	34	22.0	0.0	7.0	1.6	29.0	4.7	6.4	1.7	0.081	10.3
24	298	Lohajang	Munshiganj	368	0	3	50	10.4	0.0	0.4	2.4	10.7	4.4	6.4	2.0	0.042	10.0
25	342	Munshiganj	Munshiganj	31	0	1	95	0.9	0.0	0.1	4.5	1.0	4.3	4.5	0.2	0.032	10.0
26	446	Serajdikhan	Munshiganj	376	2	0	182	10.6	0.1	0.0	8.5	10.6	4.1	5.7	1.6	0.037	10.0
27	469	Sreenagar	Munshiganj	498	0	5	288	14.0	0.0	0.6	13.5	14.6	4.7	6.5	1.8	0.041	15.5
28	493	Tongibari	Munshiganj	100	5	0	166	2.8	0.1	0.0	7.8	3.0	4.1	5.0	0.9	0.040	10.0
29	66	Bhaluka	Mymensingh	177	1	182	366	5.0	0.0	22.8	17.2	27.8	4.7	9.7	5.0	0.013	4.4
30	164	Fulbaria	Mymensingh	127	9	349	116	3.6	0.3	43.6	5.5	47.5	1.7	13.4	11.7	0.008	6.2
31	179	Gaffargaon	Mymensingh	112	0	356	303	3.2	0.0	44.5	14.2	47.7	3.3	10.3	7.0	0.017	5.5
32	340	Muktagacha	Mymensingh	54	7	320	38	1.5	0.2	40.0	1.8	41.7	3.9	12.4	8.5	0.016	7.7
33	276	Mymensingh	Mymensingh	648	2	237	28	18.2	0.1	29.6	1.3	47.9	4.8	10.9	6.1	0.021	7.7
34	494	Trishal	Mymensingh	19	9	260	101	0.5	0.3	32.5	4.8	33.3	5.4	13.9	8.5	0.016	5.8
35	359	Narayanganj	Narayanganj	32	0	2	65	0.9	0.0	0.3	3.1	1.2	1.8	2.3	0.5	0.027	10.0
36	426	Rupganj	Narayanganj	82	4	92	431	2.3	0.1	11.5	20.2	13.9	4.8	9.9	5.1	0.012	4.9
37	54	Basail	Tangail	1430	0	84	93	40.2	0.0	10.5	4.3	50.7	4.6	6.9	2.3	0.126	10.0
38	73	Bhuapur	Tangail	685	0	42	4	19.3	0.0	5.3	0.2	24.5	4.9	6.3	1.4	0.078	14.0
39	133	Delduar	Tangail	983	0	125	2	27.6	0.0	15.6	0.1	43.3	4.5	7.5	3.0	0.085	13.9
40	172	Ghatail	Tangail	2670	0	220	69	75.1	0.0	27.5	3.2	102.6	4.5	6.5	2.0	0.114	10.0
41	184	Gopalpur	Tangail	1931	0	161	1	54.3	0.0	20.1	0.1	74.4	3.9	7.1	3.2	0.108	15.0
42	241	Kalihati	Tangail	2545	0	131	15	71.6	0.0	16.4	0.7	88.0	4.7	7.8	3.1	0.097	12.0
43	303	Madhupur	Tangail	1647	7	256	73	46.3	0.2	32.0	3.4	78.5	4.6	7.7	3.1	0.053	10.0
44	316	Mirzapur	Tangail	1931	2	255	75	54.3	0.1	31.9	3.5	86.2	8.0	10.4	2.4	0.098	9.8
45	348	Nagarpur	Tangail	2350	0	30	523	66.1	0.0	3.8	24.5	69.8	5.1	7.1	2.0	0.121	12.6
46	448	Shakhipur	Tangail	598	0	227	108	16.8	0.0	28.4	5.1	45.2	4.5	12.4	7.9	0.013	6.7
47	480	Tangail	Tangail	1215	0	109	12	34.2	0.0	13.6	0.6	47.8	4.3	6.6	2.3	0.079	14.7
			Total	36652	152	5822	5948	1031	4	728	279	1763					
			Average										4.8	8.1	3.3	0.059	10.4

B:\TAB243.WK1

Figure: II.4.1

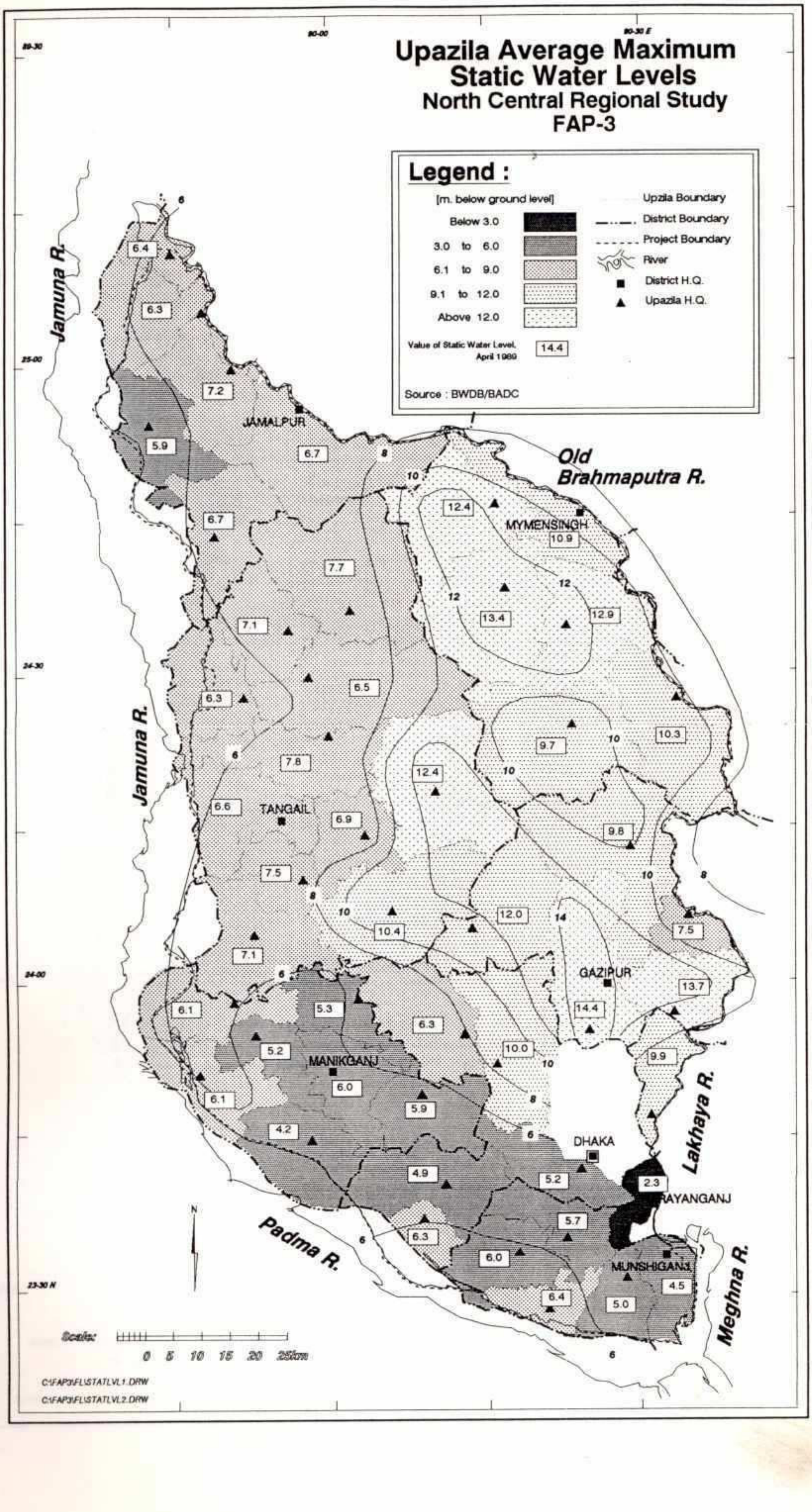

Upazila Average Maximum Static Water Levels
North Central Regional Study
FAP-3
Legend :
[m. below ground level]
Below 3.0
3.0 to 6.0
6.1 to 9.0
9.1 to 12.0
Above 12.0
Value of Static Water Level, April 1989
14.4
Upzila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : BWDB/BADC
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
MUNSHIGANJ
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\STATLVL1.DRW
C:\FAP3\FL\STATLVL2.DRW

Figure: II.4.2

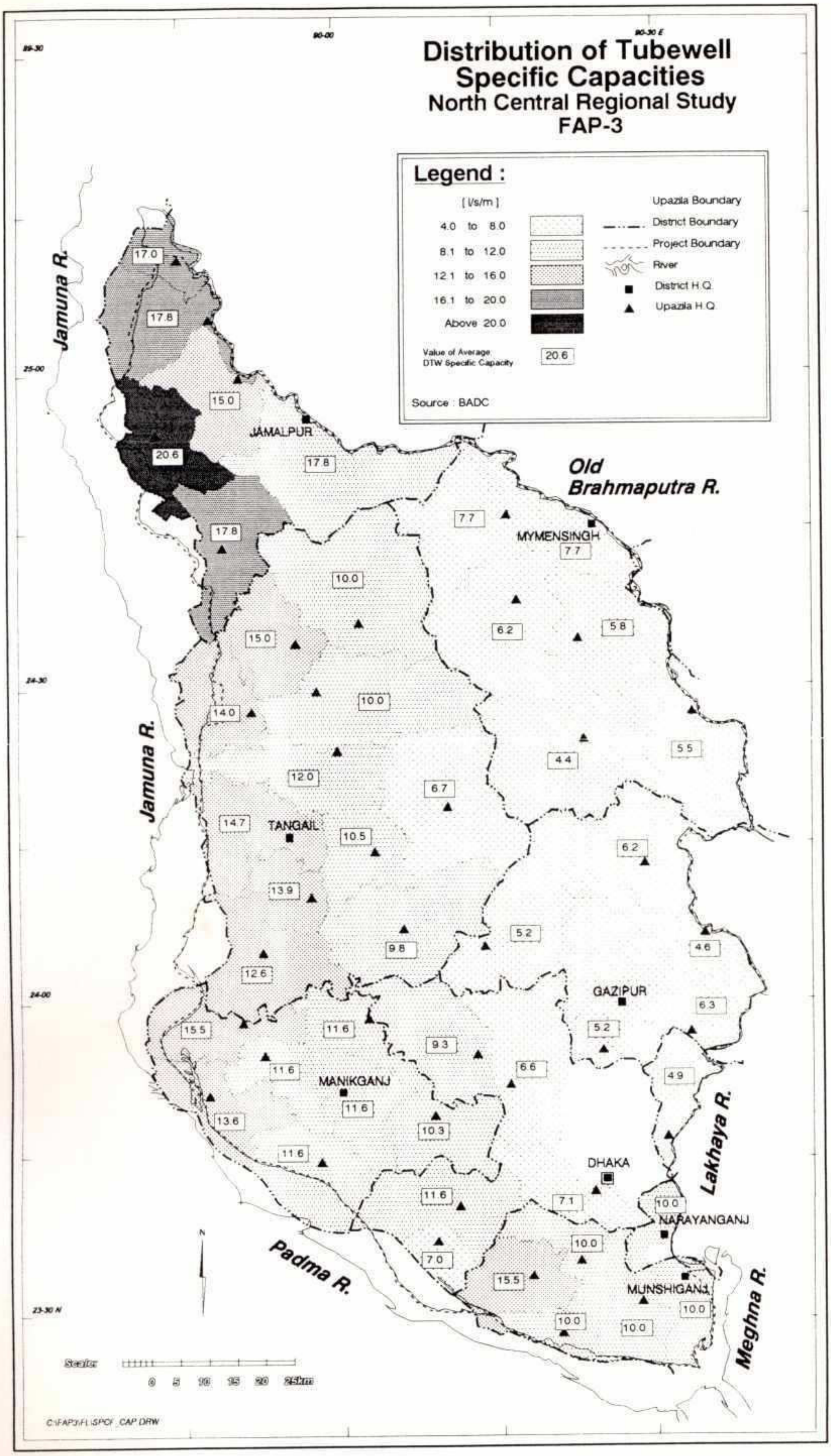
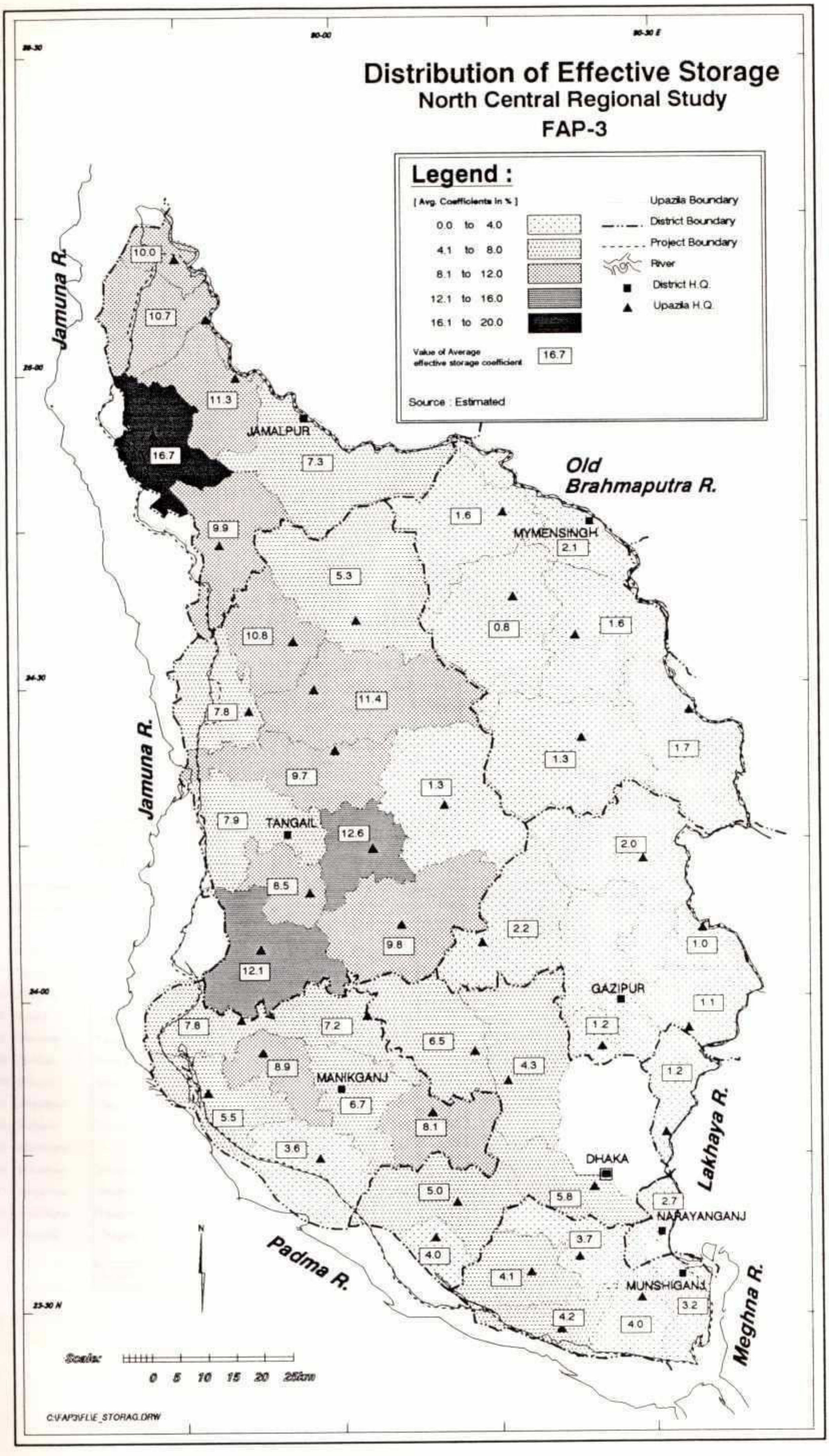

Distribution of Tubewell
Specific Capacities
North Central Regional Study
FAP-3
Legend :
[l/s/m]
4.0 to 8.0
8.1 to 12.0
12.1 to 16.0
16.1 to 20.0
Above 20.0
Value of Average DTW Specific Capacity
20.6
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : BADC
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
17.0
17.8
15.0
20.6
17.8
17.8
7.7
7.7
10.0
15.0
6.2
5.8
14.0
10.0
5.5
4.4
12.0
6.7
14.7
10.5
6.2
13.9
5.2
9.8
4.6
12.6
6.3
15.5
11.6
5.2
9.3
11.6
6.6
4.9
11.6
13.6
10.3
11.6
11.6
7.1
10.0
7.0
10.0
15.5
10.0
10.0
10.0
Scale
0 5 10 15 20 25km
C:\FAP3\FL\SPCF_CAP.DRW

Figure: II.4.3



Distribution of Effective Storage
North Central Regional Study
FAP-3
Legend :
[Avg. Coefficients in %]
0.0 to 4.0
4.1 to 8.0
8.1 to 12.0
12.1 to 16.0
16.1 to 20.0
Value of Average effective storage coefficient
16.7
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Source : Estimated
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
10.0
10.7
11.3
16.7
7.3
9.9
1.6
2.1
5.3
0.8
1.6
10.8
11.4
7.8
1.7
1.3
9.7
1.3
7.9
12.6
2.0
8.5
2.2
9.8
1.0
12.1
1.1
7.8
7.2
6.5
1.2
4.3
8.9
1.2
6.7
5.5
8.1
3.6
5.0
5.8
2.7
3.7
4.0
4.1
3.2
4.2
4.0
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\E_STORAG.DRW

Nr	Upazila	District	MARY (Mm3) Useable Rechar A TOTALS NFP	PFP	STW	DTW 1	DTW 2	HTW	RESOURCE POTENTIAL SUMMARY (mm) USEABLE RECHARGE UPAZILA TOTALS NFP STW	NFP DSSTW	NFP DTW 1	NFP DTW 2	NFP HTW	PFP STW	PFP DSSTW	PFP DTW 1	PFP DTW 2	PFP HTW
1	Dhamrai	Dhaka	203	18	123	189	189	189	240	402	660	644	646	240	402	614	614	614
2	Dohar	Dhaka	97	9	39	79	55	67	159	259	520	360	440	159	259	520	360	440
3	Keraniganj	Dhaka	144	13	51	115	76	94	159	305	686	458	564	159	305	686	458	564
4	Nawabganj	Dhaka	162	15	89	151	144	130	239	364	660	589	530	239	364	618	589	530
5	Savar	Dhaka	162	15	76	155	135	103	163	272	577	481	369	163	272	554	481	369
6	Joydebpur	Gazipur	167	16	42	57	34	33	91	122	165	98	96	91	122	165	98	96
7	Kaliakoir	Gazipur	177	17	56	97	60	59	127	181	310	192	189	127	181	310	192	189
8	Kaliganj	Gazipur	113	10	21	33	23	19	79	107	166	118	95	79	107	166	118	95
9	Kapasia	Gazipur	202	19	22	58	37	41	39	63	164	105	115	39	63	164	105	115
10	Sreepur	Gazipur	239	23	65	150	107	88	90	141	324	231	191	90	141	324	231	191
11	Dewanganj	Jamalpur	303	28	281	281	281	281	475	725	729	729	729	475	677	677	677	677
12	Islampur	Jamalpur	271	25	255	255	255	255	516	784	791	791	791	516	743	743	743	743
13	Jamalpur	Jamalpur	250	24	244	244	244	244	339	520	521	521	521	339	506	506	506	506
14	Madarganj	Jamalpur	178	16	166	166	166	166	776	776	776	776	776	720	720	720	720	720
15	Melandaha	Jamalpur	134	13	130	130	130	130	560	560	560	560	560	542	542	542	542	542
16	Sharishabari	Jamalpur	135	13	132	132	132	132	506	524	524	524	524	506	511	511	511	511
17	Daulatpur	Manikganj	187	17	123	170	170	170	385	580	883	883	804	385	580	801	801	801
18	Ghior	Manikganj	139	12	68	122	122	111	248	472	960	874	768	248	472	842	842	768
19	Harirampur	Manikganj	211	19	46	107	85	75	96	187	436	349	306	96	187	436	349	306
20	Manikganj	Manikganj	125	11	73	117	117	116	212	378	647	647	600	212	378	605	605	600
21	Saturia	Manikganj	116	10	74	107	107	107	301	482	755	755	722	301	482	693	693	693
22	Shivalaya	Manikganj	211	19	59	129	108	90	187	325	711	594	496	187	325	711	594	496
23	Singair	Manikganj	143	13	115	133	133	133	345	549	682	682	682	345	549	634	634	634
24	Lohajang	Munshiganj	327	31	37	74	59	57	186	290	574	458	441	186	290	574	458	441
25	Munshiganj	Munshiganj	140	13	35	69	55	53	147	227	446	356	343	147	227	446	356	343
26	Serajdikhan	Munshiganj	307	29	48	94	75	72	178	271	525	421	406	178	271	525	421	406
27	Sreenagar	Munshiganj	188	17	60	118	103	84	203	306	597	523	424	203	306	597	523	424
28	Tongibari	Munshiganj	186	17	43	83	66	64	191	291	564	452	436	191	291	564	452	436
29	Bhaluka	Mymensingh	194	19	42	83	48	57	63	94	188	108	129	63	94	188	108	129
30	Fulbaria	Mymensingh	200	20	58	80	62	54	99	120	165	127	111	99	120	165	127	111
31	Gaffargaon	Mymensingh	231	22	67	120	85	80	127	171	305	216	203	127	171	305	216	203
32	Muktagacha	Mymensingh	151	14	54	91	73	54	134	173	290	233	174	134	173	290	233	174
33	Mymensingh	Mymensingh	175	17	69	139	110	80	131	184	371	294	214	131	184	371	294	214
34	Trishal	Mymensingh	126	12	43	62	43	38	135	174	248	172	151	135	174	248	172	151
35	Narayanganj	Narayanganj	78	7	22	49	43	30	190	257	573	498	353	190	257	573	498	353
36	Rupganj	Narayanganj	182	16	21	42	27	28	62	91	179	112	118	62	91	179	112	118
37	Basail	Tangail	103	9	94	94	94	94	537	589	589	589	589	537	538	538	538	538
38	Bhuapur	Tangail	160	14	124	148	148	148	359	555	715	715	715	359	555	662	662	662
39	Delduar	Tangail	105	9	97	97	97	97	421	614	614	614	614	421	570	570	570	570
40	Ghatail	Tangail	214	20	206	206	206	206	474	474	474	474	474	457	457	457	457	457
41	Gopalpur	Tangail	124	11	115	115	115	115	574	574	574	574	574	534	534	534	534	534
42	Kalihati	Tangail	180	16	164	164	164	164	441	618	618	618	618	441	563	563	563	563
43	Madhupur	Tangail	244	24	172	241	241	241	227	359	512	512	512	227	359	506	506	506
44	Mirzapur	Tangail	223	20	183	203	203	203	254	499	608	608	608	254	499	554	554	554
45	Nagarpur	Tangail	172	16	163	163	163	163	510	596	596	596	596	510	563	563	563	563
46	Shakhipur	Tangail	183	18	61	99	75	60	108	141	228	173	138	108	141	228	173	138
47	Tangail	Tangail	167	15	152	152	152	152	415	612	633	633	633	415	577	577	577	577
		TOTAL	8428	80[illegible]	4483	5958	5415	5225										

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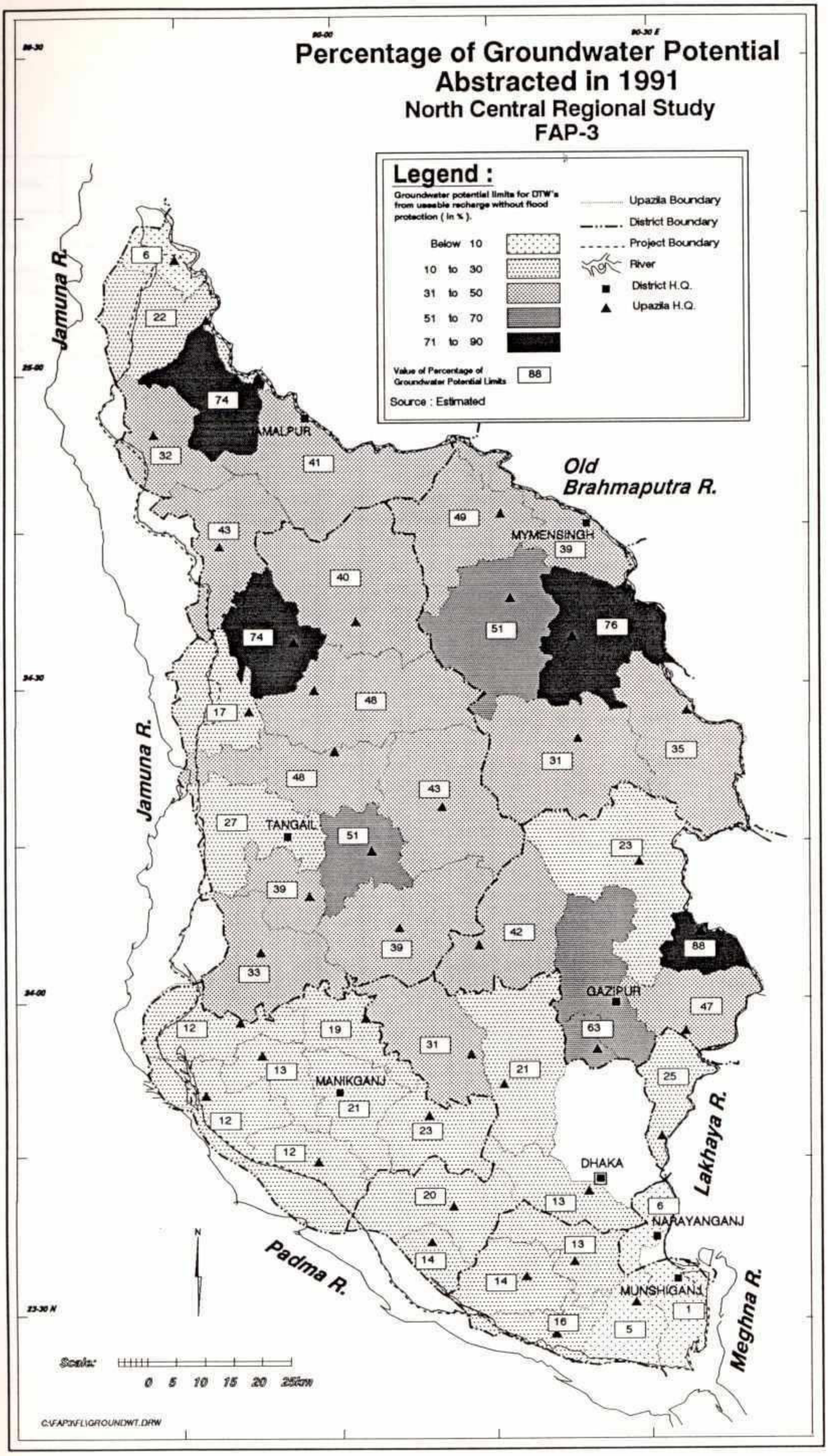
Figure: II.4.4



Percentage of Groundwater Potential Abstracted in 1991
North Central Regional Study
FAP-3
Legend :
Groundwater potential limits for DTW's from useable recharge without flood protection (in %).
Below 10
10 to 30
31 to 50
51 to 70
71 to 90
Value of Percentage of Groundwater Potential Limits
88
Source : Estimated
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Jamuna R.
Old Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
6
22
74
32
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Scale:
0 5 10 15 20 25km
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TABLE II.4.4

North Central Region : Groundwater Resource Potential Limits

Usable Recharge (Mm3) and NFP Usable Recharge Groundwater Potential

Nr	Upazila	District	Usable Recharge (Mm3) NFP	PFP	FFP	NFP STW F0	STW F1	STW F2	STW F3	DSSTW F0	DSSTW F1	DSSTW F2	DSSTW F3	DTW-1 F0	DTW-1 F1	DTW-1 F2	DTW-1 F3	DTW-2 F0	DTW-2 F1	DTW-2 F2	DTW-2 F3	HTW F0
1	Dhamrai	Dhaka	203	189	114	24	34	54	74	74	84	104	123	258	268	288	308	198	208	228	248	198
2	Dohar	Dhaka	97	91	67	9	12	18	24	24	27	33	39	79	82	88	94	55	58	64	70	67
3	Keraniganj	Dhaka	144	137	95	2	7	17	27	27	31	41	51	115	119	129	139	76	81	91	101	94
4	Nawabganj	Dhaka	162	151	103	28	34	46	58	58	65	77	89	174	180	192	204	144	150	163	175	130
5	Savar	Dhaka	162	155	121	0	4	25	46	24	35	55	76	186	192	204	217	135	141	153	165	103
6	Joydebpur	Gazipur	167	165	151	0	4	18	32	8	15	29	42	57	60	64	68	34	36	41	45	33
7	Kaliakoir	Gazipur	177	174	155	0	6	23	40	14	23	40	56	97	100	107	114	60	63	70	77	59
8	Kaliganj	Gazipur	113	108	87	1	4	10	16	7	9	15	21	33	34	36	38	23	24	26	29	19
9	Kapasia	Gazipur	202	198	182	3	5	9	14	12	14	18	22	58	60	63	67	37	39	42	46	41
10	Sreepur	Gazipur	239	238	231	2	10	26	42	25	33	49	65	130	154	164	173	107	112	121	130	88
11	Dewanganj	Jamalpur	303	281	219	94	114	156	198	198	218	260	302	597	618	659	701	529	549	591	633	416
12	Islampur	Jamalpur	271	255	207	85	103	140	177	177	195	232	269	531	549	586	623	473	491	528	565	368
13	Jamalpur	Jamalpur	250	244	223	76	93	128	163	163	181	216	250	488	506	541	576	391	408	443	478	376
14	Madarganj	Jamalpur	178	166	130	110	129	168	206	206	225	264	302	577	596	635	673	525	544	583	621	399
15	Melandaha	Jamalpur	134	130	115	67	81	108	135	135	148	175	202	392	406	433	460	342	355	382	409	281
16	Sharishabari	Jamalpur	135	132	122	67	79	105	131	131	143	169	195	377	389	415	441	336	349	373	400	263
17	Daulatpur	Manikganj	187	170	95	40	48	65	82	82	90	106	123	240	248	265	281	210	218	235	251	170
18	Ghior	Manikganj	139	122	57	4	10	23	36	36	42	55	68	158	164	177	190	126	133	146	159	111
19	Harirampur	Manikganj	211	196	134	2	6	15	24	24	28	37	46	107	111	120	129	85	90	98	107	75
20	Manikganj	Manikganj	125	117	80	9	15	28	41	41	47	60	73	162	168	181	194	131	137	150	163	116
21	Saturia	Manikganj	116	107	61	19	24	35	47	47	52	61	74	151	157	168	179	125	130	141	152	111
22	Shivalaya	Manikganj	211	192	119	9	14	24	34	34	39	49	59	129	134	144	134	108	113	123	133	90
23	Singair	Manikganj	143	133	85	30	38	55	72	72	81	98	115	232	240	257	274	185	194	211	228	176
24	Lohajang	Munshiganj	327	316	257	11	13	19	24	24	27	32	37	74	77	82	87	59	62	67	72	57
25	Munshiganj	Munshiganj	140	133	99	10	13	14	23	23	25	30	35	69	72	77	82	55	58	63	68	53
26	Serajdikhan	Munshiganj	307	295	239	15	18	25	32	32	33	42	48	94	97	104	110	75	78	85	92	72
27	Sreenagar	Munshiganj	188	178	116	20	24	32	40	40	44	52	60	118	122	130	138	103	107	115	123	84
28	Tongibari	Munshiganj	186	176	104	13	16	22	28	28	31	37	43	83	85	91	97	66	69	75	81	64
29	Bhaluka	Mymensingh	194	191	191	0	6	17	28	14	19	31	42	83	86	91	97	48	51	56	62	57
30	Fulbaria	Mymensingh	200	200	195	21	26	37	48	31	36	47	58	80	82	86	90	62	64	68	72	54
31	Gaffargaon	Mymensingh	231	222	191	16	23	36	30	33	40	53	67	120	123	130	137	85	88	95	102	80
32	Muktagacha	Mymensingh	151	149	141	15	20	31	42	27	33	43	54	91	93	98	103	73	75	80	85	54
33	Mymensingh	Mymensingh	175	172	161	14	21	35	49	33	40	55	69	139	143	151	158	110	114	122	130	80
34	Trishal	Mymensingh	126	123	114	5	11	22	34	15	21	32	43	62	64	68	72	43	45	49	53	38
35	Narayanganj	Narayanganj	78	72	46	11	12	14	16	16	17	20	22	49	30	53	55	43	44	46	49	30
36	Rupganj	Narayanganj	182	163	137	1	4	9	15	8	11	16	21	42	44	46	49	27	28	31	33	28
37	Basail	Tangail	103	94	59	39	50	72	94	94	105	127	149	300	311	333	355	238	249	271	293	229
38	Bhuapur	Tangail	160	148	98	37	45	63	80	80	89	107	124	247	256	273	291	212	221	238	256	177
39	Delduar	Tangail	105	97	71	36	43	57	72	72	79	93	108	209	216	231	245	180	187	202	216	151
40	Ghatail	Tangail	214	206	181	96	122	173	225	225	250	302	353	703	728	780	831	559	585	636	687	538
41	Gopalpur	Tangail	124	115	89	74	86	109	132	132	144	167	190	354	366	389	412	311	323	346	369	258
42	Kalihati	Tangail	180	164	108	58	72	100	129	129	143	171	200	396	410	439	467	330	344	373	401	292
43	Madhupur	Tangail	244	241	231	45	58	83	108	108	121	146	172	344	357	382	408	274	286	312	337	263
44	Mirzapur	Tangail	223	203	133	0	0	39	93	48	75	129	183	364	382	418	454	262	280	316	352	251
45	Nagarpur	Tangail	172	163	130	60	77	112	147	147	165	200	235	478	495	530	565	400	418	452	487	346
46	Shakhipur	Tangail	183	181	174	13	20	35	47	27	34	48	61	99	102	108	113	75	78	84	89	60
47	Tangail	Tangail	167	152	102	57	68	88	109	109	120	140	161	307	318	339	359	268	278	299	320	222
		TOTAL	8428	8005	6320																	

PFP Usable Recharge Groundwater Potential (Mm3)

Nr	Upazila	STW F0	STW F1	STW F2	STW F3	DSSTW F0	DSSTW F1	DSSTW F2	DSSTW F3	DTW-1 F0	DTW-1 F1	DTW-1 F2	DTW-1 F3	DTW-2 F0	DTW-2 F1	DTW-2 F2	DTW-2 F3	HTW F0
1	Dhamrai	24	34	54	74	74	84	104	123	189	189	189	189	189	189	189	189	189
2	Dohar	9	12	18	24	24	27	33	39	79	82	88	91	55	58	64	70	67
3	Keraniganj	2	7	17	27	27	31	41	51	115	119	129	137	76	81	91	101	94
4	Nawabganj	28	34	46	58	58	65	77	89	151	151	151	151	144	150	151	151	130
5	Savar	0	4	25	46	24	35	55	76	155	155	155	155	135	141	135	155	103
6	Joydebpur	0	4	18	32	8	15	29	42	57	60	64	68	34	36	41	45	33
7	Kaliakoir	0	6	23	40	14	23	40	56	97	100	107	114	60	63	70	77	59
8	Kaliganj	1	4	10	16	7	9	13	21	33	34	36	38	23	24	26	29	19
9	Kapasia	3	5	9	14	12	14	18	22	58	60	63	67	37	39	42	46	41
10	Sreepur	2	10	26	42	25	33	49	65	130	134	164	173	107	112	121	130	88
11	Dewanganj	94	114	156	198	198	218	260	281	281	281	281	281	281	281	281	281	281
12	Islampur	85	103	140	177	177	195	232	255	255	255	255	255	255	255	255	255	255
13	Jamalpur	76	93	128	163	163	181	216	244	244	248	244	244	244	244	244	244	244
14	Madarganj	110	129	166	166	166	166	166	166	166	166	166	166	166	166	166	166	166
15	Melandaha	67	81	108	130	130	130	130	130	130	130	130	130	130	130	130	130	130
16	Sharishabari	67	79	105	131	131	132	132	132	132	132	132	132	132	132	132	132	132
17	Daulatpur	40	48	65	82	82	90	106	125	170	170	170	170	170	170	170	170	170
18	Ghior	4	10	23	36	36	42	55	68	122	122	122	122	122	122	122	122	111
19	Harirampur	2	6	15	24	24	28	37	46	107	111	120	129	85	90	93	107	75
20	Manikganj	9	15	28	41	41	47	60	73	117	117	117	117	117	117	117	117	116
21	Saturia	19	24	35	47	45	52	63	74	107	107	107	107	107	107	107	107	107
22	Shivalaya	9	14	24	34	34	39	49	59	129	134	144	154	108	113	123	133	90
23	Singair	30	38	55	72	72	81	98	115	133	133	133	133	133	133	133	133	133
24	Lohajang	11	13	19	24	24	27	32	37	74	77	82	87	59	62	67	72	57
25	Munshiganj	10	13	18	23	25	25	30	35	69	72	77	82	55	58	63	68	53
26	Serajdikhan	15	18	25	32	32	35	42	48	94	97	104	110	75	78	85	92	72
27	Sreenagar	20	24	32	40	40	44	52	60	118	122	130	138	103	107	115	123	84
28	Tongibari	13	16	22	28	28	31	37	43	83	85	91	97	66	69	75	81	64
29	Bhaluka	0	6	17	28	14	19	31	42	83	86	91	97	48	51	56	62	57
30	Fulbaria	21	26	37	48	31	36	47	54	80	82	86	90	62	64	68	72	54
31	Gaffargaon	16	23	36	30	35	40	53	67	120	123	130	137	85	88	95	102	80
32	Muktagacha	15	20	31	42	27	33	43	54	91	93	98	103	73	75	80	85	54
33	Mymensingh	14	21	35	49	33	40	55	69	139	143	151	158	110	114	122	130	80
34	Trishal	5	11	22	34	15	21	32	45	62	64	68	72	43	43	49	53	38
35	Narayanganj	11	12	14	16	16	17	20	22	49	30	53	55	41	44	46	49	30
36	Rupganj	1	4	9	15	8	11	16	21	42	44	46	49	27	28	31	33	28
37	Basail	39	30	72	94	94	94	94	94	94	94	94	94	94	94	94	94	94
38	Bhuapur	37	45	65	80	80	89	107	124	148	148	148	148	148	148	148	148	148
39	Delduar	36	45	57	72	72	79	93	97	97	97	97	97	97	97	97	97	97
40	Ghatail	96	122	173	206	206	206	206	206	206	206	206	206	206	206	206	206	206
41	Gopalpur	74	86	109	113	115	115	115	115	115	115	115	115	115	115	115	115	115
42	Kalihati	58	72	100	129	129	143	164	164	164	164	164	164	164	164	164	164	164
43	Madhupur	45	58	83	108	108	121	146	172	241	241	241	241	241	241	241	241	241
44	Mirzapur	0	0	39	93	48	75	129	183	203	203	203	203	203	203	203	203	203
45	Nagarpur	60	77	112	147	147	163	163	163	163	163	163	163	163	163	163	163	163
46	Shakhipur	13	20	35	47	27	34	48	61	99	102	108	113	75	78	84	89	60
47	Tangail	57	68	88	109	109	120	140	152	152	152	152	152	152	152	152	152	152
	TOTAL																	

Resource Potential Summary (Mm3) and (mm) — Useable Recharge Upazila Totals

Nr	Upazila	(Mm3) NFP STW	NFP DSSTW	NFP DTW 1	NFP DTW 2	NFP HTW	PFP STW	PFP DSSTW	PFP DTW 1	PFP DTW 2	PFP HTW	(mm) NFP STW	NFP DSSTW	NFP DTW 1	NFP DTW 2	NFP HTW	PFP STW	PFP DSSTW	PFP DTW 1	PFP DTW 2	PFP HTW
1	Dhamrai	74	123	203	198	198	74	123	189	189	189	240	402	660	644	646	240	402	614	614	614
2	Dohar	24	39	79	55	67	24	39	79	55	67	159	259	520	360	440	159	259	520	360	440
3	Keraniganj	27	51	115	76	94	27	51	115	76	94	159	305	686	658	564	159	305	686	458	564
4	Nawabganj	58	89	162	144	150	58	89	151	144	130	239	364	660	589	530	239	364	618	589	530
5	Savar	46	76	162	135	103	46	76	155	135	103	163	272	577	481	369	163	272	554	481	369
6	Joydebpur	32	42	57	34	33	32	42	52	34	33	91	122	165	98	96	91	122	165	98	96
7	Kaliakoir	40	56	97	60	59	40	56	97	60	59	127	181	310	192	189	127	181	310	192	189
8	Kaliganj	16	21	33	23	19	16	21	33	23	19	79	107	166	118	95	79	107	166	118	95
9	Kapasia	14	22	58	37	41	14	22	58	37	41	59	61	164	105	115	59	63	164	105	115
10	Sreepur	42	65	130	107	88	42	65	130	107	88	90	141	324	231	191	90	141	324	231	191
11	Dewanganj	198	302	303	303	303	198	281	281	281	281	475	725	729	729	729	475	677	677	677	677
12	Islampur	177	269	271	271	271	177	255	255	255	255	536	788	791	791	791	516	743	743	743	783
13	Jamalpur	163	230	250	250	250	163	244	244	244	244	339	520	521	521	521	339	506	506	506	506
14	Madarganj	178	178	178	178	178	166	166	166	166	166	776	776	776	776	776	720	720	720	720	720
15	Melandaha	134	134	134	134	134	130	130	130	130	130	560	560	560	560	560	542	542	542	542	542
16	Sharishabari	131	135	135	135	135	131	132	132	132	132	506	524	524	524	524	506	511	511	511	511
17	Daulatpur	82	123	187	187	170	82	123	170	170	170	385	580	833	833	804	385	580	801	801	801
18	Ghior	36	68	139	126	111	36	68	122	122	111	248	472	960	874	768	248	472	842	842	768
19	Harirampur	24	46	107	85	75	24	46	107	85	75	96	187	436	349	306	96	117	436	349	306
20	Manikganj	41	73	125	125	116	41	73	115	117	116	212	378	647	647	600	212	378	605	605	600
21	Saturia	47	74	116	116	111	47	74	107	107	107	301	482	755	755	722	301	482	693	693	693
22	Shivalaya	34	59	129	108	90	34	59	129	108	90	187	325	711	594	496	187	325	711	594	496
23	Singair	72	115	143	143	143	72	115	133	133	133	345	549	682	682	682	345	549	634	634	634
24	Lohajang	24	37	74	59	57	24	37	74	59	57	186	290	574	458	441	186	290	574	431	441
25	Munshiganj	23	35	69	55	53	23	35	69	55	53	147	227	446	356	343	147	227	446	356	343
26	Serajdikhan	32	48	94	75	72	32	48	94	75	72	178	271	525	421	406	178	271	525	421	406
27	Sreenagar	40	60	118	103	84	40	60	118	103	84	203	306	597	523	424	203	306	597	523	424
28	Tongibari	28	43	83	66	64	28	43	83	66	64	191	291	564	452	436	191	291	564	452	436
29	Bhaluka	28	42	83	48	57	28	42	83	48	57	63	94	188	108	129	63	94	188	108	129
30	Fulbaria	48	58	80	62	54	48	58	80	62	54	99	120	165	127	111	99	120	165	127	111
31	Gaffargaon	50	67	120	85	80	50	67	120	85	80	127	171	305	216	203	127	171	305	216	203
32	Muktagacha	42	54	91	73	54	42	54	91	73	54	134	173	290	233	174	134	173	290	233	174
33	Mymensingh	49	69	139	110	80	49	69	139	110	80	131	184	371	294	214	151	184	371	294	214
34	Trishal	34	43	62	43	38	34	43	62	43	38	135	174	248	172	151	135	174	248	172	151
35	Narayanganj	16	22	49	43	30	16	22	49	43	30	190	257	573	498	353	190	257	573	498	353
36	Rupganj	15	21	42	27	28	15	21	42	27	28	62	91	179	112	118	62	91	179	112	118
37	Basail	94	103	103	103	105	94	94	94	94	94	537	589	589	589	589	537	538	538	538	538
38	Bhuapur	80	124	160	160	160	80	124	148	148	148	359	555	715	715	713	359	355	662	662	662
39	Delduar	72	105	105	105	105	72	97	97	97	97	421	614	614	614	614	421	570	570	570	570
40	Ghatail	214	214	214	214	214	206	206	206	206	206	474	474	474	474	476	457	457	457	457	437
41	Gopalpur	124	124	124	124	124	115	115	115	115	115	574	574	574	574	574	534	534	534	534	534
42	Kalihati	129	180	180	180	180	129	164	164	164	164	441	618	618	618	638	441	563	563	563	563
43	Madhupur	108	172	244	244	244	108	172	241	241	241	227	359	512	532	512	227	359	506	506	506
44	Mirzapur	93	183	223	223	223	93	183	203	203	203	254	499	608	608	608	254	899	554	554	554
45	Nagarpur	147	172	172	172	172	147	163	163	163	163	530	596	596	596	396	510	563	563	563	563
46	Shakhipur	47	61	99	75	60	47	61	99	75	60	108	141	228	173	138	108	141	228	173	138
47	Tangail	109	161	167	167	167	109	152	152	151	152	415	612	633	633	633	415	577	577	577	577
	TOTAL	3332	4613	6226	5648	5424	3298	6483	5958	5413	5225										

B:\TAB244.WK1

CHAPTER 5
GROUNDWATER DEVELOPMENT PLANNING

5.1 Approach

The general objective of groundwater development planning as defined by the MPO, is to achieve full development of groundwater resources by the year 2010.

For the purposes of the North Central Regional Study, the main development planning requirements are taken to be:

a) To examine and quantify the likely impact of flood protection measures on groundwater resources and corresponding development limits.

b) Predict and quantify the expected growth of groundwater irrigation with and without flood protection for economic analysis of alternative FCD options.

c) To prepare a development plan for groundwater based irrigation which takes into account any new flood control and drainage measures proposed for the study area, and relevant economic and environmental factors.

Future expansion of groundwater irrigation will depend on resource potential limits and irrigable land areas as well as public sector demands and market forces.

5.2 Growth Rates

Shallow Tubewells

Historic growth in shallow tubewell numbers has been controlled mainly by government policies and market factors. During the early 1980's growth was rapid, but numbers remained static in the mid 1980's due to restrictions on equipment imports. Since 1985, the private sector has assumed control and the equipment market has been deregulated, allowing rapid growth to resume. Statistics for the period 1985 to 1989 are summarized in Tables II.5.1 and II.5.2.

TABLE II.5.1
National Growth in STW Numbers

Years	National Total	Annual Increase	Percentage Growth
1988-1986	145,000	--	--
1986-1987	159,000	14,000	10%
1987-1988	183,000	24,000	15%
1988-1989	223,000	40,000	22%

195

TABLE II.5.2

Growth of STW Numbers for North Central Region 1988-1989

District	1988	1989	Percentage Growth
Manikganj	2,715	3,755	38%
Dhaka	2,118	2,798	32%
Munshiganj	832	1,431	72%
Gazipur	598	790	32%
Tangail	14,695	17,994	22%
Jamalpur	8,086	9,475	17%
Mymensingh	3,785	4,438	17%
Total	**32,829**	**40,681**	**24%**

The national percentage growth rate of 22% for 1988-1989 is similar to the achieved in the study area, and is likely to be indicative of the future limits to growth rates assuming present free market policies are continued. However, considering the high densities of shallow tubewells already occupying the most favourable areas, an annual growth of no more than 10% of the current total numbers, or approximately 4,000 suction mode tubewells per year is more likely.

Deep tubewells

Deep tubewells have in the past, been installed by the public sector (mainly BADC) and growth has been almost entirely "project" driven. In this case, financial, budgetary and logistical factors, as well as 75% subsidies on capital costs, were the main determinants. Growth peaked in the late 1980's at around 2-3000 units per year. During 1992, changes in government policy are expected, which will include measures for terminating public sector deep tubewell development, phased elimination of subsidies and market deregulation.

Future growth of force mode tubewells therefore remains speculative, but is likely to be relatively slow in the initial years after subsidies are withdrawn.

The upper limits to growth of DTWs will be constrained at least in the short to medium term by contractor and equipment capabilities. Nationally, there are currently around 200 deep tubewell contractors fully equipped with plant and personnel, who, with no constraints on finance, sites and materials could complete around 4000 DTWs annually. Of that total, and considering the overall national requirement for DTWs, around 30% should be sited in the North Central Region.

Based on the above considerations, the assumed future rates of growth for DTWs, nationally and in the study area, are summarised in Table II.5.3.

Figure: II.5.1

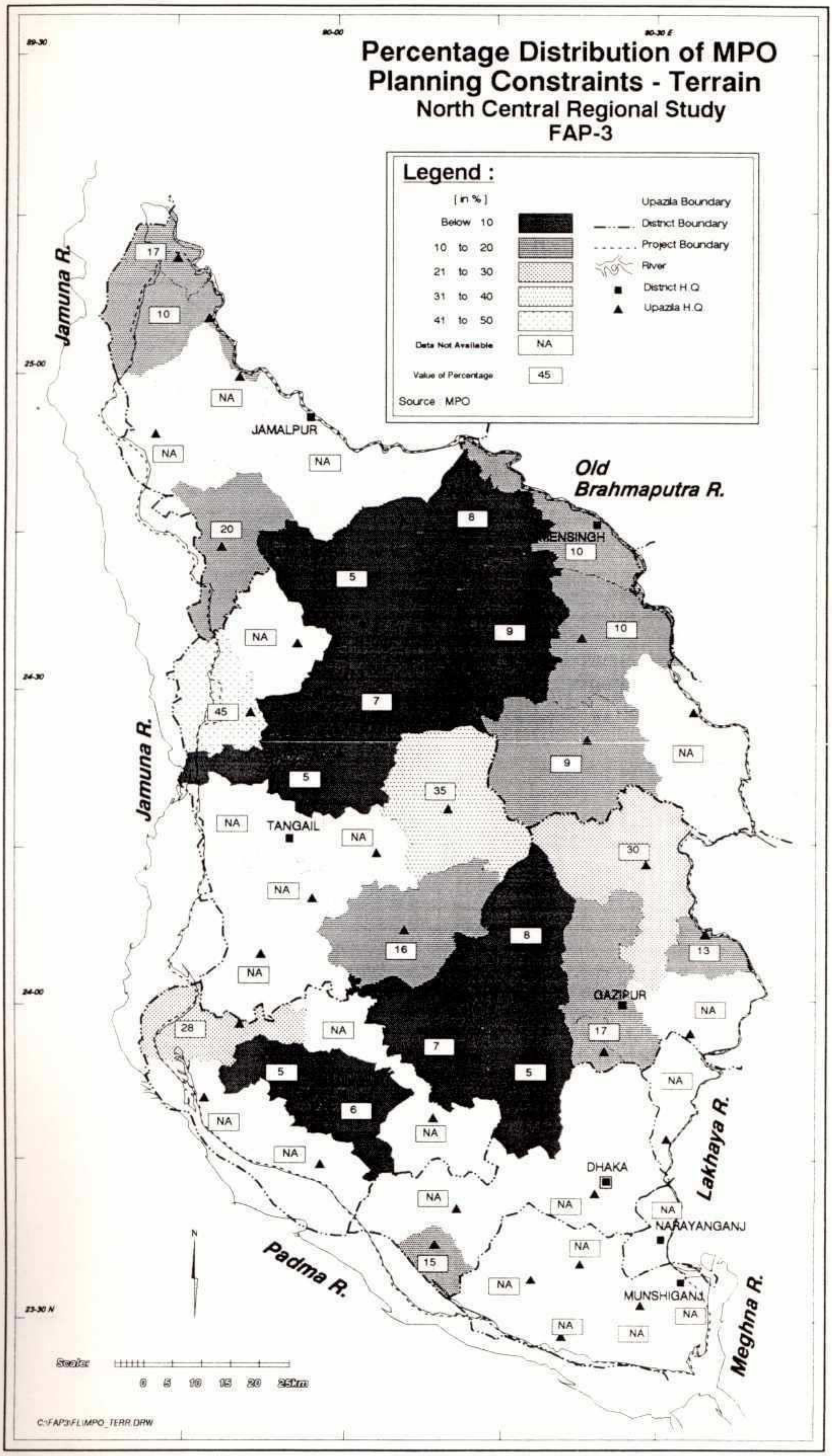
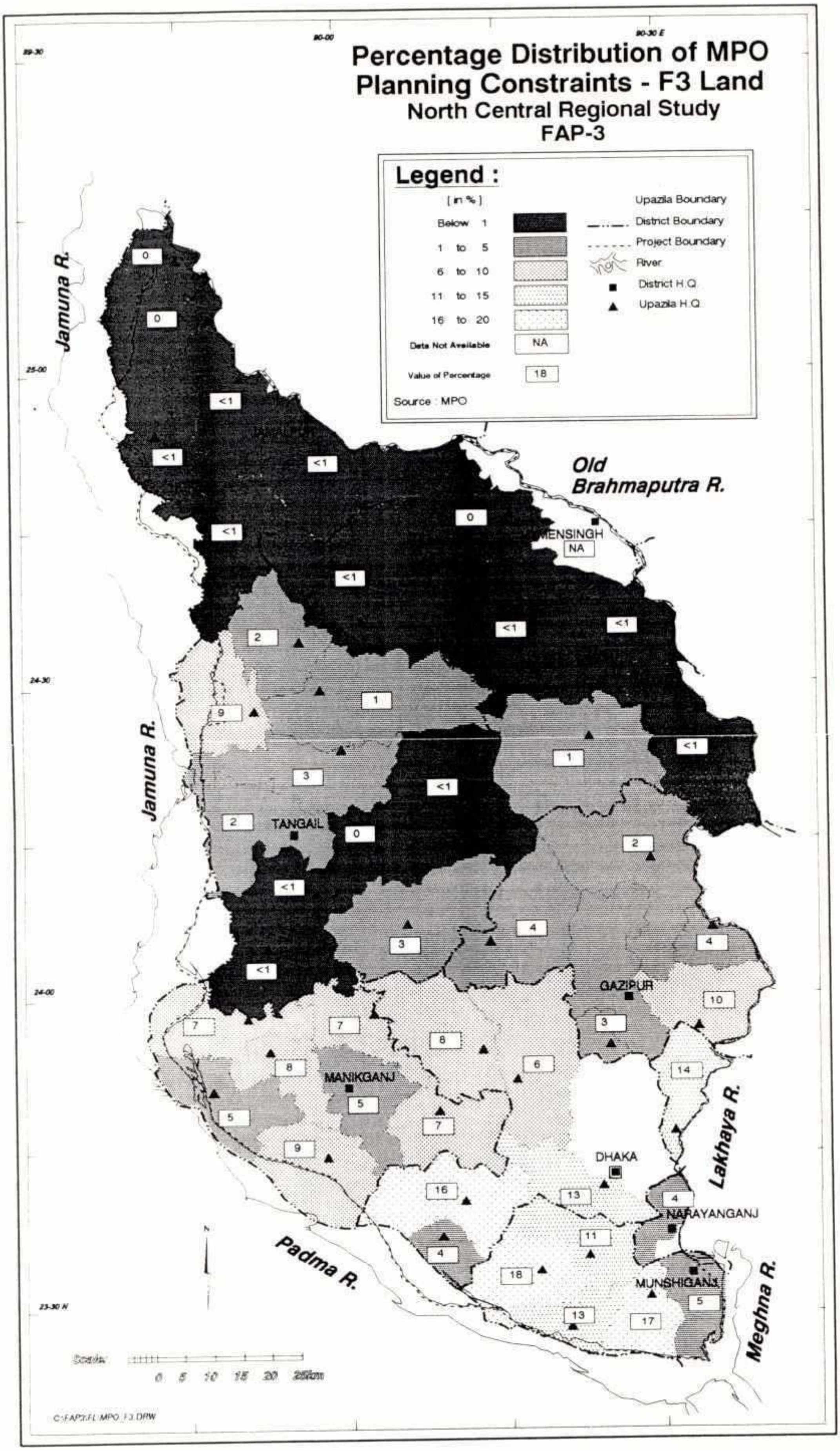

Percentage Distribution of MPO
Planning Constraints - Terrain
North Central Regional Study
FAP-3
Legend :
[in %]
Below 10
10 to 20
21 to 30
31 to 40
41 to 50
Data Not Available
NA
Value of Percentage
45
Source MPO
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q
Upazila H.Q
Jamuna R.
Old Brahmaputra R.
Lakhaya R.
Meghna R.
Padma R.
JAMALPUR
TANGAIL
GAZIPUR
DHAKA
NARAYANGANJ
MUNSHIGANJ
17
10
NA
20
8
5
9
45
7
35
30
16
13
28
6
15
Scale
0 5 10 15 20 25Km
C:\FAP3\FL\MPO_TERR.DRW

Figure: II.5.2



Percentage Distribution of MPO Planning Constraints - F3 Land
North Central Regional Study
FAP-3
Legend :
[in %]
Below 1
1 to 5
6 to 10
11 to 15
16 to 20
Data Not Available
NA
Value of Percentage
18
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q
Upazila H.Q
Source : MPO
Jamuna R.
Old Brahmaputra R.
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Meghna R.
Padma R.
Scale
0 5 10 15 20 25Km
C:\FAP3\FL\MPO_F3.DRW

Figure: II.5.3

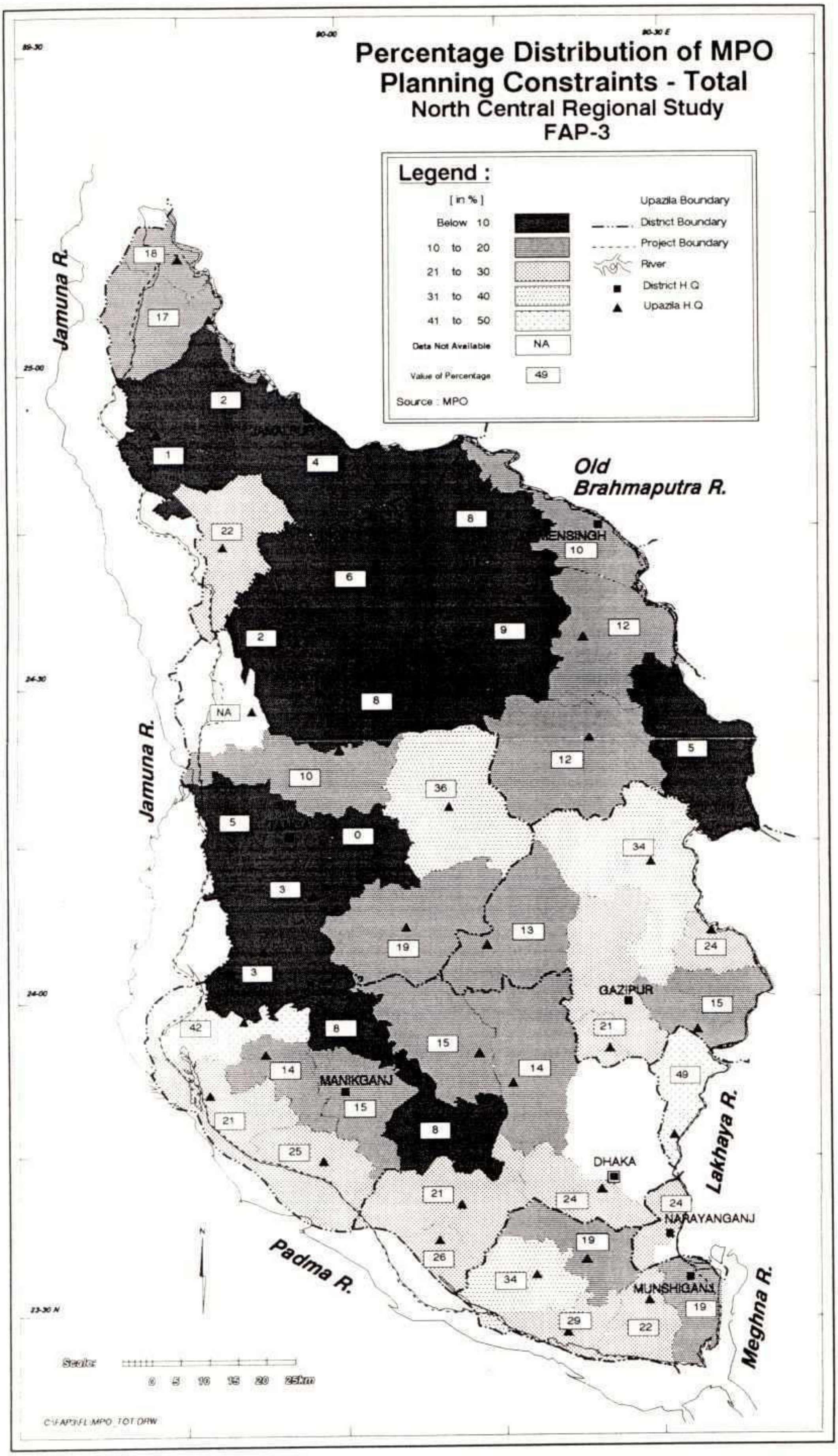

Percentage Distribution of MPO
Planning Constraints - Total
North Central Regional Study
FAP-3
Legend :
[in %]
Below 10
10 to 20
21 to 30
31 to 40
41 to 50
Data Not Available
NA
Value of Percentage
49
Source : MPO
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q
Upazila H.Q
Jamuna R.
Old Brahmaputra R.
MYMENSINGH
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Meghna R.
Padma R.
Scale
0 5 10 15 20 25km
C:\FAP3\FL\MPO_TOT.DRW

TABLE II.5.3

Assumed Growth Rates for Deep Tubewells

Period	Growth Rate (%)	National		NCR	
		Annual Growth (units)	Cumulative Total (units)	Annual Growth (units)	Cumulative Total (units)
1990(operating)	--	--	22,000	--	5,640
1990-1995	5	2,200	33,000	660	8,940
1995-2000	10	3,300	49,500	990	13,890
2000-2005	7	3,465	66,825	1,040	19,090
2005-2010	5	3,340	83,525	1,000	24,090

Availability of irrigable land is not regarded as a significant constraint to growth of irrigation at present, but is likely to become a factor as the limits are approached. The growth rates above are applicable to both unprotected and flood protected conditions until land availability becomes limiting.

5.3 Resource Potential Limits

MPO procedures for assessment of resource potential, incorporate a variety of planning constraints to account for land suitability, flood hazards, difficult terrain, poor quality groundwater and existing/planned surface water irrigation. Deductions for these constraints are made in terms of both land availability and corresponding resource potential in arriving at the final planning figures for available resources. The MPO planning constraints for the study area are summarised in Table II 5.4 and Figures II.5.1 - II.5.3. This procedure is inappropriate for application to the NCR study in the following main respects:

a) Deductions from resource potential for land suitability appear unnecessary in a regionally continuous, permeable aquifer as exists in the NCR region.

b) Other deductions from resource potential are applied for macro planning purposes which increase discrepancies between the resource estimates and actual development. For example, deductions for terrain in the Madhupur Tract apply mainly to high land, not to low land where shallow tubewells are concentrated.

c) The values of the planning constraints vary erratically between adjacent areas. For example, terrain constraints vary from 30% in Sreepur to zero in Gaffargaon, and from 45% in Bhuapur to zero in Delduar.

In view of the above considerations, the analysis of groundwater resource potential limits for the study area has been based on an approximate development target of 80% of all F0-F3 land, which corresponds to 65-75% of the gross area in most thanas. No deductions from resource potential have been made. More detailed consideration of terrain and agricultural constraints being undertaken for the present study, may allow further refinement.

TABLE II.5.4
North Central Region : Summary of MPO Planning Constraints

Nr	Upazila	District	MPO Planning Constraints(%)					
			F3	F4/water	Water	Terrain	Surface Water Salinity	Total
1	Dhamrai	Dhaka	8.0	0.4	0.0	7.0		15.4
2	Dohar	Dhaka	4.3	5.9	0.9	15.0		26.1
3	Keraniganj	Dhaka	13.2	10.4	0.0			23.7
4	Nawabganj	Dhaka	16.1	1.2	3.5			20.8
5	Savar	Dhaka	6.3	1.1	1.4	5.0		13.8
6	Joydebpur	Gazipur	3.5	0.0	0.8	17.0		21.3
7	Kaliakoir	Gazipur	3.8	1.3	0.2	8.0		13.3
8	Kaliganj	Gazipur	9.6	1.7	3.8			15.1
9	Kapasia	Gazipur	4.3	2.5	3.8	13.0		23.7
10	Sreepur	Gazipur	2.2	0.5	1.1	30.0		33.8
11	Dewanganj	Jamalpur	0.0	0.0	0.7	17.0		17.7
12	Islampur	Jamalpur	0.0	5.2	2.2	10.0		17.4
13	Jamalpur	Jamalpur	0.3	2.6	1.4			4.3
14	Madarganj	Jamalpur	0.1	0.0	1.3			1.4
15	Melandaha	Jamalpur	0.1	0.4	1.7			2.2
16	Sharishabari	Jamalpur	0.2	0.7	1.3	20.0		22.3
17	Daulatpur	Manikganj	6.8	7.3	0.0	28.0		42.1
18	Ghior	Manikganj	8.0	1.1	0.0	5.0		14.1
19	Harirampur	Manikganj	9.0	13.7	2.3			25.0
20	Manikganj	Manikganj	5.3	3.3	0.0	6.0		14.6
21	Saturia	Manikganj	6.6	1.7	0.0			8.3
22	Shivalaya	Manikganj	4.9	16.3	0.1			21.3
23	Singair	Manikganj	6.9	1.3	0.0			8.2
24	Lohajang	Munshiganj	13.3	15.6	0.3			29.3
25	Munshiganj	Munshiganj	5.1	11.5	2.0			18.6
26	Serajdikhan	Munshiganj	11.5	6.7	0.6			18.8
27	Sreenagar	Munshiganj	18.3	8.3	7.6			34.2
28	Tongibari	Munshiganj	16.8	3.3	1.8			21.9
29	Bhaluka	Mymensingh	1.0	0.0	1.1	10.0		12.1
30	Fulbaria	Mymensingh	0.1	0.0	0.3	9.0		9.4
31	Gaffargaon	Mymensingh	0.7	3.3	0.7			4.6
32	Muktagacha	Mymensingh	0.0	0.0	0.5	8.0		8.5
33	Mymensingh	Mymensingh		0.0		10.0		10.0
34	Trishal	Mymensingh	0.4	1.7	0.3	10.0		12.4
35	Narayanganj	Narayanganj	4.0	20.1	0.0			24.0
36	Rupganj	Narayanganj	13.5	2.7	0.4		32.0	48.5
37	Basail	Tangail	0.0	0.0	0.0			0.0
38	Bhuapur	Tangail	9.0	0.0	0.0	45.0		54.0
39	Delduar	Tangail	2.3	2.5	0.0			4.8
40	Ghatail	Tangail	1.3	0.0	0.0	7.0		8.3
41	Gopalpur	Tangail	1.6	0.0	0.0			1.6
42	Kalihati	Tangail	3.0	1.7	0.0	5.0		9.7
43	Madhupur	Tangail	0.8	0.0	0.0	5.0		5.8
44	Mirzapur	Tangail	3.3	0.0	0.0	16.0		19.3
45	Nagarpur	Tangail	0.5	2.7	0.0			3.2
46	Shakhipur	Tangail	0.7	0.0	0.0	35.0		35.7
47	Tangail	Tangail	0.9	1.6	0.0			2.5

The analysis of the impact of flood protection on resource potential limits, considering existing development patterns and approximate capability of irrigable land is presented in Table II.5.5 and Figure II.5.4 to II.5.7. The methodology and salient results are discussed below.

Water Demand

Irrigation demands are estimated for the development objective of 80% of all F0-F3 land based on an average water duty of 160 ha/Mm3.

Reserves for potable water supply are estimated from projected population in year 2010 (80% growth 1981-2010) with per capita consumption of 50 l/day (Table II 5.6). Potable reserves are then added to irrigation demand to obtain total water demand.

Residual Water Demands

Residual water demands are estimated by subtracting all current (1991) minor irrigation abstractions, including low lift pumps, from total water demand.

Present Situation

Estimated irrigation water demands and current (1991) minor irrigation development are compared in Table II 5.5. Figures II.5.4 to II.5.6 shown patterns of present development relative to estimated demand.

Minor irrigation of all types currently meets approximately 37% of demand in the project area, ranging from 12% in Munshiganj to 95% in Gopalpur (Tangail). Only 5% of demand is supplied by LLPs which are concentrated in areas south of Dhaka, especially Munshiganj.

Groundwater Irrigation Limits

Percentages of irrigation demand (excluding existing LLPs) which could be supplied from groundwater, for flood protected and unprotected cases, are given in Table II.5.5. The distribution of demand deficits is shown in Figure II.5.7.

Without flood protection, groundwater would be sufficient to satisfy all residual irrigation demand in 34 thanas of the study area. Groundwater resource deficits are evident in the remaining 13 studied thanas which are located in the Madhupur Tract (Gazipur, Mymensingh and Tangail).

The provision of partial flood protection (Table II.5.5), would have no significant effect on the degree or pattern of deficits in the study area. Only one thana, Ghatail shows any change, and this is insignificant (4 percent of total demand) relative to the precision of the assessments.

Figure: II.5.4

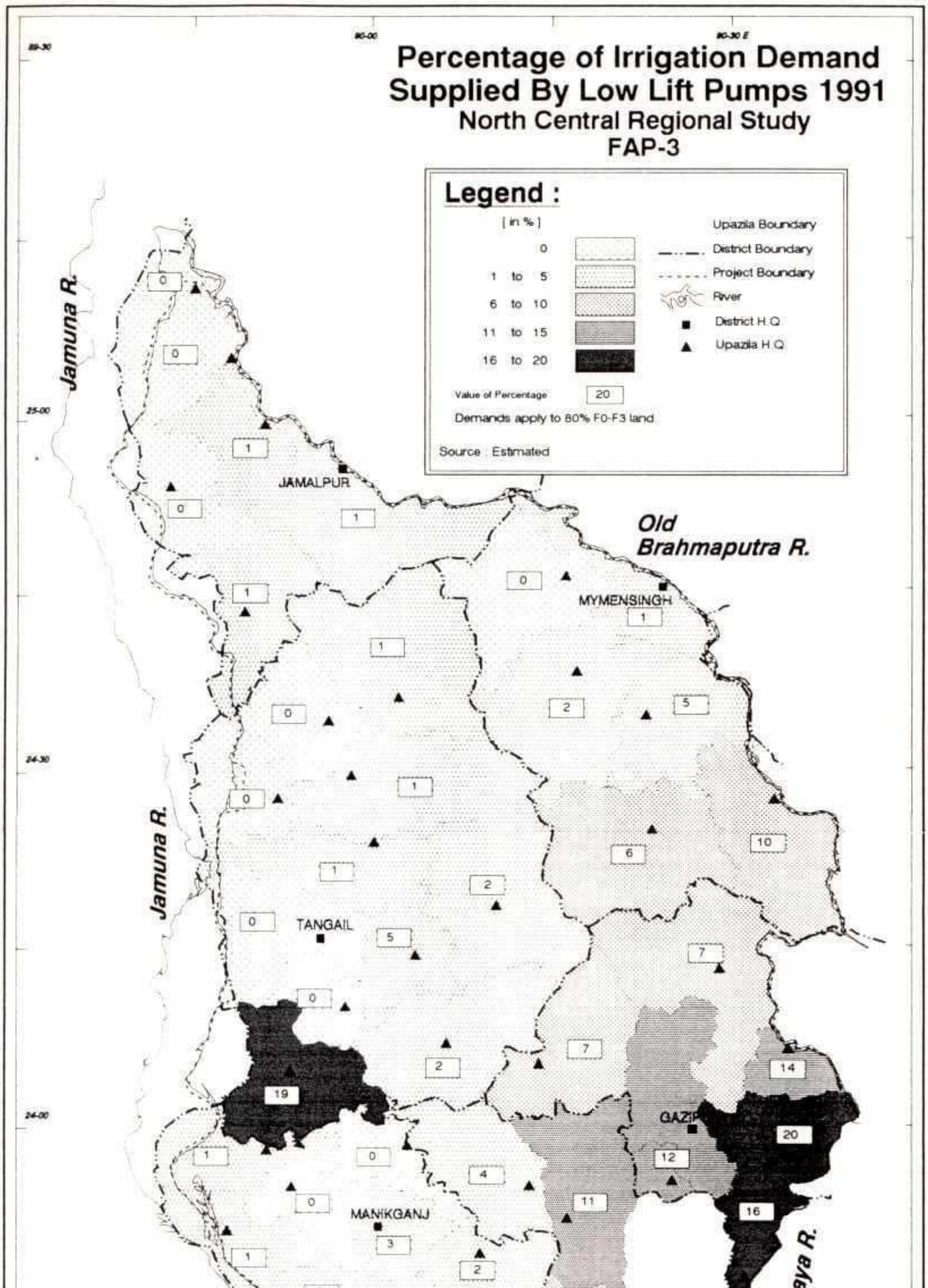

Percentage of Irrigation Demand
Supplied By Low Lift Pumps 1991
North Central Regional Study
FAP-3
Legend :
[in %]
0
1 to 5
6 to 10
11 to 15
16 to 20
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q
Upazila H.Q
Value of Percentage
20
Demands apply to 80% F0-F3 land
Source : Estimated
Jamuna R.
Old
Brahmaputra R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Padma R.
Meghna R.
0 5 10 15 20 25km

Figure: II.5.5

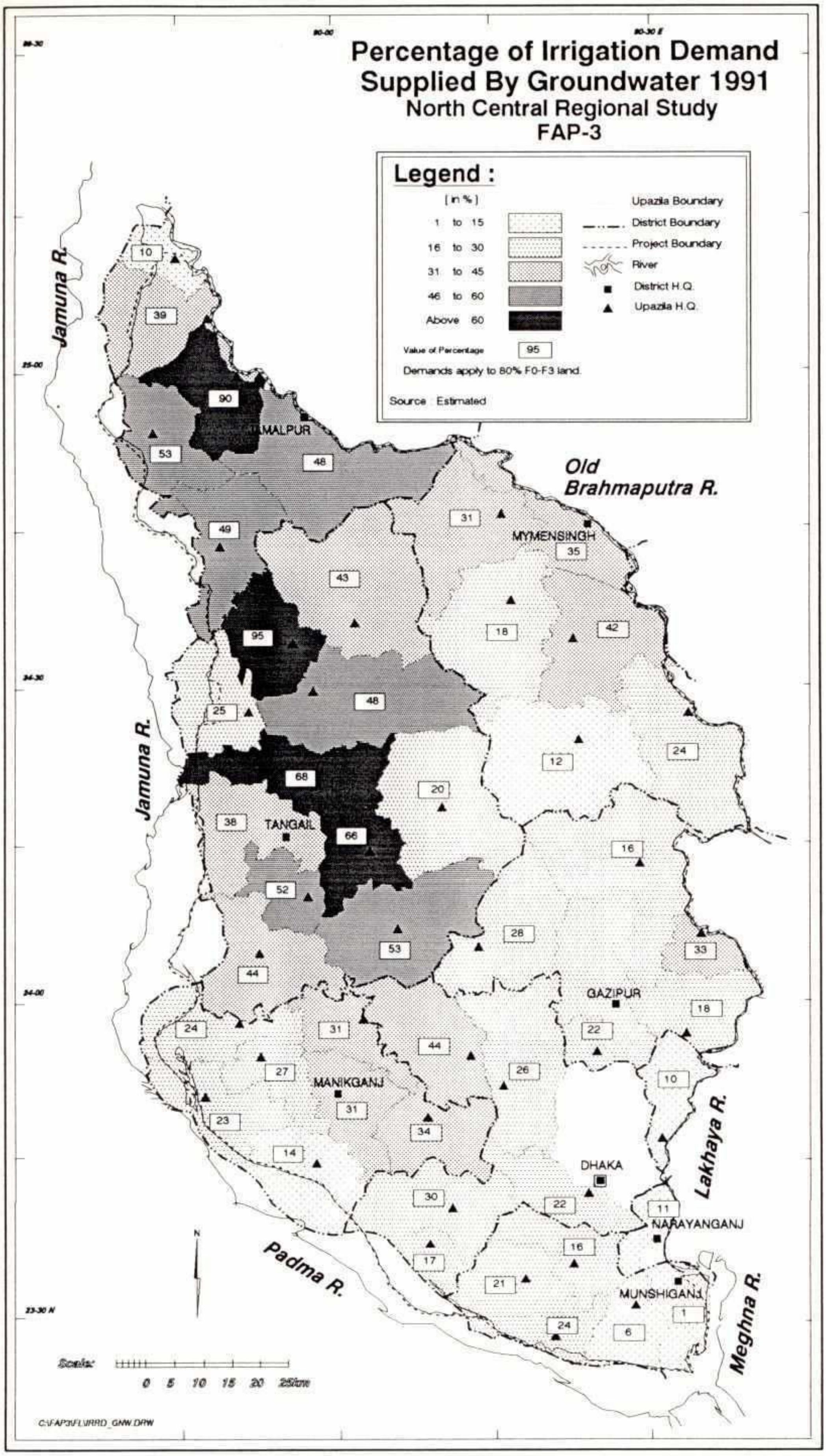

Percentage of Irrigation Demand
Supplied By Groundwater 1991
North Central Regional Study
FAP-3
Legend :
[in %]
1 to 15
16 to 30
31 to 45
46 to 60
Above 60
Value of Percentage
95
Demands apply to 80% F0-F3 land.
Source : Estimated
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Jamuna R.
Old
Brahmaputra R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Padma R.
Meghna R.
Scale:
0 5 10 15 20 25km
C:\FAP3\FLUIRRD_GNW.DRW

Figure: II.5.6

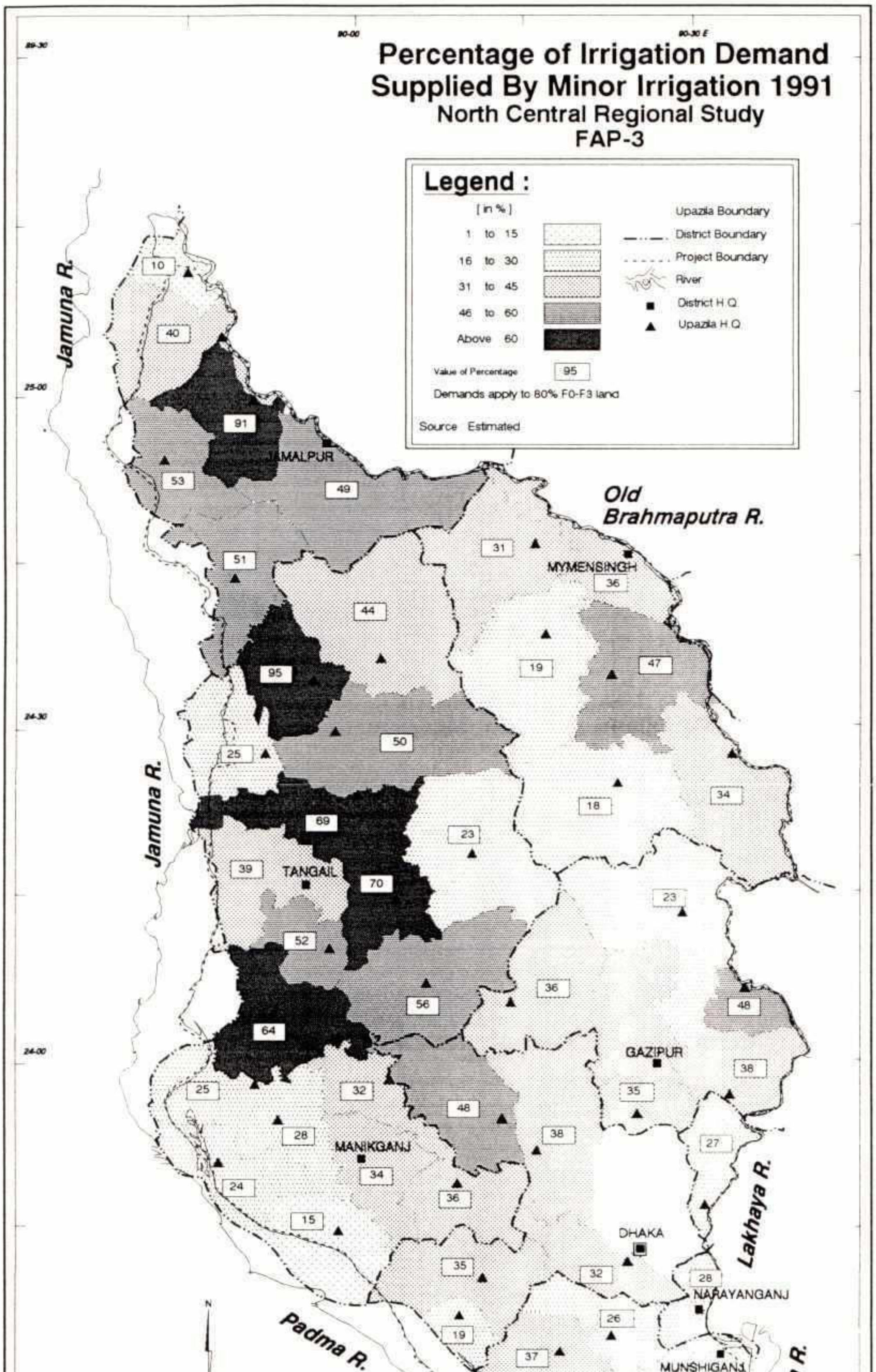
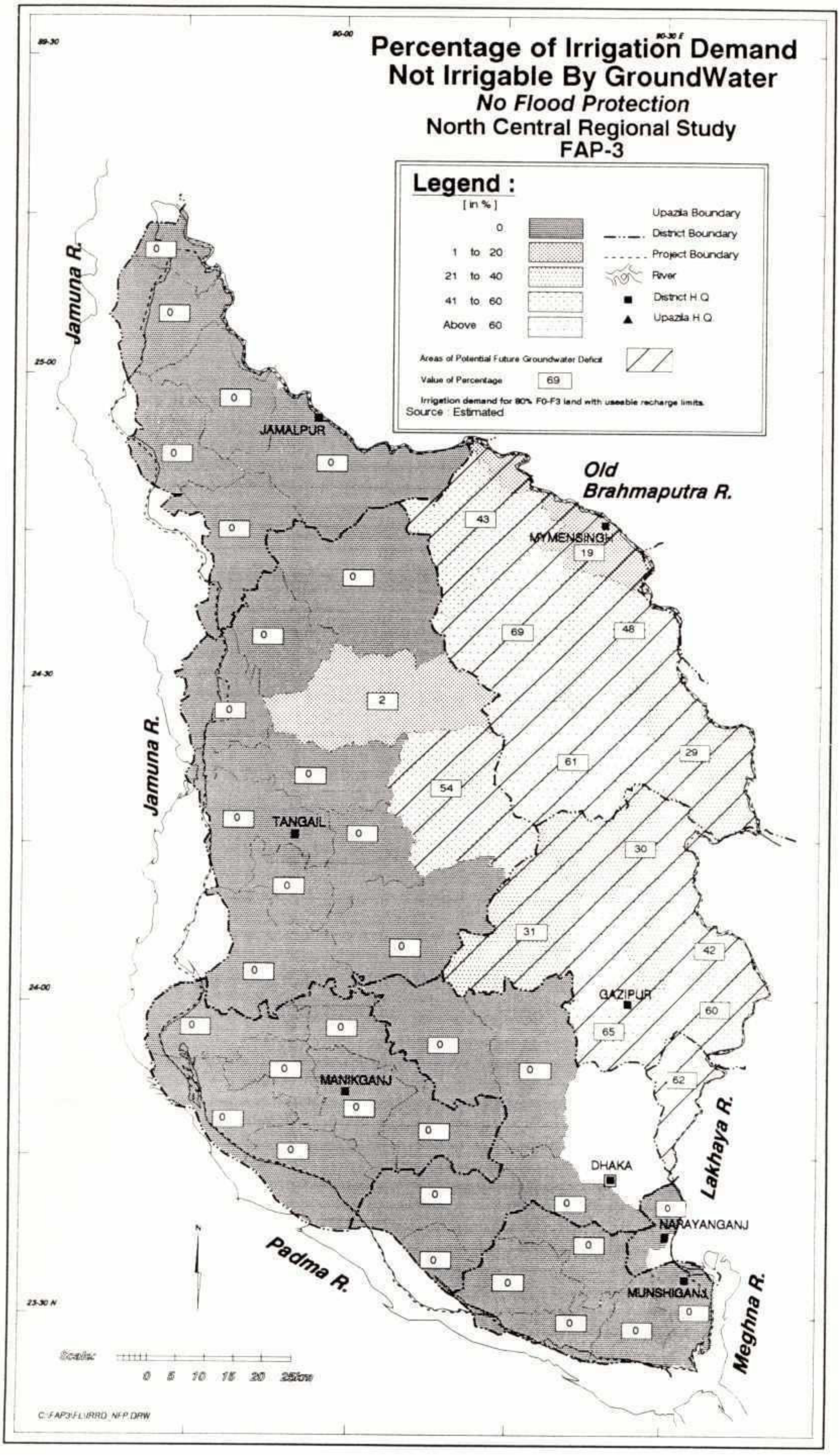

