People's Republic of Bangladesh
Ministry of Irrigation, Water Development
and Flood Control

Flood Plan Coordination Organisation

Southwest Area Water Resources Management Project

United Nations Development Programme
(BGD/88/038)

Asian Development Bank
(TA No 1498-BAN)

FAP 4

FINAL REPORT

Volume 5

Hydrology, Hydrogeology and RAOM

August 1993

Sir William Halcrow & Partners Ltd.

in association with
Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
Sthapati Sangshad Limited

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Hydrology

SOUTHWEST AREA WATER RESOURCES MANAGEMENT PROJECT

HYDROLOGY

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ACRONYMS AND ABBREVIATIONS

BARC	Bangladesh Agricultural Research Council
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CAT	Coordination Advisory Team
FAO	Food and Agricultural Organisation of the United Nations
FAP-25	Flood Action Plan Component No. 25 (Flood Modelling and Management)
MPO	Master Plan Organisation
SWMC	Surface Water Modelling Centre

1 INTRODUCTION

1.1 General

The study area covers an area of approximately 40,450 km^2 or 28% of Bangladesh's total area. The region is bounded by the Indian border to the west, by the Ganges-Padma and Lower Meghna rivers in the north and east and by the Bay of Bengal to the south. The region is characterised by a large number of interconnected rivers and channels and a diversity of agro-ecological zones as described in the Main Report. The two main fresh water carriers are the Gorai-Madhumati river which offtakes from the Ganges and the Arial Khan river which offtakes from the Padma. The region comes under the tidal influence which is felt as far upstream as Jessore and the mouth of the Arial Khan. The effects of saline intrusion are also felt seasonally in a significant part of the region.

Agriculture is the most important economic activitiy in the Southwest Area. Fisheries and forestry also play an important role in the region.

1.2 Objectives

The objectives of the hydrological analysis are to provide information for regional planning. These include:

- estimation of potential evapotranspiration for calculation of crop water requirements
- rainfall analysis and estimation of design storms for drainage systems
- estimation of expected flows and growth factors for floods
- estimation of design levels for flood protection
- regional water balance
- assessment of saline intrusion

1.3 Data Requirements and Availability

Data required for the study includes discharges, water levels, tidal ranges, salinity, rainfall and other climatic data including evaporation, relative humidity, temperature, wind speed and sunshine hours.

For a regional study and pre-feasibility studies of individual schemes, the time frame chosen for carrying out water balances is usually a month. For more detailed analysis however, a shorter time step may be required. Although historical water level data is available at a large number of stations in the study area, not all stations have complete and long records. Discharge data is available for a far fewer number of stations as a large part of the region comes under the tidal influence. The data collection programme was therefore geared towards obtaining essential data at selected stations in the region with a view to gaining an overall impression of the hydrological characteristics of the area. The stations were selected so as to provide a good spread in the region where long term data existed. Data was also collected at other stations where it was readily available.

The national agencies responsible for collecting these data are the BWDB and the BMD. BWDB collects data on water levels, discharges, salinities, rainfall and evaporation whereas BMD is responsible for collecting general climatic data. BIWTA also collects data on water levels, but these primarily relate to water depths for navigational purposes. The SWMC has also conducted its own data collection programme mainly for tidal levels, discharges and salinity measurements. Although a vast amount of historical data exists, not all of it has been computerised. Various agencies including MPO, Northwest Hydraulics Consultants and FAP-25 have computerised part of the data collected from BWDB. BARC also maintains a database of climatic data collated from BMD records and is currently updating this database.

2 CLIMATE

2.1 Data Availability

Climatic data was available from BMD at 7 stations in the study area for the period 1965 to 1990. The availability of mean monthly maximum, minimum and mean temperature, relative humidity, wind speed and sunshine hour data is shown in Tables 2.1 to 2.4. This data is primarily required for the calculation of potential evapotranspiration.

Pan evaporation data was collected at 10 stations maintained by BWDB in the project area for the period 1966 to 1990. Availability of evaporation data is shown in Tables 2.5 and 2.6.

The location of climatic stations is shown in Figure 2.1. Climatic parameters at various sites in the study area are shown in Figures 2.2 to 2.8 and Tables 2.7 to 2.13.

2.2 Temperature

The mean temperature in the study area ranges from a minimum of 19°C in January to a maximum of 30°C in May. There is very little variation across the region with differences of the order of 1°C. The mean annual temperature varies from 25.8°C at Barisal to 26.6°C at Khulna.

2.3 Relative Humidity

The region has high relative humidity and ranges from a mean annual relative humidity of 76% at Jessore to 85% at Bhola. The coastal regions are, as expected, more humid than inland areas and rarely experience relative humidity below 75%.

2.4 Wind Speed

Wind speed data at the BMD climatic stations is reported as an average for the day in knots for the predominant wind direction at 10 m height. The records indicate a significant variation in the mean wind speed across the region. At Faridpur, the mean annual wind speed is 3.3 knots whereas at Jessore the mean annual wind speed is 6.3 knots. The monthly distribution of the wind speed also varies from a flattened distribution at Barisal and Khulna to a markedly peaked distribution at Bhola, Faridpur, Jessore and Patuakhali with the peak occuring in April. The wind speed distribution at Satkhira shows a dual peak occuring in April and August.

2.5 Sunshine Hours

The study area experiences a wide variation in the distribution of sunshine hours, ranging from a mean annual minimum of 5.2 hours at Patuakhali to a maximum of 7.0 hours at Barisal and Faridpur. As would be expected the sunshine hours in the monsoon season from June to September are much lower than during the rest of the year where in excess of 8.5 hours of sunshine are not uncommon.

2.6 Evaporation

Evaporation in Bangladesh is usually measured using a modified Class A Pan which has an extra 5 inches of freeboard above the water surface as compared to a normal Class A Pan.

A pan coefficient of 0.7 is used by BWDB to convert pan evaporation to open water evaporation.

Evaporation in the region varies from 935 mm at Patuakhali to 1150 mm at Benarpota. As discussed in the following section, the evaporation rates are on the low side as compared to the evapotranspiration estimates.

2.7 Evapotranspiration

Evapotranspiration was calculated from mean monthly values of the climatic data at each station. The Doorenbos and Pruitt modification of the Penman method as outlined in the FAO Irrigation and Drainage Paper No. 24 is widely applied in Bangladesh and was used for estimating the potential evapotranspiration. Climatic data used for estimating the potential evapotranspiration was collected from BMD and covers the period from 1965 to 1990.

Estimates of solar radiation and mean duration of maximum possible sunshine hours were made from standard tables based on latitudes. A reflection coefficient of 0.25 was used. Wind speed data is reported by BMD as an average for the day in knots for the predominant wind direction at 10 m height. Estimates of potential evapotranspiration are sensitive to wind data and efforts should be made to corroborate the results with actual field measurements in the future. Monthly potential evapotranspiration computed at 7 stations in the study area together with previous estimates made by BARC are shown in Tables 2.14a and 2.14b. The computed potential evapotranspiration rates at Bhola and Jessore are 1312 mm and 1675 mm respectively.

A comparison with previous studies shows that the evapotranspiration calculated using recent climatic data is higher than previously reported. The annual variation is of the order of 5% except at Satkhira where the variation is as much as 20% (Table 2.15). This discrepancy may be due in part to the availability of longer term climatic records which result in better estimates.

It may be noted here that the calculated annual potential evapotranspiration values are higher than the reported annual pan evaporation values by as much as 65%. This discrepancy cannot be explained and needs to be looked at carefully if pan evaporation data is to be used. A higher reliability is attached to the computed potential evapotranspiration as it is a function of a number of climatic parameters and does not rely on the measurement of a single parameter.

Table 2.1

Availability of Monthly Maximum, Minimum and Mean Temperature Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Barisal	E–02		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	Faridpur	E–14	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
3	Jessore	E–17	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C
4	Khulna	E–20	C	C		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	Bhola	E–39		C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C
6	Patuakhali	E–41									C		C	C	C	C	C		C	C	C	C	C	C	C	C		
7	Satkhira		C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	

Table 2.2

Availability of Mean Monthly Relative Humidity Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Barisal	E–02	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	Faridpur	E–14	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
3	Jessore	E–17	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C
4	Khulna	E–20	C	C		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	Bhola	E–39		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
6	Patuakhali	E–41									C		C	C	C	C	C		C	C	C	C	C	C	C	C		
7	Satkhira		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	

C Collected

Table 2.3

Availability of Mean Monthly Wind Speed Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Barisal	E-02	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	Faridpur	E-14	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
3	Jessore	E-17	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C
4	Khulna	E-20	C	C		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	Bhola	E-39		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
6	Patuakhali	E-41									C		C	C	C	C	C		C	C	C	C	C	C	C	C		
7	Satkhira		C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	

Table 2.4

Availability of Mean Monthly Bright Sunshine Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Barisal	E-02		C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C
2	Faridpur	E-14																					C	C	C	C	C	C
3	Jessore	E-17			C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
4	Khulna	E-20																				C	C	C	C	C	C	C
5	Bhola	E-39																	C	C	C	C	C	C	C	C	C	C
6	Patuakhali	E-41																					C	C	C	C	C	C
7	Satkhira																					C	C	C	C	C	C	C

C Collected

Table 2.5

Availability of Daily Evaporation Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Amla	E-01			C			C	C	C	C	C	C	C	C	C	C							C	C	C	C	C
2	Barisal	E-02			C			C	C	C	C	C	C	C	C	C	C							C	C	C	C	C
3	Benarpota	E-04			C			C	C	C	C	C	C	C	C	C	C							C	C	C	C	C
4	Faridpur	E-14			C			C	C	C	C	C	C	C										C	C	C	C	C
5	Jessore	E-17			C			C	C	C	C	C	C	C	C	C	C							C	C	C	C	C
6	Khulna	E-20			C			C	C	C	C	C	C	C	C	C	C							C	C	C		
7	Bagerhat	E-34			C			C	C	C	C	C	C	C	C	C									C	C	C	C
8	Bhola	E-39					C		C	C	C	C	C	C	C	C	C								C	C	C	C
9	Patuakhali	E-41					C		C	C	C	C	C	C	C	C	C								C	C	C	C
10	Pirojpur	E-42					C		C	C	C	C	C	C	C	C	C								C	C	C	C

Table 2.6

Availability of Monthly Evaporation Data

Sl.No.	Station Name	Station No.	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Amla	E-01			C	C		C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C
2	Barisal	E-02			C	C		C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C
3	Benarpota	E-04			C	C		C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C
4	Faridpur	E-14			C	C		C	C	C	C	C	C	C	C						C	C	C	C	C	C	C	C
5	Jessore	E-17			C	C		C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C
6	Khulna	E-20			C	C		C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C		
7	Bagerhat	E-34			C	C		C	C	C	C	C	C	C	C	C					C	C	C	C	C	C	C	C
8	Bhola	E-39					C	C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C
9	Patuakhali	E-41					C	C	C	C	C	C	C	C	C	C	C				C	C	C	C	C	C	C	C
10	Pirojpur	E-42					C	C	C	C	C	C	C	C	C	C	C	C					C	C	C	C	C	C

C   Collected

Table 2.7

Mean Monthly Maximum Temperature (°C) (1965-1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	25.7	25.9	24.6	25.8	26.4	25.8	25.9
Feb	28.4	28.5	27.8	28.9	28.9	28.5	28.7
Mar	32.0	31.9	32.7	33.3	33.3	32.1	33.2
Apr	33.2	32.8	34.2	35.8	34.7	32.7	35.3
May	33.1	32.8	33.5	35.1	34.1	32.9	35.1
Jun	31.5	31.3	32.0	32.9	32.5	31.3	33.2
Jul	30.7	30.5	31.3	31.9	31.7	30.8	31.9
Aug	30.8	30.6	31.3	31.9	31.5	30.7	32.0
Sep	31.3	31.2	31.6	32.3	32.0	31.0	32.1
Oct	31.2	31.3	31.2	31.9	32.0	31.6	32.3
Nov	29.3	29.5	28.7	29.7	30.1	29.4	30.2
Dec	26.3	26.7	25.2	26.4	26.8	26.6	26.8
Annual	30.3	30.3	30.3	31.3	31.2	30.3	31.4

Source: BMD

Table 2.8

Mean Monthly Minimum Temperature (°C) (1965-1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	12.0	12.7	12.1	11.6	13.1	13.9	12.6
Feb	14.9	15.7	14.2	14.2	15.8	16.4	15.6
Mar	20.1	20.5	19.1	19.5	20.8	21.1	20.6
Apr	23.7	23.8	23.0	23.7	24.2	24.1	24.3
May	24.9	24.9	24.3	25.0	25.5	25.2	25.2
Jun	25.8	25.5	25.6	25.8	26.3	25.8	26.2
Jul	25.6	25.7	25.8	25.9	26.2	25.6	26.0
Aug	25.7	25.8	26.0	25.9	26.2	25.7	26.0
Sep	25.7	25.5	25.8	25.6	26.1	25.6	25.8
Oct	23.7	23.8	23.8	23.3	24.4	24.3	23.8
Nov	18.6	19.2	18.9	18.0	19.8	21.2	18.7
Dec	13.3	14.1	13.6	12.4	14.5	15.9	13.6
Annual	21.2	21.4	21.0	20.9	21.9	22.1	21.5