Percentage of Irrigation Demand
Supplied By Minor Irrigation 1991
North Central Regional Study
FAP-3
Legend :
[in %]
1 to 15
16 to 30
31 to 45
46 to 60
Above 60
Value of Percentage
95
Demands apply to 80% F0-F3 land
Source Estimated
Upazila Boundary
District Boundary
Project Boundary
River
District H.Q.
Upazila H.Q.
Jamuna R.
Old
Brahmaputra R.
Padma R.
Lakhaya R.
Meghna R.
JAMALPUR
MYMENSINGH
TANGAIL
GAZIPUR
MANIKGANJ
DHAKA
NARAYANGANJ
MUNSHIGANJ
10
40
91
53
49
51
31
36
44
95
19
47
25
50
18
34
69
23
39
70
23
52
56
36
48
64
25
32
48
35
38
28
38
27
24
34
36
15
35
32
28
19
26
37
12
31
14
N
Scale:
0 5 10 15 20 25km
C:\FAP3\FL\IRRD_MNR.DRW

Figure: II.5.7



Percentage of Irrigation Demand
Not Irrigable By GroundWater
No Flood Protection
North Central Regional Study
FAP-3
Legend :
[in %]
0
1 to 20
21 to 40
41 to 60
Above 60
Upazila Boundary
District Boundary
Project Boundary
River
District H Q
Upazila H Q
Areas of Potential Future Groundwater Deficit
Value of Percentage
69
Irrigation demand for 80% F0-F3 land with useable recharge limits
Source : Estimated
Jamuna R.
Old Brahmaputra R.
JAMALPUR
MYMENSINGH
TANGAIL
MANIKGANJ
GAZIPUR
DHAKA
NARAYANGANJ
MUNSHIGANJ
Lakhaya R.
Padma R.
Meghna R.
43
19
69
48
2
61
29
54
30
31
42
65
60
62
Scale
0 5 10 15 20 25km
C:\FAP3\FL\IRRD_NFP.DRW

TABLE II.5.5

North Central Region : Groundwater Development

Nr	Upazila	District	F0-F3 %	Area F0-F3 km2	Demand F0-F3 80% mm	Potable Reserve Mm3	Potable Reserve mm	Useable Recharge NFP mm	Useable Recharge FFP mm
1	Dhamrai	Dhaka	93.4	287	467	9	28	660	614
2	Dohar	Dhaka	86.1	131	430	5	31	638	602
3	Keraniganj	Dhaka	79.0	132	395	12	70	860	821
4	Nawabganj	Dhaka	88.9	218	445	8	32	660	618
5	Savar	Dhaka	91.8	257	459	8	30	577	554
6	Joydebpur	Gazipur	92.8	322	464	7	22	480	474
7	Kaliakoir	Gazipur	92.4	288	462	5	17	569	558
8	Kaliganj	Gazipur	86.4	170	432	5	28	572	549
9	Kapasia	Gazipur	86.8	306	434	8	23	572	560
10	Sreepur	Gazipur	93.8	433	469	8	17	518	515
11	Dewanganj	Jamalpur	92.6	385	463	8	19	729	677
12	Islampur	Jamalpur	88.1	302	441	7	21	791	743
13	Jamalpur	Jamalpur	89.1	429	446	14	29	521	506
14	Madarganj	Jamalpur	93.9	216	469	5	24	776	720
15	Melandaha	Jamalpur	92.4	221	462	7	28	560	542
16	Sharishabari	Jamalpur	90.6	234	453	7	28	524	511
17	Daulatpur	Manikganj	87.4	185	437	5	21	883	801
18	Ghior	Manikganj	90.2	131	451	4	24	960	842
19	Harirampur	Manikganj	76.3	186	381	5	21	863	803
20	Manikganj	Manikganj	90.1	174	450	6	33	647	605
21	Saturia	Manikganj	93.1	144	465	4	29	755	693
22	Shivalaya	Manikganj	76.3	138	381	4	21	1166	1061
23	Singair	Manikganj	93.3	196	466	7	31	682	634
24	Lohajang	Munshiganj	77.5	100	387	4	28	2536	2454
25	Munshiganj	Munshiganj	79.3	123	397	5	31	902	858
26	Serajdikhan	Munshiganj	85.4	132	427	6	36	1724	1655
27	Sreenagar	Munshiganj	79.4	156	397	6	31	953	902
28	Tongibari	Munshiganj	86.9	127	435	6	38	1274	1204
29	Bhaluka	Mymensingh	94.7	419	474	7	16	437	431
30	Fulbaria	Mymensingh	94.2	457	471	11	22	413	413
31	Gaffargaon	Mymensingh	87.5	343	437	10	26	589	566
32	Muktagacha	Mymensingh	92.3	289	461	8	27	482	475
33	Mymensingh	Mymensingh	83.3	312	417	14	39	467	461
34	Trishal	Mymensingh	89.5	223	448	7	28	506	495
35	Narayanganj	Narayanganj	62.2	53	311	6	74	905	841
36	Rupganj	Narayanganj	87.9	208	440	9	40	772	692
37	Basail	Tangail	90.9	160	455	5	29	589	538
38	Bhuapur	Tangail	95.2	213	476	4	20	715	662
39	Delduar	Tangail	92.2	157	461	5	27	614	570
40	Ghatail	Tangail	93.6	422	468	9	19	474	457
41	Gopalpur	Tangail	89.3	193	447	7	31	574	534
42	Kalihati	Tangail	87.8	256	439	9	32	618	563
43	Madhupur	Tangail	95.2	455	476	9	18	512	506
44	Mirzapur	Tangail	89.3	327	447	10	26	608	554
45	Nagarpur	Tangail	87.8	254	439	8	27	596	563
46	Shakhipur	Tangail	96.1	418	480	6	13	421	416
47	Tangail	Tangail	89.2	235	446	9	35	633	577
		Total		11538		338			
		Average	88		442		28	729	689

Upazila Groundwater Resource Potential Limit (mm)

Nr	NFP STW	NFP DSSTW	NFP DTW-1	NFP DTW-2	NFP HTW	PFP STW	PFP DSSTW	PFP DTW-1	PFP DTW-2	PFP HTW
1	240	402	660	644	646	240	402	614	614	614
2	159	259	520	360	440	159	259	520	360	440
3	159	305	686	458	564	159	305	686	458	564
4	239	364	660	589	530	239	364	618	589	530
5	163	272	577	481	369	163	272	554	481	369
6	91	122	165	98	96	91	122	165	98	96
7	127	181	310	192	189	127	181	310	192	189
8	79	107	166	118	95	79	107	166	118	95
9	39	63	164	105	115	39	63	164	105	115
10	90	141	324	231	191	90	141	324	231	191
11	475	725	729	729	729	475	677	677	677	677
12	516	784	791	791	791	516	743	743	743	743
13	339	520	521	521	521	339	506	506	506	506
14	776	776	776	776	776	720	720	720	720	720
15	560	560	560	560	560	542	542	542	542	542
16	506	524	524	524	524	506	511	511	511	511
17	385	580	883	883	804	385	580	801	801	801
18	248	472	960	874	768	248	472	842	842	768
19	96	187	436	349	306	96	187	436	349	306
20	212	378	647	647	600	212	378	605	605	600
21	301	482	755	755	722	301	482	693	693	693
22	187	325	711	594	496	187	325	711	594	496
23	345	549	682	682	682	345	549	634	634	634
24	186	290	574	458	441	186	290	574	458	441
25	147	227	446	356	343	147	227	446	356	343
26	178	271	525	421	406	178	271	525	421	406
27	203	306	597	523	424	203	306	597	523	424
28	191	291	564	452	436	191	291	564	452	436
29	63	94	188	108	129	63	94	188	108	129
30	99	120	165	127	111	99	120	165	127	111
31	127	171	305	216	203	127	171	305	216	203
32	134	173	290	233	174	134	173	290	233	174
33	131	184	371	294	214	131	184	371	294	214
34	135	174	248	172	151	135	174	248	172	151
35	190	257	573	498	353	190	257	573	498	353
36	62	91	179	112	118	62	91	179	112	118
37	537	589	589	589	589	537	538	538	538	538
38	359	555	715	715	715	359	555	662	662	662
39	421	614	614	614	614	421	570	570	570	570
40	474	474	474	474	474	457	457	457	457	457
41	574	574	574	574	574	534	534	534	534	534
42	441	618	618	618	618	441	563	563	563	563
43	227	359	512	512	512	227	359	506	506	506
44	254	499	608	608	608	254	499	554	554	554
45	510	596	596	596	596	510	563	563	563	563
46	108	141	228	173	138	108	141	228	173	138
47	415	612	633	633	633	415	577	577	577	577
Total										
Average	266	369	519	469	449	263	359	496	450	433

Existing Development 1991 / Percent Total F0-F3 Demand / Percent Max Groundwater Potential

Nr	STW	STW mm	DSSTW mm	DTW mm	LLP mm	Total Gwater mm	Total All mm	Gwater %	LLP %	All %	NFP %	PFP %
1	1339	123	1	81	20	204	224	44	4	48	31	33
2	384	71	0	1	9	72	81	17	2	19	14	14
3	448	76	0	12	38	87	126	22	10	32	13	13
4	1159	133	0	1	23	134	157	30	5	35	20	22
5	199	20	1	100	52	121	173	26	11	38	21	22
6	172	14	0	90	56	104	160	22	12	35	63	63
7	283	26	0	106	33	132	166	28	7	36	42	42
8	22	3	1	75	87	79	166	18	20	38	47	47
9	1542	123	0	21	63	144	206	33	14	48	88	88
10	132	8	0	65	34	73	107	16	7	23	23	23
11	611	41	0	3	0	44	44	10	0	10	6	7
12	1885	155	0	18	2	173	174	39	0	40	22	23
13	1889	110	1	103	6	215	220	48	1	49	41	42
14	1998	244	0	5	0	250	250	53	0	53	32	35
15	3143	369	0	46	7	415	421	90	1	91	74	77
16	1783	194	0	29	6	223	229	49	1	51	43	44
17	704	93	0	13	3	106	110	24	1	25	12	13
18	363	71	0	53	1	123	124	27	0	28	13	15
19	302	35	0	17	7	52	59	14	2	15	12	12
20	467	68	0	70	14	138	152	31	3	34	21	23
21	518	94	0	51	2	145	147	31	0	32	19	21
22	358	56	0	30	5	86	91	23	1	24	12	12
23	884	119	0	40	8	159	166	34	2	36	23	25
24	419	91	0	3	25	94	120	24	7	31	16	16
25	15	3	0	1	43	4	47	1	11	12	1	1
26	427	67	0	0	45	67	112	16	10	26	13	13
27	522	74	0	9	63	83	146	21	16	37	14	14
28	137	26	0	0	33	26	59	6	8	14	5	5
29	151	10	0	48	27	58	85	12	6	18	31	31
30	90	5	0	79	7	84	91	18	2	19	51	51
31	154	11	0	95	43	106	149	24	10	34	35	35
32	100	9	0	132	1	142	143	31	0	31	49	49
33	894	67	0	77	5	144	149	35	1	36	39	39
34	41	5	0	183	21	187	209	42	5	47	76	76
35	96	31	0	3	54	34	88	11	17	28	6	6
36	135	16	0	28	72	44	117	10	16	27	25	25
37	1539	246	0	53	21	299	320	66	5	70	51	56
38	776	98	0	21	0	118	119	25	0	25	17	18
39	973	161	0	81	0	241	242	52	0	52	39	42
40	2851	178	0	48	6	226	232	48	1	50	48	49
41	2689	350	0	72	1	422	423	95	0	95	74	79
42	2602	251	0	47	4	298	302	68	1	69	48	53
43	2500	147	1	59	4	207	211	43	1	44	40	41
44	1869	144	0	94	11	237	248	53	2	56	39	43
45	1850	180	0	15	85	195	280	44	19	64	33	35
46	505	33	0	65	11	98	108	20	2	23	43	43
47	1168	125	0	46	2	171	172	38	0	39	27	30
Total	43088											
Average		97	0	49	23	146	169	33	5	38	32	33

Groundwater Irrigation Limits 80% F0-F3 Land excluding LLP / Losses to Ultimate Gwater Potential due To Flood Protection / Gwater Potential Reduction with HTW constraint

Nr	NFP mm	NFP Percent Demand	PFP mm	PFP Percent Demand	Losses mm	Losses Ha 1000	Losses % Demand	% potentials NFP	% potentials PFP
1	447	100	447	100	0	0.0	0	0	0
2	422	100	422	100	0	0.0	0	0	0
3	357	100	357	100	0	0.0	0	0	0
4	422	100	422	100	0	0.0	0	0	0
5	407	100	407	100	0	0.0	0	9	9
6	144	35	144	35	0	0.0	0	33	33
7	293	69	293	69	0	0.0	0	36	36
8	139	40	139	40	0	0.0	0	32	32
9	141	38	141	38	0	0.0	0	18	18
10	307	70	307	70	0	0.0	0	38	38
11	463	100	463	100	0	0.0	0	0	0
12	439	100	439	100	0	0.0	0	0	0
13	440	100	440	100	0	0.0	0	0	0
14	469	100	469	100	0	0.0	0	0	0
15	455	100	455	100	0	0.0	0	0	0
16	447	100	447	100	0	0.0	0	0	0
17	434	100	434	100	0	0.0	0	0	0
18	450	100	450	100	0	0.0	0	0	0
19	375	100	375	100	0	0.0	0	18	18
20	436	100	436	100	0	0.0	0	0	0
21	464	100	464	100	0	0.0	0	0	0
22	376	100	376	100	0	0.0	0	0	0
23	458	100	458	100	0	0.0	0	0	0
24	362	100	362	100	0	0.0	0	0	0
25	353	100	353	100	0	0.0	0	3	3
26	382	100	382	100	0	0.0	0	0	0
27	334	100	334	100	0	0.0	0	0	0
28	402	100	402	100	0	0.0	0	0	0
29	172	39	172	39	0	0.0	0	25	25
30	143	31	143	31	0	0.0	0	22	22
31	279	71	279	71	0	0.0	0	27	27
32	263	57	263	57	0	0.0	0	34	34
33	332	81	332	81	0	0.0	0	35	35
34	220	52	220	52	0	0.0	0	31	31
35	257	100	257	100	0	0.0	0	0	0
36	138	38	138	38	0	0.0	0	15	15
37	434	100	434	100	0	0.0	0	0	0
38	475	100	475	100	0	0.0	0	0	0
39	461	100	461	100	0	0.0	0	0	0
40	455	98	438	95	17	1.2	4	0	0
41	445	100	445	100	0	0.0	0	0	0
42	435	100	435	100	0	0.0	0	0	0
43	472	100	472	100	0	0.0	0	0	0
44	436	100	436	100	0	0.0	0	0	0
45	354	100	354	100	0	0.0	0	0	0
46	215	46	215	46	0	0.0	0	36	36
47	444	100	444	100	0	0.0	0	0	0
Total						1.2			
Average	363	86	362	86	0		0	9	9

B:\TAB255.WK1

TABLE II.5.6

North Central Region : Potable Reserves

Population growth 1981-2010 : 80 %
Potable water demand : 50 lcd

Nr	Upazila	District	Area (km2)	Population (1000)	Population (1000)	Potable Demand Mm3
1	Dhamrai	Dhaka	307.4	266	479	9
2	Dohar	Dhaka	151.8	145	261	5
3	Keraniganj	Dhaka	166.9	361	650	12
4	Nawabganj	Dhaka	244.8	242	436	8
5	Savar	Dhaka	280.1	261	470	8
6	Joydebpur	Gazipur	347.2	231	416	7
7	Kaliakoir	Gazipur	311.5	165	297	5
8	Kaliganj	Gazipur	197.2	169	304	5
9	Kapasia	Gazipur	352.8	250	450	8
10	Sreepur	Gazipur	461.9	239	430	8
11	Dewanganj	Jamalpur	416.0	246	443	8
12	Islampur	Jamalpur	343.0	221	398	7
13	Jamalpur	Jamalpur	481.2	424	763	14
14	Madarganj	Jamalpur	230.2	169	304	5
15	Melandaha	Jamalpur	239.6	206	371	7
16	Sharishabari	Jamalpur	258.3	226	407	7
17	Daulatpur	Manikganj	211.8	139	250	5
18	Ghior	Manikganj	144.7	109	196	4
19	Harirampur	Manikganj	244.3	162	292	5
20	Manikganj	Manikganj	193.0	194	349	6
21	Saturia	Manikganj	154.3	137	247	4
22	Shivalaya	Manikganj	181.3	119	214	4
23	Singair	Manikganj	209.6	202	364	7
24	Lohajang	Munshiganj	128.9	112	202	4
25	Munshiganj	Munshiganj	155.3	149	268	5
26	Serajdikhan	Munshiganj	178.4	197	355	6
27	Sreenagar	Munshiganj	197.1	191	344	6
28	Tongibari	Munshiganj	146.3	170	306	6
29	Bhaluka	Mymensingh	442.9	216	389	7
30	Fulbaria	Mymensingh	485.4	330	594	11
31	Gaffargaon	Mymensingh	391.7	319	574	10
32	Muktagacha	Mymensingh	313.3	257	463	8
33	Mymensingh	Mymensingh	374.2	446	803	14
34	Trishal	Mymensingh	249.3	217	391	7
35	Narayanganj	Narayanganj	85.8	196	353	6
36	Rupganj	Narayanganj	236.1	293	527	9
37	Basail	Tangail	175.7	155	279	5
38	Bhuapur	Tangail	223.6	136	245	4
39	Delduar	Tangail	170.3	143	257	5
40	Ghatail	Tangail	450.6	264	475	9
41	Gopalpur	Tangail	215.9	205	369	7
42	Kalihati	Tangail	291.9	286	515	9
43	Madhupur	Tangail	477.7	263	473	9
44	Mirzapur	Tangail	366.1	294	529	10
45	Nagarpur	Tangail	288.9	244	439	8
46	Shakhipur	Tangail	435.2	172	310	6
47	Tangail	Tangail	263.2	281	506	9
	Total		12873	10419	18754	338

Source : Population Data from BBS : Upazila Statistics 1988

5.4 Planning Unit Analysis

The thanawise analysis of minor irrigation and groundwater resource potential for the study area has been re-evaluated in terms of the 13 planning units, by considering the proportions of each thana in each PU. The results are summarised in Table II.5.7. which presents PU averages and totals for key development and resource parameters. A brief discussion of the characteristics of each PU is given below.

PU 1

This PU is located in Jamalpur and Tangail districts. The aquifer conditions are among the best in the North Central region, with average storage coefficient exceeding 12% and tubewell specific capacities of 17 l/s/m. At present, maximum SWL averages 6.5m at the end of April, allowing STWs to operate in almost all areas.

Existing minor irrigation is well developed and already meets some 60% of estimated irrigation demand. STWs are the dominant method in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the estimated residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 6%, but this would have no significant effect on resources which would still substantially exceed demand.

PU2

This PU is located in Jamalpur and Tangail districts. The aquifer conditions, which are similar to PA1, are favourable, with average storage coefficient exceeding 9% and tubewell specific capacities of 14 l/s/m. At present, maximum SWL averages 6.9m at the end of April, allowing STWs to operate in almost all areas.

Existing minor irrigation is very intensive and already meets some 64% of estimated irrigation demand. STWs are the dominant method in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the estimated residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 5%, but this would have no significant effect on resources which would still substantially exceed demand.

PU3

This PU is located in mainly in Mymensingh district. The terrain is predominantly Madhupur Tract. The aquifer conditions are relatively unfavourable, with storage coefficient averaging only 1.8% and tubewell specific capacities of averaging 6.5 l/s/m. At present, maximum SWL averages 11.8m at the end of April, allowing STWs to operate only on the lowest land. Force mode tubewells are required for irrigation over most of this area.

Existing minor irrigation currently meets some 34% of estimated irrigation demand. DTWs are the dominant technology. The assessment indicates that under present conditions, groundwater could supply a maximum of 60% of the estimated residual irrigation demand in PU3, due to the unfavourable aquifer conditions.

The introduction of partial flood protection would have little effect on groundwater recharge (2% reduction), and would not affect resource potential, which is already constrained by aquifer conditions.

PU4

This PU is located mainly in Tangail district. The aquifer conditions, which are similar to PA2, are favourable, with average storage coefficient exceeding 10% and tubewell specific capacities averaging 11 l/s/m. At present, maximum SWL averages 7.1m at the end of April, allowing STWs to operate in almost all areas.

Existing minor irrigation is well developed and already meets some 57% of estimated irrigation demand. STWs are the dominant method in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the estimated residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 7%, but this would have no significant effect on resources which could still satisfy irrigation demand. Although the assessment indicates a decline in groundwater resource potential in Ghatail by about 4%, this is considered to be insignificant relative to the precision of the estimate.

PU5

This PU is located in Gazipur, Mymensingh and Tangail districts. The terrain is predominantly Madhupur Tract. The aquifer conditions, which are similar to PA3, are relatively unfavourable, with storage coefficient averaging 3.5% and tubewell specific capacities averaging 7.1 l/s/m. At present, maximum SWL averages 11.4m at the end of April, allowing STWs to operate only on the lowest land. Force mode tubewells are required for irrigation over most of this area.

Existing minor irrigation currently meets some 32% of estimated irrigation demand. DTWs are the dominant technology. The assessment indicates that under present conditions, groundwater could supply a maximum of 65% of the estimated residual irrigation demand in PA5, due to the unfavourable aquifer conditions.

The introduction of partial flood protection would have little effect on groundwater recharge (2% reduction), and would not affect resource potential, which is already constrained by aquifer conditions.

PU6

This PU is located mainly in Tangail district. The aquifer conditions, which are similar to PU4, are favourable, with average storage coefficient exceeding 9% and tubewell specific capacities averaging 12.8 l/s/m. At present, maximum SWL averages 7.5m at the end of April, allowing STWs to operate in most areas.

Existing minor irrigation is moderately well developed and already meets some 46% of estimated irrigation demand. STWs are the dominant method in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the estimated residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 8%, but this would have no significant effect on resources which would still substantially exceed irrigation demand.

PU7

This PU is located mainly in Dhaka and Manikganj districts. The aquifer conditions, are favourable, with average storage coefficient exceeding 7% and tubewell specific capacities averaging 10.4 l/s/m. At present, maximum SWL averages 7.6m at the end of April, allowing STWs to operate in most areas.

Existing minor irrigation is moderately well developed and already meets some 38% of estimated irrigation demand. Both STWs and DTWs are important in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the estimated residual irrigation demand except in Kaliakoir..

The introduction of partial flood protection would reduce groundwater recharge by about 7%, but this would have no significant effect on resources which would still substantially exceed irrigation demand.

PU8

This PU is located in Gazipur and Dhaka districts. The terrain is predominantly Madhupur Tract. The aquifer conditions are unfavourable, with storage coefficient averaging only 3.2% and tubewell specific capacities of 6 l/s/m. At present, maximum SWL averages 11.3m at the end of April, allowing STWs to operate only on the lowest land. Force mode tubewells are required for irrigation over most of this area.

Existing minor irrigation currently meets some 36% of estimated irrigation demand. DTWs and LLPs are the dominant technologies. The assessment indicates that under present conditions, groundwater could supply a maximum of 80% of the estimated residual irrigation demand in PU8, due to the unfavourable aquifer conditions.

The introduction of partial flood protection would have little effect on groundwater recharge (3% reduction), and would not affect resource potential, which is already constrained by aquifer conditions.

PU9

This PU is located in Gazipur and Narayanganj districts. The terrain is predominantly Madhupur Tract. The aquifer conditions are the poorest in the North Central region, with storage coefficient averaging only 1.2% and tubewell specific capacities of 5.6 l/s/m. At present, maximum SWL averages 11.7m at the end of April, allowing STWs to operate only on the lowest land. Force mode tubewells are required for irrigation over most of this area.

Existing minor irrigation currently meets some 35% of estimated irrigation demand. DTWs and LLPs are the dominant technologies. The assessment indicates that under present conditions, groundwater could supply a maximum of 42% of the estimated residual irrigation demand in PU9, due to the unfavourable aquifer conditions.

The introduction of partial flood protection would have little effect on groundwater recharge (4% reduction), and would not affect resource potential, which is already constrained by aquifer conditions.

PU10

This PU is located mainly in Dhaka and Manikganj districts. The aquifer conditions are favourable, with average storage coefficient of 6% and tubewell specific capacities averaging 12.5 l/s/m. At present, maximum SWL averages 7.4m at the end of April, allowing STWs to operate in most areas.

Existing minor irrigation is relatively limited and meets some 26% of estimated irrigation demand. STWs are the dominant technology in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 9%, but this would have no significant effect on resources which would still substantially exceed irrigation demand.

PU11

This PU is located in Dhaka, Keraniganj and Narayanganj districts. The aquifer conditions are moderate, with average storage coefficient of 5% and tubewell specific capacities averaging 7.9 l/s/m. At present, maximum SWL averages 6m at the end of April, allowing STWs to operate in most areas.

Existing minor irrigation is relatively limited and meets some 31% of estimated irrigation demand. STWs and LLPs are the dominant technologies in this area. The assessment indicates that under present conditions, groundwater could supply 100% of the residual irrigation demand.

The introduction of partial flood protection would reduce groundwater recharge by about 5%, but this would have no significant effect on resources which could still satisfy irrigation demand.

PU12

This PU is located in Dhaka, Gazipur and Narayanganj districts and covers the Dhaka metropolitan area. The present assessment covers only the parts in Narayanganj district which are outside the urban area.

The aquifer conditions are relatively unfavourable, with storage coefficient averaging 2.4%, and tubewell specific capacities of 9 l/s/m. Maximum SWLs vary considerably, from 3m in Narayanganj up to 9m in Rupganj. Force mode tubewells are normally required for irrigation development in Rupganj.

Existing minor irrigation is relatively limited and currently meets some 28% of estimated irrigation demand. STWs and LLPs are the dominant technologies, particularly in Narayanganj. The assessment indicates that under present conditions, groundwater could supply a maximum of 88% of the estimated residual irrigation demand in PU12, due to relatively unfavourable aquifer conditions.

The introduction of partial flood protection would reduce groundwater recharge by about 8%, but this would not affect resource potential, which is already constrained by aquifer conditions.

Special conditions apply in the Dhaka metropolitan area where intensive abstractions for municipal and industrial water supply have caused permanent depression of piezometric levels in the deep aquifer. The situation has been studied in detail by Dhaka WASA. Expansion of municipal water supply abstractions in areas outside the urban area is under consideration. This could affect irrigated agriculture in areas surrounding the city.

PU13

This PU is located in Dhaka, Munshiganj and Narayanganj districts. The aquifer conditions are moderate, with storage coefficient averaging 3.2%, and tubewell specific capacities of 10.5 l/s/m. At present, maximum SWL averages 5.6m at the end of April, allowing STWs to operate in most areas.

Existing minor irrigation is relatively limited and currently meets some 24% of estimated irrigation demand. STWs and LLPs are the dominant technologies. The assessment indicates that under present conditions, groundwater could supply 100% of residual irrigation demand in PU13.

The introduction of partial flood protection would reduce groundwater recharge by about 5%, but this would have no significant effect on resources which could still satisfy irrigation demand.

TABLE II.5.7
Planning Unit Summary

		Planning Unit												
		1	2	3	4	5	6	7	8	9	10	11	12	13
LAND AREAS														
Gross	km2	894	740	1724	762	2125	1144	901	420	770	672	250	80	1015
F0–F3 Land	%	91.7	91.1	89.8	91.4	93.8	89.7	92.1	92.1	89.0	83.8	78.6	67.0	82.2
WATER DEMAND														
Irrigation (80% F0–F3)	mm	459	456	449	457	469	448	460	461	445	419	393	335	411
Potable Reserve	mm	25	27	27	19	18	28	31	25	27	25	62	68	34
AVERAGE AQUIFER CONDITIONS														
Storage Coefficient	%	12.4	9.1	1.8	10.4	3.5	9.4	7.1	3.2	1.2	6.2	4.9	2.4	3.9
DTW Specific Capacity	l/s/m	17.4	14.1	6.5	11.2	7.1	12.8	10.4	6.0	5.6	12.5	7.9	9.1	10.5
Maximum SWL	m	6.5	6.9	11.8	7.1	10.4	7.5	7.6	11.3	11.9	7.4	6.0	3.7	5.8
Seasonal Fluctuation	m	1.9	2.6	7.9	2.4	5.4	2.4	2.4	4.7	6.1	1.6	1.2	1.4	1.6
GROUNDWATER RESOURCES														
Useable Recharge NFP	mm	663	563	496	587	486	650	690	558	583	921	915	880	1282
Useable Recharge PFP	mm	628	535	485	543	476	597	641	542	557	839	871	813	1224
Groundwater Potential NFP														
STW	mm	597	458	134	452	159	410	274	141	75	202	166	166	182
DSSTW	mm	661	524	180	556	226	578	449	221	106	348	288	226	280
DTW	mm	663	563	281	587	328	647	682	433	187	680	634	500	549
Groundwater Potential PFP														
STW	mm	574	442	134	447	159	410	274	141	75	202	166	166	182
DSSTW	mm	628	504	180	522	225	549	449	221	106	348	288	226	280
DTW	mm	628	535	281	543	322	594	633	420	187	641	631	500	546
PRESENT MINOR IRRIGATION														
STW	Ha*1000	32.9	24.2	6.3	24.2	19.7	28.0	15.2	1.4	3.2	7.9	2.3	0.3	10.5
DSSTW	Ha*1000	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
DTW	Ha*1000	4.4	7.4	28.9	5.7	23.7	9.4	9.0	6.7	7.6	2.9	1.1	0.2	0.4
LLP	Ha*1000	0.5	0.4	4.7	0.9	6.1	4.5	2.2	3.2	7.8	1.0	1.7	0.8	5.8
Total Groundwater	Ha*1000	37.3	31.6	35.3	30.0	43.6	37.4	24.3	8.1	10.9	10.7	3.4	0.5	10.9
Total All	Ha*1000	37.7	32.0	40.0	30.8	49.7	41.9	26.5	11.3	18.7	11.7	5.2	1.3	16.6
STW	mm	247	229	21	204	57	152	102	21	22	72	59	29	61
DSSTW	mm	0	0	0	0	0	0	0	1	0	0	0	0	0
DTW	mm	28	58	113	46	72	52	59	100	62	29	20	8	2
LLP	mm	3	3	17	9	19	21	13	48	69	8	43	57	35
Total Groundwater	mm	275	287	134	250	129	204	161	122	84	101	79	37	63
Total All Types	mm	278	290	151	259	148	225	174	170	153	109	122	94	98
PRESENT MINOR IRRIGATION														
Percentage of Demand														
Groundwater	%	60	64	30	55	28	45	35	26	19	24	20	11	15
LLP	%	1	1	4	2	4	5	3	10	16	2	11	17	9
All Minor Irrigation	%	61	65	34	57	32	50	38	36	35	26	31	28	24
Percentage of Groundwater Potential														
NFP	%	44	52	49	44	39	33	24	34	48	14	12	9	11
PFP	%	46	54	49	47	40	36	26	34	48	15	12	9	11
FUTURE G'WATER DEVELOPMENT LIMITS														
PERCENT IRRIGATION DEMAND														
NFP	%	100	100	59	100	65	100	99	80	42	100	100	88	100
PFP	%	100	100	59	99	65	100	99	80	42	100	100	88	100
GROUNDWATER RESOURCE DEFICITS														
PERCENT IRRIGATION DEMAND														
NFP	%	0	0	41	0	35	0	1	20	58	0	0	12	0
PFP	%	0	0	41	1	35	0	1	20	58	0	0	12	0
LOSSES DUE TO PFP	%	0	0	0	1	0	0	0	0	0	0	0	0	0

B:\TAB257.WK1

CHAPTER 6
ENVIRONMENTAL IMPACT OF GROUNDWATER DEVELOPMENT

6.1 General

Current GOB policies for development of groundwater as set out in the National Water Plan, specify the full development of the country's groundwater resources as a primary objective. This principle should be followed in formulating the groundwater development plan for the NCR. The environmental impact of groundwater development on the scale envisaged by these policies could have significant environmental impact in the following main respects:

a) Reduction of dry season groundwater baseflows to surface water, including rivers and some static surface water bodies such as lakes and beels.

b) Reduce dry season capillary contribution to soil moisture from the water table, in areas where soil moisture currently allows cultivation without irrigation.

c) Declining dry season groundwater levels affecting the operation of tubewells used for rural water supply.

It should be noted that these environmental impacts of groundwater development are to a large extent independent of the provision of flood protection.

6.2 Impact on Surface Water

Increased groundwater development will reduce baseflows to rivers and to some static water bodies which are wholly or partly sustained by groundwater during the winter season. This will result in some reduction of river flows and in water levels of static water bodies.

There has been little study or monitoring of the effects of groundwater development on surface water in Bangladesh, and data is insufficient to quantify the current position. Analysis of historic river flows is complicated by natural variations in flows from year to year as a result of changes in channel morphology and direct irrigation pumping (low lift pumps). For static water bodies, quantitative information on volumes of water, historic or current agricultural use and water levels fluctuations, is generally unavailable.

Some limited theoretical assessments have been conducted in the past based on strip models, of which the must detailed is described in the Bangladesh Water Balance Studies Report of 1983. The principal conclusions of this analysis were :

a) Intensive tubewell development will generally reduce natural base flows of rivers by up to 30%.

b) Where LLPs are in use, their direct affects on river flows will be the most significant factor, and the influence of tubewell development will generally be minimal.

Further modelling and monitoring studies of the effects of groundwater development on river and static surface water bodies will be required for a detailed assessment.

A range of possible measures for minimising or eliminating the impact of groundwater development on surface water availability may be considered. These include:

a) Diversion of water from major rivers in order to maintain or augment dry season flows in the smaller rivers.

b) Conjunctive use of groundwater for augmentation of small rivers and static water bodies during critical dry periods using tubewells.

Both the above techniques are widely used for environmental control and would be technically feasible in Bangladesh. However, use of pumped groundwater would present financial and operational problems.

6.3 Rural Water Supply

Decline of groundwater levels in Bangladesh during to increased groundwater abstraction for irrigation has already affected hand tubewells used for rural water supply in some localities. Rural water supply agencies particularly UNICEF, are implementing programmes for replacement of suction mode hand pumps with new Tara force lift pumps in these areas. The maximum design lift of these pumps is 15m, which may constrain the full development of groundwater resource potential in parts of the Madhupur Tract. Table II.5.5 shows the thanas of the study area which would be affected. Potable water supply development in these areas should be seen in the context of force mode pumps, storage tanks and reticulation.

Groundwater development for irrigation should always be accompanied by parallel programmes to provide adequate force lift tubewells to satisfy rural water supply needs.

6.4 Soil Moisture Levels

With declining groundwater levels accompanying extensive groundwater development, it is likely that capillary contributions to soil moisture from shallow water tables will be reduced in some areas where cultivation is currently possible without irrigation. Further studies of the loss in agricultural benefits associated with these effects is required for a reliable quantitative assessment. This situation would also affect natural vegetation, flora and fauna. These aspects merit careful monitoring and investigation.

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Flood Action Plan
FAP 3
North Central Regional Study

Supporting Report II.5
Hydraulic Model

February 1993

SR II.5
Hydraulic Model

Financed by: Commission of the European Communities and
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Consortium:
BCEOM, Compagnie Nationale du Rhone
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Flood Action Plan

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The Regional Water Resources Development Plan - Final Report consists of the following:-

Main Volume REGIONAL WATER RESOURCES DEVELOPMENT PLAN

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ABBREVIATIONS AND ACRONYMS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zone
BADC	Bangladesh Agricultural Development Corp.
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BB	Bangladesh Bank
BBS	Bangladesh Bureau of Statistics
BCAL	Bangladesh Census of Agricultural Livestock
BCAS	Bangladesh Centre for Advanced Studies
BCEOM	French Engineering Consultants
BFDC	Bangladesh Fisheries Development Corp.
BIDS	Bangladesh Institute of Development Studies
BIWTA	Bangladesh Inland Water Transport Auth.
BJRI	Bangladesh Jute Research Institute
BKB	Bangladesh Krishi Bank
BNPP	Bangladesh National Physical Plan. Board
BRAC	Bangladesh Rural Advancement Committee
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BUET	Bangladesh University of Engg.Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CAS	Catch Assessment Survey
CAT	Coordination Advisory Team
CCCE	Caisse Centrale de Coopération Economique
CEC	Commission of European Communities
CIP	Chandpur Irrigation Project
CNR	Compagnie National du Rhône
CPM	Coarse Pilot Model
CS	Consultants' Studies
DAE	Department of Agricultural Extension
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DHI	Danish Hydraulics Institute
DOE	Department of Environment
DOF	Department of Fisheries
DOS	Disk Operating System
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
DUL	Desh Upodesh Ltd.
EEC	European Economic Community
EIA	Environmental Impact Assessment
EIP	Early Implementation Programme
FAO	Food & Agricul.Organ.of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control,Drainage & Irrigation Project
FFYP	Fourth Five Year Plan
FHS	Flood Hydrology Study
FMM	Flood Management Modelling
FPCO	Flood Plan Co-ordination Organisation
FRI	Fisheries Research Institute
FRSS	Fisheries Resources Survey System
FSR	Farming Research System
FWP	Food for Work Programme
FY	Financial Year
GOB	Government of Bangladesh
GW	Groundwater
HTW	Hand Tubewell
HYV	High Yielding Variety
IDA	International Development Agency
IRRI	International Rice Research Institute
JICA	Japanese International Cooperation Agency
JPPS	Jamalpur Priority Project Study
LAD	Least Available Depth
LGEB	Local Government Engineering Bureau
ME	Ministry of Education
MF	Ministry of Finance
MIWDFC	Minist.of Irrig., Water Dev.& Flood Control
ML	Ministry of Land
MLGRDC	Minist.of Local Govt.,Rural Dev.& Coop.
MOA	Ministry of Agriculture
MOEF	Ministry of Environment and Forestry
MOFL	Ministry of Fisheries & Livestock
MOSTI	Manually Operated Shallow T/W for Irrig.
MP	Ministry of Planning
MPO	Master Plan Organisation
NARS	National Agril.Research Sys.in Bangladesh
NCA	Net Cultivable Area
NCR	North Central Region
NCRM	North Central Regional Model
NCRMG	North Central Regional Model Group
NCRS	North Central Regional Study
NFMP	New Fisheries Management Policy
NGO	Non Government Organisation
NGR	Natural Growth Rate
NWP	National Water Plan
O&M	Operation and Maintenance
ODA	Overseas Development Administration (UK)
PA	Planning Area
PFDS	Public Foodgrain Distribution System
POE	Panel of Experts
PSO	Principal Scientific Officer
PU	Planning Unit
PWD	Public Works Datum
RARS	Regional Agricultural Research Station
RHD	Roads and Highways Department
SATEC	French Engineering Consultants
SOB	Survey of Bangladesh
SPARRSO	Space Research & Remote Sensing Organ.
SRDI	Soil Resources Development Institute
SRP	Systems Rehabilitation Project
SRTI	Sugarcane Research and Training Institute
STW	Shallow Tube Well
SWMC	Surface Water Modelling Centre
SWSMP	Surface Water Simul.Model. Programme
TOR	Terms of Reference
Tk	Taka
UFO	Upazila Fisheries Officer
UNDP	United Nations Development Programme

CHAPTER 1
INTRODUCTION

1.1 Objectives

The hydraulic modelling activities are central to the impact assessment of the interventions investigated in the development of a regional plan for the North Central Region. The modelling is carried out using computer-based software to provide a simulation of water levels and discharges at selected points in the regional river network. These outputs are used as inputs to a post-processing program which provides quantitative estimates of changes in flooding characteristics that might arise from implementation of each intervention tested.

The Terms of Reference do not elaborate the specific detailed tasks required of the hydraulic model. Implicit in the overall objectives of the study is the need for a tool by which means the future development scenarios may be compared with respect to the relative impact of flood control and drainage measures. For the purposes of this planning-level study, these implications have been taken to mean the relative changes in flooded area, (and hence, flood water levels in the rivers), for each intervention. The hydraulic model MIKE 11 provides this tool which furnishes the basic information. It is important to emphasise that the limits of the computer modelling go as far as providing this comparative tool and do not extend to the provision of any definitive solutions, which are the responsibility of numerous multi-disciplinary inputs to the study.

1.2 Scope of the Report

This report covers the model set-up, model calibration and subsequent hydraulic model studies carried out in Phase 2 of the North Central Regional Study. It does not include details of the calibration of the NAM hydrologic component, since this was undertaken during the Bridging Studies, (NCRS 1991c), and no significant modifications were made during the course of this Study. The report does not cover the assessment of any other non-hydraulic impacts of options studied, as these are described in the main report and other supporting reports.

It is intended that this report should also provide as complete a statement as possible of the structure of the model for both the "existing" and alternative "improved" situations to assist any future users in developing the model further for use at feasibility and outline design stages, if required.

Certain data, relevant to the set-up, calibration and operation of the model is considered too voluminous for inclusion in this report in its complete form. Such data has been incorporated into a separate document in its full form, to be kept as a Study File to provide a reference for future developers and users of the model. Included in this present report are representative examples of this data only as is indicated.

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1.3 The Modelling System

1.3.1 Background

In the mid 1980's, the Danish Hydraulics Institute, (DHI), assisted the GOB in executing the Surface Water Modelling Programme, Phase 1 (SWMSMP-I) with funding from UNDP. A Phase II was initiated in late 1989 with funding provided by DANIDA. The SWMC, under which the SWMSP-II is executed , was established as a separate administrative unit under WARPO (previously MPO) in early 1990 and is intended to serve WARPO. BWDB and other GOB agencies in all planning and design activities relating to the control and utilisation of water resources in Bangladesh. Computer software has been provided by DHI, supported by a team of expatriate specialists. These teams are now engaged on setting up regional models of the country, based on the MIKE11 modelling system.

With the inception of the studies under the Flood Action Plan, the SWMC has provided copies of the modelling software to each of the regional FAP teams. The assembly of the North Central regional model commenced in September 1990 at the SWMC with support from the FAP-3 Bridging Hydromodeller. After handover to the FAP-3 Phase 2 hydromodeller, work continued at the SWMC on the development of a Coarse Pilot Model, (CPM), for use with the study. At all stages of the basic model development, the modelling staff of FAP-3 have worked closely with the SWMC.

The SWMC has continued to work on improving the North Central Regional Model (NCRM) and have carried out further data collection and model development, so that the Model has reached Full Model status by the beginning of 1993 and should be at Verified Model status later in 1993.

1.3.2 The Hydrological Model NAM

The MIKE11 software suite made available to the FAP-3 study consisted of 2 modules. The first, (by virtue of the order of execution), is the NAM hydrologic module. This module provides input hydrographs for the subsequent hydrodynamic module.

The NAM component is a "lumped" conceptual type of rainfall-runoff model which accounts for the moisture content in various interrelated storage zones. The "lumped" term indicates that the parameters and variables for each sub-catchment are average values for the entire sub-catchment and spacial variation is ignored. The model can operate on any time-step, with input data of rainfall and evaporation and monthly groundwater abstraction rates, to produce a resultant runoff hydrograph comprised of daily values of discharge at the outfall of the catchment considered. The resultant data is passed through an external file for input to the hydrodynamic component, (MIKE11-HD).

The details of the NAM model may be found in the MIKE11 Users' Guide, (DHI 1989a).
In the absence of suitably located discharge measurement stations, the NAM model was calibrated against groundwater levels, obtained from the network of wells and boreholes located throughout the region, each catchment being assigned a single well or borehole judged to be representative of the total.

Fuller details of the NAM component calibration may be found in the Coarse Pilot Model Bridging Study report, (NCRS 1991c). The Pilot NAM model for the NCR has been calibrated against two catchments in the NCRM by the SWMC and further work is going on in this regard.

1.3.3 The Hydrodynamic Model

The MIKE11-HD or hydrodynamic component of the MIKE11 software suite simulates water levels and discharges at selected points in the river system. The algorithms employed are based on the Abbott-Ionescu finite difference solution of the Barre de St. Venant equations describing one-dimensional flow in open channels. The model represents flow in rivers, through structures and over flood plains.

The model is used to simulate the river system response to rainfall and, in the case of the North Central Region, the influences of the major boundary rivers. Full details of the modelling package is given in the MIKE11 Users' Guide (DHI 1989a).

1.4 The River System

The North Central region of Bangladesh is characterised by the major rivers forming the physical boundary. These rivers, the Jamuna in the west, Padma to the south, Old Brahmaputra to the north and Meghna in the east, dominate the drainage from the region. The Jamuna and Padma rivers exert a major influence over the flooding characteristics when their discharges are above average.

Rivers within the region play a dual role. During "normal" years, they act as internal drainage channels, conveying the flood waters derived from rainfall on the region. At times when the flows in the boundary rivers are higher than average, some of these internal watercourses act as conduits for the flood waters of the boundary rivers, resulting in abnormally high water levels and discharges and, in some locations, re-defining the drainage pattern within the region. During periods of severe inundation from the Jamuna and padma rivers, the drainage pattern of rivers in the west and south of the region become undefined, with the direction of flood plain flow often independent of the internal river system, except very late in the season when water levels subside.

The region is effectively divided into two by the Madhupur Tract, (an area of higher ground extending from Dhaka to Jamalpur). The drainage of the area to the west of the Madhupur Tract is influenced by the spills from the Jamuna while the response of the eastern area is dominated by the floods generated by "local" rainfall. The Old Brahmaputra does not greatly influence the flood characteristics of this eastern sub-region.

CHAPTER 2
MODEL DEVELOPMENT

2.1 Model Set-up

2.1.1 General

The model developed for the North Central Regional Study, (FAP-3), is a coarse pilot model. Under the strict definitions used by the Surface Water Modelling Centre, this means that certain existing features may be lumped or included implicitly, for example, smaller channels and structures. It is not expected that models of this category will achieve great accuracy, but the results should be adequate for planning and pre-feasibility level studies.

The coarse pilot model for the North Central region was developed by initially splitting the region into the two sub-areas, west and east of the Madhupur Tract. A single model representation of the region was not possible, since the MIKE11 software supplied to the study team was DOS based and therefore limited to a hardware address space of 640 Kilobytes. Translated into physical storage terms, this limits the number of grid points within the model at which water level and discharge may be calculated. In addition, the larger the model, the longer the run times required - a significant factor when considering the time frame of the modelling activities.

When splitting the regional model into two sub-models, care was taken in defining the division points such that these were reduced to the minimum and that a common monitored boundary was present. The split locations were the Jhenai offtake on the Jhenai River and at Demra on the Lakhya River. Both of these locations are BWDB water level stations, with Demra having the additional advantage of being a discharge measurement station.

Because the Old Brahmaputra exerts only a minor influence over the eastern sub-model area, it was decided to separate this river from the eastern sub-model and consider it as an independent sub-model. There are no major connected distributaries from the Old Brahmaputra into the eastern sub-model and the bifurcation into the Lakhya is controlled by the water level at Toke, which is a BWDB water level station.

Having the regional model split into 3 sub-models does not necessarily preclude the Old Brahmaputra sub-model being incorporated into either the east or the west sub-models for the purposes of testing various options. However, it is not possible to incorporate the west and east model into one model due to the aforementioned computer memory limitations.

The MIKE11 hydrodynamic model produces simulations of water levels and discharges at selected points in the river system. The North Central Regional Study requires that the output of the model be translated into resultant areas of flooding in pre-defined planning units. There is presently no built-in module that calculates this, and a separate program was written, specific to the model set-up used. Having flooded areas as the end-result also means that there is essentially an additional level of calibration required, but little information is available as to the precise extent and duration of flooding in the selected planning units. In addition, the model structure assumes that the flood plains are attached to the nodal points such that there is an intimate contact between the water level on the flood plain and that in the river. This is clearly not the case for all river reaches and associated flood plains, but the coarse pilot model cannot incorporate such detail at this present time due to lack of precise topographic information and computer operating system size limitations. More details of the limitations of the CPM are given in Section 3.2.

2.1.2 Incorporation of Flood Plains

One of the objectives of the modelling was to simulate the degree of flooding associated with certain hydrologic events and the effect on this flooding of engineering interventions. It is therefore necessary to construct a model which, within the constraints of data availability and accuracy, goes some way towards representing this phenomenon.

Initially, no flood plains were incorporated in the model, cross sections extending only marginally past banktop level were available. A methodology was employed that was initiated by the Surface Water Modelling Centre, (SWMC) and was based on the flood cells as defined by the Centre.

The boundaries of each flood cell attached to each nodal point were digitized. A computer file containing the MPO 1 sq. km. database of levels was referenced and the levels contained within the limits of the digitized flood cell were processed to produce an area-elevation characteristic of the cell (see Section 2.2.1). Dividing the abscissae of the curve by the reach length, (spacing between adjacent nodal points), produced a width-elevation characteristic which could then be "attached" to the cross section.

In a number of cases, the resulting flood plain characteristic curve did not compare well with the cross section, in that, either the flood plain was entirely above the cross section, or entirely below the lowest bed level. Generally, however, the flood plain curve showed a reasonable agreement, although some adjustment to the curve was necessary to achieve compatibility.

A major drawback to this methodology is that there is no spacial discrimination in the characteristic curve, that is, the location and extent of any high or low ground in the flood cell cannot be referenced with respect to the river channel. The resolution of 1 km. for the spot levels does not permit accurate representations of the micro-topography of the flood plains which can be an important factor in determining the linkages, (if they exist), between river and flood plain. As a consequence of this deficiency, and having regard to the constraints due to computer memory limitations and the time available for model development, the flood plains were configured as extensions of the cross sections and hence the model was exclusively 1-dimensional. This necessary approximation obviously limits the accuracy of representation which is particularly significant when considering such interventions as compartmentalisation. It is intended to improve the accuracy and representation at feasibility levels of study.

In the above configuration, the behaviour of the water level on the flood plains matches that of the river water level. That is, when the water level in the river rises, the flood plain water level rises the same amount and coincidentally in time. A similar response occurs when the river level recedes.

Flood plain boundaries were delineated on a 1:250,000 scale map, which was based on SPOT imagery and, in the absence of definitive information, the boundary between two adjacent rivers was assumed to follow the mid-point between the two river alignments. Man-made boundaries, such as rivers or embankments were also included, although the justification for road boundaries may be suspect due to the possibility of numerous culverts transmitting flow between adjacent flood plains.

More detailed information on the topography and hence flow in the floodplains can be progressively introduced to the model. As well as improving the model, this will also increase the size and run time of the model; as well as the time taken to set up and calibrate.

2.1.3 The Eastern Sub-model

A schematic diagram of the eastern sub-model is given as Figure II.5.1. The rivers modelled therein are the Banar, Sutia, Khiro, Khiro South, Kaoraid and part of the Lakhya[1]. The Shila River, while being moderately sized carries only local drainage flow, its contribution can be implicitly included by means of the runoff from the NAM catchment.

Table II.5.1 shows the allocated river cross sections which were extracted from the database for use in the eastern sub-model. The source of these cross sections is also shown. Not all sections in the data base were used in the model owing to some doubt as to their validity with respect to datum errors, location uncertainty and unexplained inconsistencies between adjacent sections.

TABLE II.5.1

Allocated Cross-sections used in the Eastern sub-model

ALLOCATED CROSS-SECTIONS						
River Specifications				Cross-Sections Used		
Topo-ID	Name	Upstream	Downstream	Upstream	Downstream	No.
SWMC	BANAR	37.00	46.00	37.00	46.00	2
SWMC	BANAR	60.00	91.00	60.00	90.00	5
DUL-1991	BANAR	91.00	120.00	91.00	120.00	7
DUL-1991	KHIRO_S	0.00	39.00	0.00	38.00	7
DUL-1991	KHIRO	0.00	45.00	0.00	45.00	11
DUL-1991	SUTIA	0.00	62.00	0.00	60.00	15
DUL-1991	KAORAID	0.00	14.00	0.00	14.00	4
1989-90	LAKHYA	0.00	93.00	0.00	93.00	17

Source: CS 1991

The sub-model was initially defined with 6 boundary locations. Of these, 3 were water level boundaries, (measured at BWDB stations), and 3 were discharge boundaries (theoretically with zero discharge, but in order to avoid potential instabilities in the model, a constant discharge of 10 m^3/s was applied, to be deducted on analysis of results). During the later stages of calibration, a change to the set-up of the Banar river was necessary, and this resulted in an additional boundary point,(Q=0), at chainage 60.00. Table II.5.2 shows the details of the eastern sub-model boundaries.

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[1] Where possible, local names have been used for rivers,but occasionally it has been necessary to construct names of branches of watercourses for convenience. Reference to the set-up figures and official maps will relate the given names to those used in the model.

TABLE II.5.2

Eastern Sub-model Boundaries

River	Location	BWDB No.	Chainage	Type
Banar	Basuri	8	37.0	Water Level
Banar	-	-	60.0	QC=0
Khiro	Head	-	0.0	QC=0
Kaoraid	Head	-	0.0	QC=0
Lakhya	Toke	229	0.0	Water Level
Lakhya	Demra	179	90.5	Water Level & Q
Sutia	Head	-	0.0	QC=0

Source: CS 1991

It has not been found necessary to incorporate any structures, (broad-crested weirs, special weirs etc.), in the east sub-model to effect an acceptable calibration. Should greater accuracy and resolution be required in the future, such structures may well be required at certain locations, (e.g. spill points along river embankments).

2.1.4 The Western Sub-model

A schematic diagram of the western sub-model is given as Figure II.5.2. The rivers modelled include the Balu, Bangshi, Bansi South, Barinda, Buriganga, Chatal, Chatal South, Dhaleswari, Dhantara Khal, Elangjani, Futikjani, Ichamati, Jhenai, Jhenai East, Jhenai West, Karnatali, Lakhya, Louhajang, Makar, Nanglai North, Nanglai South, Old Dhaleswari, Pungli, Turag, Tongi Khal, and a number of artificial spill channels from the Jamuna River. In all, there are 30 river branches and 246 nodal points in the western sub-model.

The most complex of all the 3 sub-models, the western sub-model has 15 boundaries, 13 of these being water level boundaries and the remaining 2 as discharge boundaries. The discharge boundaries are located at the "source" of internal rivers and, as such, are allocated zero discharge, (although in practice, a small discharge is applied, for stability reasons). The model is "connected" to the eastern sub-model and the Old Brahmaputra sub-model at Lakhpur, (on the Lakhya), and Jhenai Offtake, (on the Jhenai), respectively. As stated previously, it is possible to join the Old Brahmaputra sub-model to the western sub-model but not possible to join it to the eastern sub-model. Table II.5.3 shows the boundaries of the western sub-model.

The western sub-model, located with its western boundary along the left bank of the Jamuna river, contains a number of "spill" channels, some of which may be attributed to actual watercourses and others are incorporated as artificial channels. The dimensions of these artificial channels are chosen to represent the combined effects of numerous small channels and, as such, do not necessarily represent actual physical features. The spill channels are incorporated in order to represent the effects of the spillage of water from the Jamuna river into the North Central region, which can take place either when the Jamuna levels are high enough to overtop any embankment, or when the general bank height is exceeded.

TABLE II.5.3

Western Sub-model Boundaries

River	Location	BWDB No.	Chainage	Type
Balu	Pubail	7	0.0	Water Level
Bangshi	Madhupur	12	29.0	Water Level
Chatal	Head	-	0.0	QC=0
Chatal_s	Jagannathganj	48	20.6	Water Level
Dhaleswari	Kalagachia	71	148.0	Water Level
Futikjani	Head	-	0.0	QC=0
Ichamati	Offtake from Padma[1]	-	44.0	Water Level
Jhenai	Offtake of Jhenai	134B	5.0	Water Level
Lakhya	Lakhpur	177	43.5	Water Level
Makar	Porabari	50	0.0	Water Level
Old Dhaleswari	Serajganj	49	0.0	Water Level
Spchannel1	Serajganj	49	0.0	Water Level
Spchannel2	Offtake from Jamuna[2]	-	0.0	Water Level
Spchannel3 (Dhaleswari)	Porabari	50	0.0	Water Level
Sk(hask)	Offtake from Jamuna[2]	-	0.0	Water Level

Note : [1] Interpolated from Baruria Transit and Mawa observed water level.
[2] Interpolated from Serajganj and Porabari observed water level.

Source CS 1991

It is very difficult to represent all possible spill locations. Indeed, such locations vary from flood season to flood season, necessitating a different model structure from year to year. The spill channels that have been incorporated into the CPM at this time are those thought to have a major impact on the regional flooding and drainage patterns. There is still scope for improvement in this aspect of the model, but the additional detail may well cause the memory limits to be exceeded under the DOS operating system.

Table II.5.4 shows the cross section database from which river sections were abstracted for use in the sub-model.

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TABLE II.5.4

Allocated Cross-section used in Western sub-model from Data Base

ALLOCATED CROSS-SECTIONS						
River Specifications				Cross-Sections Used		
Topo-ID	Name	Upstream	Downstream	Upstream	Downstream	No.
1989-90	BALU	0.00	30.00	0.00	30.00	8
1987-88	BANGSHI	29.00	122.00	29.00	118.00	14
1987-88	BANGSHI	122.00	153.00	130.00	153.00	4
DUL-1991	BARINDA	0.00	30.70	0.00	30.70	8
1989-90	BURIGANGA	0.00	21.50	4.50	21.50	6
1988-89	DHALESWARI	8.50	48.00	8.50	48.00	8
1988-89	DHALESWARI	48.00	148.00	48.00	148.00	19
DUL-1990	ELANGJANI	1.00	29.00	1.00	28.00	7
1986-87	KALIGANGA	0.00	62.00	0.00	60.00	10
1989-90	LAKHYA	43.50	115.00	43.50	112.50	12
DU 1990-91	LOUHAJANG	1.00	59.80	1.00	59.80	15
DUL-1990	NANGLAI_S	0.00	16.00	0.00	14.00	5
DUL-1990	PUNGLI	0.00	55.50	0.00	55.50	12
DUL-1990	TONGI_K	1.00	15.00	1.00	15.00	4
DUL-1990	TURAG	0.00	14.00	0.00	14.00	4
WDB1989-90	TURAG	14.001	54.50	14.001	54.50	10
DUL-1990	BANSI_SOUTH	31.00	70.60	31.00	70.60	9
DUL-1991	DHANTARA K	1.00	14.25	1.00	14.25	4
DUL-1991	KARNATALI	1.00	11.40	1.00	9.15	3
JBA	O DHALESWARI	0.00	45.60	0.00	43.315	10
JBA	SPCHANNEL1	0.00	6.543	0.00	6.543	3
JBA	SPCHANNEL2	0.00	7.20	0.00	7.20	3
JBA	SPCHANNEL3	0.00	8.533	0.00	8.533	3
JBA	MAKAR	0.00	8.616	0.00	8.616	3
JBA	SK(HASK)	0.00	7.01	0.00	7.01	2
SWMC_91	ICHAMATI	0.00	44.00	0.00	44.00	5
DUL-1990	CHATAL	0.00	36.50	0.00	35.00	8
DUL-1990	CHATAL	36.50	55.00	40.00	55.00	4
DUL-1990	CHATAL_S	0.00	20.60	0.00	20.60	4
DUL-1990	JHENAI	5.00	89.80	5.00	89.80	17
DUL-1990	JHENAI_WEST	0.00	10.50	0.00	4.85	2
DUL-1990	JHENAI_EAST	0.00	32.00	0.00	32.00	7
DUL-1990	FUTIKJANI	0.00	51.00	0.00	51.00	9
DUL-1991	NANGLAI_N	0.00	17.00	0.00	15.00	4

Source: CS 1991

2.1.5 The Old Brahmaputra Sub-model

A schematic diagram of the Old Brahmaputra sub-model is given as Figure II.5.3. This model primarily consists of the Old Brahmaputra river, together with a short reach of the Jhenai river up to the Jhenai Offtake water level station.

Table II.5.4 shows the 3 boundary conditions used in the definition of the sub-model, that on the Jhenai being the common boundary with the western sub-model. Field investigation has shown that neither the Sutia river nor the Banar river are freely connected with the Old Brahmaputra. The Banar being cut off by an embankment and the Sutia head gated, the purpose of which is to exclude Old Brahmaputra flows.

TABLE II.5.5
Old Brahmaputra Sub-model Boundaries

River	Location	BWDB No.	Chainage	Type
Jhenai	Offtake of Jhenai	134B	5.0	Water Level
Old Brahmaputra	Kholabarichar	46.7L	0.0	Water Level
Old Brahmaputra	Toke	229	187.5	Water Level

Source: CS 1991

2.2 Data Sources

2.2.1 Topographic Data

Topographic data used in the construction of the models were predominantly obtained from existing survey and mapping sources. These sources and the data provided are given in ?

The 1:50,000 scale SPOT imagery was used to produce a 1:250,000 scale "base map" on which the locations of the rivers and main roads were indicated. This base map was then used to present the hydrometric station locations, location of river cross sections and flood plain delineation.

MPO database of land levels, based on a 1 km. square grid, was used to derive the flood plain elevation data. The land levels of this database originate from the 4" to the mile irrigation maps, which are dated from 1957 onwards to 1968. This database is incomplete, not all areas in the North Central Region being covered and its suitability is under question, since some river alignments have changed and all topographical features may not be accurately represented. Notwithstanding these reservations, the database is available in a convenient form and, certainly for planning level studies, may be considered as being representative, given the time constraints on obtaining any additional topographic mapping.

Aerial photographs were available for a large part of the North Central region to a scale of 1:50,000, but some areas were found to be missing, the prints having been withdrawn for security reasons. As a consequence of this, detailed study of the river setup near the Jamuna/Futikjani region was not possible. In this case, recourse was made to the black and white SPOT images, with their lower resolution.

1:20,000 scale photographs were available for the Jamuna "corridor" only, with some gaps in the coverage as for the 1:50,000 scale. These photographs will be useful if used in conjunction with a stereoscope which will assist in the location of low zones and potential spill channels from the Jamuna. Such an analysis would be appropriate for further refinements of the model for local level analysis.

TABLE II.5.6

Topographic Data and Sources

Data Source	Data	Year of Origin
Survey of Bangladesh	1:50,0000 Topo maps 4" & 8"/mile contour maps	updated to 1991 various to 1968
DANINA (SWMC)	1:50,000 B&W SPOT Images	1989
CCCE	1:50,000 Multispectral SPOT	1989
MPO	1km.sq.computerised data base of land levels	various to 1968
FINNMAP	1:50,000 Aerial Photographs (Partial coverage) 1:20,000 Aerial Photographs (Partial coverage)	1990 1990

Source : Various as shown

2.2.2 River cross-section data

The main source of cross-section survey data was the BWDB Morphology Division cross-section surveys, dated from 1985 to 1990. These sections were difficult to locate on the maps, as they were not geo-referenced and several index maps were not consistent. This factor is a significant contributor to the problems of model calibration and is addressed in more detail in Chapter 5 of this report. During the Bridging Period, consistency checks were made on the cross-sections and therefore this phase of the modelling activities concentrated on resolving any remaining anomalies that arose during the course of model calibration.

The BWDB cross-section data was augmented by additional surveys executed under the Phase I study by Desh Upodesh Ltd. The specifications for these sections were drawn up by the Phase I study in March 1990. The survey program was split into 2 phases, the first phase consisting of some 421 km. of river, surveyed from May 1990 to October, 1990, with a break for the monsoon period. The second phase comprised 362 km. and was completed by February, 1991.

The DUL survey was performed using old 1:50,000 scale maps as reference for section location. In a number of cases, the river course had changed considerably since the publication of the maps and it often proved difficult to locate the cross-section both on the ground and later on the revised SPOT image based maps. Consequently, there remains some doubt as to the accuracy of the section locations and hence with the resulting calibrations. In addition, anomalies between elevations of the banks and beds of some rivers and the associated flood plain data, (derived from the MPO data), remain unresolved. Second order surveys by FINNMAP, relating to certain bench marks in the North

Central region were anticipated to go some way to rectify the problem, but timing of the release of such data has precluded a rigorous analysis and subsequent adjustment of sections could not be made.

Additional sources of cross-section survey data were the SWMC and the Dhaleswari Mitigation Project, which commissioned surveys in the area of the Old Dhaleswari offtake and spill channels from the Jamuna. The SWMC cross-section surveys used were those on the Ichamati and Banar rivers, but this programme of survey is on-going, with additional information being provided at intervals.

2.2.3 Hydrometric data

Much of the hydrometric data collected during the Bridging Period has been utilised for this phase of modelling. The primary data source for hydrometric data was the Surface Water Hydrology Directorate of the BWDB, although some additional data collection by Desh Upodesh Ltd. during the Bridging Period provided information in areas not covered by BWDB.

Tables II.5.7 and II.5.8 give a summary of the hydrometric data collected for the purposes of the modelling activities

2.3 Calibration

Having set up the basic structure of the model, there follows a process of proving that it is adequate to reproduce the system which it is intended to represent. This process is two stage, one of calibration and thence, verification. In the calibration exercise, the model is adjusted such that a given data set of observed values is reproduced by the model. The verification of the model follows by checking its performance against an additional set of observed values which were not included in the original data set used for calibration. It is often found that the deviations of the model results for verification runs are greater than those during calibration. It is difficult to define objective criteria for assessing the quality of a model calibration. Often the modeller must rely on his experience and subjective judgement to decide whether or not to halt the calibration. There has been no work done in the NCRS in the definition of objective criteria for model calibration adequacy, purely subjective judgement has dictated the progress of the modelling. This is in accordance with FAP-25 recommendations.

Within the definition of "proving" above, the CPM for the North Central region has been calibrated but not verified, since comparison with other data sets resulted in minor adjustments being made and, hence, the calibration data set was extended to include both 1987 and 1989. Table II.5.9 to Table II.5.14 quantify the deviations from observed values resulting from the present calibration. It is notable that the smallest deviations occur during the monsoon period, which is the period which has the greatest significance for the NCRS. It is clear that if the study were to be concerned with water levels and discharges during the dry season, much additional work would remain to be done to effect a satisfactory model structure to reproduce these periods.

However, during the monsoon season the rivers and flood plains are hydraulically sensitive, with small changes in water level potentially causing significant changes in flooded area. Tables II.5.9 to II.5.11 show that the mean error in water levels vary from 0.09m to 0.47m during the monsoon, and Tables II.5.12 to II.5.14 that the mean error in annual maximum water levels vary from 0.14m to 1.15m. Such a magnitude of error is high for a flood plain country and large model errors could mask the impact of engineering interventions. The later improved versions of the NCRM should improve the situation, and it is expected that subsequent modelling to be used at the Feasibility Study level, will provide more reliable and more accurate results.

TABLE II.5.7

Collected Water Level Data

River	Location	No.	T	87-88	88-89	89-90	90-91
Balu	Pubail	7	T	X	X	X	X
	Demra	7.5	T	X	X	X	X
Banar	Basuri	8		X	X	X	X
	Kaoraid	9	T	X	X	X	X
	Trimohoni	9.5		X	X	X	X
	Narayanpur	SG-13					+
Bangshi	Madhupur	12		X	X	X	X
	Kawaljani	13		X	X	X	X
	Mirzapur	14		X	*	X	X
	Nayarhat	14.5	T	*	*	X	X
Buriganga	Dhaka(Mill Barak)	42	T	*	*	X	X
	Hariharpara	43	T	X	*	-	-
Chatal	Madarganj	SG-1					+
Dhaleswari	Tilli	68		X	X	X	X
	Jagir	68.5		*	*	*	*
	Savar	69	T	-	-	X	X
	Kalatia	70	T	X	X	X	X
	Rekabi Bazar	71A	T	-	X	X	X
	Kalagachia	71	T	X	X	X	X
Dhantara	Benupur	SG-11					+
Elangjani	Hinganagar	SG-10					+
Futikjani	Bhuapur	SG-6					+
	Kalihati	SG-7					+
Ganges	Baruria Transit	91.9L		X	X	X	X
	Mawa	93.5L	T	-	X	X	X
Jamuna	Kholabarichar	46.7L		X	X	X	X
	Bahadurabad (Tr.)	46.9L		X	X	X	X
	Jagannathganj	48		X	X	X	X
	Serajganj	49		X	X	X	X
	Porabari	50		X	X	X	X
Jhenai	Offtake of Jhenai	134B		X	X	X	X
	Baushi Rly Bridge	134A		X	*	X	X
	Dhanbari	SG-2					+
	Gopalpur	SG-4					+
Jhenai_East	Gopalpur	SG-3					+
	Gopalpur	SG-5					+
Kaliganga	Taragahat	137A		X	X	X	X
Khiro	Phulbaria	SG-12					+
Lakhya	Lakhpur	177	T	X	X	X	X
	Demra	179	T	X	X	X	X
Louhajang	Kagmary	SG-9					+
OLd Dhaleswari	Jugini	186		X	*	X	X
Old Brahmaputra	Jamalpur	225		X	X	X	X
	Offtake of Sutia	227		X	X	X	X
	Mymensingh	228.5		X	X	X	X
	Toke	229	T	X	X	X	X
	Bhairab Bazar Rly	230.1	T	X	X	X	X
Pungli	Jokerchar	134		X	*	X	X
	Surooj	SG-8					+
Sutia	Trisal	SG-14					+
Tongi Khal	Tongi	299	T	X	*	X	X
	Tongi	SG-15	T				+
Turag	Kaliakoir	301		X	X	X	X
	Mirpur	302	T	X	*	X	X

Source CS 1991

Notes:
- X : Full hydrological year data available, ex BWDB Hydrology
- * : Only few months data available.
- + : Only monsoon season data available, temporary gauge stations by DUL.
- - : Not available

TABLE II.5.8

Collected Discharge Station Data

River	Location	No.	T	87-88	88-89	89-90	90-91
Balu	Demra	7.5	T	o	*	*	-
Banar	Narayanpur	SG-13					+
Bangshi	Mirzapur	14		X	X	X	o
	Nayarhat	14.5	T	*	o	*	o
Chatal	Madarganj	SG-1					+
Dhaleswari	Jagir	68.5		*	*	*	o
Dhantara	Benupur	SG-11					+
Elangjani	Hinganagar	SG-10					+
Futikjani	Bhuapur	SG-6					+
	Kalihati	SG-7					+
Ganges	Baruria Transit	91.9L		X	X	X	-
	Mawa	93.5L	T	*	*	X	-
Jamuna	Bahadurabad(Tr.)	46.9L		X	X	X	-
Jhenai	Dhanbari	SG-2					+
	Gopalpur	SG-4					+
Jhenai_East	Gopalpur	SG-3					+
	Gopalpur	SG-5					+
Kaliganga	Taraghat	137A		X	X	X	o
Khiro	Phulbaria	SG-12					+
Lakhya	Demra	179	T	X	X	X	-
Louhajang	Kagmary	SG-9					+
Old Brahmaputra	Mymenshing	228.5		X	X	X	o
	Bhairab Bazar Rly	230.1	T	*	*	*	-
Pungli	Jokerchar	134		*	*	*	o
	Surooj	SG-8					+
Sutia	Trisal	SG-14					+
Tongi Khal	Tongi	SG-15	T				+
Turag	Kaliakoir	301		X	X	X	o
	Mirpur	302	T	*	o	*	-

Note:
X : Continuous BWDB rated discharges available.
o : Only observed discharges available.
* : Only few months continuous discharges available.
+ : Only monsoon observed discharges available, temporary gauge stations by DUL.
- : Not available.

Source : CS 1991

The model was initially calibrated with data from 1989-90 water year, which represents what may be termed a "normal" year in the North Central region. Later, comparison was made with the 1987-88 water year, the results of which prompted some changes to the model setup and, hence, 1987-88 was included in the calibration data set.

Each sub-model was calibrated independently, an approach which, apart from reducing the size of the model, permitted each calibration run to be made within an acceptable length of time. During the calibration process, the model often "crashed", (that is, the model became unstable), necessitating the re-run of the model with shorter time steps. Run times of up to 8 hours were necessary in the early programme for the calibration of the western sub-model, but later modifications to the setup permitted much shorter run times. Separation of the regional system into sub-models in no way compromised the accuracy of the model, since the points at which the models were divided were identified by water level observation stations.

It should be noted that most often, what seems to be an instability in the model is not due to the model software itself, but is caused by the user; either because of errors in the model input or by forcing the model to simulate a physically unrealistic situation. Such seemingly instabilities may thus be taken by the user as a warning and should lead to a check of input data and model setup.

Reference to ? and to ? shows the degree of coincidence between the simulated and observed water levels and discharges at comparison stations located within the sub-models. Owing to remaining uncertainties in the raw data for water level, some of the discrepancies may well result from incorrect observations or gauge post datum errors, rather than poor calibration. Likewise, some doubt concerning the validity of the stage/discharge relationships at measurement stations has resulted in discharge comparisons with observed measurements, rather than a continuous time series based on rating equations.

At several sites, the dry season calibration was poor. These features could be attributed to:

- changes in the section geometry between the time of survey and the year of the model run
- the general coarseness of the model in not representing discrete features which could affect the flow
- bench mark errors
- variation in the roughness coefficient with depth

Particular problems were encountered at the Khiro/Banar confluence, where flood plain elevations were very inconsistent with the surveyed cross sections and some judgement was required as to how the flood plain was to be incorporated. Similar problems were encountered at certain locations in the western sub-model, but these were not as pronounced and were reconciled much more easily.

The accuracy of the overall model, and the component sub-models, is expressed in terms of the average deviation of the simulated water level to the observed, for a number of stations. ? to ? show the results of this analysis and it can be seen that all models represent the water level fluctuations with a good degree of accuracy during the monsoon periods of 1987 and 1989. 1988 results, due to the extreme spills from the Jamuna and overland flow not represented in the model, does not show such good agreement,except for the Old Brahmaputra submodel.

In general, the calibration of the eastern sub-model was quite good, bearing in mind the previous statements regarding inconsistency of data. Errors are lower during the monsoon period, which is to be expected, since greater attention was paid to this part of the year and with higher levels, other factors, such as channel roughness variations, are less pronounced. Table II.5.9 to Table II.5.11 give the average deviations for sub-seasonal periods and the standard deviation of this error. The eastern sub-model shows the smallest average deviation from observed, although only 3 stations were available for comparison in this sub-model. The deviation for 1987 is the smallest for the pre-monsoon and monsoon periods, but 1988 and 1989 show similar, (and probably more representative), deviations. Table II.5.12 to Table II.5.14 express the deviation of the simulated annual maximum water level from the observed, in terms of its value and, as a measure of the temporal accuracy of the model, the errors in level simulated at the time of the observed annual maximum.

TABLE II.5.9

Average Relative Errors in Water Levels for Overall Model & each Sub-model, (1987)

Model	Pre Monsoon		Monsoon		Post Monsoon	
	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation
NCRM	0.53	0.13	0.24	0.06	0.40	0.05
Western	0.71	0.19	0.31	0.08	0.44	0.09
Eastern	0.12	0.04	0.09	0.04	0.18	0.07
Old Brah.	0.38	0.04	0.28	0.09	0.37	0.06

Source: CS 1991

TABLE II.5.10

Average Relative Errors in Water Level for Overall Model & each Sub- model, (1988)

Model	Pre Monsoon		Monsoon		Post Monsoon	
	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation
NCRM	0.60	0.13	0.31	0.12	0.43	0.10
Western	0.80	0.19	0.41	0.21	0.69	0.28
Eastern	0.17	0.09	0.15	0.06	0.19	0.06
Old Brah.	0.42	0.14	0.21	0.08	0.30	0.03

Source CS 1991

TABLE II.5.11

Average Relative errors in Water Level for Overall Model & each sub-model, (1989)

Model	Pre Monsoon		Monsoon		Post Monsoon	
	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation	Mean error (m)	Standard Deviation
NCRM	0.52	0.14	0.23	0.03	0.25	0.09
Western	0.71	0.19	0.25	0.07	0.33	0.14
Eastern	0.17	0.06	0.18	0.05	0.12	0.03
Old Brah.	0.31	0.05	0.47	0.16	0.39	0.03

Source: CS 1991

TABLE II.5.12

Model Errors for the 1987 Flood

Model	Annual Max. Level (m)		Level at Time of Annual Max. (m)	
	Mean	Standard Deviation	Mean	Standard Deviation
NCRM	0.31	0.31	0.37	0.32
Western	0.43	0.32	0.53	0.30
Eastern	0.14	0.04	0.15	0.05
Old Brahmaputra	0.19	0.19	0.22	0.24

Source: CS 1991

TABLE II.5.13

Model Errors for the 1988 Flood

Model	Annual Max. Level (m)		Level at Time of Annual Max. (m)	
	Mean	Standard Deviation	Mean	Standard Deviation
NCRM	0.76	0.70	0.88	0.83
Western	1.15	0.61	1.36	0.71
Eastern	0.17	0.02	0.17	0.02
Old Brahmaputra	0.15	0.15	0.15	0.15

Source: CS 1991

TABLE II.5.14

Model Errors for the 1989 Flood

Model	Annual Max. Level (m)		Level at Time of Annual Max. (m)	
	Mean	Standard Deviation	Mean	Standard Deviation
NCRM	0.22	0.26	0.22	0.26
Western	0.22	0.25	0.22	0.25
Eastern	0.16	0.19	0.15	0.18
Old Brahmaputra	0.52	0.34	0.52	0.34

Source: CS 1991

The eastern sub-model shows very good agreement between the observed and simulated water levels at all comparison stations, with the exception of Kaoraid for 1989. This station shows deviations of approximately 0.5 metres consistently from early July, 1989 to late October, 1989. In view of the coincidence of the pattern of fluctuations of water level during this period, (although displaced by 0.5 metres), it is reasonable to assume that the error is due to an undocumented change in gauge datum.

Calibration for discharge was only possible at the southern boundary of the model at Demra. This meant that the internal discharges as generated by the model were not possible to verify, since no discharge comparison stations exist within the sub-model for the years run.

Not unexpectedly, the western sub-model proved to be the most difficult to calibrate. Reference to Table II.5.9 to Table II.511 will show that the mean deviation in water level for the monsoon season in 1988 was 30% greater than that in 1987 and 64% greater than the same period in 1989. The standard deviation of these values is also much greater in 1989.

The higher than normal deviations for the year 1988 may be explained by considering the basic structural setup of the western sub-model. With the complex pattern of spill channels from the Jamuna influencing the flow regime of the region, any changes in the physical setup of these channels will affect the model results from year to year. The precise locations of these spill channels are difficult to define, overbank flow occurring almost randomly and embankment breaches impossible to predict. There is unlikely to be a single unique model which will represent the precise configuration of the North Central region. Cycles of aggradation and degradation of the mouths of offtakes and spill channels mean that flow volumes and times of overspill change not only from year to year, but within year also, as the sand bars that form at the mouths are gradually degraded.

In general, discharges are difficult to reproduce in the western sub-model, since there are only water level upstream boundaries and few comparison stations in the northern part of the sub-model. Discharges are particularly poorly reproduced at Jagir and Kaliakoir for all years, although 1989 shows lower water levels than observed, 1987 also lower, but less so, and 1988 is particularly low in the peak.

The discrepancy in discharge simulation may, in part, be attributed to incorrect or inadequate survey of the bifurcation of the rivers, the discharge for a given water level being reduced if the cross sectional area of the offtake is too small. The poor agreement between both water level and discharge at Kawaljani and Mirzapur is less easy to explain. It is clear that there is a major setup error in this part of the model which must be resolved before any future studies are undertaken. Survey of the Bangshi river is out of date and the updating of this must be a priority. The water level peak in 1988 has not been reproduced satisfactorily and this may be due to changes in spill channel setup during the flood season.

It is generally agreed that 1988 was an exceptional year in terms of the magnitude of discharges in the Jamuna and the amount of the consequent flooding. To attempt to accurately model the conditions prevailing at that time would be very difficult, for the reasons stated above. Consequently, more attention was paid to the years 1987 and 1989 for calibration purposes, these years representing "normal" high flood conditions from the Jamuna and a "normal" year respectively.

In order to meet with the schedule of the study, it was necessary to terminate the calibration of the sub-models by the end of September, 1991. At this point in time, the western sub-model calibrations were not particularly good, particularly for Kawaljani on the Bangshi river. Reference to the appropriate cases in ? to ? show the 6 station average deviations of simulated from observed water levels for the years 1987 to 1989, inclusive. It is probable that the model structure requires significant modification to accurately reproduce the system. The addition of artificial spill channels from the rivers into flood cells, (particularly in the western sub-model, where rivers are now known to be elevated above the flood plain), will consume significant additional computer memory which will exceed the DOS limit.

TABLE II.5.15

Water Level Comparison Stations - Eastern Sub-model

River	Location	No.	T	Branch (MIKE11)	Chainage	B
Banar	Basuri	8		BANAR	37.0	B
	Kaoraid	9	T	BANAR	114.5	
	Trimohoni	9.5		BANAR	120.0	
	Narayanpur	SG-13		BANAR	83.0	
Khiro	Phulbaria	SG-12		KHIRO	33.0	
Lakhya	Lakhpur	177	T	LAKHYA	43.5	B
	Demra	179	T	LAKHYA	90.5	B
Sutia	Trisal	SG-14		SUTIA	39.0	

Source: CS 1991

TABLE II.5.16

Discharge Comparison Station - Eastern Sub-model

River	Location	No.	T	Branch (M11)	Chainage
Banar	Narayanpur	SG-13		BANAR	83.0
Khiro	Phulbaria	SG-12		KHIRO	33.0
Lakhya	Demra	179	T	LAKHYA	95.0

Source: CS 1991

TABLE II.5.17

Water Level Comparison Stations - Western Sub-model

River	Location	No.	T	Branch (M11)	Chainage	B
Balu	Pubail	7	T	BALU	0.0	B
	Demra	7.5	T	BALU	30.0	
Bangshi	Madhupur	12		BANGSHI	29.0	
	Kawaljani	13		BANGSHI	70.0	
	Mirzapur	14		BANGSHI	107.0	
	Nayarhat	14.5	T	BANGSHI	144.0	
Buriganga	Dhaka(Mill Barak)	42	T	BURIGANGA	11.5	
	Hariharpara	43	T	BURIGANGA	21.5	
Chatal	Madarganj	SG-1		CHATAL	24.0	
Dhaleswari	Tilli	68		DHALESWARI	37.8	
	Jagir	68.5		DHALESWARI	66.0	
	Savar	69	T	DHALESWARI	98.5	
	Kalatia	70	T	DHALESWARI	110.0	
	Rekabi Bazar	71A	T	DHALESWARI	141.0	
	Kalagachia	71	T	DHALESWARI	148.0	B
Dhantara	Benupur	SG-11		DHANTARA	9.1	
Elangjani	Hinganagar	SG-10		ELANGJANI	14.0	
Futikjani	Bhuapur	SG-6		FUTIKJANI	14.0	
	Kalihati	SG-7		FUTIKJANI	33.9	
	Jagannathganj	48		CHATAL_S	20.6	B
	Serajganj	49		O DHALESWARI	0.0	B
	Porabari	50		SPCHANNEL3	0.0	B
Jhenai	Offtake of Jhenai	134B		JHENAI	5.0	B
	Baushi Rly Bridge	134A		JHENAI	35.0	
	Dhanbari	SG-2		JHENAI	58.0	
	Gopalpur	SG-4		JHENAI	78.0	
Jhenai_East	Gopalpur	SG-3		JHENAI_EAST	2.5	
	Gopalpur	SG-5		JHENAI_EAST	17.5	
Kaliganga	Taraghat	137A		KALIGANGA	14.0	
Louhajang	Kagmary	SG-9		LOUHAJANG	12.0	
Old Dhaleswari	Jugini	186		O DHALESWARI	29.5	
	Toke	229	T	O_BRAMAPUTRA	187.5	B
Pungli	Jokerchar	134		PUNGLI	3.0	
	Surooj	SG-8		PUNGLI	22.5	
Tongi Khal	Tongi	299	T	TONGI_K	5.0	
	Tongi	SG-15	T	TONGI_K	15.0	
Turag	Kaliakoir	301		TURAG	0.0	
	Mirpur	302	T	TURAG	50.0	

Source: CS 1991

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TABLE II.5.18
Discharge Comparison Stations - Western Sub-model

River	Location	No.	T	Branch (M11)	Chainage
Balu	Demra	7.5	T	BALU	30.0
Bangshi	Mirzapur	14		BANGSHI	107.0
	Nayarhat	14.5	T	BANGSHI	144.0
Chatal	Madarganj	SG-1		CHATAL	24.0
Dhaleswari	Jagir	68.5		DHALESWARI	66.0
Dhantara	Benupur	SG-11		DHANTARA	9.1
Elangjani	Hinganagar	SG-10		ELANGJANI	14.0
Futikjani	Bhuapur	SG-6		FUTIKJANI	14.0
	Kalihati	SG-7		FUTIKJANI	33.9
Jhenai	Dhanbari	SG-2		JHENAI	58.0
	Gopalpur	SG-4		JHENAI	78.0
Jhenai_East	Gopalpur	SG-3		JHENAI_EAST	2.5
	Gopalpur	SG-5		JHENAI_EAST	17.5
Kaliganga	Taraghat	137A		KALIGANGA	14.0
Louhajang	Kagmary	SG-9		LOUHAJANG	12.0
Pungli	Jokerchar	134		PUNGLI	3.0
	Surooj	SG-8		PUNGLI	22.5
Tongi Khal	Tongi	SG-15	T	TONGI_K	15.0
Turag	Kaliakoir	301		TURAG	0.0
	Mirpur	302	T	TURAG	50.0

Source CS 1991

TABLE II.5.19
Water Level Comparison Stations - Old Brahmaputra Sub-model

River	Location	No.	T	Branch (M11)	Chainage	B
Jamuna	Kholabarichar	46.7L		O_BRAMAPUTRA	0.0	B
Jhenai	Offtake of Jhenai	134B		JHENAI	5.0	B
Old Brahmaputra	Jamalpur	225		O_BRAMAPUTRA	63.0	
Old Brahmaputra	Offtake of Sutia	227		O_BRAMAPUTRA	109.0	
Old Brahmaputra	Mymensingh	228.5		O_BRAMAPUTRA	124.0	
Old Brahmaputra	Toke	229	T	O_BRAMAPUTRA	187.5	B

Source: CS 1991

CHAPTER 3
MODELLING ENGINEERING INTERVENTIONS

3.1 General approach

The approach to the modelling of engineering interventions was influenced by both the time available for modelling and the status of the model itself. A detailed, rigorous approach was not felt to be justified at this stage, since the uncertainties remaining in the model were still large enough to produce misleading results, if absolute values were expected, but not necessarily so for relative comparisons.