Source: BMD

Table 2.9

Mean Monthly Temperature (°C) (1965–1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	18.9	19.4	18.4	18.9	19.8	19.9	19.3
Feb	21.7	22.1	21.1	21.6	22.4	22.5	22.3
Mar	26.2	26.2	25.9	26.4	27.1	26.7	27.0
Apr	28.5	28.3	28.6	29.8	29.5	28.4	29.8
May	29.0	28.9	29.0	30.1	29.9	29.2	30.1
Jun	28.7	28.4	28.8	29.4	29.4	28.7	29.7
Jul	28.2	28.2	28.6	28.9	29.0	28.3	29.0
Aug	28.3	28.2	28.7	28.9	29.0	28.3	29.0
Sep	28.5	28.4	28.7	29.0	29.2	28.4	29.0
Oct	27.5	27.6	27.6	27.7	28.2	28.0	28.1
Nov	24.0	24.4	23.8	23.9	25.0	25.2	24.5
Dec	19.8	20.4	19.5	19.5	20.7	21.2	20.2
Annual	25.8	25.9	25.7	26.2	26.6	26.2	26.5

Source: BMD

Table 2.10

Mean Monthly Relative Humidity (%) (1965–1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	79	82	75	71	73	73	70
Feb	75	78	68	65	71	70	67
Mar	75	80	64	63	70	73	65
Apr	80	83	70	68	75	79	70
May	82	85	79	75	78	82	74
Jun	88	89	87	85	87	86	83
Jul	90	90	88	88	89	88	87
Aug	90	90	87	87	88	87	88
Sep	89	89	86	86	87	86	86
Oct	86	87	82	81	83	83	82
Nov	82	83	78	75	78	79	75
Dec	80	82	77	73	75	74	71
Annual	83	85	78	76	80	80	77

Source: BMD

Table 2.11

Mean Monthly Wind Speed (Knots) (1965-1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	4	3	3	5	3	3	5
Feb	4	4	3	5	3	4	5
Mar	4	4	3	6	4	5	6
Apr	5	6	5	9	5	7	6
May	5	5	4	8	5	6	6
Jun	5	5	4	7	5	5	5
Jul	5	5	4	7	5	5	5
Aug	5	5	4	7	5	5	6
Sep	4	4	3	6	4	4	5
Oct	4	4	3	5	3	4	5
Nov	4	4	2	5	3	4	5
Dec	4	3	2	5	3	3	4
Annual	4.4	4.3	3.3	6.3	4.0	4.6	5.3

Note: Wind speed is reported as the mean 24 hourly value in the predominant direction at 10 m height

Source: BMD

Table 2.12

Mean Monthly Bright Sunshine (Hours) (1965-1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	8.6	6.4	8.0	7.8	8.2	7.3	7.9
Feb	8.7	6.8	8.4	8.1	8.2	6.9	8.2
Mar	8.5	7.1	7.8	8.0	8.4	7.3	8.5
Apr	8.6	6.9	7.9	8.1	8.8	6.2	8.9
May	7.7	5.9	7.6	7.7	7.7	5.8	8.0
Jun	4.4	3.4	5.4	5.2	4.6	2.5	4.3
Jul	4.0	2.8	4.1	4.0	3.5	2.3	3.6
Aug	4.4	3.5	5.4	4.8	4.7	3.2	4.7
Sep	5.3	4.0	5.2	5.0	4.5	3.4	5.1
Oct	7.5	6.0	7.6	7.1	7.4	4.4	7.6
Nov	8.2	6.5	8.0	7.8	8.0	5.6	7.9
Dec	8.5	6.2	8.1	7.7	8.1	7.0	8.0
Annual	7.0	5.5	7.0	6.8	6.8	5.2	6.9

Source: BMD

Table 2.13

Mean Monthly Evaporation (mm) (1965–1990)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Amla	Benarpota	Bagerhat	Pirojpur
Jan	60	67	55	61	62	57	57	62	60	63
Feb	68	66	63	70	73	60	74	78	83	65
Mar	104	96	102	113	111	92	123	119	121	94
Apr	113	102	119	132	131	112	153	144	131	110
May	108	107	111	120	129	112	138	145	123	113
Jun	77	91	87	93	96	89	109	104	98	81
Jul	62	75	71	78	77	70	88	86	73	60
Aug	65	76	73	79	82	70	89	85	72	71
Sep	68	80	75	73	74	68	83	90	75	70
Oct	83	86	77	80	77	80	85	91	92	87
Nov	69	79	68	71	72	67	77	79	84	79
Dec	60	77	57	66	64	59	64	67	67	70
Annual	936	1002	957	1037	1049	935	1141	1150	1079	964

Source: BWDB, MPO

Table 2.14a

Modified Penman Potential Evapotranspiration (mm)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	90	63	84	98	91	85	98
Feb	117	90	99	113	102	96	113
Mar	163	142	151	181	163	161	186
Apr	177	157	176	206	191	162	199
May	180	154	179	206	190	164	208
Jun	127	114	130	143	132	110	131
Jul	123	110	125	133	121	108	125
Aug	123	113	128	140	131	115	134
Sep	118	105	119	127	115	103	125
Oct	126	111	123	128	122	98	133
Nov	100	87	101	109	101	87	111
Dec	87	67	84	92	87	81	94
Annual	1530	1312	1498	1675	1547	1369	1657

Source: Computed from recent climatic data

Table 2.14b

Modified Penman Potential Evapotranspiration (mm)

	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Jan	84.6		84.6	92.4	88.4		83.1
Feb	100.8		95.8	109.2	107.0		102.2
Mar	140.7		145.7	167.7	149.7		146.3
Apr	160.2		174.3	213.6	161.7		160.5
May	168.6		182.6	216.1	171.4		178.9
Jun	117.9		121.8	139.5	114.9		118.8
Jul	120.3		137.0	139.2	118.4		118.4
Aug	114.1		136.7	137.0	113.5		111.9
Sep	115.2		126.9	122.7	112.2		112.2
Oct	114.1		124.9	126.2	119.7		73.8
Nov	97.8		129.3	99.9	102.9		71.4
Dec	81.5		81.2	84.6	88.0		102.3
Annual	1415.9		1540.9	1648.1	1447.8		1379.8

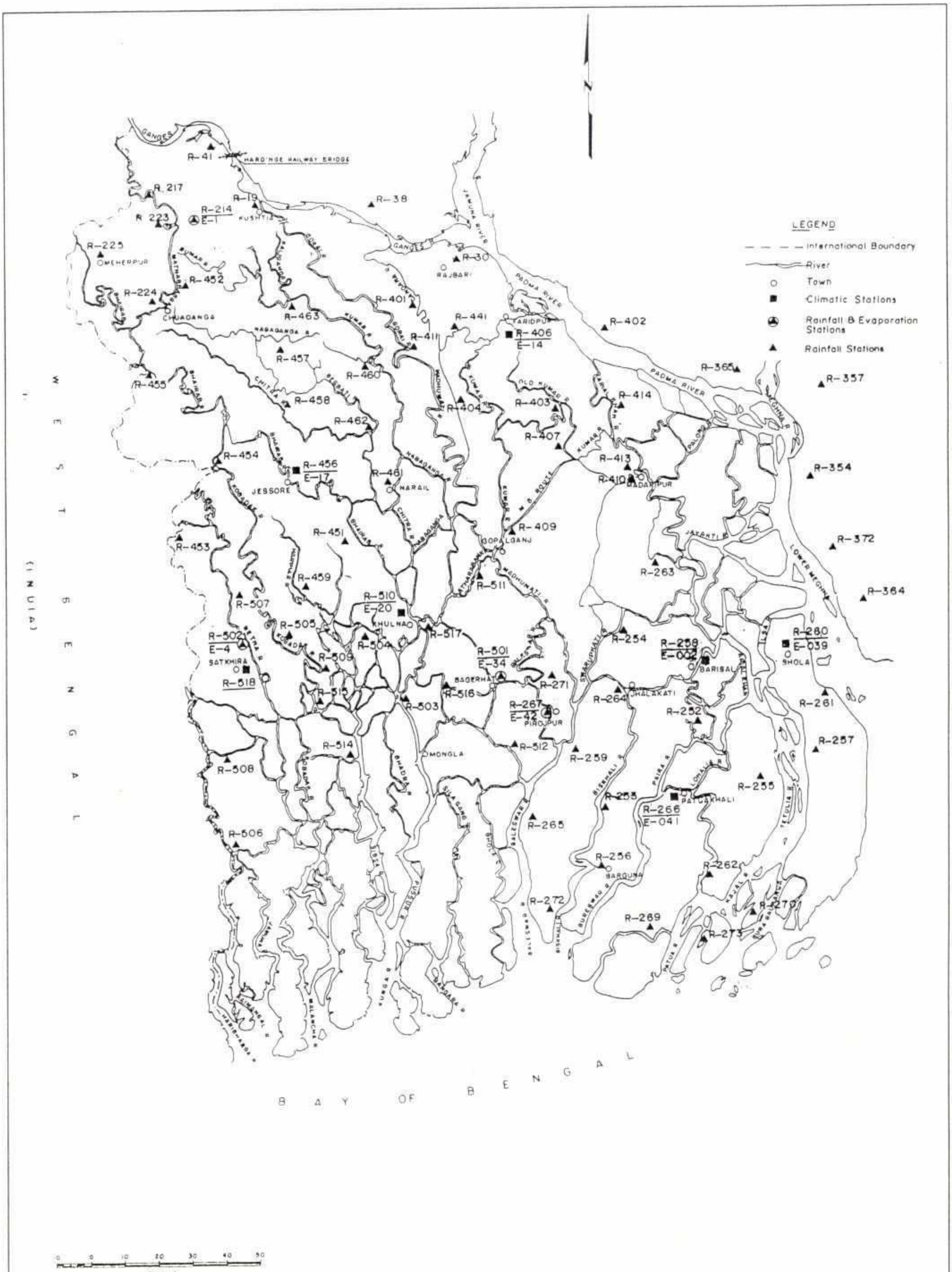
Source: BARC Soils and Irrigation Publication No. 11, 1982

Table 2.15

Deviation from BARC (1982) Estimates (%)

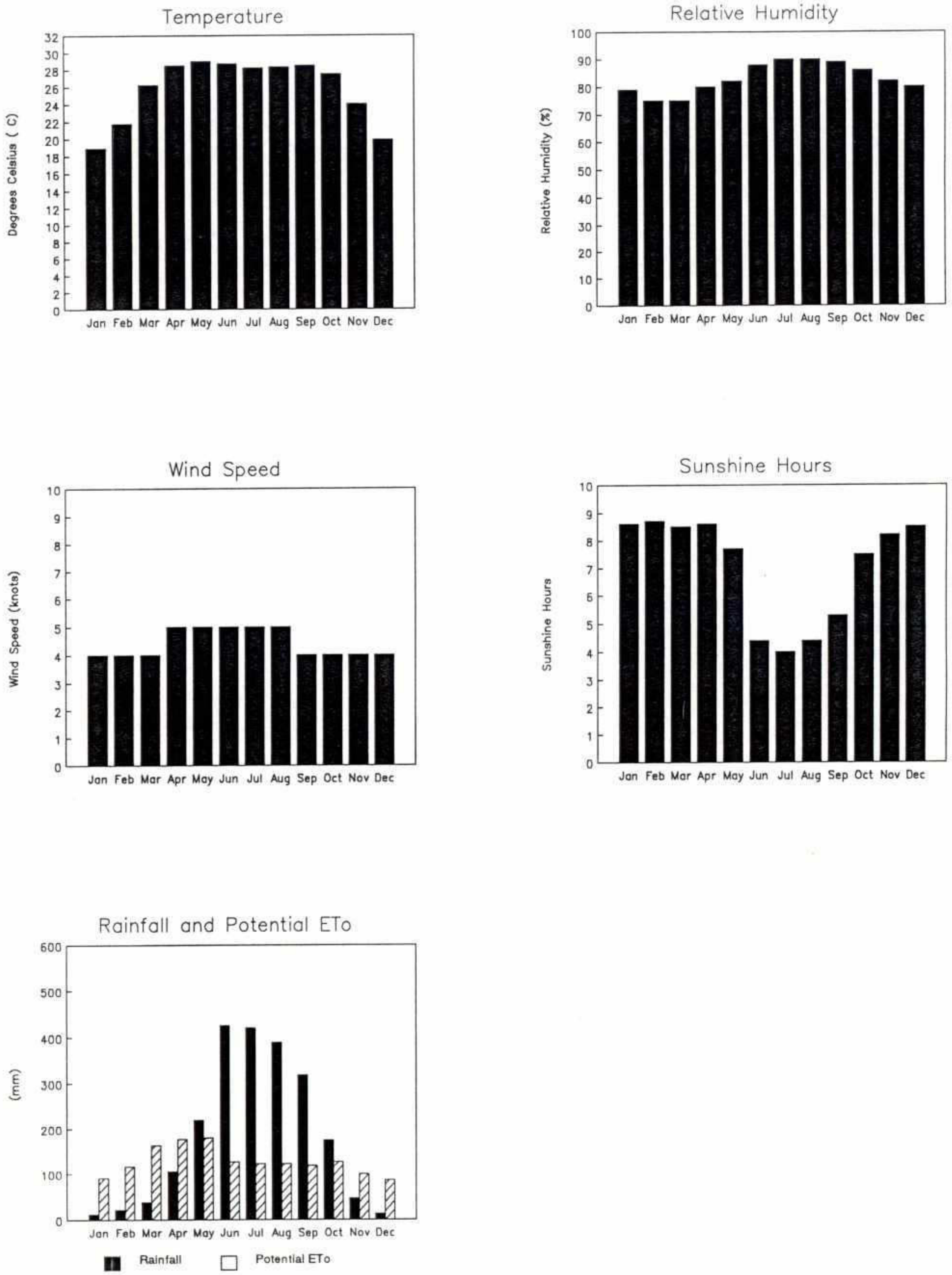
	Barisal	Bhola	Faridpur	Jessore	Khulna	Patuakhali	Satkhira
Annual	8.1		-2.8	1.6	6.8		20.1