The year 1989 was chosen to represent "normal" conditions throughout the region. Results published by FAP-25, (Flood Hydrology Study), indicate that this choice is justified as statistical analysis shows the return period water levels for that year to be approximately 1 year. Experience during calibration had shown that to attempt to model 1988 conditions would result in gross inaccuracies, although, as a comparative example, one run was made for an embankment along the Jamuna, Dhaleswari and Kaliganga. Care should be take in the interpretation of the results of this run. For the pre-feasibility runs, 1987 was used to illustrate the effect of the proposed Dhaleswari-Kaliganga embankment on the water levels for that year. Return period for the water levels experienced in that year vary from location to location, but those for Porabari, which is adjacent to the major spill channels from the Jamuna into the region, are approximately 1 in 15 year.

Using the purpose-written post-processing program to determine the extent of the flooded areas in each planning unit, comparisons were made against the base case, (existing situation, no intervention), to test the effectiveness of each configuration. Imposition of embankments was simulated by moving the appropriate bank marker on the cross sections used in the MIKE11 model

3.2 Limitations of the Coarse Pilot Model

The Terms of Reference of the study require the use of a Coarse Pilot Model (CPM) of the river system of the North Central region to assist in the formulation of a Water Development Plan for the region. This CPM has been developed from October, 1990 to the present. The deadlines for the study dictated that a suitable model should be ready to investigate the impact of various engineering interventions by month 7 of the study, at the latest.

Due to the relatively short time frame of the study, and the complexity of the river system of the region, it was necessary to reduce the degree of detail of the model to a level whereby the major objectives of the modelling exercises could be achieved. In particular, this meant that the detailed structure of the flood plains could not be incorporated in the CPM. The simplification of assuming flood cells attached to the river cross-sections reduces memory requirements of the model and facilitates the model construction process. However, this form of construction, while appropriate for meeting study deadlines, suffers from the drawback of not rigorously representing the mechanism of flooding in some of the river systems of the North Central region, particularly those in the south-west of the region.

The use of a 1-dimensional model for investigating the effects of embankment schemes results in limitations to both the detail that can be modelled and to the degree of accuracy of the results. The limitations in detail mainly concern the representation of the flood plains and the interaction of the river channels with these flood plains.
1-dimensional modelling assumes that the adjacent flood plains are drainage flood plains, i.e. the water level on the flood plains is the same as that in the river and there is a common water surface joining the two elements. 2-

dimensional, (or quasi 2-dimensional), modelling assumes that the water level in the river and flood plain can be different at some stages of flow and that water commences to spill onto the flood plains when the water level in the river reaches a predetermined fixed level. In the absence of more detailed survey, this phenomenon is represented in MIKE11 by shallow v-shaped weirs offtaking the main channel at defined locations. If survey of the khals is available, the points of interaction may be represented by the khal cross section.

The concept of quasi 2-dimensional modelling is not expected to be employed at the Pilot Model stage. It cannot be entertained at the Coarse Pilot Model stage of this study for the following reasons:-

1. Quasi 2-dimensional models at a regional scale would be far too complex and exceed the memory capacity of the present DOS based version.

2. The collection of additional river survey and topographic information required would be outside the capabilities and time-frame of the present study.

3. The additional time required for the calibration of a quasi 2-dimensional model at a regional scale would be more than that presently available.

Perhaps the most important point arising from the inability to employ a quasi 2-dimensional model is that which relates to the effect of embankments. In a drainage flood plain, (where there is a common water surface joining river and flood plain), embanking a river would, in theory, eliminate flooding from the river. Rainfall inundation would continue behind the embankments. The embanking of a river in such a system is modelled by moving the bank "marker", (which indicates the limit of cross section to be considered in the computation), to a point close to the bank of the river as indicated in the cross section in the model. This has the effect of reducing the cross sectional area of flow and hence raising the water level in the river.

If, as is the case in almost all the western part of the NCR, the river banks are higher than the adjacent flood plain, (in some cases, the river bed is higher also), lateral overbank spill takes place when the river level is sufficiently high. Some flow takes place at lower stages through the khal system which serves to pass water onto the flood plains. Modelling of this overbank spill is not possible with the 1-dimensional model presently developed for the NCR and therefore the procedure of moving the bank "marker", as previously described, would represent the construction of an embankment of infinite height, with no provision for intermediate heights to be tested. **Thus the effect of lower embankments, which would be designed to be overtopped by a flood of higher return period than design, cannot be tested.** For this degree of detail, quasi 2-dimensional modelling must be employed.

Water levels and discharges simulated in the model are of acceptable accuracy for planning level studies, (refer to calibration results), but the criterion by which development options were to be assessed in the NCRS was to be based on areas of flooding in pre-defined planning units. The assumption of the contiguous flood plain structure has resulted in maximum water level estimation and consequent flooded areas being approximately correct from field verification. The variation of flooded area, particularly during the monsoon season, however, is clearly not fully representative. The model results show that flooded areas reduce as the water level in the rivers reduce. In reality, because the flood plains are separated from the river by levees, flood waters cannot return to the river until the river levels have receded sufficiently to permit drainage via small khals. This would mean that flooding would commence earlier by virtue of the direct rainfall on the flood plain, (it would be unable to reach the river due to the levees), and would be of a greater duration as drainage would be impeded by high water levels in the river at the point of return to the river system. During the high river level period, flood waters from the river would spill over into the flood plain and augment the flooding from direct rainfall. If water levels recede marginally during this period, but direct rainfall continues, the flooded areas would not reduce, as is implied in the present model structure.

This situation is clearly unsatisfactory. However, the flooding simulated by the present model is felt to be indicative of the actual situation and the analyses are based on comparative studies and not on absolutes. Therefore, while the model may not be absolutely accurate in this matter, it serves the purpose of this level of study adequately, given an understanding of the situation outlined above.

The setup and calibration of the model is based on available data. In some cases, this data is of questionable quality and the end result of the model reflects this. The deviations of the simulated outputs from the model from the "recorded" values may indeed be indicative of errors in the model calibration and setup, but they may equally well be attributed to errors in the original input data. Bench mark errors, incorrect gauge board readings, poor discharge measurements and stage discharge ratings could all contribute to apparent "errors" in the simulated model output. Chapter 5 discusses the requirements for future work to improve the data quality aspect.

It should be noted that MIKE11 represents two dimensional flow patterns through a network of one dimensional branches, referred to as a quasi two dimensional flow representation. The level of resolution is constrained only by available data, the address space (DOS or UNIX) and the time required to set up, calibrate and run the model. The limitations of the FAP3 model (flooded areas, embankment overtopping, rainfall on and evaporation from areas protected by embankments, regulated drainage, pumped drainage etc.) are due to these constraints, and not the MIKE 11 software.

3.3 Drainage options

For the Interim Report (NCRS 1991d) stage of the study, 4 drainage options were investigated, using the model to simulate the effects. These are identified as Run Nos. H1, H2, H3 and H4 in ?

Runs H1 and H2 were essentially similar in concept; that of improving the conveyance of the lower reaches of the Dhaleswari and Buriganga rivers such that the lower water levels provided greater drainage head for the upper reaches and the bankfull discharge capacity would be increased accordingly. In order to model this concept a simplified approach was followed. Since conveyance is directly proportional to the roughness of the channel, increasing the Strickler coefficient in the selected reach would be equivalent to the physical activity of widening or deepening the channel. To adjust the geometry of the cross sections of the model would necessitate the re-punching of a number of sections. It would be difficult at this early stage to determine whether the section should be widened or deepened, or both. Therefore, the option of changing the Strickler coefficient was deemed to be the best expedient, given the constraints of timing for the study; however it is recognised that with large drainage channels this approach may introduce serious mass conservation errors. Further detail of analysis will be required at the Feasibility Study level.

The first run was by way of a test of sensitivity. The Strickler coefficient was increased by 100%, (a degree of conveyance improvement that would be clearly impractical), and the model run for 1989, with no other changes. The results may be expressed in a number of ways. Table II.5.20 shows the changes in water level at various chainages in the Dhaleswari and Buriganga rivers resulting from these theoretical improvements and it can be seen that the reductions in peak water level are minimal, particularly in the Buriganga. The explanation for this lies in the close proximity of these river reaches to the Lower Meghna, which is essentially a fixed boundary and which exerts a controlling influence on the outfalls of the rivers.

TABLE II.5.20

Change in Maximum Levels due to 100% Conveyance Improvement on Lower Dhaleswari & Buriganga River.

Dhaleswari River				Buriganga River			
Chainage (Km)	Base Case(1989) (m PWD)	Option H1 (m PWD)	Diff (m)	Chainage (Km)	Base Case(1989) (m PWD)	Option H1 (m PWD)	Diff (m)
101.5	5.89	5.66	-0.23	4.5	5.02	4.94	-0.08
107.5	5.88	5.64	-0.24	9.0	5.00	4.93	-0.07
112.5	5.63	5.31	-0.32	11.5	5.00	4.93	-0.07
117.5	5.36	5.09	-0.27	15.5	4.98	4.92	-0.06
122.5	5.17	4.99	-0.18	18.5	4.97	4.92	-0.05
128.5	5.01	4.93	-0.08	21.5	4.97	4.92	-0.05

Source: CS 1991

Table II.5.21 shows the effects of a 25% increase in the conveyance of the lower reaches of the Dhaleswari and Buriganga, (Run H2). While this order of increase is much more practically realistic, the effects of such changes are, naturally, even less than those for a 100% increase.

TABLE II.5.21

Change in Maximum Levels due to 25% Conveyance Improvement on Lower Dhaleswari & Buriganga River

Dhaleswari River				Buriganga River			
Chainage (Km)	Base Case(1989) (m PWD)	Option H2 (m PWD)	Diff (m)	Chainage (Km)	Base Case(1989) (m PWD)	Option H2 (m PWD)	Diff (m)
101.5	5.89	5.80	-0.09	4.5	5.02	4.98	-0.04
107.5	5.88	5.78	-0.10	9.0	5.00	4.97	-0.03
112.5	5.63	5.50	-0.13	11.5	5.00	4.97	-0.03
117.5	5.36	5.25	-0.11	15.5	4.98	4.95	-0.03
122.5	5.17	5.10	-0.07	18.5	4.97	4.95	-0.02
128.5	5.01	4.97	-0.04	21.5	4.97	4.95	-0.02

Source: CS 1991

In terms of the reduction in area flooded resulting from these localised river improvements, owing to the minimal nature of the water level reductions, the corresponding flooded area reduction is almost negligible and, with the degree of resolution of the topographic data, would be meaningless to attempt comparative quantification.

Run H3 was directed to a more local drainage problem. The reach of the Bangshi river from Kawaljani to Mirzapur is severely meandering and it was required to determine the effects of straightening this reach on its conveyance. If the conveyance could be enhanced, the water levels for a given discharge would be lower, (thus permitting better drainage), and the bankfull discharge would be increased.

To model this, the conveyance of the section was increased by adjusting the Strickler coefficient by a suitable proportion. The reduction in the overall length of the reach brought about by the canalisation was calculated. This would result in an increase in slope over the reach, given that the bed elevation at the start and end would be unchanged. The effect of this can be reproduced by adjusting the value of the Strickler coefficient in direct proportion to the square root of the ratio of the old and new reach lengths thus:

$$M_2 = M_1 \sqrt{\frac{L_1}{L_2}}$$

Where:- M_2= new value of Strickler coefficient, M_1= old value of Strickler coefficient, L_2= improved length of river, L_1= unimproved length of river.

It is interesting to note the effects on the waterlevels in this reach which result from canalisation. ? shows that there is a maximum reduction of 0.28 metres at chainage 72.0, the effect gradually reducing further downstream until, at chainage 100.0 there is an increase in water level. This will occur because the canalisation improves the conveyance, thus reducing upstream water levels, increasing the available head and consequent discharge through the reach. This increased discharge must then pass through the downstream, unimproved section, which it cannot do without causing additional afflux.

TABLE II.5.22

Change in Maximum Levels in the Bangshi River due to Canalization from Kawaljani to Mirzapur

Chainage (Km)	67.0	72.0	79.0	87.0	94.5	100.0	107.0
Base Case (1989) (m PWD)	10.87	10.63	10.00	9.07	8.43	8.23	8.18
Option H3 (m PWD)	10.69	10.35	9.75	8.89	8.40	8.28	8.26
Diff (m)	-0.18	-0.28	-0.25	-0.18	-0.03	+0.05	+0.08

Source: CS 1991

The final option investigated under this category was designed to reduce the discharge passing through the lower Dhaleswari by diverting some of the flow in the Kaliganga into the Padma through artificial channels. Reducing the discharge in the lower Dhaleswari would have the effect of lowering the water levels and increasing the drainage potential of the Buriganga.

Two channels were assumed as constructed from the Kaliganga at chainage 20.0, (length 12.0 km), and from the Dhaleswari chainage 112.5, (37.0 km. in length). These channels were assumed to be embanked and thus would not contribute to the spill. They would be controlled at their outfall with the Padma by structures which would prevent backflow should the Padma water levels exceed the water levels in the Kaliganga at the drain offtakes.

Reference to ? shows that, despite the size of the channels proposed, (area of flow approximately 600 m^2 for the Kaliganga channel and 1000 m^2 for the Dhaleswari channel), the reduction in discharge in both the Dhaleswari and Kaliganga is minimal and this option is not likely to be worth following up in greater detail.

TABLE II.5.23

Change in Maximum Discharge due to Division Channels from Kaliganga & Dhaleswari River

Dhaleswari River				Kaliganga River			
Chainage (Km)	Base Case (1989) (m^3/sec)	Option H4 (m^3/sec)	Change on Base Case in %	Chainage (Km)	Base Case (1989) (m^3/sec)	Option H4 (m^3/sec)	Change on Base Case in %
104.50	494	521	+5.47	11.00	1469	1491	+1.50
108.75	491	527	+7.33	17.00	1468	1490	+1.50
115.00	1876	1873	-0.16	23.00	1455	1361	-6.46
120.00	2128	2067	-2.87	29.25	1451	1353	-6.75
125.00	2182	2113	-3.16	35.75	1453	1354	-6.81
130.75	2278	2203	-3.29	43.00	1431	1334	-6.78

Source: CS 1991

Figure II.5.6.1 shows the time series of water levels at Kalatia to illustrate the change in water level at this station resulting from all drainage options combined.

One clear issue arises out of the exercise. The drainage of the North Central region is heavily dependent on the outfall conditions to the Lower Meghna. As long as the water levels in the major boundary rivers are high, the impediment to effective drainage remains.

3.4 Embankment Options

The second basic option available was that of providing embankments along the main rivers, both boundary and internal. Two alignments were modelled which had the aim of reducing, (or eliminating), the incursion of the Jamuna overbank spillage into the region. No finite limits were set on the height of the embankments investigated, it being assumed that they were of sufficient height not to overtop, even in the most extreme floods.

To incorporate the embankments into the model, the cross sections along the river to be embanked were modified by adjusting the left or right bank marker accordingly. This procedure does no permit the "fine tuning" of set-back distances, since the extent of the physical cross section is limited, (before it becomes flood plain, represented by a characteristic curve). Therefore, in most cases, the location of the embankment is defined by the extent of actual bank survey, which varies from around 50 metres to 200 metres. In practice, the precise location of the embankment does not have a significant impact on the accuracy of the model outputs, since the topographical data is too coarse to give anything but approximations.

Table II.5.24 summarises the effects of the two embankment alignments on the 1989 water levels at selected comparison stations in the western sub-model. Run H5, simulating the Jamuna embankment, assumes the imposition of a full-height embankment along the left bank of the Jamuna, commencing at Bahadurabad, in the north,and terminating at Aricha, in the south. The Dhaleswari offtake is assumed to remain open, but in this particular run, all other offtakes are assumed closed and no drainage options are included.

TABLE II.5.24
Change in Maximum Levels between Base Case and Embanked Conditions

Location	River	Chainage (Km)	Base Case (1989) (m PWD)	With Embankment on Jamuna(H5)		With Embankment on Jamuna, Dhaleswari & Kaliganga(H11)	
				Level (m PWD)	Diff. (m)	Level (m PWD)	Diff (m)
Baushi Br.	Jhenai	35.0	15.00	16.20	+1.20	15.95	+0.95
Kawaljani	Bangshi	75.0	10.27	10.74	+0.47	10.56	+0.29
Mirzapur	Bangshi	107.0	8.18	7.94	-0.24	7.38	-0.80
Nayarhat	Bangshi	144.0	6.06	5.82	-0.24	6.10	+0.04
Jokerchar	Pungli	3.0	12.35	9.86	-2.49	9.59	-2.76
Jugini	O Dhaleswari	26.7	11.54	10.12	-1.42	13.09	+1.55
Tilli	Dhaleswari	37.8	8.90	8.65	-0.25	10.04	+1.14
Jagir	Dhaleswari	66.0	7.01	6.82	-0.19	6.17	-0.84
Kalatia	Dhaleswari	110.0	5.86	5.69	-0.17	6.10	+0.24
Taraghat	Kaliganga	14.0	8.03	7.84	-0.19	9.13	+1.10

Source CS 1991

The embankment configuration simulated in run H5 can be seen to exacerbate conditions in the north of the region, since the closure of the Chatal South prevents the drainage of the Chatal/Jhenai system in that area. ? shows the change in water levels at Baushi Bridge station resulting from the imposition of a full embankment along the Jamuna, with the Chatal South closed. Water levels in the Pungli and Old Dhaleswari are significantly reduced, again, due to the cutoff of the offtake.

Run H11, simulating the second embankment configuration, assumes a similar embankment along the Jamuna from Bahadurabad to Bhuapur, then following the left bank of the Old Dhaleswari, Dhaleswari and Kaliganga as far as Kalatia. All offtakes from these rivers are assumed to be closed, with the exception of the Chatal South. This was left open to permit free drainage from the Jamalpur Priority Project area, although ? shows the water levels increase at Baushi Bridge and Kawaljani. This is attributed to the higher backwater effects from an embanked Jamuna encroaching into the area through the open Chatal South offtake. Increased water levels would be experienced on the Bangshi, Old Dhaleswari, Dhaleswari and Kaliganga.

Table II.5.25 shows the changes in discharge that would result at selected locations as a result of the imposition of the above embankments. Clearly the significant increase in discharge at Baushi Bridge is a result of the increased water levels at this location and the increases on other rivers similarly result from increased water levels. Reduction in discharges result from offtakes of distributaries being fully closed.

TABLE II.5.25
Change in Maximum Discharges between Base Case and Embanked Conditions

Location	River	Chainage (Km)	Base Case (1989) (m^3/sec)	With Embankment on Jamuna(H5)		With Embankment on Jamuna, Dhaleswari & Kaliganga(H11)	
				Discharge (m^3/sec)	Change on Base Case in %	Discharge (m^3/sec)	Change on Base Case in %
Baushi Br	Jhenai	36.50	164	650	+296.34	361	+120.12
Kawaljani	Bangshi	73.50	300	531	+77.00	419	+39.67
Mirzapur	Bangshi	108.50	602	554	-7.97	432	-28.24
Nayarhat	Bangshi	145.50	796	605	-23.99	262	-67.09
Outfall	Pungli	52.75	424	251	-40.80	221	-47.88
Outfall	Louhajang	57.90	205	96	-53.17	39	-80.98
Outfall	Barinda	29.55	283	216	-23.67	27	-90.46
Jugini	O Dhalesari	28.14	341	-31	-109.09	649	+90.32
Tilli	Dhaleswari	40.87	1578	1503	-4.75	2786	+76.55
Jagir	Dhaleswari	69.25	105	90	-14.29	29	-72.38
Kalatia	Dhaleswari	111.25	1878	1628	-13.31	2329	+24.01
Taraghat	Kaliganga	17.00	1468	1415	-3.61	2746	+87.06

Source: CS 1991

3.5 Combined Options

The most likely development scenario for further investigation would be some combination of both drainage and embankment options. To this end, further hydraulic model runs were made which investigated the overall impacts on the flooding regime from numerous combinations of drainage and embankment options. The complete inventory of hydraulic model runs made is given as Table II.5.27.

Table II.5.26 summarises, planning unit by planning unit, the effects on the maximum extent of area flooded of the various combinations investigated using the hydraulic model. Note that the effects on planning units 3 and 9 are zero, due to the options tested being confined to the western sub-model, planning units 3 and 9 are located almost exclusively in the eastern sub-model.

Percentages of flooded area are expressed as percentages of the Net Cultivable Area of the planning unit and relate to the year 1989 only. Run H9 relates to 1988 and is not included in the Table. Run H12 investigated the extent of flooding in planning units 10 and 13 if the areas were poldered, with no drainage permitted. Results for this run, using the NAM model only, are given in ? , which show that an average accumulation of around 0.45 metres depth of water would result in both planning units, given no drainage permitted. The objective of this run was to illustrate the high degree of rainwater inundation that could occur and the order of magnitude of any pumping required to effectively alleviate the problem.

TABLE II.5.26

Maximum Flooded Area in Different Options in % of Net Cultivable Area

Planning Units	Base Case (1989) (in % of NCA*)	Max. flooded Area (% of NCA) After Interventions									
		H2	H3	H4	H5	H6	H7	H8	H10	H11	H13
1	27	27	27	27	36	36	20	20	28	28	29
2	41	41	41	41	56	56	43	43	54	54	26
3	49	49	49	49	49	49	49	49	49	49	49
4	74	74	72	74	72	71	59	58	67	69	51
5	22	22	22	22	23	23	20	21	22	22	17
6	82	81	81	79	46	43	43	39	41	43	42
7	78	75	76	70	68	63	62	38	39	52	61
8	40	39	39	39	37	30	33	30	33	35	32
9	31	31	31	31	31	31	31	31	31	31	31
10	90	88	88	80	83	77	76	94	99	109	76
11	92	90	90	89	90	88	87	88	88	95	87
13	85	83	83	82	82	80	80	80	79	85	80

Note: * NCA = Net Cultivable Area

Source: CS 1991

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TABLE II.5.27
Summary of Model Runs

Run Number	Year	Description
H00	1988	Existing Conditions
H0	1989	Existing Conditions
H1	1989	Conveyance improvement of 100% on lower Dhaleswari and Buriganga
H2	1989	As H1 but 25% conveyance improvement
H3	1989	H2 + Canalization of Bangshi (Kawaljani - Mirzapur)
H4	1989	H2 + diversion channels from Kaliganga & Dhaleswari to Padma
H5	1989	Embankment on left bank of Jamuna from Bahadurabad to Aricha, only Dhaleswari open, no drainage options
H6	1989	H5 with drainage options included
H7	1989	H6 with flows at Jhenai offtake restricted to 75 cumecs maximum
H8	1989	Embankment on left bank of Jamuna from Bahadurabad to Bhuapur, along left bank of Dhaleswari & Kaliganga + drainage options + restricted Jhenai offtake flows
H9	1988	H8 + lower Chatal offtake open
H10	1989	H9 for 1989
H11	1989	H10 without drainage
H12	1989	Rainwater accumulation in planning units 10 & 13, no drainage (NAM only)
H13	1989	H7 + controlled lower Chatal offtake + Baushi Bridge flows restricted to 50 cumecs maximum

Source: CS 1991

CHAPTER 4
PROCESSING OF RESULTS

4.1 General Approach and Assumptions

Output from the MIKE11 hydrodynamic module is available in the form of time series tables or plots of water level and discharge at all "h" points and "q" points respectively, (an "h" point is generally located at a river cross section input into the model structure, but can be a software generated point if the physical spacing of cross sections exceeds the maximum specified distance, and a "q" point is located midway between "h" points).

As is described in a separate supporting document, (SR IX) the North Central Region was sub-divided into 13 "planning units" for the purposes of assessing the development options available and constraints to such development for each unit. The impact of the model in this exercise was to attempt the quantification of the extent of flooding in each of the delineated planning units. Quite clearly, some form of post-processing was required to translate the standard outputs of the MIKE11 model into the information useable by the economists and engineers. No such post-processing package has yet been developed as a standard module for MIKE11 and it was therefore necessary to develop a "custom made" version for the North Central Study. FAP 25 has initiate work on producing a flood management model (FMM) which includes post-processing of the MIKE 11 outputs in late 1992

The post-processing software was conceived employing existing data related to flood plains. In view of the relatively short time available for the development of additional software for the Study, only the existing MPO topographical database was employed, which was also used in the derivation of the extended cross sections used in the model[1].

The programming environment used was Microsoft QuickBasic, version 4.5, which is an easy to use structured language and can be readily modified, if required. It should be noted that the resulting program is not considered to be the most elegant solution available, time constraints precluding the development of a fully refined, totally user-friendly version.

The program is based on a number of necessary assumptions, some of which are related to the development time available and others to the amount and type of data available.

During the development of the model, flood plains were incorporated at each river cross section by "attaching" a width-elevation curve to the physical river cross section. This width-elevation curve is itself derived from an area-elevation curve calculated by digitizing the boundaries of each nodal point flood cell defined on a map and interacting with the MPO database of levels that fall within these boundaries. Division of the result by the average flood cell length yields a width-elevation curve. Having the water level information at each nodal point within the model and the area-elevation curve appropriate to that nodal point, it is a simple exercise to calculate the area of flooding at each node for any water level.

---

[1] Refer to model general set-up, Chapter 2

The planning unit delineation of the region is often based on the alignment of watercourses, (a sensible assumption, since a watercourse is a physical entity and may be easily identified on the ground). This delineation results in a nodal point flood cell being attributed to 2 planning units, often in unequal proportions.

Since the intermediate area-elevation curve has no spatial meaning within the flood cell, (it does not indicate the location of high and low points relative to the river bank), it is assumed that the shape of the curve holds good for incremental parts of the flood cell, i.e. the whole flood cell is the sum of smaller flood cells which have the same shape as the total, but which are suitably reduced in scale. Using this assumption, apportioning a flood cell between two adjacent planning areas becomes simply a matter of arithmetic proportionality.

4.2 Methodology

Presented with a map delineating the sub-regional planning units overlaying the rivers and their associated flood plains, a file was constructed for each river which contained information related to each nodal point, (identified by number in an upstream to downstream direction), and the proportion of the associated flood plain to be allocated to the contiguous planning area. Table II.5.28 shows the structure of this file, the first column representing the nodal point number, the second the planning unit number and the final column showing the proportion of the nodal point flood plain to be allocated to that planning unit. These proportions were estimated by eye only, since accurate measurement would be too time consuming and the degree of resolution required at this level of study did not warrant it.

The MIKE11 results file for each river, containing water levels at each nodal point, was exported in ASCII text file format for the period April 1st to December 31st only, (275 values), since we were not concerned with dry season waterlevels and this also restricted the size of the arrays necessary in the program. The number of nodal points at which water levels were represented should agree with the number of nodal points identified in the file containing allocations of flood plains to planning units described above.

The final major data file for the program contained the nodal point flood plain data, (area-elevation data), which was derived from the digitization exercise. This was a simple ASCII file for each river nodal point by nodal point, containing 2 columns, one listing the elevation and the other the corresponding flood plain area. Thus for any elevation, the corresponding area could be found by interpolation between two adjacent values.

TABLE II.5.28

Example of Structure of P.pla File (Pungli River)

Node No.	Planning Unit No.	Factor
1	4	1
2	4	0.7
2	6	0.3
3	4	0.5
3	6	0.5
4	4	0.5
4	6	0.5
5	4	0.6
5	6	0.4
6	4	0.5
6	6	0.5
7	4	0.6
7	6	0.4
8	6	1
9	4	0.4
9	6	0.6
10	4	0.3
10	6	0.7
11	4	0.2
11	6	0.8
12	6	1

Source: CS 1991

4.3 Program Description

The program consists of 9 modules, each called in turn after completion of the previous module. The invoking filename is "FLOOD", which is a compiled BASIC, (.EXE), file and, as such, does not need to be run in the QuickBasic environment. These files must all reside in the same directory, but the user is free to decide which directory. They are as follows:

FLOOD.EXE FLOODF0.EXE FLOODF1.EXE FLOODF2.EXE
AREA.EXE AREAF0.EXE AREAF1.EXE AREAF2.EXE
TOTAREA.EXE

Before invoking the program, the user must ensure that the following sub-directories are resident on the computer:

a) C:\PLAN
b) C:\AREAELEV
c) C:\TEMPWL
d) C:\TEMPFF
e) C:\TEMPEL
f) C:\M11RES

Sub-directory C:\PLAN should contain all files with a .PLA extension. These files contain the relevant river and planning area data, as shown in Table II.5.28.

Sub-directory C:\AREAELEV contains all files with the .FLA extension, which are the flood plain area-elevation data files for each river and for all nodes of the river. An example of the structure of this file is given in Table II.5.29.

TABLE II.5.29

Example of Structure of .fla File

Chainage	No. of Data	
0	6	
Elevation	Width (m)	Area (Km^2)
10.37	401.36	1.00
10.52	802.73	2.01
10.58	1204.09	3.01
10.61	1605.46	4.01
10.82	2408.18	6.02
11.13	2809.55	7.02
Chainage	No. of Data	
3000	8	
Elevation	Width (m)	Area (Km^2)
10.64	196.30	0.98
10.82	392.60	1.96
10.85	588.90	2.94
10.95	785.20	3.93
11.04	981.50	4.91
11.07	1177.79	5.89
11.13	1570.39	7.85
11.34	1766.69	8.83

Source: CS 1991

Sub-directories C:\TEMPWL, C:\TEMPFF, and C:\TEMPEL are used to store intermediate calculations and no initial files are required to be installed in these sub-directories.

Sub-directory C:\M11RES contains the water level output files from MIKE11, in ASCII text file format, (.TXT extension), and should have the same name as those listed in OUTPUT.DAT contained in the C:\PLAN sub-directory. An example of the structure of a typical file is given in Table II.5.30.?.

TABLE II.5.30
Example of Structure of OUTPUT.DAT File

River	File Name	Year	No. Of Nodes
Balu	Balu89	1989	8
Bansi_s	Bansis89	1989	8
Barinda	Barind89	1989	8
Bangshi	Bangsh89	1989	20
Buri	Burig89	1989	6
Chatal	Chatal89	1989	6
Dha	Dhales89	1989	24
Dhantara	Dhanta89	1989	4
Elang	Elang89	1989	7
Futik	Futik89	1989	8
Ichamati	Ichama89	1989	5
Jhenai	Jhenai89	1989	17
Jhenai_e	Jhen_e89	1989	7
Jhenai_w	Jhen_w89	1989	3
Kali	Kaliga89	1989	10
Karna	Karnat89	1989	3
Lakhya_w	Lakh_w89	1989	12
Louha	louhaj89	1989	15
Nan_n	Nangln89	1989	4
Nan_s	Nangls89	1989	4
Pungli	Pungli89	1989	12
Tongi_k	Tongi89	1989	4
Turag	Turag89	1989	15

Source: CS 1991

The program initially sets up a loop which analyses each river in turn, node by node. The file OUTPUT.DAT is read, which provides the information as to the order in which the rivers should be considered, the name of the MIKE11 results text file, the year to be analysed, and the number of nodal points on each river.

The structure of the MIKE11 text file is such that it contains the results for all the nodes of the river and it must therefore be re-ordered and re-written to separate files for each node. These files are written to the sub-directory C:\TEMPWL. The area-elevation curves for each river are next sub-divided into separate files for each node and these files are written to the C:\TEMPEL sub-directory. There are now two files containing information related to each separate node of the river - one of output water levels and one containing the area-elevation curve for the flood plain associated with that nodal point.

The program then takes each daily water level, in turn, from the file and compares this level with the first, (lowest), elevation of the flood plain. If the water level is lower than the lowest flood plain elevation, there is no flooding and the next water level is considered. If the water level is greater than the lowest flood plain elevation, the water level is compared with next lowest flood plain elevation, and so on until a point is reached where the water level lies between 2 points on the area-elevation curve of the flood plain. By a process of interpolation, the total area inundated at this water level is calculated and stored in a temporary file. This procedure is repeated for each day at each node and for each river.

The above routine calculates the **total** area flooded at each node. For the purposes of this study, it is required to determine the flooded area in terms of flood phase categories, (F0,F1,F2,F3). By subtracting the flood phase depth from the simulated water level at each node and repeating the above area calculation, the breakdown of flooded areas into the various flood phases may be obtained. The next three modules, chained to each of the preceding modules, essentially repeat the first module but use the revised flood depth.

When all flooded areas for each flood phase for each node and for each river have been calculated, the program then chains to a module "AREA" which allocates a proportion of each **total** flooded area at each node to the appropriate planning unit. In common with the previous "FLOOD" module, there are a series of "AREA" modules, each representing a different flood phase. After all these modules have run, a series of files are stored containing the flooded area for each flood phase for each river at each nodal point. The final module, "TOTAREA", then considers each river, in turn, and sums the flooded areas for each flood phase for each planning unit.

The final program output is an ASCII file containing, planning unit by planning unit, the total flooded area for each flood phase.

4.4 Program Listing - Flood

A suite of programs written in the Microsoft QuickBasic environment which converts the water level output from MIKE11 to the areas flooded in each of the North Central Region Study "Planning Areas".

The listing below is partial only, in that there are a number of modules which are similar to the main modules reproduced here, but differ only in the level at which the flooded area is calculated. To economise on space, only one version of each module is listed here. A full listing is available from the program diskette.

PROGRAM LANGUAGE: QuickBasic Version 4.5, **AUTHOR:** D.K.Milton (BCEOM), **DATE:** November 1991

4.4.1 Flood

```
*****************************************************************************************************
'opening sub-routine and variable declarations
DECLARE SUB areacalc (nodes%, nolevels%)
DECLARE SUB dinput ()
DECLARE SUB resultinput ()
OPTION BASE 1
DEFSNG A-Z
DEFINT D, N, P
'$DYNAMIC
DIM SHARED wl!(275), fplevel!(70), fparea!(70)
DIM SHARED points%
DIM SHARED totalarea!(28, 275), location%, k%, nodes%, floodedarea(275), m%, count%
DIM SHARED result$, River$, year%, arelev$, day%
DIM SHARED record$(275)
DIM SHARED records%
CLOSE
CLS
'open file containing list of rivers, results file, year of results and number of nodes per river
OPEN "c:\plan\output.dat" FOR INPUT AS #4
DO WHILE NOT EOF(4)
        INPUT #4, River$, result$, year%, nodes%
        CLS
        CALL resultinput 'input waterlevels for each section
        CALL dinput ' input level/area data and write to separate files
        FOR m% = 1 TO nodes% ' for each nodal point in turn...
                CLS : LOCATE 8, 15
                PRINT "Processing River " + River$
                LOCATE 10, 15
                PRINT "Reading waterlevel data for node .." + LTRIM$(STR$(m%))
      ' read daily water levels for each nodal point
                OPEN "c:\tempw\tempwl" + LTRIM$(STR$(m%)) + ".wl" FOR INPUT AS #3
                day% = 1
                        DO WHILE NOT EOF(3)
                                INPUT #3, wl!(day%)
                                day% = day% + 1
                        LOOP
                records% = day% - 1
                CLOSE #3
                CLS : LOCATE 8, 15
                PRINT "Processing River " + River$
                LOCATE 10, 15
                PRINT "Reading area/elevation data for node..." + LTRIM$(STR$(m%))
        'read in level/area data for nodal point
                OPEN "c:\tempe\tempel" + LTRIM$(STR$(m%)) + ".fpl" FOR INPUT AS #1
                i = 1
                        DO WHILE NOT EOF(1)
                        INPUT #1, fplevel(i), fparea(i)
                        i = i + 1
                        LOOP
                nolevels% = i - 1
                CLOSE #1
                nodes% = m%
        'calculate total flooded area for each water level
                CLS : LOCATE 16, 15
                PRINT "Calçulating total flooded area for each day"
                'call sub-routine to calculate flooded areas
                CALL areacalc(nodes%, nolevels%)

        'consider next nodal point in river
        NEXT m%
        'write floodphase data for each river to file
```

```
CLS : LOCATE 12, 15
PRINT "Writing floodphase data to file"
OPEN "c:\tempff\" + River$ + ".ff1" FOR OUTPUT AS #1
FOR count% = 1 TO nodes%
          FOR day% = 1 TO records%
                    PRINT #1, totalarea(count%, day%)
          NEXT day%
NEXT count%
CLOSE #1
'erase temporary files
KILL "c:\tempw\*.wl"
KILL "c:\tempe\*.fpl"
CLS : LOCATE 12, 20
PRINT "Floodphase data written to file"

LOOP  ' consider next river in output.dat list
CHAIN "floodf0" 'repeat the calculations using water level reduced
          'by 0.3m (max depth for F0 category flooding
```

This module is repeated for each floodphase level required, the initial water level being reduced by the succeeding floodphase depth.

```
END
******************************************************************************************************
```

4.4.2 Sub-routine - Areacalc

```
******************************************************************************************************
REM $STATIC
DEFSNG D, N, P
SUB areacalc (nodes%, nolevels%)
'calculates total flooded area for each
'water level, section by section
day% = 1
     floodedarea(day%) = 0
DO WHILE day% <= records%
     IF wl!(day%) <= fplevel(1) THEN GOTO increment
                    k = 2
   'compare with next highest ground level
                    DO WHILE k <= nolevels%
          'if greater than this compare with next highest level
                    IF wl!(day%) >= fplevel(k) THEN GOTO TryAgain
          'if not, calculate total area flooded at this waterlevel
                              GOTO CalcArea

          TryAgain:
          'if waterlevel higher than greatest ground level
          'area flooded is equal to greatest area of flood plain
                                        IF k = nolevels% THEN
                                                  floodedarea(day%) = fparea(k): GOTO skip

          ' compare with next ground level
                              ELSE
                              k = k + 1
                              END IF
                    LOOP
          CalcArea:
                    floodedarea(day%) = (((fparea(k) - fparea(k - 1)) * (wl!(day%) - fplevel(k - 1))) / (fplevel(k)
                                        - fplevel(k - 1)) + fparea(k - 1))

          skip:
                    totalarea(nodes%, day%) = floodedarea(day%): day% = day% + 1: GOTO iterate

          increment:
                    totalarea(nodes%, day%) = 0
                    day% = day% + 1
          iterate:
LOOP
END SUB
******************************************************************************************************
```

4.4.3 Sub-Routine - Dinput

```
************************************************************************************************
SUB dinput
CLS : LOCATE 12, 15
PRINT "Opening Area/elevation data file for River :" + River$
OPEN "c:\areaelev\" + River$ + ".fla" FOR INPUT AS #1
location% = 1
CLS : LOCATE 12, 15
PRINT "Writing area/elevation data for each node"

DO WHILE location% <= nodes%
     OPEN "c:\tempel\tempel" + LTRIM$(STR$(location%)) + ".fpl" FOR OUTPUT AS #2
     INPUT #1, a, points, d
     ON ERROR GOTO oops
     LINE INPUT #1, dummy$
          FOR k = 1 TO points
               INPUT #1, fplevel(k), w, fparea(k)
               PRINT #2, fplevel(k), fparea(k)
               'PRINT location%
               ' PRINT fplevel(k), fparea(k)
          NEXT k
     CLOSE #2

     location% = location% + 1
     IF location% > nodes% THEN EXIT DO
     INPUT #1, BLANKLINE
LOOP
CLOSE #1


END SUB
************************************************************************************************
```

4.4.4 Sub-routine - Result input

```
************************************************************************************************
SUB resultinput
DIM waterlevel(28, 275)

LOCATE 12, 15
PRINT "Opening Mike 11 Results file for River :" + River$'file with .TXT extension

OPEN "c:\m11res\" + result$ + ".txt" FOR INPUT AS #1
count% = FIX(nodes% / 5)
residual = nodes% MOD 5
recnos = 275 ' MIKE11 water level output data from 1st April to 31st December only
start = 1: finish = 5: k = 1
IF nodes% < 5 THEN GOTO resid
DO WHILE k <= count%
    FOR m = 1 TO 19
      LINE INPUT #1, dummy$
    NEXT m
      FOR day = 1 TO recnos

           INPUT #1, a, b, c, d, e, waterlevel(start, day), waterlevel(start + 1, day), waterlevel(start + 2, day),
waterlevel(start + 3, day), waterlevel(start + 4, day)
      NEXT day
      FOR m = 1 TO 5
```

```
        LINE INPUT #1, dummy$
      NEXT m
    start = start + 5
    k = k + 1
  LOOP
IF residual = 0 THEN GOTO filer
resid:
    FOR m = 1 TO 19
      LINE INPUT #1, dummy$
    NEXT m
        OPEN "c:\temp.rec" FOR OUTPUT AS #2
        FOR day = 1 TO recnos
           LINE INPUT #1, record$(day)
           x = LEN(record$(day))
           x = x - 16
           record$(day) = RIGHT$(record$(day), x)
           PRINT #2, record$(day)
        NEXT day
      CLOSE #2
      OPEN "c:\temp.rec" FOR INPUT AS #2
      FOR day = 1 TO recnos
         FOR i = start TO start + residual - 1
           INPUT #2, waterlevel(i, day)
         NEXT i
      NEXT day
  CLOSE #2
  filer:
  CLOSE #1
  m = 1
  DO WHILE m <= nodes%
  OPEN "c:\tempw\tempwl" + LTRIM$(STR$(m)) + ".wl" FOR OUTPUT AS #1
  FOR day = 1 TO recnos

       PRINT #1, waterlevel(m, day)
  NEXT day
  CLOSE #1
  m = m + 1
  LOOP
  END SUB
*************************************************************************************************
```

4.4.5 Module Listing - Area

```
*******************************************************************************************
 DECLARE SUB period30 ()
 DIM SHARED node(50), pla%(50), factor(50), pla%
 DIM SHARED areaflooded(13, 275), areaflood(13, 27), period
 DIM totalarea(28, 275)
 CLS
 OPEN "c:\plan\output.dat" FOR INPUT AS #3
 DO WHILE NOT EOF(3)
           INPUT #3, River$, a$, b, c
           OPEN "c:\plan\" + River$ + ".pla" FOR INPUT AS #1
           OPEN "c:\tempff\" + River$ + ".ff1" FOR INPUT AS #2
           i = 1
           DO WHILE NOT EOF(1)
                     INPUT #1, node(i), pla%(i), factor(i)
                     PRINT node(i), pla%(i), factor(i)
                     i = i + 1
           LOOP
           CLOSE #1
           total = i - 1
           maxnodes = node(total)

           FOR node = 1 TO maxnodes
```

```
                FOR day% = 1 TO 275
                INPUT #2, totalarea(node, day%)
                NEXT day%
        NEXT node
        FOR i = 1 TO total
                FOR day% = 1 TO 275
                areaflooded(pla%(i), day%) = areaflooded(pla%(i), day%)
                                        + (totalarea(node(i), day%) * factor(i))
                NEXT day%
        NEXT i
        CLOSE #2
        CALL period30
        OPEN "c:\plan\" + River$ + ".arl" FOR OUTPUT AS #1
        FOR pla% = 1 TO 13
                FOR period = 1 TO 27
                PRINT #1, areaflood(pla%, period)
                LOCATE 12, 15: PRINT "Writing Total Area Flooded to File"
                LOCATE 14, 20: PRINT "for River " + UCASE$(River$)
                NEXT period
        NEXT pla%
        CLOSE #1
        ERASE areaflooded, areaflood
LOOP
CLOSE #3
CHAIN "areaf0"
        'Repeat this module for each flood phase level
****************************************************************************************

'sub-routine for calculation of 10 day period totals for flooded areas
SUB period30
period = 1
day% = 1
FOR pla% = 1 TO 13
'areaflood(pla%, period) = 0
   DO WHILE period <= 27
      SELECT CASE period
            CASE IS = 6, 12, 15, 21, 27
                  total = 11
            CASE ELSE
                  total = 10
      END SELECT

      DO WHILE k <= total
            areaflood(pla%, period) = areaflood(pla%, period) + areaflooded(pla%, day%)
            day% = day% + 1
            k = k + 1
      LOOP
      areaflood(pla%, period) = areaflood(pla%, period) / total
'      PRINT areaflood(pla%, period), pla%, period
      day% = day% - 1
      period = period + 1
      k = 1
LOOP
period = 1: day% = 1
NEXT pla%
END SUB
****************************************************************************************************
```

4.4.6 Module - Totarea

This module aggregates the flooded areas in each planning area for each river into a regional total for each planning area, independent of river. It is the final phase of the program.

```
OPTION BASE 1
DIM areatot(13, 27)
```

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```
DIM areaf0(13, 27), areaf1(13, 27), areaf2(13, 27), areaf3(13, 27)
DIM totareaf0(13, 27), totareaf1(13, 27), totareaf2(13, 27), totareaf3(13, 27)
' Create a file containing the directory listings of each sub-file
'containing the flooded areas for each planning area, river by river
SHELL "dir c:\plan\*.ar? |sort >filelist"
'initialise compounded areas to zero
   OPEN "filelist" FOR INPUT AS #1
      FOR i = 1 TO 5
      LINE INPUT #1, dummy$
      NEXT i
DO WHILE NOT EOF(1)
      LINE INPUT #1, filelist1$
      LINE INPUT #1, filelist2$
      LINE INPUT #1, filelist3$
      LINE INPUT #1, filelist4$
      filename$ = "c:\plan\" + RTRIM$(LEFT$(filelist1$, 8)) + ".ar1"
   OPEN filename$ FOR INPUT AS #2
      filename$ = "c:\plan\" + RTRIM$(LEFT$(filelist2$, 8)) + ".ar2"
   OPEN filename$ FOR INPUT AS #3
      filename$ = "c:\plan\" + RTRIM$(LEFT$(filelist3$, 8)) + ".ar3"
   OPEN filename$ FOR INPUT AS #4
      filename$ = "c:\plan\" + RTRIM$(LEFT$(filelist4$, 8)) + ".ar4"
   OPEN filename$ FOR INPUT AS #5