Figure 2.1



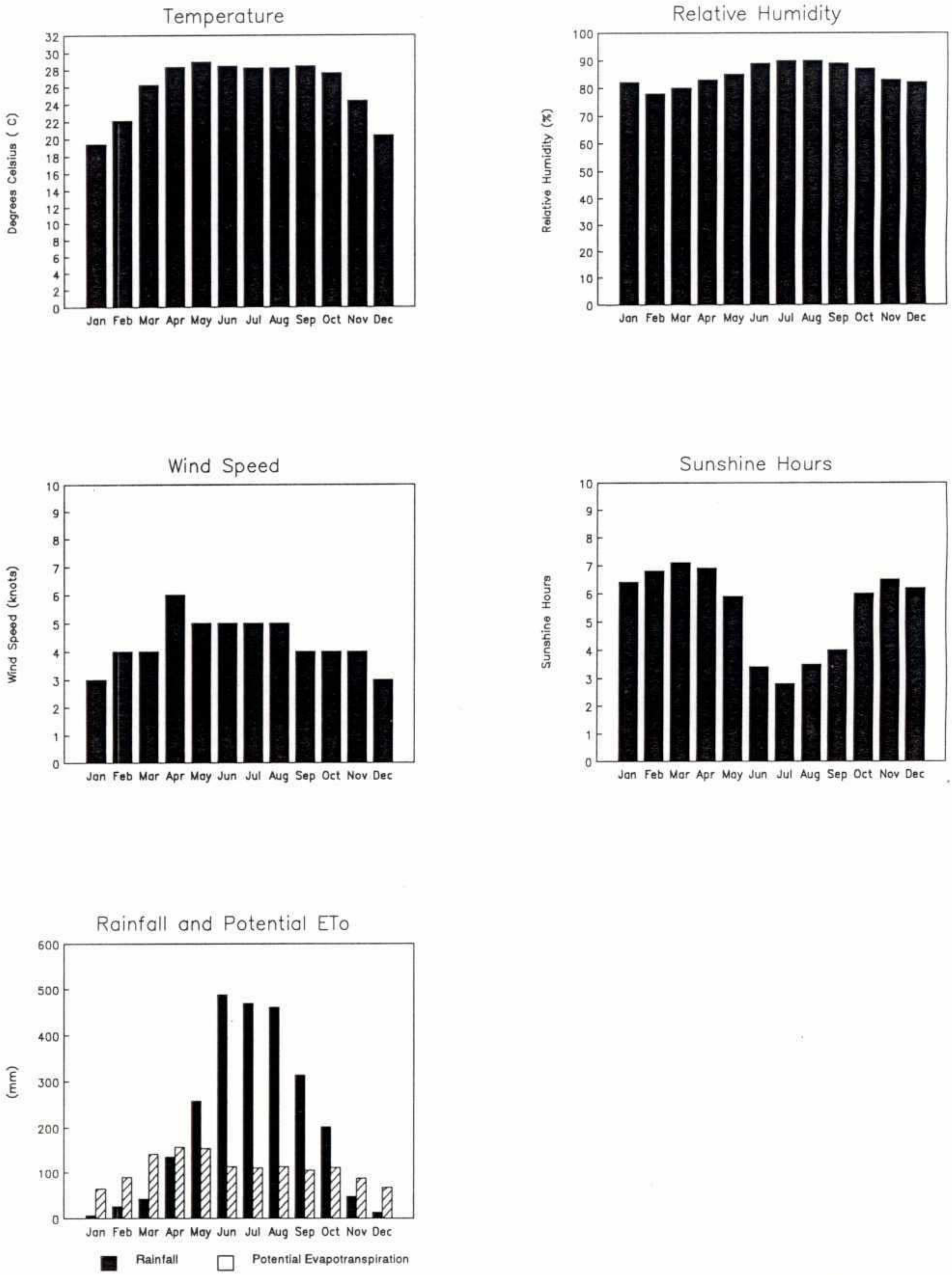
Location of Hydroclimatic Stations

Figure 2.2



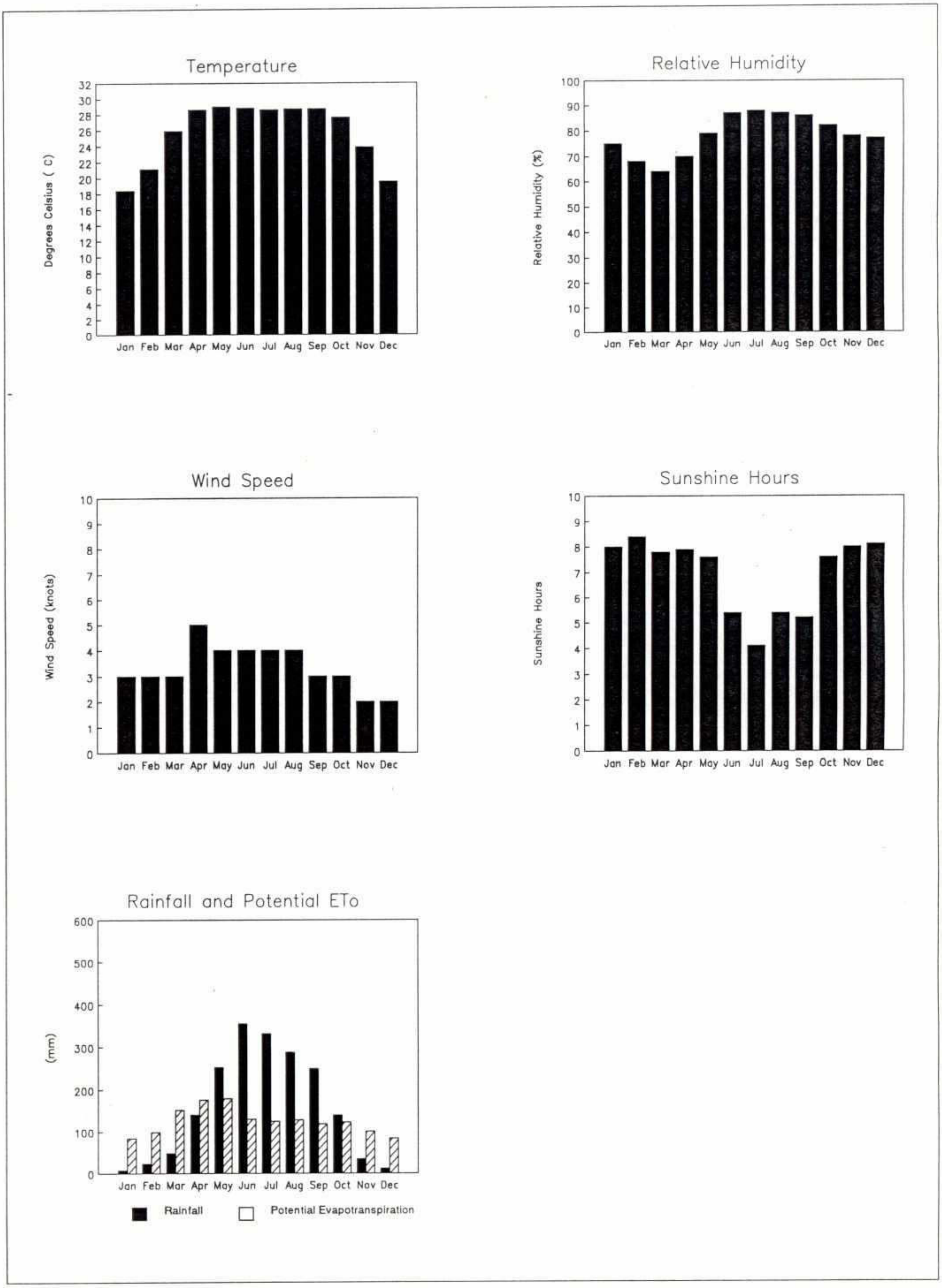
Climatic Data at Barisal

Figure 2.3



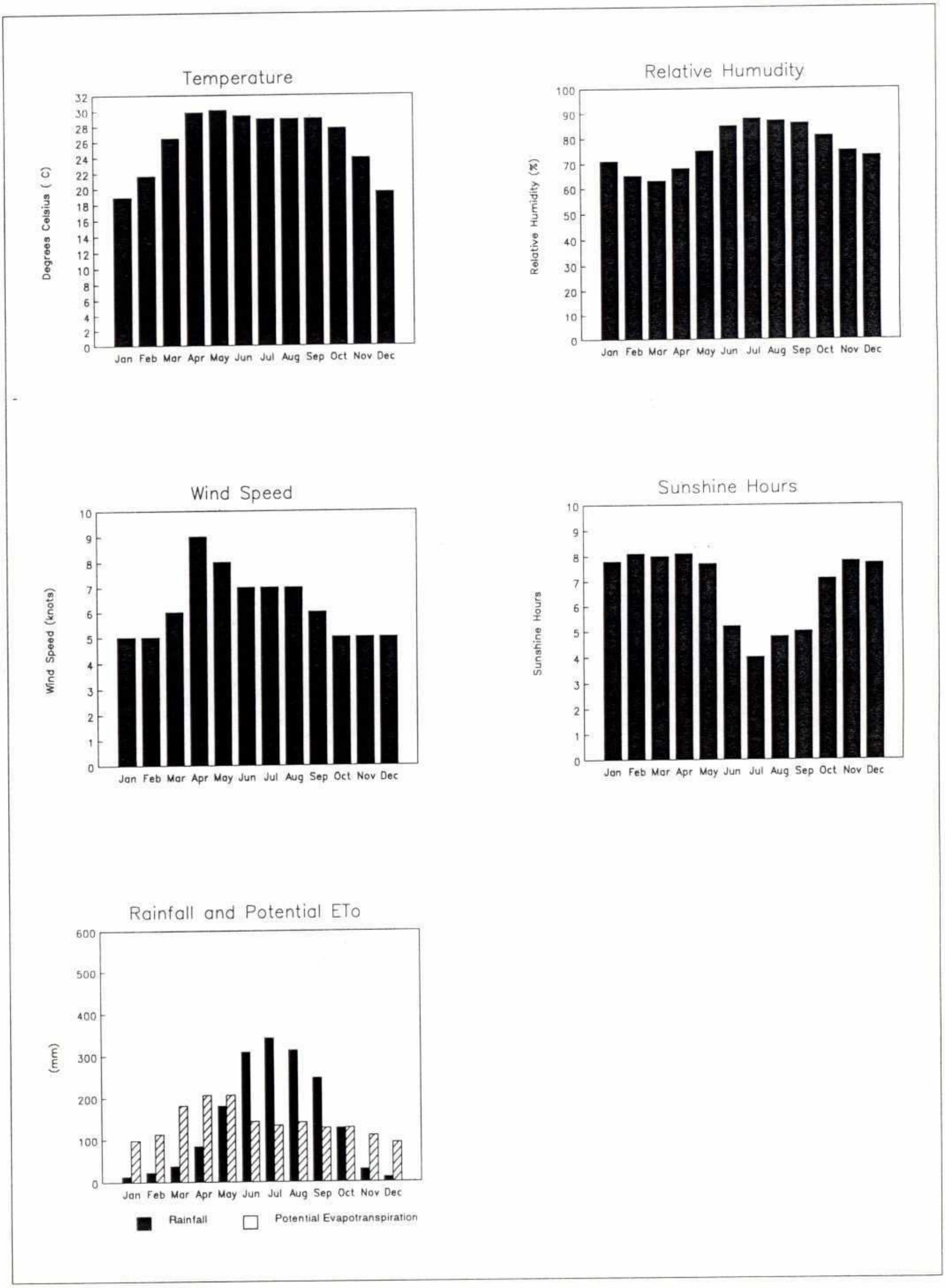
Climatic Data at Bhola

Figure 2.4



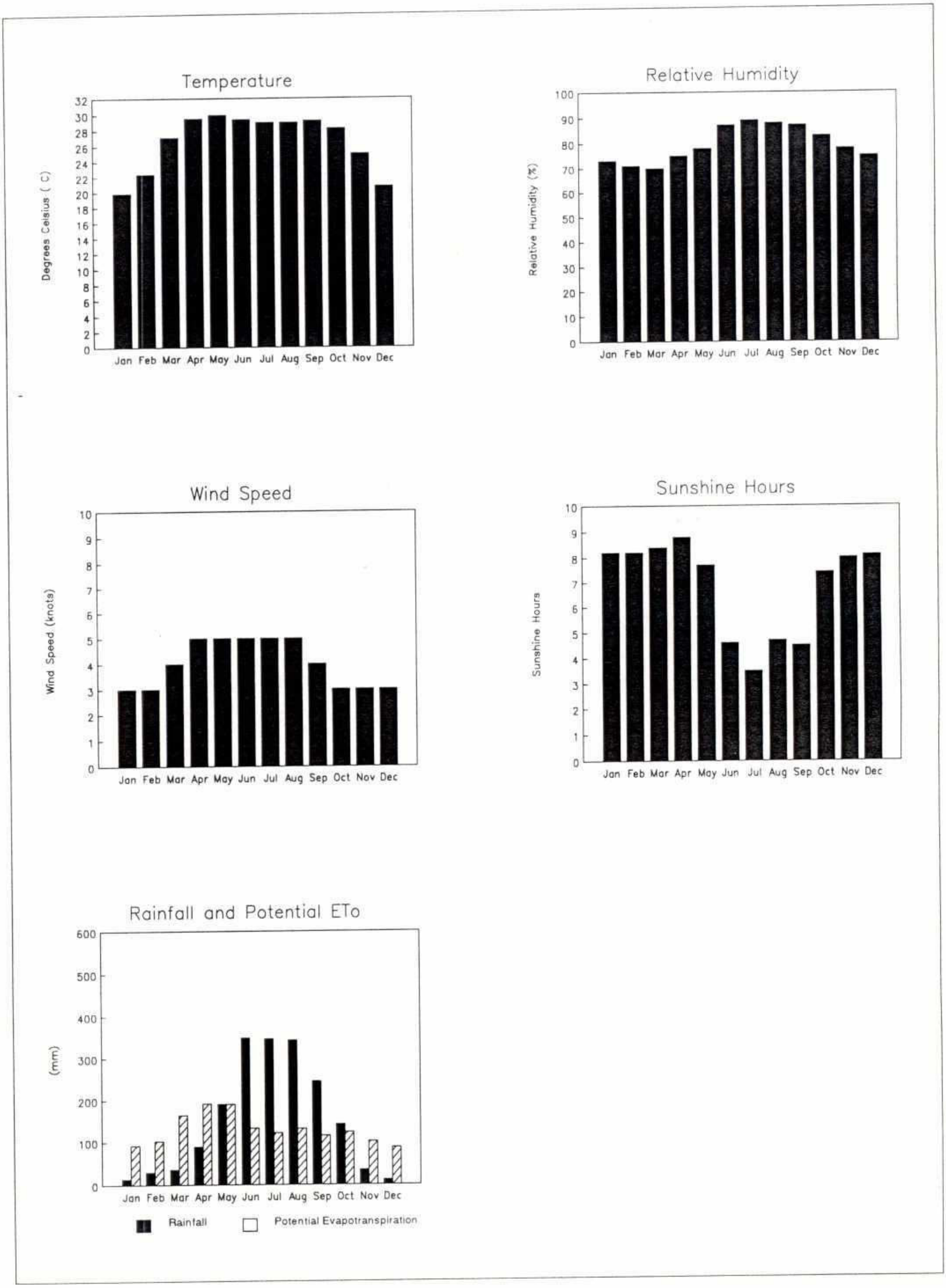
Climatic Data at Faridpur

Figure 2.5



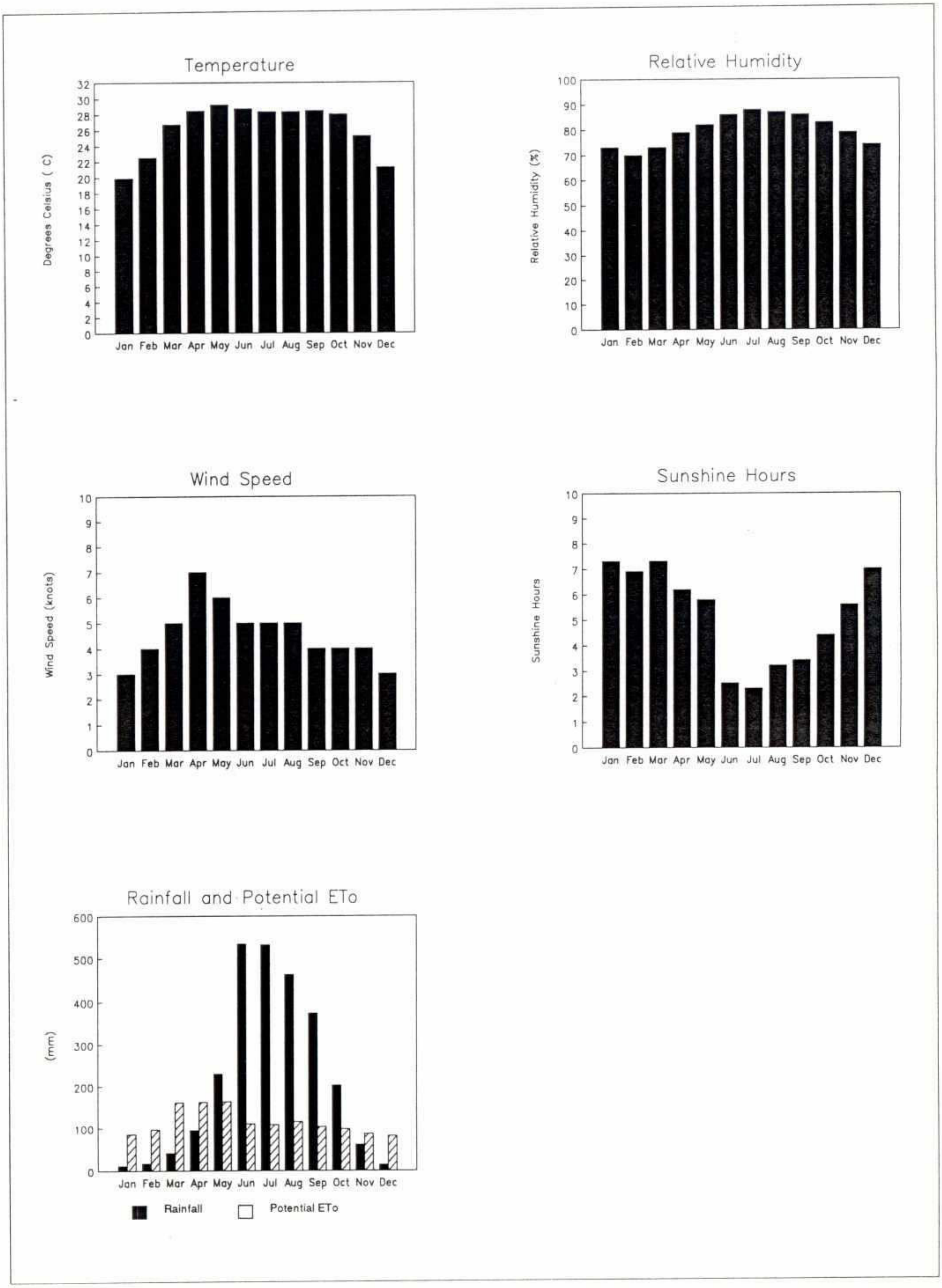
Climatic Data at Jessore

Figure 2.6



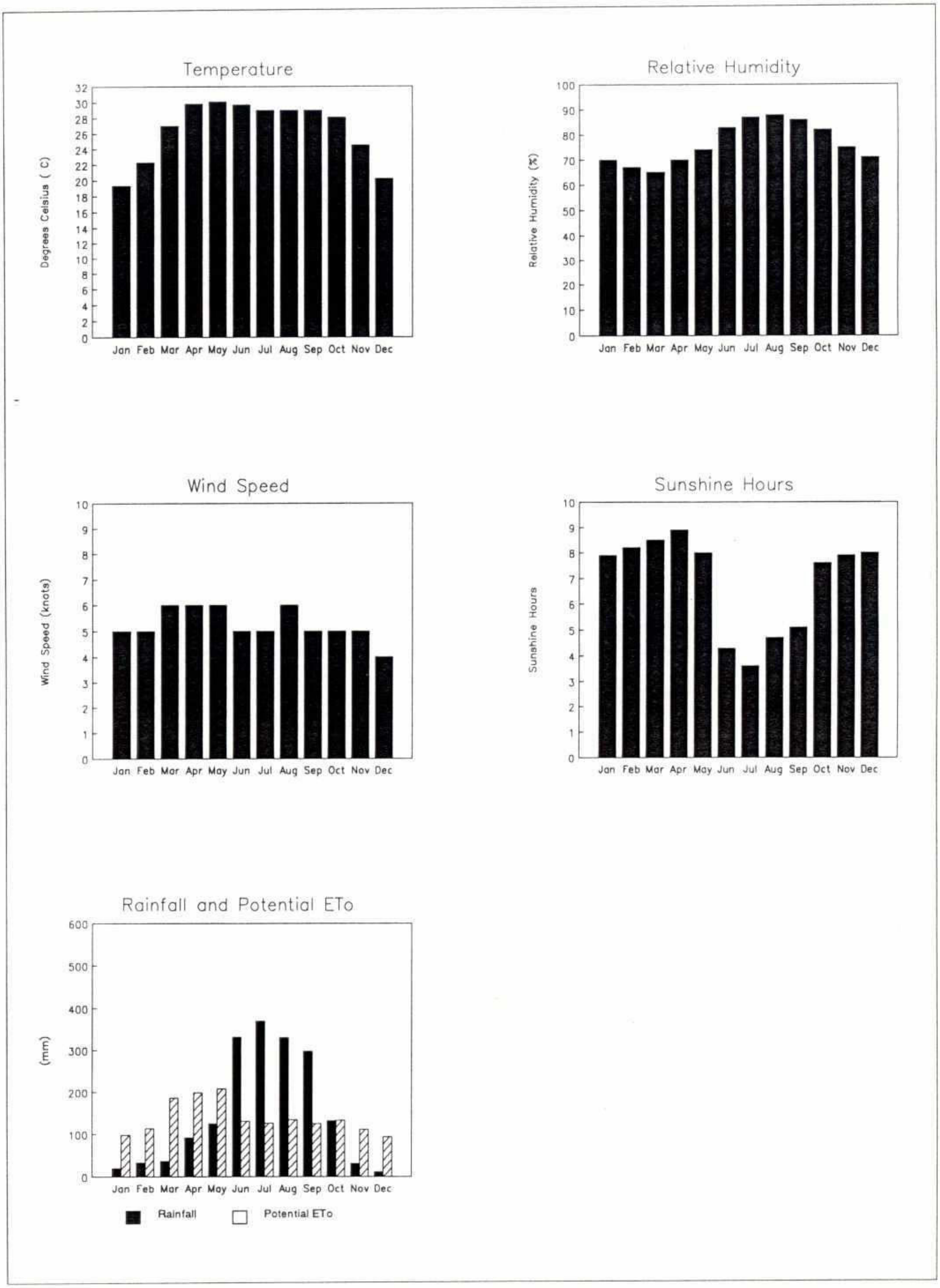
Climatic Data at Khulna

Figure 2.7



Climatic Data at Patuakhali

Figure 2.8



Climatic Data at Satkhira

3 RAINFALL

3.1 Data Availability

Rainfall data is available at 70 stations in the Southwest Area. Data at a further 7 stations adjacent to the study area was also collected to supplement the rainfall records at the boundary catchments of the region. The location of the rainfall stations is shown in Figure 2.1. It can be seen from Figure 2.1 that the study area has a good rainfall station coverage except in the Sundarbans. Table 3.1 shows the availability of rainfall data at these stations. Data is generally available from 1965 to 1990 and at a majority of the stations the record is complete.

Most of the rainfall data upto 1988 has been computerised and was made available to the FAP studies by Northwest Hydraulic Consultants Ltd. and is kindly acknowledged. Recent data to March 1991 was collected from SWMC and has been entered into our database.

3.2 Data Verification

Random checks were made to identify typographical errors in the computerised data. Basic statistical analyses of the daily rainfall data was done to identify outliers. The outlier values were checked against nearby stations and where this was not corroborated the data was flagged and discarded from further analysis. Checks were also made for inconsistencies in the data by a visual comparison of data plots of a group of rainfall stations and by comparison of mean monthly and annual values. Correlation analyses was carried out for all stations with their neighbouring stations and double mass plots were checked at selected stations identified as being less reliable through correlation analyses. Account was taken of the length of the record at each station. Previous studies by FAP-5 have identified stations R-365 and R-357 as having suspect data and studies by FAP-25 identified station R-266 as having inconsistent data from 1964 onwards. The following stations were identified as having poor correlation with their neighbouring stations. Stations R-365 and R-266 have been included for checking.

Target Station	Check Stations
R-254 Banaripara	R-258, R-263, R-264, R-271, R-409,R-511
R-262 Golachipa	R-255, R-256, R-266, R-269, R-273
R-265 Mathbaria	R-253, R-256, R-259, R-506, R-512, R-514
R-515 Paikgacha	R-503, R-505, R-508, R-509, R-514, R-518
R-266 Patuakhali	R-252, R-253, R-255, R-256, R-259, R-262
R-365 Munshiganj	R-354, R-357, R-402, R-410, R-413, R-414

Double Mass plots for the stations are show in Figures 3.1 to 3.3. The cumulative rainfall at each target station is plotted against the cumulative average rainfall for the group of check stations for overlapping years of record.

It can be seen from Figure 3.1 that station R-254 clearly experienced some change from 1981 onwards. Recent data at this station should be treated with caution and has not been included in the regional planning.

The mass plot suggests that station R-262 experienced some changes between 1969 and 1983. The slope of the mass curve is similar before 1969 and after 1983. Although a discrepancy exists, the data at this station has not been rejected for the purpose of regional planning. The record needs to be examined more closely if it is to be used for detailed planning.

The double mass plot for station R-265 shows a change over the years with a slight increase in the slope of the mass curve after 1984. It should be noted however, that amongst the group of check stations, stations R-514 and R-506 which lie to the west of station R-265 are at quite a distance away from it. The data at this station should also be looked at more closely if it is to be used for detailed planning although it may be retained for the purpose of regional planning.

Station R-515 shows a series of changes in the slope of the mass curve with a significant jump in the curve from 1979 to 1980. The data at this station should be treated with caution and has not been included for the purpose of regional planning.

The mass curve for station R-266 shows a slight change in the slope of the curve from 1973 onwards. However, this change is not significant and the data at this station has been included for the regional planning studies. It may be noted here that the previous study by FAP-25 looked at the longer term record (1902 to 1989) at this station and the mass plot showed a distinct change in the records at this station from 1962 onwards. However, a more detailed analysis is required before rejecting the recent records at this station given that they correlate well with the records at adjacent stations.