      FOR pla% = 1 TO 13
         FOR period = 1 TO 27
          INPUT #2, areatot(pla%, period)
          INPUT #3, areaf0(pla%, period)
          INPUT #4, areaf1(pla%, period)
          INPUT #5, areaf2(pla%, period)
          areaf3(pla%, period) = areaf2(pla%, period)
          areaf2(pla%, period) = areaf1(pla%, period) - areaf2(pla%, period)
          areaf1(pla%, period) = areaf0(pla%, period) - areaf1(pla%, period)
          areaf0(pla%, period) = areatot(pla%, period) - areaf0(pla%, period)
          totareaf0(pla%, period) = totareaf0(pla%, period) + areaf0(pla%, period)
          totareaf1(pla%, period) = totareaf1(pla%, period) + areaf1(pla%, period)
          totareaf2(pla%, period) = totareaf2(pla%, period) + areaf2(pla%, period)
          totareaf3(pla%, period) = totareaf3(pla%, period) + areaf3(pla%, period)
         NEXT period
      NEXT pla%
   CLOSE #2
   CLOSE #3
   CLOSE #4
   CLOSE #5
   ERASE areaf0, areaf1, areaf2, areaf3, areatot
   LOOP
   CLOSE #1
   CLS
   LOCATE 12, 15
   INPUT "Enter name of final result file to save:"; floodres$
   OPEN floodres$ FOR OUTPUT AS #1
   PRINT #1, "Summary of Flooded Area by Flood Phase"
   PRINT #1, "(Expressed in km2 for 10 day periods)"
   FOR pla% = 1 TO 13
         PRINT #1, "Planning Area "; pla%
         FOR period = 1 TO 27
              PRINT #1, totareaf0(pla%, period), totareaf1(pla%, period), totareaf2(pla%, period),
                             totareaf3(pla%, period)
           NEXT period
           PRINT #1,
           PRINT #1,
   NEXT pla%
   CLOSE #1
   END
```

****

CHAPTER 5
FUTURE WORK REQUIRED

5.1 Survey and Topographic Data

Reference has been made in previous sections of this report to the quality of the survey and topographic data available for the present stage of the modelling activities. Numerous anomalies prevail with respect to the cross section survey data, in terms of the absolute elevations measured. Some bench mark errors are likely to be the cause of this and these should be checked rigorously. FINNMAP have carried out a second-order levelling exercise in part of the North Central region, and once these data are fully available, they should provide valuable insight into the inconsistencies.

Careful examination of the relative bed elevations at river bifurcation points will permit more accurate modelling of the allocation of discharges through each component reach. Lack of survey at a number of these points presently requires artificial sections to be introduced in order to reach a satisfactory agreement at the nearby discharge comparison stations.

Location of cross-sections on the rivers has proved to be a difficult exercise, particularly since non of the survey data was geo-referenced accurately, (In recent months the use of geodetic position survey devices, GPS, has become possible in Bangladesh. GPS will give an accuracy of better than 100 metres, which is suitable for modelling purposes). The BWDB sections are normally fixed and marked by permanent monuments, which should facilitate their location. The additional surveys by DUL and the SWMC were based on field identification from 1:50,000 mapping, often out of date. Referencing these sections on the revised base map produced from SPOT imagery often lead to significant errors in positioning and hence in assigning chainages to the sections. Clearly, it would be difficult to re-locate these sections on the ground and it is likely that they will have to be used for the foreseeable future at their present locations. However, should additional survey be carried out, geo-referencing of the locations should be a pre-requisite of the specifications.

In terms of the requirements of the NCRS modelling exercises, the accuracy of the topographical features of the river banks and flood plains determine the overall suitability of the model. There is a serious lack of up-to-date contour details which would permit the realistic representation of flood plain or flood cell data in studies which seek to go beyond pre-feasibility level. Required data will be specified in the TOR for the Feasibility Studies.

Development of studies beyond planning and pre-feasibility level will necessitate significant improvements in the quality and resolution of survey and topographic data. This should not present insuperable problems, since it is reasonable to expect that some reduction in the size of the area of interest will result from increasing the level of the study from pre-feasibility to feasibility, for example.

A component of the Flood Action Plan, (FAP 19), is to begin work on the production of Digital Terrain Models, (DTM's), which are to be based on compartment, sub-regional and regional scale models. It is understood that these will be represented by the Tangail model, (FAP 20), Jamalpur Priority Project model, (FAP 3.1), and the North Central Regional Study respectively. When completed, these DTM's will give a valuable insight into the configuration of the flood plains, in addition to providing a tool for the processing of MIKE11 output. However, for the time being, the data used by the DTM's will be based, (particularly on a regional level), on the existing levels digitized from the 4" and 8" to the mile irrigation maps and hence may not be completely representative of the present situation.

5.2 Hydrometric Data

Calibration of the hydrodynamic model relies on the correct simulation of both water level and discharge at existing hydrometric stations. It is therefore important that there are not only sufficient comparison stations, appropriately located, but that the quality of the data with which the simulated output is compared, is also of the highest standard possible. There are consequently two aspects of hydrometric data to be addressed - that of quantity and that of quality.

The quantity factor in hydrometric data is not necessarily restricted to the length of record of a particular station. In the context of the hydrodynamic modelling, it refers more to the number and location of stations which are required to give credence to the calibration of the model. In the North Central regional model, there are large areas of uncertainty in the validity of the calibration due to lack of corroborating evidence. The SWMC have initiated a programme of monitoring under a Memorandum of Agreement with BWDB at certain locations in the region. While this is contributing significantly to the database, some additional stations could be recommended as worthy of installation. Sub-models for more specific purposes may require additional stations related to their unique needs.

Comments in the earlier chapter of this report, dealing with the calibration and resulting "errors" of the model, indicate that greater attention should be paid to the overall quality and reliability of the data used in the model. Water level data is the most fundamental form of hydrometric data and it is essential that the integrity of such data is beyond question. Almost all water level stations in the North Central region are "manually" operated. That is, an observer is paid to read a staff gauge 5 times each day, normally 0600, 0900, 1200, 1500, and 1800 hours. Should a flood event occur outside these regular reporting hours, there is a likelihood that the peak will be missed.

Unless very strict monitoring of observers performance is maintained, it cannot be guaranteed that the recorded data is correct. Any data lost in this way cannot be recovered accurately and with confidence, (although, in some cases, correlation with a nearby station might be acceptable). It is clearly outside the resources of the data collection agency to maintain an additional staff of field monitors and so there is considerable trust placed in the observer.

The practice of moving gauge posts at times of high flow should be discouraged. It is an additional potential source of error, the quantification of which can be difficult, at best, and impossible, at worst. While it would represent a significant additional investment, permanent gauge boards should be installed at sites where such movement of gauge board presently occurs. These new gauge boards should be of substantial construction and not of the existing bamboo poles. Accurate levelling of the newly installed gauge plates should be done and repeated on an annual basis, or when any movement is suspected to have taken place.

A long term solution to the problem of the quality of water level data is required. Probably the most reliable method would be to replace all manual gauges with automatic systems. The precise type of automatic recorder that suits the conditions in Bangladesh would be the subject of some debate, it could well be based on microprocessor technology for storage of data, which could then be downloaded into the central processing computer. To avoid costly installations, the water levels sensors could be based on pressure transducers, rather than the conventional float and stilling well configuration. It would be naive to neglect the problems associated with security of any installation, but Bangladesh is not unique in this respect and some method would be practical for the local situation.

5.3 Modelling

The North Central regional study has devised a Coarse Pilot Model for use in planning studies and pre-feasibility studies. There remain many aspects of the model that would benefit from further work. Indeed, the SWMC is presently refining this CPM and hope to have a Pilot Model operating by April, 1992.

The experience gained by the modellers of FAP3 will greatly assist the future work of the SWMC. Throughout the study, close cooperation has been maintained with the North Central Model Group at the SWMC, interchange of ideas and experience, proving invaluable. This section of the report seeks to identify those aspects of the construction of the Pilot version of the NCRM that should be looked at further.

Flood plains may be incorporated in the model in 2 distinct ways:considering them as directly attached to the river cross-section, in which case there is assumed to be a free and direct interchange of water between flood plain and river, or to consider them as individual flooded areas, linked to the rivers only by virtue of overspill "weirs", the flood waters returning to the river system at a different location. The CPM assumes the former to be the case and, as such, is a purely one-dimensional model. Clearly, this is not so in all river reaches. However, the complexities involved in defining the discrete flooded areas and the precise locations of the spill and return flow, precluded the initial construction of the model in this way. An additional consideration was the need to confine the size of the model such that it could be accommodated within the DOS operating system limits. Since the model, as constructed, uses some 83% of the DOS memory, (for the western sub-model), it was assumed that to include all additional flooded areas and spill weirs needed for a quasi two-dimensional model would exceed the limit. This can be overcome by converting the model to the UNIX operating system, but this was not within the plan of the study, nor in the immediate plans of the SWMC.

Further study should be made of the spill characteristics of the Jamuna such that the model more closely represents the correct volume of discharge spilling into the region in the north and south west. By virtue of these spills, it can be said that no unique model exists for the region, since the location, (and volume), of the spills vary from flood event to flood event. Breaches in the existing embankment can appear anywhere and aggradation and degradation of the mouths of spill channels causes variations in the flow characteristics at these points. Notwithstanding these difficulties, it should be possible to study the areas in question in sufficient detail to present a sensible overall configuration that improves on the present CPM structure.

REFERENCES

DHI 1989a Danish Hydraulic Institute, MIKE11 Users' Manual

DHI 1989b Danish Hydraulic Institute, MIKE11 Reference Manual, (3 Volumes)

NCRS 1990 North Central Regional Study - Bridging Period, Discharge Measurements & Collection of Additional Data, Desh Upodesh Ltd., October, 1990

NCRS 1991a North Central Regional Study - Phase 1, Final Report - Monthly Water Level Statement, Desh Upodesh Ltd., January, 1991

NCRS 1991b North Central Regional Study - Bridging Period, Cross Sectional Survey, Desh Upodesh Ltd., April, 1991

NCRS 1991c North Central Regional Study - Bridging Study, Coarse Pilot Model BCEOM April, 1991

NCRS 1991d North Central Regional Study - Interim Report, November 1991.

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Main Text Figures

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Figure 5.1 Schematized Representation of Eastern Sub-Model

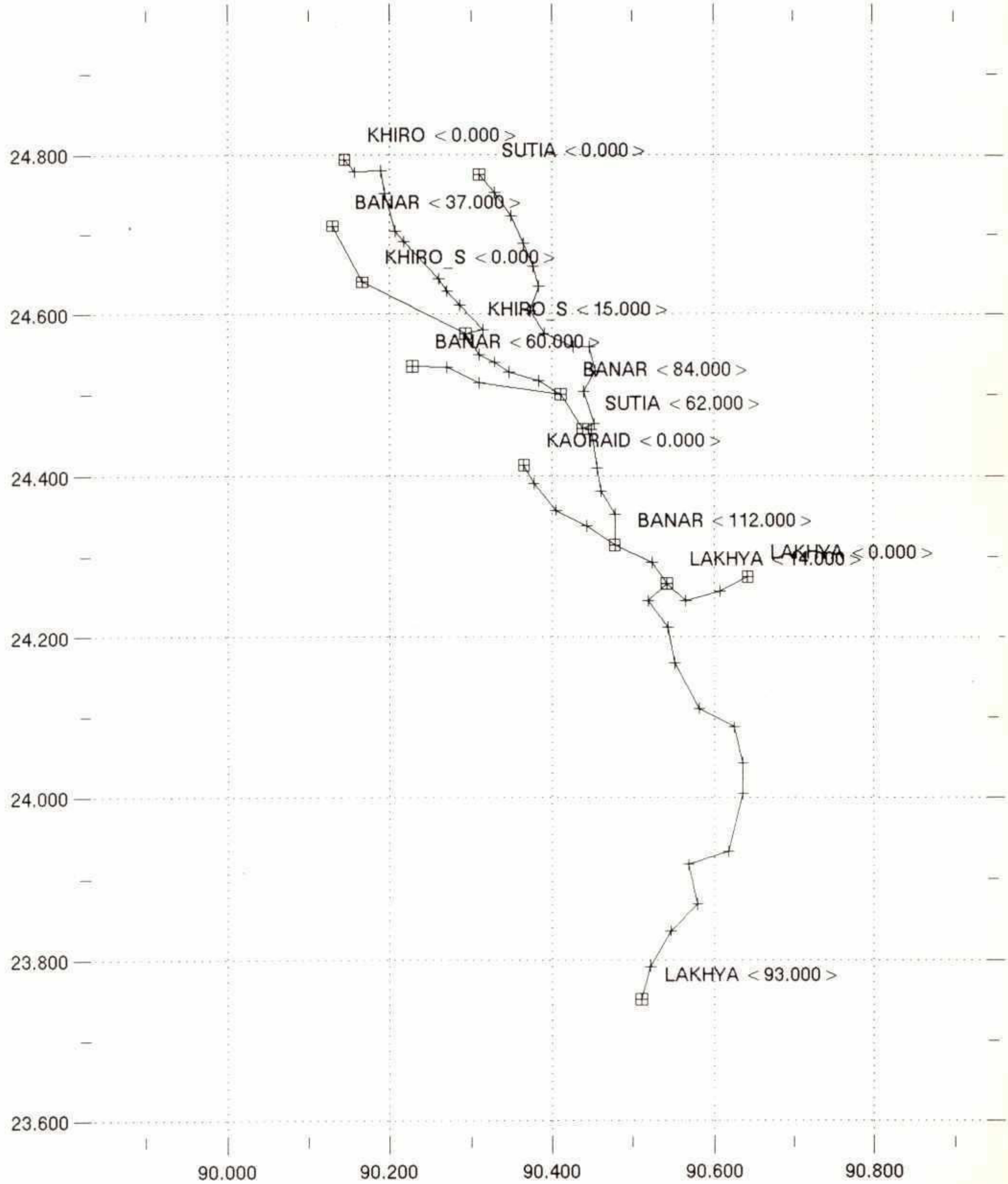

Figure 5.2 Schematized Representation of Western Sub-Model

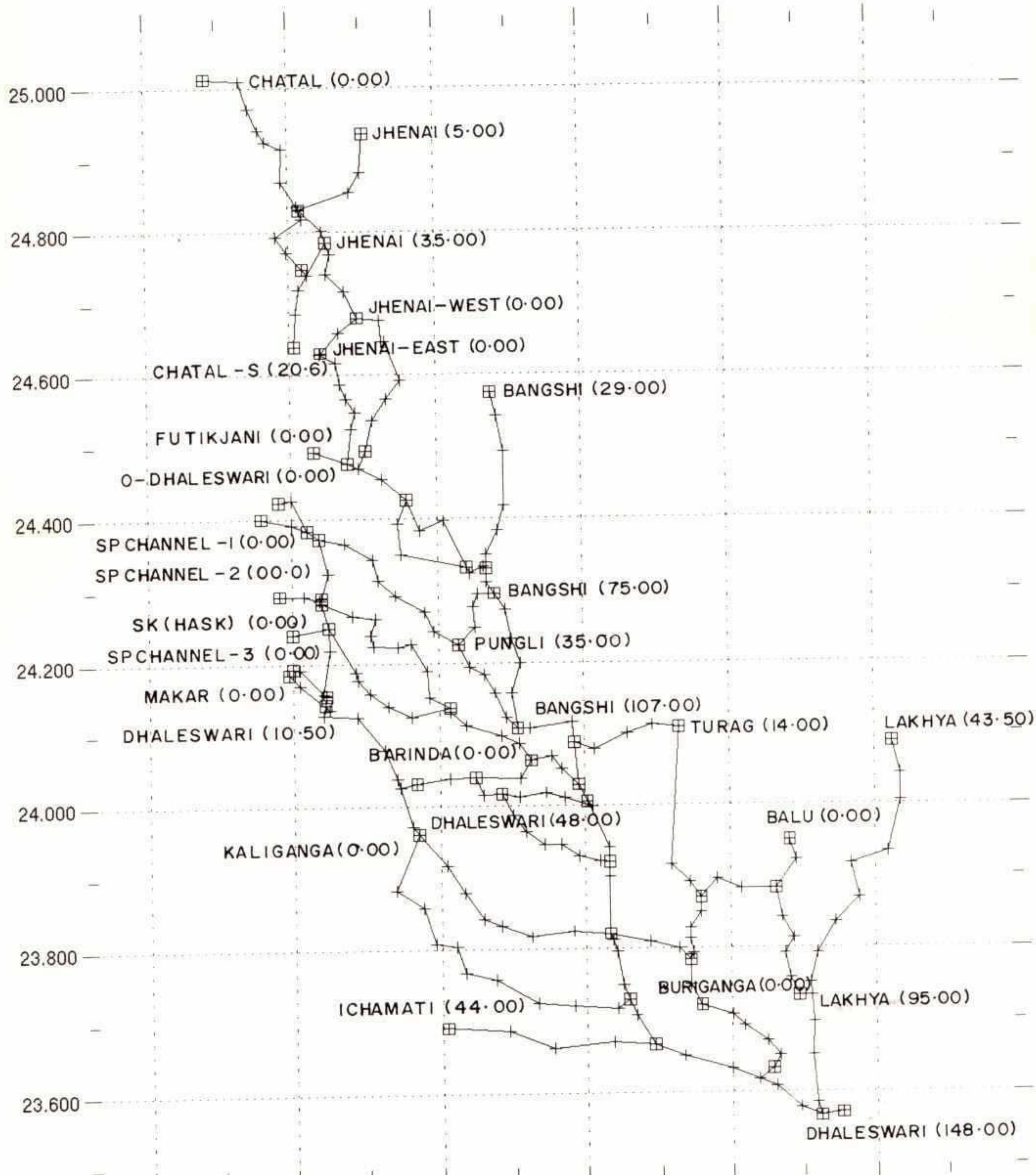

Figure 5.3 **Schematized Representation of Old Brahmaputra Sub-Model**

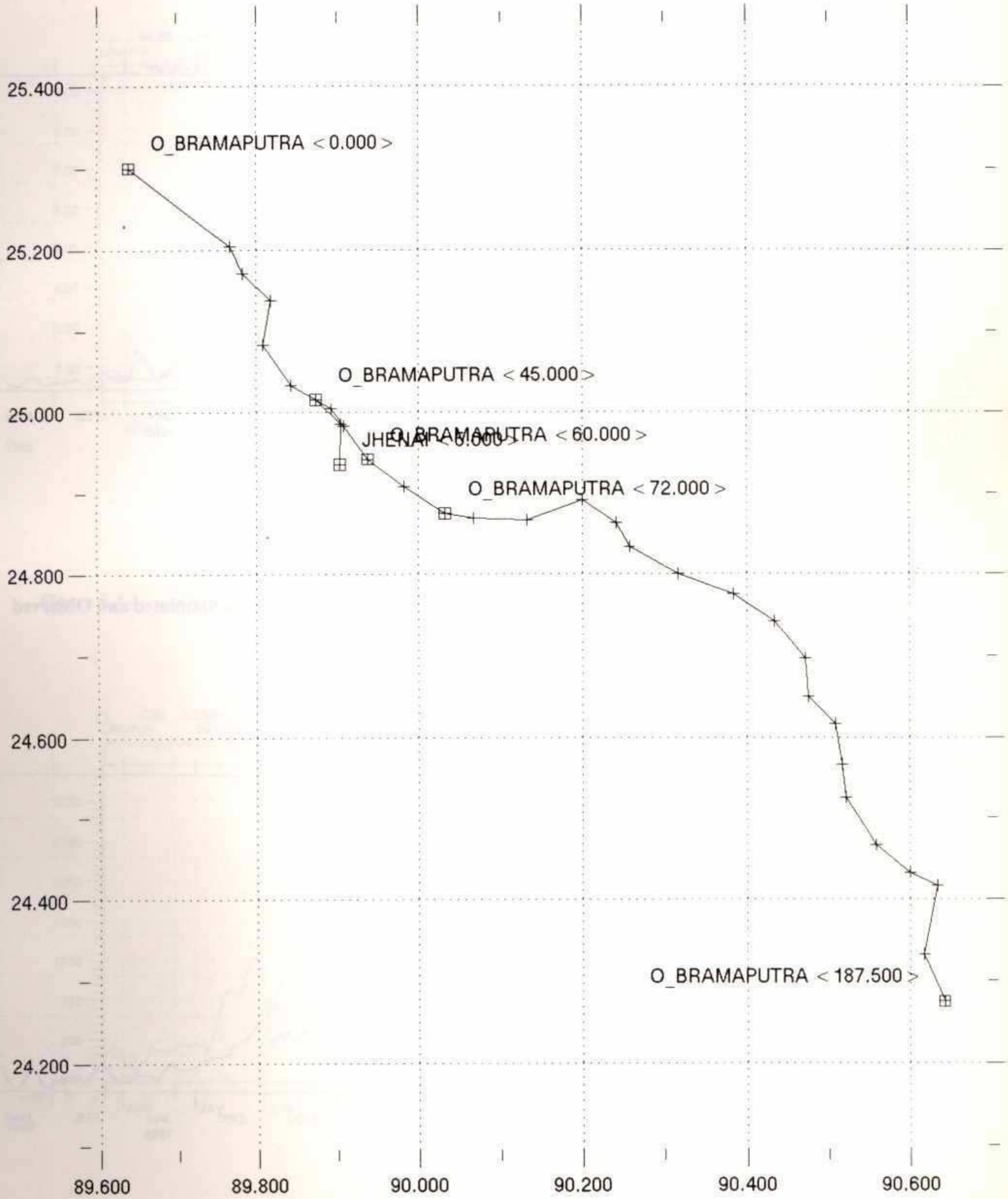

Figure 5.4.1 Comparison of Water Level Hydrograph at Kaoraid between Simulated and Observed

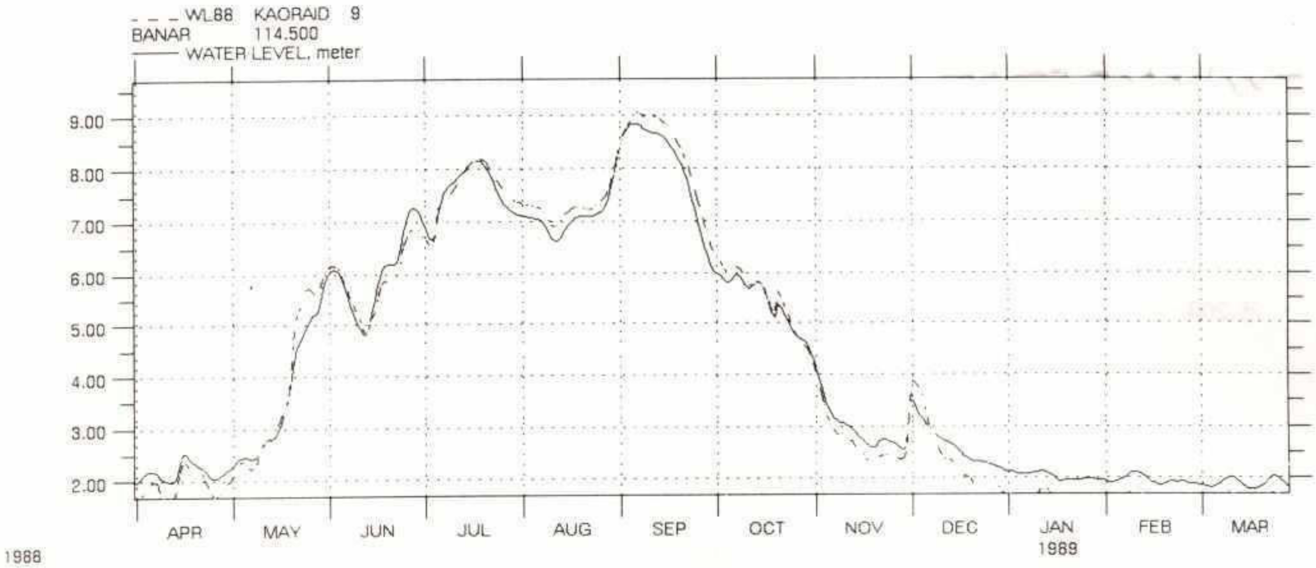

Figure 5.4.2 Comparison of Water Level Hydrograph at Trimohoni between Simulated and Observed

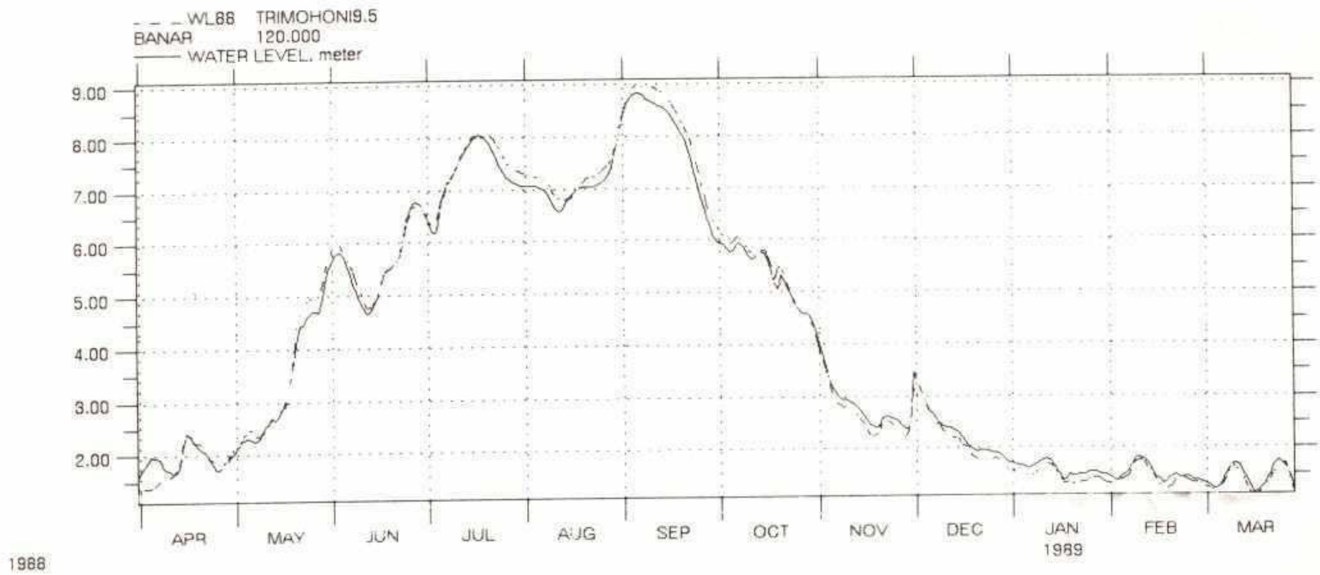

Figure 5.4.3 Comparison of Water Level Hydrograph at Lakhpur between Simulated and Observed

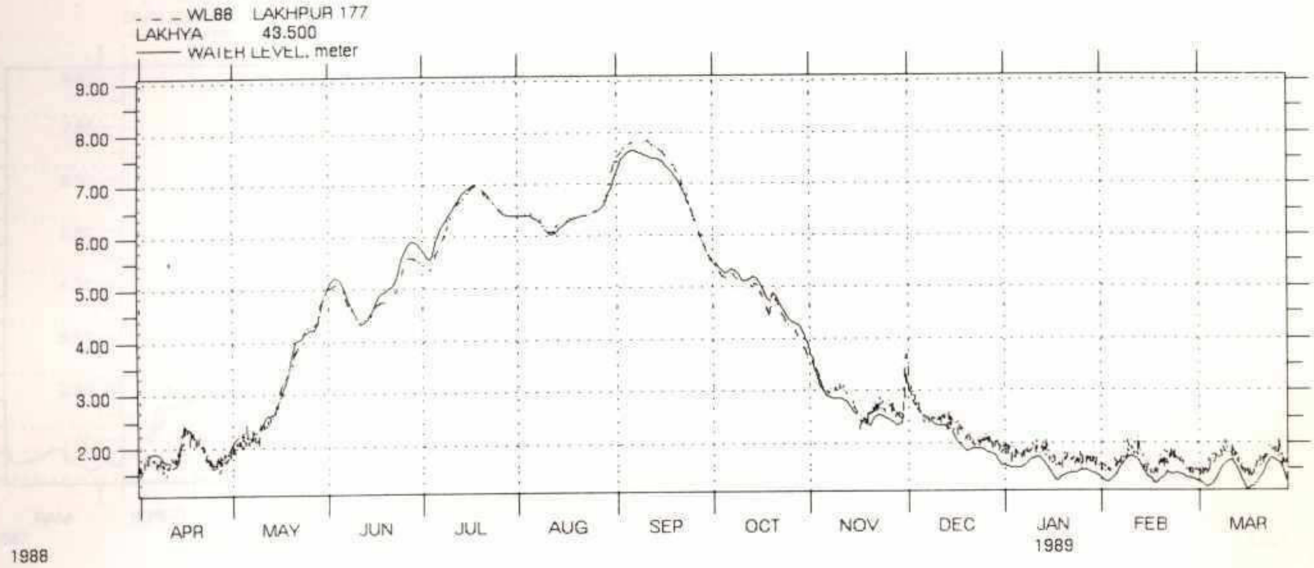

Figure 5.4.4 Comparison of Discharge Hydrograph at Demra between Simulated and Observed

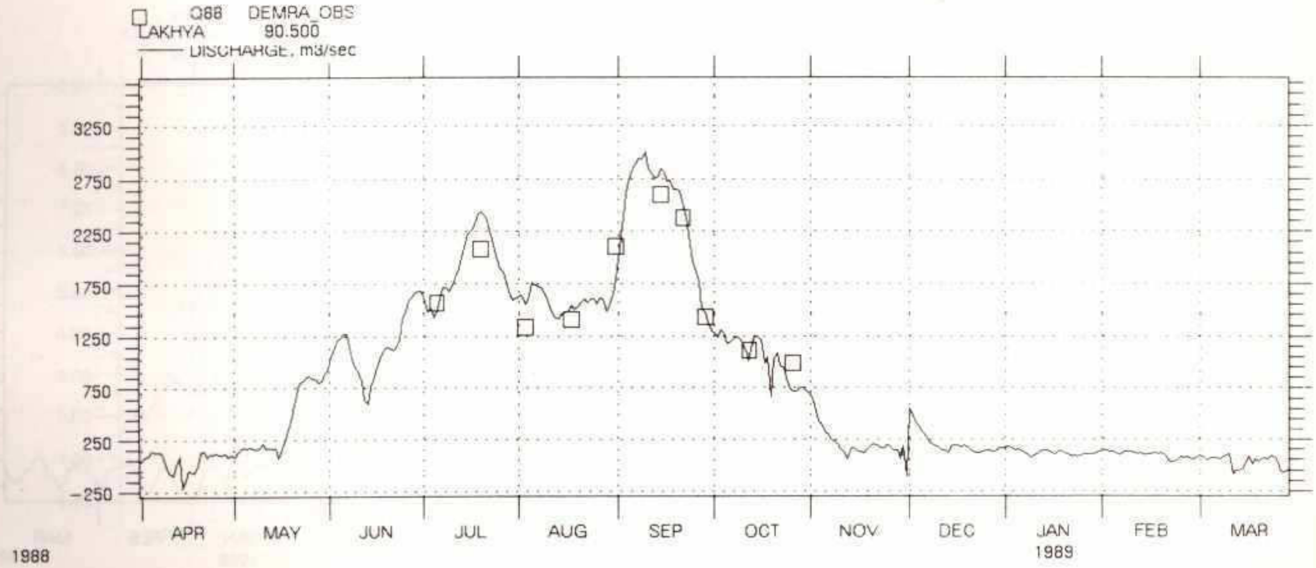

Figure 5.4.5 **Comparison of Water Level Hydrograph at Mirzapur between Simulated and Observed**

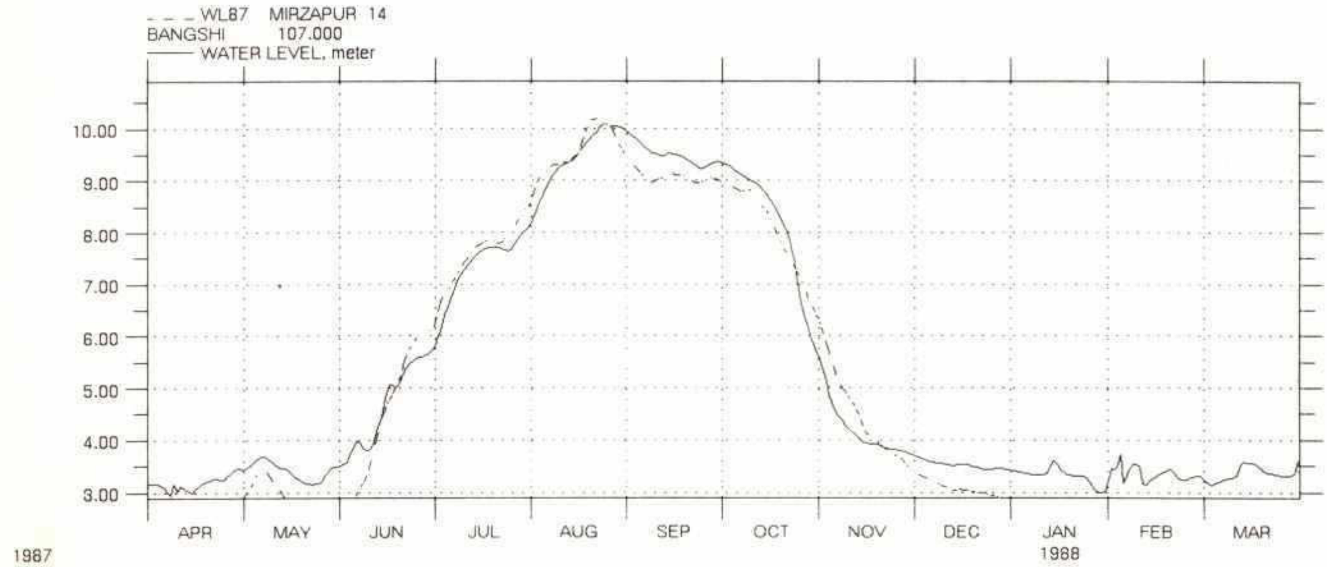

Figure 5.4.6 **Comparison of Water Level Hydrograph at Nayarhat between Simulated and Observed**

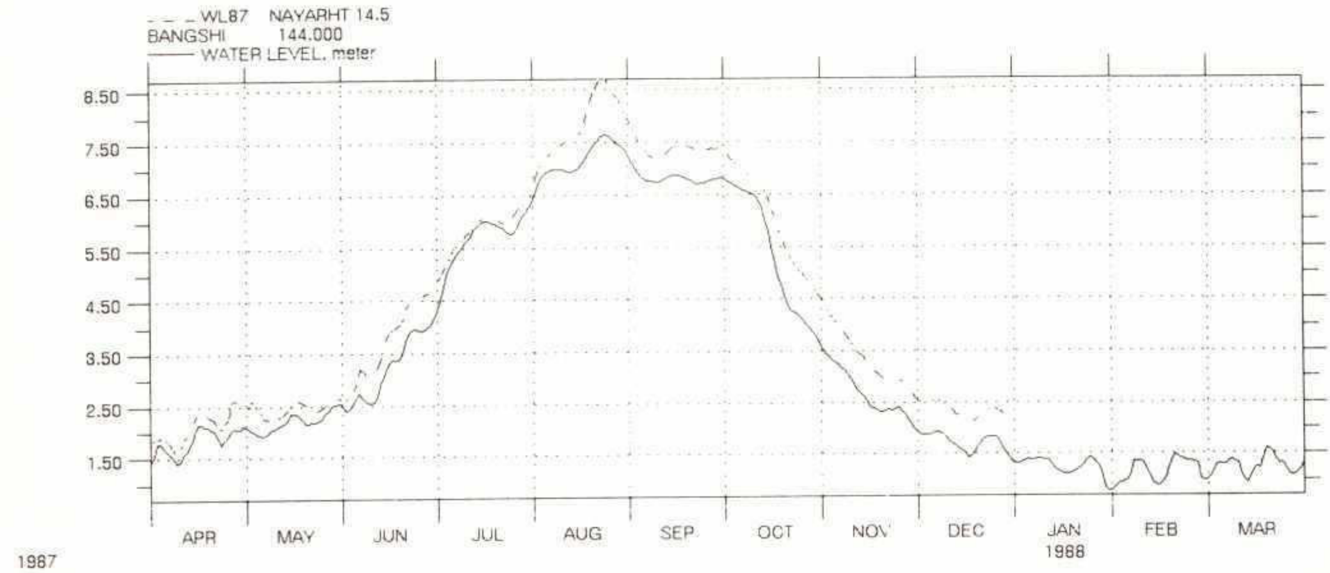

Figure 5.4.7 Comparison of Water Level Hydrograph at Kalatia between Simulated and Observed

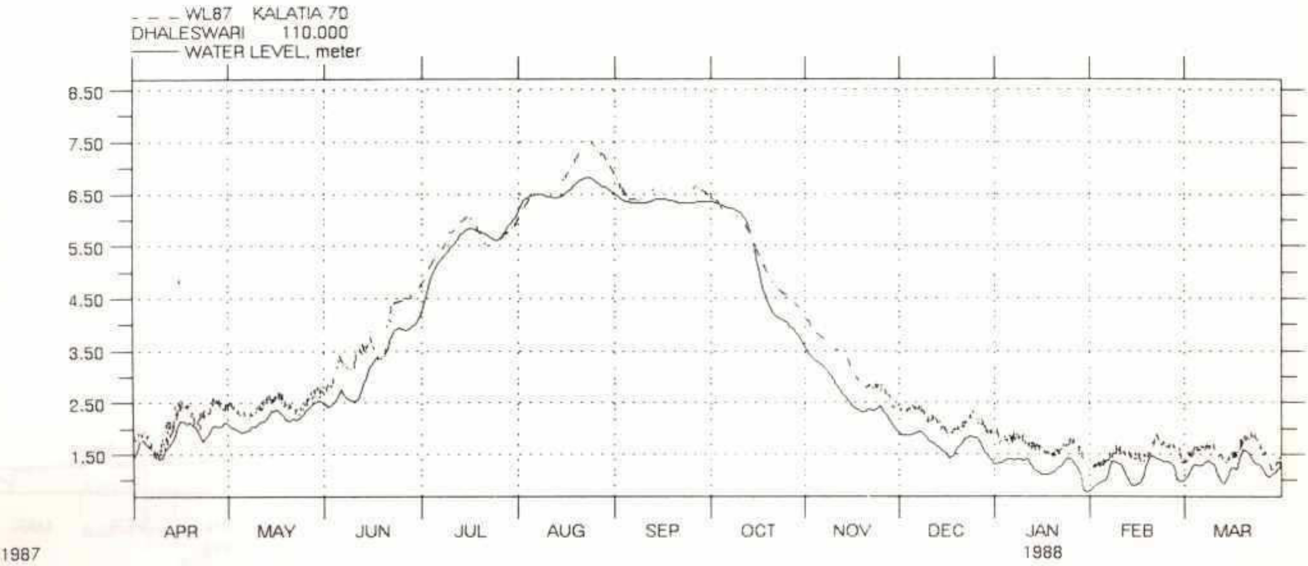

Figure 5.4.8 Comparison of Water Level Hydrograph at Taraghat between Simulated and Observed

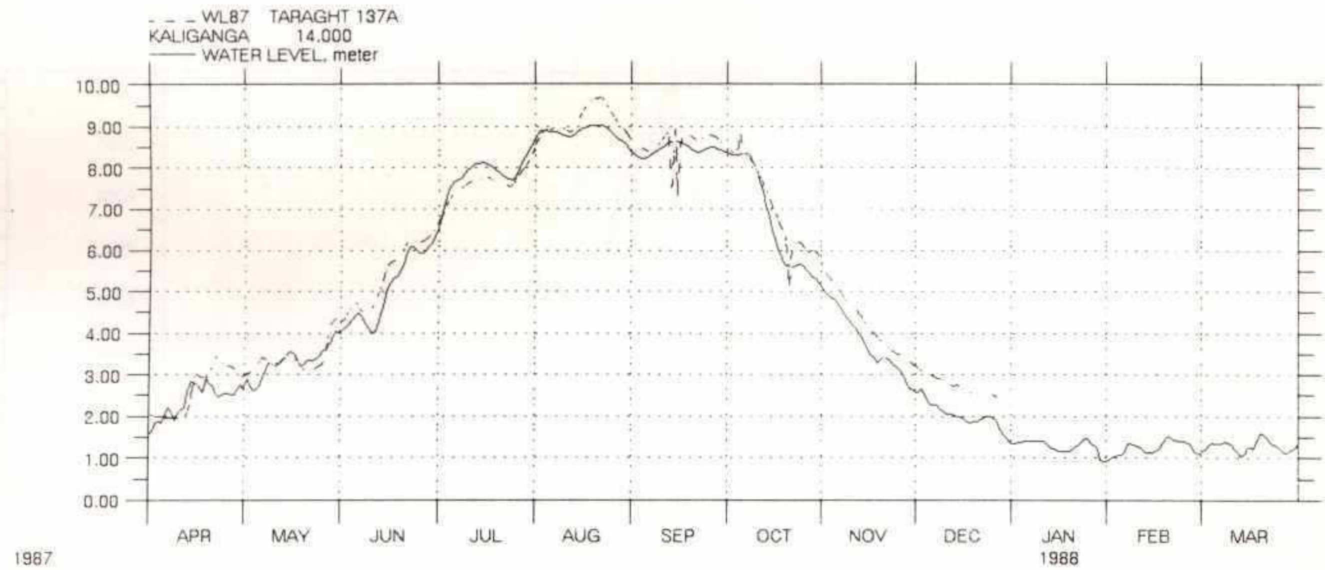

Figure 5.4.9 Comparison of Water Level Hydrograph at Jamalpur between Simulated and Observed

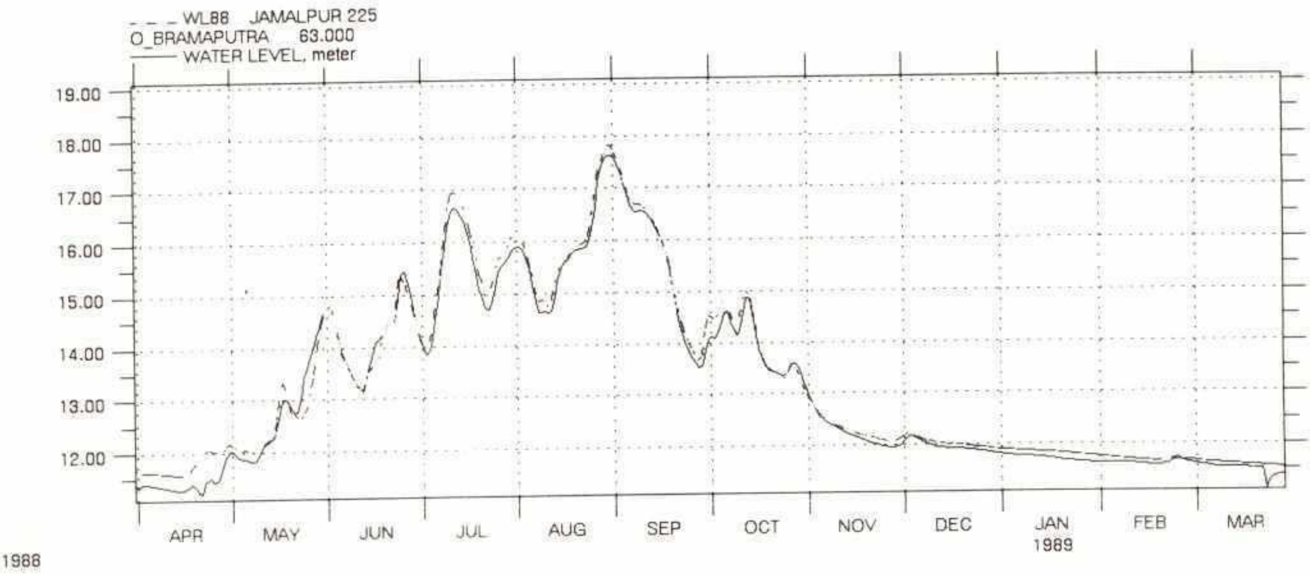

Figure 5.4.10 Comparison of Water Level Hydrograph at Offtake Sutia between Simulated and Observed

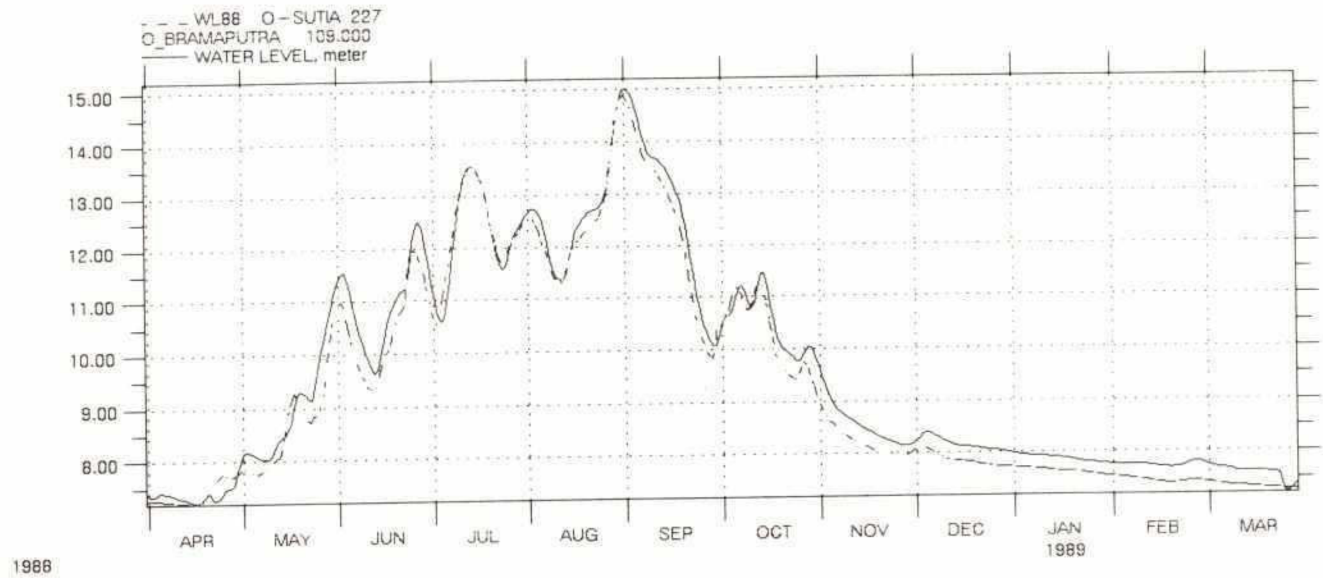

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Figure 5.4.11 **Comparison of Water Level Hydrograph at Mymenshing between Simulated and Observed**

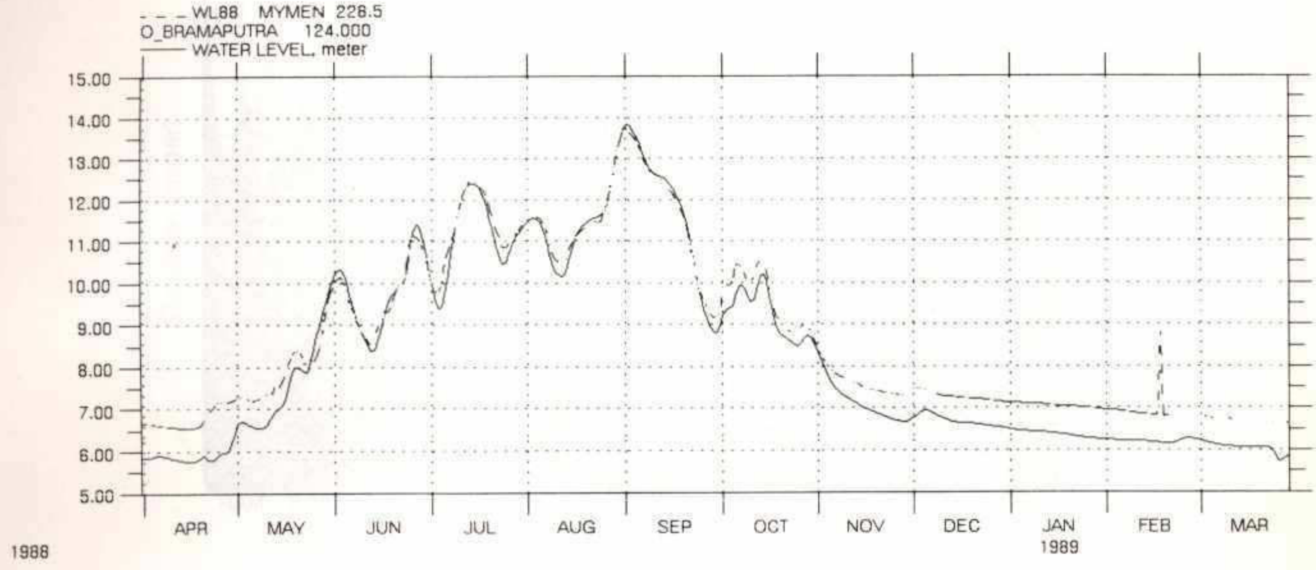

Figure 5.4.12 **Comparison of Discharge Hydrograph at Mymenshing between Simulated and Observed**

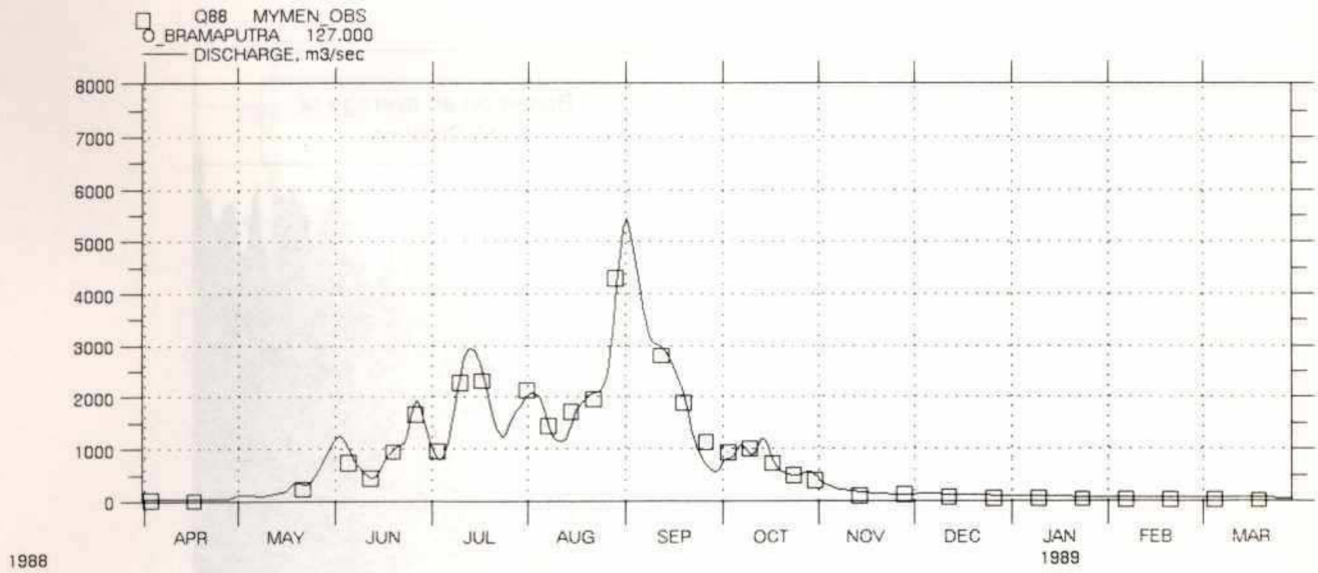

Figure 5.5.1 Model Deviation for 1987 Flood - North Central Regional Model

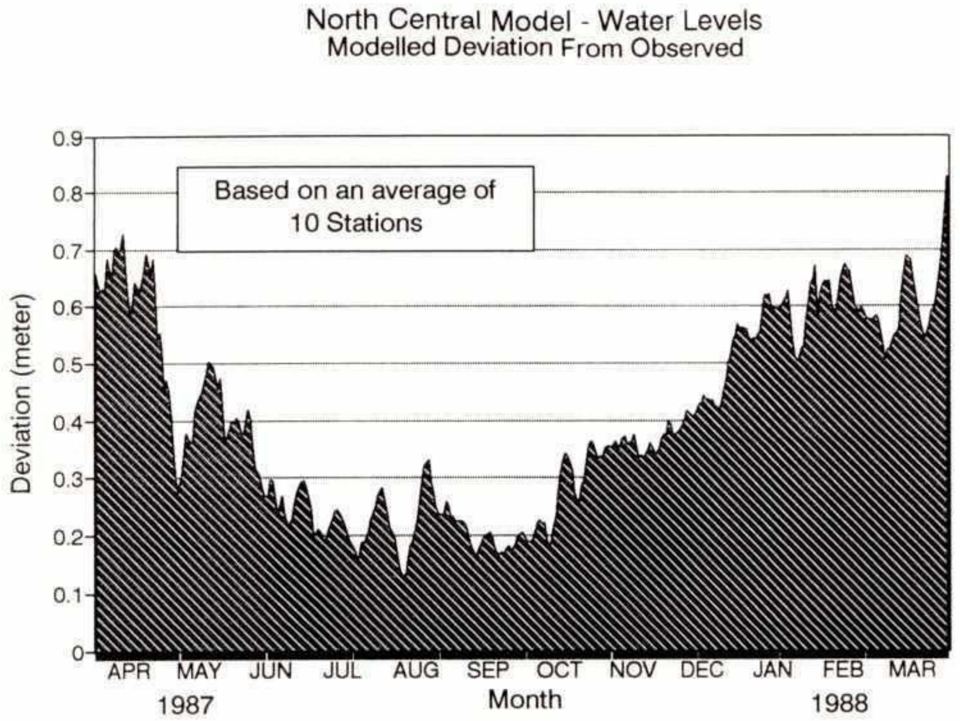

Figure 5.5.2 Model Deviation for 1988 Flood - North Central Regional Model

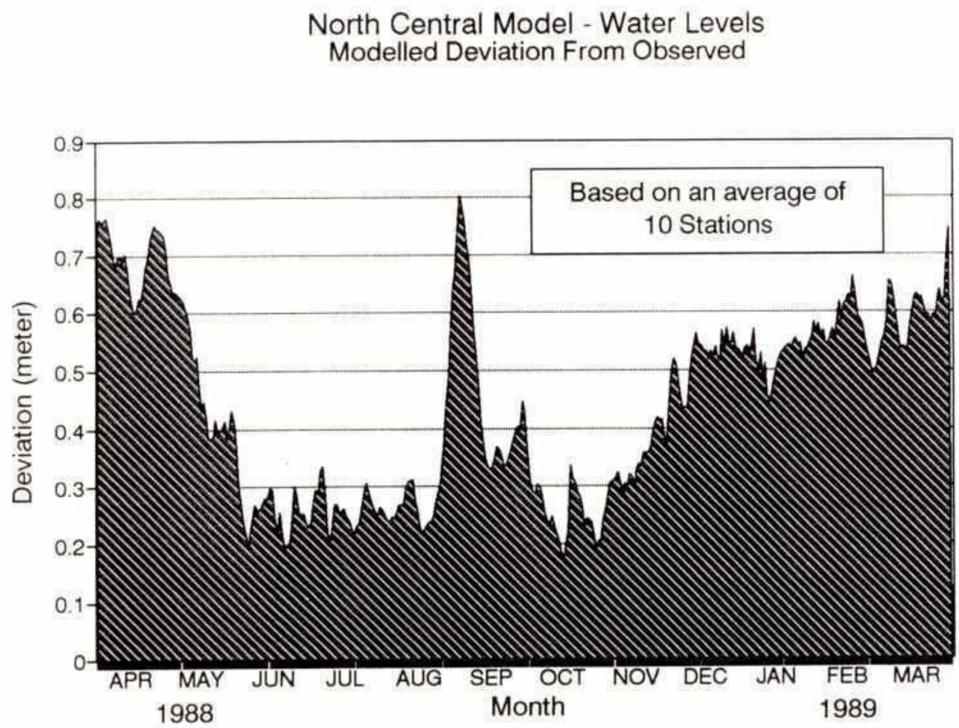

Figure 5.5.3 **Model Deviation for 1987 Flood - Western Sub-Model**

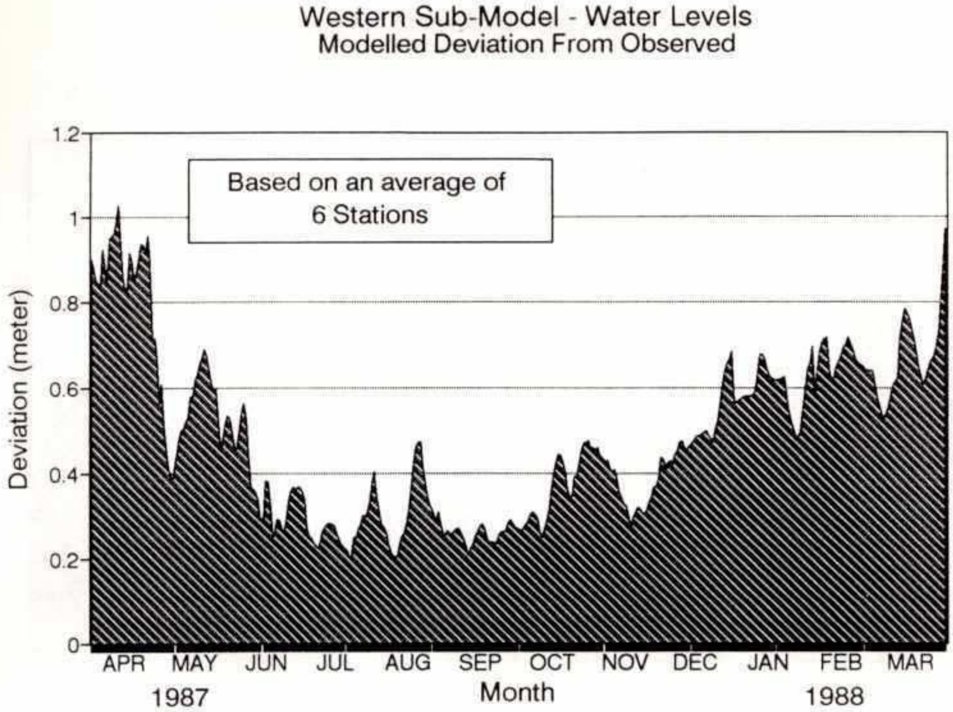

Figure 5.5.4 **Model Deviation for 1988 Flood - Western Sub-Model**

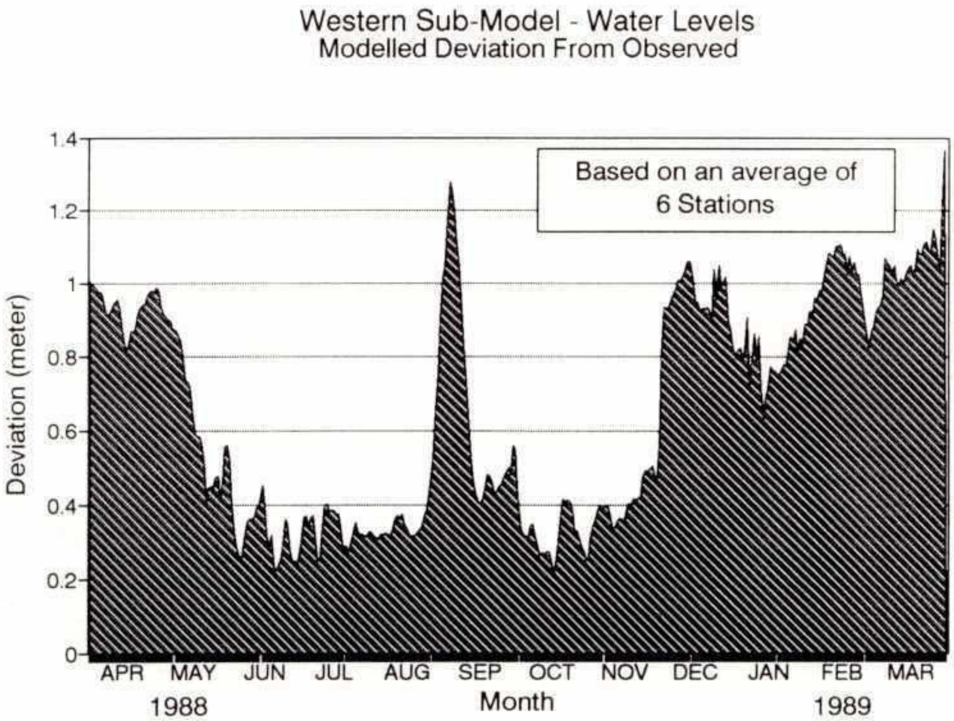

Figure 5.5.5 Model Deviation for 1989 Flood - North Central Regional Model

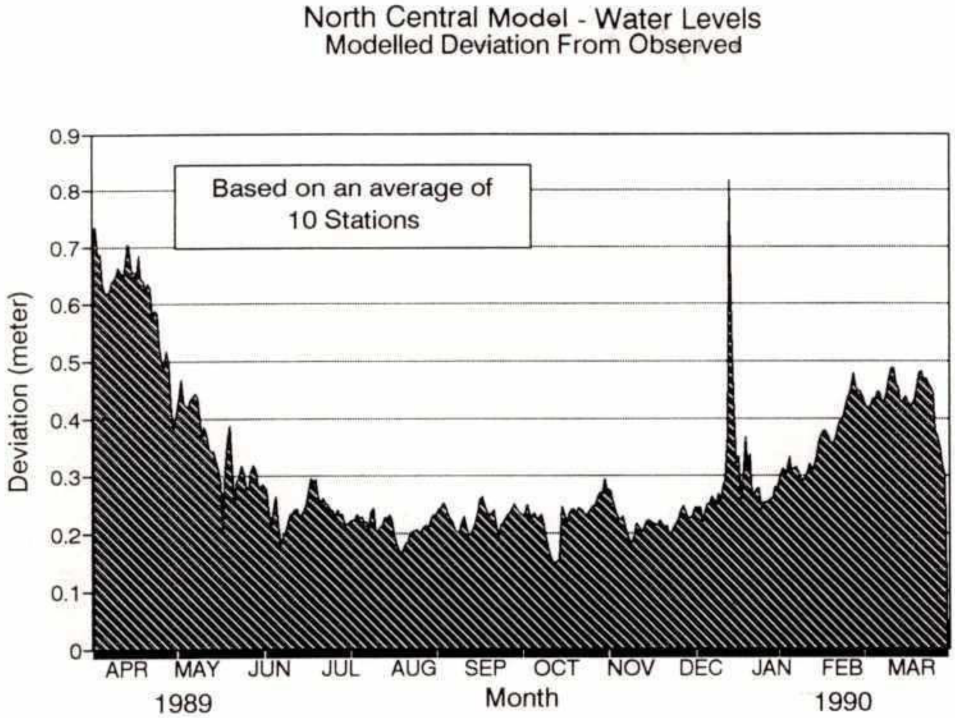

Figure 5.5.6 Model Deviation for 1989 Flood - Western Sub-Model

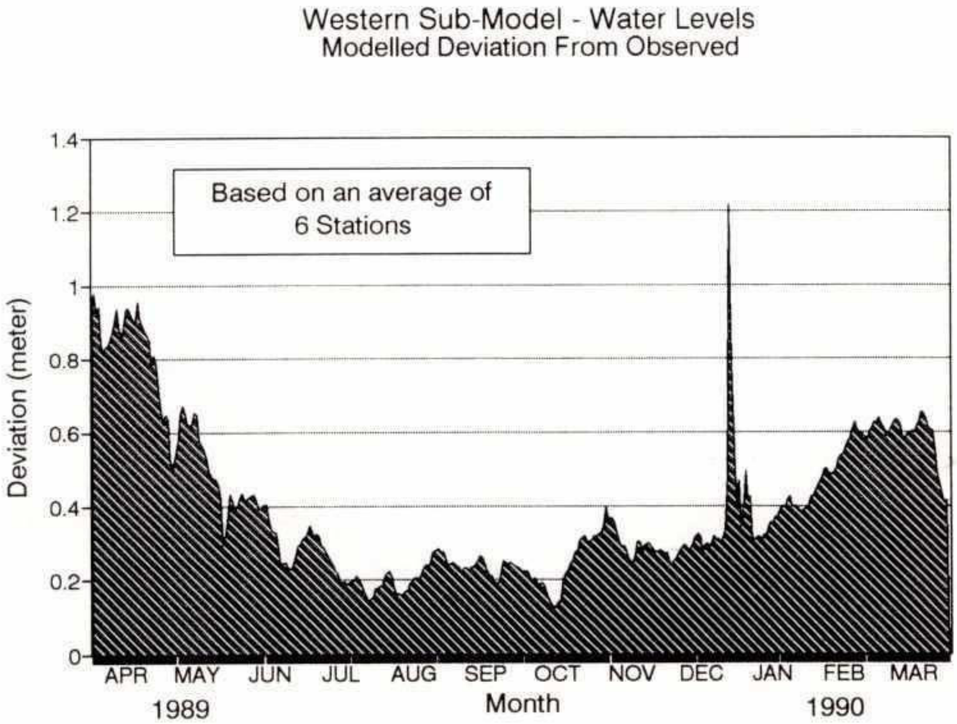

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Figure 5.5.7 Model Deviation for 1987 Flood - Eastern Sub-Model

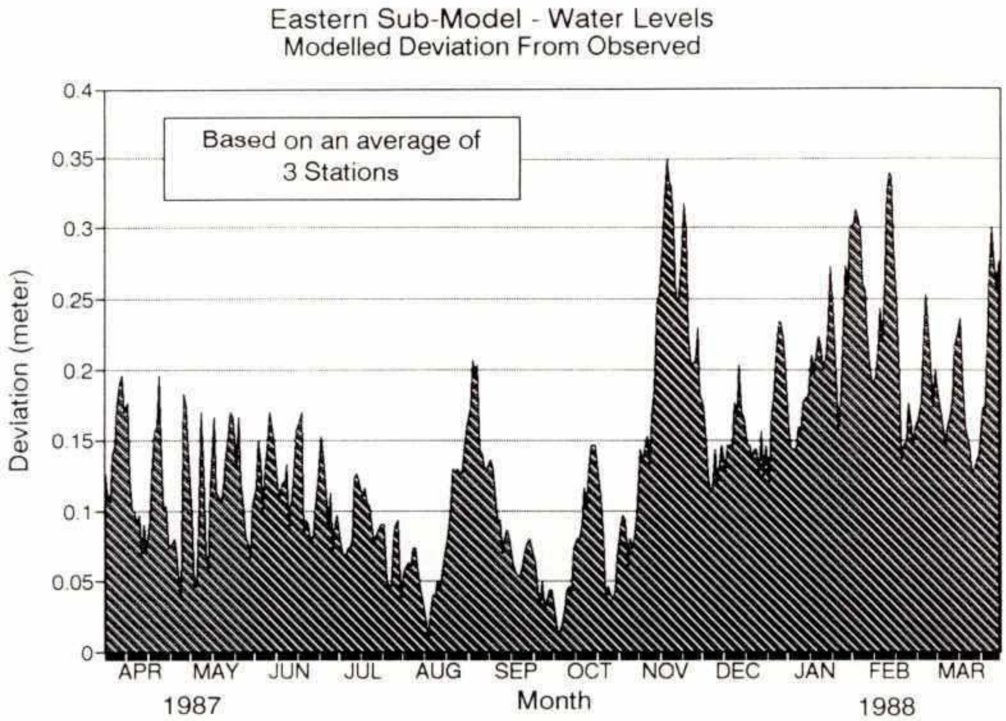

Figure 5.5.8 Model Deviation for 1988 Flood - Eastern Sub-Model

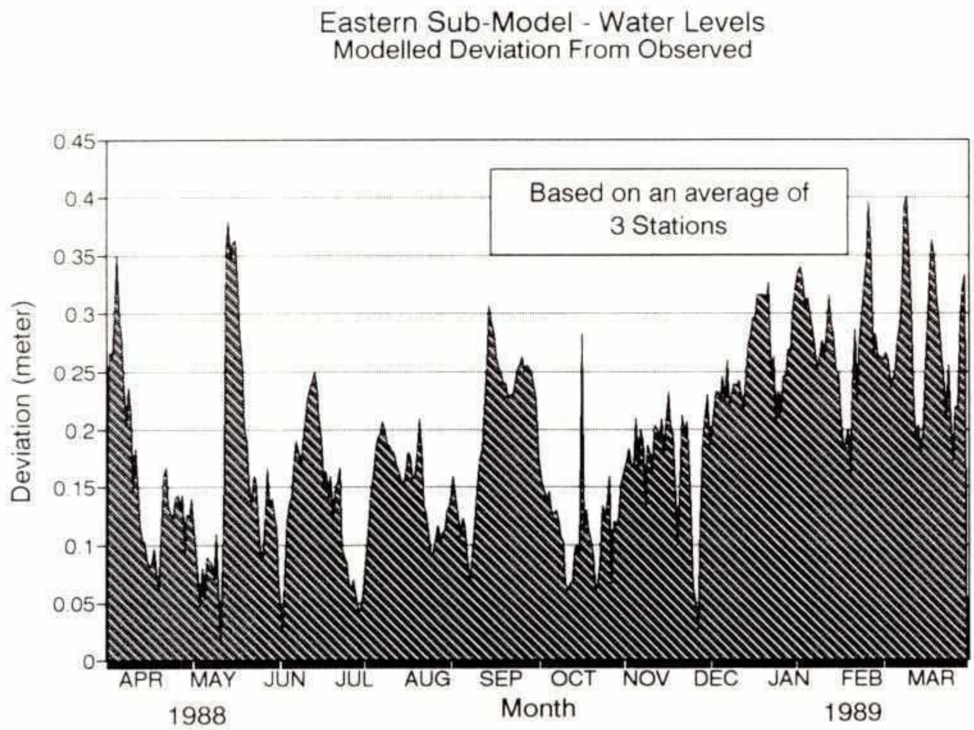

Figure 5.5.9 Model Deviation for 1987 Flood - Old Brahmaputra Sub-Model

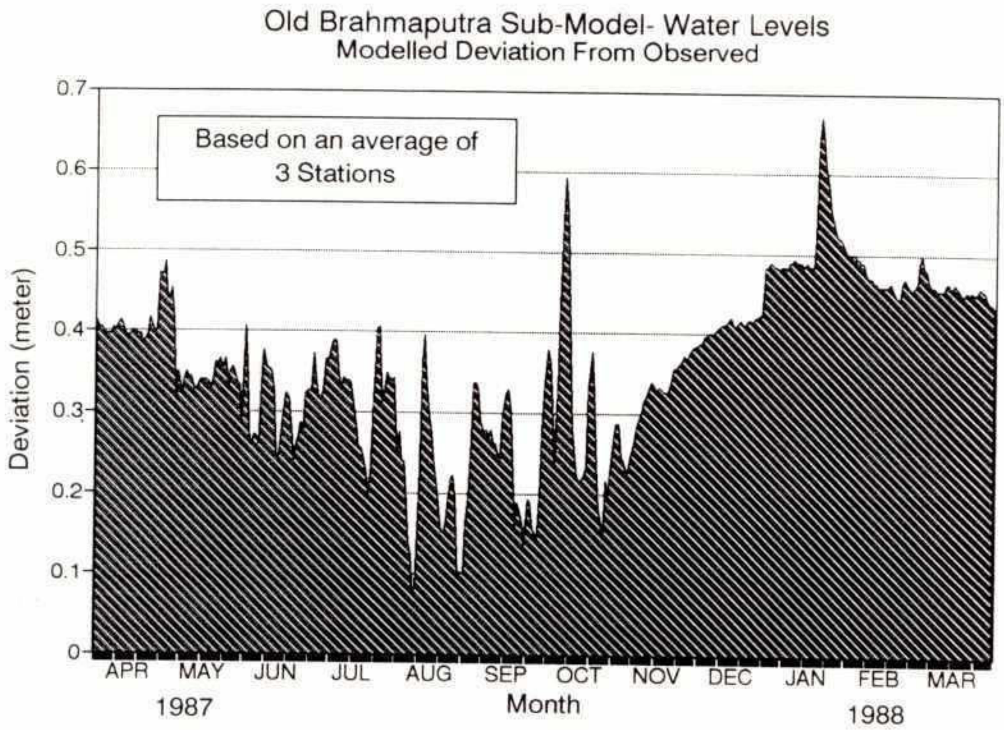

Figure 5.5.10 Model Deviation for 1988 Flood - Old Brahmaputra Sub-Model

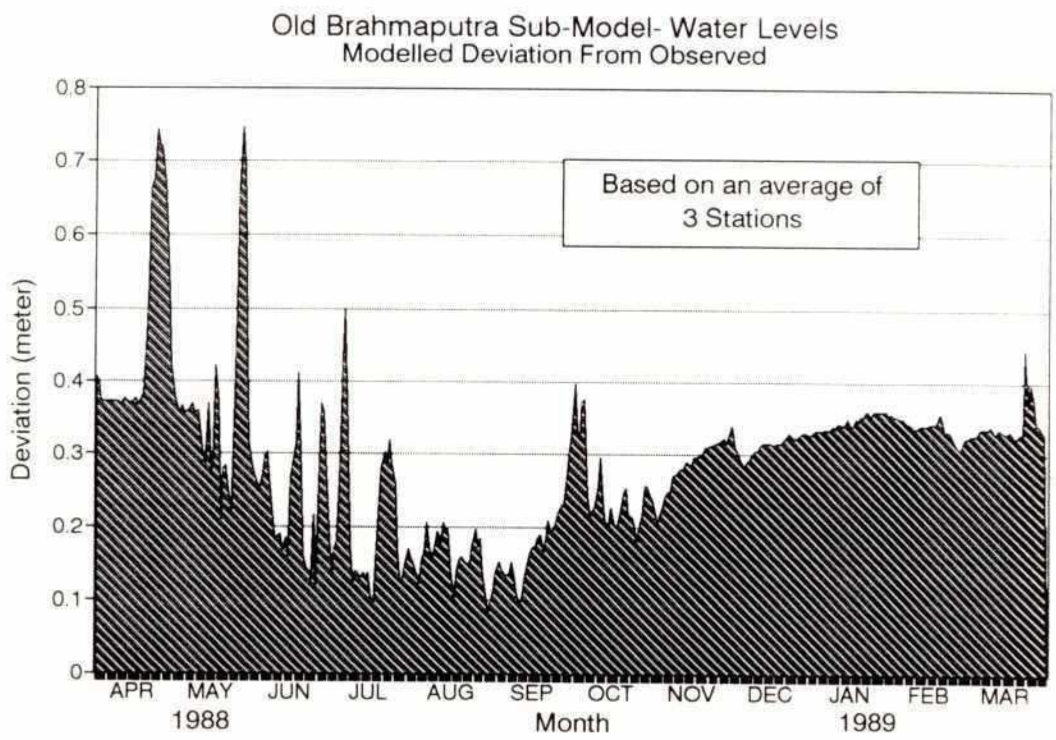

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Figure 5.5.11 Model Deviation for 1989 Flood - Eastern Sub-Model

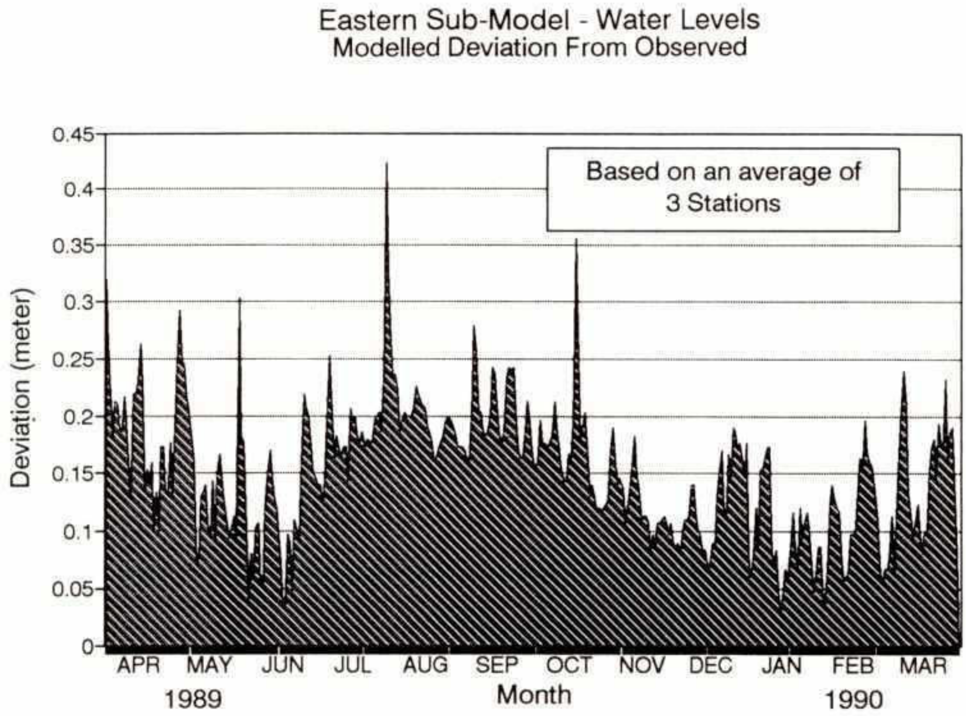

Figure 5.5.12 Model Deviation for 1989 Flood - Old Brahmaputra Sub-Model

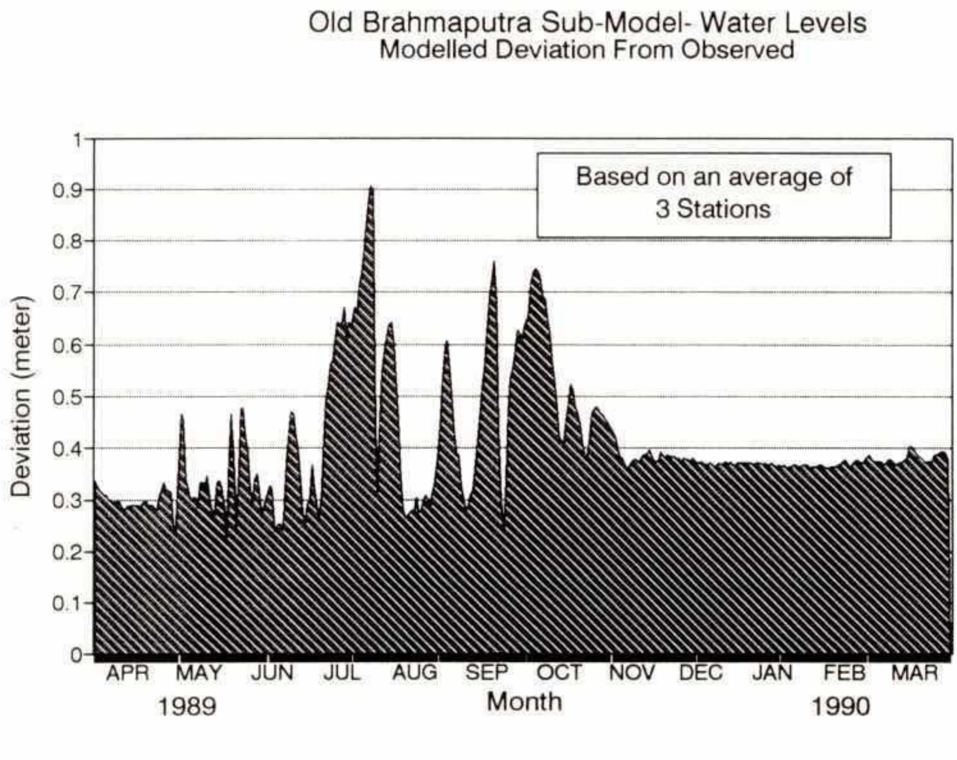

Figure 5.6.1 **Comparison of Water Level Hydrograph at Kalatia between Base Case and Drainage Option**

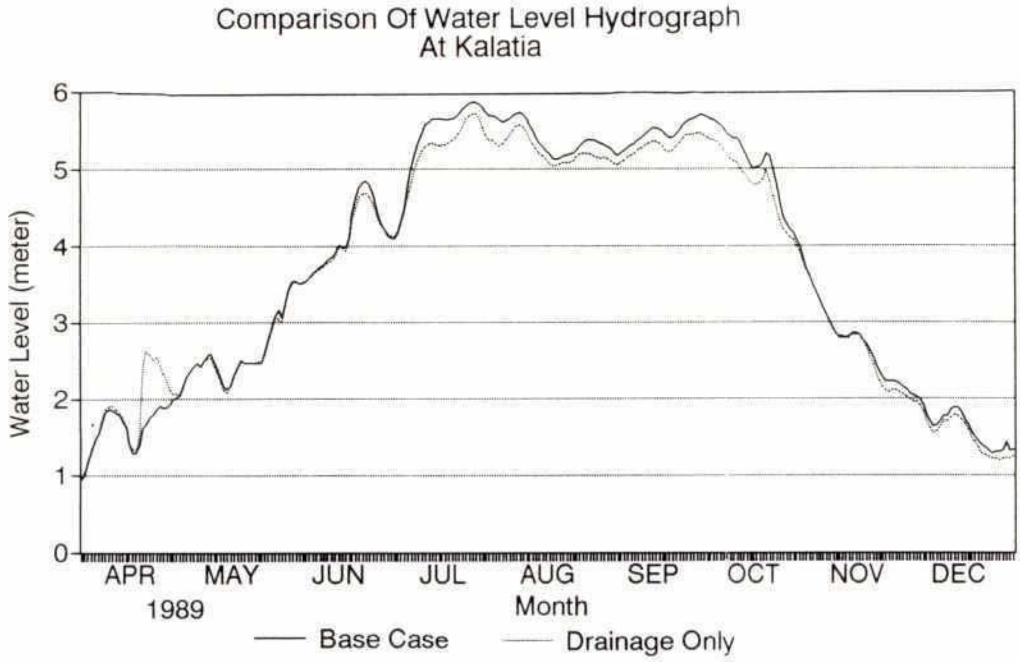

Figure 5.6.2 **Comparison of Water Level Hydrograph at Baushi Railway Bridge between Base Case and Full Embankment Option**

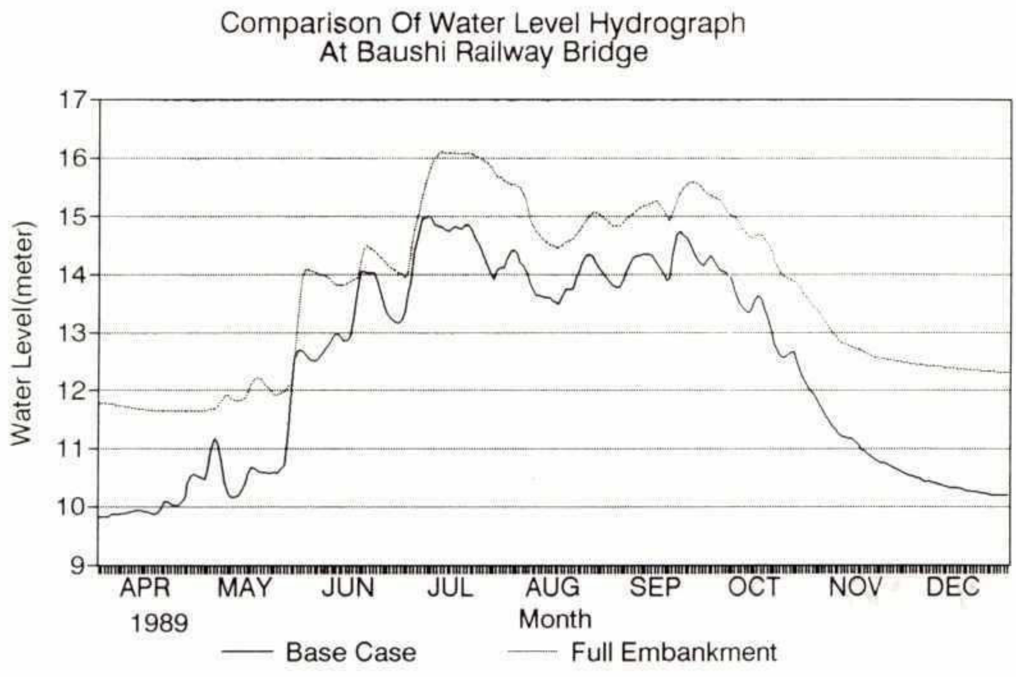

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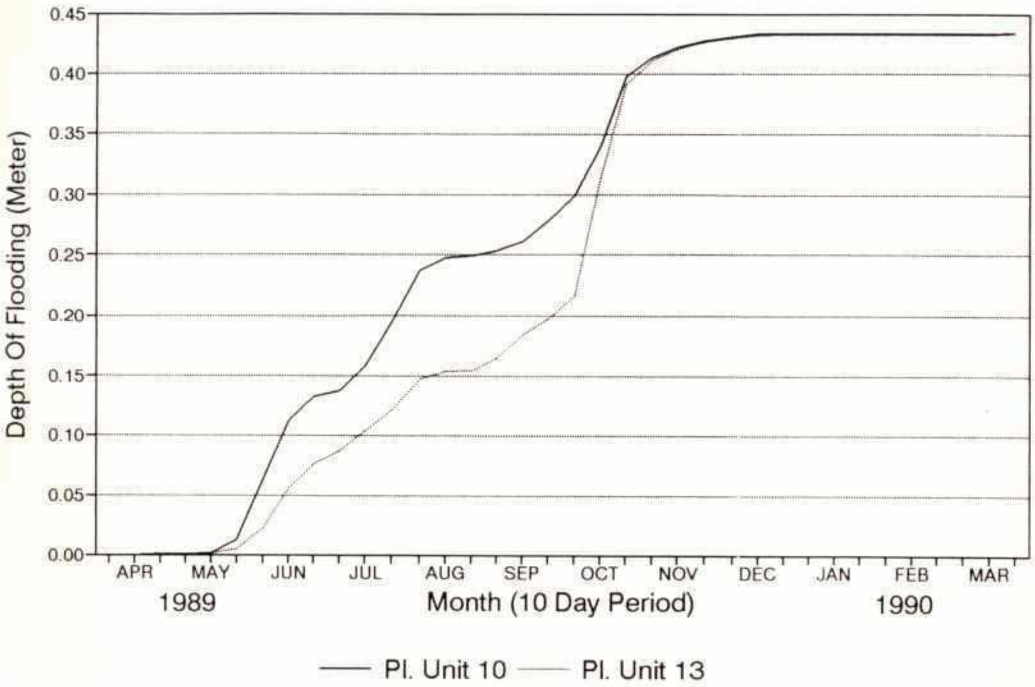
Figure 5.6.3 **Cumulative Depth of Flooding in Planning Unit 10 and 13**



SR II.5

Appendix I
Supporting Tables and Figures

Table II.1 Setup of the eastern sub-model

A.5.1 RIVER SYSTEM

8	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstream connection	
1	SWMC	BANAR	37.000	46.000	10000			KHIRO_S	0.000
2	SWMC	BANAR	60.000	91.000	10000			SUTIA	62.000
3	DUL-1991	KHIRO_S	0.000	39.000	10000	KHIRO_S	0.000	BANAR	84.000
4	DUL-1991	BANAR	91.000	120.000	4000	SUTIA	62.000	LAKHYA	14.000
5	DUL-1991	SUTIA	0.000	62.000	10000			SUTIA	62.000
6	DUL-1991	KHIRO	0.000	45.000	10000			KHIRO_S	15.000
7	DUL-NEW	KAORAID	0.000	14.000	10000			BANAR	112.000
8	1989-90	LAKHYA	0.000	93.000	10000				

Table II.2 Catchments of the eastern sub-model

A.5.0	CATCHMENTS				
	Catchment name	Area (km2)	River name	Upstr. chain.	Dnstr. chain.
12					
1	CAT-4	170.00	BANAR	37.000	37.000
2	CAT-4	25.00	BANAR	37.000	46.000
3	CAT-4	190.00	BANAR	60.000	91.000
4	CAT-4	255.00	KHIRO	0.000	45.000
5	CAT-4	210.00	KHIRO_S	0.000	39.000
6	CAT-5	365.00	SUTIA	0.000	62.000
7	CAT-5	197.00	LAKHYA	14.000	14.000
8	CAT-7	185.00	BANAR	91.001	114.000
9	CAT-7	578.00	KAORAID	0.000	14.000

A.5.0 CATCHMENTS

	Catchment name	Area (km2)		
	River name		Upstr. chain.	Dnstr. chain.
10	CAT-7	62.00		
	LAKHYA		14.000	14.000
11	CAT-12	74.00		
	BANAR		114.000	120.000
12	CAT-12	823.00		
	LAKHYA		0.000	93.000

Table II.3 Setup of the western sub-model

A.5.1 RIVER SYSTEM

34	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
1	1989-90	BALU	0.000	30.000	10000			LAKHYA	95.000
2	1987-88	BANGSHI	29.000	122.000	10000			BANGSHI	122.000
3	1987-88	BANGSHI	122.000	153.000	10000	BANGSHI	122.000	DHALESWARI	98.500
4	DUL-1991	BARINDA	0.000	30.700	10000	DHALESWARI	34.500	BANGSHI	130.000
5	1989-90	BURIGANGA	0.000	21.500	10000	BURIGANGA	0.000	DHALESWARI	133.000
6	1988-89	DHALESWARI	8.500	48.000	8000	O DHALESWARI	45.600	DHALESWARI	48.000
7	1988-89	DHALESWARI	48.000	148.000	10000	DHALESWARI	48.000		
8	DUL-1990	ELANGJANI	1.000	29.000	10000	O DHALESWARI	29.586	LOUHAJANG	41.000
9	1986-87	KALIGANGA	0.000	62.000	10000	DHALESWARI	48.000	DHALESWARI	110.000

A.5.1 RIVER SYSTEM

	Topo – ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
10	1989-90	LAKHYA	43.500	115.000	10000			DHALESWARI	145.000
11	DU 1990-91	LOUHAJANG	1.000	59.800	10000	O DHALESWARI	23.808	BARINDA	20.600
12	DUL-1990	NANGLAI_S	0.000	16.000	10000	BANGSHI	75.000	PUNGLI	35.000
13	DUL-1990	PUNGLI	0.000	55.500	10000	O DHALESWARI	10.484	BANGSHI	107.000
14	DUL-1991	TONGI_K	1.000	15.000	10000	TURAG	40.000	BALU	8.000
15	DUL-1990	TURAG	0.000	14.000	10000	BANGSHI	122.000	TURAG	14.000
16	WDB1989-90	TURAG	14.001	54.500	10000	TURAG	14.000	BURIGANGA	0.000
17	DUL-1990	BANSI_SOUTH	31.000	70.600	10000	BARINDA	9.100	BANGSHI	144.000
18	DUL-1991	DHANTARA K	1.000	14.250	10000	BANSI_SOUTH	40.100	BANGSHI	133.000

A.5.1 RIVER SYSTEM

No.	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
19	DUL-1991	KARNATALI	1.000	11.400	10000	DHALESWARI	98.500	TURAG	50.000
20	JBA	O DHALESWARI	0.000	45.600	5000			O DHALESWARI	45.600
21	JBA	SPCHANNEL1	0.000	6.543	10000			O DHALESWARI	7.073
22	JBA	SPCHANNEL2	0.000	7.200	10000			O DHALESWARI	21.726
23	JBA	SPCHANNEL3	0.000	8.533	10000			O DHALESWARI	45.600
24	JBA	MAKAR	0.000	8.616	10000			DHALESWARI	10.500
25	JBA	SK(HASK)	0.000	7.010	10000			O DHALESWARI	29.586
26	SWMC_91	ICHAMATI	0.000	44.000	10000	DHALESWARI	117.500		
27	DUL-1990	CHATAL	0.000	36.500	10000			JHENAI	27.000

A.5.1 RIVER SYSTEM

No.	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
28	DUL-1990	CHATAL	36.500	55.000	10000	JHENAI	27.000	CHATAL_S	7.000
29	DUL-1990	CHATAL_S	0.000	20.600	10000	JHENAI	35.000		
30	DUL-1990	JHENAI	5.000	89.800	10000			FUTIKJANI	12.500
31	DUL-1990	JHENAI_WEST	0.000	10.500	10000	JHENAI	53.000	JHENAI_EAST	0.000
32	DUL-1990	JHENAI_EAST	0.000	32.000	10000	JHENAI_EAST	0.000	FUTIKJANI	9.000
33	DUL-1990	FUTIKJANI	0.000	51.000	10000			BANGSHI	69.500
34	DUL-1991	NANGLAI_N	0.000	17.000	10000	FUTIKJANI	25.000	FUTIKJANI	43.000

Table II.4 Catchments of the western sub-model

A.5.0 CATCHMENTS

	Catchment name	Area (km2)	River name	Upstr. chain.	Dnstr. chain.
43					
1	CAT-2	481.00	JHENAI	5.001	79.000
2	CAT-2	182.00	CHATAL	3.000	55.000
3	CAT-2	50.00	CHATAL_S	0.000	20.600
4	CAT-2	31.00	JHENAI_WEST	0.000	10.500
5	CAT-2	32.00	JHENAI_EAST	0.000	12.000
6	CAT-3	45.00	BANGSHI	29.000	34.000
7	CAT-6	496.00	BANGSHI	34.001	66.000
8	CAT-6	62.00	JHENAI	79.001	89.800
9	CAT-6	62.00	JHENAI_EAST	12.001	32.000

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A.5.0	CATCHMENTS			
	Catchment name	Area (km2)		
	River name	Upstr. chain.	Dnstr. chain.	
10	CAT-6	195.00		
	FUTIKJANI	0.000	50.000	
11	CAT-6	71.00		
	NANGLAI_N	0.000	15.000	
12	CAT-9	302.00		
	PUNGLI	0.000	55.500	
13	CAT-9	262.00		
	BANGSHI	66.001	112.000	
14	CAT-9	71.00		
	NANGLAI_S	0.000	16.000	
15	CAT-9	201.00		
	LOUHAJANG	1.000	55.000	
16	CAT-9	101.00		
	ELANGJANI	1.000	29.000	
17	CAT-9	71.00		
	O DHALESWARI	0.000	25.000	
18	CAT-10	599.00		
	TURAG	0.000	28.000	

A.5.0	CATCHMENTS			
	Catchment name	Area (km2)		
		River name	Upstr. chain.	Dnstr. chain.
19	CAT-11	100.00		
		BALU	1.000	20.000
20	CAT-11	50.00		
		TONGI_K	6.000	15.000
21	CAT-12	420.00		
		LAKHYA	43.500	96.000
22	CAT-12	74.00		
		BALU	20.001	30.000
23	CAT-13	25.00		
		O DHALESWARI	25.001	45.000
24	CAT-13	593.00		
		DHALESWARI	8.500	60.000
25	CAT-13	82.00		
		BARINDA	0.000	7.000
26	CAT-13	125.00		
		KALIGANGA	0.000	12.000
27	CAT-14	8.00		
		LOUHAJANG	55.001	59.800

A.5.0	CATCHMENTS		
	Catchment name	Area (km2)	
	River name	Upstr. chain.	Dnstr. chain.
28	CAT-14	114.00	
	BARINDA	7.001	30.700
29	CAT-14	103.00	
	BANGSHI	112.001	130.000
30	CAT-14	99.00	
	BANSI_SOUTH	35.000	70.600
31	CAT-14	57.00	
	DHANTARA K	1.000	14.250
32	CAT-15	205.00	
	TURAG	28.001	49.000
33	CAT-15	71.00	
	TONGI_K	1.000	6.000
34	CAT-15	40.00	
	KARNATALI	1.000	11.400
35	CAT-16	496.00	
	KALIGANGA	12.001	62.000
36	CAT-16	901.00	
	DHALESWARI	60.001	130.000

A.5.0 CATCHMENTS

	Catchment name	Area (km2)		
	River name	Upstr. chain.	Dnstr. chain.	
37	CAT-16	105.00		
	BANGSHI	130.001	153.000	
38	CAT-17	273.00		
	BURIGANGA	0.000	21.500	
39	CAT-17	27.00		
	DHALESWARI	130.001	140.000	
40	CAT-17	42.00		
	TURAG	49.001	54.500	
41	CAT-18	464.00		
	LAKHYA	96.001	115.000	
42	CAT-18	51.00		
	DHALESWARI	140.001	148.000	
43	CAT-16	250.00		
	ICHAMATI	0.000	44.000	
44				
45				

Table II.5 Specification of broadcrested weir used on the Old Dhaleswari riv

A.5.3 BROADCRESTED WEIR

STRUCTURE no. 1 at :
River name : O DHALESWARI Topo ID : JBA
Chainage : 0.754

Head loss factor	Inflow	Outflow	Free overflow
Positive flow	0.50	1.00	1.00
Negative flow	0.50	1.00	1.00

Valve regulation ....: 0

Structure geometry: Number of levels: 3

Level	Width (m)
12.00	80.00
13.50	200.00
14.00	300.00

Level	Width (m)

A.5.3-1 BROADCRESTED WEIR - Q-h RELATIONS

STRUCTURE no. 1 at : Cross sec. upstr. Cross sec dnstr.
River name : O DHALESWARI 0.000 1.507
Chainage : 0.754

No. of Q-h relations : 8
h_min (> 12.00): 12.00
h_max (< 14.00): 14.00

Flow, free overflow :

		Upstream water level +		Weir		
	Qc	Pos.flow	Neg.flow	Water-lev	Width	Area
1	0.00	12.00	12.00	12.00	80.00	0.00
2	42.13	12.49	12.49	12.29	102.86	26.12
3	130.10	12.96	12.95	12.57	125.71	58.78
4	259.10	13.41	13.39	12.86	148.57	97.96
5	429.83	13.85	13.82	13.14	171.43	143.67
6	643.93	14.27	14.22	13.43	194.29	195.92
7	923.01	14.71	14.63	13.71	242.86	257.45
8	1273.13	15.13	15.01	14.00	300.00	335.00

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Table II.6 Specification of the broadcrested weir used on the Dhaleswari river

A.5.3 BROADCRESTED WEIR

STRUCTURE no. 2 at :
River name : DHALESWARI Topo ID : 1988-89
Chainage : 48.500

Head loss factor	Inflow	Outflow	Free overflow
Positive flow	0.50	1.00	1.00
Negative flow	0.50	1.00	1.00

Valve regulation ....: 0
Structure geometry: Number of levels: 2

Level	Width (m)
7.00	30.00
9.00	35.00

Level	Width (m)

A.5.3-1 BROADCRESTED WEIR – Q-h RELATIONS

STRUCTURE no. 2 at : Cross sec. upstr. 48.000 Cross sec dnstr. 49.000
River name : DHALESWARI
Chainage : 48.500

No. of Q-h relations : 8
h_min (> 7.00): 7.00
h_max (< 9.00): 9.00

Flow, free overflow :

	Qc	Upstream water level + Pos.flow	Upstream water level + Neg.flow	Weir Water-lev	Weir Width	Weir Area
1	0.00	7.00	7.00	7.00	30.00	0.00
2	14.47	7.50	7.50	7.29	30.71	8.67
3	41.27	8.00	7.99	7.57	31.43	17.55
4	76.45	8.49	8.48	7.86	32.14	26.63
5	118.67	8.98	8.97	8.14	32.86	35.92
6	167.19	9.47	9.46	8.43	33.57	45.41
7	221.55	9.96	9.95	8.71	34.29	55.10
8	281.43	10.45	10.44	9.00	35.00	65.00

Table II.7 Setup of the Old Brahmaputra sub-model

A.5.1 R I V E R S Y S T E M

4

	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
1	1988-89	O_BRAMAPUTRA	0.000	60.000	10000			O_BRAMAPUTRA	60.000
2	1988-89	O_BRAMAPUTRA	60.000	72.000	5000	O_BRAMAPUTRA	60.000	O_BRAMAPUTRA	72.000
3	1988-89	O_BRAMAPUTRA	72.000	187.500	10000	O_BRAMAPUTRA	72.000		
4	DUL-1990	JHENAI	0.000	5.000	10000	O_BRAMAPUTRA	45.000		

Table II.8 Catchments of the Old Brahmaputra sub-model

A.5.0	CATCHMENTS		
	Catchment name	Area (km2)	
3	River name	Upstr. chain.	Dnstr. chain.
1	CAT-1	1135.00	
	O_BRAMAPUTRA	12.001	130.000
2	CAT-8	800.00	
	O_BRAMAPUTRA	130.001	187.500
3	CAT-19	614.00	
	O_BRAMAPUTRA	0.000	12.000

Table II.9 Setup of western sub-model - Embankments along Jamuna

A.5.1 R I V E R S Y S T E M

28	Topo – ID	River name	Km. upstr.	Km. dwnstr.	dx–max(m)	Upstream connection		Downstrean connection	
1	1989-90	BALU	0.000	30.000	10000			LAKHYA	95.000
2	1987-88	BANGSHI	29.000	122.000	10000			BANGSHI	122.000
3	1987-88	BANGSHI	122.000	153.000	10000	BANGSHI	122.000	DHALESWARI	98.500
4	DUL-1991	BARINDA	0.000	30.700	10000	DHALESWARI	34.500	BANGSHI	130.000
5	1989-90	BURIGANGA	0.000	21.500	10000	BURIGANGA	0.000	DHALESWARI	133.000
6	1988-89	DHALESWARI	8.500	48.000	8000	O DHALESWARI	45.600	DHALESWARI	48.000
7	1988-89	DHALESWARI	48.000	148.000	10000	DHALESWARI	48.000		
8	DUL-1990	ELANGJANI	1.000	29.000	10000	O DHALESWARI	29.586	LOUHAJANG	41.000
9	1986-87	KALIGANGA	0.000	62.000	10000	DHALESWARI	48.000	DHALESWARI	110.000

A.5.1 RIVER SYSTEM

	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
10	1989-90	LAKHYA	43.500	115.000	10000			DHALESWARI	145.000
11	DU 1990-91	LOUHAJANG	1.000	59.800	10000	O DHALESWARI	23.808	BARINDA	20.600
12	DUL-1990	NANGLAI_S	0.000	16.000	10000	BANGSHI	75.000	PUNGLI	35.000
13	DUL-1990	PUNGLI	0.000	55.500	10000	O DHALESWARI	10.484	BANGSHI	107.000
14	DUL-1991	TONGI_K	1.000	15.000	10000	TURAG	40.000	BALU	8.000
15	DUL-1990	TURAG	0.000	14.000	10000	BANGSHI	122.000	TURAG	14.000
16	WDB1989-90	TURAG	14.001	54.500	10000	TURAG	14.000	BURIGANGA	0.000
17	DUL-1990	BANSI_SOUTH	31.000	70.600	10000	BARINDA	9.100	BANGSHI	144.000
18	DUL-1991	DHANTARA K	1.000	14.250	10000	BANSI_SOUTH	40.100	BANGSHI	133.000

A.5.1 RIVER SYSTEM

	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
19	DUL-1991	KARNATALI	1.000	11.400	10000	DHALESWARI	98.500	TURAG	50.000
20	JBA	O DHALESWARI	0.000	45.600	5000			O DHALESWARI	45.600
21	JBA	SPCHANNEL3	0.000	8.533	10000			O DHALESWARI	45.600
22	SWMC_91	ICHAMATI	0.000	44.000	10000	DHALESWARI	117.500		
23	DUL-1990	CHATAL	0.000	36.500	10000			JHENAI	27.000
24	DUL-1990	JHENAI	5.000	89.800	10000			FUTIKJANI	12.500
25	DUL-1990	JHENAI_WEST	0.000	10.500	10000	JHENAI	53.000	JHENAI_EAST	0.000
26	DUL-1990	JHENAI_EAST	0.000	32.000	10000	JHENAI_EAST	0.000	FUTIKJANI	9.000
27	DUL-1990	FUTIKJANI	0.000	51.000	10000			BANGSHI	69.500
28	DUL-1991	NANGLAI_N	0.000	17.000	10000	FUTIKJANI	25.000	FUTIKJANI	43.000

Table II.10 Setup of western sub-model - Embankments on Jamuna, Dhaleswari & Kaliganga

A.5.1 R I V E R S Y S T E M

35	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection		Downstrean connection	
1	1989-90	BALU	0.000	30.000	10000			LAKHYA	95.000
2	1987-88	BANGSHI	29.000	122.000	10000			BANGSHI	122.000
3	1987-88	BANGSHI	122.000	153.000	10000	BANGSHI	122.000	DHALESWARI	98.500
4	DUL-1991	BARINDA	0.000	30.700	10000			BANGSHI	130.000
5	1989-90	BURIGANGA	0.000	21.500	10000	BURIGANGA	0.000	DHALESWARI	133.000
6	1988-89	DHALESWARI	8.500	48.000	8000	O DHALESWARI	45.600	DHALESWARI	48.000
7	1988-89	DHALESWARI	49.000	148.000	10000				
8	DUL-1990	ELANGJANI	1.000	29.000	10000			LOUHAJANG	41.000
9	1986-87	KALIGANGA	0.000	62.000	10000	DHALESWARI	48.000	DHALESWARI	110.000

A.5.1 RIVER SYSTEM

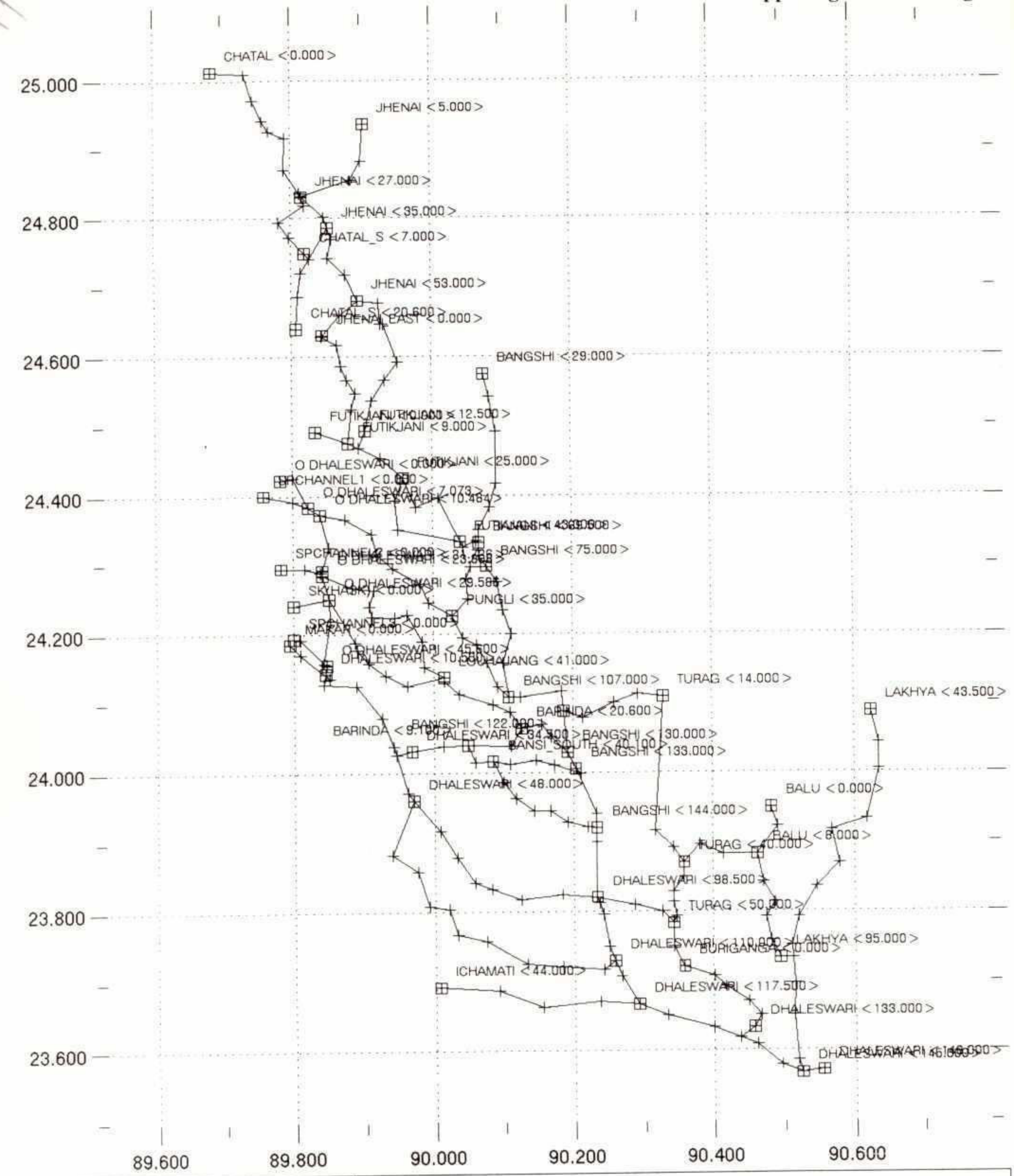
No.	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)
	Upstream connection		Downstrean connection		
10	1989-90	LAKHYA	43.500	115.000	10000
			DHALESWARI	145.000	
11	DU 1990-91	LOUHAJANG	1.000	59.800	10000
			BARINDA	20.600	
12	DUL-1990	NANGLAI_S	0.000	16.000	10000
	BANGSHI	75.000	PUNGLI	35.000	
13	DUL-1990	PUNGLI	0.000	55.500	10000
			BANGSHI	107.000	
14	DUL-1991	TONGI_K	1.000	15.000	10000
	TURAG	40.000	BALU	8.000	
15	DUL-1990	TURAG	0.000	14.000	10000
	BANGSHI	122.000	TURAG	14.000	
16	WDB1989-90	TURAG	14.001	54.500	10000
	TURAG	14.000	BURIGANGA	0.000	
17	DUL-1990	BANSI_SOUTH	31.000	70.600	10000
	BARINDA	9.100	BANGSHI	144.000	
18	DUL-1991	DHANTARA K	1.000	14.250	10000
	BANSI_SOUTH	40.100	BANGSHI	133.000	

A.5.1 RIVER SYSTEM

No.	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)	Upstream connection	Upstream km	Downstrean connection	Downstream km
19	DUL-1991	KARNATALI	1.000	11.400	10000	DHALESWARI	98.500	TURAG	50.000
20	JBA	O DHALESWARI	0.000	45.600	5000			O DHALESWARI	45.600
21	JBA	SPCHANNEL1	0.000	6.543	10000			O DHALESWARI	7.073
22	JBA	SPCHANNEL2	0.000	7.200	10000			O DHALESWARI	21.726
23	JBA	SPCHANNEL3	0.000	8.533	10000			O DHALESWARI	45.600
24	JBA	MAKAR	0.000	8.616	10000			DHALESWARI	10.500
25	JBA	SK(HASK)	0.000	7.010	10000			O DHALESWARI	29.586
26	SWMC_91	ICHAMATI	0.000	44.000	10000	DHALESWARI	117.500		
27	DUL-1990	CHATAL	0.000	36.500	10000			JHENAI	27.000

A.5.1 RIVER SYSTEM

	Topo - ID	River name	Km. upstr.	Km. dwnstr.	dx-max(m)
	Upstream connection		Downstrean connection		
28	DUL-1990	JHENAI	5.000	89.800	10000
			FUTIKJANI	12.500	
29	DUL-1990	JHENAI_WEST	0.000	10.500	10000
	JHENAI	53.000	JHENAI_EAST	0.000	
30	DUL-1990	JHENAI_EAST	0.000	32.000	10000
	JHENAI_EAST	0.000	FUTIKJANI	9.000	
31	DUL-1990	FUTIKJANI	0.000	51.000	10000
			BANGSHI	69.500	
32	DUL-1991	NANGLAI_N	0.000	17.000	10000
	FUTIKJANI	25.000	FUTIKJANI	43.000	
33	ARTIFICIAL	DIVCHANNEL1	0.000	12.000	10000
	KALIGANGA	20.000			
34	ARTIFICIAL	DIVCHANNEL2	0.000	8.000	10000
	DHALESWARI	112.500	ICHAMATI	7.500	
35	ARTIFICIAL	DIVCHANNEL2	8.000	37.000	10000
	ICHAMATI	7.500			



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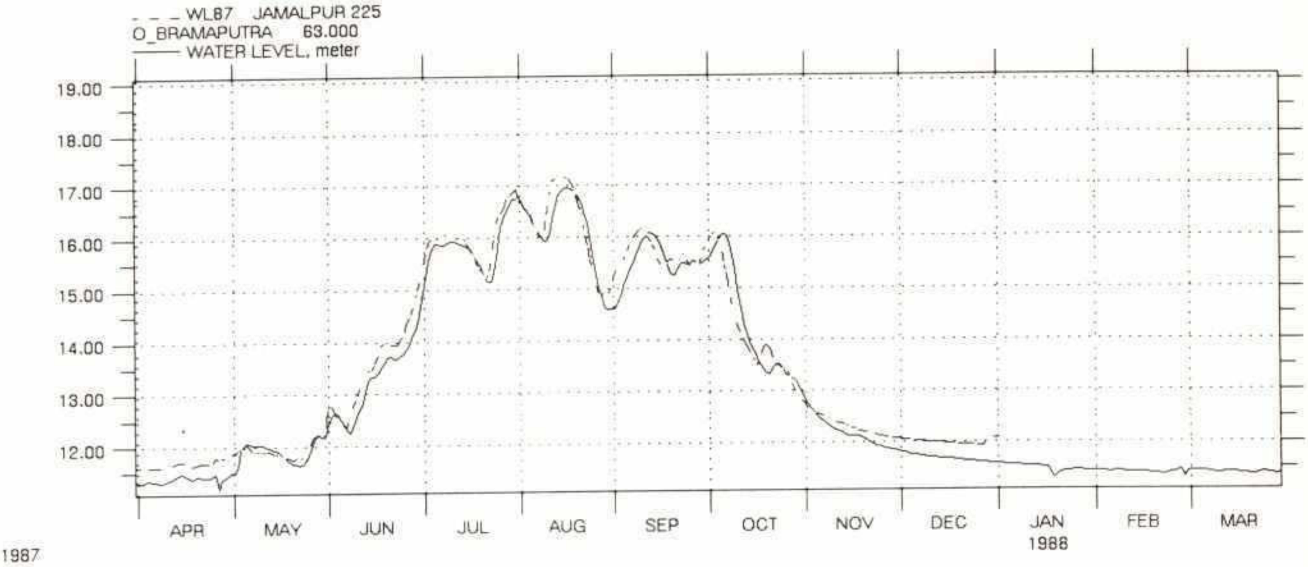
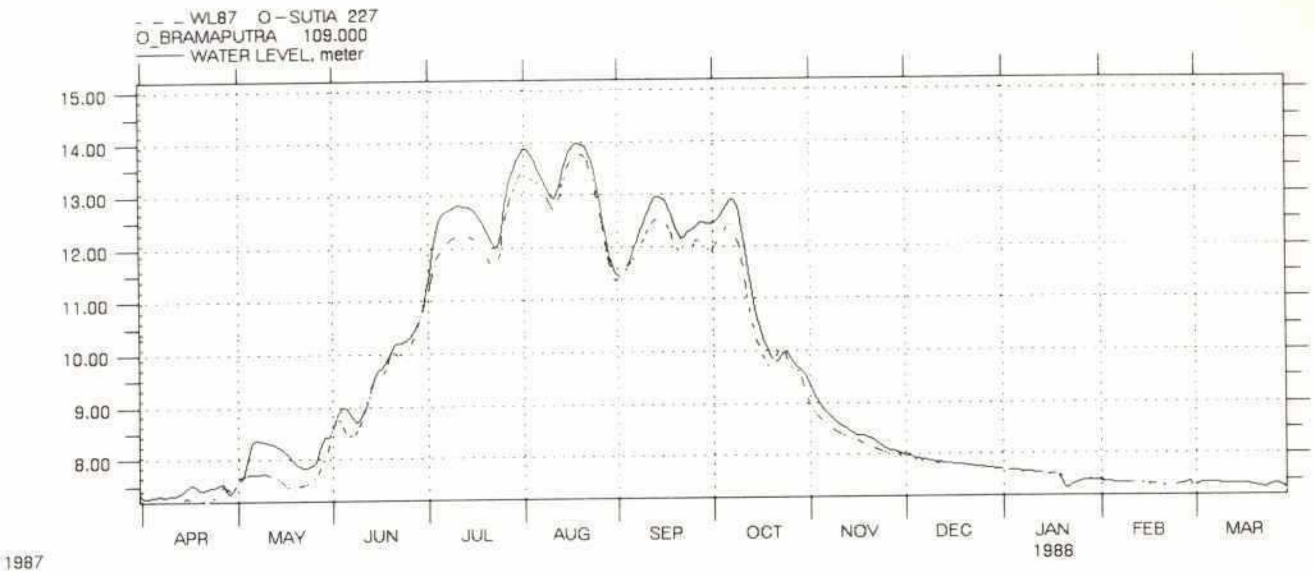
	MIKE 11 Dwg no.:





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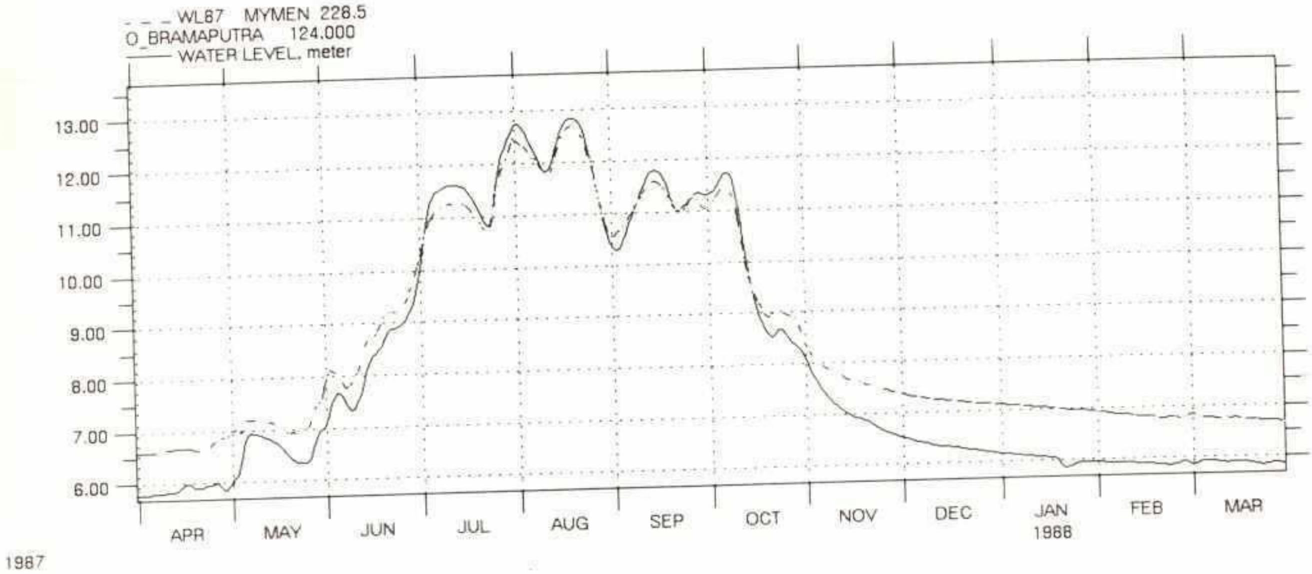
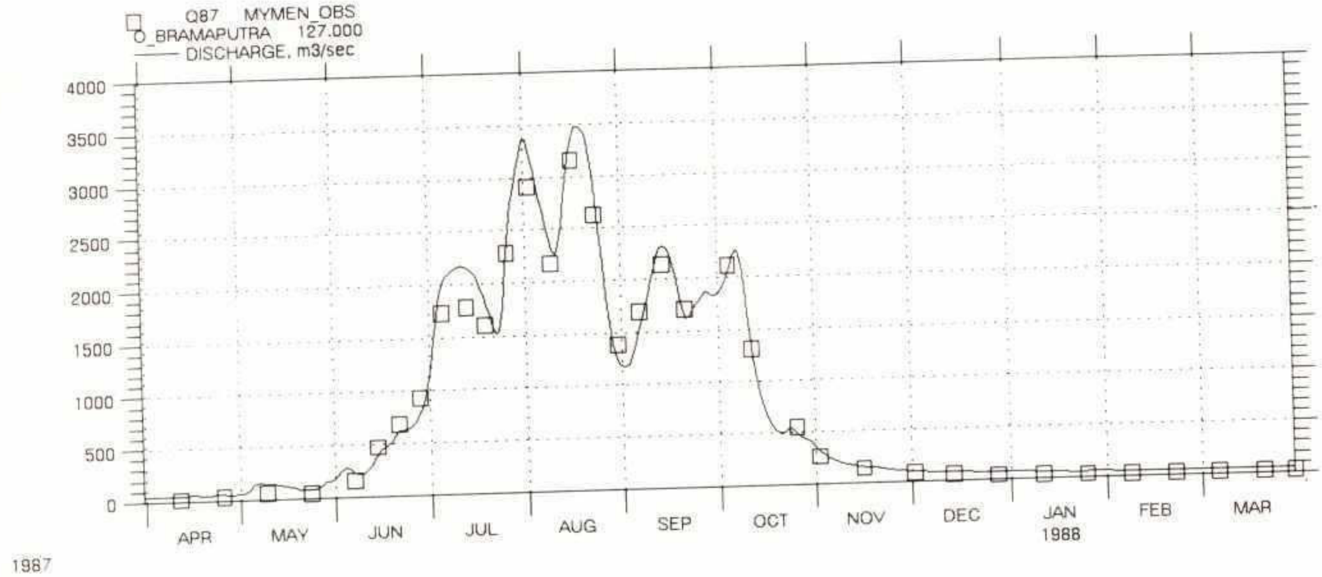
3/3





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		MIKE 11
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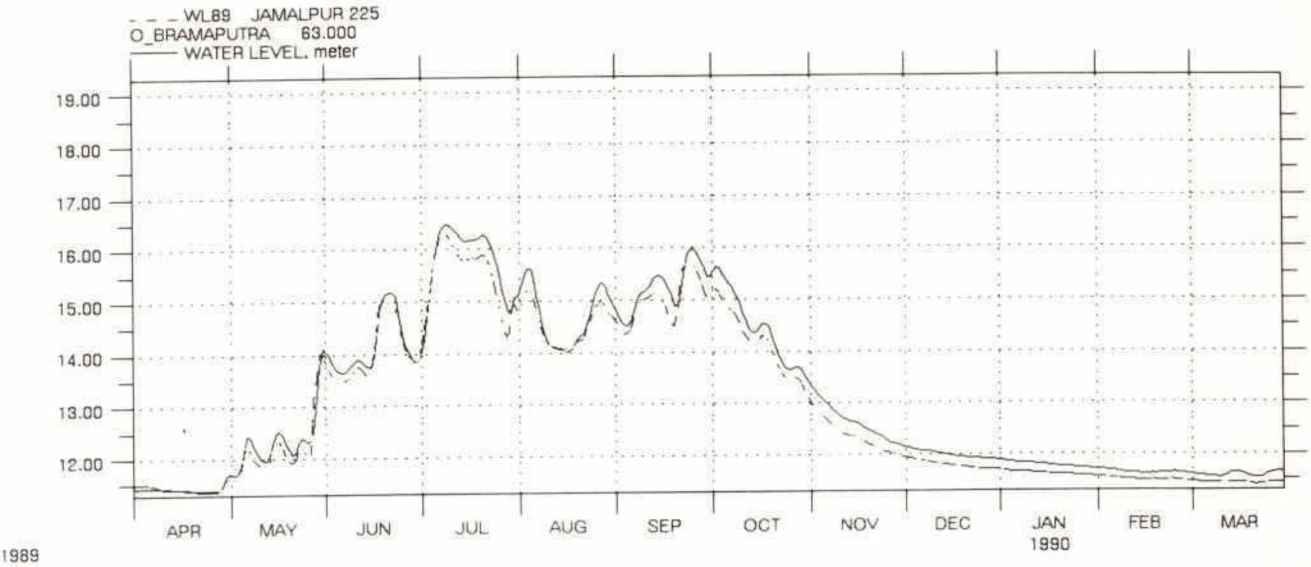
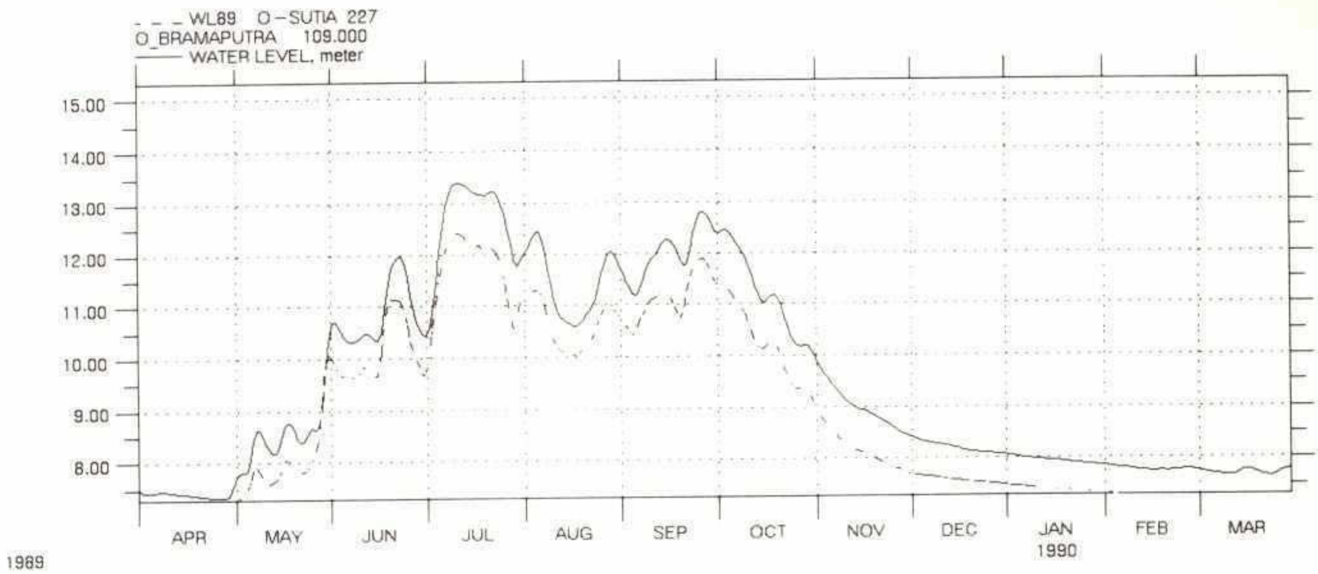
314





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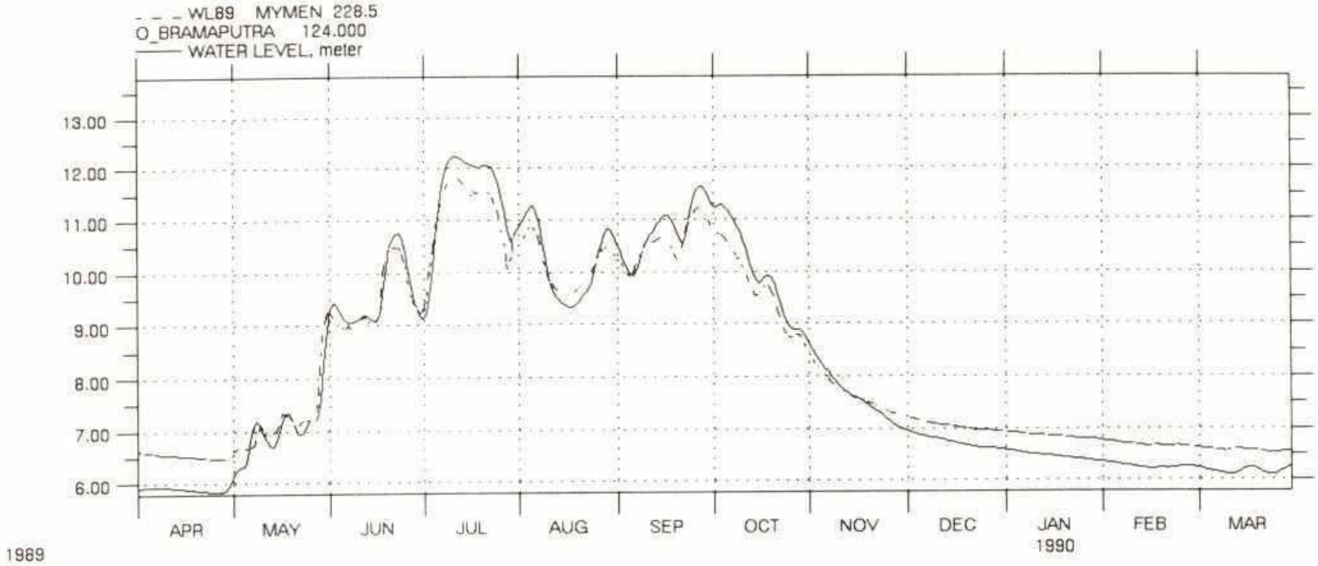

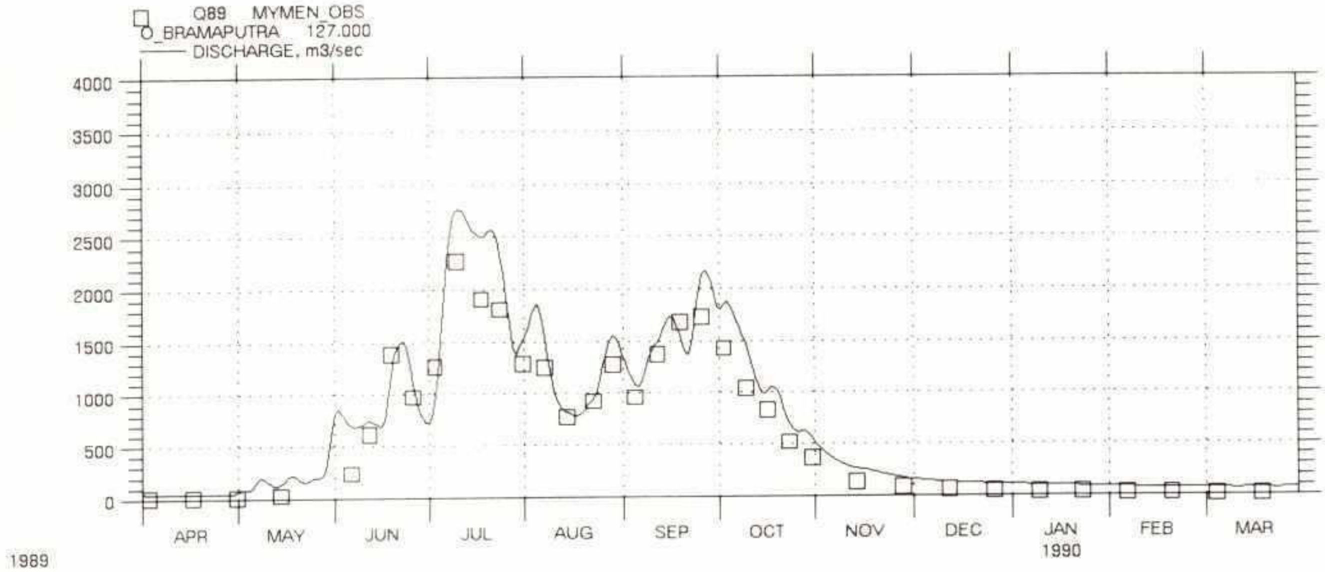

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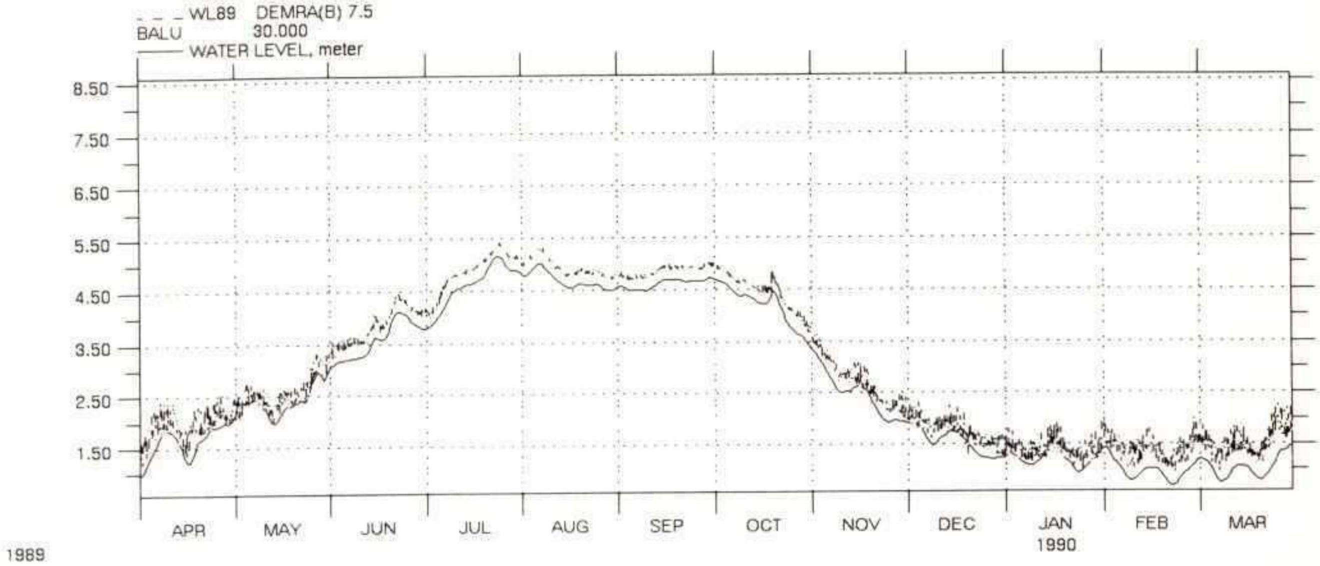
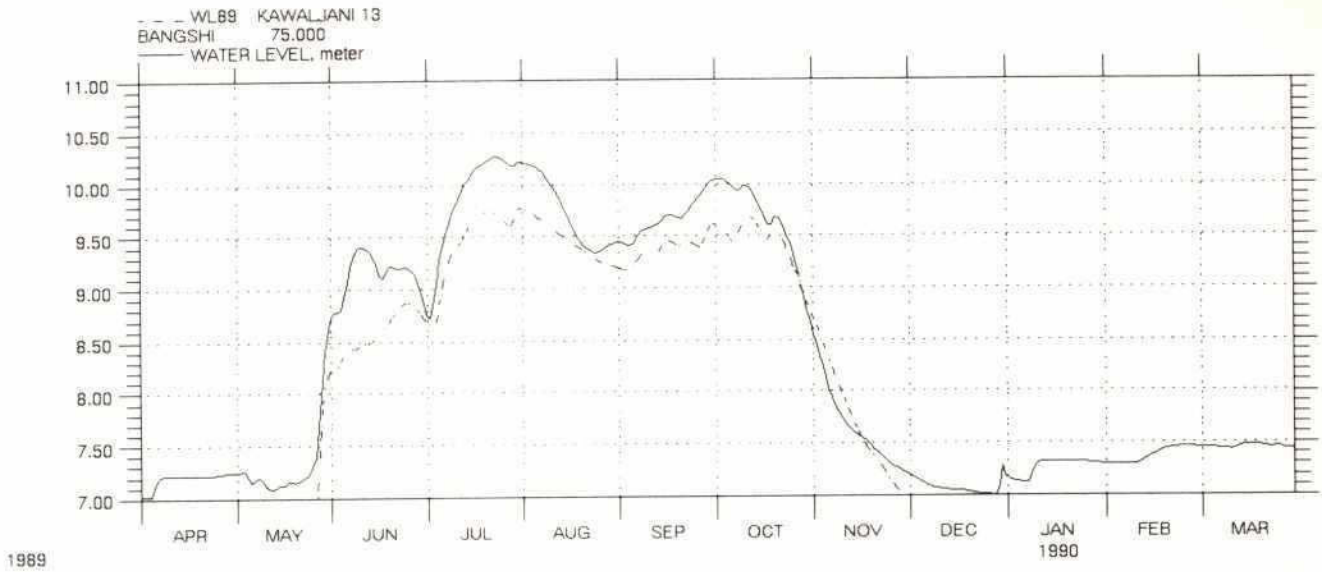
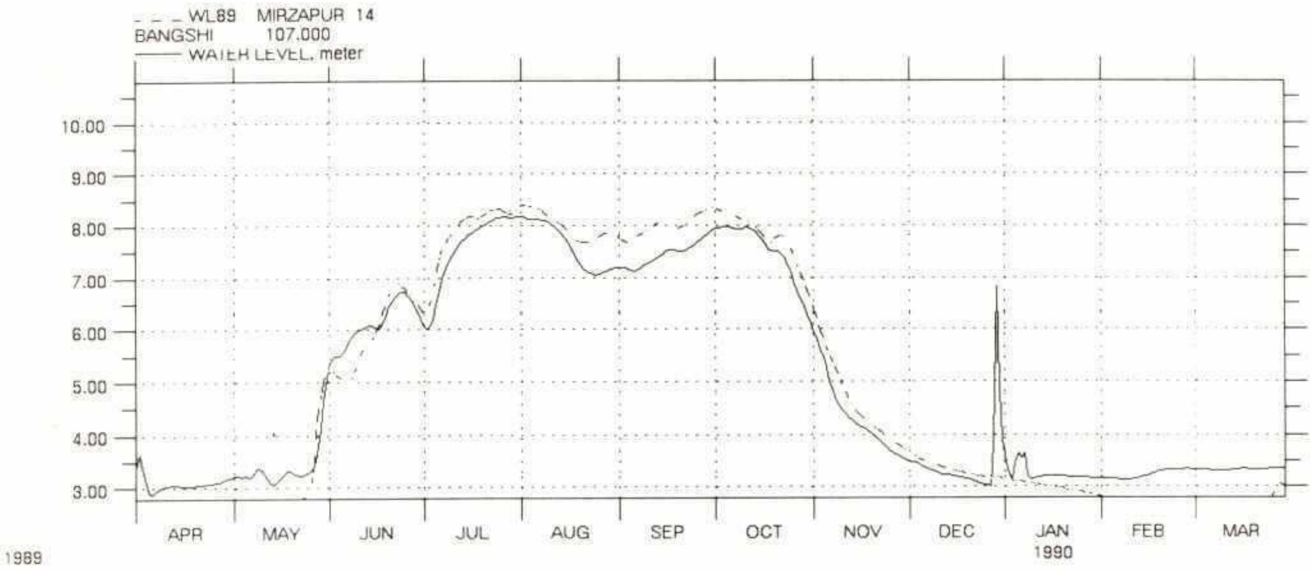
316

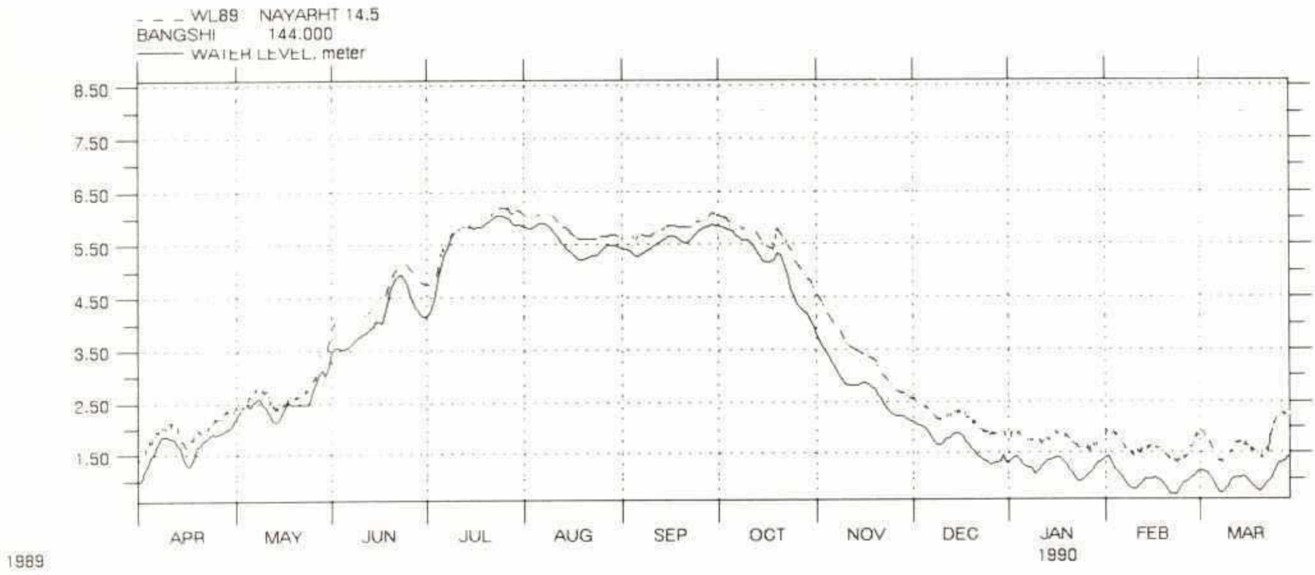




S W M C	NORTH CENTRAL WESTERN SUB - MODEL CALIBRATION RUN - 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 - OCT - 1991, 10:38	**MIKE 11** Dwg no.:

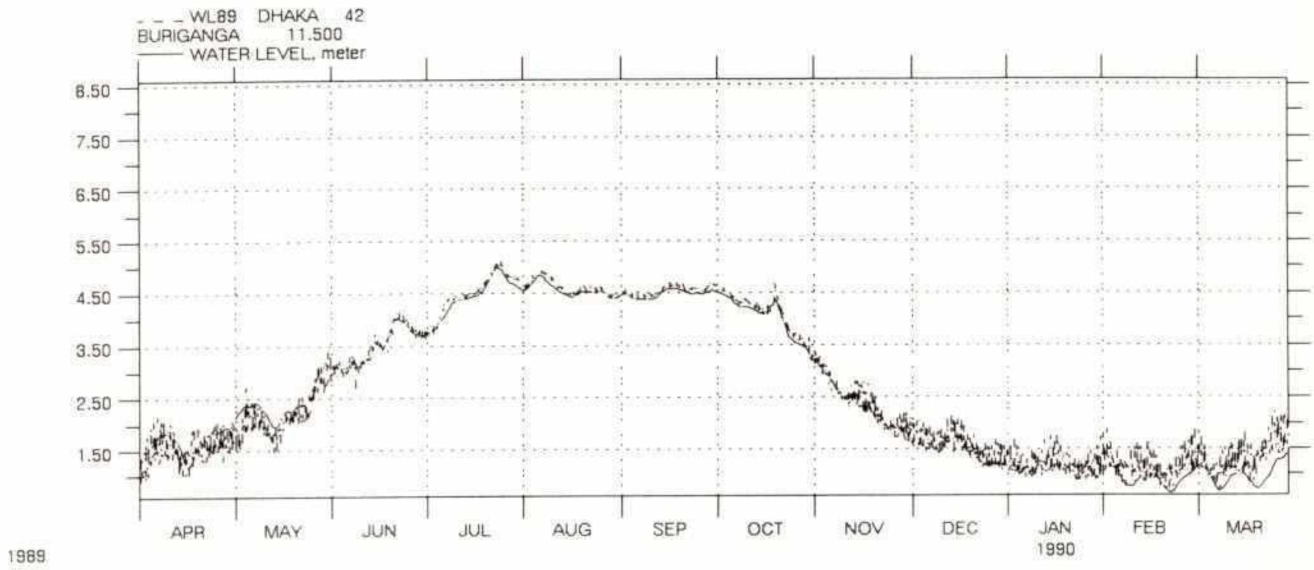
317

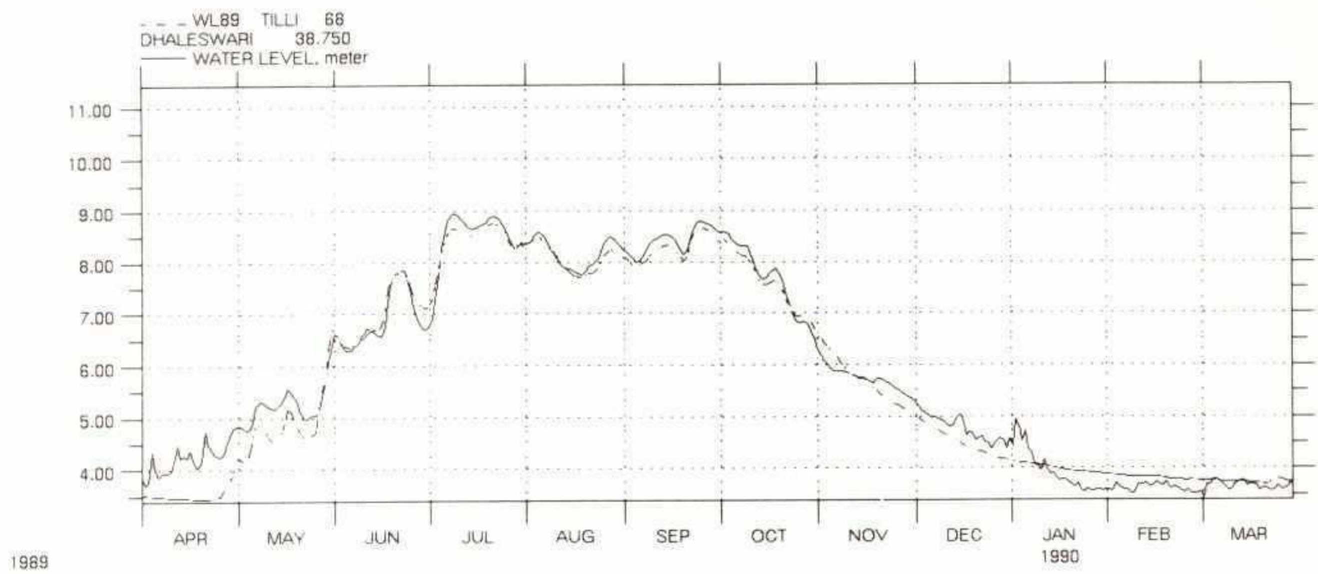




S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

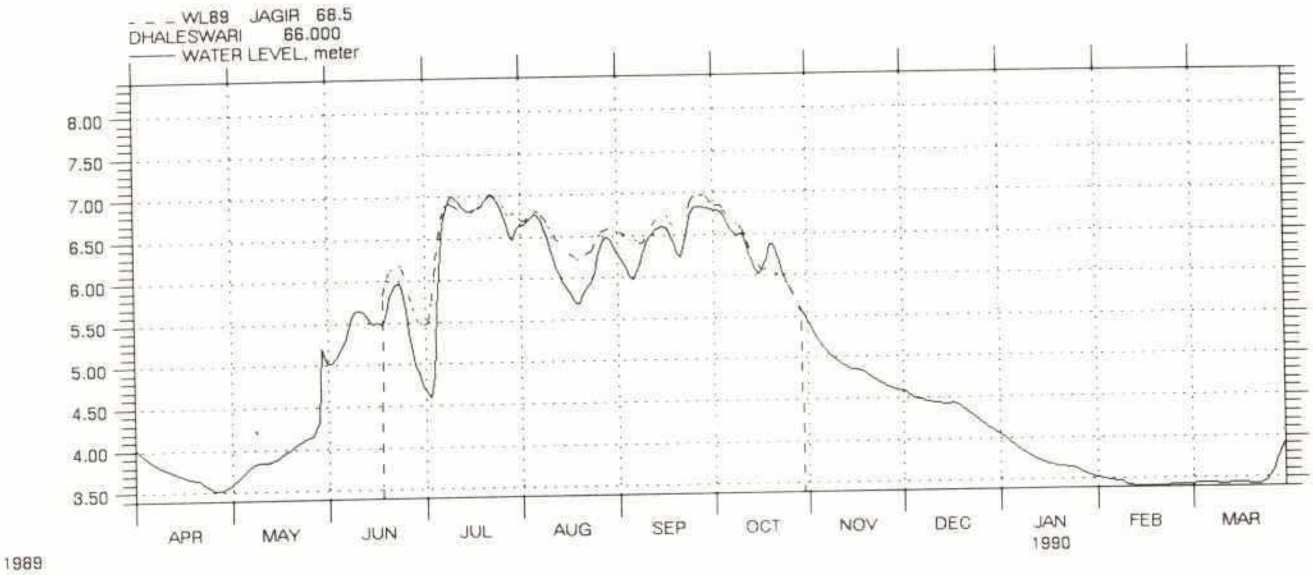
318

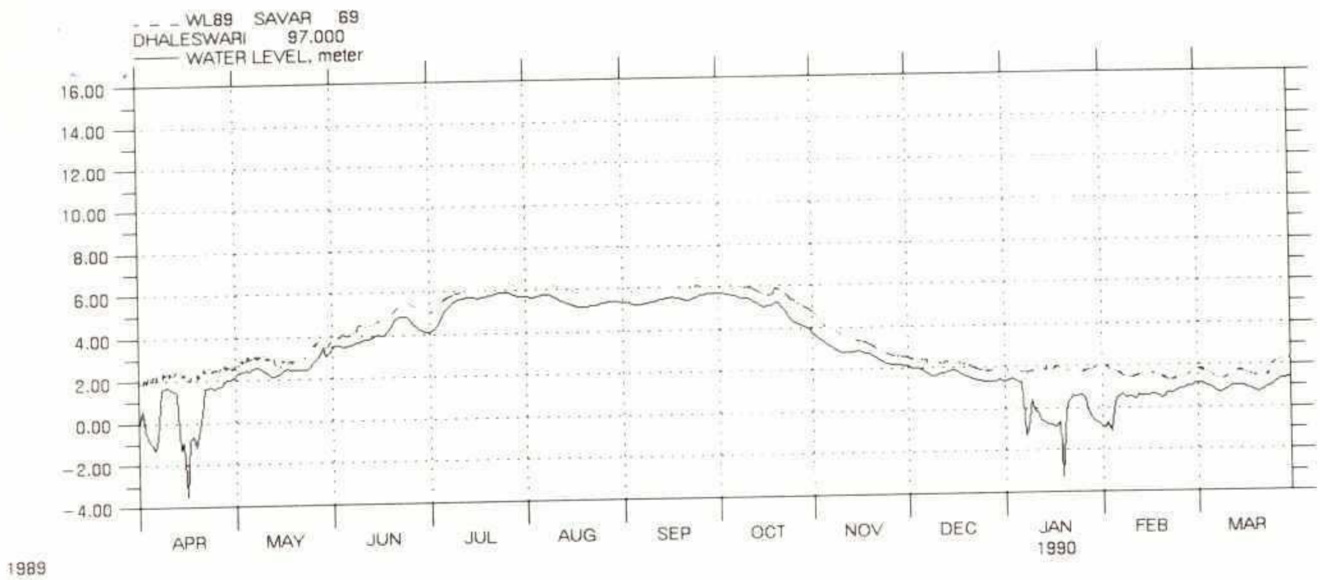




S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

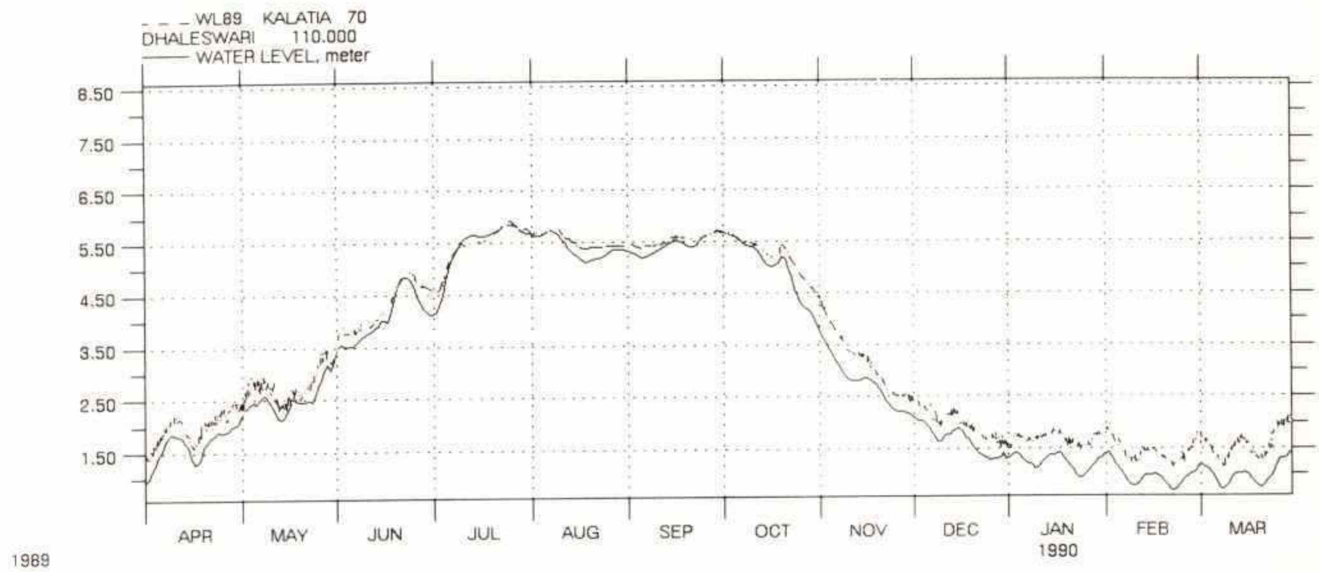
319

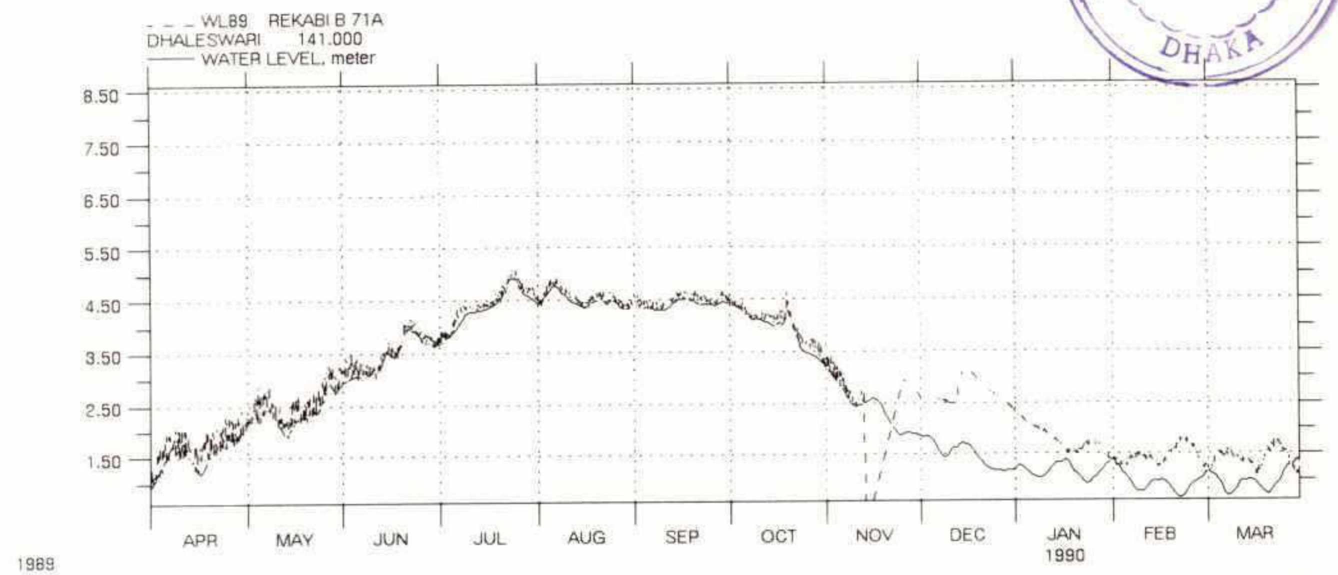




SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
		MIKE 11
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	Dwg no.:

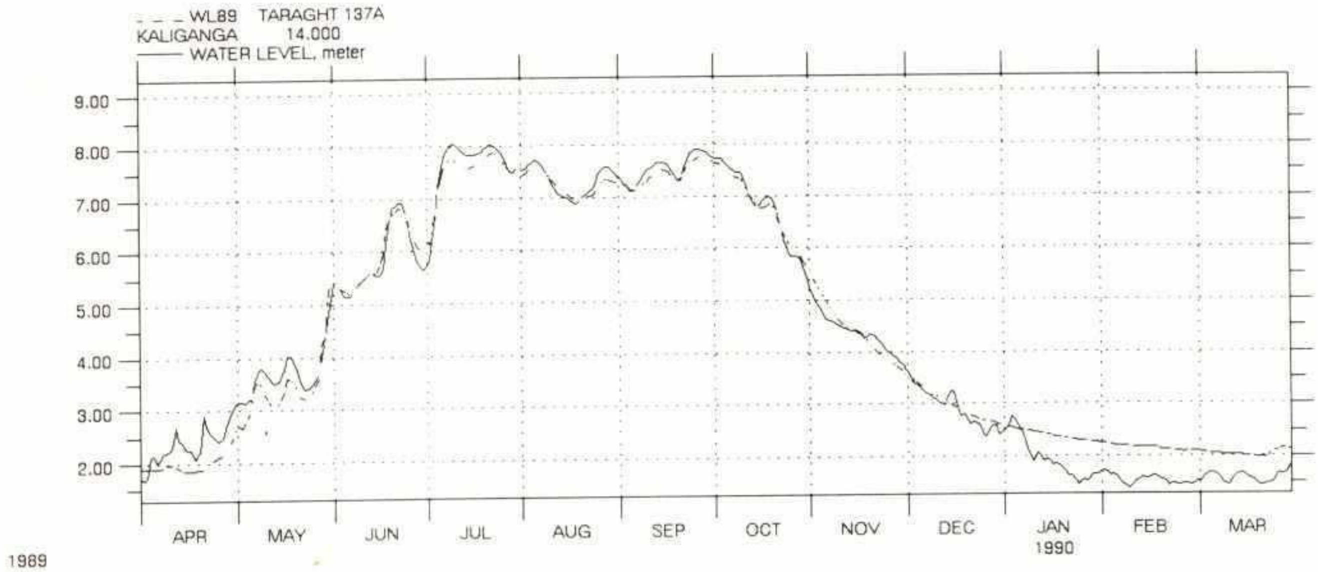
320

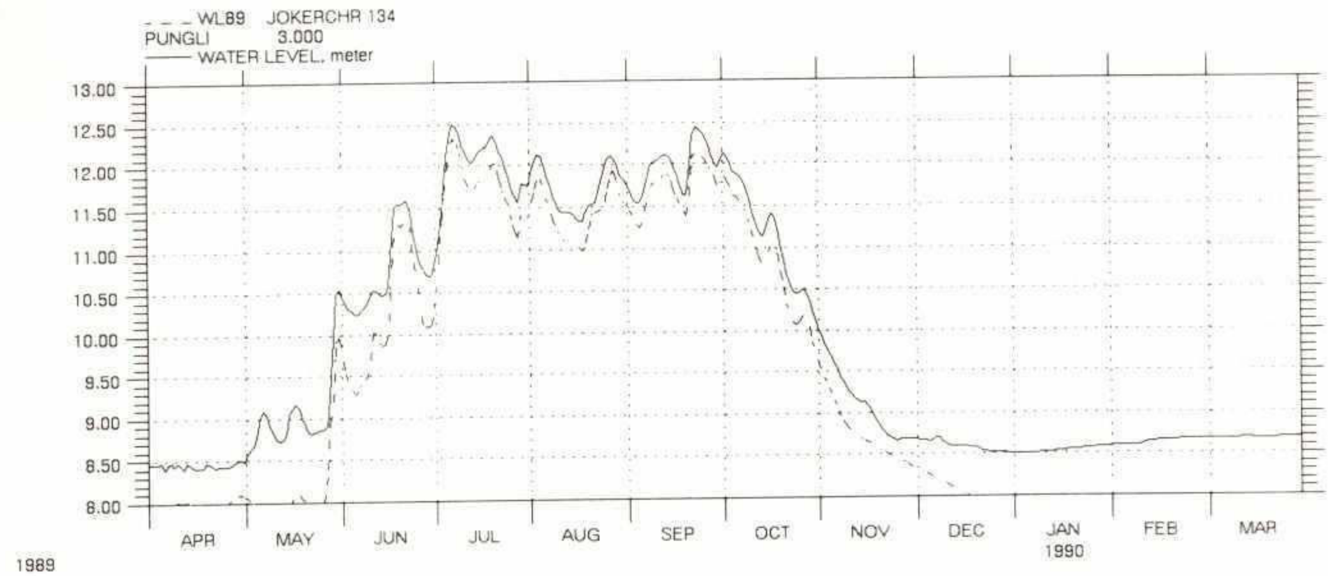




SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	MIKE 11 Dwg no.:

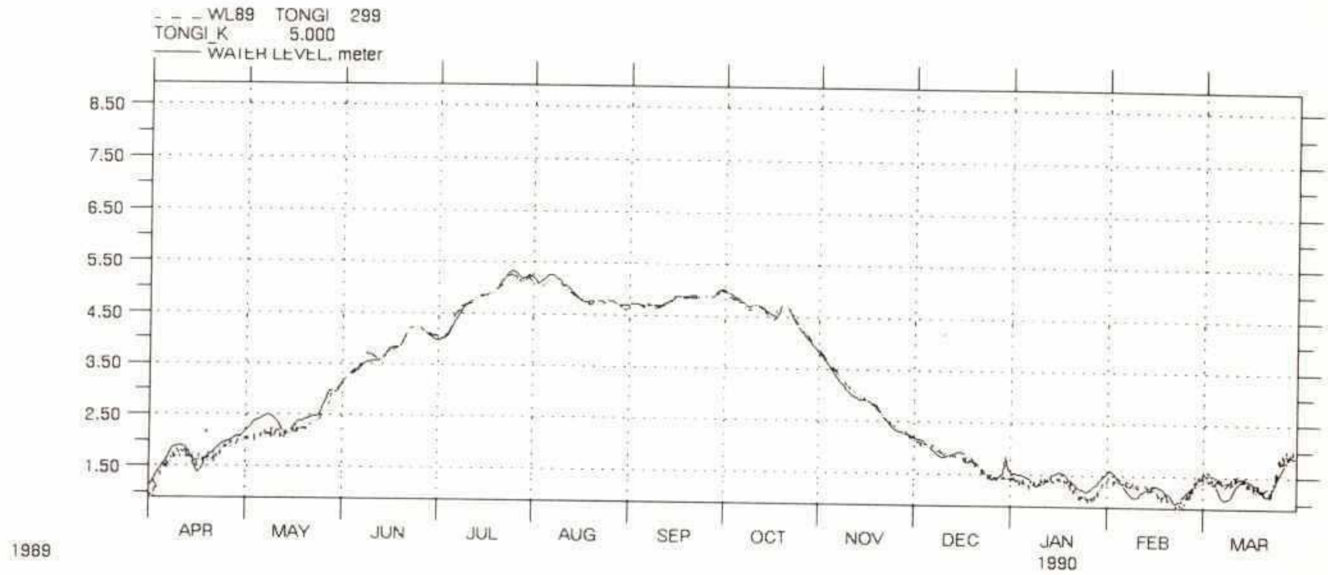
321

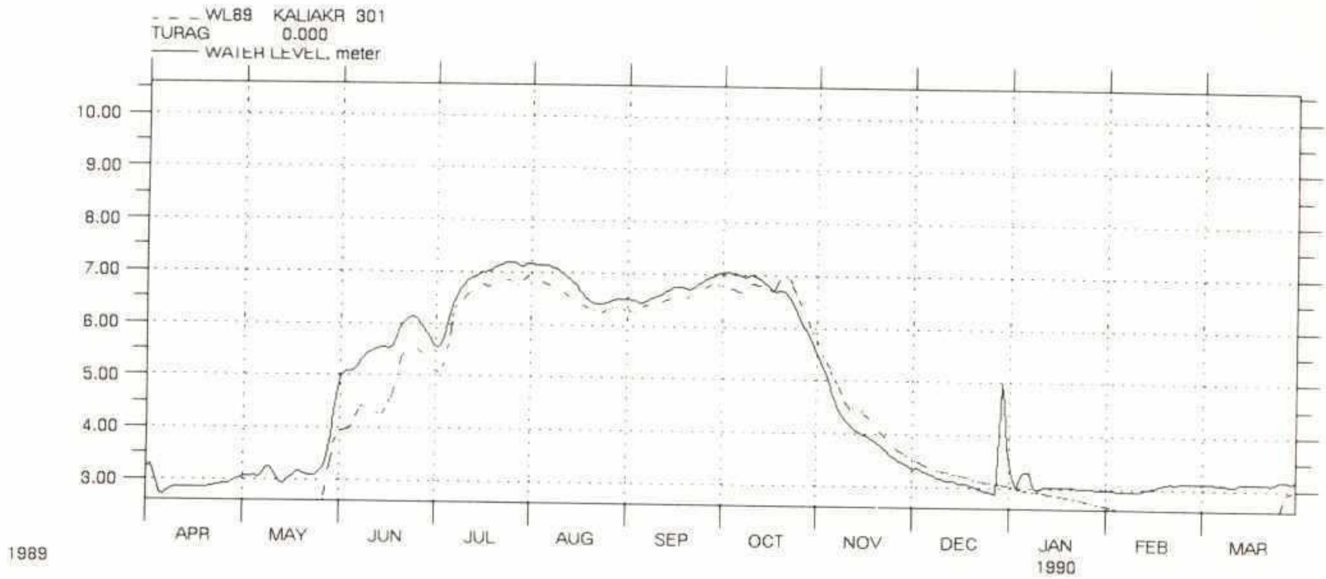




S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

322

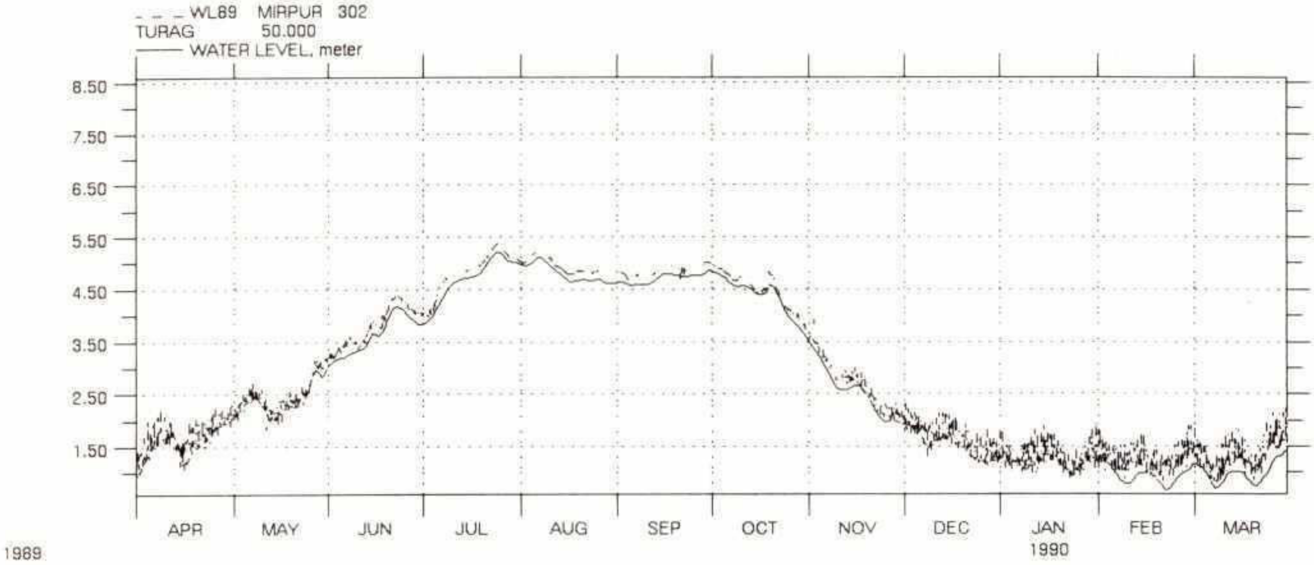


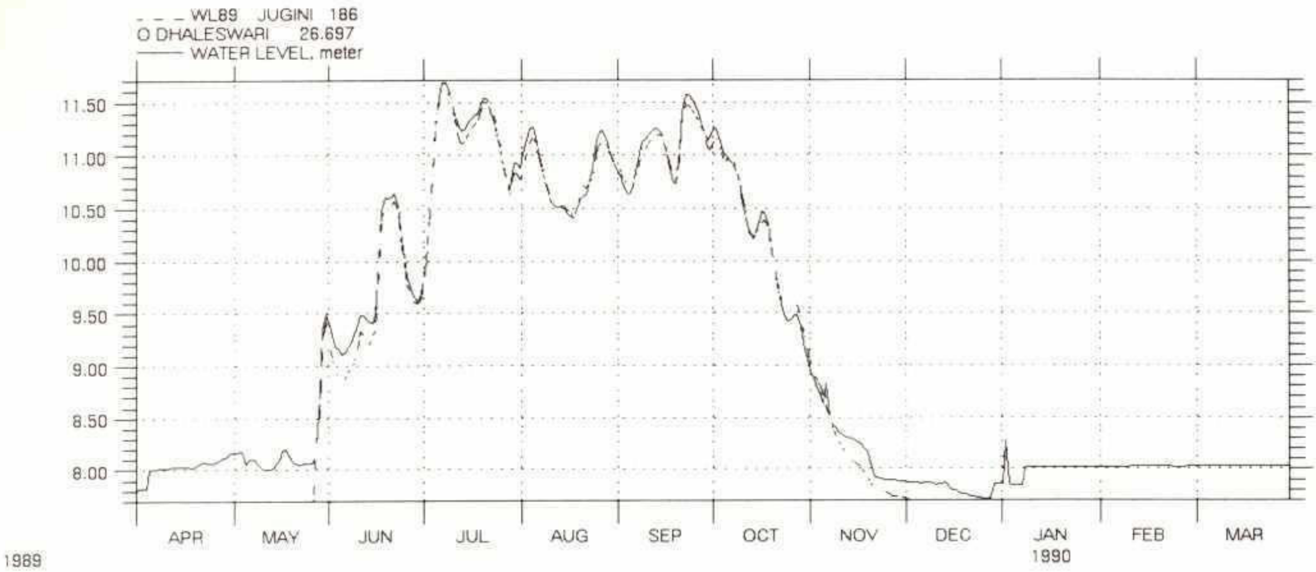


SWMC	NORTH CENTRAL WESTERN SUB - MODEL CALIBRATION RUN - 1989 DATA

DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 - OCT - 1991, 10:38	**MIKE 11** Dwg no.:

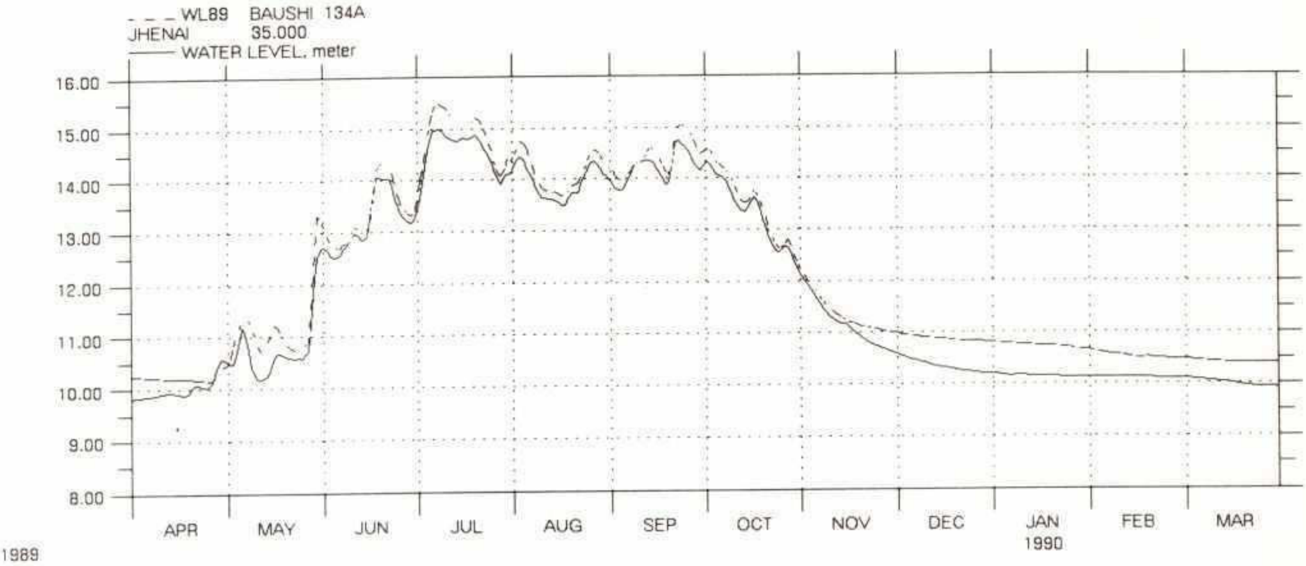
323





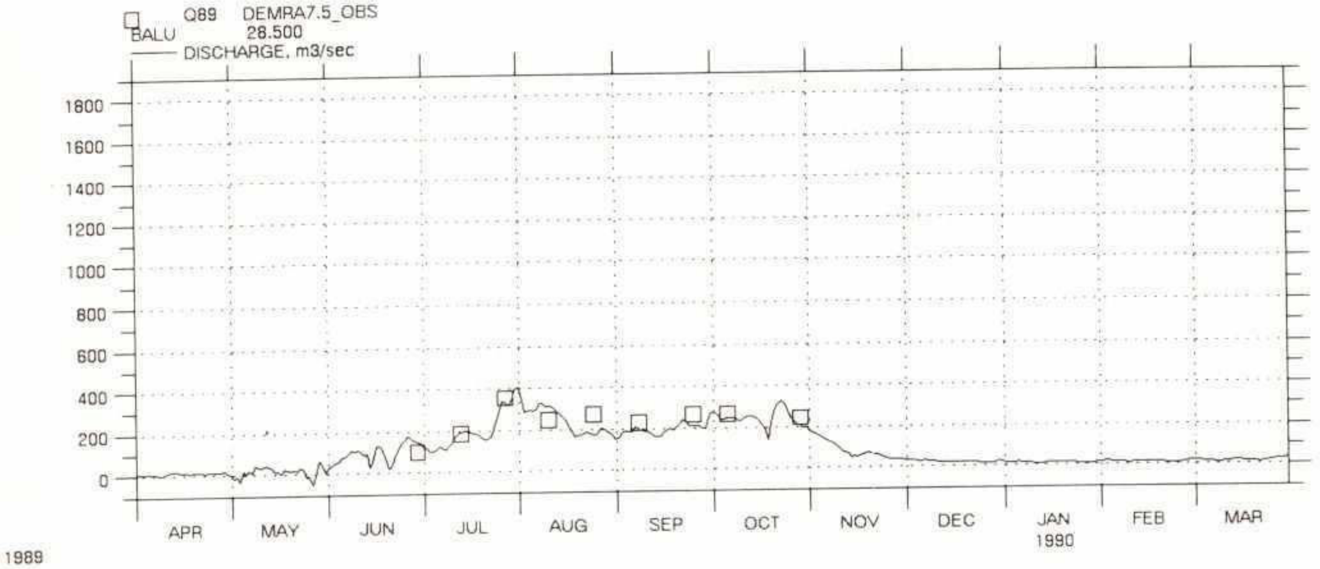
S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

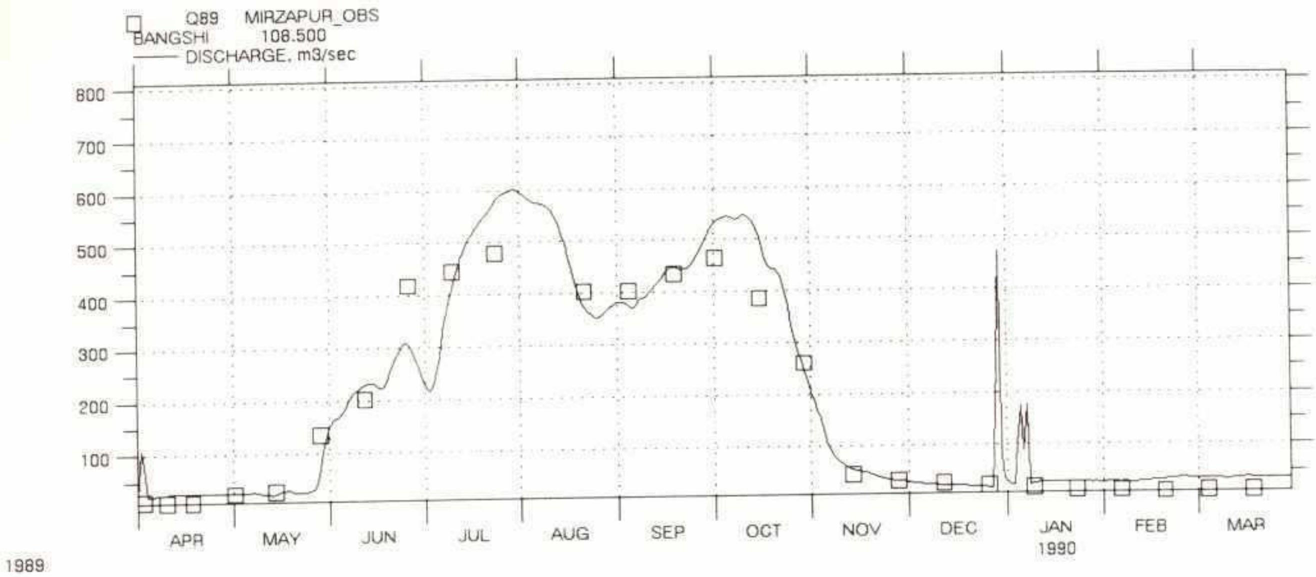
324



SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

325





SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
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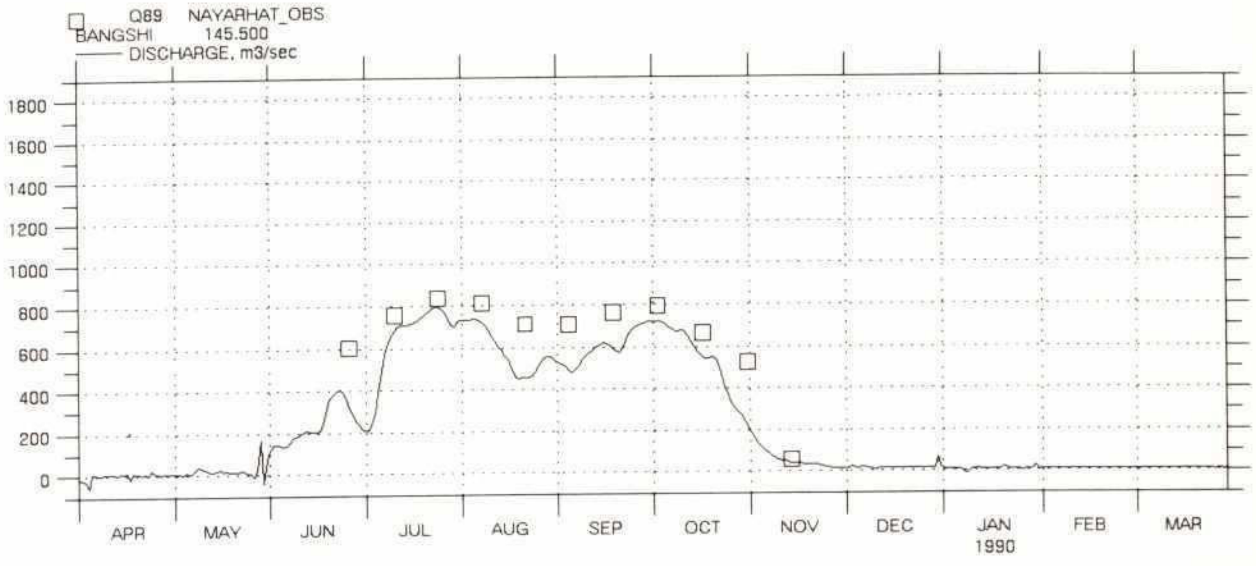
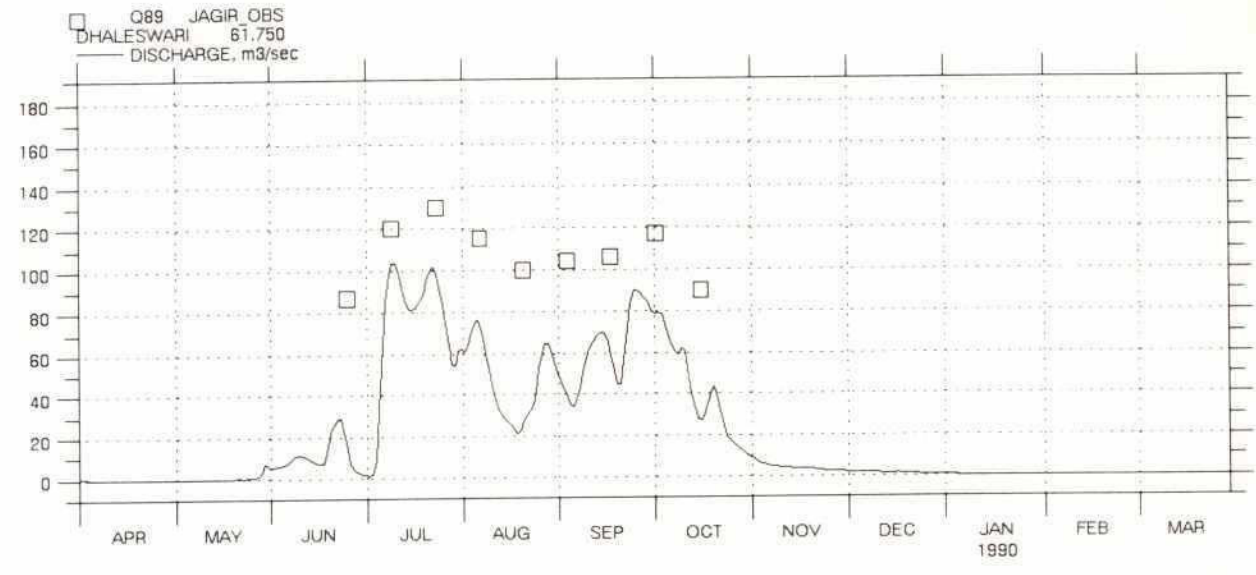
326





S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
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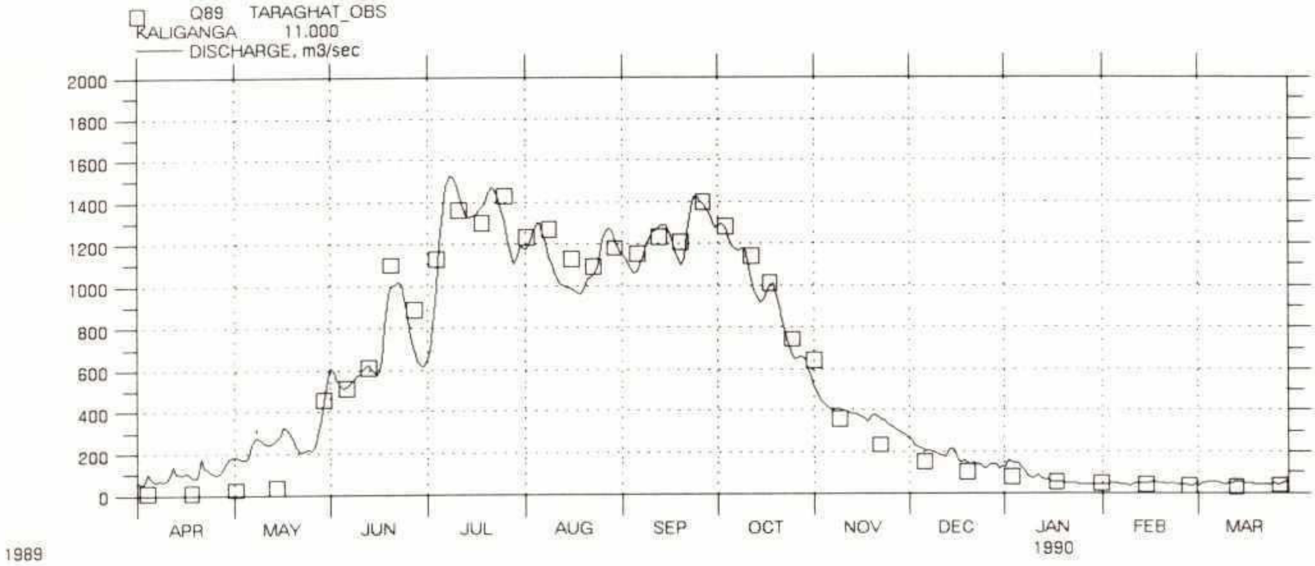
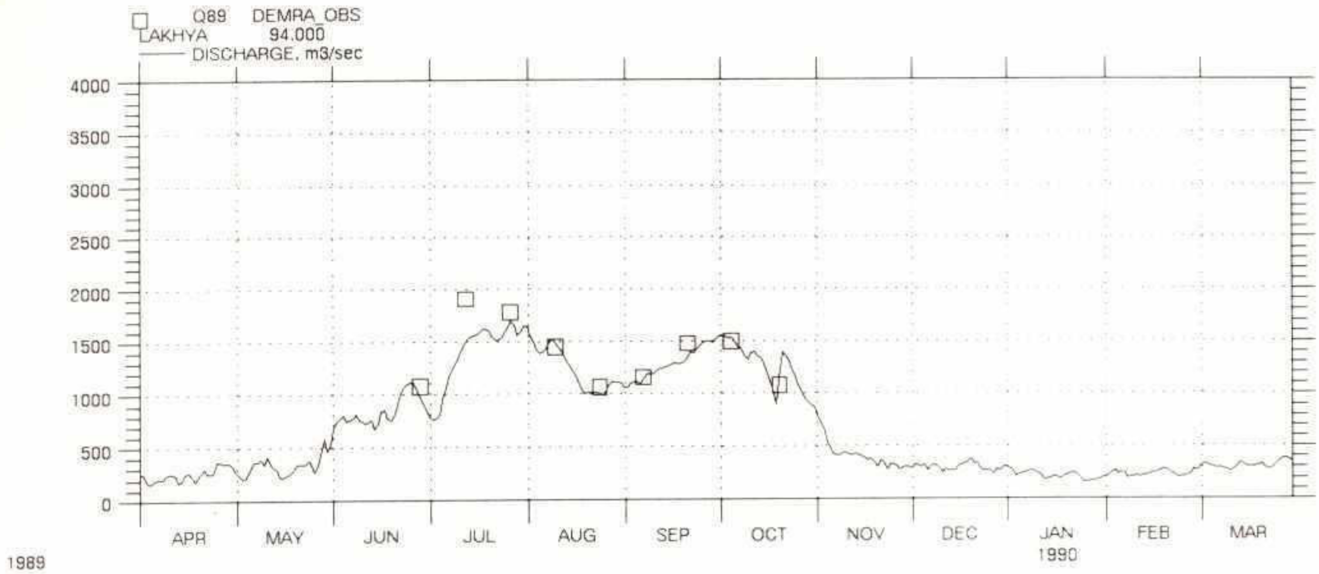
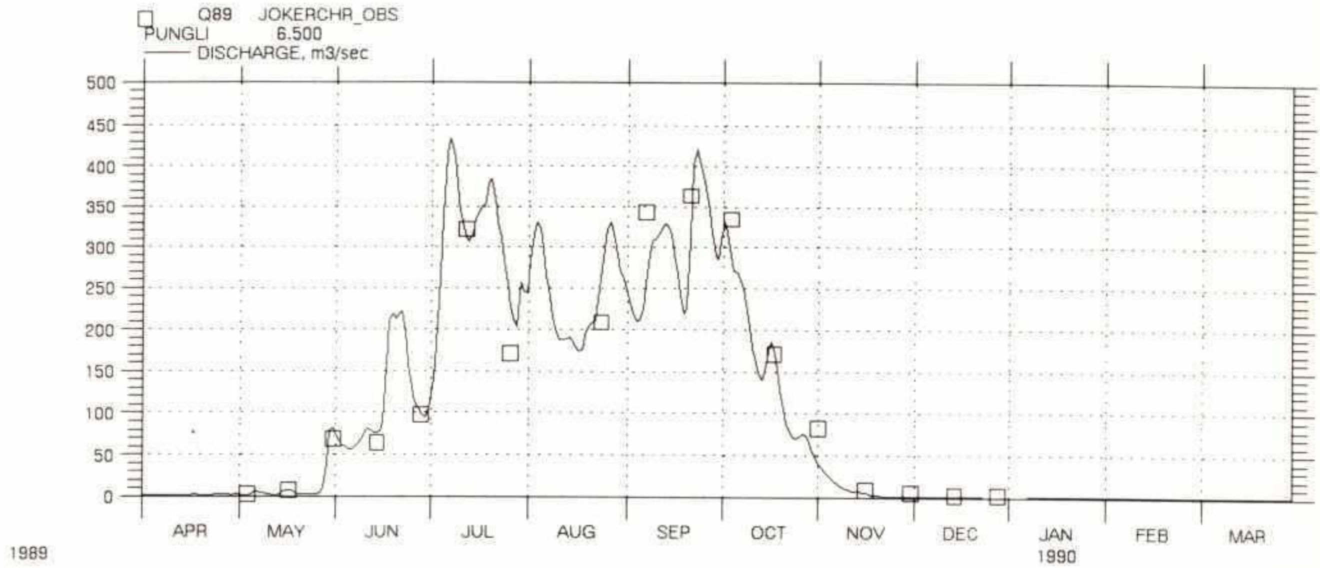
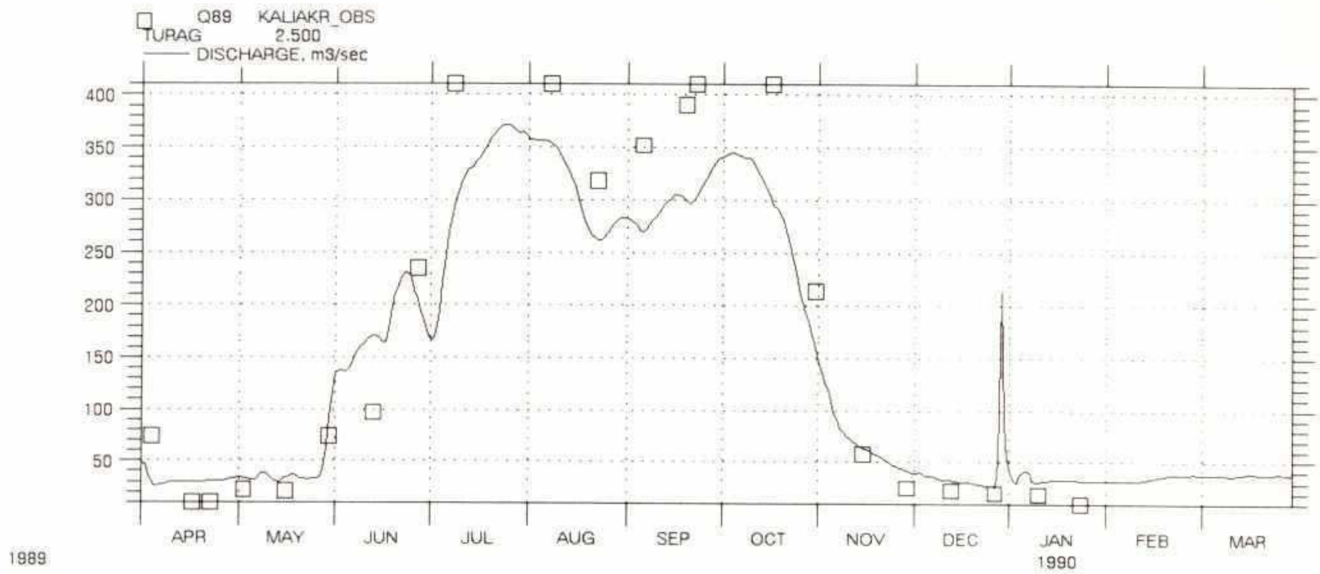




S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

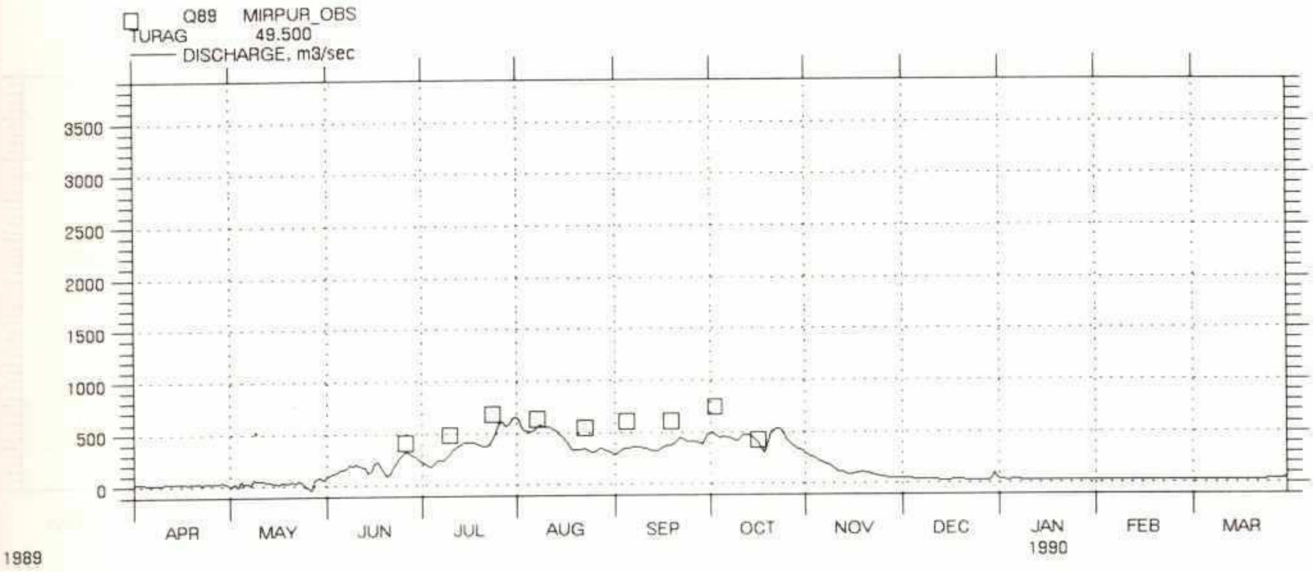
328





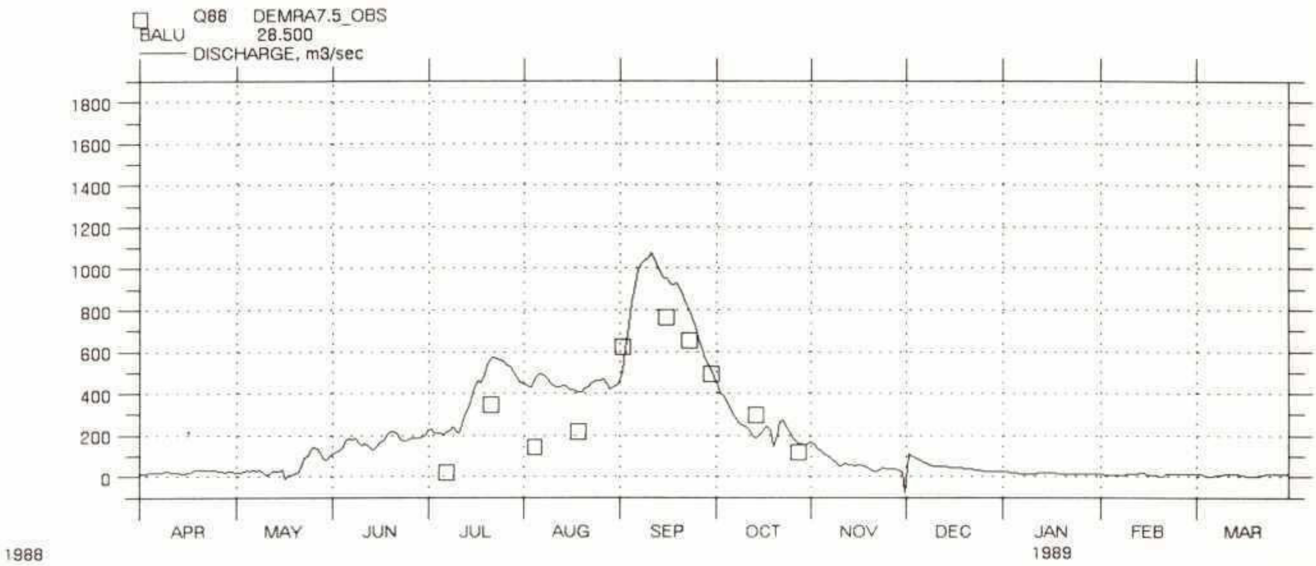
S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	**MIKE 11** Dwg no.:

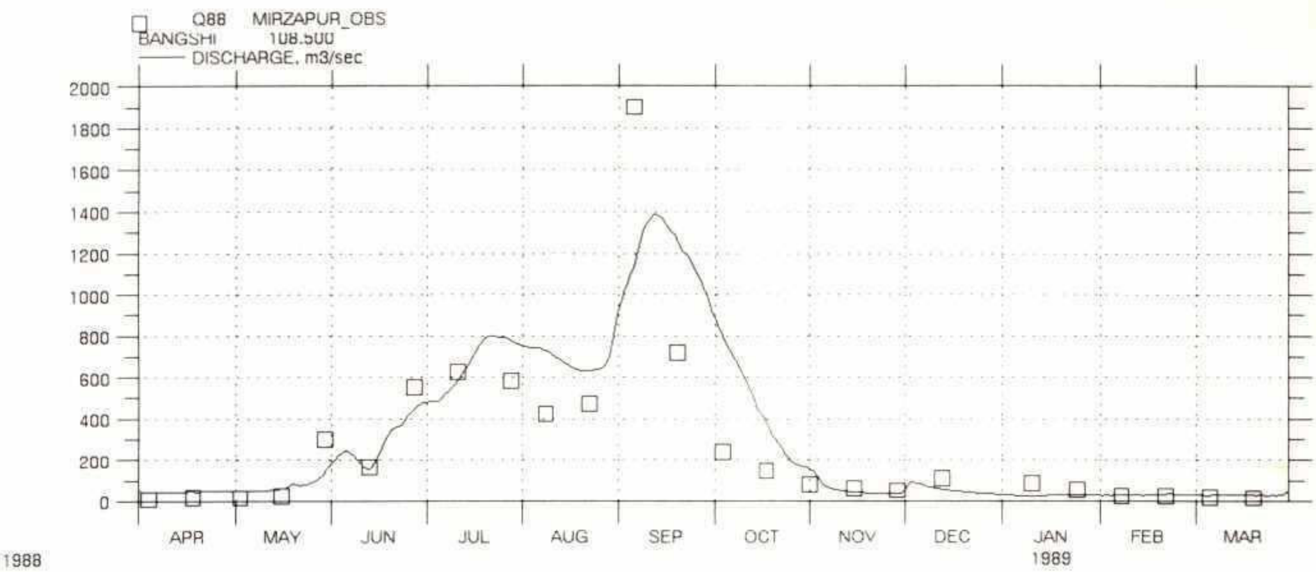
329



SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1989 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL89_W.RRF	BOUNDARY FILE : NCRM_W89.BSF CALCULATED : 14 – OCT – 1991, 10:38	MIKE 11 Dwg no.:

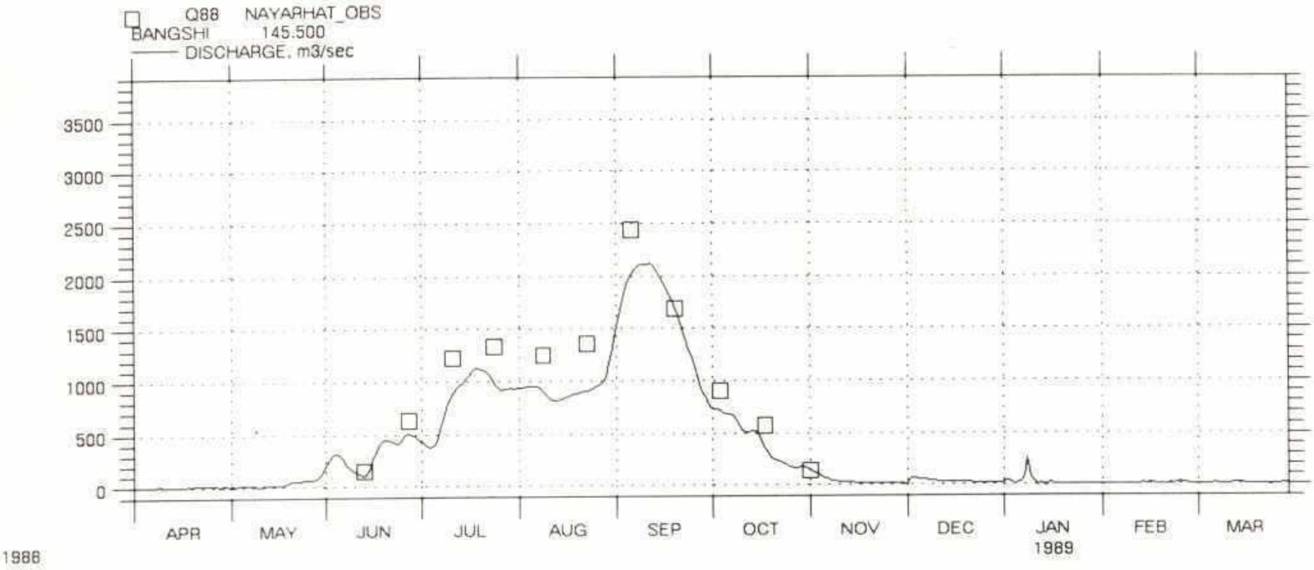
330

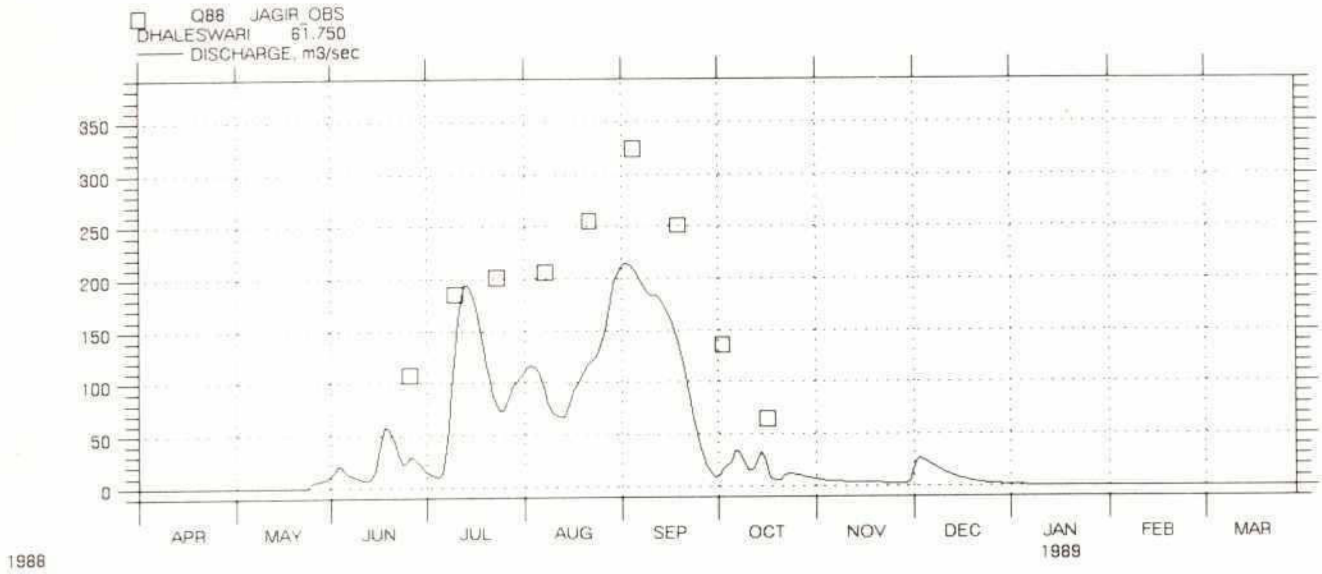




SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

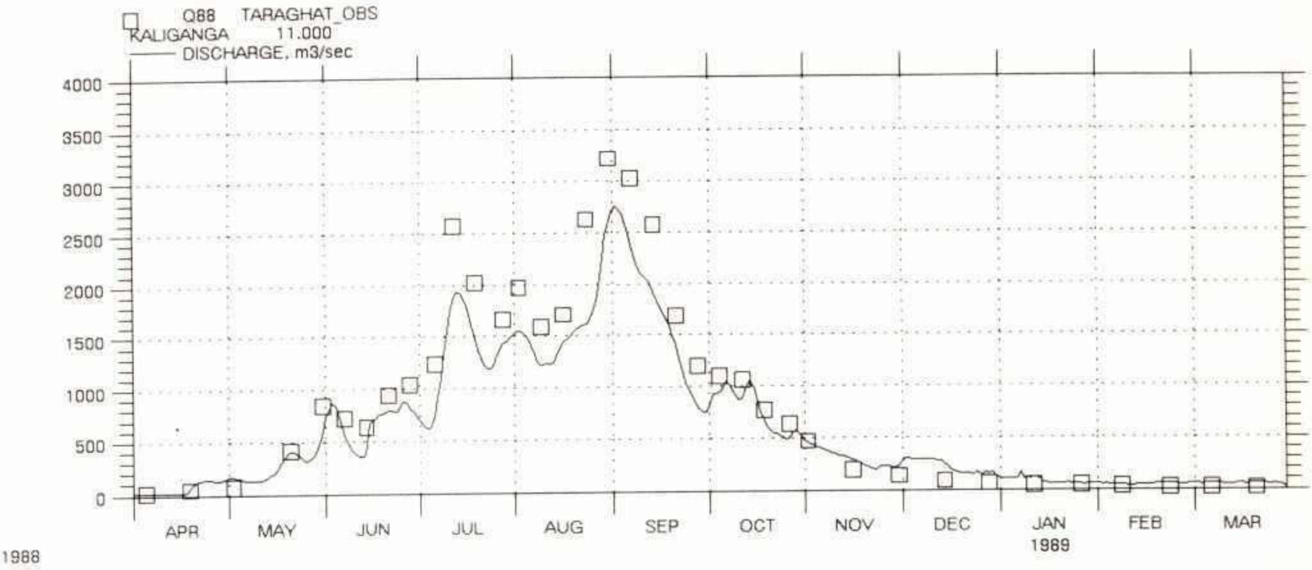
331

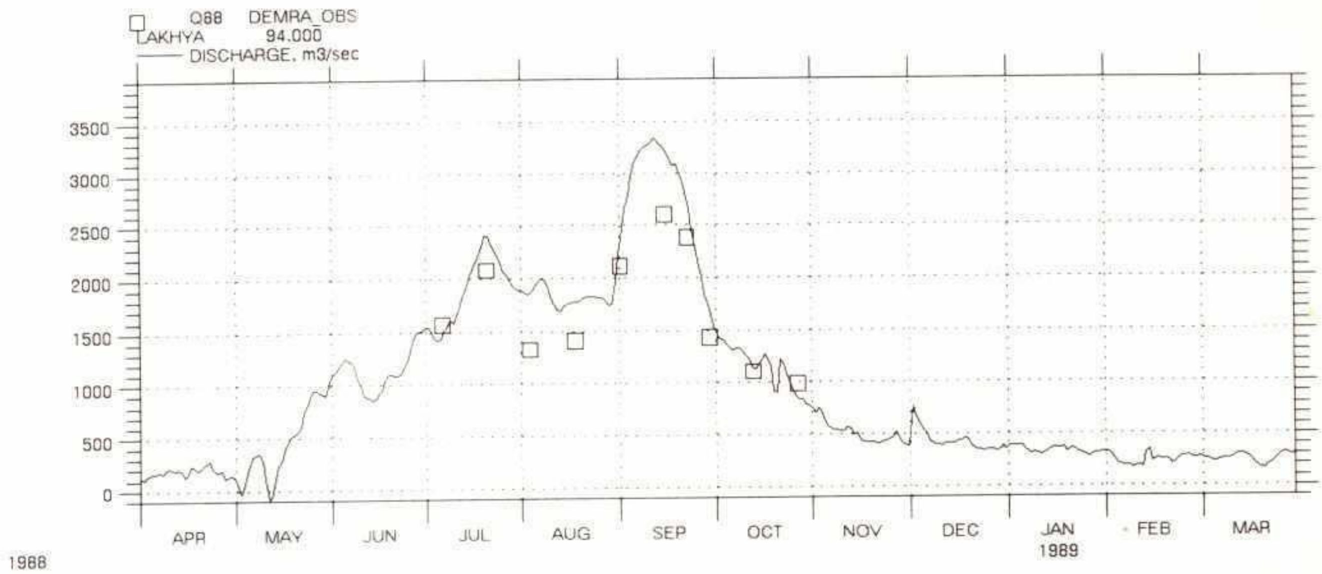




SWMC	NORTH CENTRAL WESTERN SUB - MODEL CALIBRATION RUN - 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 - OCT - 1991, 16:56	MIKE 11 Dwg no.:

332





SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
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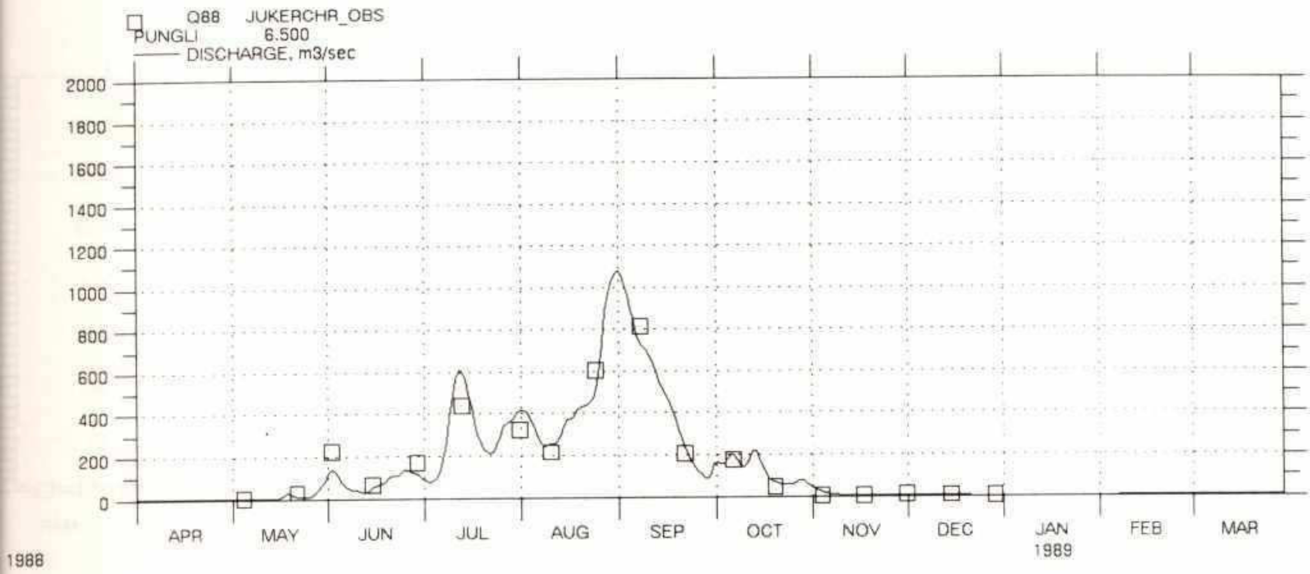
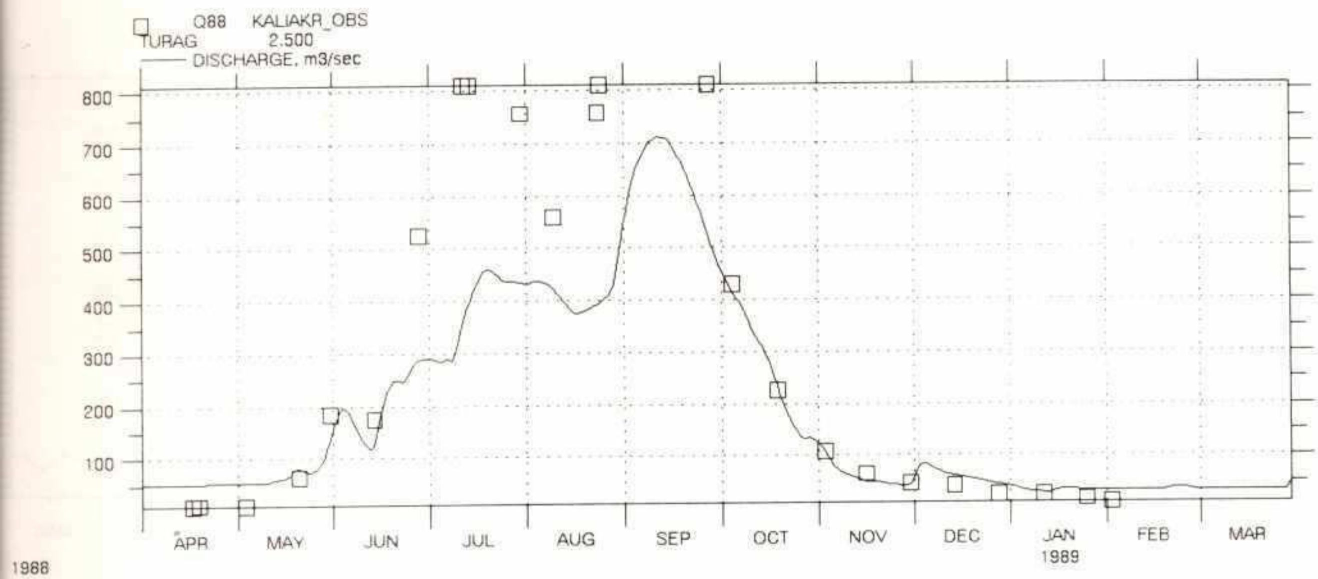
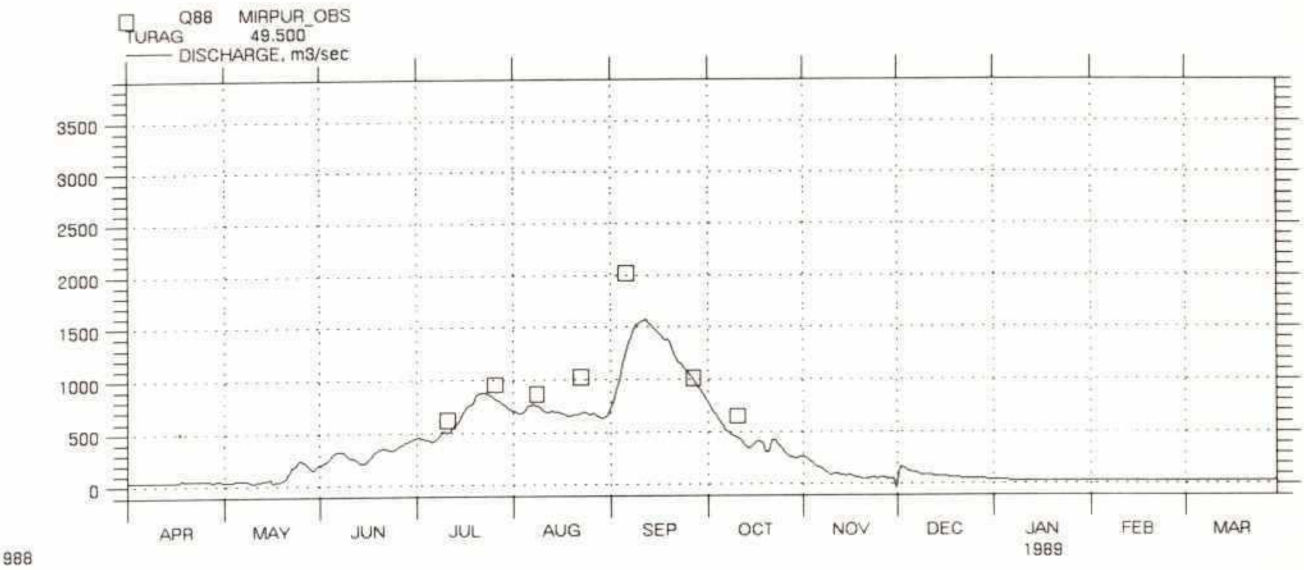