The mass curve for station R-365 clearly shows that the station experienced some changes from 1970 to 1986. The slope of the curve is similar prior to and after this period. The data at this station has therefore not been included for the regional planning studies.

The rainfall records were also checked for stationarity using the Armsen test which is equivalent to a rank correlation test of Kendall. The test checks for stationarity at the 95% significance level. The results are shown in Table 3.2. The annual rainfall at the following stations showed an increasing trend in their records.

Station No	Station Name
R-261	Daulat Khan
R-267	Pirojpur
R-372	Raipur (Noakhali)
R-414	Shibchar
R-455	Dattanagar
R-456	Jessore
R-457	Jhenaidah
R-458	Kaliganj (Jessore)
R-502	Benerpota
R-504	Dumuria
R-510	Khulna

Long term annual rainfall records (1902 to 1991) at 8 stations listed below were also available.

Station No	Station Name
R-019	Kushtia
R-258	Barisal
R-267	Pirojpur
R-406	Faridpur
R-456	Jessore
R-501	Bagerhat
R-510	Khulna
R-518	Satkhira

These were checked for trends and the records at Bagerhat (R-501) and Khulna (R-510) showed an increasing trend. The results of the trend analysis are shown in Table 3.3. The data at these stations should be treated with caution if used for detailed design and a further stage of verification of the records should be carried out before discarding the data.

3.3 Design Storms

Frequency analysis of rainfall data has been carried out to compute the storm rainfall frequencies for drainage design. Daily rainfall data at all stations except stations R-254, R-365, R-357 and R-515 was analysed. Extreme value analysis was done by fitting General Extreme Value distributions to the data and the distribution giving the best fit was chosen for that station. The results of the analysis for 1 day, 2 day, 5 day and 10 day rainfall totals are shown in Tables 3.4 to 3.7.

3.4 Annual Rainfall Distribution

Isohyets of mean, median and 80% probable annual rainfall were prepared and are shown in Figures 3.4 to 3.6. The data at all the stations except those identified earlier as being unreliable was used. The data used for generating the isohyets is shown in Tables 3.8 to 3.10 and covers the period from 1962 to 1990.

The mean annual rainfall increases from 1500 mm in the north west to about 2900 mm in the south east of the study area with an overall mean across the region of about 2000 mm. The isohyets for the median annual rainfall generally follow a similar pattern as the isohyets for the mean annual rainfall. The lower values of the median annual rainfall isohyets show that the annual rainfall distribution is positively skewed as one would expect in this region.

Figure 3.7 shows the box-plots of annual rainfall data at selected stations in the region. Mean, median and 80% probable monthly rainfall at all stations in the region are shown in Tables 3.11 to 3.13.

3.5 Representativeness of Recent Rainfall Records

A comparison of the long term record (1902 to 1990) at selected stations was also done with recent data (1962 to 1990) and the statistics are compared in Table 3.14. Figure 3.8 shows the box-plots at selected stations comparing the two sets of data. It can be seen from Table 3.14 that the percentage difference in the means of the annual rainfall computed from the long term record and the recent data is less than 5% except at Bagerhat (R-501). The mean annual rainfall in the last 29 years is generally higher except at Pirojpur (R-267) and Kushtia (R-019). These figures suggest that any design for flood levels and drainage systems based on the rainfall data from 1962 to 1990 will tend to be conservative.

Table 3.1

Availibility of Daily Rainfall Data

Sl.No.	Station No.	Station Name	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	R- 019	Kushtia	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	R- 030	Rajbari	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
3	R- 038	Sujanagar	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
4	R- 041	Bheramara	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	R- 214	Amla	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
6	R- 217	Sikarpur (Pragpur)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7	R- 223	Hogalbaria		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8	R- 224	Chuadanga	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
9	R- 225	Meherpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10	R- 252	Bakerganj	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
11	R- 253	Bamna	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
12	R- 254	Banaripara	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
13	R- 255	Bauphal	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
14	R- 256	Barguna	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
15	R- 257	Barhanuddin	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
16	R- 258	Barisal	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
17	R- 259	Bhandaria	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
18	R- 260	Bhola	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
19	R- 261	Daulatkhan	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
20	R- 262	Golachipa	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
21	R- 263	Gournadi	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
22	R- 264	Jhalakati	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
23	R- 265	Mathbaria	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
24	R- 266	Patuakhali	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
25	R- 267	Pirojpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
26	R- 269	Khepupara					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
27	R- 270	Anjurhat (Mayerchar)					C	C	C	C	C	C	C	C	C	C												
28	R- 271	Nazirpur					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
29	R- 272	Patharghata					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
30	R- 273	Rangabali					C	C	C	C	C	C	C	C	C	C												

C Collected

Contd...

Table 3.1

Availibility of Daily Rainfall Data

Sl.No.	Station No.	Station Name	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
31	R- 354	Chandpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
32	R- 357	Daudkandi	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
33	R- 364	Lakshmipur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
34	R- 365	Munshiganj	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
35	R- 372	Raipur (Noakhali)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
36	R- 401	Baliakandi	C	C	C	C	C	C	C	C	C	C	C	C	C	C												
37	R- 402	Bhagyakul	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
38	R- 403	Bhanga	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C					C	C	C	C
39	R- 404	Bhusna (Boalmari)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C
40	R- 406	Faridpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
41	R- 407	Fatehpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
42	R- 409	Haridaspur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
43	R- 410	Madaripur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
44	R- 411	Madhukhali	C																					C	C	C	C	C
45	R- 413	Palong	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
46	R- 414	Shibchar	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
47	R- 451	Abhoynagar	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
48	R- 452	Alamdanga	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
49	R- 453	Benapole	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
50	R- 454	Chaugacha	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
51	R- 455	Dattanagar	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
52	R- 456	Jessore	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
53	R- 457	Jhenaidah	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
54	R- 458	Kaliganj (Jessore)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
55	R- 459	Keshabpur	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
56	R- 460	Magura	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
57	R- 461	Narail	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
58	R- 462	Salikha	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
59	R- 463	Sailkupa	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
60	R- 501	Bagerhat	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

C Collected

Contd...

Table 3.1

Availibility of Daily Rainfall Data

Sl.No.	Station No.	Station Name	Year																									
			65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
61	R- 502	Benerpota	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
62	R- 503	Chalna	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
63	R- 504	Dumuria	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
64	R- 505	Islamkati	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
65	R- 506	Kaikhali	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
66	R- 507	Kalaroa	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
67	R- 508	Kaliganj (Khulna)	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
68	R- 509	Kapilmuni	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
69	R- 510	Khulna	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
70	R- 511	Mollahat	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
71	R- 512	Morrelganj	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
72	R- 513	Nakipur	C	C	C	C	C	C	C	C	C	C	C	C	C	C												
73	R- 514	Nalianala	C	C	C	C	C	C	C	C	C	C	C	C	C	C												
74	R- 515	Paikgacha	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
75	R- 516	Rampal	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
76	R- 517	Rupsa - East	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C										
77	R- 518	Satkhira	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

C Collected

Table 3.2

Trend Analysis of Annual Rainfall (1965 - 1991)

Sl.No.	Station No.	Station Name	Standard Normal Deviate	Probability = P(z)
1	R 019	Kushtia	1.2508	0.894
2	R 030	Rajbari	1.6115	0.946
3	R 038	Sujanagar	1.1658	0.878
4	R 041	Bheramara	0.1635	0.565
5	R 214	Amla	0.2102	0.583
6	R 217	Sikarpur (Pragpur)	0.7331	0.768
7	R 223	Hogalbaria	0.0701	0.528
8	R 224	Chuadanga	1.1021	0.865
9	R 225	Meherpur	0.8397	0.799
10	R 252	Bakerganj	0.4713	0.681
11	R 253	Bamna	0.2569	0.601
12	R 254	Banaripara	0.7549	0.775
13	R 255	Bauphal	0.4849	0.686
14	R 256	Barguna	0.4149	0.661
15	R 257	Barhanuddin	0.0744	0.530
16	R 258	Barisal	0.3970	0.654
17	R 259	Bhandaria	0.8339	0.798
18	R 260	Bhola	1.4176	0.922
19	R 261	Daulatkhan	2.9052	0.998 *
20	R 262	Golachipa	0.1622	0.564
21	R 263	Gournadi	0.7240	0.765
22	R 264	Jhalakati	1.1658	0.878
23	R 265	Mathbaria	0.5516	0.709
24	R 266	Patuakhali	1.0043	0.842
25	R 267	Pirojpur	1.6752	0.953 *
26	R 269	Khepupara	0.5516	0.709
27	R 270	Anjurhat (Mayerchar)	0.0000	0.500
28	R 271	Nazirpur	0.6818	0.752
29	R 272	Patharghata	0.4198	0.663
30	R 273	Rangabali	0.6008	0.726
31	R 354	Chandpur	0.0701	0.528
32	R 357	Daudkandi	1.4796	0.931
33	R 364	Lakshmipur	0.4939	0.689
34	R 365	Munshiganj	1.0977	0.864
35	R 372	Raipur (Noakhali)	2.4990	0.994 *
36	R 401	Baliakandi	0.1095	0.544
37	R 402	Bhagyakul	0.3967	0.654
38	R 403	Bhanga	0.8111	0.791
39	R 404	Bhusna (Boalmari)	0.8682	0.807
40	R 406	Faridpur	0.6164	0.731
41	R 407	Fatehpur	0.4905	0.688
42	R 409	Haridaspur	0.2641	0.604
43	R 410	Madaripur	1.0666	0.857
44	R 411	Madhukhali	0.0000	0.500
45	R 413	Palong	0.1322	0.553

Contd....

Table 3.2

Trend Analysis of Annual Rainfall (1965 – 1991)

Sl.No.	Station No.	Station Name	Standard Normal Deviate	Probability = P(z)
46	R 414	Shibchar	2.0836	0.981 *
47	R 451	Abhoynagar	0.1056	0.542
48	R 452	Alamdanga	-0.0234	0.491
49	R 453	Benapole	0.2718	0.607
50	R 454	Chaugacha	0.7193	0.764
51	R 455	Dattanagar	1.8047	0.964 *
52	R 456	Jessore	2.2482	0.988 *
53	R 457	Jhenaidah	1.7633	0.961 *
54	R 458	Kaliganj (Jessore)	3.0636	0.999 *
55	R 459	Keshabpur	0.6204	0.732
56	R 460	Magura	0.4713	0.681
57	R 461	Narail	0.4226	0.664
58	R 462	Salikha	0.4530	0.675
59	R 463	Sailkupa	1.3642	0.914
60	R 501	Bagerhat	0.7462	0.772
61	R 502	Benerpota	1.8420	0.967 *
62	R 503	Chalna	0.4867	0.687
63	R 504	Dumuria	2.0588	0.980 *
64	R 505	Islamkati	0.0528	0.521
65	R 506	Kaikhali	0.5516	0.709
66	R 507	Kalaroa	0.4905	0.688
67	R 508	Kaliganj (Khulna)	0.0701	0.528
68	R 509	Kapilmuni	1.4262	0.923
69	R 510	Khulna	2.0092	0.978 *
70	R 511	Mollahat	0.0324	0.513
71	R 512	Morrelganj	0.2271	0.590
72	R 513	Nakipur	0.5853	0.721
73	R 514	Nalianala	1.4234	0.923
74	R 515	Paikgacha	0.2060	0.582
75	R 516	Rampal	0.0906	0.536
76	R 517	Rupsa – East	0.9455	0.828
77	R 518	Satkhira	0.7053	0.760

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 3.3

Trend Analysis of Long Term Annual Rainfall at Selected Stations (1902 – 1991)

Sl. No.	Station No.	Station Name	Standard Normal Deviate	Probability = P(z)
1	R 019	Kushtia	1.1248	0.870
2	R 258	Barisal	0.2379	0.594
3	R 267	Pirojpur	0.9793	0.836
4	R 406	Faridpur	1.2978	0.903
5	R 456	Jessore	1.2674	0.897
6	R 501	Bagerhat	2.1401	0.984 *
7	R 510	Khulna	1.9383	0.974 *
8	R 518	Satkhira	1.0809	0.860

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 3.4

Design Storm Frequencies - 1 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
1	R 019	Kushtia	118	159	184	206	232	250	267	GEV 3
2	R 030	Rajbari	115	158	192	229	285	333	388	GEV 2
3	R 038	Sujanagar	104	145	173	199	233	259	284	EV1
4	R 041	Bheramara	101	143	174	207	254	294	338	GEV 2
5	R 214	Amla	105	146	174	200	235	260	286	EV1
6	R 217	Sikarpur (Pragpur)	105	151	194	247	338	429	544	GEV 2
7	R 223	Hogalbaria	97	127	144	159	177	189	200	GEV 3
8	R 224	Chuadanga	115	151	178	206	246	279	316	GEV 2
9	R 225	Meherpur	94	143	176	207	247	276	305	GEV 3
10	R 252	Bakerganj	116	160	188	212	243	264	284	GEV 3
11	R 253	Bamna	128	167	194	219	252	276	301	EV1
12	R 254	Banaripara	131	177	208	237	276	304	333	EV1 *
13	R 255	Bauphal	143	196	231	264	308	340	373	EV1
14	R 256	Barguna	129	168	188	203	218	227	234	GEV 3
15	R 257	Barhanuddin	152	191	217	241	274	298	322	GEV 2
16	R 258	Barisal	144	195	225	250	279	299	316	GEV 3
17	R 259	Bhandaria	135	181	213	246	290	325	362	GEV 2
18	R 260	Bhola	151	185	204	219	236	247	257	GEV 3
19	R 261	Daulatkhan	134	175	201	227	260	285	310	EV1
20	R 262	Golachipa	148	204	240	275	321	355	389	EV1
21	R 263	Gournadi	129	161	177	188	200	207	212	GEV 3
22	R 264	Jhalakati	137	201	240	275	317	346	373	GEV 3
23	R 265	Mathbaria	138	181	210	237	273	299	326	EV1
24	R 266	Patuakhali	157	204	232	257	286	306	325	GEV 3
25	R 267	Pirojpur	146	205	243	278	322	354	384	GEV 3
26	R 269	Khepupara	136	177	204	229	262	287	312	GEV 3
27	R 270	Anjurhat (Mayerchar)	119	155	179	202	231	254	276	EV1
28	R 271	Nazirpur	153	229	279	328	390	437	484	EV1
29	R 272	Patharghata	173	228	256	276	297	309	319	GEV 3
30	R 273	Rangabali	156	182	200	216	238	254	270	EV1
31	R 354	Chandpur	129	177	200	217	233	242	248	GEV 3
32	R 357	Daudkandi	118	154	175	194	217	232	247	GEV 3 *
33	R 364	Lakshmipur	116	160	187	213	244	267	289	GEV 3
34	R 365	Munshiganj	119	168	201	232	272	303	333	EV1 *
35	R 372	Raipur (Noakhali)	118	161	190	217	253	279	306	GEV 2
36	R 401	Baliakandi	96	126	146	165	189	208	226	EV1
37	R 402	Bhagyakul	152	212	250	286	331	364	397	GEV 3
38	R 403	Bhanga	115	160	190	219	256	283	311	EV1
39	R 404	Bhusna (Boalmari)	116	147	169	190	217	238	259	GEV 2
40	R 406	Faridpur	117	161	184	203	223	235	245	GEV 3
41	R 407	Fatehpur	126	173	208	245	298	343	391	GEV 2
42	R 409	Haridaspur	125	165	195	226	271	308	349	GEV 2
43	R 410	Madaripur	133	176	205	232	268	294	321	EV1
44	R 411	Madhukhali	145	181	195	205	213	217	220	GEV 3
45	R 413	Palong	124	173	205	236	277	307	337	EV1

Contd....

Table 3.4

Design Storm Frequencies - 1 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
46	R 414	Shibchar	95	140	170	200	239	269	300	GEV 2
47	R 451	Abhoynagar	121	177	222	270	342	405	476	GEV 2
48	R 452	Alamdanga	122	154	170	182	195	203	209	GEV 3
49	R 453	Benapole	104	164	208	255	321	376	436	GEV 2
50	R 454	Chaugacha	126	176	212	249	301	344	390	GEV 2
51	R 455	Dattanagar	119	180	225	273	343	402	466	GEV 2
52	R 456	Jessore	127	184	223	263	317	359	403	GEV 2
53	R 457	Jhenaidah	117	152	176	201	235	263	292	GEV 2
54	R 458	Kaliganj (Jessore)	116	165	202	241	298	346	398	GEV 2
55	R 459	Keshabpur	128	179	213	245	287	318	349	EV1
56	R 460	Magura	119	162	191	218	253	280	306	EV1
57	R 461	Narail	129	182	221	261	319	365	415	GEV 2
58	R 462	Salikha	125	175	209	243	287	322	357	GEV 2
59	R 463	Sailkupa	118	162	191	219	256	283	310	EV1
60	R 501	Bagerhat	138	215	267	316	379	427	474	EV1
61	R 502	Benerpota	120	175	211	246	291	325	358	EV1
62	R 503	Chalna	120	184	227	270	326	369	413	GEV 2
63	R 504	Dumuria	138	192	230	269	323	366	412	GEV 2
64	R 505	Islamkati	105	147	175	201	235	261	287	EV1
65	R 506	Kaikhali	125	177	209	239	277	304	330	GEV 3
66	R 507	Kalaroa	121	183	231	284	362	430	506	GEV 2
67	R 508	Kaliganj (Khulna)	130	181	211	238	271	293	314	GEV 3
68	R 509	Kapilmuni	135	190	221	247	276	295	312	GEV 3
69	R 510	Khulna	128	183	225	271	338	396	461	GEV 2
70	R 511	Mollahat	116	177	226	282	370	450	542	GEV 2
71	R 512	Morrelganj	106	164	203	239	287	323	358	EV1
72	R 513	Nakipur	143	183	206	225	247	261	274	GEV 3
73	R 514	Nalianala	117	170	221	287	407	533	699	GEV 2
74	R 515	Paikgacha	120	159	187	216	257	291	327	GEV 2 *
75	R 516	Rampal	128	190	232	273	327	369	411	GEV 2
76	R 517	Rupsa - East	133	205	267	340	458	568	701	GEV 2
77	R 518	Satkhira	127	181	223	269	338	397	464	GEV 2

Note : * Not used in regional planning.

Table 3.5

Design Storm Frequencies - 2 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distributio
			2	5	10	20	50	100	200	
1	R 019	Kushtia	153	219	263	304	359	399	439	EV1
2	R 030	Rajbari	150	206	251	303	385	459	545	GEV 2
3	R 038	Sujanagar	142	193	234	277	342	399	462	GEV 2
4	R 041	Bheramara	138	204	257	314	400	474	558	GEV 2
5	R 214	Amla	135	194	240	290	363	426	496	GEV 2
6	R 217	Sikarpur (Pragpur)	143	208	261	318	407	484	573	GEV 2
7	R 223	Hogalbaria	135	182	214	244	282	312	341	EV1
8	R 224	Chuadanga	154	202	238	277	332	378	428	GEV 2
9	R 225	Meherpur	131	199	240	276	318	347	374	GEV 3
10	R 252	Bakerganj	169	236	285	335	406	463	524	GEV 2
11	R 253	Bamna	198	265	309	352	407	449	491	GEV 2
12	R 254	Banaripara	185	256	303	348	407	451	495	EV1 *
13	R 255	Bauphal	192	259	304	347	403	445	487	EV1
14	R 256	Barguna	195	265	312	357	414	457	501	EV1
15	R 257	Barhanuddin	207	259	292	322	358	384	409	GEV 3
16	R 258	Barisal	181	252	302	353	422	476	533	GEV 2
17	R 259	Bhandaria	217	288	332	373	422	457	491	GEV 3
18	R 260	Bhola	199	244	274	303	340	368	396	EV1
19	R 261	Daulatkhan	201	273	330	392	484	565	655	GEV 2
20	R 262	Golachipa	224	316	376	434	510	566	622	EV1
21	R 263	Gournadi	173	218	248	277	315	343	371	EV1
22	R 264	Jhalakati	194	284	343	400	474	529	584	EV1
23	R 265	Mathbaria	210	268	298	323	348	364	378	GEV 3
24	R 266	Patuakhali	222	291	331	365	406	433	458	GEV 3
25	R 267	Pirojpur	207	304	371	437	526	594	665	GEV 2
26	R 269	Khepupara	217	279	320	360	410	448	486	GEV 3
27	R 270	Anjurhat (Mayerchar)	216	259	278	291	303	309	314	GEV 3
28	R 271	Nazirpur	241	370	456	541	652	736	821	GEV 2
29	R 272	Patharghata	244	329	375	413	453	478	499	GEV 3
30	R 273	Rangabali	247	288	318	348	391	425	461	GEV 2
31	R 354	Chandpur	156	226	273	318	376	419	463	EV1
32	R 357	Daudkandi	174	222	254	285	324	354	383	EV1 *
33	R 364	Lakshmipur	182	242	278	309	345	369	391	GEV 3
34	R 365	Munshiganj	175	256	309	360	426	475	525	EV1 *
35	R 372	Raipur (Noakhali)	167	220	256	290	334	367	399	EV1
36	R 401	Baliakandi	133	178	209	238	276	305	334	GEV 2
37	R 402	Bhagyakul	192	257	298	338	388	425	460	GEV 3
38	R 403	Bhanga	157	210	246	279	323	356	389	EV1
39	R 404	Bhusna (Boalmari)	161	214	248	280	321	351	380	GEV 3
40	R 406	Faridpur	146	207	248	287	338	376	414	EV1
41	R 407	Fatehpur	179	241	284	327	384	428	474	GEV 2
42	R 409	Haridaspur	179	248	298	349	421	480	542	GEV 2
43	R 410	Madaripur	184	246	288	328	379	418	456	EV1
44	R 411	Madhukhali	172	240	285	328	384	426	468	EV1
45	R 413	Palong	172	239	281	321	370	406	440	GEV 3

Contd....

Table 3.5

Design Storm Frequencies – 2 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
46	R 414	Shibchar	137	193	228	260	299	326	352	GEV 3
47	R 451	Abhoynagar	179	272	348	434	568	689	830	GEV 2
48	R 452	Alamdanga	157	204	235	263	298	324	349	GEV 3
49	R 453	Benapole	150	233	296	363	459	540	628	GEV 2
50	R 454	Chaugacha	175	250	306	364	447	515	588	GEV 2
51	R 455	Dattanagar	163	246	308	373	468	548	634	GEV 2
52	R 456	Jessore	176	252	303	351	414	461	508	EV1
53	R 457	Jhenaidah	151	196	232	271	330	381	439	GEV 2
54	R 458	Kaliganj (Jessore)	153	232	294	363	468	560	666	GEV 2
55	R 459	Keshabpur	168	252	315	380	474	552	637	GEV 2
56	R 460	Magura	157	226	271	314	371	413	455	EV1
57	R 461	Narail	170	246	300	355	431	492	556	GEV 2
58	R 462	Salikha	182	250	297	345	409	459	511	GEV 2
59	R 463	Sailkupa	147	205	245	286	343	388	435	GEV 2
60	R 501	Bagerhat	199	315	391	465	560	631	703	EV1
61	R 502	Benerpota	155	242	311	386	500	599	711	GEV 2
62	R 503	Chalna	172	256	312	366	436	488	540	EV1
63	R 504	Dumuria	195	284	351	424	532	623	725	GEV 2
64	R 505	Islamkati	144	204	248	295	362	418	478	GEV 2
65	R 506	Kaikhali	173	255	314	373	454	519	587	GEV 2
66	R 507	Kalaroa	162	253	330	420	566	702	865	GEV 2
67	R 508	Kaliganj (Khulna)	169	245	292	336	389	427	463	GEV 3
68	R 509	Kapilmuni	175	263	321	377	449	503	557	EV1
69	R 510	Khulna	178	250	301	353	424	480	539	GEV 2
70	R 511	Mollahat	176	272	348	433	564	679	811	GEV 2
71	R 512	Morrelganj	168	256	314	370	443	497	551	EV1
72	R 513	Nakipur	186	256	304	353	420	472	527	GEV 2
73	R 514	Nalianala	159	231	294	368	491	606	747	GEV 2
74	R 515	Paikgacha	176	236	281	330	400	460	525	GEV 2 *
75	R 516	Rampal	190	287	351	413	492	552	611	EV1
76	R 517	Rupsa – East	185	280	355	436	560	667	789	GEV 2
77	R 518	Satkhira	165	257	336	430	585	732	911	GEV 2

Note : * Not used in regional planning.

Table 3.6

Design Storm Frequencies – 5 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distributio
			2	5	10	20	50	100	200	
1	R 019	Kushtia	204	291	351	410	489	550	612	GEV 2
2	R 030	Rajbari	212	302	377	463	599	723	870	GEV 2
3	R 038	Sujanagar	207	278	332	390	475	548	629	GEV 2
4	R 041	Bheramara	192	273	334	398	491	569	653	GEV 2
5	R 214	Amla	181	253	301	346	406	450	494	EV1
6	R 217	Sikarpur (Pragpur)	192	287	363	446	574	686	814	GEV 2
7	R 223	Hogalbaria	205	288	342	395	463	514	565	EV1
8	R 224	Chuadanga	199	267	316	366	435	491	549	GEV 2
9	R 225	Meherpur	179	275	338	399	478	537	596	EV1
10	R 252	Bakerganj	233	327	405	495	637	766	918	GEV 2
11	R 253	Bamna	286	390	459	525	610	674	738	EV1
12	R 254	Banaripara	249	358	438	520	637	733	836	GEV 2 *
13	R 255	Bauphal	284	384	450	514	596	658	720	EV1
14	R 256	Barguna	314	416	484	550	634	697	760	EV1
15	R 257	Barhanuddin	299	376	426	472	530	571	612	GEV 3
16	R 258	Barisal	254	358	432	507	611	694	781	GEV 2
17	R 259	Bhandaria	295	399	472	545	646	726	810	GEV 2
18	R 260	Bhola	283	358	409	458	523	573	623	GEV 2
19	R 261	Daulatkhan	313	427	512	602	731	839	956	GEV 2
20	R 262	Golachipa	330	482	582	678	802	895	988	EV1
21	R 263	Gournadi	251	319	365	408	464	507	549	EV1
22	R 264	Jhalakati	263	371	444	515	610	682	755	GEV 2
23	R 265	Mathbaria	328	406	444	472	499	515	527	GEV 3
24	R 266	Patuakhali	307	412	476	533	602	650	695	GEV 3
25	R 267	Pirojpur	277	404	495	589	719	824	936	GEV 2
26	R 269	Khepupara	336	445	528	616	745	854	974	GEV 2
27	R 270	Anjurhat (Mayerchar)	339	410	439	457	473	481	486	GEV 3
28	R 271	Nazirpur	344	511	622	728	865	967	1070	EV1
29	R 272	Patharghata	378	511	581	636	694	730	759	GEV 3
30	R 273	Rangabali	374	473	539	604	688	752	817	GEV 2
31	R 354	Chandpur	211	304	365	423	499	556	613	EV1
32	R 357	Daudkandi	272	370	434	497	577	637	698	EV1 *
33	R 364	Lakshmipur	270	361	418	473	541	591	639	GEV 3
34	R 365	Munshiganj	272	390	455	508	566	603	635	GEV 3 *
35	R 372	Raipur (Noakhali)	247	313	357	399	453	493	534	EV1
36	R 401	Baliakandi	179	242	289	339	410	469	534	GEV 2
37	R 402	Bhagyakul	264	335	380	421	471	507	542	GEV 3
38	R 403	Bhanga	212	291	343	394	459	508	556	EV1
39	R 404	Bhusna (Boalmari)	229	318	376	432	503	556	609	GEV 3
40	R 406	Faridpur	204	288	344	398	467	519	571	EV1
41	R 407	Fatehpur	220	311	388	479	627	765	932	GEV 2
42	R 409	Haridaspur	245	340	408	477	572	649	729	GEV 2
43	R 410	Madaripur	243	334	394	452	526	582	638	EV1
44	R 411	Madhukhali	221	326	396	463	549	614	679	EV1
45	R 413	Palong	239	340	407	471	554	616	678	EV1

Contd....