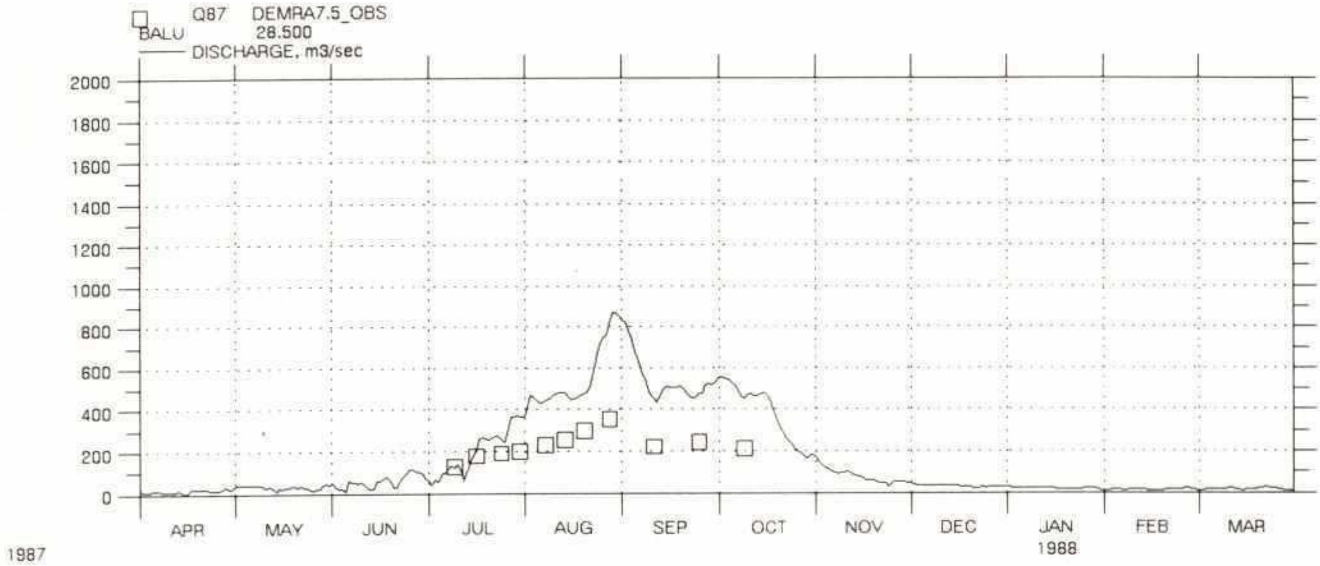
SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

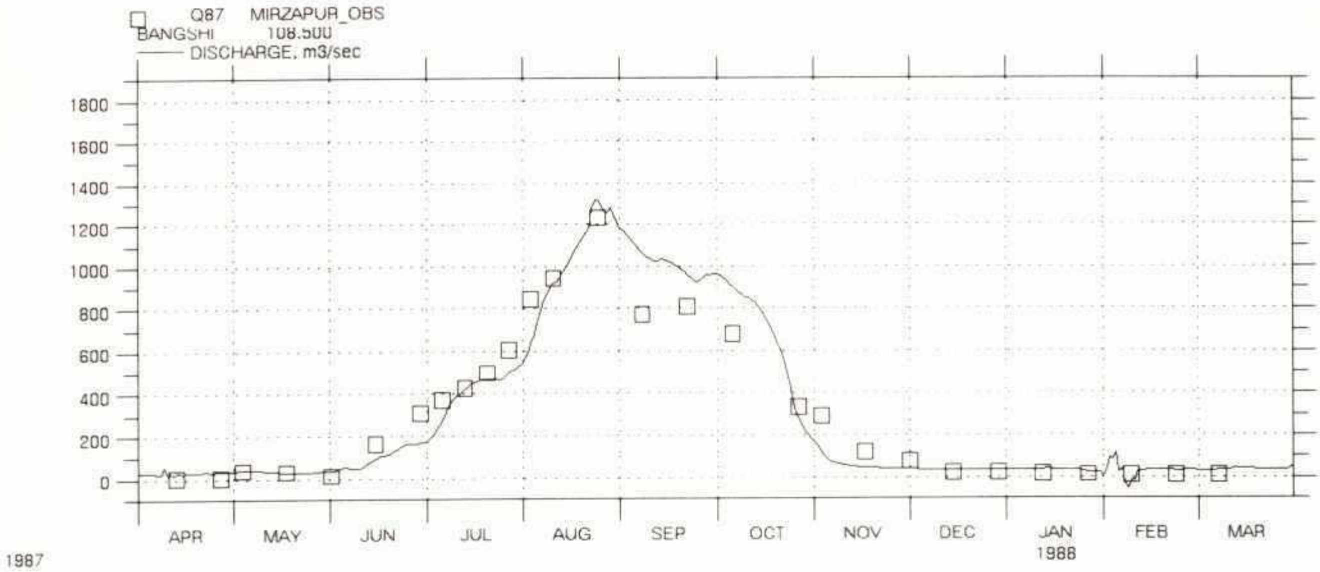
334



SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

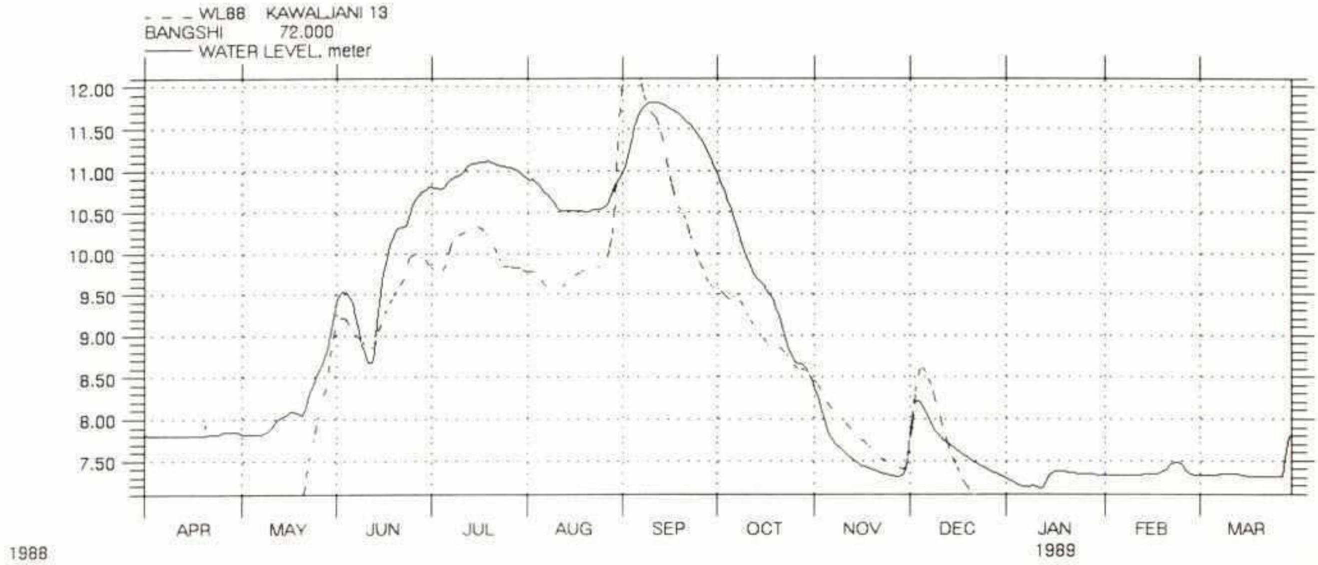
335

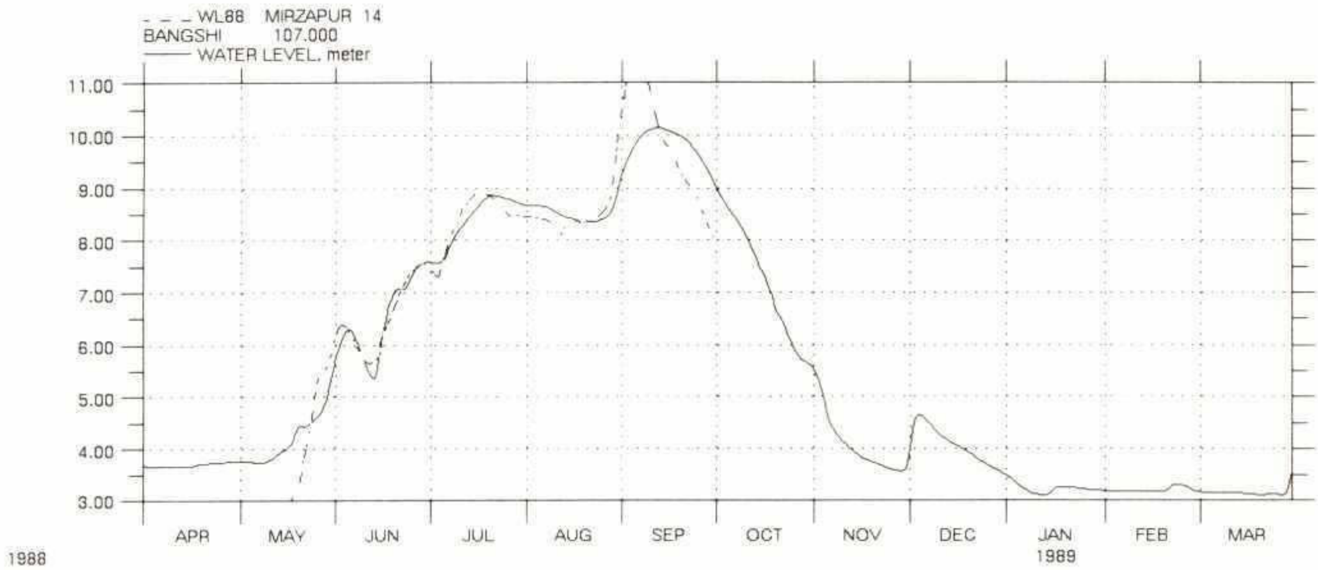




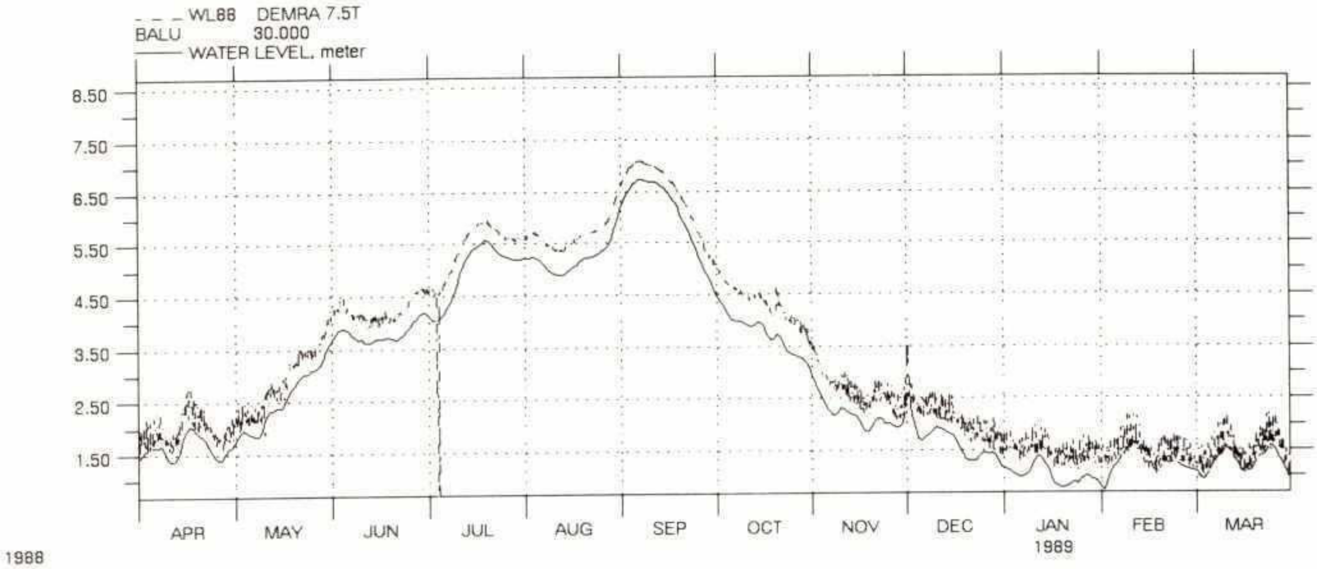
SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1987 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL87_W.RRF	BOUNDARY FILE : NCRM_W87.BSF CALCULATED : 14 – OCT – 1991, 12:57	MIKE 11 Dwg no.:

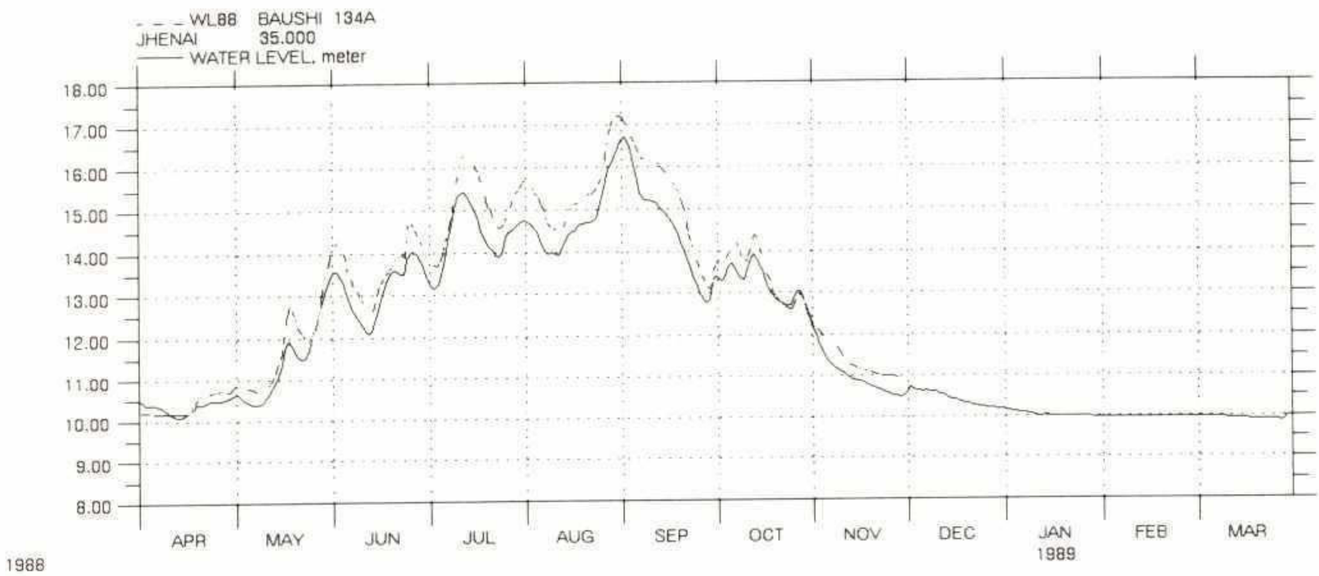
336



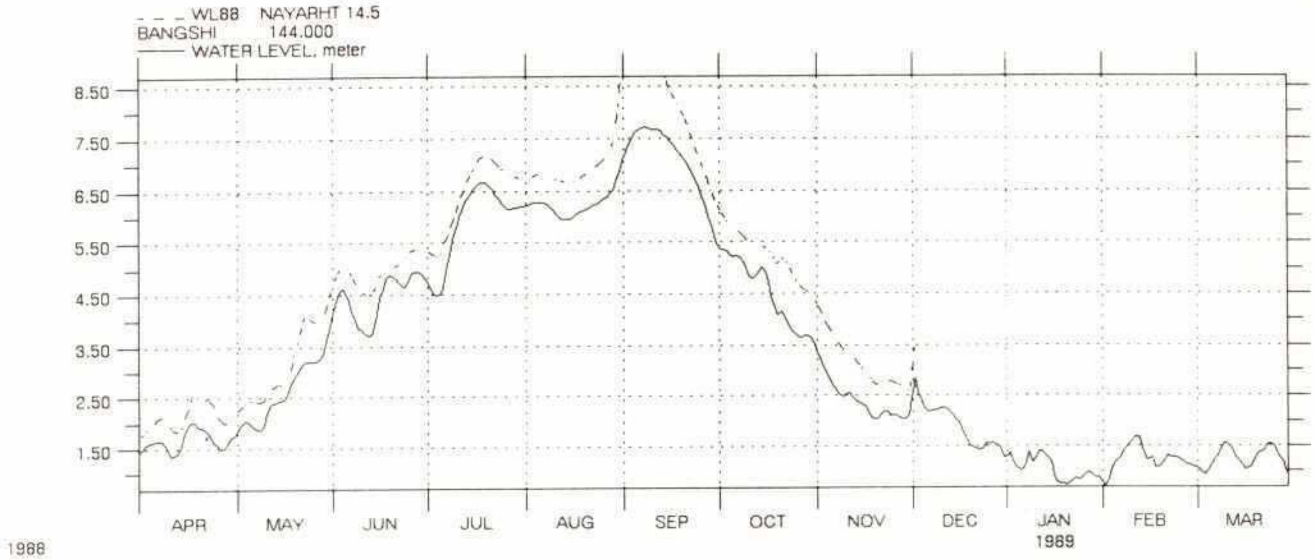


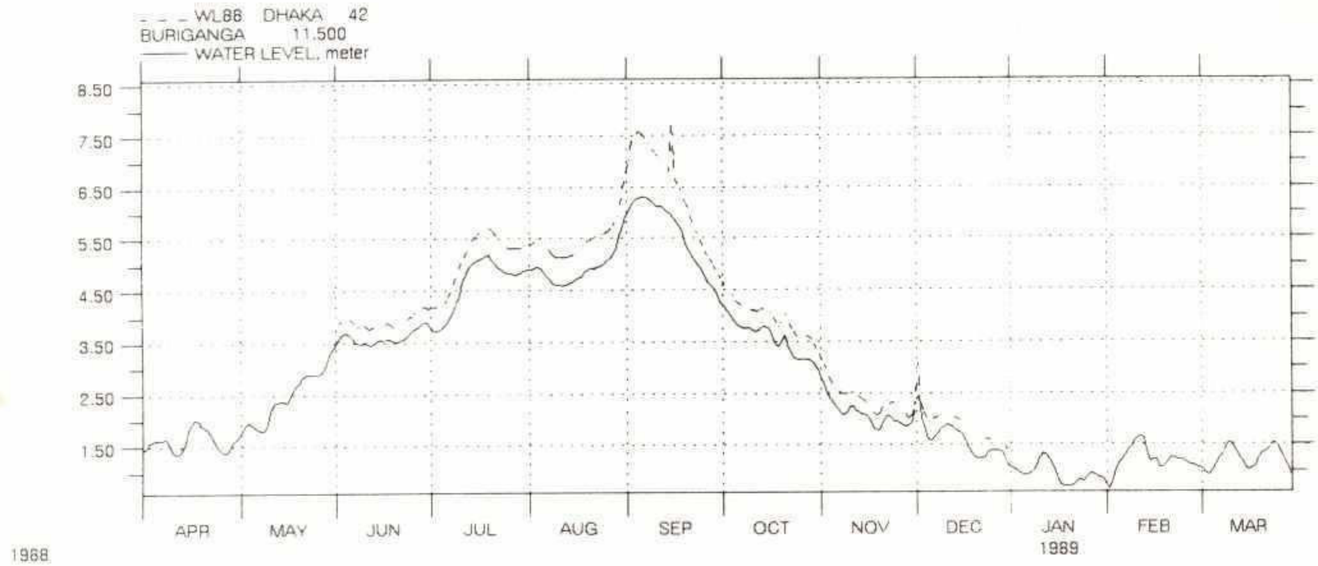
S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:





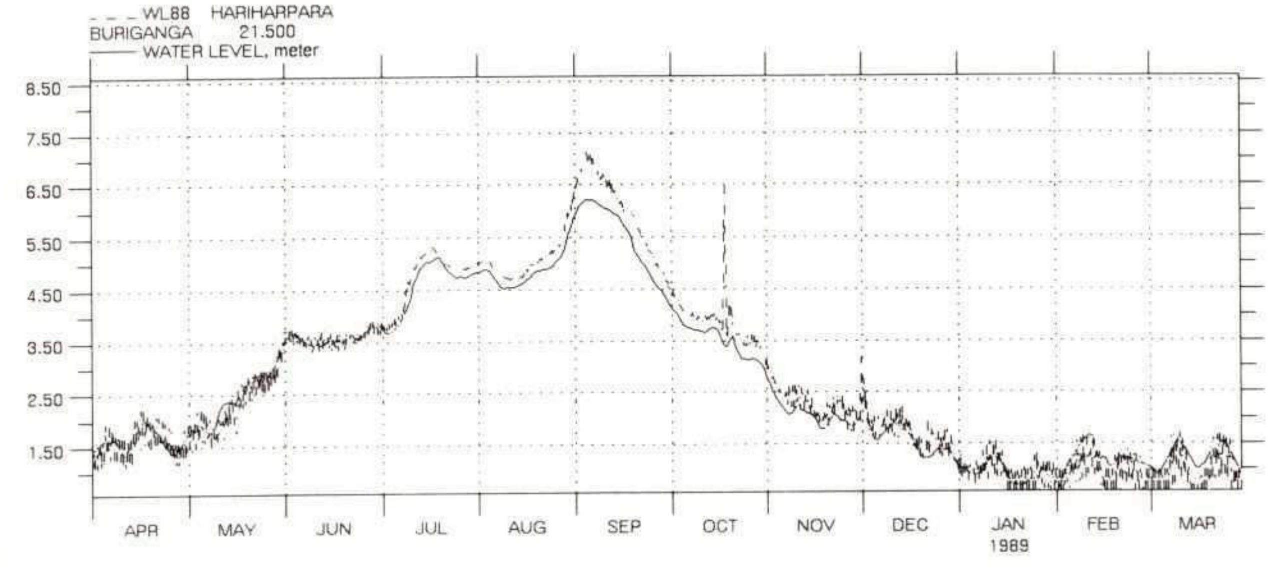
S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

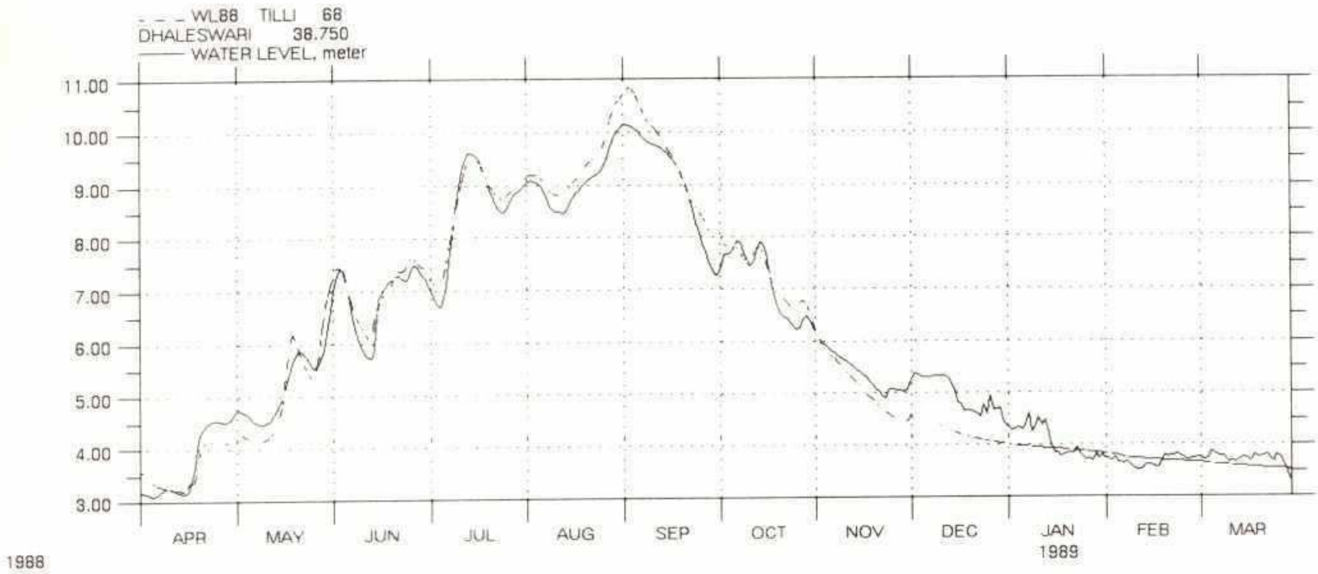




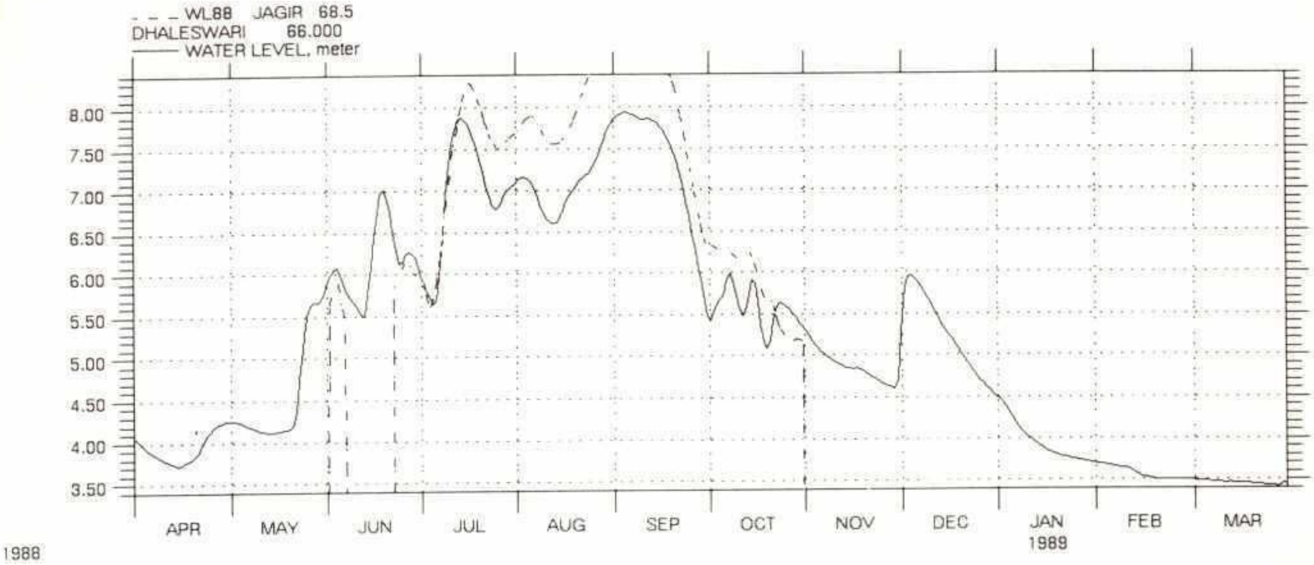
SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

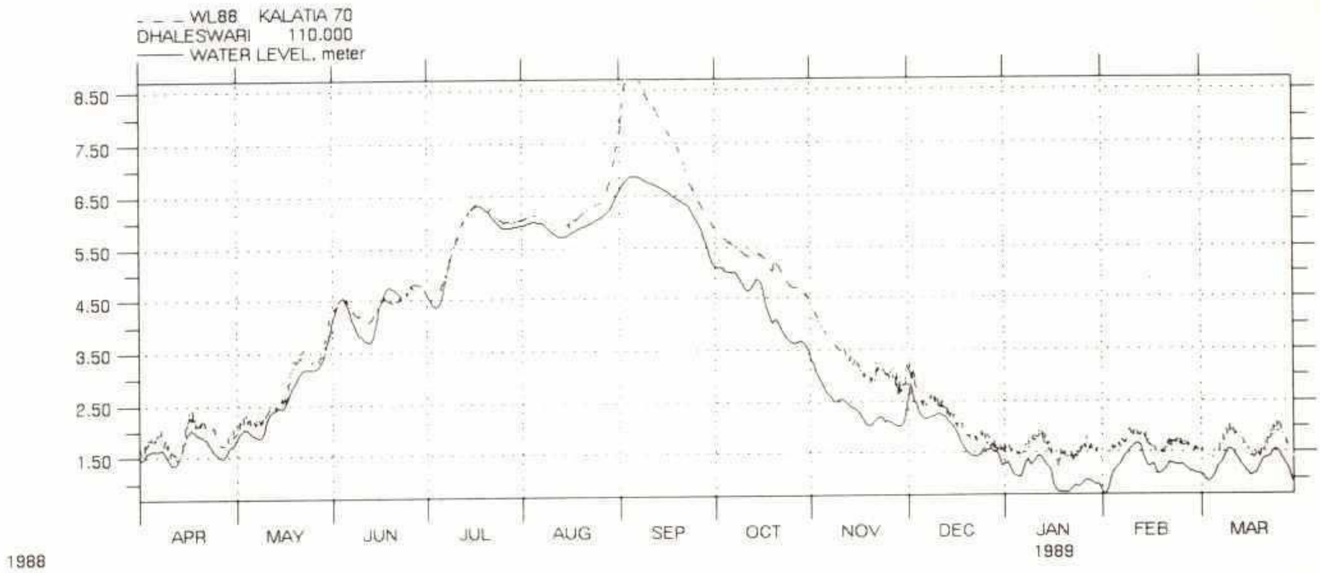
339





S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:





SWMC	NORTH CENTRAL WESTERN SUB - MODEL CALIBRATION RUN - 1988 DATA	
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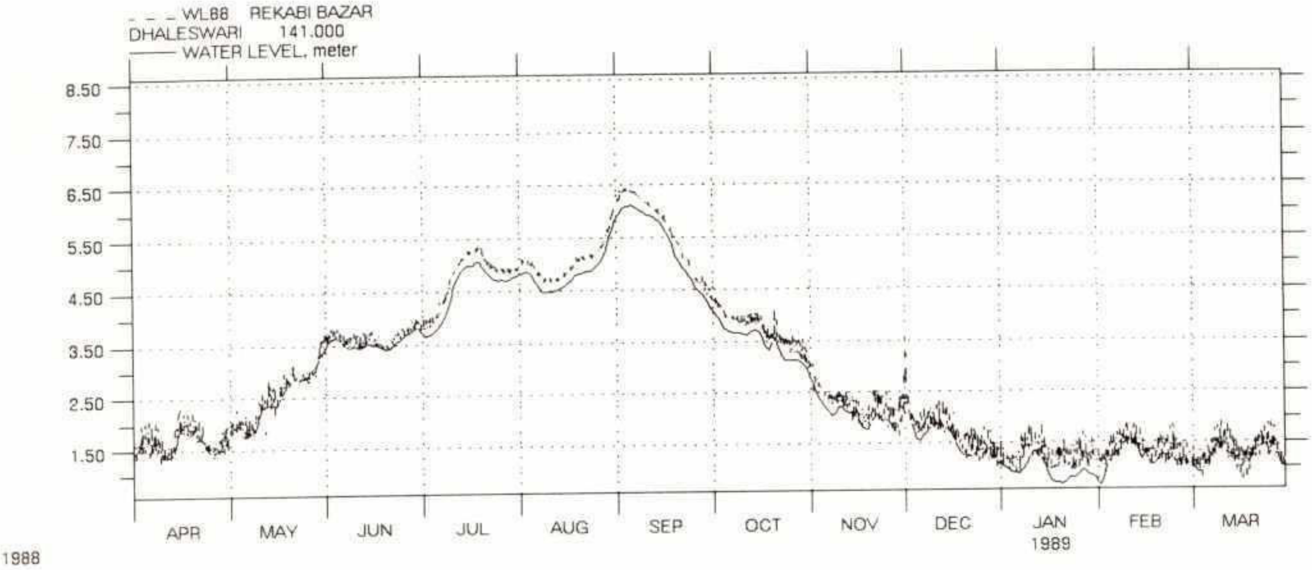
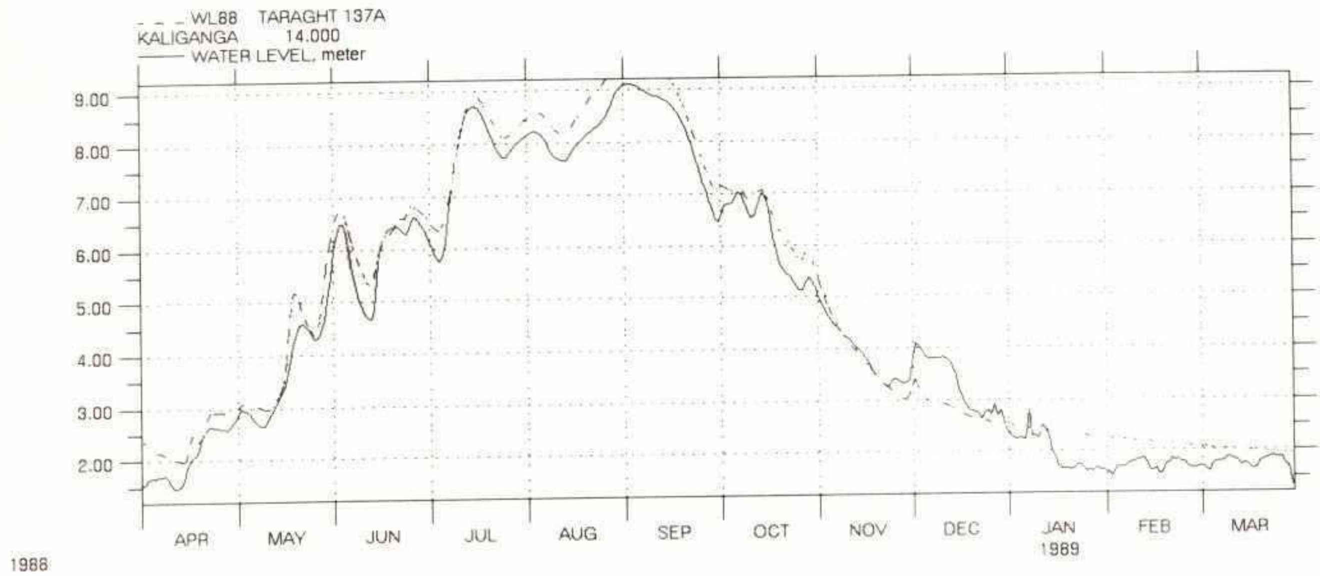
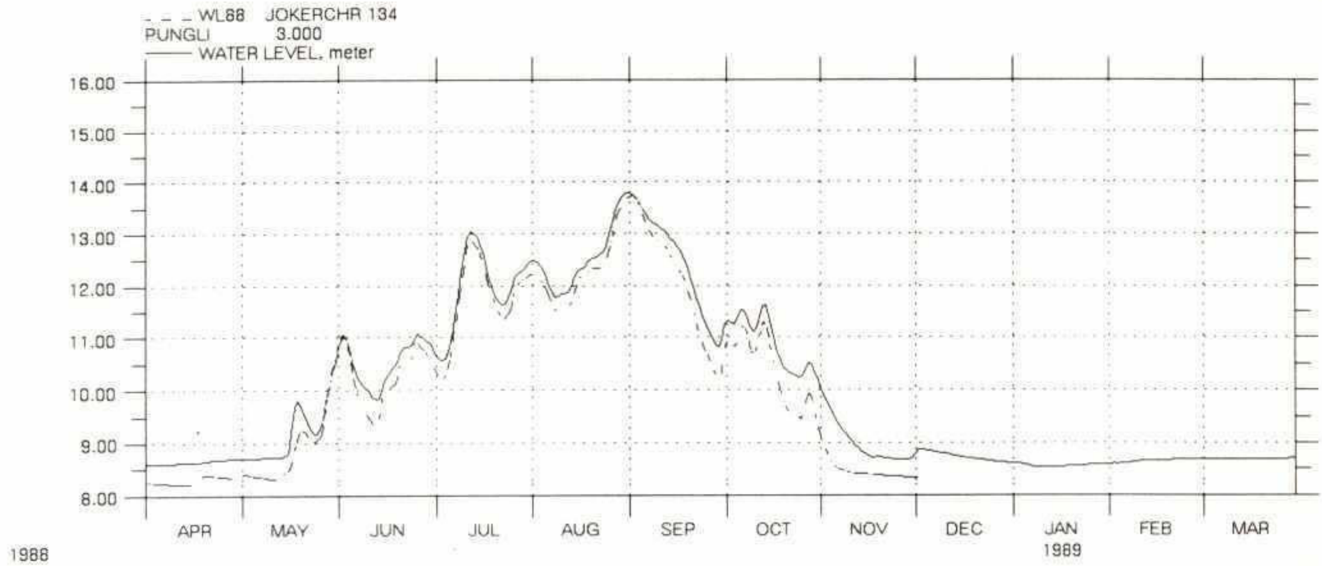
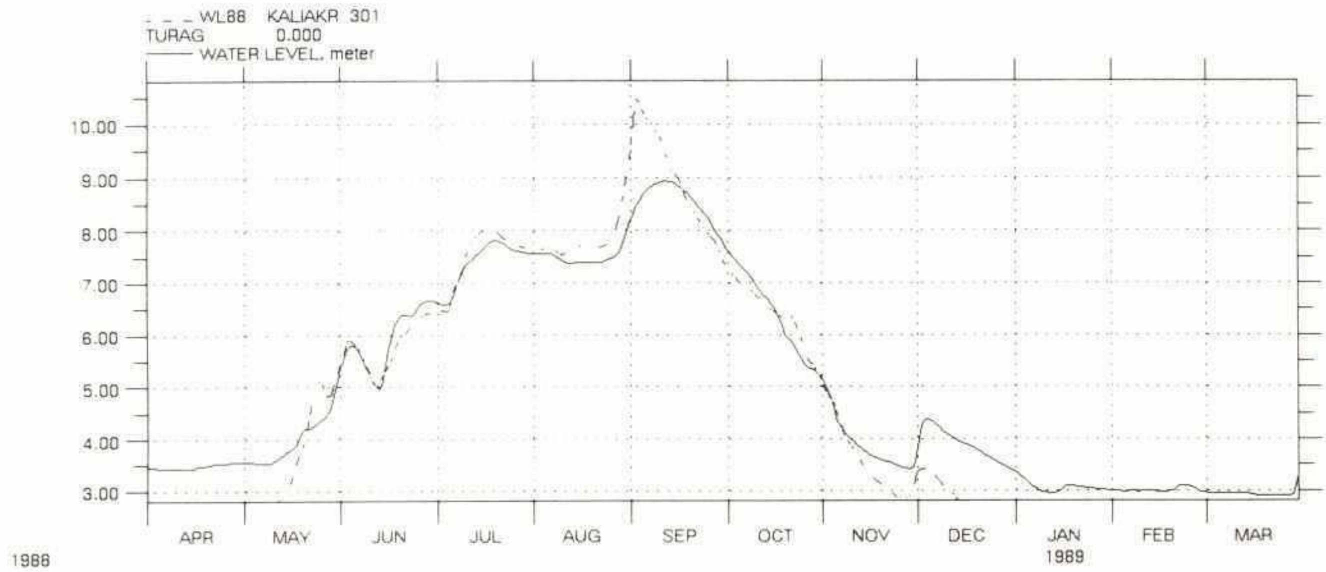




SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

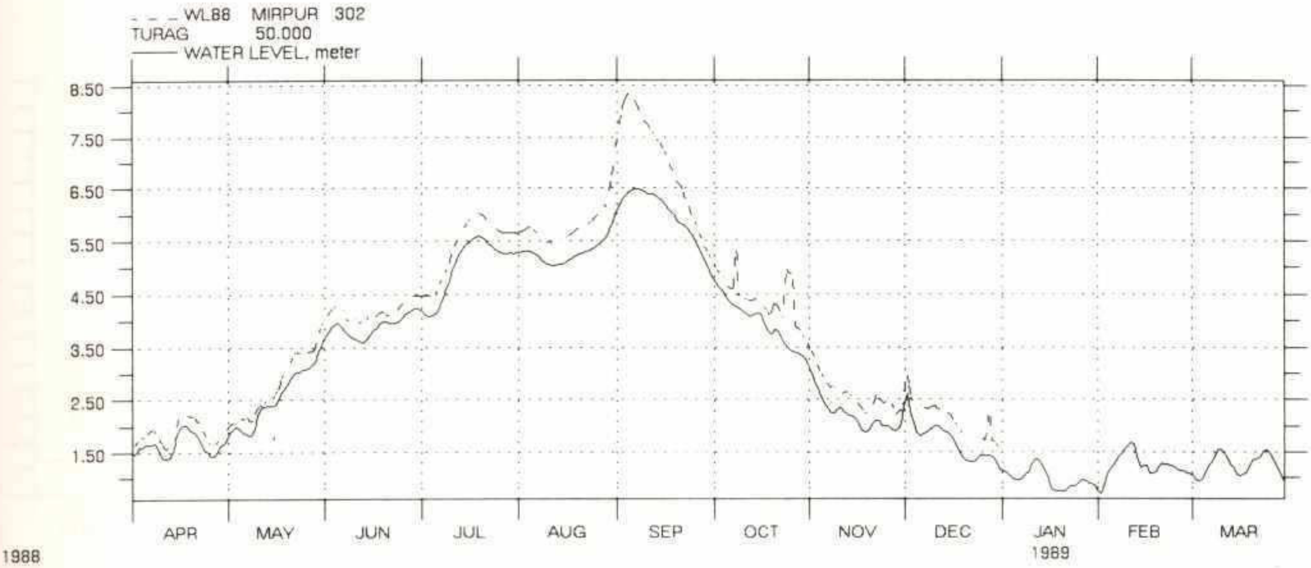
342

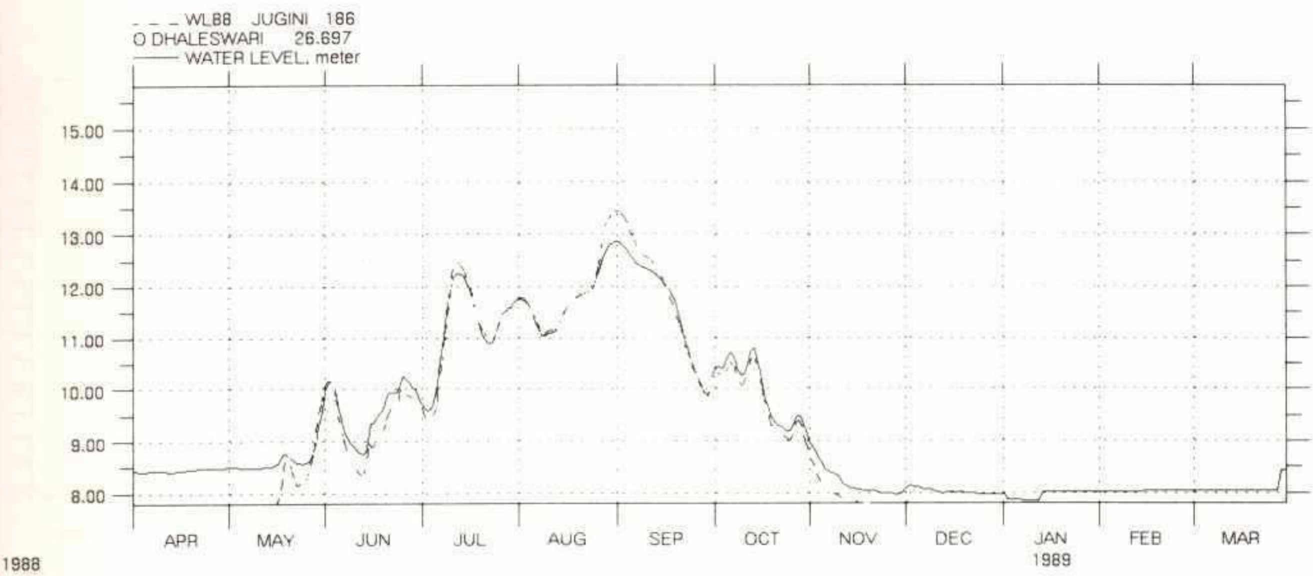




S W M C	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	**MIKE 11** Dwg no.:

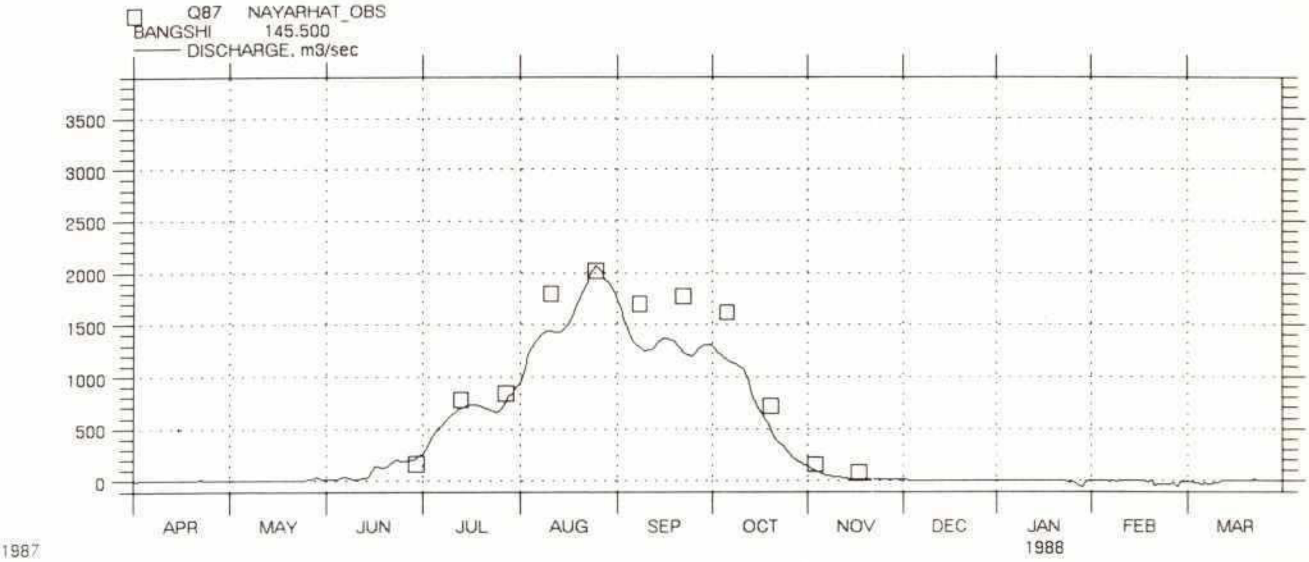
343

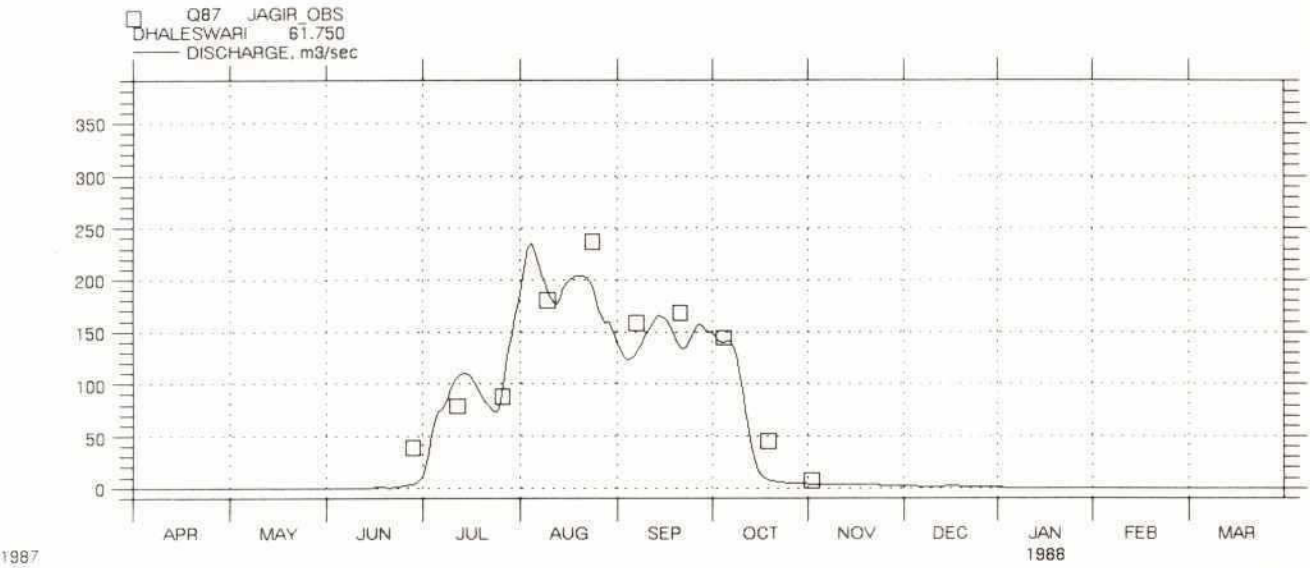




SWMC	NORTH CENTRAL WESTERN SUB – MODEL CALIBRATION RUN – 1988 DATA	
DATA FILE : NCRM_W.RDF RESULT FILE : CAL88_W.RRF	BOUNDARY FILE : NCRM_W88.BSF CALCULATED : 16 – OCT – 1991, 16:56	MIKE 11 Dwg no.:

344





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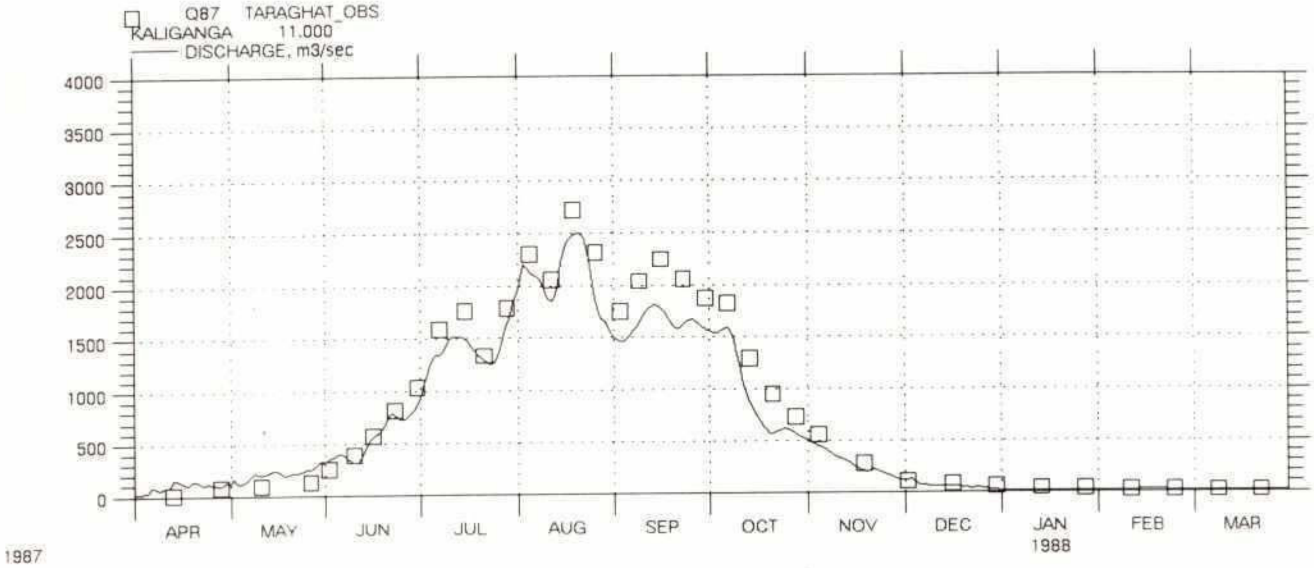

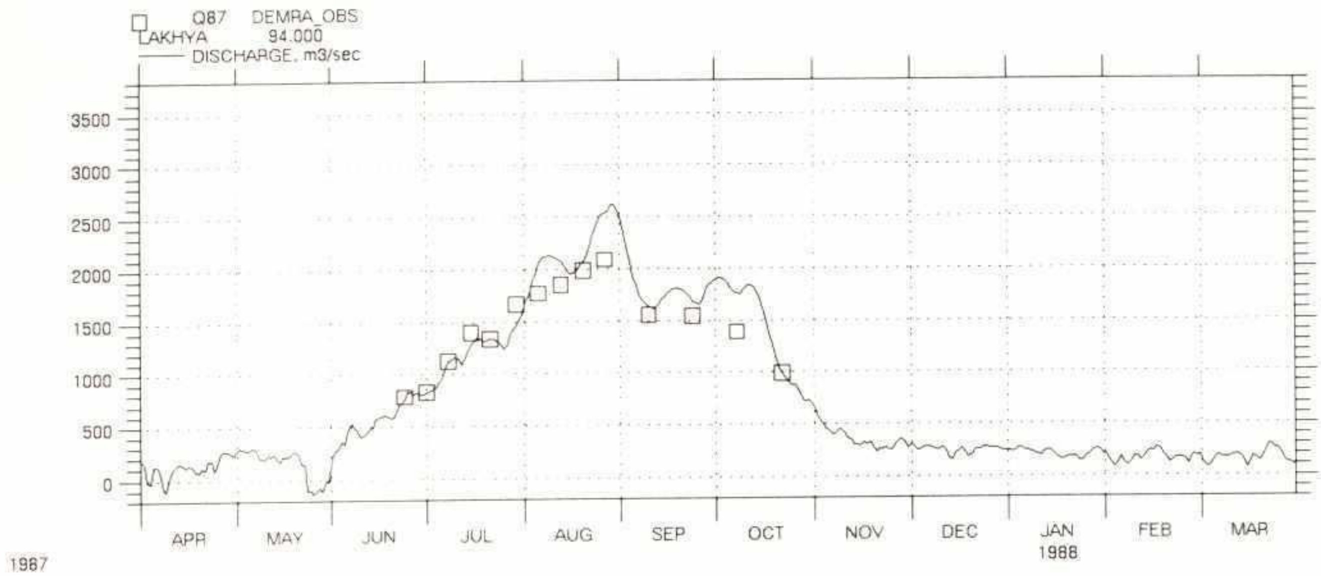

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CALIBRATION RUN - 1987 DATA

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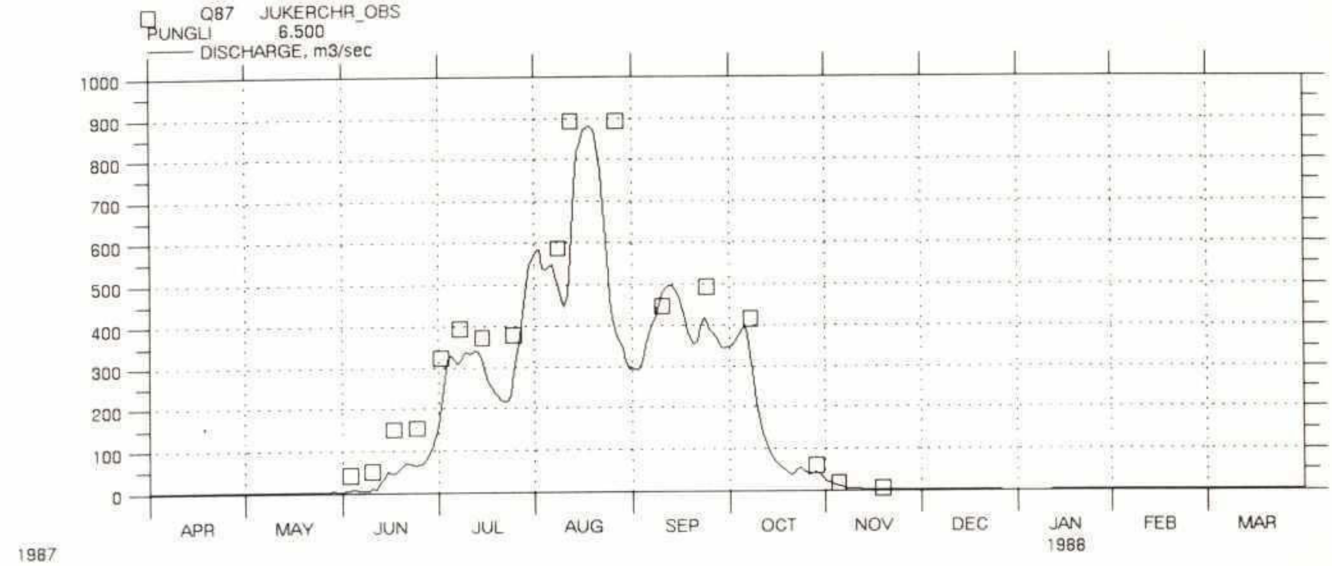

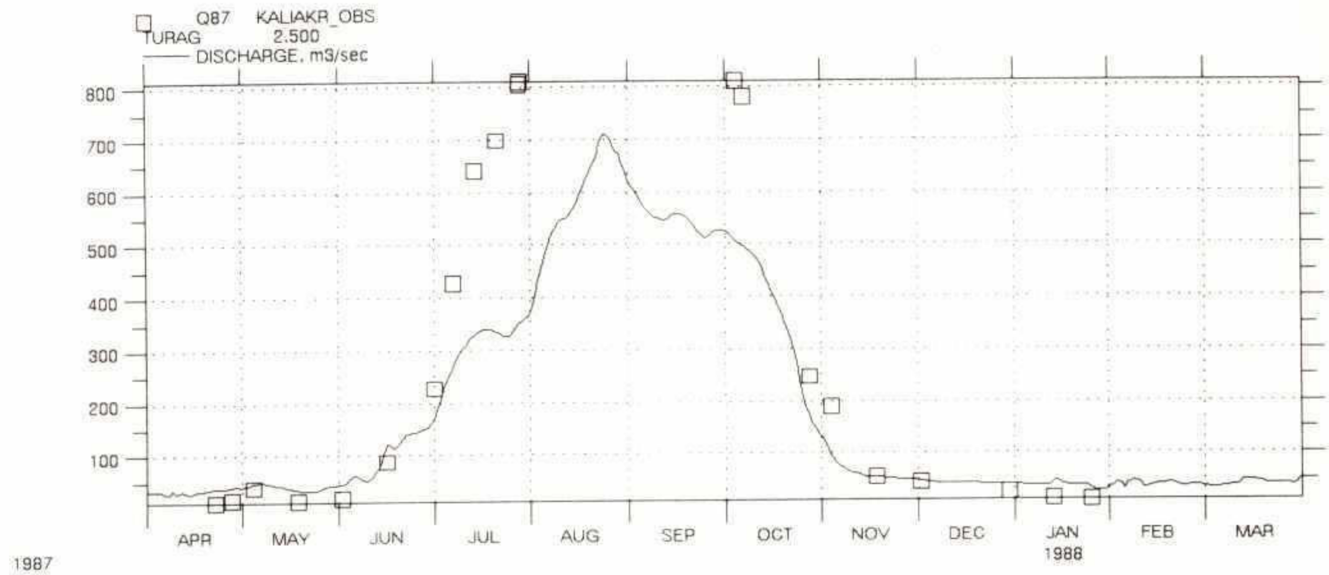

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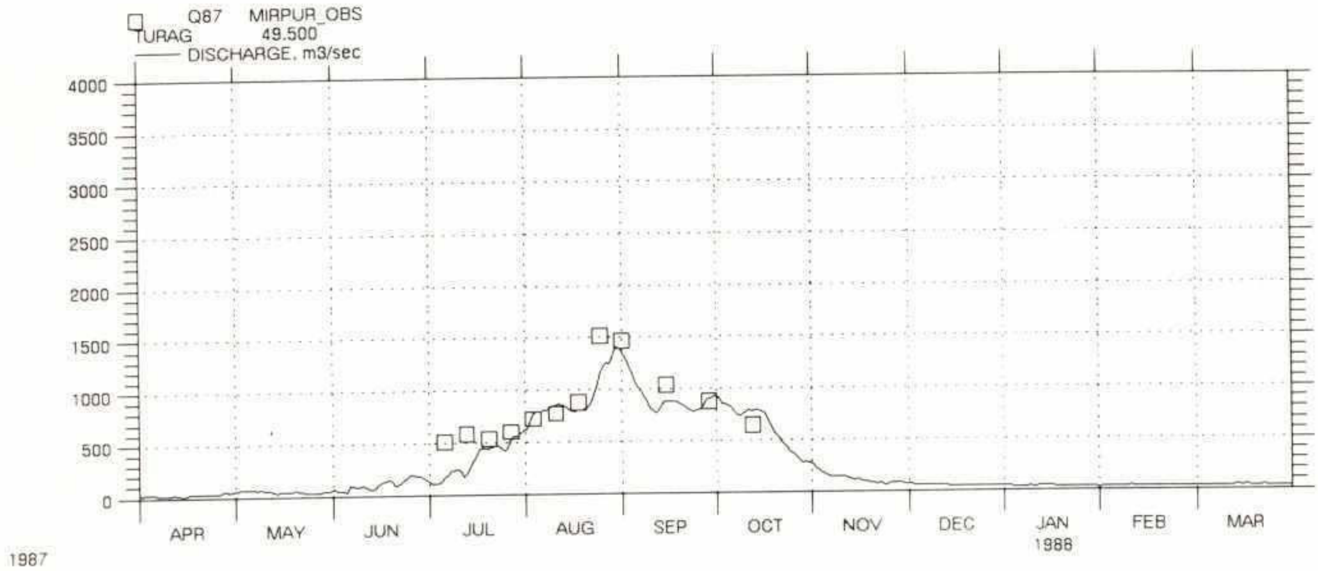

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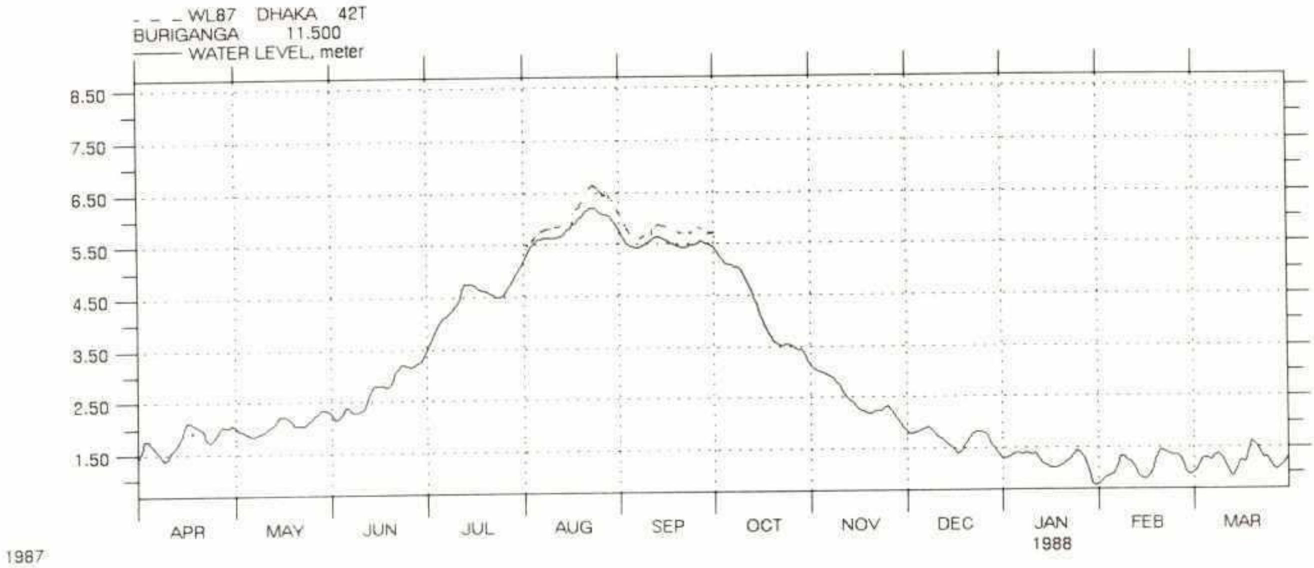

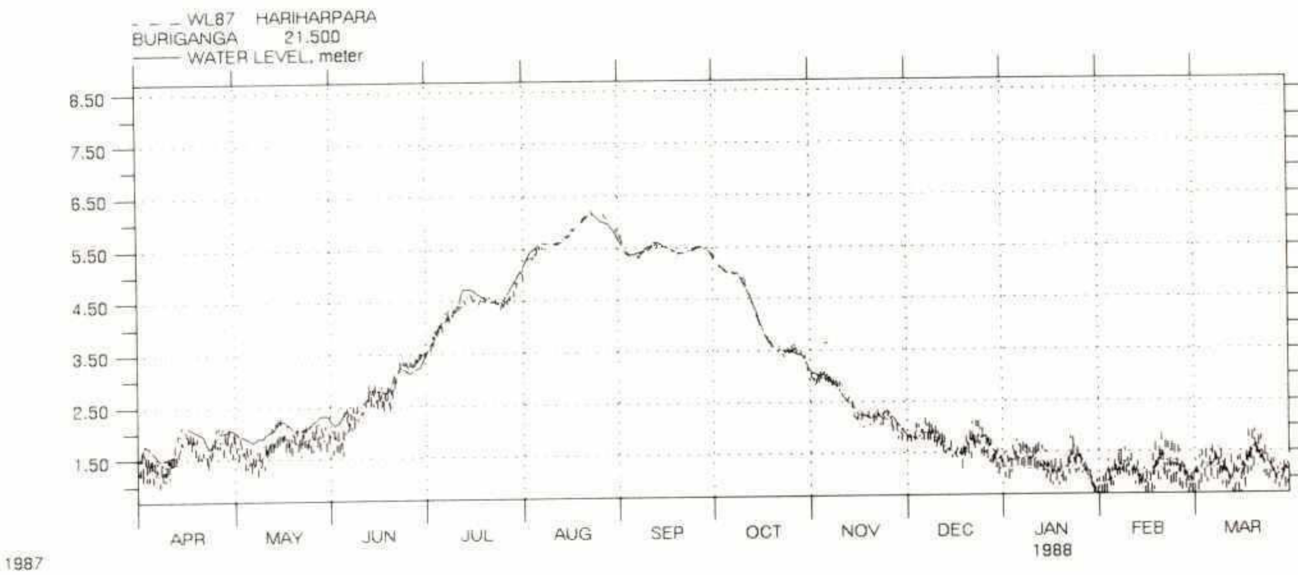

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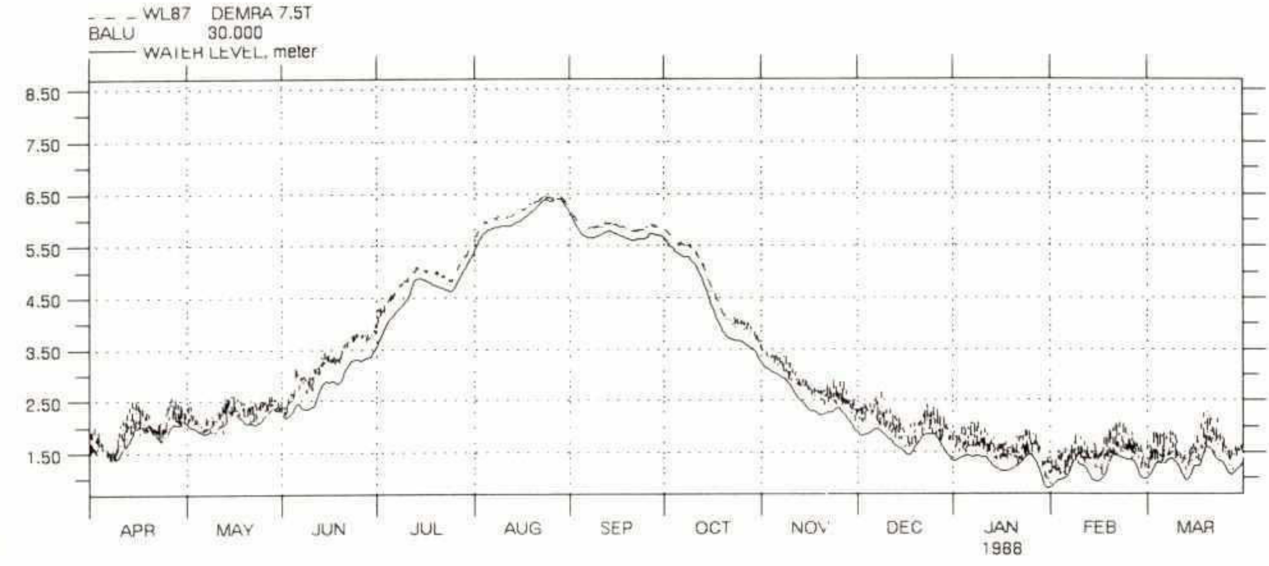

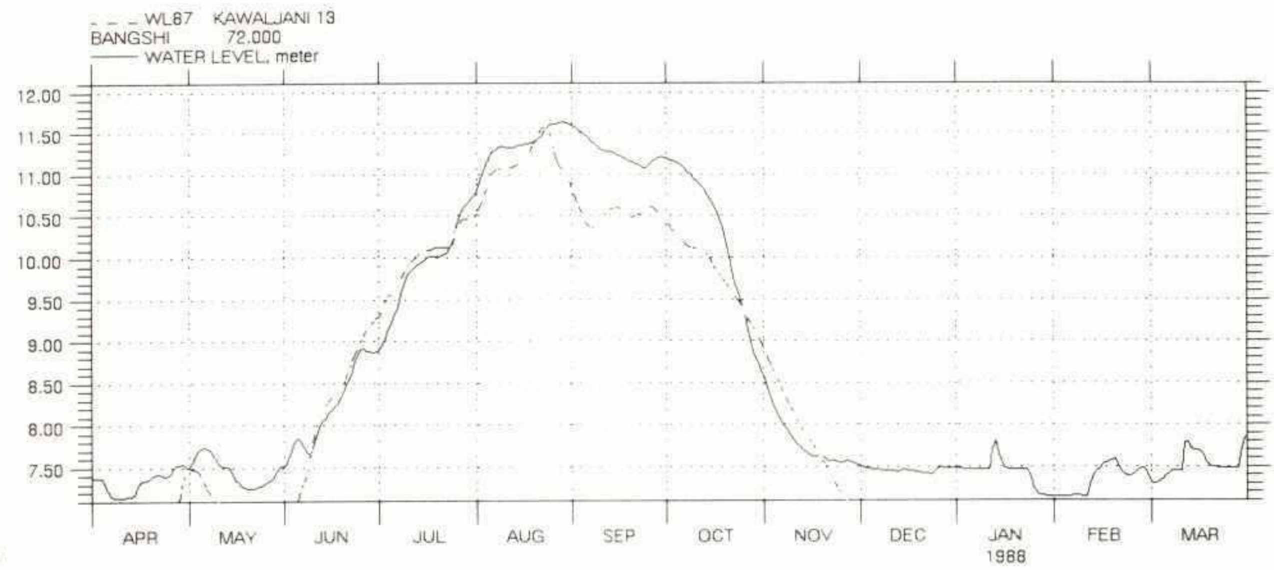

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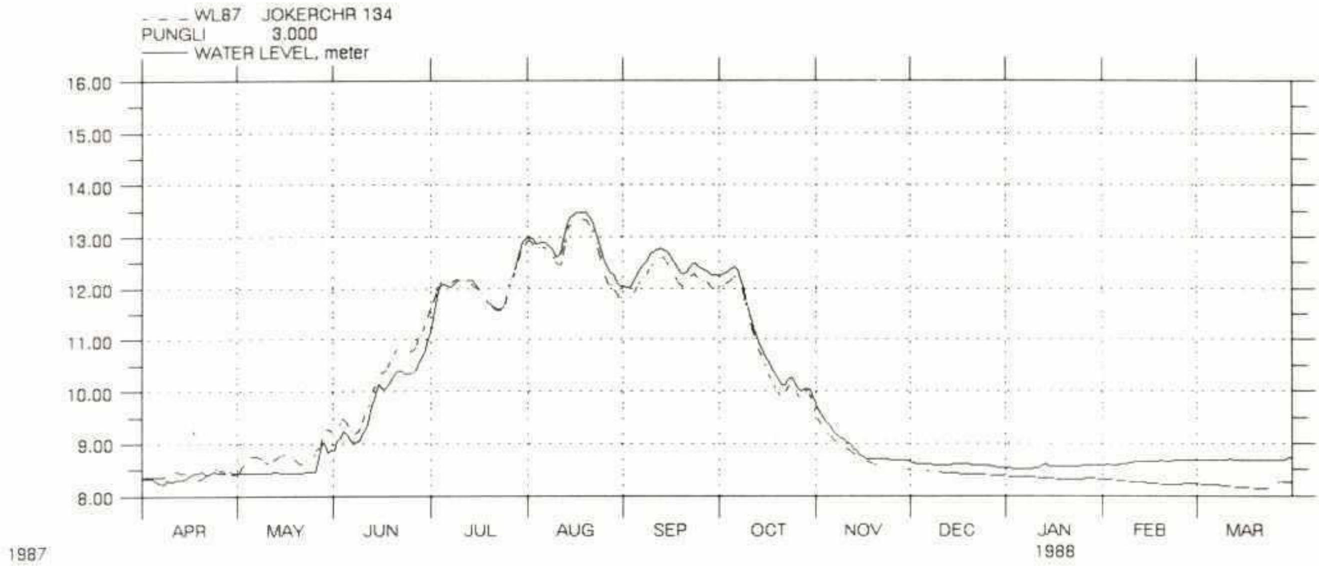

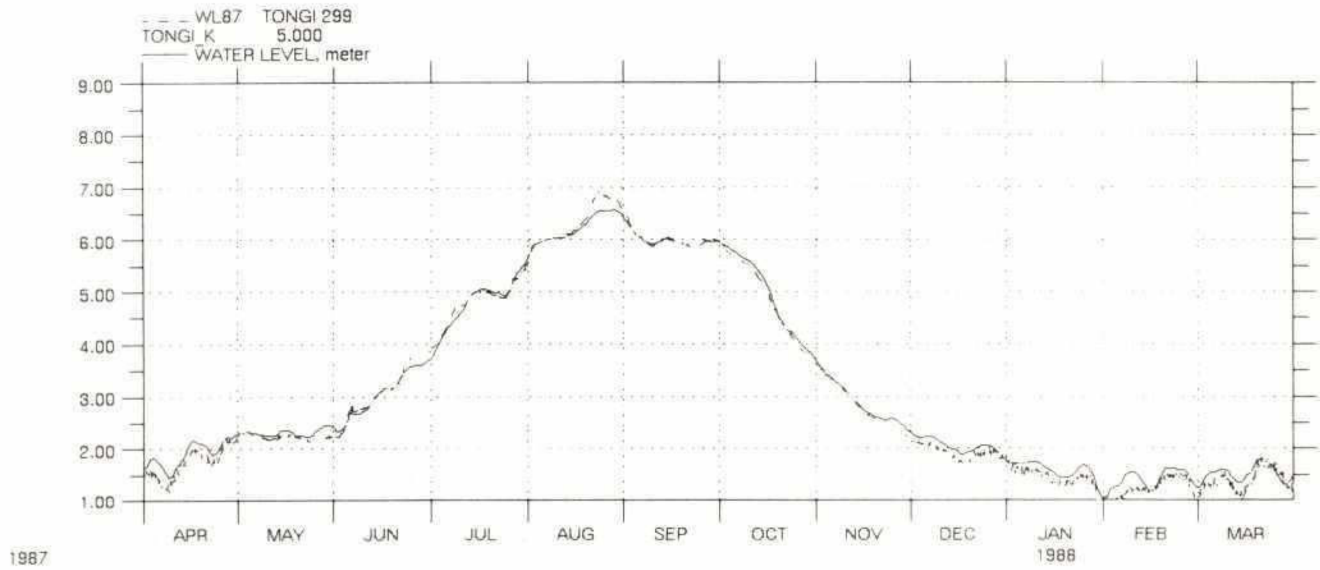

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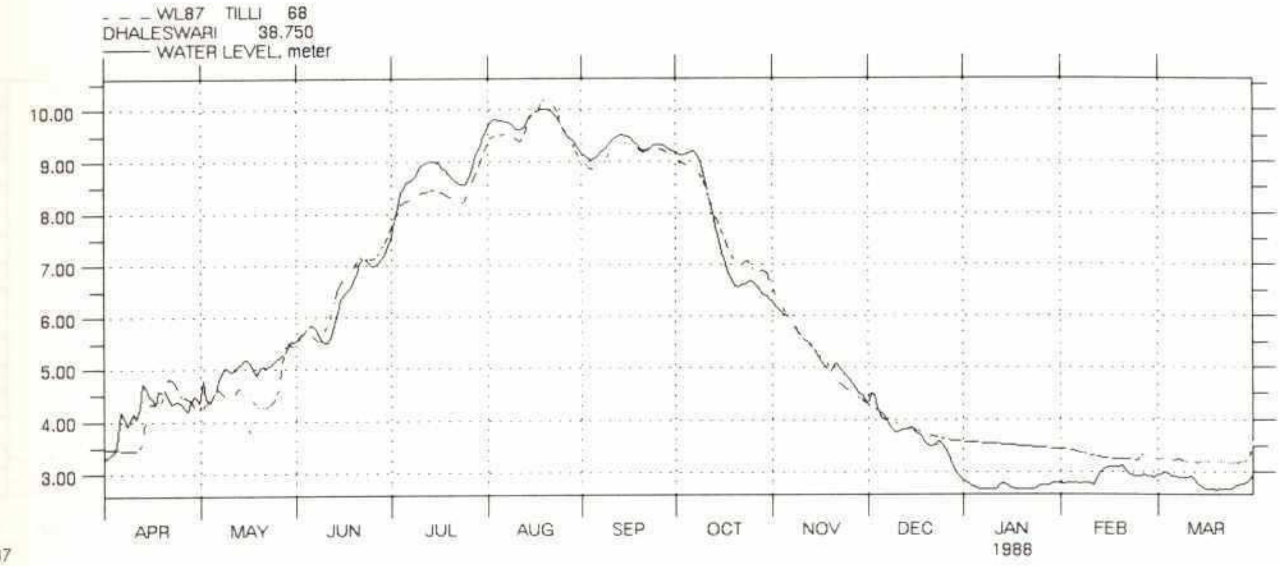

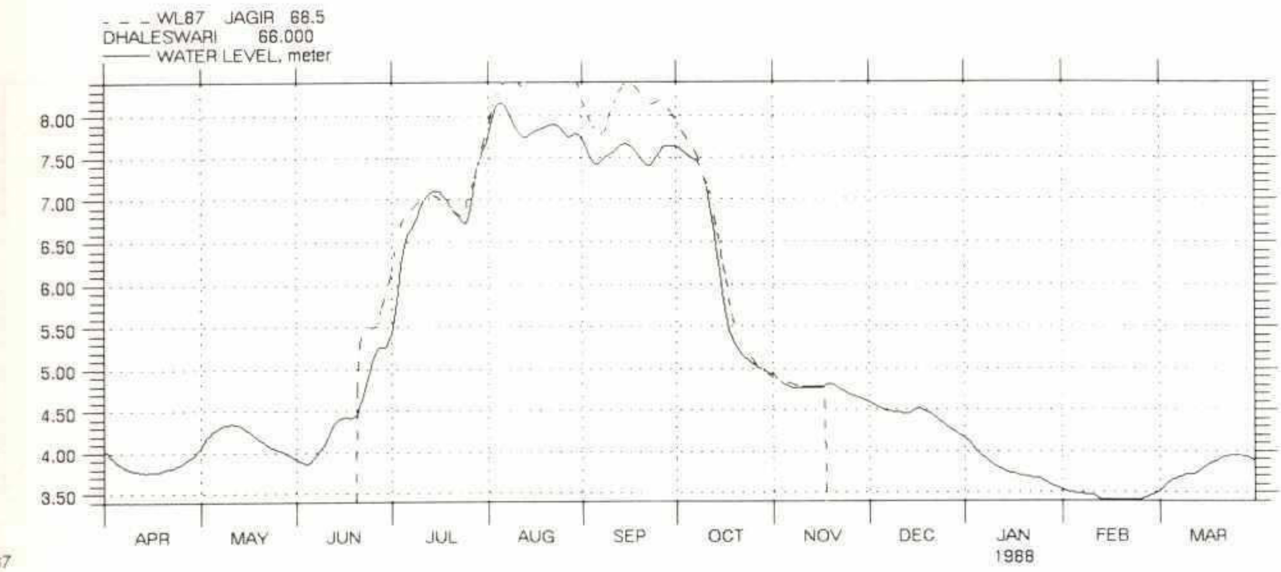

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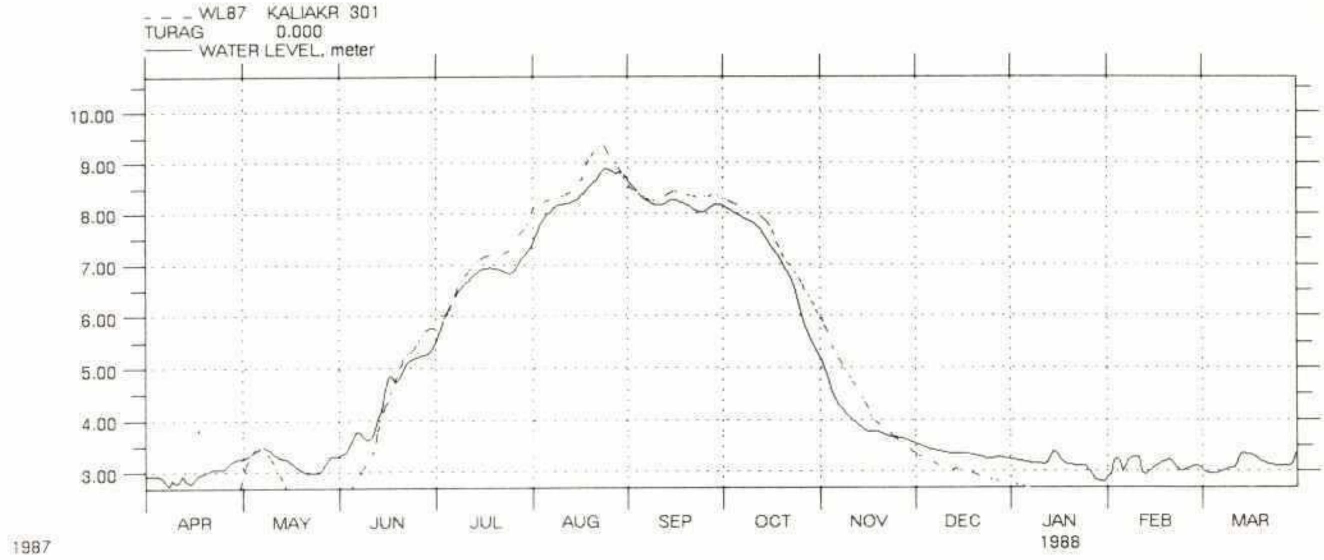

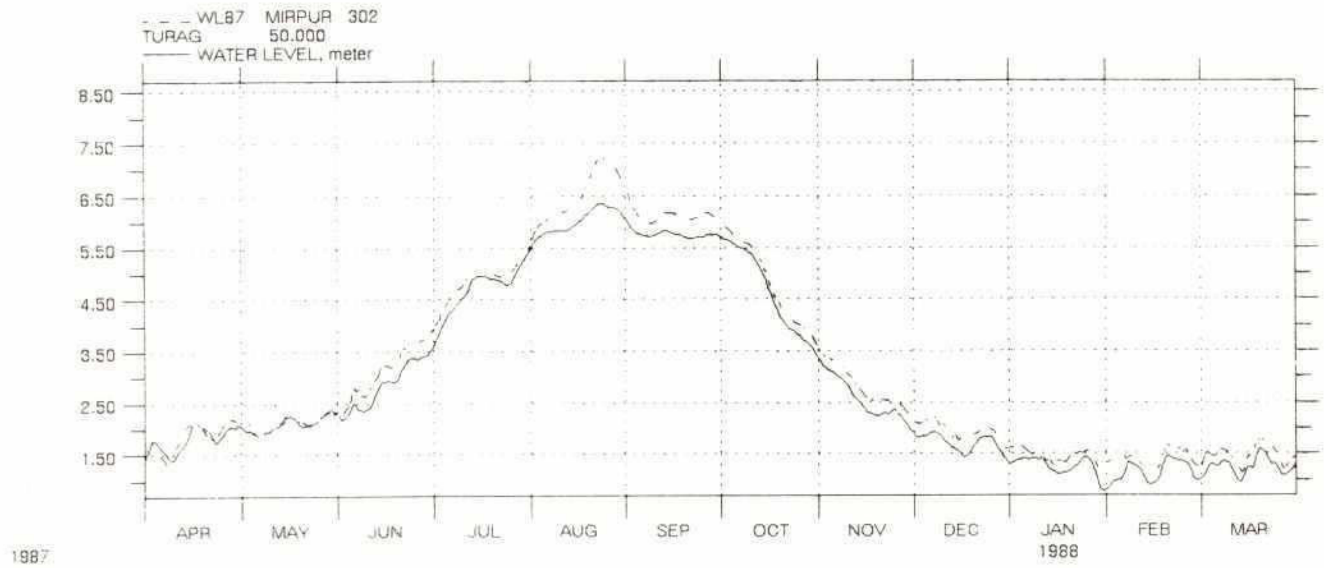

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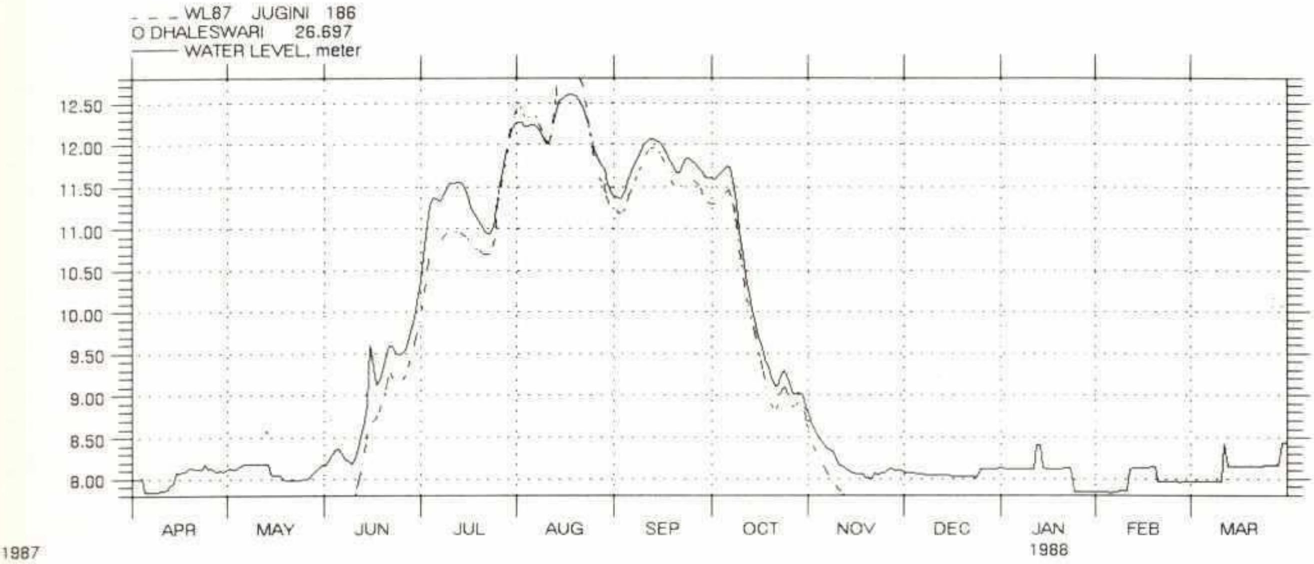

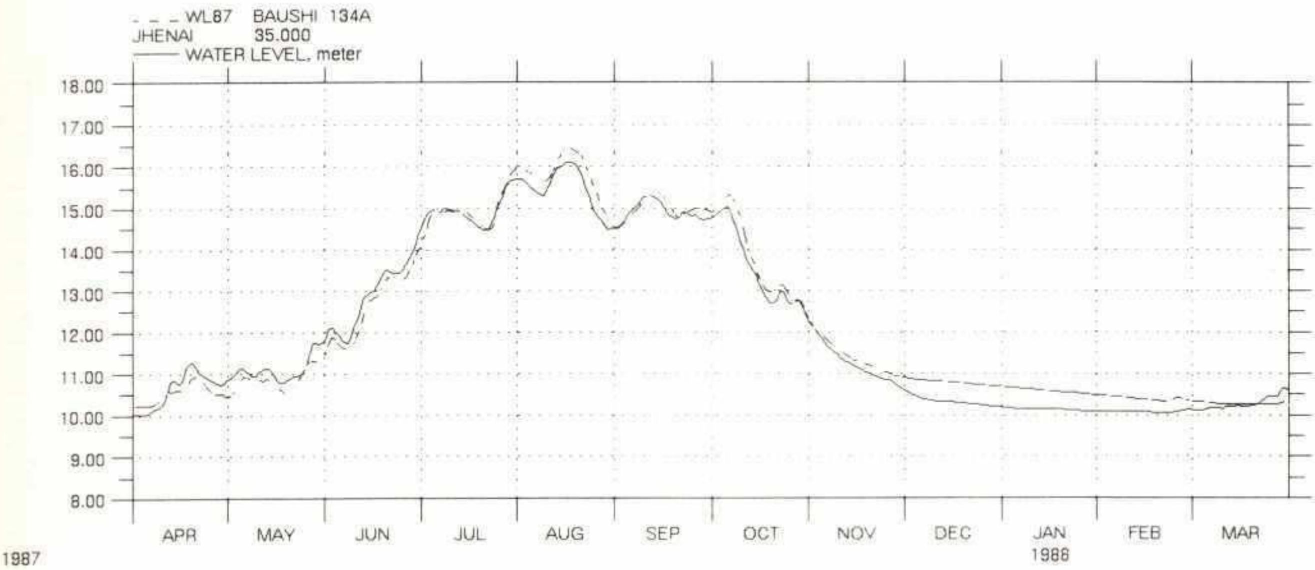

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CALIBRATION RUN - 1989 DATA

MIKE 11

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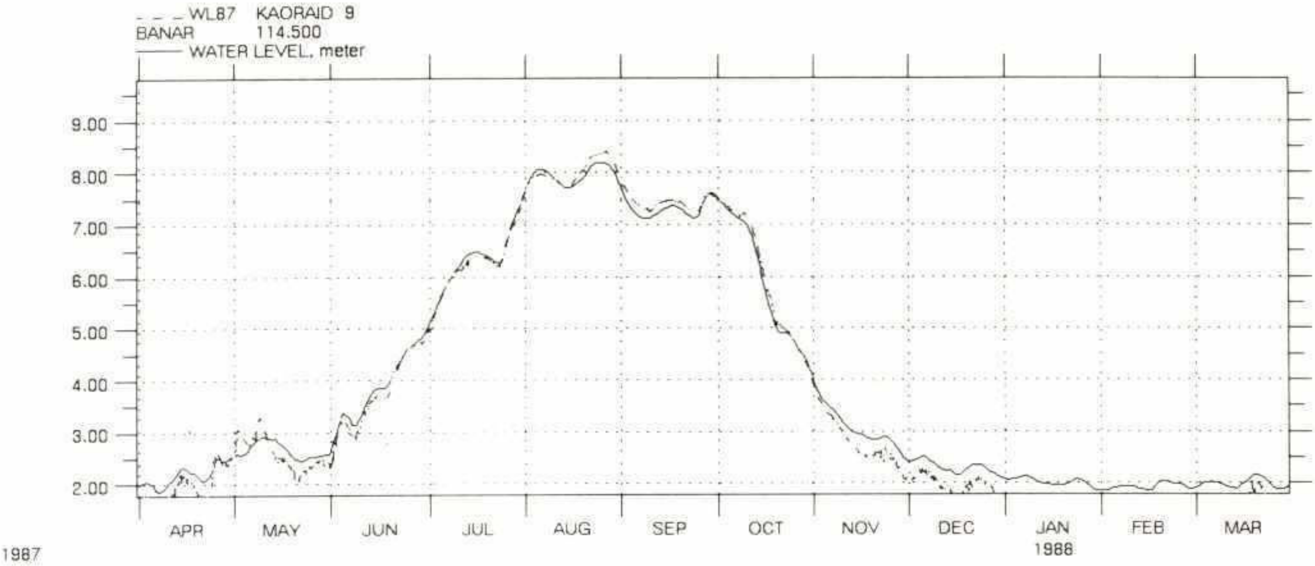

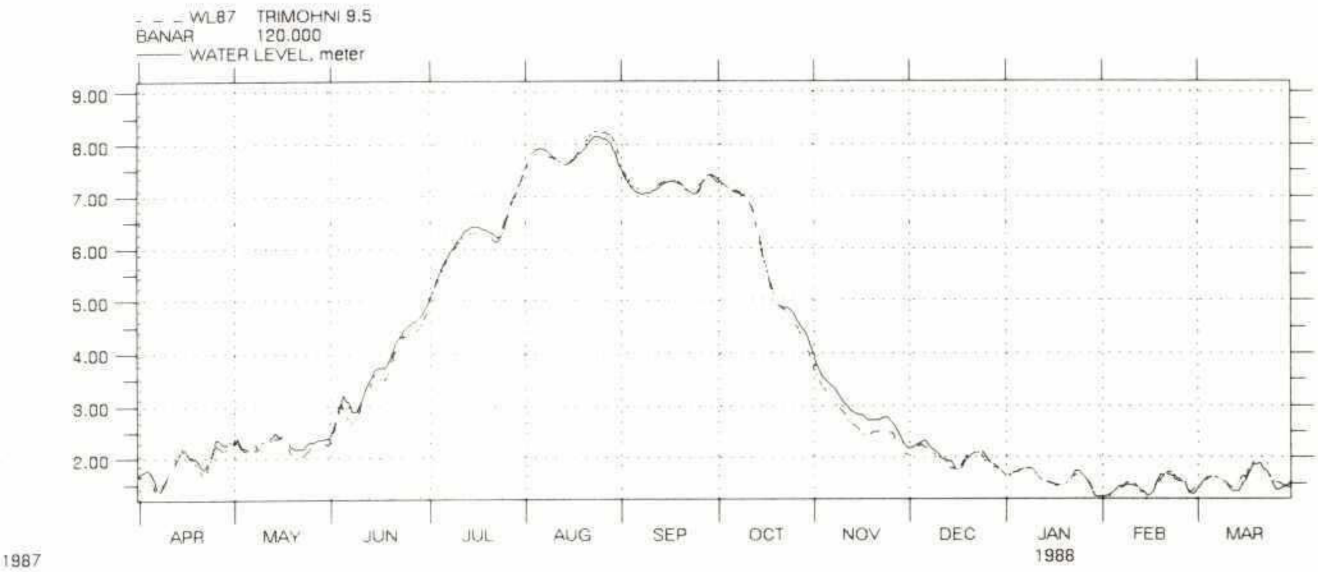

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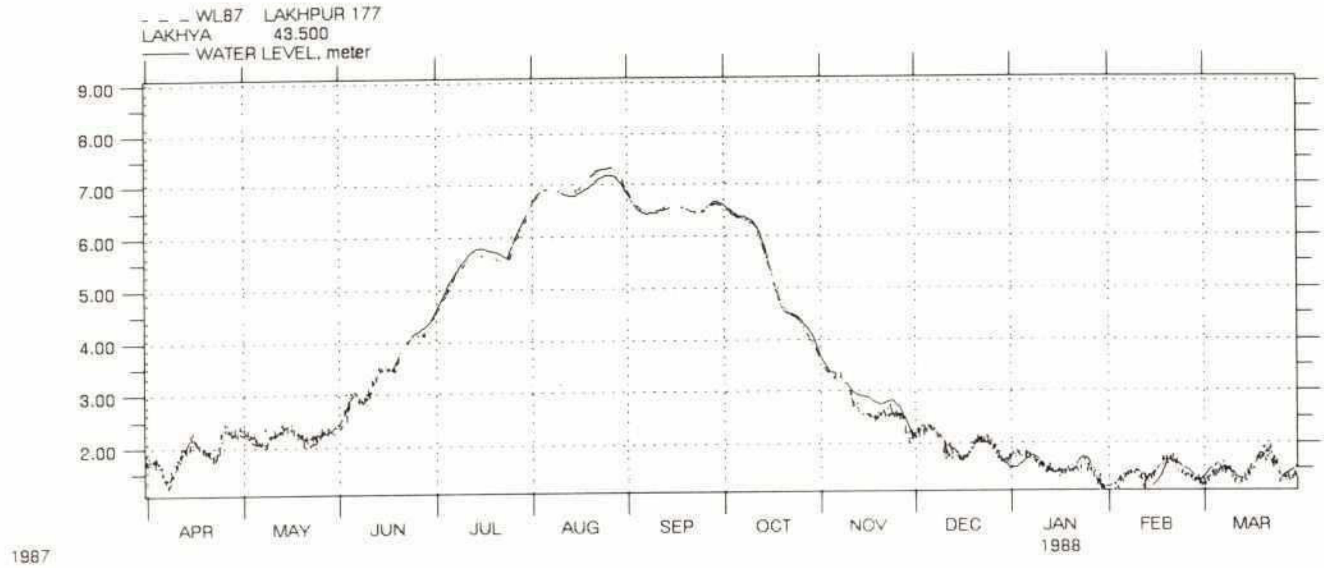

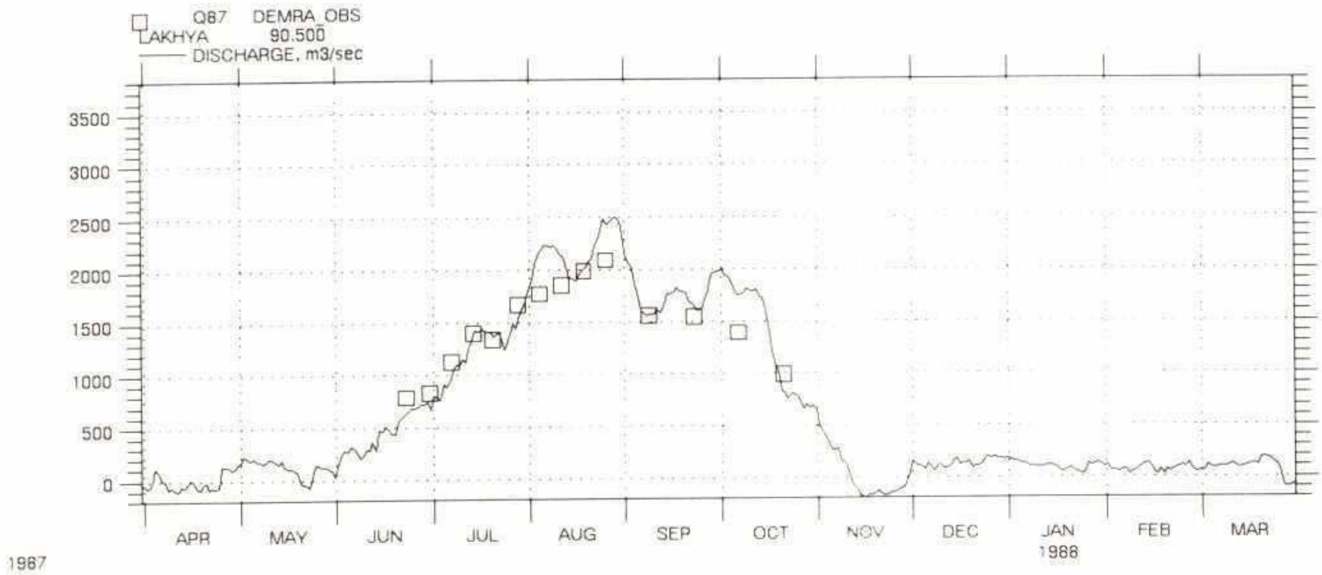

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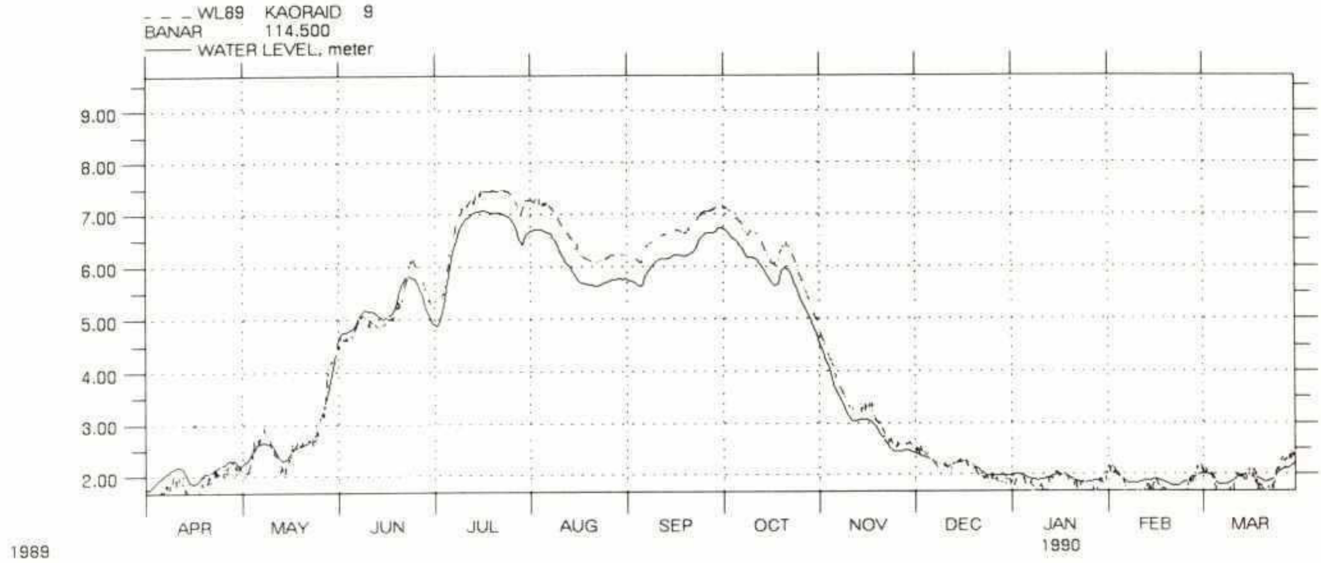

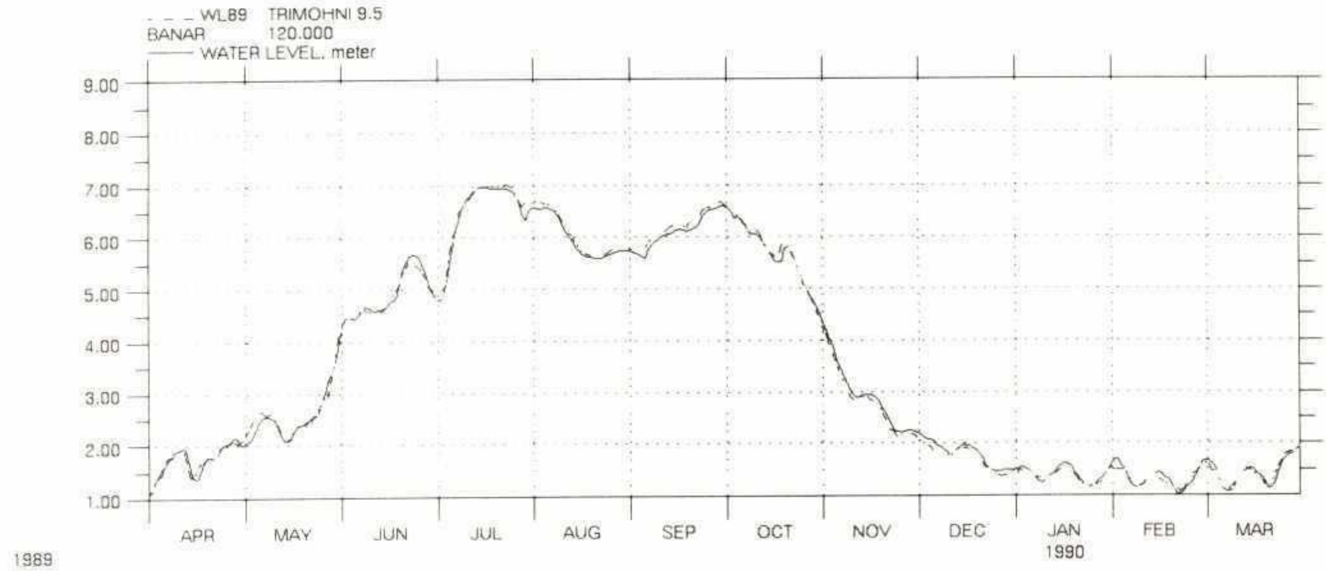

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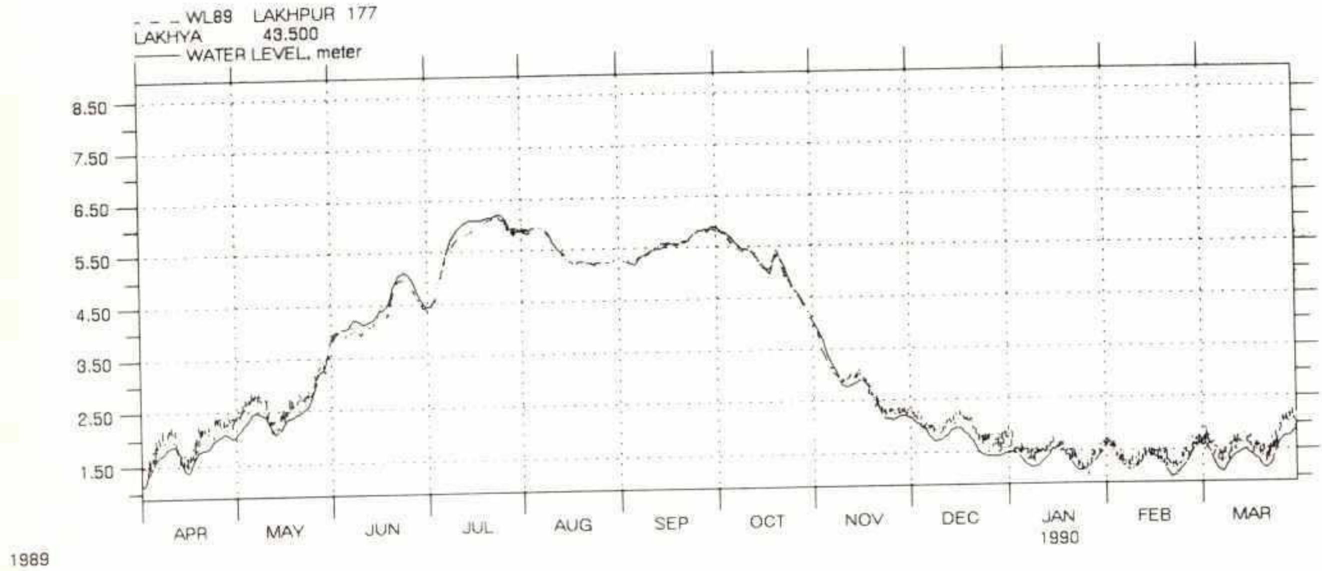

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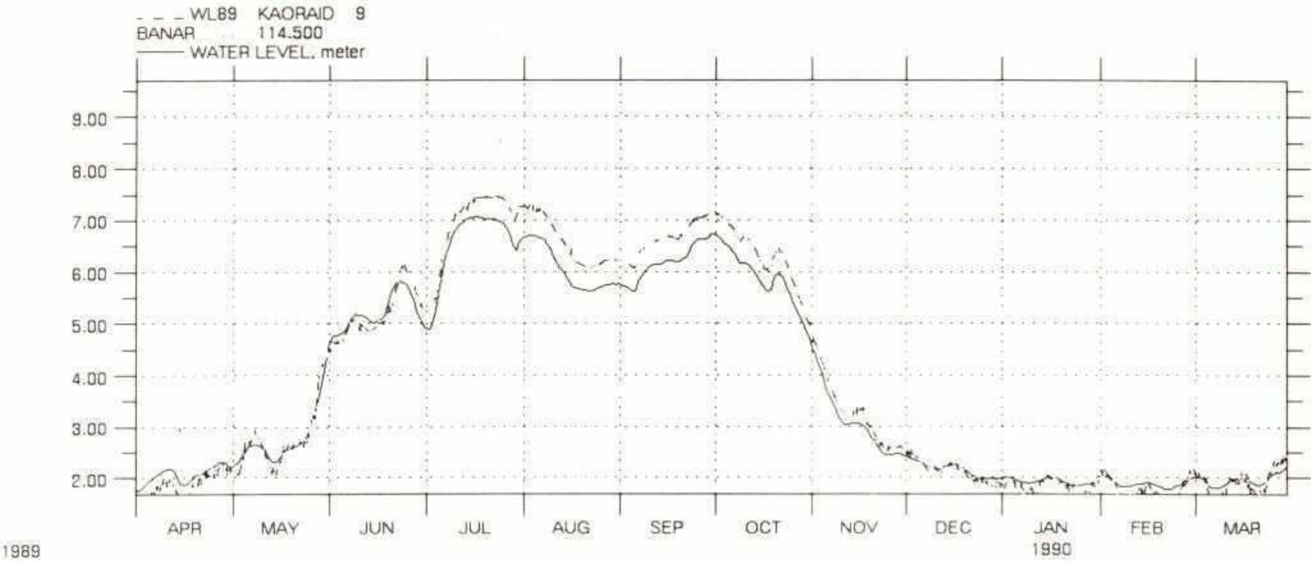

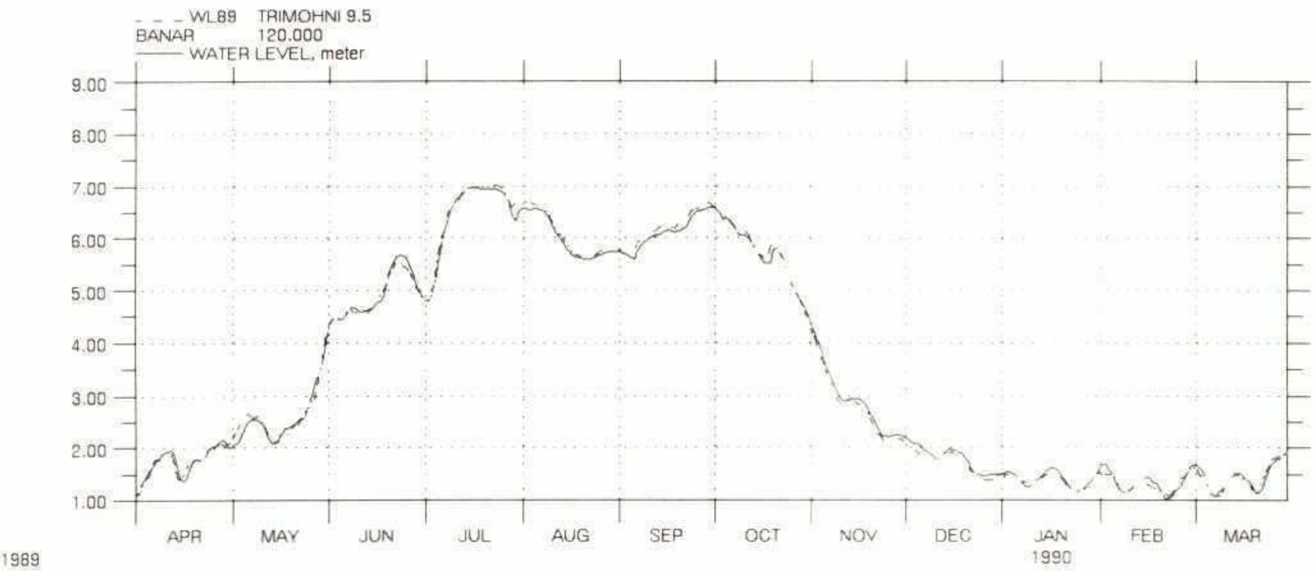

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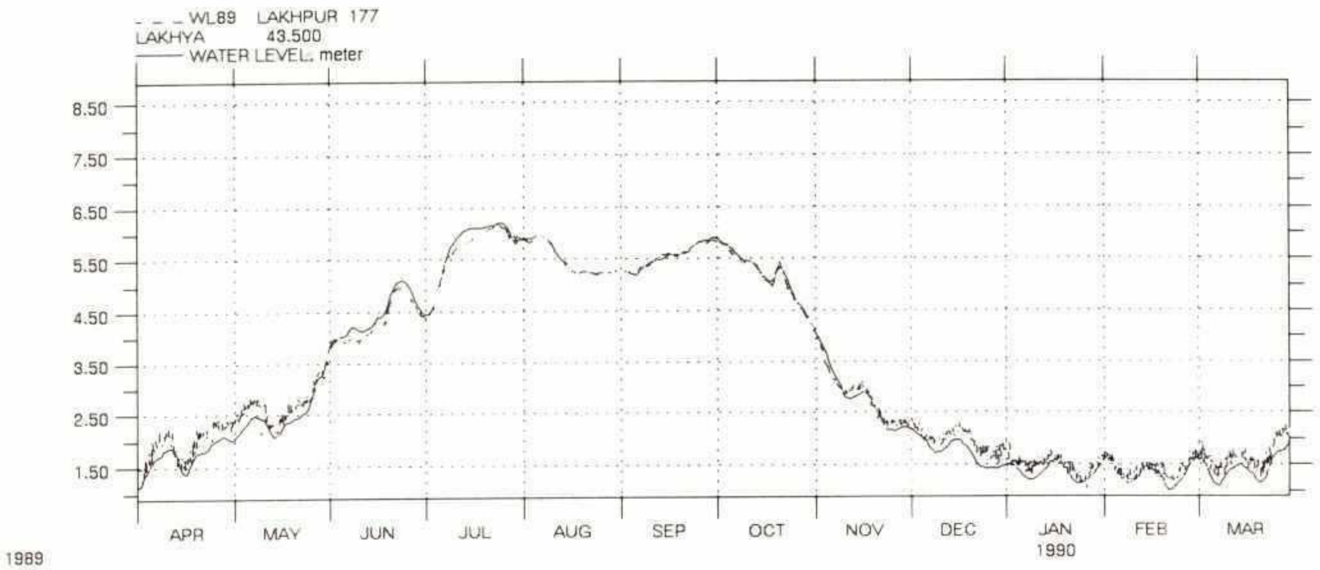

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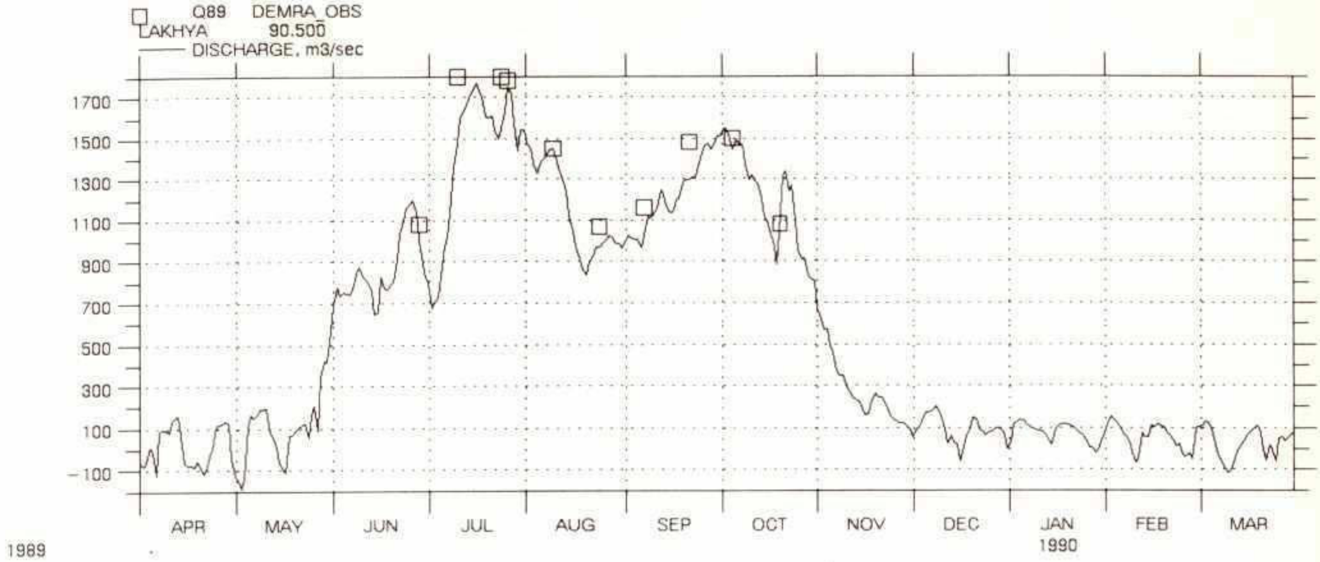

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SR II.5

Appendix II
Pre-feasibility Studies - Hydraulic Modelling

APPENDIX II
PRE-FEASIBILITY STUDIES-HYDRAULIC MODELLING

1. Introduction

This Appendix presents the hydraulic model information relating to the various Pre-feasibility Reports for the selected Schemes. Reference is also made to SR VIII where more general information relating to the Schemes is presented. Each major selected scheme, or combination of scheme, has been modelled using the DHI developed software package, MIKE11 from which the North Central Regional Model, (NCRM), has been constructed. The NCRM is in the Coarse Pilot stage. For further details of model construction, calibration and operation, reference should be made to the section 2 of SR II.5, and to the software manuals issued by DHI to model users.

Modelling activities for the schemes selected for analysis at pre-feasibility level were based on essentially the same model as that used for the initial screening studies, at Interim Report stage. Therefore, it should be noted that the enhancements to the overall results for this pre-feasibility level stem primarily from improvements in the engineering and costing details and not to any significant improvements to the model. Minor changes to the description of flood plains were made to the Dhaleswari and Kaliganga rivers in an attempt to reproduce the probable modification to flooding characteristics resulting from the imposition of an embankment on one side of these rivers. No other modifications to the basic model were made for these pre-feasibility runs.

For these pre-feasibility runs, 1989 data was used as that year is considered to be representative of "normally" occurring floods. An additional run was made using 1987 data as this year represented, (with respect to main river flows), approximately a 1 in 15 year event at Porabari on the Jamuna. Runs with 1988 data were not made as this year is considered to be poorly simulated in the model and any results would be misleading.

2. Limitations to modelling

The use of a 1-dimensional model for investigating the effects of embankment schemes results in limitations to both the detail that can be modelled and to the degree of accuracy of the results. The limitations in detail mainly concern the representation of the flood plains and the interaction of the river channels with these flood plains.

1-dimensional modelling assumes that the adjacent flood plains are drainage flood plains, i.e. the water level on the flood plains is the same as that in the river and there is a common water surface joining the two elements. 2-dimensional, (or quasi 2-dimensional), modelling assumes that the water level in the river and flood plain can be different at some stages of flow and that water commences to spill onto the flood plains when the water level in the river reaches a predetermined fixed level. In the absence of more detailed survey, this phenomenon is represented in MIKE11 by shallow v-shaped weirs offtaking the main channel at defined locations. If survey of the khals is available, the points of interaction may be represented by the khal cross section.

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The concept of quasi 2-dimensional modelling is not expected to be employed at the Pilot Model stage. It cannot be entertained at the Coarse Pilot Model stage of this study for the following reasons:-

1. Quasi 2-dimensional models at a regional scale would be far too complex and exceed the memory capacity of the present DOS based version.

2. The collection of additional river survey and topographic information required would be outside the capabilities and time-frame of the present study.

3. The additional time required for the calibration of a quasi 2-dimensional model at a regional scale would be more than that presently available.

Perhaps the most important point arising from the inability to employ a quasi 2-dimensional model is that which relates to the effect of embankments. In a drainage flood plain, (where there is a common water surface joining river and flood plain), embanking a river would, in theory, eliminate flooding from the river. Rainfall inundation would continue behind the embankments. The embanking of a river in such a system is modelled by moving the bank "marker", (which indicates the limit of cross section to be considered in the computation), to a point close to the bank of the river as indicated in the cross section in the model. This has the effect of reducing the cross sectional area of flow and hence raising the water level in the river.

If, as is the case in almost all the western part of the NCR, the river banks are higher than the adjacent flood plain, (in some cases, the river bed is higher also), lateral overbank spill takes place when the river level is sufficiently high. Some flow takes place at lower stages through the khal system which serves to pass water onto the flood plains. Modelling of this overbank spill is not possible with the 1-dimensional model presently developed for the NCR and therefore the procedure of moving the bank "marker", as previously described, would represent the construction of an embankment of infinite height, with no provision for intermediate heights to be tested. **Thus the effect of lower embankments, which would be designed to be overtopped by a flood of higher return period than design, cannot be tested.** For this degree of detail, quasi 2-dimensional modelling must be employed. Figure 1 shows the fundamental differences between models required for both 1- and 2-dimensional simulations.

3. Jamalpur Priority Project Area Modelling

Concurrent with this study, other consultants are undertaking a feasibility study of the Jamalpur area, part of the river system of which is contained in the NCRM. The JPPS model contains more detail than the Coarse Regional Model, in that it is quasi 2-dimensional in structure and represents more of the minor rivers of the area.

To maintain compatibility between the two studies, the JPPS model was used in order to test the effects of the proposals for that area. This approach was also used because the DOS operating system memory precluded the two models from being combined and run together. In practice, since the only interaction between the JPPS area and the rest of the NCR is via the Jhenai river at Baushi Bridge, (for which boundary conditions can be specified), any intervention imposed within the JPPS area may be treated as independent of the rest of the region. In addition, it is always desirable to use the most detailed model available, although there remain reservations as to the accuracy of the JPPS model due to the lack of internal calibration points.

4. Layout of this report

Each scenario is modelled and the results are presented in graphical form. There were 35 runs of the model made for these pre-feasibility studies and it is impractical to reproduce the full MIKE11 water level and discharge output for each of the runs, together with some 13 pages of post-processing data output for each run. The output has therefore been restricted to a graph showing the change of flooding characteristics resulting from each regional scheme, (or variation of scheme), Planning Unit by Planning Unit. Thus the impact of the scheme on the existing flood conditions in the Planning Unit can be seen at a glance.

The scenarios are examined in turn. Their primary designation is given, together with any sub-designation given to a possible variation. Reference to Table II.2 will give the relationship between model runs and the particular scenario examined in that run. For modelling purposes, the possible engineering interventions have been separated and identified as "elements". Thus a particular scenario can be represented by a run consisting of one or more elements in combination. Table II.1 gives the elements included, with the corresponding element number. This should then be cross-referenced with column 2 of Table II.2.

A brief physical description of each scenario is given, together with the changes to the basic model setup required to simulate this configuration. There then follows a brief explanation of the probable reasons for changes indicated by the model. It should be noted that there are two base cases:- one without Jamuna bridge being constructed and the second with Jamuna bridge constructed.

5. Basic Methodology

The following pages describe the engineering interventions tested. In order to represent the proposed structural alterations to the existing situation, certain tools are available to the modeller within the framework of the MIKE11 software, subject to the limitations described above. The means by which such interventions are represented in the various model runs are described below, since they are often repeatedly used in model runs.

a. Embankments

In the 1-dimensional model used for this study, embankments alongside the rivers are represented by reducing the cross section considered as contributing to the area of flow. This is done in the model by moving the bank "markers", (points which are used to define the limits of the channel and flood plain), to appropriate locations nearer the river banks. Thus for a given discharge, the cross sectional area of flow is smaller and hence the river level rises accordingly.

As explained previously, (Section 2), embankment heights protecting against specific return period events cannot be simulated in a 1-dimensional model, since lateral spillage cannot be represented.

b. Control structures

Modifications to the flow in the river network are achieved by means of control structures, of which there are various types. MIKE11 allows for the representation of some of these types to varying degrees of complexity. In general, the more complex the structural representation, the more data required to define it and its operation.

Structures proposed at the pre-feasibility level fall into two categories: fully controlled or semi-controlled. Fully controlled implies that the flow through the structure may be regulated in terms of both timing and quantity. Thus the flow through the structure may vary from zero, (gate closed-fully controlled situation), to the unregulated maximum, (gate fully open).

Gates may be operated as a function of upstream head, both upstream and downstream head, or be time dependent. Since the control of a gate as a function of head requires a detailed knowledge of the proposed operational sequence, (not likely at this pre-feasibility level), no such structures are employed in the model. Time dependent operation is simpler, requiring the construction of a boundary file which describes the sequence of opening and closing.

Note that "fully controlled" in terms of a structure does not necessarily imply the same as "fully controlled" in terms of a flood control scheme. It is technically possible to have a fully controlled structure as an element in a "controlled flooding" type overall scheme.

Semi-controlled structures imply that control of the discharge only is possible, such as the case of a weir or culvert. In these cases, the discharge is controlled by reducing the cross sectional area of flow, ("throttling"). Unfortunately, if the discharge at a certain distributary is required to be throttled to a certain absolute value, this cannot be done directly in the model. It is necessary to employ a trial and error process, choosing certain values of weir or culvert width and running the model to check the resulting discharge. This is a time-consuming task, (especially when run-times for the model are of the order of 4 hours), and therefore, in some cases, the values of discharge simulated exceed that required. However, it is assumed that any future feasibility study would address this aspect in greater detail and endeavour to size that required structure more accurately.

Culverts have been employed to represent controlled inlets to and outlets from the model. Where negative flow is not required, (in the case of a flap gate), this can be easily simulated within MIKE11.

For the operation of control structures, time related gate movements should be used where available for recorded evetns. Where the operation data are not available an operation rule should be devised based on a discussion wuth the gate operators or in the synthetic case as required to achieve the desired control. Throttling to an absolute discharge is difficult to achieve in practice and requires operational control based on instantaneous sensing of the discharge and the use of an operating rule. This problem should not be viewed as a model limitation.

c. River improvements

The conveyance of a watercourse may be enhanced in a number of ways. The river section may be increased by widening and/or deepening the channel, thereby either conveying more discharge for the same level or the same discharge at a lower level. Re-alignment of a river will alter its slope and therefore its carrying capacity.

The adjustment of the conveyance of a river may be represented in the model by suitable adjustment of the roughness factor for the chosen reach. This is simpler and quicker than re-defining the cross sections, but has the same effect. Thus any river improvement is represented in the model by an adjustment of the roughness coefficient by the appropriate amount.