Table 3.6

Design Storm Frequencies – 5 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
46	R 414	Shibchar	217	296	338	372	409	431	451	GEV 3
47	R 451	Abhoynagar	263	395	498	610	777	922	1084	GEV 2
48	R 452	Alamdanga	210	269	306	341	385	417	448	GEV 3
49	R 453	Benapole	227	338	412	483	575	644	713	EV1
50	R 454	Chaugacha	239	353	439	530	661	771	890	GEV 2
51	R 455	Dattanagar	229	326	393	459	547	615	685	GEV 2
52	R 456	Jessore	241	343	414	484	577	649	722	GEV 2
53	R 457	Jhenaidah	202	270	329	400	516	626	761	GEV 2
54	R 458	Kaliganj (Jessore)	229	336	410	483	581	657	736	GEV 2
55	R 459	Keshabpur	234	342	418	493	594	674	756	GEV 2
56	R 460	Magura	217	312	379	445	535	606	679	GEV 2
57	R 461	Narail	242	343	412	479	568	637	706	GEV 2
58	R 462	Salikha	249	345	418	495	606	700	803	GEV 2
59	R 463	Sailkupa	212	303	373	448	559	652	757	GEV 2
60	R 501	Bagerhat	275	419	515	606	725	813	902	EV1
61	R 502	Benerpota	221	339	418	494	591	664	737	EV1
62	R 503	Chalna	235	351	428	501	596	668	739	EV1
63	R 504	Dumuria	284	394	467	537	628	696	764	EV1
64	R 505	Islamkati	207	288	343	397	469	525	582	GEV 2
65	R 506	Kaikhali	254	377	464	552	673	770	871	GEV 2
66	R 507	Kalaroa	235	358	449	543	675	784	900	GEV 2
67	R 508	Kaliganj (Khulna)	227	337	411	484	580	654	729	GEV 2
68	R 509	Kapilmuni	235	357	439	516	617	693	768	EV1
69	R 510	Khulna	245	334	393	450	523	578	633	EV1
70	R 511	Mollahat	271	403	500	603	749	870	1000	GEV 2
71	R 512	Morrelganj	262	384	465	543	643	719	794	EV1
72	R 513	Nakipur	244	339	412	492	610	711	824	GEV 2
73	R 514	Nalianala	224	330	423	533	715	888	1099	GEV 2
74	R 515	Paikgacha	249	341	402	461	536	593	649	EV1 *
75	R 516	Rampal	271	400	485	566	671	750	828	GEV 3
76	R 517	Rupsa – East	266	382	460	534	630	702	774	EV1
77	R 518	Satkhira	232	348	446	560	743	912	1114	GEV 2

Note : * Not used in regional planning.

Table 3.7

Design Storm Frequencies - 10 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years) 2	5	10	20	50	100	200	Fitted Distribution
1	R 019	Kushtia	260	365	439	512	611	689	769	GEV 2
2	R 030	Rajbari	275	380	460	546	672	780	899	GEV 2
3	R 038	Sujanagar	264	355	427	507	628	735	855	GEV 2
4	R 041	Bheramara	262	360	419	472	536	581	622	GEV 3
5	R 214	Amla	233	318	375	429	500	552	605	EV1
6	R 217	Sikarpur (Pragpur)	250	364	445	528	641	732	827	GEV 2
7	R 223	Hogalbaria	274	378	447	513	598	662	725	EV1
8	R 224	Chuadanga	256	336	391	446	520	577	636	GEV 2
9	R 225	Meherpur	225	342	419	493	589	661	733	EV1
10	R 252	Bakerganj	339	471	579	700	886	1053	1245	GEV 2
11	R 253	Bamna	389	528	620	709	824	909	995	EV1
12	R 254	Banaripara	330	451	530	605	700	770	839	GEV 3 *
13	R 255	Bauphal	404	537	625	709	818	900	982	EV1
14	R 256	Barguna	426	552	635	715	819	896	973	EV1
15	R 257	Barhanuddin	426	548	632	716	829	917	1007	GEV 2
16	R 258	Barisal	332	458	544	629	742	830	920	GEV 2
17	R 259	Bhandaria	402	532	630	733	881	1005	1140	GEV 2
18	R 260	Bhola	394	490	549	603	668	714	757	GEV 3
19	R 261	Daulatkhan	450	588	673	750	845	912	976	GEV 3
20	R 262	Golachipa	475	662	764	847	938	995	1045	GEV 3
21	R 263	Gournadi	328	414	471	526	597	650	702	EV1
22	R 264	Jhalakati	329	454	536	615	718	794	871	EV1
23	R 265	Mathbaria	433	564	650	733	841	921	1001	EV1
24	R 266	Patuakhali	405	540	624	701	797	865	930	GEV 3
25	R 267	Pirojpur	362	499	589	676	788	872	955	EV1
26	R 269	Khepupara	461	588	675	759	871	957	1044	GEV 2
27	R 270	Anjurhat (Mayerchar)	457	535	571	596	620	633	643	GEV 3
28	R 271	Nazirpur	409	579	692	800	940	1045	1150	EV1
29	R 272	Patharghata	492	635	712	775	842	885	921	GEV 3
30	R 273	Rangabali	478	613	702	788	899	982	1065	EV1
31	R 354	Chandpur	290	404	479	551	645	715	785	EV1
32	R 357	Daudkandi	386	520	609	694	804	886	969	EV1 *
33	R 364	Lakshmipur	376	516	609	698	814	900	986	EV1
34	R 365	Munshiganj	345	498	585	657	738	790	836	GEV 3 *
35	R 372	Raipur (Noakhali)	345	427	470	505	542	565	584	GEV 3
36	R 401	Baliakandi	239	322	377	430	498	549	599	GEV 3
37	R 402	Bhagyakul	340	420	466	506	552	582	610	GEV 3
38	R 403	Bhanga	277	368	428	486	561	617	672	EV1
39	R 404	Bhusna (Boalmari)	294	401	472	540	627	693	759	EV1
40	R 406	Faridpur	264	362	427	489	570	630	691	EV1
41	R 407	Fatehpur	283	391	485	596	777	949	1157	GEV 2
42	R 409	Haridaspur	317	412	475	535	615	675	735	GEV 2
43	R 410	Madaripur	310	414	482	548	633	697	761	EV1
44	R 411	Madhukhali	271	393	473	550	650	725	800	EV1
45	R 413	Palong	308	430	511	588	688	764	838	EV1

Contd....

Table 3.7

Design Storm Frequencies - 10 Day Maximum Rainfall (mm)

Sl.No.	Station No.	Station Name	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
46	R 414	Shibchar	290	405	474	535	607	656	702	GEV 3
47	R 451	Abhoynagar	339	480	581	685	831	949	1074	GEV 2
48	R 452	Alamdanga	252	324	376	429	502	560	620	GEV 2
49	R 453	Benapole	271	401	487	570	677	757	837	EV1
50	R 454	Chaugacha	296	419	511	606	741	852	973	GEV 2
51	R 455	Dattanagar	287	408	489	567	670	748	827	GEV 2
52	R 456	Jessore	303	419	497	571	668	740	813	GEV 2
53	R 457	Jhenaidah	266	342	405	475	586	685	801	GEV 2
54	R 458	Kaliganj (Jessore)	293	409	487	561	657	728	800	EV1
55	R 459	Keshabpur	304	428	512	593	701	783	866	GEV 2
56	R 460	Magura	283	402	480	556	654	727	800	EV1
57	R 461	Narail	297	404	471	533	610	665	718	GEV 3
58	R 462	Salikha	320	447	537	628	755	855	961	GEV 2
59	R 463	Sailkupa	267	367	447	537	674	796	935	GEV 2
60	R 501	Bagerhat	364	542	660	774	921	1031	1140	EV1
61	R 502	Benerpota	280	415	504	590	700	783	866	EV1
62	R 503	Chalna	297	436	528	617	731	817	903	EV1
63	R 504	Dumuria	359	496	587	674	787	871	955	EV1
64	R 505	Islamkati	282	375	432	483	544	587	627	GEV 3
65	R 506	Kaikhali	330	483	589	694	836	945	1058	GEV 2
66	R 507	Kalaroa	304	449	545	637	757	846	936	GEV 2
67	R 508	Kaliganj (Khulna)	293	426	509	584	677	744	807	GEV 3
68	R 509	Kapilmuni	295	445	544	639	761	854	945	EV1
69	R 510	Khulna	317	416	478	535	604	654	701	GEV 3
70	R 511	Mollahat	359	510	610	706	831	924	1017	EV1
71	R 512	Morrelganj	352	498	596	689	810	900	990	EV1
72	R 513	Nakipur	343	454	529	602	697	770	843	GEV 2
73	R 514	Nalianala	306	450	567	699	903	1084	1295	GEV 2
74	R 515	Paikgacha	331	438	509	577	665	731	797	EV1 *
75	R 516	Rampal	350	512	617	714	837	927	1014	GEV 3
76	R 517	Rupsa - East	335	458	548	642	775	885	1004	GEV 2
77	R 518	Satkhira	298	436	548	674	869	1044	1245	GEV 2

Note : * Not used in regional planning.

Table 3.8

Mean Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
1	R- 019	Kushtia	23 58.0 N	89 2.0 E	1516.8
2	R- 030	Rajbari	23 46.0 N	89 40.3 E	1700.7
3	R- 038	Sujanagar	23 56.0 N	89 24.5 E	1655.6
4	R- 041	Bheramara	24 1.0 N	89 0.2 E	1479.5
5	R- 214	Amla	23 54.3 N	88 56.0 E	1463.4
6	R- 217	Sikarpur (Pragpur)	24 1.1 N	88 46.8 E	1416.7
7	R- 223	Hogalbaria	24 2.2 N	88 52.3 E	1568.4
8	R- 224	Chuadanga	23 39.0 N	88 51.0 E	1549.7
9	R- 225	Meherpur	23 45.7 N	88 38.0 E	1453.7
10	R- 252	Bakerganj	22 32.7 N	90 20.4 E	2178.0
11	R- 253	Bamna	22 19.7 N	90 6.0 E	2349.6
12	R- 254	Banaripara	22 47.0 N	90 10.0 E	2112.5 #
13	R- 255	Bauphal	22 25.1 N	90 33.8 E	2611.4
14	R- 256	Barguna	22 9.0 N	90 7.0 E	2528.1
15	R- 257	Barhanuddin	22 29.9 N	90 43.1 E	2734.3
16	R- 258	Barisal	22 42.0 N	90 22.5 E	2174.6
17	R- 259	Bhandaria	22 29.2 N	90 3.8 E	2356.7
18	R- 260	Bhola	22 41.0 N	90 39.1 E	2452.8
19	R- 261	Daulatkhan	22 37.0 N	90 46.8 E	2824.1
20	R- 262	Golachipa	22 10.0 N	90 24.7 E	3141.4
21	R- 263	Gournadi	22 58.4 N	90 14.1 E	2173.8
22	R- 264	Jhalakati	22 39.0 N	90 11.3 E	2011.3
23	R- 265	Mathbaria	22 17.6 N	89 57.6 E	2478.3
24	R- 266	Patuakhali	22 22.3 N	90 21.3 E	2570.3
25	R- 267	Pirojpur	22 34.5 N	89 57.3 E	2089.4
26	R- 269	Khepupara	21 59.0 N	90 13.8 E	2761.9
27	R- 270	Anjurhat (Mayerchar)	22 7.6 N	90 39.3 E	2631.8
28	R- 271	Nazirpur	22 42.5 N	89 58.8 E	2062.1
29	R- 272	Patharghata	22 3.0 N	89 58.6 E	2555.9
30	R- 273	Rangabali	21 57.3 N	90 24.7 E	2593.4

* Sum of monthly means.
# Data not used.

Contd....