d. Jamuna Bridge proposals

Incorporation of the Jamuna Bridge into the model structure impacts mainly on the northern intake of the Dhaleswari and the first spill channel south. These two channels will be cut off by the bridge approach and protection works respectively. In addition, the Dhaleswari Mitigation Project recommended the construction of a "guide embankment" parallel to the Jamuna extending from the bridge works to just north of the southern intake of the Dhaleswari. The justification for this "guide embankment" lies in the increased differential water levels between the Jamuna and the Dhaleswari that would result from the closure of the northern intake. It was felt that without additional protection in the form of an embankment, the Jamuna could cut through to the Dhaleswari much easier with the increased head difference.

All schemes were modelled both with and without the Jamuna Bridge works, (including the "guide embankment". With the bridge works in place, the spills from the Jamuna into the Dhaleswari were significantly reduced in volume.

e. Baushi Bridge restriction

Restriction to the flow in the Jhenai at Baushi Bridge would result in significant improvements to the flooding regime downstream, Planning Units 2 & 4 in particular. It was assumed that the flow at this point could be reduced to a maximum of 50 cumecs by some form of control structure. Modelling this intervention required two different approaches, depending upon whether the NCRM or the JPPS model was employed.

In the JPPS model, the water level station at Baushi Bridge supplies an external downstream boundary. The MIKE11 software permits the option of replacing a downstream external boundary with what is termed a Q-h boundary. In this case, the user specifies the relationship between the water level and discharge at the point. Using this facility, the user can specify a set of levels and corresponding discharges which accord with his requirements. In the case of the JPPS model, the relationship was set such that the bankfull discharge was around 50 cumecs, with only marginal increases in discharge permitted for large increases in water level.

When the NCRM is used, the incorporation of the Baushi Bridge restriction cannot be made with such accuracy, since the point is no longer a downstream boundary and hence cannot be replaced with a Q-h relationship. In this case, it was decided to place a weir structure in the river and to throttle the flow in this way. The drawback to this methodology is that the flow over the structure then becomes dependent on both the upstream and downstream water levels, which themselves cannot be regulated. The user is normally forced to employ a trial and error method to arrive at a suitable constriction which delivers the required flow at maximum water surface elevations.

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Basic Scheme: RS1

Represented by Model Runs: JPPSa1, JPPSa2, JPPSb1, JPPSb2, JPPSc1, JPPSc2, JPPSd1, JPPSd2

Scheme Description: Scheme RS1 concerns the Jamalpur Priority Project area only. There are 4 basic scheme options: Option A represents the adoption of non-structural measures throughout the area in the form of flood proofing, flood preparedness etc. Option B considers the whole area to be subject to controlled flooding with internal improvements to drainage. Option C divides the area into 2 parts along the line of the Chatal river. That area to the west of the river to be the subject of non-structural interventions only and that to the east to be embanked with controlled flooding and drainage improvements. Option D considers a full scale polder around the area with the exclusion of all floods by structural means together with internal drainage improvements. Each Option has been tested with the outflows from the Jhenai river both restricted, (1) and de-restricted, (2).

Model Setup: Option A

The JPPS model was used for the investigation of the JPPS area, (Planning Unit 1). With Baushi Bridge de-restricted, no changes were required to the basic model. The restriction of Baushi Bridge was simulated by substituting a Q-h boundary condition at that point, with a maximum permitted discharge of 50 cumecs. (This method of simulating the restriction was used in all subsequent cases of runs with the JPPS model).

Option B

For this Option, an embankment was simulated around the entire area by disconnecting the spill channels into the area from the Jamuna. Flows into the area via the Chatal and Jhenai were controlled assuming the imposition of suitable sized culverts at these inlets. Outflows from the area via the Chatal South were represented by a culvert permitting flow in an outward direction only.

Option C

The construction of an embankment on the left bank of the Chatal river would prevent ingress of water into the area via the spill channels. These spill channels were disconnected from the Chatal. Inflows into the protected area via the Jhenai were again simulated by a culvert structure allowing a maximum discharge of 250 cumecs to pass. The outflow from the protected area was simulated by a 1-way culvert structure.

Option D

With the entire area surrounded by an embankment, all spill channels into the area were disconnected. Gated structures were simulated at the Chatal and Jhenai inlets such that they remained closed except for the month of June, when they were fully open. Outflows via the Chatal South were represented by a 1-way culvert structure.

Results Shown on Graphs: RS1.1, RS1.2

Additional Comments: Option C results are based on a nett cultivable area of 24000 hectares protected under the scheme. Therefore direct comparison with the Base Case, (45000 hectares), is difficult. The model shows a high proportion of the area flooded in the Base Case and this is suspected to be due to poor calibration. However, the intervention effects are shown in comparison to the Base Case. The effect of Baushi Bridge restriction is negligible with no intervention owing to the unrestricted outflow from the Chatal South. Any restriction of this outflow exacerbates the effects of the Baushi Bridge restriction.

Basic Scheme: RS2

Represented by model runs: PF16,PF36

Scheme description: This scheme is essentially an extension of RS1 with improvements to the existing railway embankment on the southern boundary of the Jamalpur Priority Project, together with the structural works required to restrict the flow at Baushi Bridge, (on the Jhenai), to 50 cumecs maximum.

Model setup: The adjustments to the Base Case model setup required for this configuration entailed the insertion of a weir structure on the Jhenai at Baushi Bridge. As this point is not a boundary in the NCRM, the Q-h type boundary employed for the JPPS model could not be used. The use of a weir structure precluded the maximum discharges at Baushi being restricted to exactly 50 cumecs, but judicious choice of the constriction size ensured a close agreement with that specified. This model run was made assuming that the Jamuna Bridge works were constructed, (PF16), and then without the bridge, (PF36). The northern intake of the Dhaleswari was cut off from the Jamuna, together with the first three spill channels downstream.

Results shown on graphs: RS2.1

Additional comments: The major effects of this intervention are manifested by a significant reduction in the maximum area flooded in Planning Units 2 and 4. In the scenario with Jamuna Bridge there are also further effects in Planning Units 6 and 7, due solely to the bridge construction.

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Basic Scheme: RS3(1)

Represented by Model Runs: PF7-PF10, PF18-PF20, PF24

Scheme Description: This represents the first phase of the Dhaleswari-Kaliganga left embankment. It would extend from the Pungli river offtake from the Dhaleswari to the Barinda river offtake. Within this basic scheme there is scope for construction alternatives. Offtakes from the Dhaleswari, (the Louhajang and Elangjani), may be either "fully controlled", (in this case, gated, but gates closed), or "semi-controlled", (an un-gated restriction of some form, such as a weir). The embankment could be considered with the Jamuna Bridge works in place or without. Likewise, the scheme could be considered in conjunction with regional drainage improvements, or without. Reference to Table II.2 shows the possible combinations that were tested.

Model Setup: With an embankment along the left bank of the Dhaleswari, it may be assumed that the spillage from the river in that direction is reduced to zero and hence the flood plain associated with the embanked reach was modified. This modification entailed the re-definition of the flood plain attached to each nodal point on the embanked reach and a re-calculating of the area-elevation curves for use in the post-processing program. The cross section in the model were modified accordingly to represent the revised flood plain.

To investigate the condition with "fully controlled" distributaries, both the Louhajang and the Elangjani were disconnected from the Dhaleswari and a new internal boundary condition, (Q=0), allocated to the upper limits of the distributaries. The condition of "semi-controlled" distributaries was represented by the insertion of a broad crested weir at each offtake. In this way, the distributaries remain connected to the Dhaleswari, but the discharge down them is restricted according to the size of weir assumed.

The setup investigating the effects with the Jamuna Bridge was as above, but the standard modifications for the bridge were also made, (see model setup for Scheme RS2). Inclusion of the regional drainage was made by varying the appropriate roughness coefficients in the .SSF file to represent the change in conveyance in the affected river reaches.

Results Shown on Graphs: RS3.1 -RS3.8

Additional Comments: The imposition of an embankment along the left bank of the Dhaleswari, (in addition to the embankment down the Jamuna), has the effect of raising water levels in the Dhaleswari. Water that would normally have spilled onto the left bank flood plain now remains confined within the channel and the remaining right bank flood plain. This lower overall cross sectional area causes a rise in the water level over the base case for a give discharge. The limitations of the model, (particularly in the description of flood plains, given the paucity of good topographic information), preclude an accurate representation of the effects on flood plain water levels, since the area-elevation curves have no spacial discrimination. The arbitrary choice of flood plain delineation between two adjacent watercourses, or the boundaries of the model, lead to uncertainties in the resulting areas of inundation.

With the rise in water level in the Dhaleswari due to the embankments, there will be a corresponding rise in water levels, (and discharges), experienced in the downstream reaches after the embankments terminate. This results in a worsening of the existing situation in Planning Unit 7, in particular.

Attention should be drawn to the differences indicated between the graphs indicating embankments with "fully controlled" structures and those with "semi-controlled" structures. In the former case, the areas flooded are reduced from the base case due to the complete closure of the distributaries. The volume of flow in the distributaries with "semi-controlled" structures depends both on the geometry of the weir adopted and the initial water level at the distributary offtake. Naturally, with the embankments, the initial water level is increased, which in itself would cause a significant increase in discharge. This discharge is reduced by constricting the offtake with a weir. In the cases simulated, it is clear that the weir size adopted has been too large to adequately reduce the flow. Feasibility level studies would seek to modify the geometry of these weirs to the optimum extent. Time has precluded such an exercise at this level of study.

Basic Scheme: RS3(2)

Represented by Model Runs: PF3-PF6, PF11, PF21-PF23, PF33

Scheme Description: This represents both the first and second phase of the Dhaleswari-Kaliganga left embankment. It would extend from the Pungli river offtake from the Dhaleswari to Kalatia. Within this basic scheme there is scope for construction alternatives. Offtakes from the Dhaleswari, (the Louhajang and Elangjani), may be either "fully controlled", (in this case, gated, but gates closed), or "semi-controlled", (an un-gated restriction of some form, such as a weir). The embankment could be considered with the Jamuna Bridge works in place or without. Likewise, the scheme could be considered in conjunction with regional drainage improvements, or without. Reference to Table II.2 shows the possible combinations that were tested.

Model Setup: With an embankment along the left bank of the Dhaleswari, it may be assumed that the spillage from the river in that direction is reduced to zero and hence the flood plain associated with the embanked reach was modified. This modification entailed the re-definition of the flood plain attached to each nodal point on the embanked reach and a re-calculating of the area-elevation curves for use in the post-processing program. The cross section in the model were modified accordingly to represent the revised flood plain.

To investigate the condition with "fully controlled" distributaries, both the Louhajang and the Elangjani were disconnected from the Dhaleswari and a new internal boundary condition, (Q=0), allocated to the upper limits of the distributaries. The condition of "semi-controlled" distributaries was represented by the insertion of a broad crested weir at each offtake. In this way, the distributaries remain connected to the Dhaleswari, but the discharge down them is restricted according to the size of weir assumed.

The setup investigating the effects with the Jamuna Bridge was as above, but the standard modifications for the bridge were also made, (see model setup for Scheme RS2). Inclusion of the regional drainage was made by varying the appropriate roughness coefficients in the .SSF file to represent the change in conveyance in the affected river reaches.

Results Shown on Graphs: RS3.9 - RS3.17

Additional Comments: The imposition of an embankment along the left bank of the Dhaleswari, (in addition to the embankment down the Jamuna), has the effect of raising water levels in the Dhaleswari. Water that would normally have spilled onto the left bank flood plain now remains confined within the channel and the remaining right bank flood plain. This lower overall cross sectional area causes a rise in the water level over the base case for a give discharge. The limitations of the model, (particularly in the description of flood plains, given the paucity of good topographic information), preclude an accurate representation of the effects on flood plain water levels, since the area-elevation curves have no spacial discrimination. The arbitrary choice of flood plain delineation between two adjacent watercourses, or the boundaries of the model, lead to uncertainties in the resulting areas of inundation. Indeed, using the Jamuna Bridge works only as a base case, the imposition of an embankment along the left bank of the Dhaleswari shows an increase in the flooded area of Planning Unit 6. This is due entirely to the way the flood plains are modelled and should not be regarded as a definitive outcome, but rather a phenomenon that must be simulated in greater detail at the next level of study and at the next level of model detail.

Continuing the embankment from the first phase mitigates the negative effects on Planning Unit 7. In this case, there is a distinct improvement on the flooding characteristics in this PU, although the evidence shows that a large part of this comes from the Jamuna Bridge works only, which has the effect of cutting off the main spill channels from the Jamuna.

Attention should be drawn to the differences indicated between the graphs indicating embankments with "fully controlled" structures and those with "semi-controlled" structures. In the former case, the areas flooded are reduced from the base case due to the complete closure of the distributaries. The volume of flow in the distributaries with "semi-controlled" structures depends both on the geometry of the weir adopted and the initial water level at the distributary offtake. Naturally, with the embankments, the initial water level is increased, which in itself would cause a significant increase in discharge. This discharge is reduced by constricting the offtake with a weir. In the cases simulated, it is clear that the weir size adopted has been too large to adequately reduce the flow. Feasibility level studies would seek to modify the geometry of these weirs to the optimum extent. Time has precluded such an exercise at this level of study.

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Basic Scheme: RS4

Represented by Model Runs: PF17, PF34

Scheme Description: This scheme represents the basic regional drainage option, which seeks to improve the capacity of selected watercourses in order to both reduce the peak water levels and to enhance the response time of the drainage system. River improvements to the Bangshi from Kauljani, (chainage 72.0), to the Dhaleswari outlet, (chainage 148.0), are proposed. This will take the form of river deepening and widening, as appropriate, although such activities in the lower reaches will have questionable effects due to the backwater effects of the lower Meghna river. In these locations, river improvements will provide additional local channel storage only.

Model Setup: Modelling channel improvements is the simplest of all simulations, in that it is only required to adjust the channel roughness in the selected reaches by a suitable factor. In each case, the relevant .SSF file has been modified from the base case and adopted with other combinations, as required.

Results Shown on Graphs: RS4.1 - RS4.2

Additional Comments: As stated above, channel improvements in the lower reaches have but a small effect on the overall improvements to the flooding characteristics. Local improvements, particularly in the Kauljani to Mirzapur reach are more significant. In more detailed studies, it is likely that there will be an improvement in the duration of flooding on a local basis, due to the lowering of the intermediate water levels, but this effect will only be felt in the close proximity of the improved reaches. Widespread effects of drainage improvements are minimal.

Basic Scheme: RS6

Represented by Model Runs: PF25-PF32

Scheme Description:

This represents the alternative alignment of the embankment scheme and may be considered in 2 phases. Phase 1 consists of an embankment from the right bank of the Pungli river to the confluence of the Old Dhaleswari with the southern intake of the Dhaleswari. The embankment to this point follows the same route as that in Scheme RS3. From this point the second phase of the embankment crosses the Dhaleswari and follows an alignment down the left bank of the Jamuna to Harirampur. Within this basic scheme there is scope for construction alternatives. Offtakes from the Dhaleswari, (the Louhajang and Elangjani), may be either "fully controlled", (in this case, gated, but gates closed), or "semi-controlled", (an un-gated restriction of some form, such as a weir). The embankment could be considered with the Jamuna Bridge works in place or without. Likewise, the scheme could be considered in conjunction with regional drainage improvements, or without. Reference to Table 2 shows the possible combinations that were tested.

Model Setup:

With an embankment along the left bank of the Dhaleswari, it may be assumed that the spillage from the river in that direction is reduced to zero and hence the flood plain associated with the embanked reach was modified. This modification entailed the re-definition of the flood plain attached to each nodal point on the embanked reach and a re-calculating of the area-elevation curves for use in the post-processing program. The cross section in the model were modified accordingly to represent the revised flood plain.

To investigate the condition with "fully controlled" distributaries, both the Louhajang and the Elangjani were disconnected from the Dhaleswari and a new internal boundary condition, (Q=0), allocated to the upper limits of the distributaries. The condition of "semi-controlled" distributaries was represented by the insertion of a broad crested weir at each offtake. In this way, the distributaries remain connected to the Dhaleswari, but the discharge down them is restricted according to the size of weir assumed.

The setup investigating the effects with the Jamuna Bridge was as above, but the standard modifications for the bridge were also made, (see model setup for Scheme RS2). Inclusion of the regional drainage was made by varying the appropriate roughness coefficients in the .SSF file to represent the change in conveyance in the affected river reaches.

Results Shown on Graphs: RS6.1 - RS6.8

Additional Comments:

The imposition of an embankment along the left bank of the Dhaleswari, (in addition to the embankment down the Jamuna), has the effect of raising water levels in the Dhaleswari. Water that would normally have spilled onto the left bank flood plain now remains confined within the channel and the remaining right bank flood plain. This lower overall cross sectional area causes a rise in the water level over the base case for a give discharge. The limitations of the model, (particularly in the description of flood plains, given the paucity of good topographic information), preclude an accurate representation of the effects on flood plain water levels, since the area-elevation curves have no spacial discrimination. The arbitrary choice of flood plain delineation between two adjacent watercourses, or the boundaries of the model, lead to uncertainties in the resulting areas of inundation. Indeed, using the Jamuna Bridge works only as a base case, the imposition of an embankment along the left bank of the Dhaleswari shows an increase in the flooded area of Planning Unit 6. This is due entirely to the way the flood plains are modelled and should not be regarded as a definitive outcome, but rather a phenomenon that must be simulated in greater detail at the next level of study and at the next level of model detail.

Continuing the embankment from the first phase mitigates the negative effects on Planning Unit 7. In this case, there is a distinct improvement on the flooding characteristics in this PU, although the evidence shows that a large part of this comes from the Jamuna Bridge works only, which has the effect of cutting off the main spill channels from the Jamuna.

Attention should be drawn to the differences indicated between the graphs indicating embankments with "fully controlled" structures and those with "semi-controlled" structures. In the former case, the areas flooded are reduced from the base case due to the complete closure of the distributaries. The volume of flow in the distributaries with "semi-controlled" structures depends both on the geometry of the weir adopted and the initial water level at the distributary offtake. Naturally, with the embankments, the initial water level is increased, which in itself would cause a significant increase in discharge. This discharge is reduced by constricting the offtake with a weir. In the cases simulated, it is clear that the weir size adopted has been too large to adequately reduce the flow. Feasibility level studies would seek to modify the geometry of these weirs to the optimum extent. Time has precluded such an exercise at this level of study.

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TABLE II.1

Structural Elements Used in Modelling Exercises

ELEMENT	DESCRIPTION
1	Drainage improvement on Bangshi from Kauljani to end of Lower Dhaleswari
2	Drainage improvement on Turag and Buriganga
3	Embankment along left bank of Dhaleswari/Kaliganga from Pungli river offtake to Kalatia
4	Jamuna Bridge proposals, (including guide bund)
5	Semi-controlled structures on Dhaleswari distributaries, (Louhajang, Elangjani, Barinda, Pungli)
6	Embankment along left bank of Dhaleswari to Barinda offtake, (Phase 1)
7	Jamuna Bridge only, (no guide bund)
8	Embankment along Dhaleswari-Jamuna to Harirampur
9	De-restriction of Baushi Bridge flows
10	Drainage improvements on lower Dhaleswari only

TABLE II.2
Reference Table of Scenarios and Associated Model Runs

RUN No.	ELEMENTS	REGIONAL SCHEME No.	SCENARIO No.	DESCRIPTION OF RUN
PF0	None	RS0	0A	Base run for 1989 with no interventions
PF1	1	RS2+RS4	15	RS2 project associated with drainage improvement on Bangshi and lower Dhaleswari through RS4 project
PF2	1+2	-	-	This run tested the effect of additional drainage improvements on Turag & Buriganga - not adopted as scheme
PF3	3	RS3A1C+RS3A2C +RS2	18C	1st & 2nd phase of Dhaleswari-Kaliganga embankment plus RS2 project
PF4	3+4	RS3B1C+RS3B2C +RS2	33C	1st & 2nd phase of Dhaleswari-Kaliganga embankment plus RS2 project with Jamuna Bridge works
PF5	3+5	RS3A1S+RS3A2S +RS2	18S	As Run PF3 but with semi-controlled structures on distributaries
PF6	3+4+5	RS3B1S+RS3B2S+ RS2	33S	As Run PF4 but with semi-controlled structures on distributaries
PF7	6	RS3A1C+RS2	16C	1st phase of Dhaleswari embankment plus RS2 project
PF8	6+4	RS3B1C+RS2	31C	1st phase of Dhaleswari embankment plus RS2 project with Jamuna Bridge works
PF9	6+5	RS3A1S+RS2	16S	As Run PF7 but with semi-controlled structures on distributaries
PF10	6+4+5	RS3B1S+RS2	31S	As Run PF8 but with semi-controlled structures on distributaries
PF11	3+1	RS3A1C+RS3A2C +RS2+RS4	19C	1st & 2nd phase of Dhaleswari embankment plus RS2 project plus drainage improvements through RS4 project
PF16	4	RS2	29	No structural development except Jamuna Bridge works
PF17	4+1	RS2+RS4	30	RS2 project with drainage improvements through RS4 project with Jamuna Bridge works
PF18	6+1	RS3A1C+RS2 +RS4	6C	1st phase of Dhaleswari embankment plus RS2 project plus drainage improvements through RS4 project
PF19	6+4+1	RS3B1C+RS2 +RS4	24C	1st ph.Dhaleswari embnk.+RS2 project+drainage improvmnt. through RS4 project with Jamuna Bridge works
PF20	6+5+4+1	RS3B1S+RS2+RS4	24S	As Run PF19 but with semi-controlled structures on distributaries
PF21	3+4+5+1	RS3B1S+RS3B2S+ RS2+RS4	26S	As Run PF22 but with semi-controlled structures on distributaries
PF22	3+4+1	RS3B1C+RS3B2C +RS2+RS4	26C	1st & 2nd ph.Dhaleswari embnk.+RS2 project,drainage improvmnt.through RS4 project with Jamuna Br.works
PF23	3+5+1	RS3A1S+RS3A2S +RS2+RS4	8S	1st & 2nd phase of Dhaleswari embankment plus RS2 project with drainage improvements through RS4 project
PF24	6+5+1	RS3A1S+RS2 +RS4	6S	As Run PF18 but with semi-controlled structures on distributaries
PF25	8	RS6A1C+RS6A2C +RS2	9C	1st & 2nd phase of Dhaleswari-Jamuna embankment to Harirampur
PF26	8+1	RS6A1C+RS6A2C +RS2+RS4	10C	1st & 2nd phase of Dhaleswari-Jamuna embankment to Harirampur with drainage improvements through RS4
PF27	8+5	RS6A1S+RS6A2S +RS2	9S	As Run PF25 but with semi-controlled structures on distributaries
PF28	8+5+1	RS6A1S+RS6A2S +RS2+RS4	10S	As Run PF26 but with semi-controlled structures on distributaries
PF29	8+4	RS6B1C+RS6B2C +RS2	27C	1st & 2nd phase of Dhaleswari-Jamuna embankment to Harirampur with Jamuna Bridge works
PF30	8+4+1	RS6B1C+RS6B2C +RS2+RS4	28C	1st & 2nd ph.Dhaleswari-Jamuna emb.to Harirampur,drain.improvmnt.through RS4 with Jamuna Br.work
PF31	8+4+5+1	RS6B1S+RS6B2S+ RS2+RS4	28S	As Run PF30 but with semi-controlled structures on distributaries
PF32	8+4+5	RS6B1S+RS6B2S+ RS2	27S	As Run PF29 but with semi-controlled structures on distributaries
PF33	3+9	RS3A1C+RS3A2C	7C	As Run PF3 but with flows at Baushi Bridge de-restricted
PF34	1+9	RS4	4	As Run PF1 but with flows at Baushi Bridge de-restricted
PF35	8+10	RS6A1C+RS6A2C	-	As Run PF25 but with drainage improvements on lower Dhaleswari only
PF36	9	RS2	11	Baushi Bridge restricted only
PF37	4	Jamuna Bridge	0B	Base run with Jamuna Bridge only
JPPSa1		RS1aY		Jamalpur P.P. through flood proofing/preparedness/warning etc. with Baushi Bridge restricted
JPPSa2		RS1aN		As Run JPPSA1 but with Baushi Bridge de-restricted
JPPSb1		RS1bY+RS2	B1	Jamalpur P.P. with controlled flooding and improved drainage with Baushi Bridge restricted
JPPSb2		RS1bN	B2	As Run JPPSB1 but with Baushi Bridge de-restricted
1JPPSc1		RS1cY+RS2	C1	Jamalpur P.P. with controlled flooding east of the Chatal, including drainage, flood proofing to the west, with Baushi Bridge restricted
JPPSc2		RS1cN	C2	As Run JPPSC1 but with Baushi Bridge de-restricted
JPPSd1		RS1dY+RS2	D1	Jamalpur P.P. with full scale polder with bank protection +structures + drainage with Baushi Bridge restricted
JPPSd2		RS1dN	D2	As Run JPPSD1 but with Baushi Bridge de-restricted

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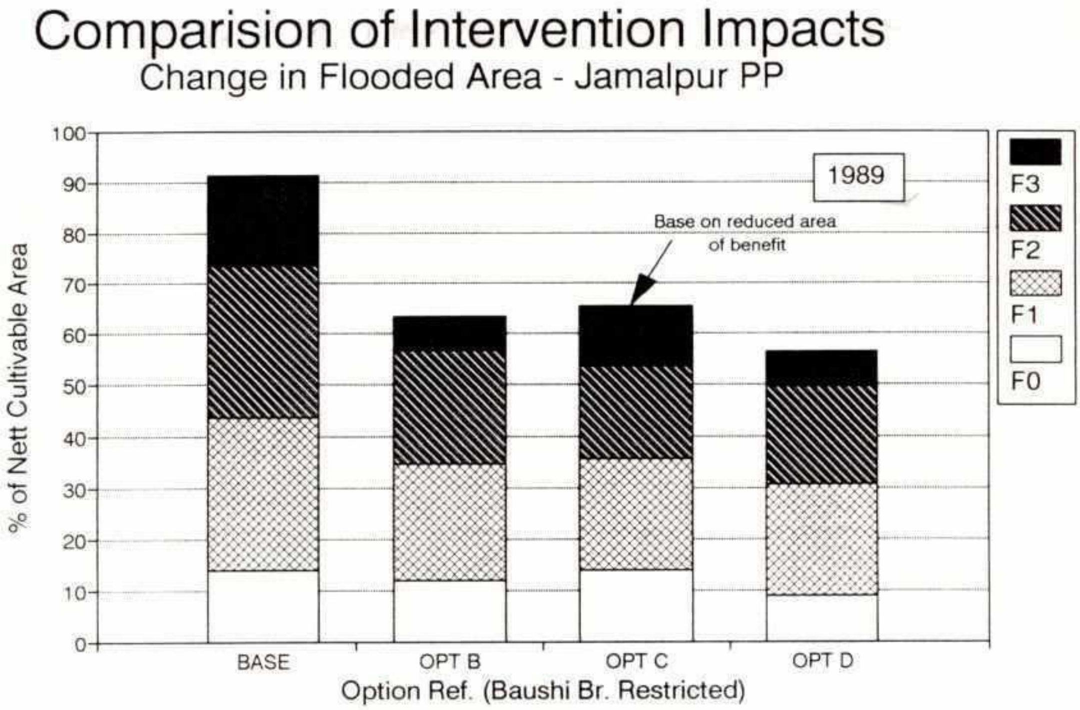
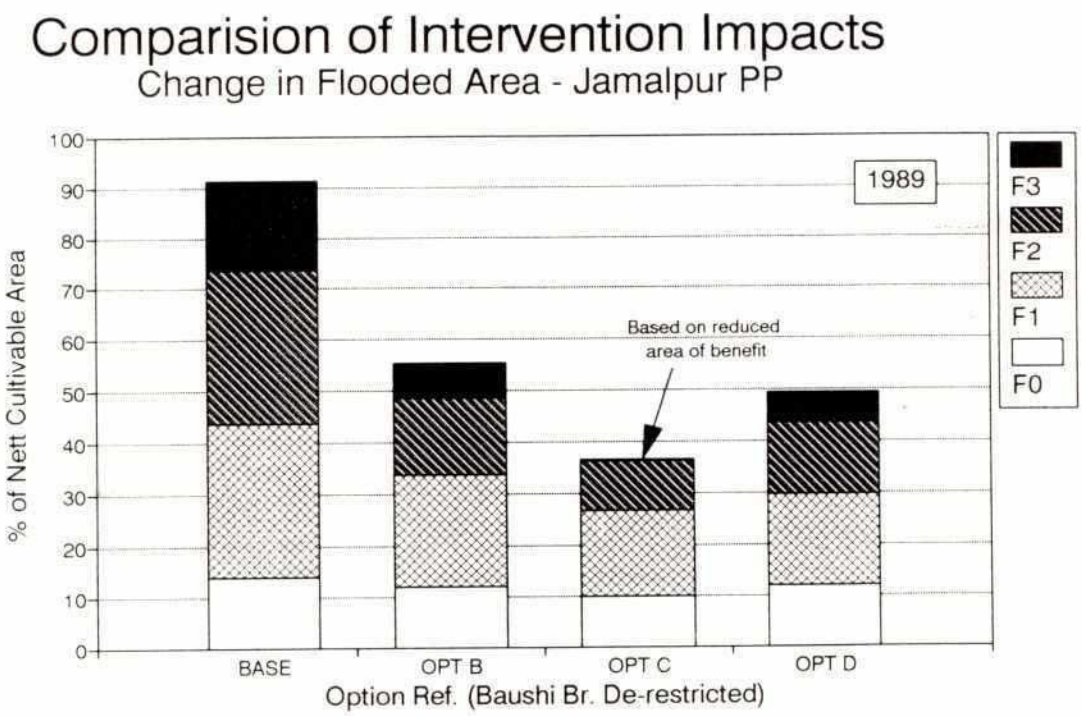
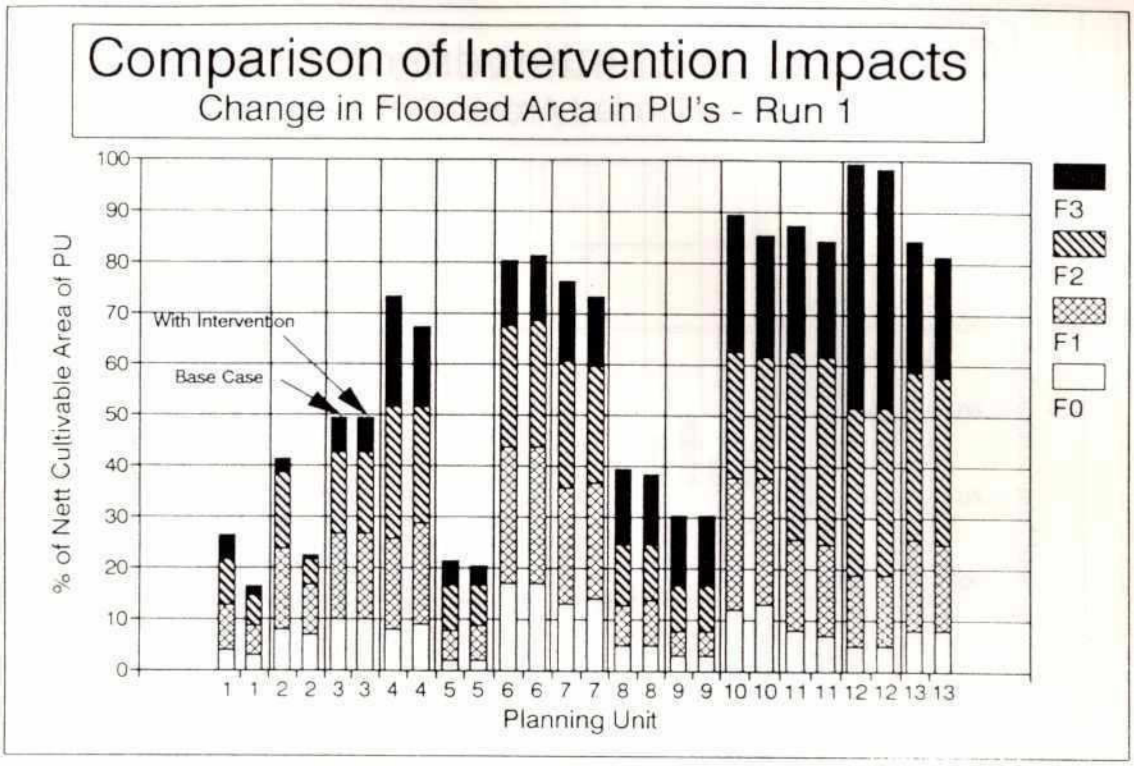
Graph RS1.1 Jamalpur Area with Baushi Bridge restricted



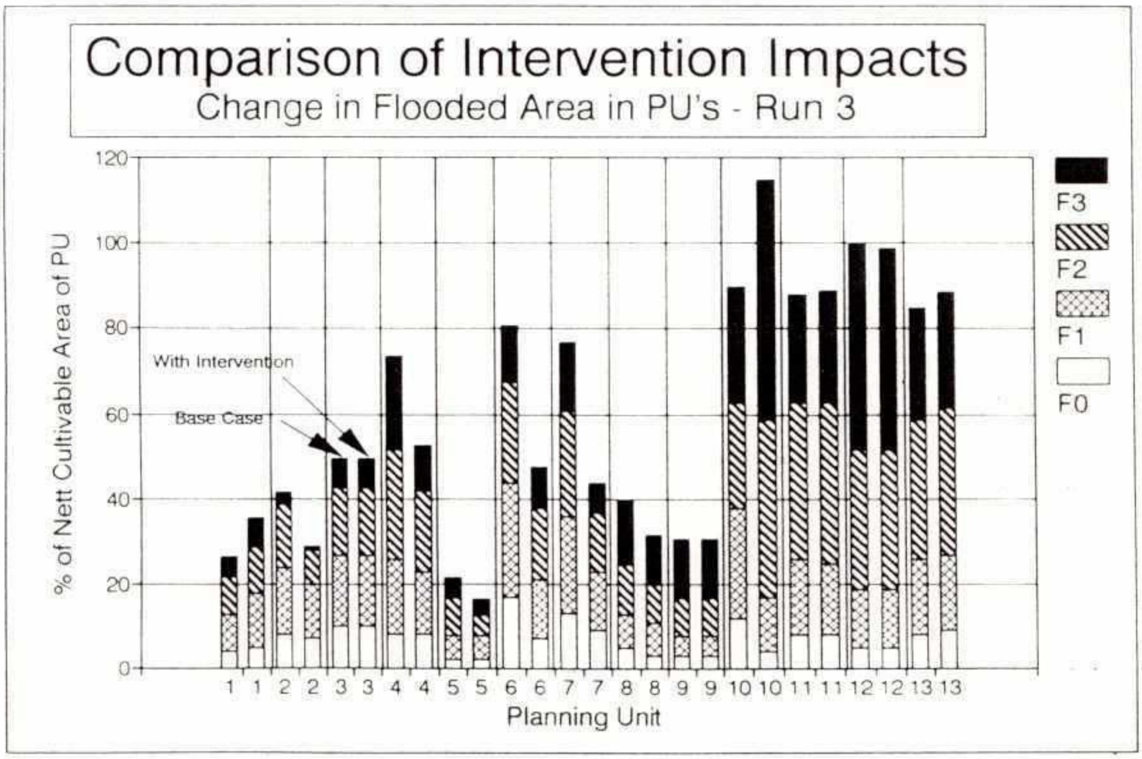
Graph RS1.2 Jamalpur Area with Baushi Bridge de-restricted



Graph RS1.22 **Regional Drainage - No Jamuna Bridge**



Graph RS1.12 **Dhaleswari - Kaliganga embankment - no drainage - no Jamuna Bridge - fully controlled distributaries**



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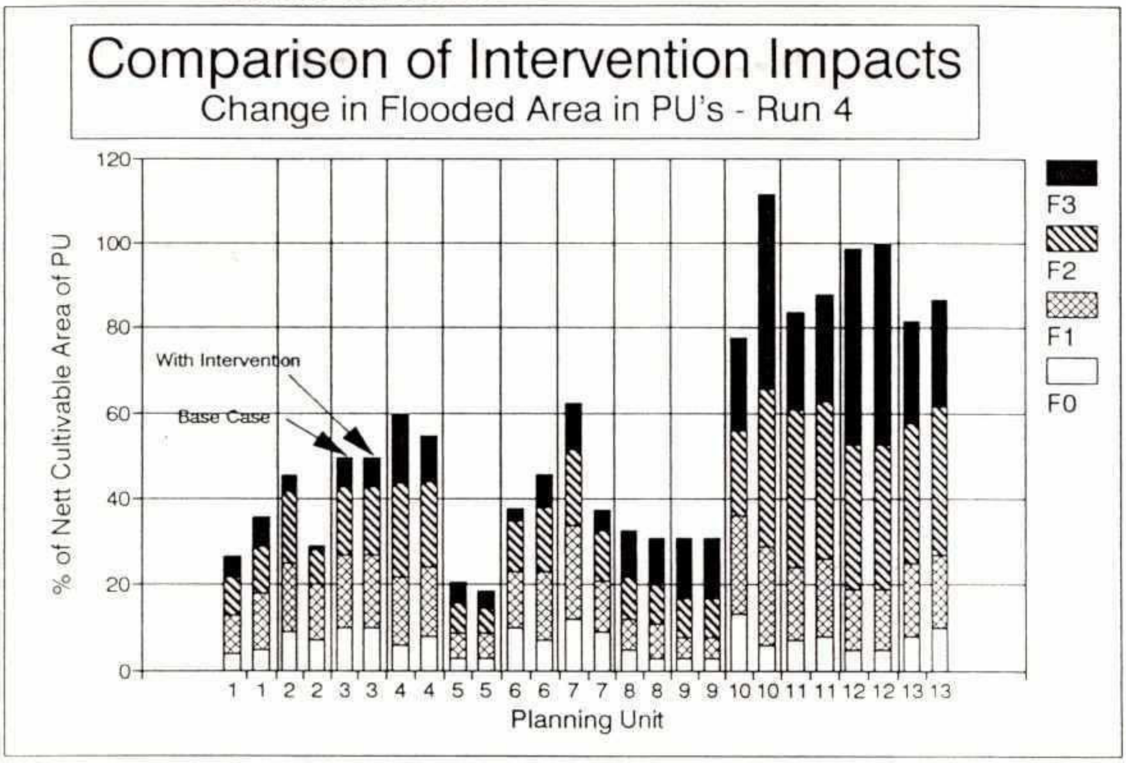
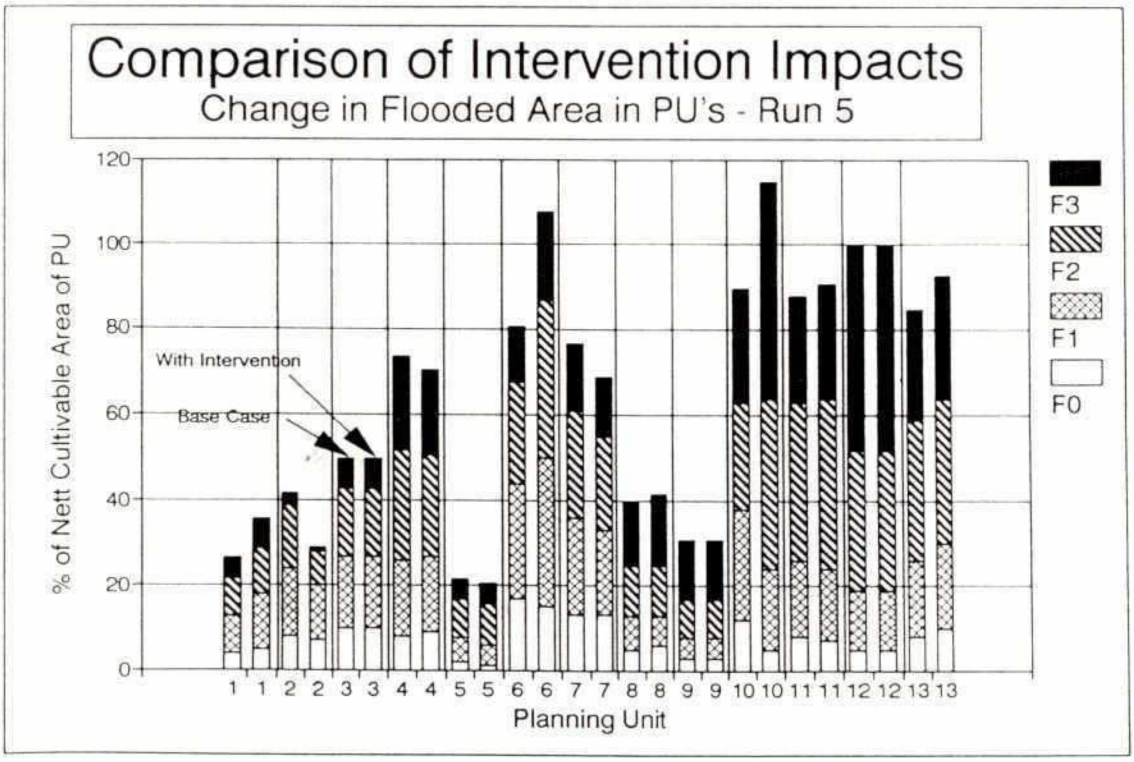
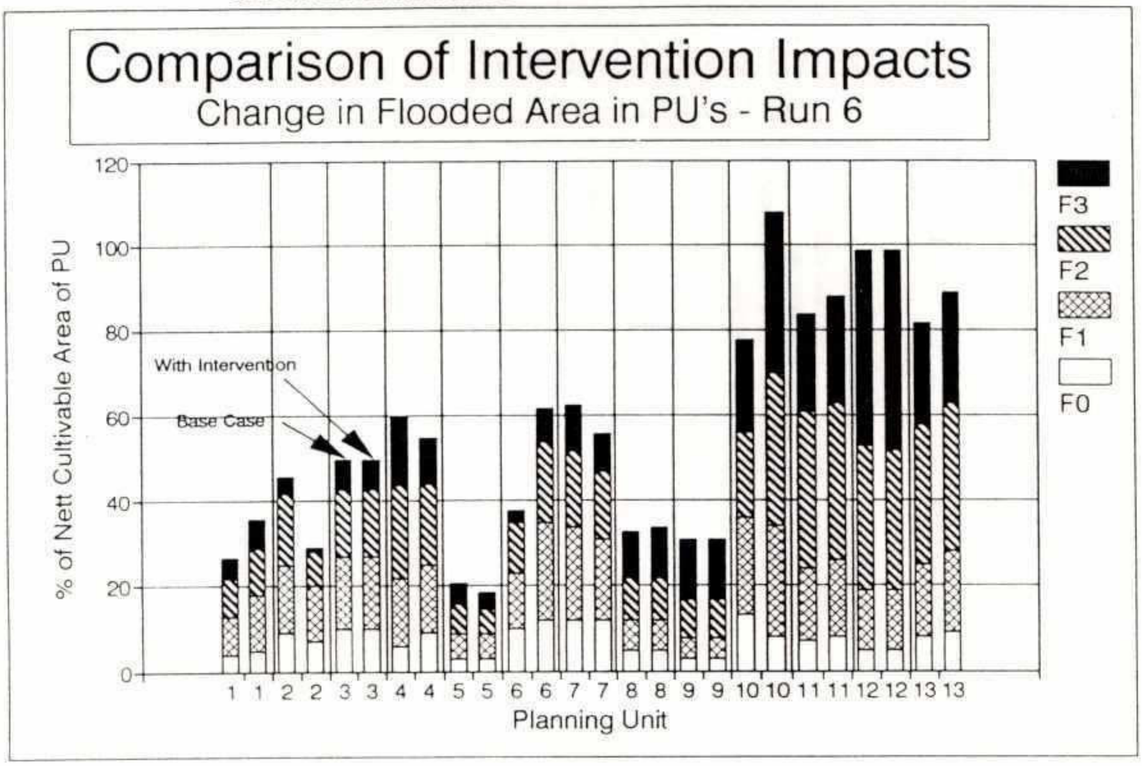
Graph RS1.13 **Dhaleswari - Kaliganga embankment - no drainage - with Jamuna Bridge - fully controlled distributaries**



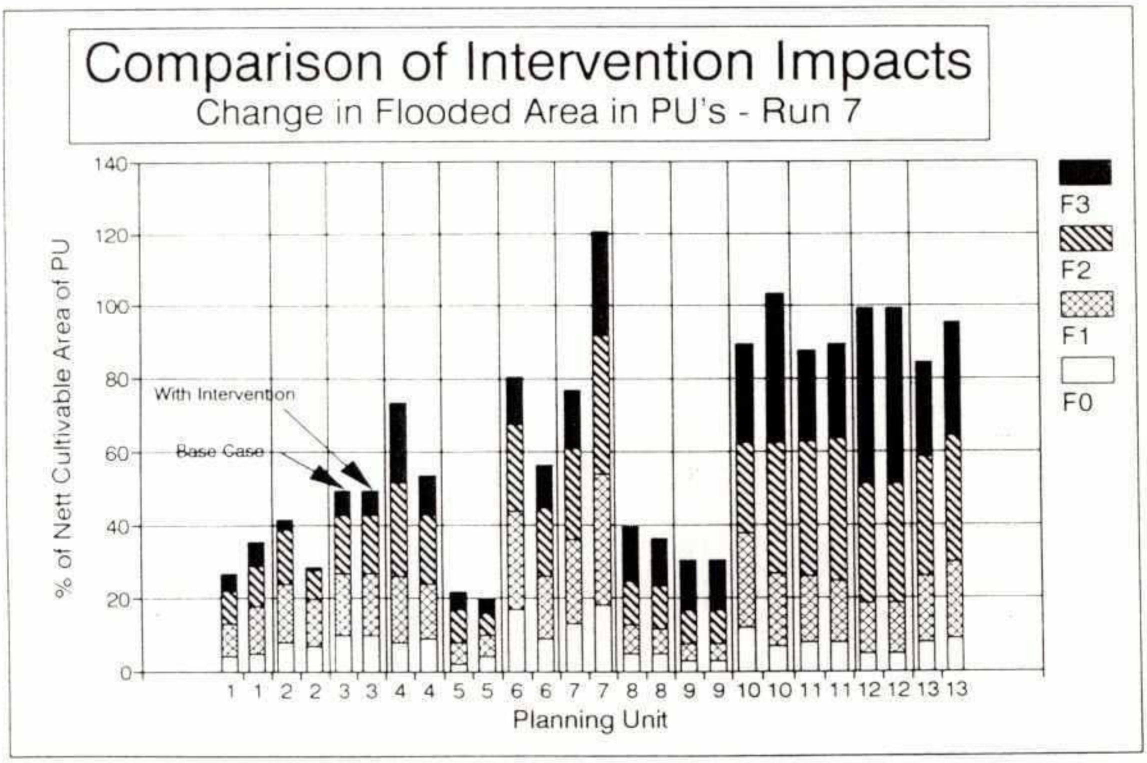
Graph RS1.14 **Dhaleswari - Kaliganga embankment - no drainage - no Jamuna Bridge - semi-controlled distributaries**



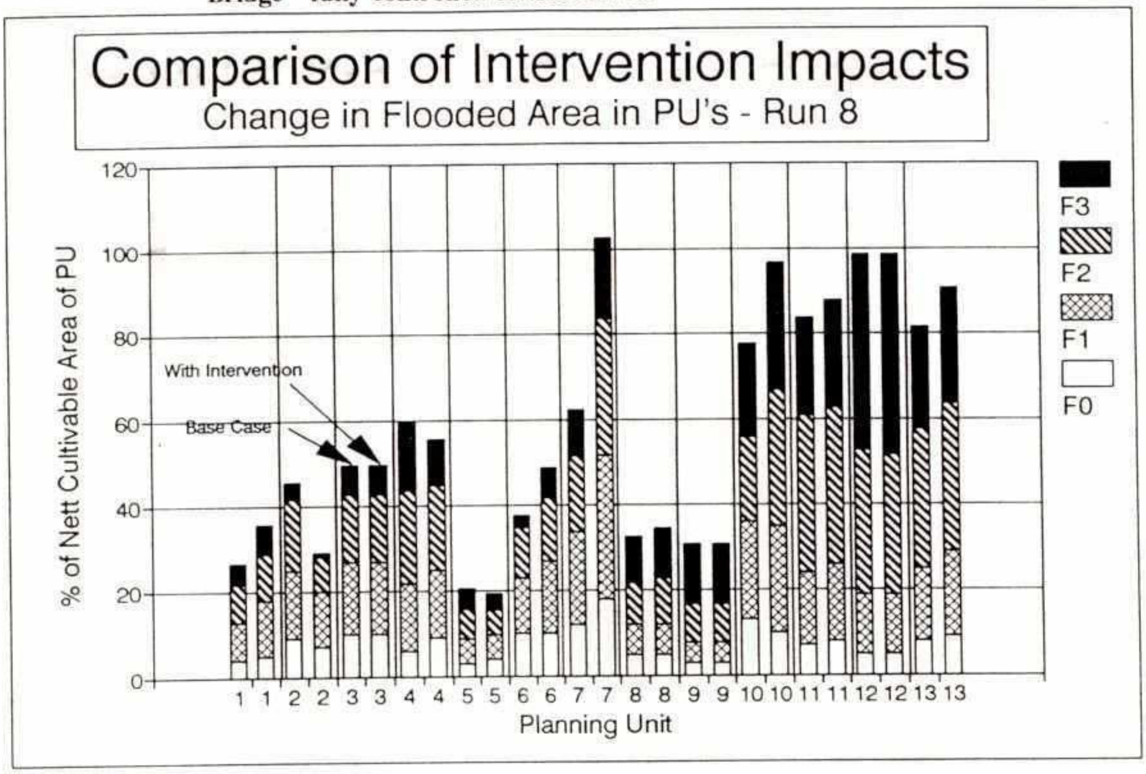
Graph RS1.15 **Dhaleswari - Kaliganga embankment - no drainage - with Jamuna Bridge - semi-controlled distributaries**



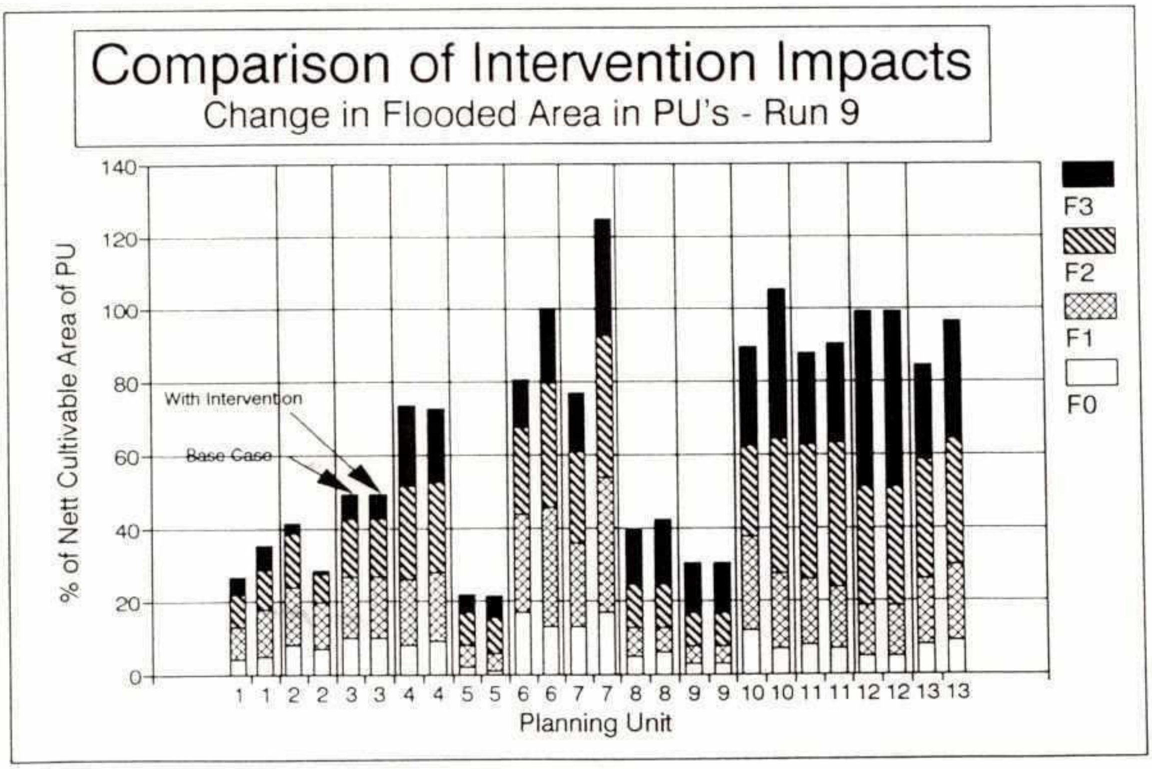
Graph RS1.4 **Dhaleswari - Kaliganga embankment, (1st Phase) - no drainage - no Jamuna Bridge - fully controlled distributaries**



Graph RS1.5 **Dhaleswari - Kaliganga embankment, (1st Phase) - no drainage - with Jamuna Bridge - fully controlled distributaries**



Graph RS1.6 **Dhaleswari - Kaliganga embankment, (1st Phase) - no drainage - no Jamuna Bridge - semi-controlled distributaries**



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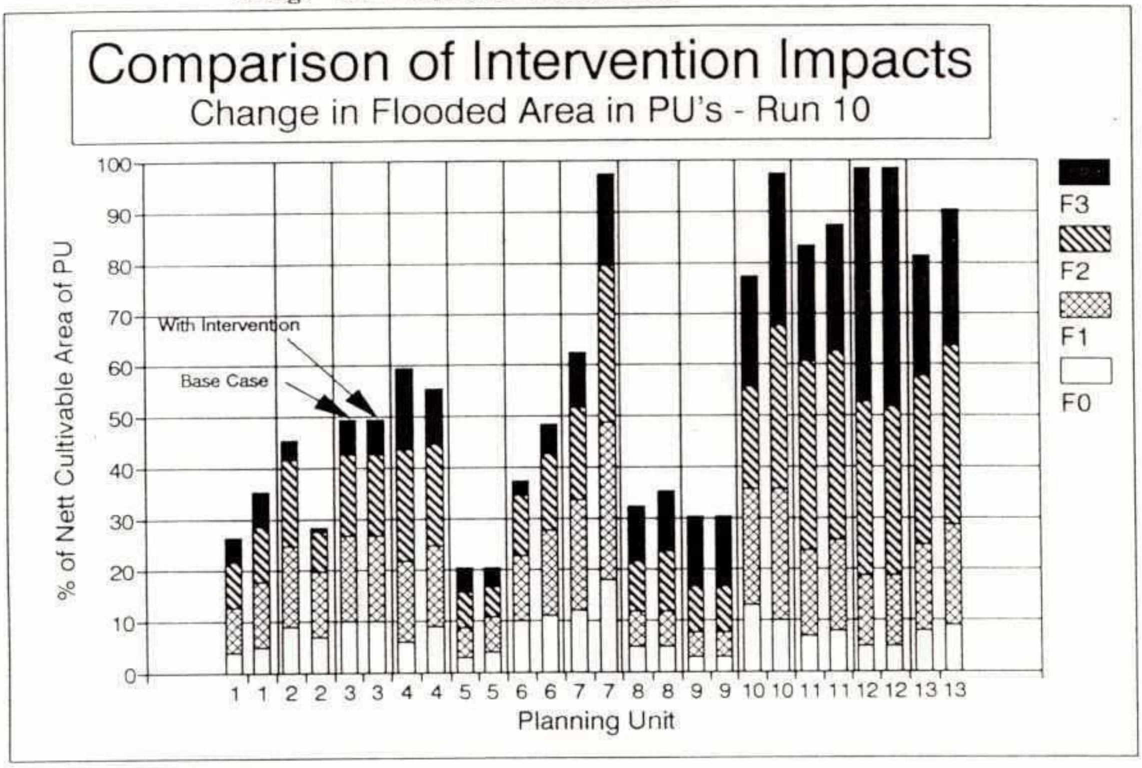
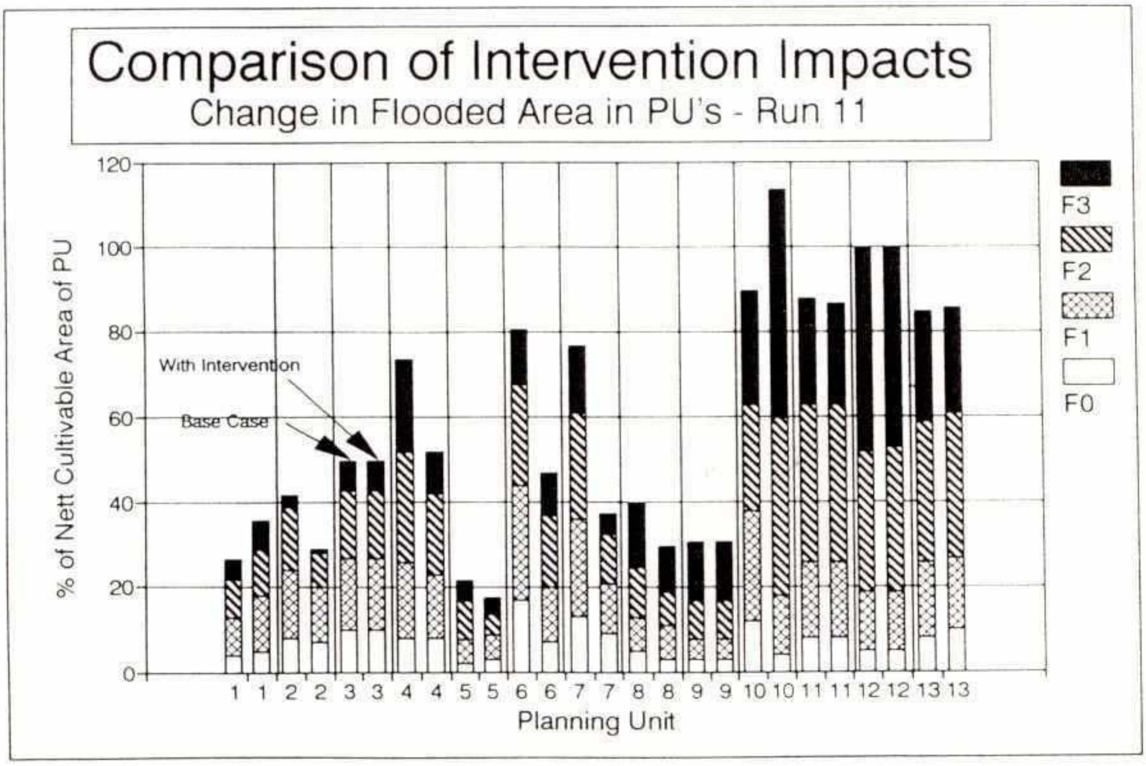
Graph RS1.7 **Dhaleswari - Kaliganga embankment, (1st Phase) - no drainage - with Jamuna Bridge - semi-controlled distributaries**



Graph RS1.16 **Dhaleswari - Kaliganga embankment - with drainage - no Jamuna Bridge - fully controlled distributaries**



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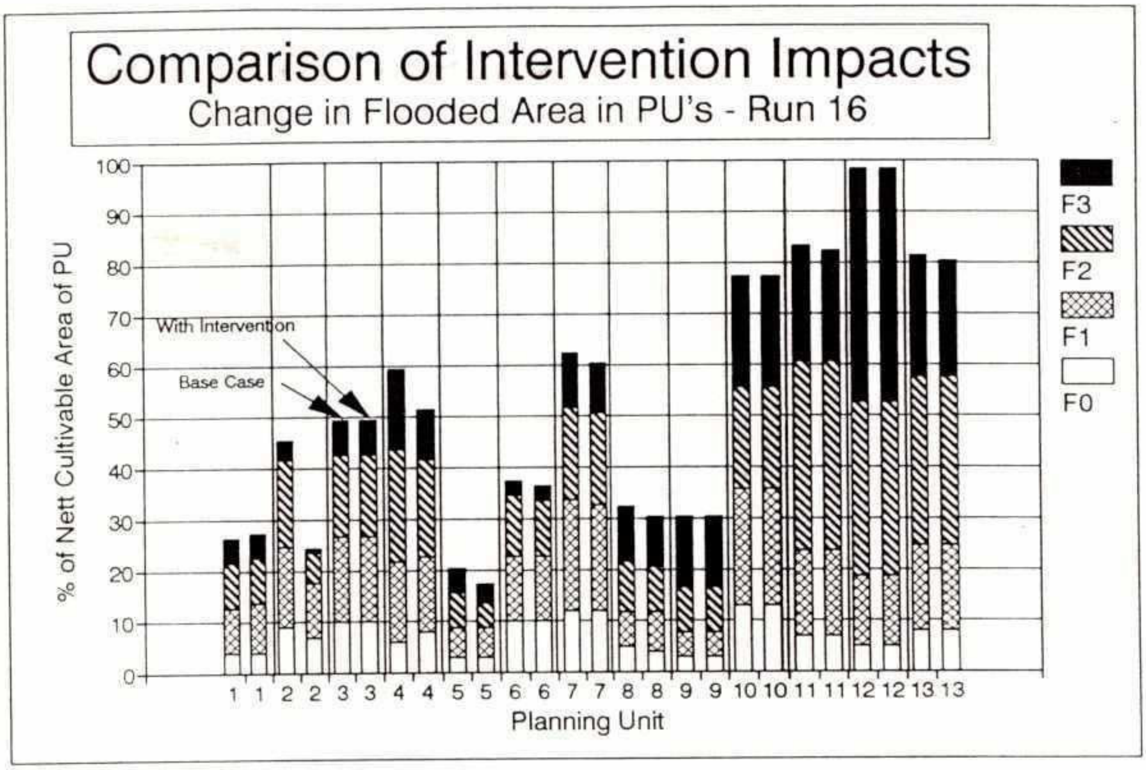
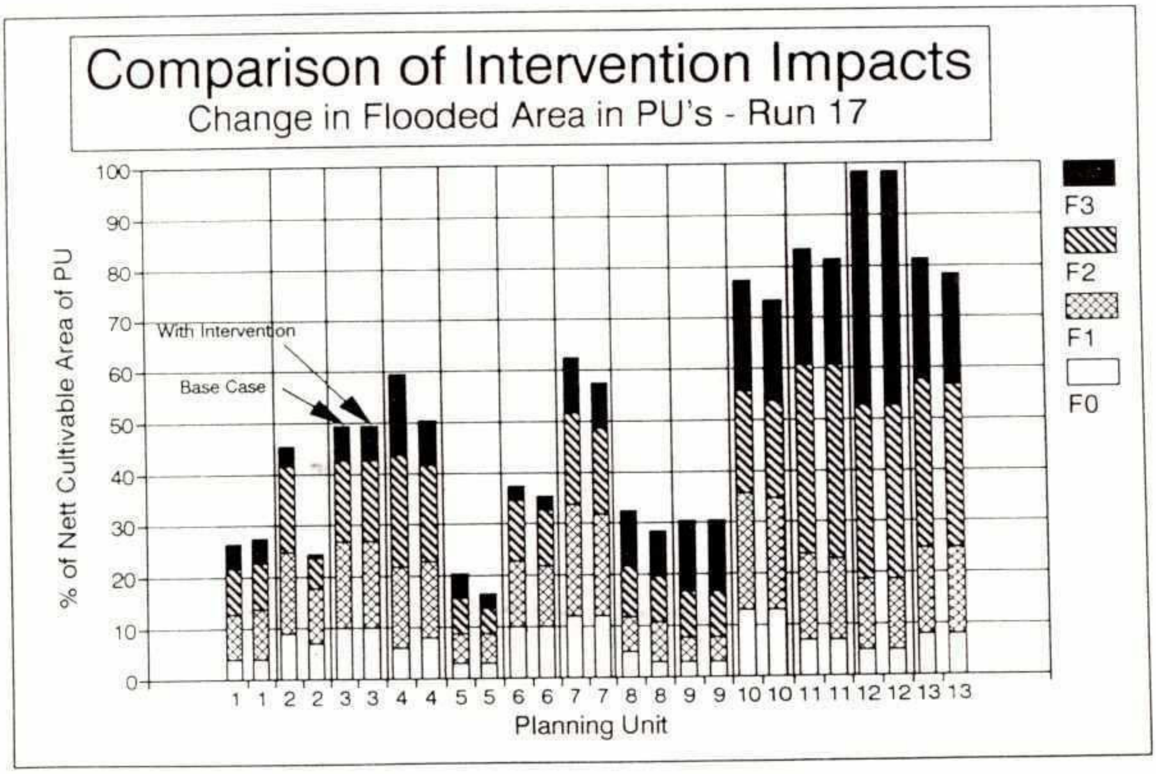
Graph RS1.3 Baushi Bridge restricted - with Jamuna Bridge - no drainage



Graph RS1.23 Regional drainage - with Jamuna Bridge



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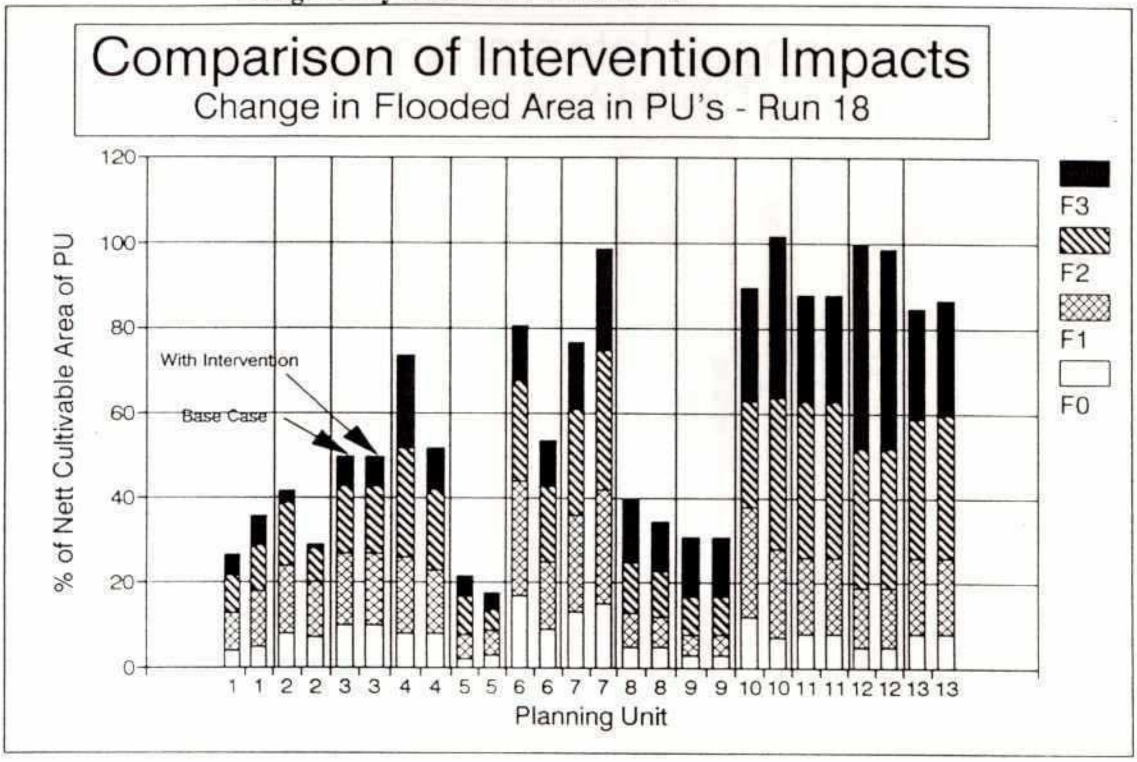
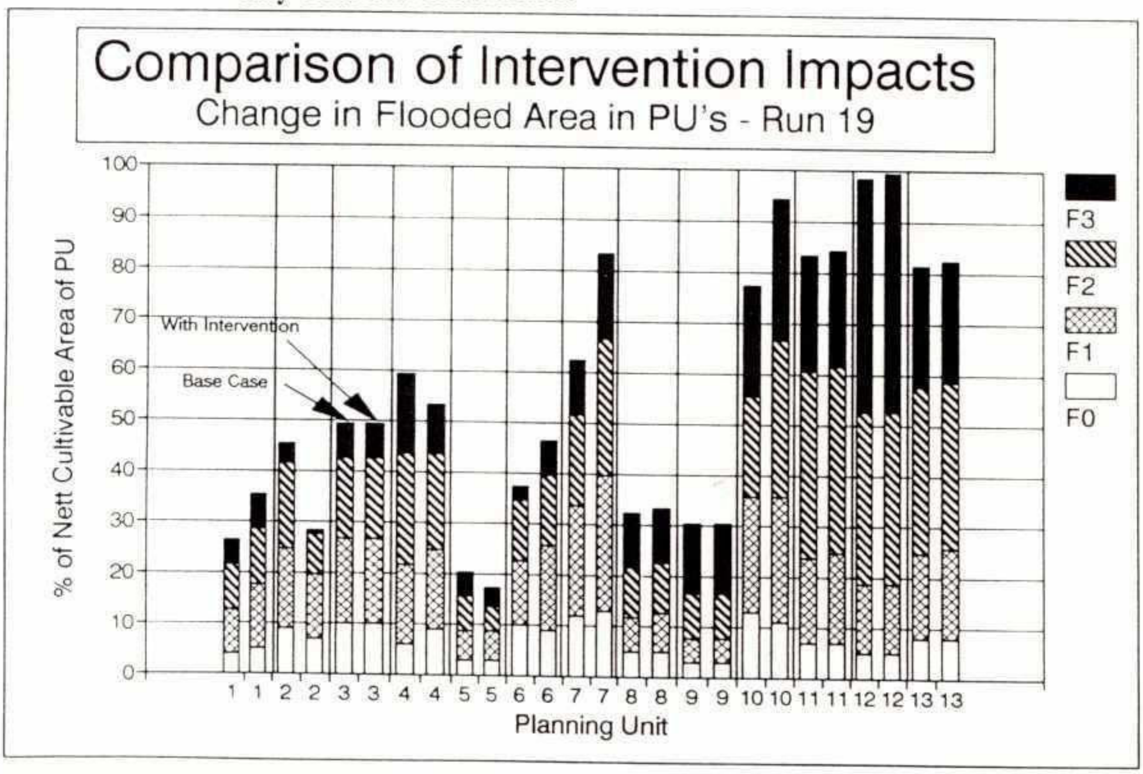
Graph RS1.8 **Dhaleswari - Kaliganga embankment, (1st Phase) - with drainage - no Jamuna Bridge - fully controlled distributaries**



Graph RS1.9 **Dhaleswari - Kaliganga embankment - with drainage - with Jamuna Bridge - fully controlled distributaries**



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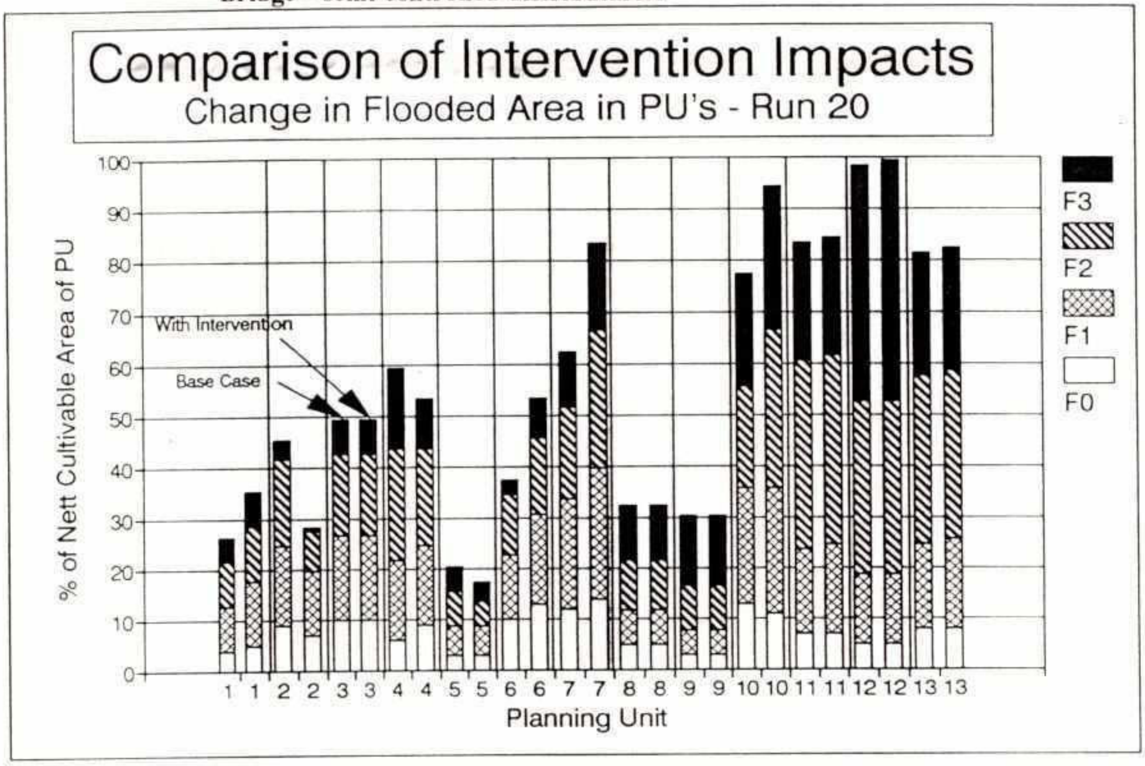
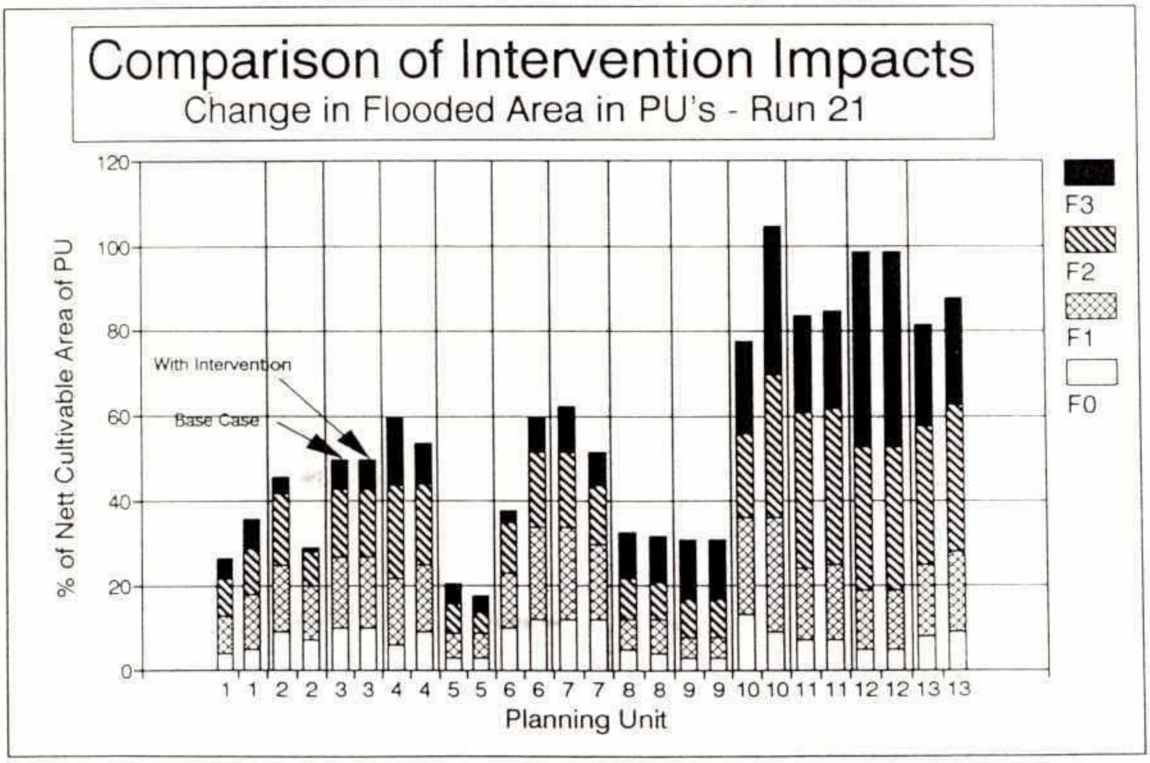
Graph RS1.10 **Dhaleswari - Kaliganga embankment, (1st Phase) - with drainage - with Jamuna Bridge - semi-controlled distributaries**



Graph RS1.17 **Dhaleswari - Kaliganga embankment - with drainage - with Jamuna Bridge - semi-controlled distributaries**



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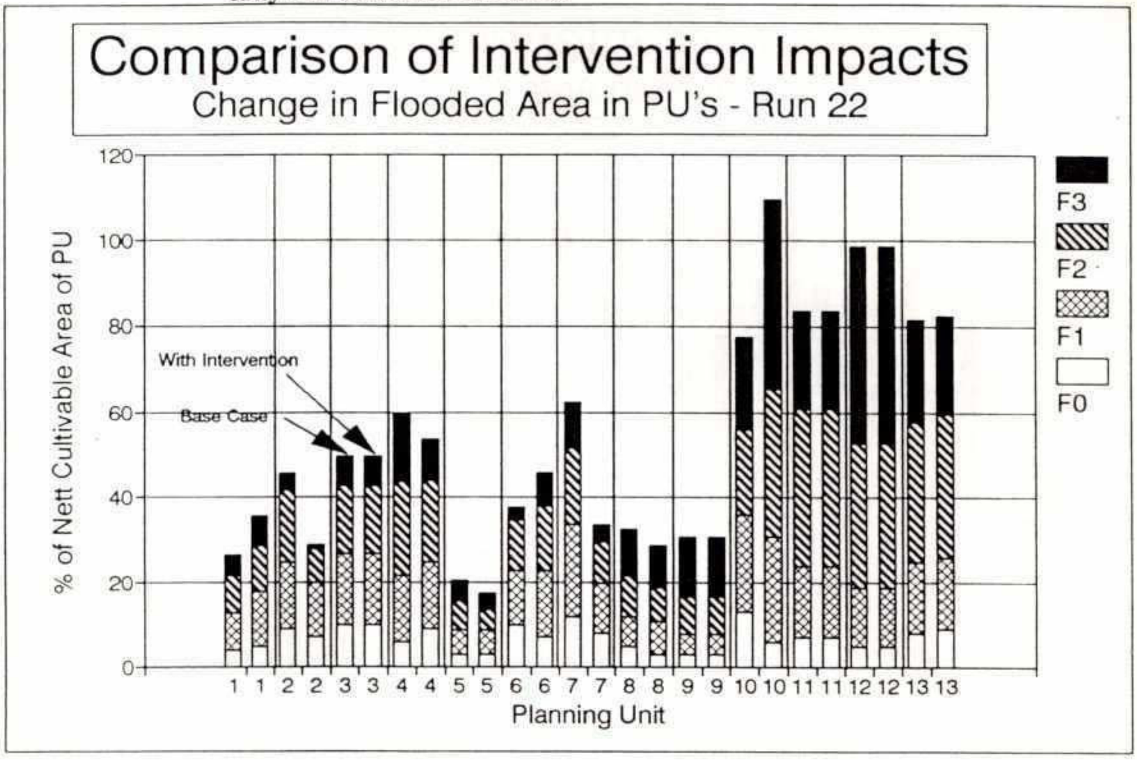
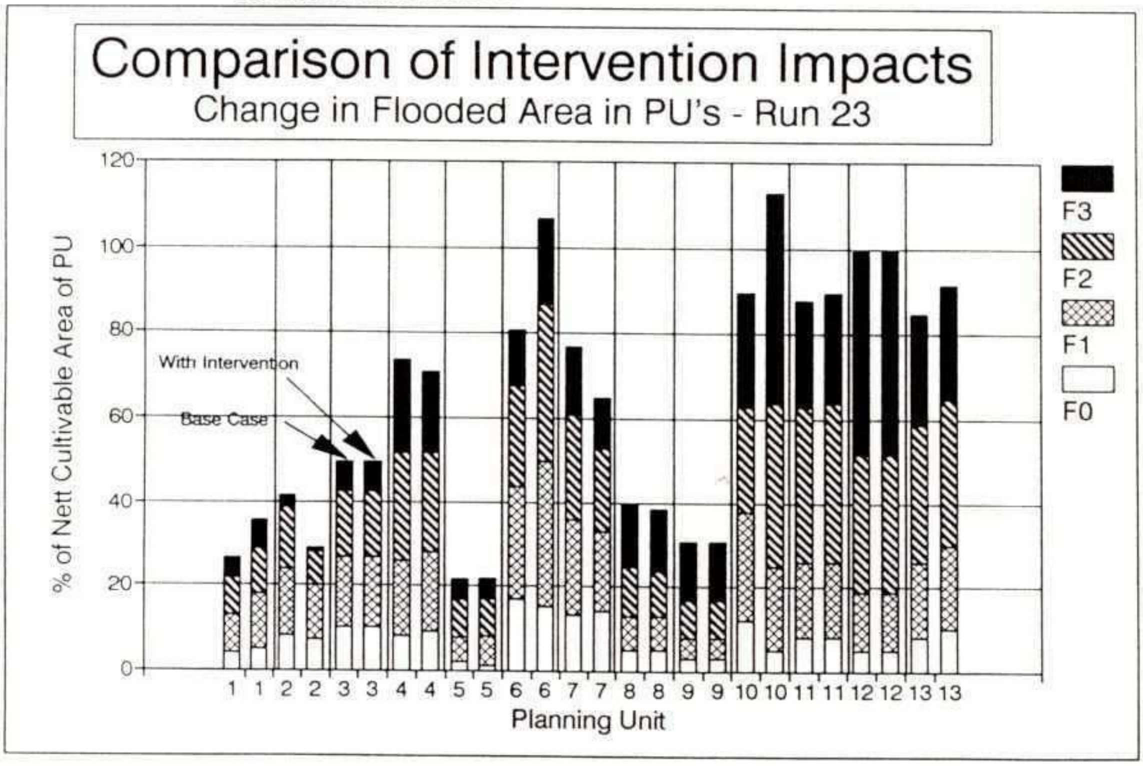
Graph RS1.18 **Dhaleswari - Kaliganga embankment - with drainage - with Jamuna Bridge - fully controlled distributaries**



Graph RS1.19 **Dhaleswari - Kaliganga embankment - with drainage - no Jamuna Bridge - semi-controlled distributaries**



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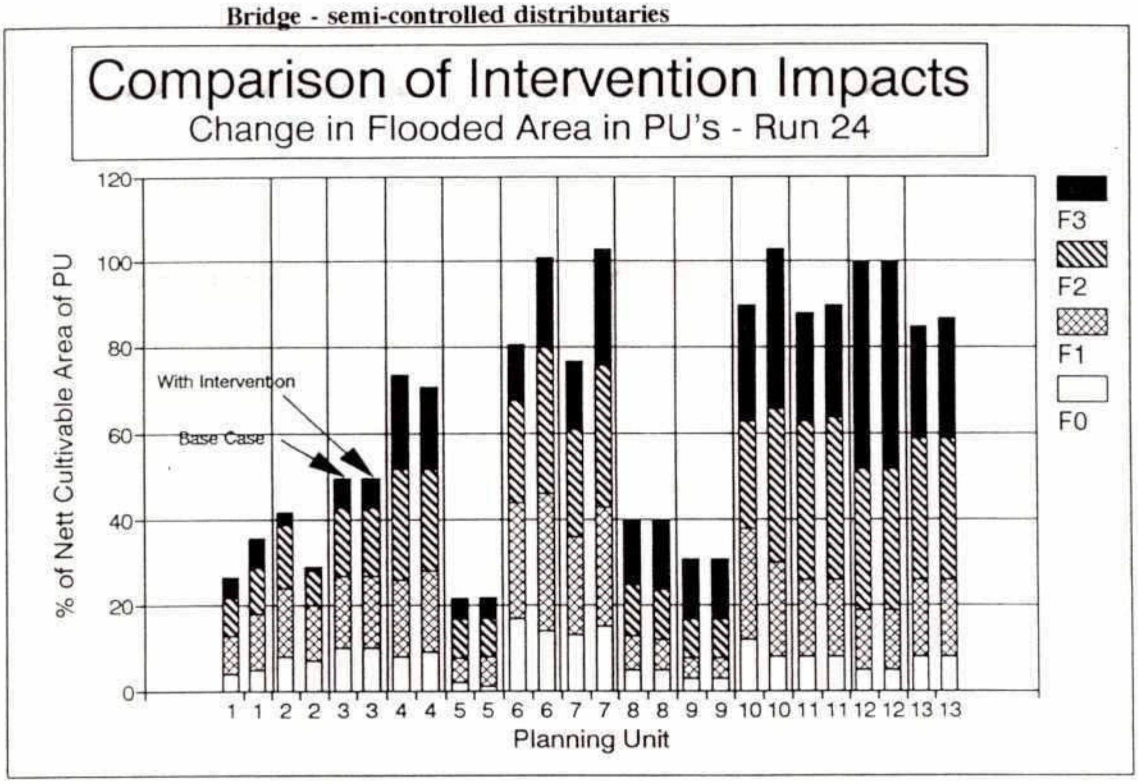
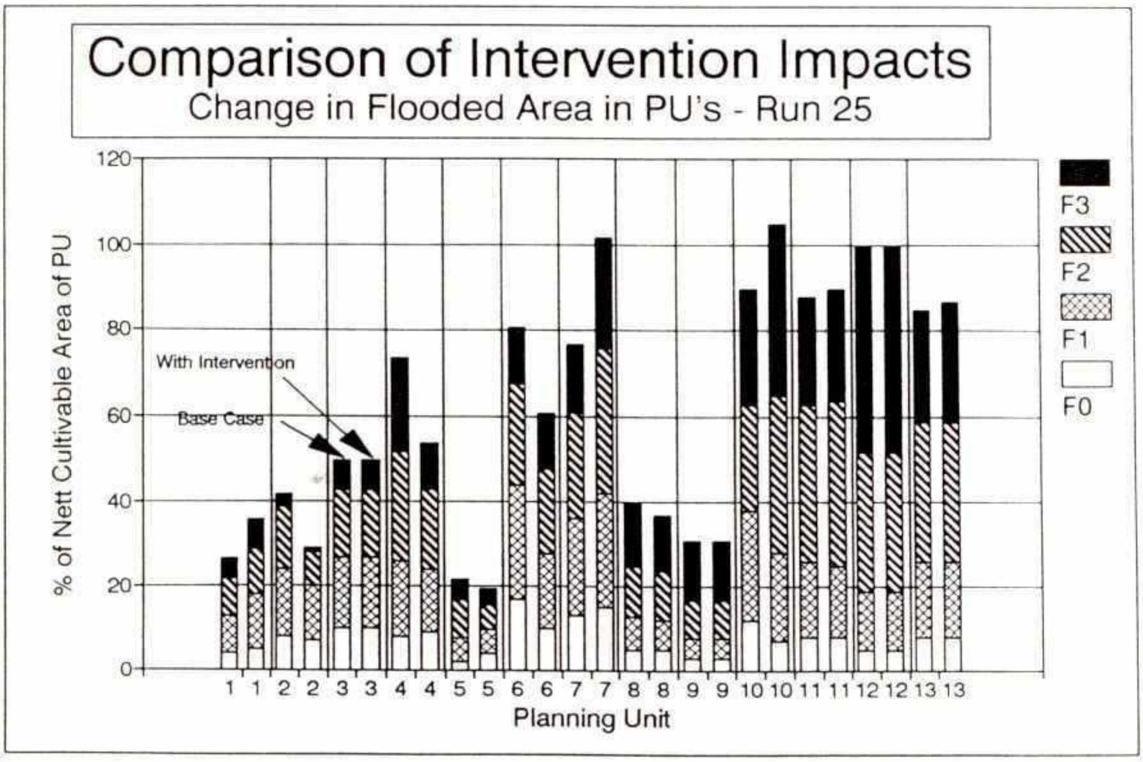
Graph RS1.11 . **Dhaleswari - Kaliganga embankment, (1st Phase) - with drainage - no Jamuna Bridge - semi-controlled distributaries**



Graph RS1.25 **Dhaleswari - Jamuna embankment - no drainage - no Jamuna Bridge - fully controlled distributaries**



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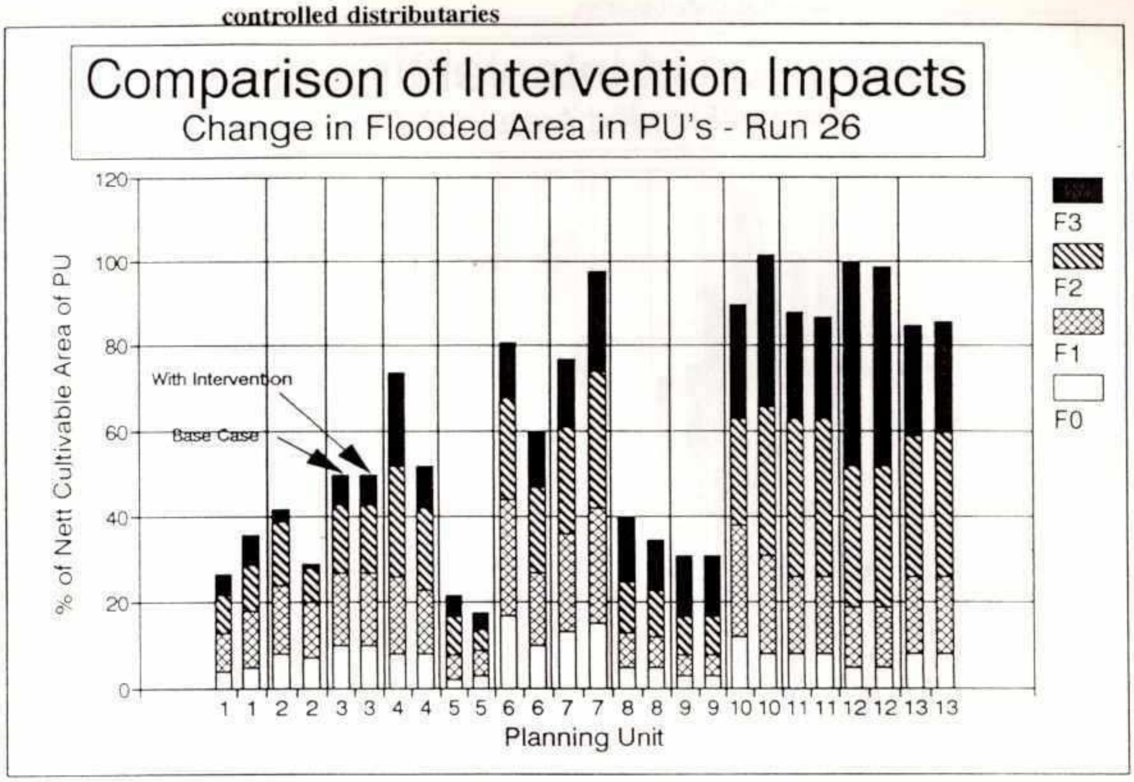
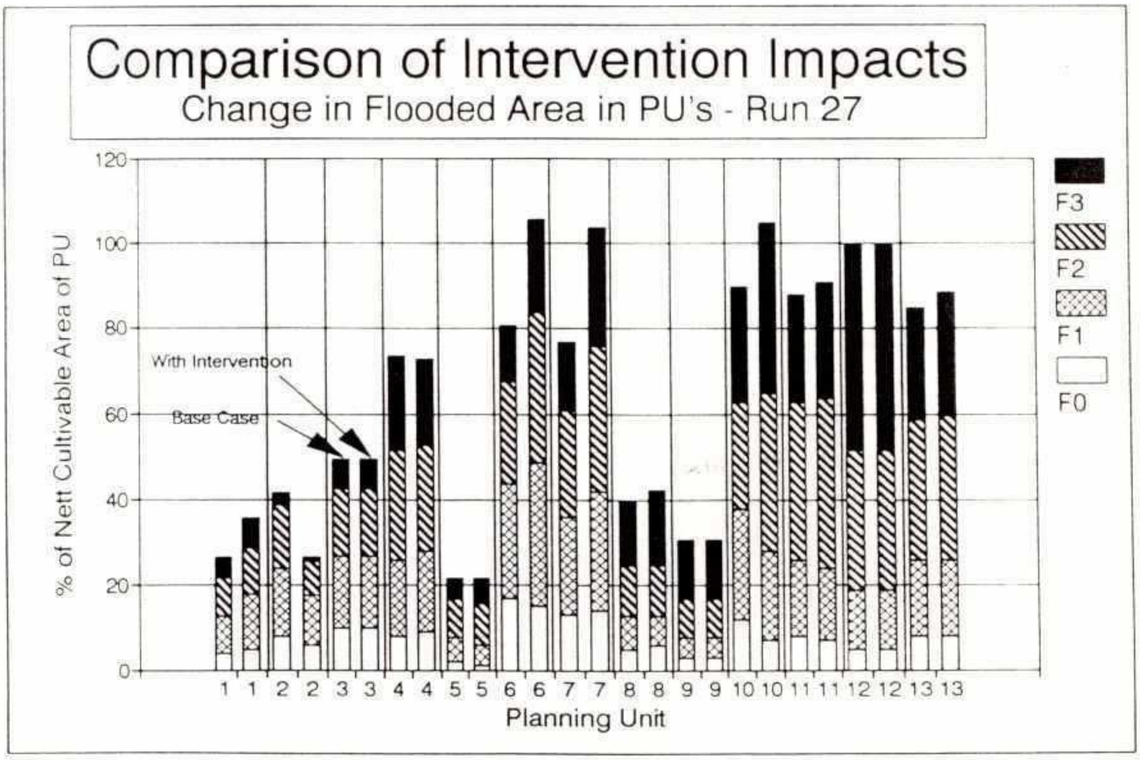
Graph RS1.26 **Dhaleswari - Jamuna embankment - with drainage - no Jamuna Bridge - fully controlled distributaries**



Graph RS1.27 **Dhaleswari - Jamuna embankment - no drainage - no Jamuna Bridge - semi-controlled distributaries**



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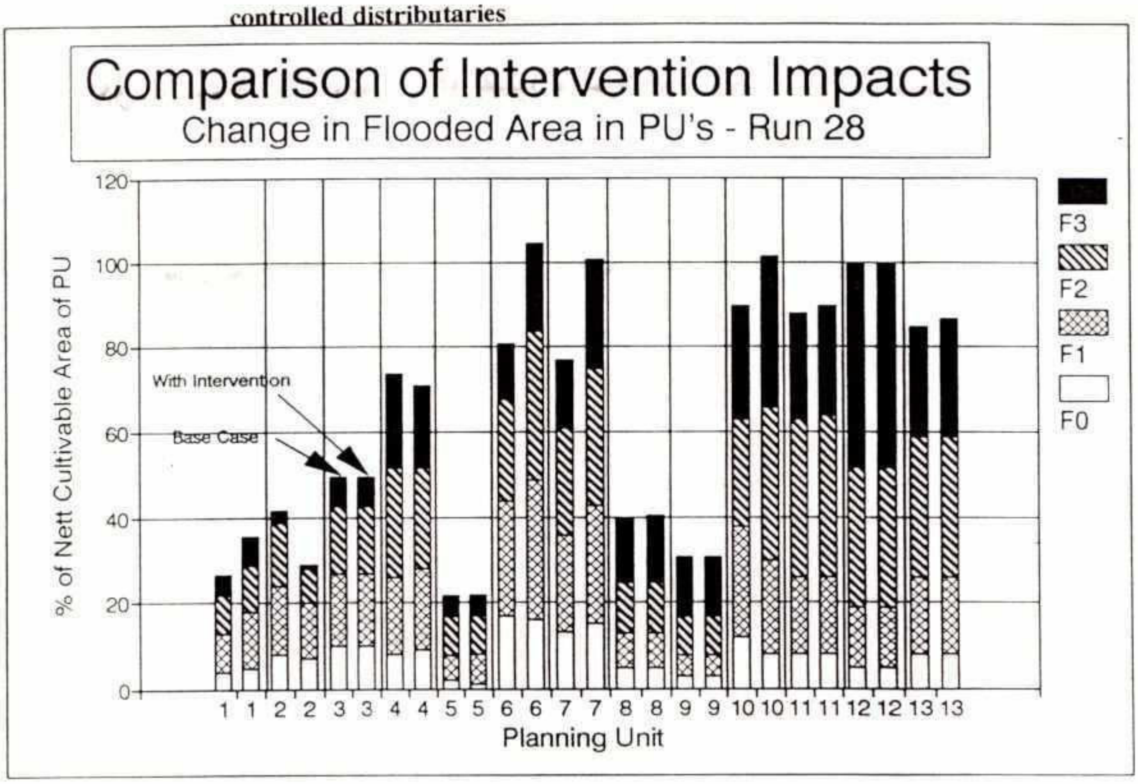
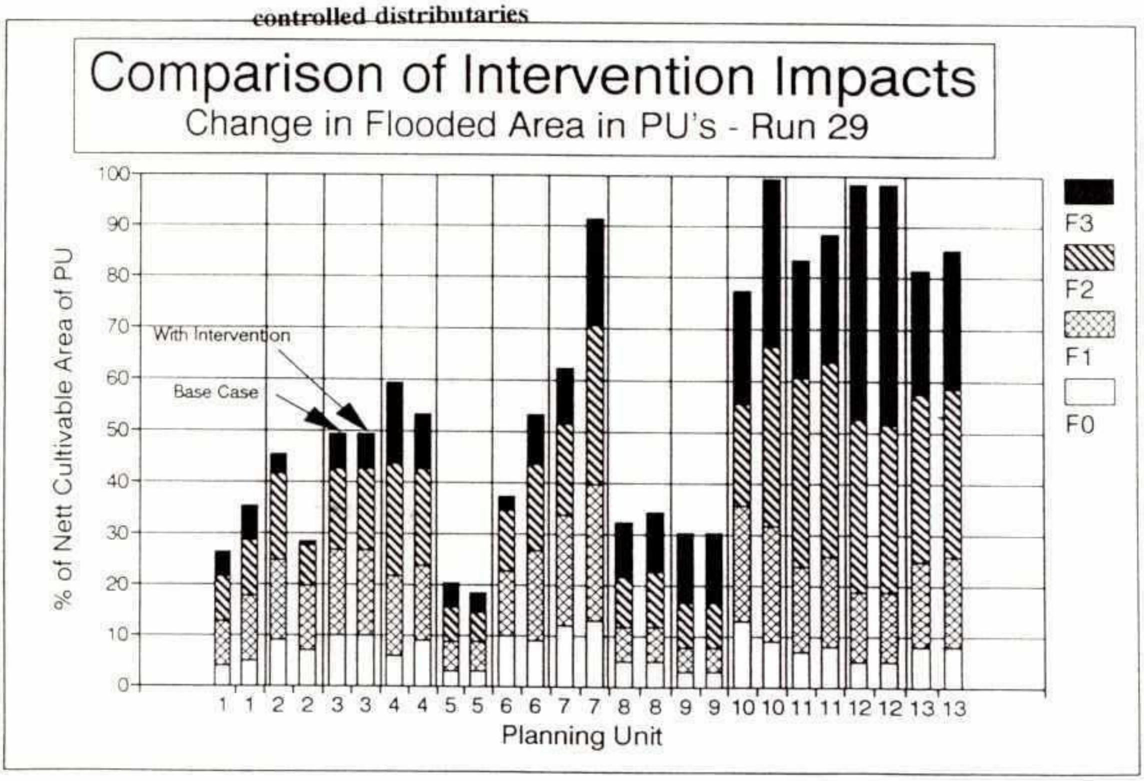
Graph RS1.28 **Dhaleswari - Jamuna embankment - with drainage - no Jamuna Bridge - semi-controlled distributaries**



Graph RS1.29 **Dhaleswari - Jamuna embankment - no drainage - with Jamuna Bridge - fully controlled distributaries**



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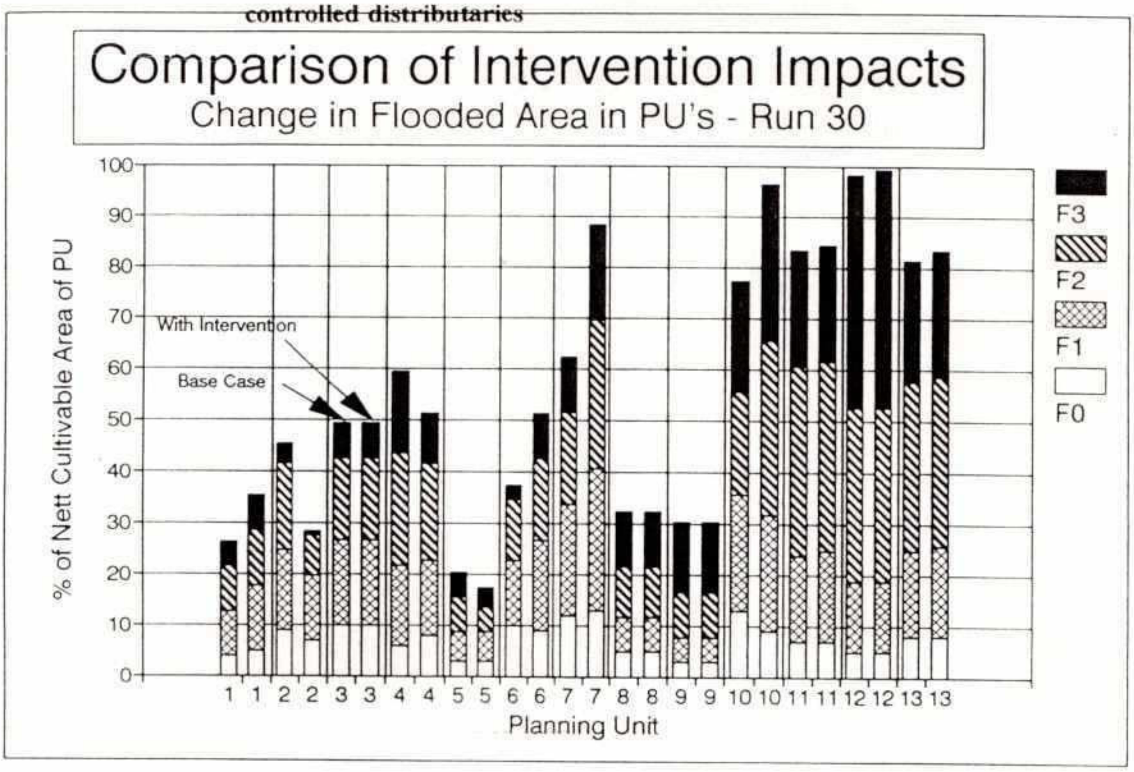
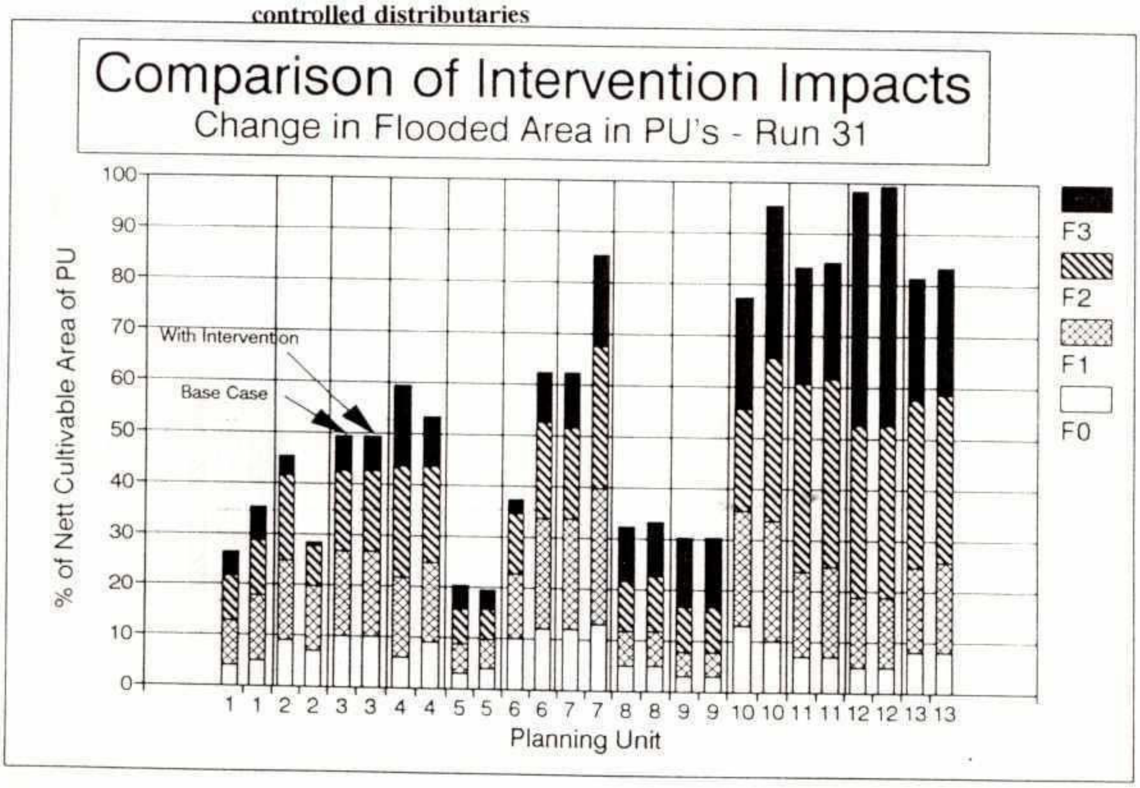
Graph RS1.30 **Dhaleswari - Jamuna embankment - with drainage - with Jamuna Bridge - fully controlled distributaries**



Graph RS1.31 **Dhaleswari - Jamuna embankment - with drainage - with Jamuna Bridge - semi-controlled distributaries**



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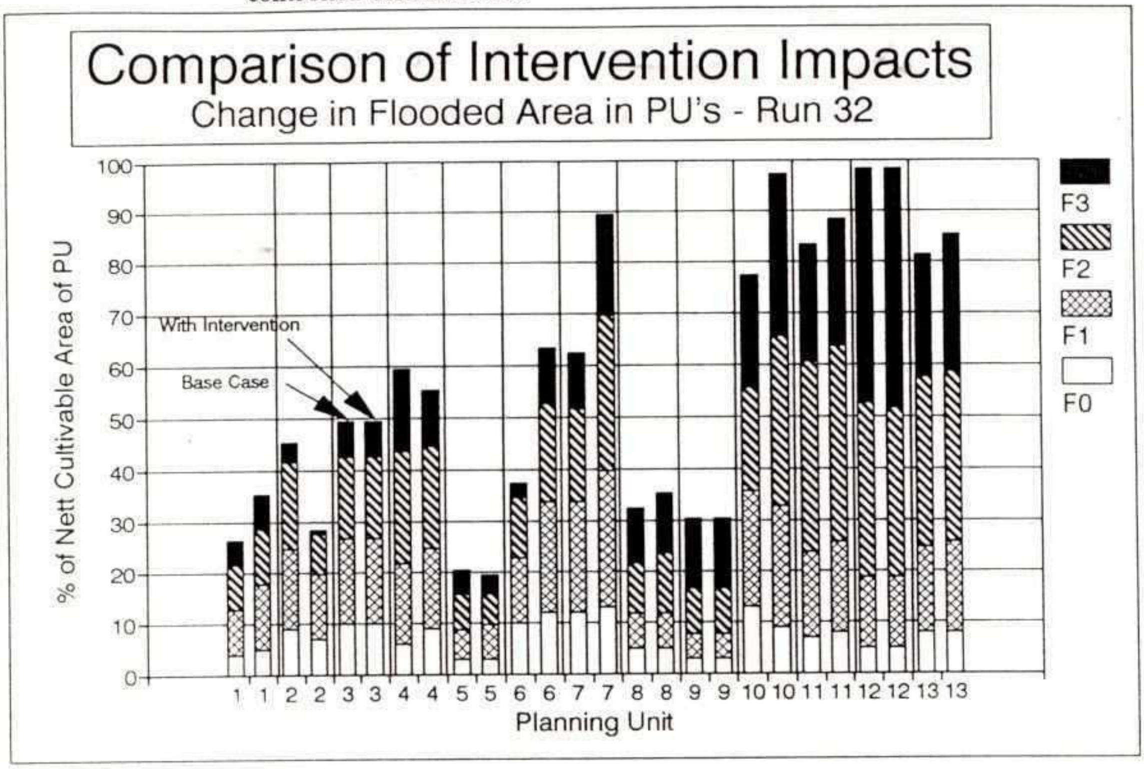
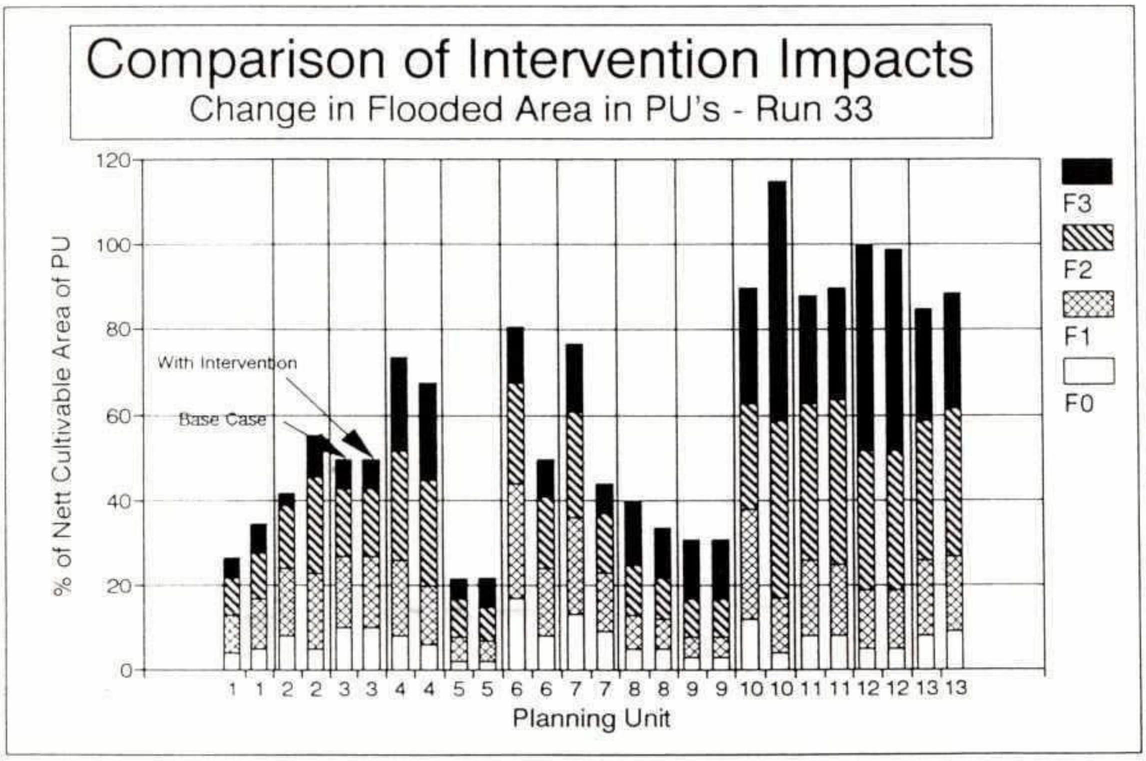
Graph RS1.32 **Dhaleswari - Jamuna embankment - no drainage - with Jamuna Bridge - semi-controlled distributaries**



Graph RS1.20 **Dhaleswari - Kaliganga embankment - no drainage - no Jamuna Bridge - fully controlled distributaries - Baushi Bridge de-restricted**



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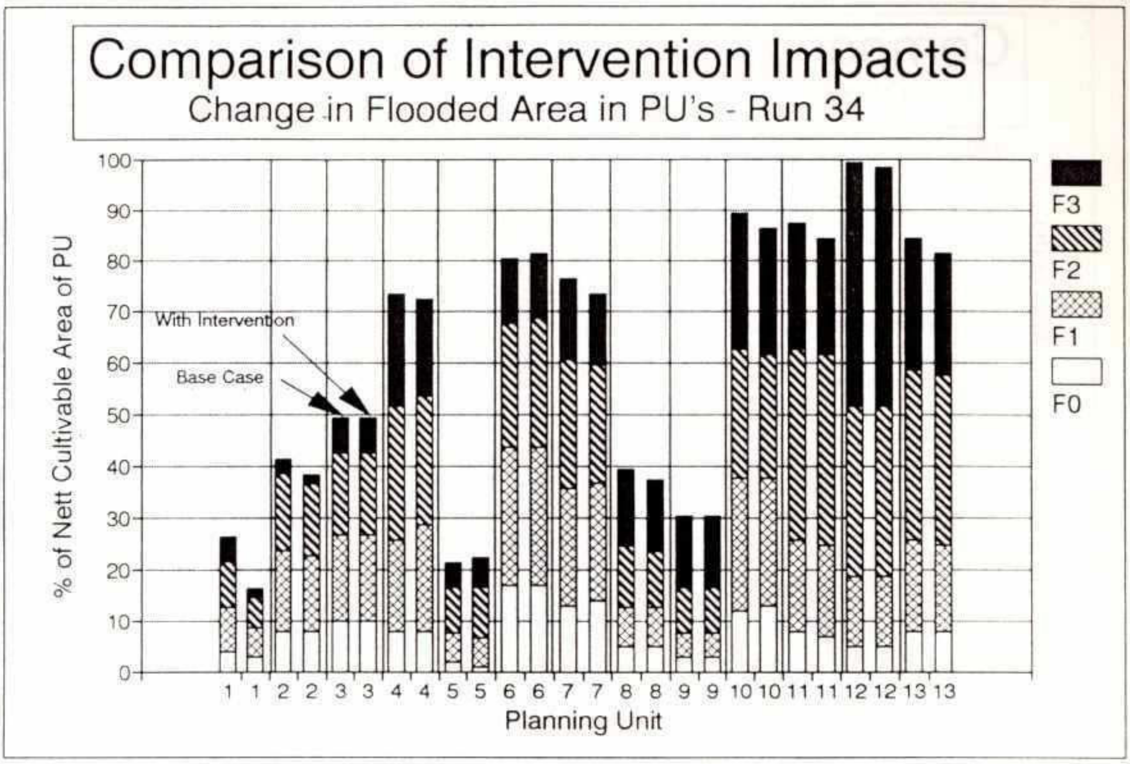
Graph RS1.24 Regional drainage - no Jamuna Bridge - Baushi Bridge de-restricted



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Graph RS1.21 **Dhaleswari - Kaliganga embankment - no drainage - with Jamuna Bridge - fully controlled distributaries - 1987 data**

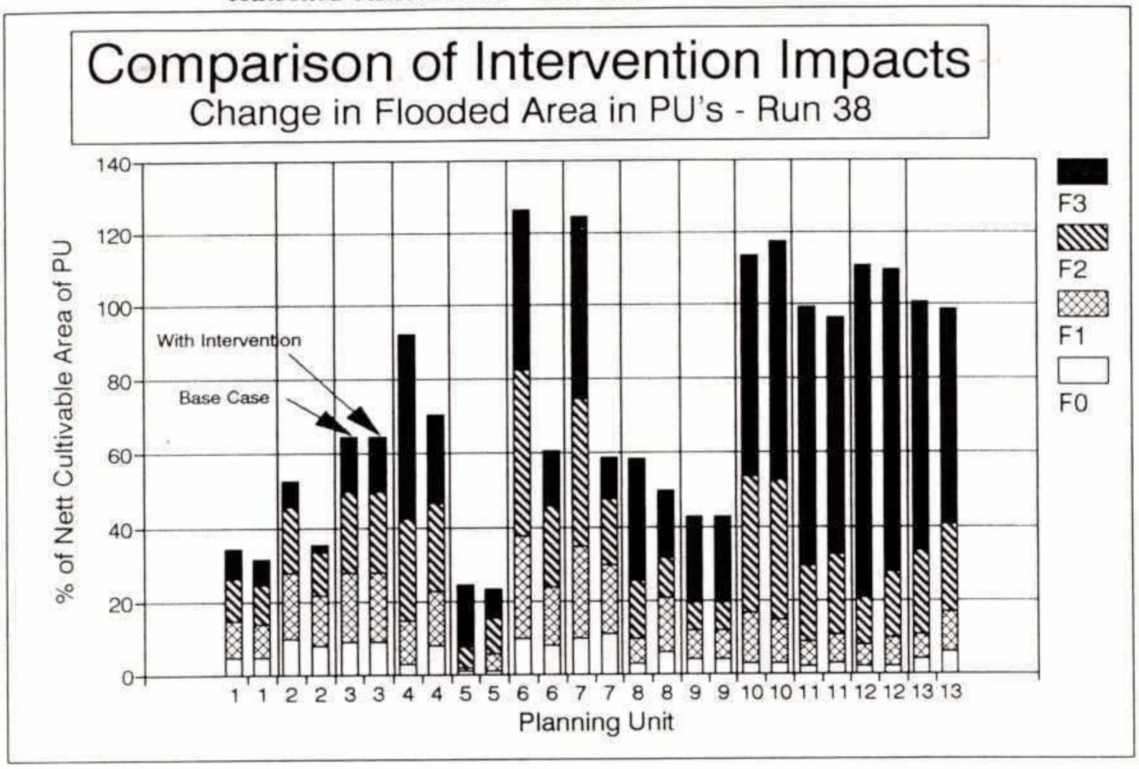

Figure II.1
Alternative Flood Plain Descriptions

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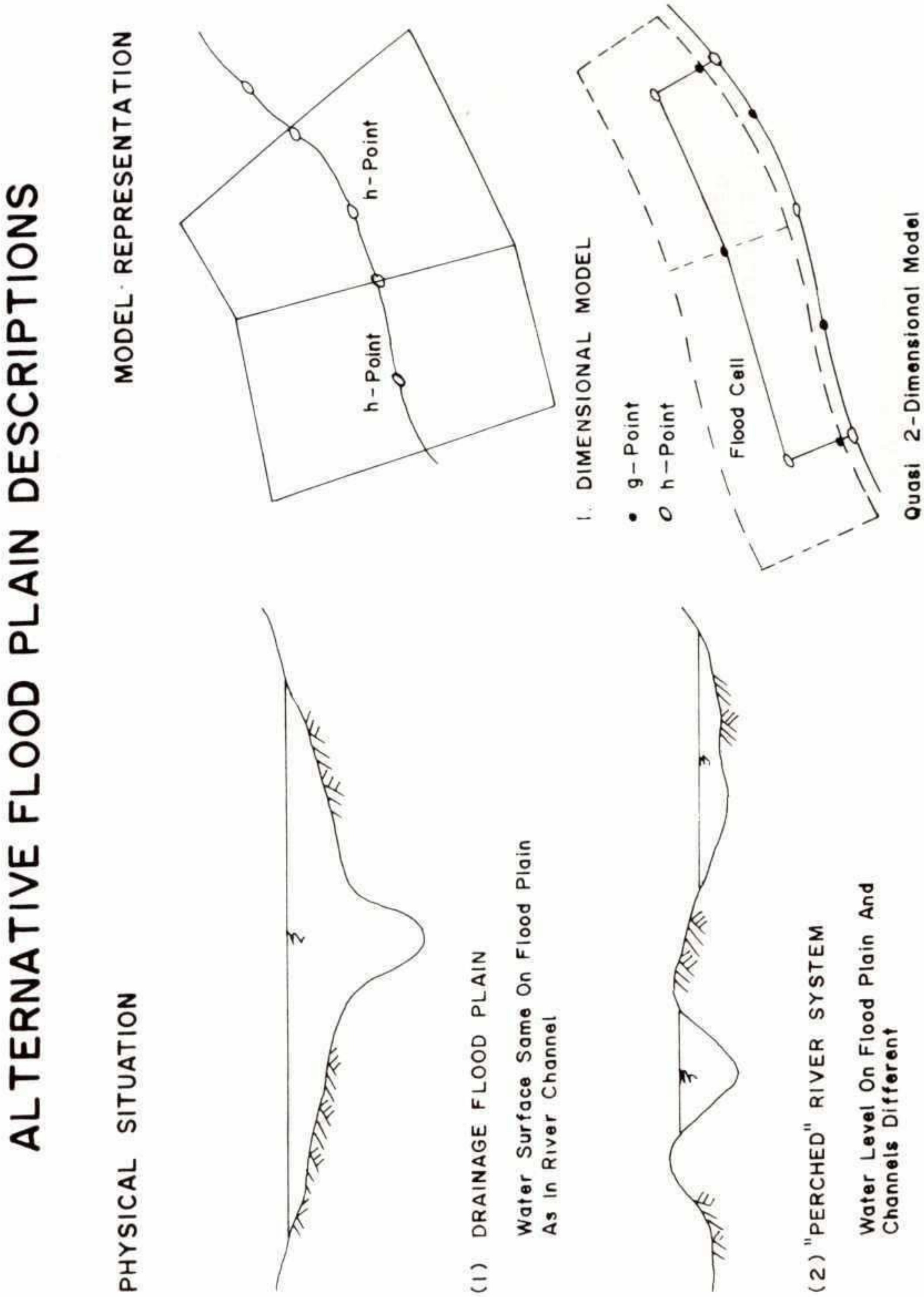

Figure II.2
Effect of Embankments - RS 3 Scheme