Table 3.8

Mean Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
31	R- 354	Chandpur	23 14.3 N	90 40.0 E	2003.8
32	R- 357	Daudkandi	23 32.0 N	90 43.0 E	2803.0 #
33	R- 364	Lakshmipur	22 56.2 N	90 50.2 E	2564.6
34	R- 365	Munshiganj	23 33.1 N	90 32.2 E	2132.2 #
35	R- 372	Raipur (Noakhali)	23 2.5 N	90 45.8 E	2111.8
36	R- 401	Baliakandi	23 38.5 N	89 33.5 E	1526.9
37	R- 402	Bhagyakul	23 30.0 N	90 13.0 E	1911.9
38	R- 403	Bhanga	23 24.0 N	89 59.0 E	1830.8
39	R- 404	Bhusna (Boalmari)	23 23.0 N	89 43.0 E	1732.5
40	R- 406	Faridpur	23 37.5 N	89 51.0 E	1877.1
41	R- 407	Fatehpur	23 15.3 N	90 0.0 E	1840.2
42	R- 409	Haridaspur	23 2.0 N	89 48.0 E	1800.7
43	R- 410	Madaripur	23 10.5 N	90 11.5 E	1981.9
44	R- 411	Madhukhali	23 33.4 N	89 38.0 E	1812.9
45	R- 413	Palong	23 13.0 N	90 20.0 E	2091.0
46	R- 414	Shibchar	23 21.5 N	90 8.5 E	2111.2
47	R- 451	Abhoynagar	23 1.0 N	89 27.0 E	1937.0
48	R- 452	Alamdanga	23 47.0 N	88 57.0 E	1514.7
49	R- 453	Benapole	23 2.0 N	88 54.5 E	1533.3
50	R- 454	Chaugacha	23 16.0 N	89 2.0 E	1627.6
51	R- 455	Dattanagar	23 26.0 N	88 50.0 E	1479.2
52	R- 456	Jessore	23 11.0 N	89 14.0 E	1705.5
53	R- 457	Jhenaidah	23 33.0 N	89 11.0 E	1602.1
54	R- 458	Kaliganj (Jessore)	23 24.0 N	89 10.0 E	1681.1
55	R- 459	Keshabpur	22 54.5 N	89 15.0 E	1767.4
56	R- 460	Magura	23 29.0 N	89 25.0 E	1745.0
57	R- 461	Narail	23 11.0 N	89 31.0 E	1727.4
58	R- 462	Salikha	23 19.0 N	89 23.0 E	1791.5
59	R- 463	Sailkupa	23 43.0 N	89 16.0 E	1680.4
60	R- 501	Bagerhat	22 40.0 N	89 46.0 E	2154.9

* Sum of monthly means.

Data not used.

Table 3.8

Mean Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
61	R- 502	Benerpota	22 44.0 N	89 5.0 E	1668.3
62	R- 503	Chalna	22 36.0 N	89 32.0 E	1807.5
63	R- 504	Dumuria	22 47.0 N	89 24.0 E	1854.5
64	R- 505	Islamkati	22 44.0 N	89 15.0 E	1498.7
65	R- 506	Kaikhali	22 12.0 N	89 5.0 E	1924.2
66	R- 507	Kalaroa	22 51.0 N	89 3.0 E	1628.7
67	R- 508	Kaliganj (Khulna)	22 27.0 N	89 2.0 E	1619.4
68	R- 509	Kapilmuni	22 41.5 N	89 19.5 E	1685.2
69	R- 510	Khulna	22 49.0 N	89 34.0 E	1822.4
70	R- 511	Mollahat	22 55.5 N	89 47.0 E	2059.8
71	R- 512	Morrelganj	22 28.0 N	89 52.0 E	2125.4
72	R- 513	Nakipur	22 22.0 N	89 4.0 E	1885.1
73	R- 514	Nalianala	22 28.0 N	89 26.0 E	1925.0
74	R- 515	Paikgacha	22 35.0 N	89 19.0 E	1767.9 #
75	R- 516	Rampal	22 34.0 N	89 39.7 E	2004.2
76	R- 517	Rupsa - East	22 49.0 N	89 32.0 E	1784.1
77	R- 518	Satkhira	22 42.0 N	89 4.0 E	1808.2

* Sum of monthly means.

Data not used.

Table 3.9

Median Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
1	R- 019	Kushtia	23 58.0 N	89 2.0 E	1325.0
2	R- 030	Rajbari	23 46.0 N	89 40.3 E	1489.8
3	R- 038	Sujanagar	23 56.0 N	89 24.5 E	1406.5
4	R- 041	Bheramara	24 1.0 N	89 0.2 E	1256.4
5	R- 214	Amla	23 54.3 N	88 56.0 E	1351.9
6	R- 217	Sikarpur (Pragpur)	24 1.1 N	88 46.8 E	1195.1
7	R- 223	Hogalbaria	24 2.2 N	88 52.3 E	1273.7
8	R- 224	Chuadanga	23 39.0 N	88 51.0 E	1387.6
9	R- 225	Meherpur	23 45.7 N	88 38.0 E	1261.7
10	R- 252	Bakerganj	22 32.7 N	90 20.4 E	1889.2
11	R- 253	Bamna	22 19.7 N	90 6.0 E	1989.1
12	R- 254	Banaripara	22 47.0 N	90 10.0 E	1833.4 #
13	R- 255	Bauphal	22 25.1 N	90 33.8 E	2377.3
14	R- 256	Barguna	22 9.0 N	90 7.0 E	2259.2
15	R- 257	Barhanuddin	22 29.9 N	90 43.1 E	2398.0
16	R- 258	Barisal	22 42.0 N	90 22.5 E	1986.4
17	R- 259	Bhandaria	22 29.2 N	90 3.8 E	2067.3
18	R- 260	Bhola	22 41.0 N	90 39.1 E	2254.7
19	R- 261	Daulatkhan	22 37.0 N	90 46.8 E	2385.4
20	R- 262	Golachipa	22 10.0 N	90 24.7 E	2712.1
21	R- 263	Gournadi	22 58.4 N	90 14.1 E	1985.8
22	R- 264	Jhalakati	22 39.0 N	90 11.3 E	1758.1
23	R- 265	Mathbaria	22 17.6 N	89 57.6 E	2166.5
24	R- 266	Patuakhali	22 22.3 N	90 21.3 E	2314.2
25	R- 267	Pirojpur	22 34.5 N	89 57.3 E	1832.2
26	R- 269	Khepupara	21 59.0 N	90 13.8 E	2430.9
27	R- 270	Anjurhat (Mayerchar)	22 7.6 N	90 39.3 E	2244.2
28	R- 271	Nazirpur	22 42.5 N	89 58.8 E	1836.6
29	R- 272	Patharghata	22 3.0 N	89 58.6 E	2276.2
30	R- 273	Rangabali	21 57.3 N	90 24.7 E	2258.3

* Sum of monthly medians.

Data not used.

Contd....

Table 3.9

Median Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
31	R- 354	Chandpur	23 14.3 N	90 40.0 E	1799.3
32	R- 357	Daudkandi	23 32.0 N	90 43.0 E	2461.2 #
33	R- 364	Lakshmipur	22 56.2 N	90 50.2 E	2136.4
34	R- 365	Munshiganj	23 33.1 N	90 32.2 E	1824.7 #
35	R- 372	Raipur (Noakhali)	23 2.5 N	90 45.8 E	1860.2
36	R- 401	Baliakandi	23 38.5 N	89 33.5 E	1433.4
37	R- 402	Bhagyakul	23 30.0 N	90 13.0 E	1631.6
38	R- 403	Bhanga	23 24.0 N	89 59.0 E	1631.8
39	R- 404	Bhusna (Boalmari)	23 23.0 N	89 43.0 E	1476.4
40	R- 406	Faridpur	23 37.5 N	89 51.0 E	1708.5
41	R- 407	Fatehpur	23 15.3 N	90 0.0 E	1663.6
42	R- 409	Haridaspur	23 2.0 N	89 48.0 E	1546.3
43	R- 410	Madaripur	23 10.5 N	90 11.5 E	1770.6
44	R- 411	Madhukhali	23 33.4 N	89 38.0 E	1579.8
45	R- 413	Palong	23 13.0 N	90 20.0 E	1977.6
46	R- 414	Shibchar	23 21.5 N	90 8.5 E	1802.9
47	R- 451	Abhoynagar	23 1.0 N	89 27.0 E	1597.3
48	R- 452	Alamdanga	23 47.0 N	88 57.0 E	1360.4
49	R- 453	Benapole	23 2.0 N	88 54.5 E	1308.9
50	R- 454	Chaugacha	23 16.0 N	89 2.0 E	1377.3
51	R- 455	Dattanagar	23 26.0 N	88 50.0 E	1268.8
52	R- 456	Jessore	23 11.0 N	89 14.0 E	1492.2
53	R- 457	Jhenaidah	23 33.0 N	89 11.0 E	1393.0
54	R- 458	Kaliganj (Jessore)	23 24.0 N	89 10.0 E	1470.4
55	R- 459	Keshabpur	22 54.5 N	89 15.0 E	1501.0
56	R- 460	Magura	23 29.0 N	89 25.0 E	1579.4
57	R- 461	Narail	23 11.0 N	89 31.0 E	1536.7
58	R- 462	Salikha	23 19.0 N	89 23.0 E	1437.5
59	R- 463	Sailkupa	23 43.0 N	89 16.0 E	1446.0
60	R- 501	Bagerhat	22 40.0 N	89 46.0 E	1920.9

* Sum of monthly medians.

Data not used.

Contd....

Table 3.9

Median Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
61	R- 502	Benerpota	22 44.0 N	89 5.0 E	1409.5
62	R- 503	Chalna	22 36.0 N	89 32.0 E	1566.6
63	R- 504	Dumuria	22 47.0 N	89 24.0 E	1563.9
64	R- 505	Islamkati	22 44.0 N	89 15.0 E	1310.8
65	R- 506	Kaikhali	22 12.0 N	89 5.0 E	1688.1
66	R- 507	Kalaroa	22 51.0 N	89 3.0 E	1349.1
67	R- 508	Kaliganj (Khulna)	22 27.0 N	89 2.0 E	1361.5
68	R- 509	Kapilmuni	22 41.5 N	89 19.5 E	1341.1
69	R- 510	Khulna	22 49.0 N	89 34.0 E	1619.5
70	R- 511	Mollahat	22 55.5 N	89 47.0 E	1802.2
71	R- 512	Morrelganj	22 28.0 N	89 52.0 E	1812.2
72	R- 513	Nakipur	22 22.0 N	89 4.0 E	1763.5
73	R- 514	Nalianala	22 28.0 N	89 26.0 E	1683.0
74	R- 515	Paikgacha	22 35.0 N	89 19.0 E	1557.9 #
75	R- 516	Rampal	22 34.0 N	89 39.7 E	1812.0
76	R- 517	Rupsa - East	22 49.0 N	89 32.0 E	1563.4
77	R- 518	Satkhira	22 42.0 N	89 4.0 E	1577.7

* Sum of monthly medians.

Data not used.

Table 3.10

80% Dependable Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
1	R- 019	Kushtia	23 58.0 N	89 2.0 E	754.3
2	R- 030	Rajbari	23 46.0 N	89 40.3 E	917.2
3	R- 038	Sujanagar	23 56.0 N	89 24.5 E	825.5
4	R- 041	Bheramara	24 1.0 N	89 0.2 E	769.2
5	R- 214	Amla	23 54.3 N	88 56.0 E	791.6
6	R- 217	Sikarpur (Pragpur)	24 1.1 N	88 46.8 E	616.3
7	R- 223	Hogalbaria	24 2.2 N	88 52.3 E	702.2
8	R- 224	Chuadanga	23 39.0 N	88 51.0 E	790.6
9	R- 225	Meherpur	23 45.7 N	88 38.0 E	722.9
10	R- 252	Bakerganj	22 32.7 N	90 20.4 E	1224.3
11	R- 253	Bamna	22 19.7 N	90 6.0 E	1217.6
12	R- 254	Banaripara	22 47.0 N	90 10.0 E	1059.0 #
13	R- 255	Bauphal	22 25.1 N	90 33.8 E	1416.0
14	R- 256	Barguna	22 9.0 N	90 7.0 E	1386.3
15	R- 257	Barhanuddin	22 29.9 N	90 43.1 E	1524.0
16	R- 258	Barisal	22 42.0 N	90 22.5 E	1240.1
17	R- 259	Bhandaria	22 29.2 N	90 3.8 E	1237.1
18	R- 260	Bhola	22 41.0 N	90 39.1 E	1363.6
19	R- 261	Daulatkhan	22 37.0 N	90 46.8 E	1460.5
20	R- 262	Golachipa	22 10.0 N	90 24.7 E	1562.2
21	R- 263	Gournadi	22 58.4 N	90 14.1 E	1058.3
22	R- 264	Jhalakati	22 39.0 N	90 11.3 E	996.5
23	R- 265	Mathbaria	22 17.6 N	89 57.6 E	1223.8
24	R- 266	Patuakhali	22 22.3 N	90 21.3 E	1440.6
25	R- 267	Pirojpur	22 34.5 N	89 57.3 E	1159.3
26	R- 269	Khepupara	21 59.0 N	90 13.8 E	1419.7
27	R- 270	Anjurhat (Mayerchar)	22 7.6 N	90 39.3 E	1222.0
28	R- 271	Nazirpur	22 42.5 N	89 58.8 E	663.2
29	R- 272	Patharghata	22 3.0 N	89 58.6 E	1295.4
30	R- 273	Rangabali	21 57.3 N	90 24.7 E	1362.9

* Sum of 80% dependable monthly rainfall.
# Data not used.

Contd....

Table 3.10

80% Dependable Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
31	R- 354	Chandpur	23 14.3 N	90 40.0 E	993.4
32	R- 357	Daudkandi	23 32.0 N	90 43.0 E	1275.3 #
33	R- 364	Lakshmipur	22 56.2 N	90 50.2 E	1335.3
34	R- 365	Munshiganj	23 33.1 N	90 32.2 E	920.3 #
35	R- 372	Raipur (Noakhali)	23 2.5 N	90 45.8 E	1068.3
36	R- 401	Baliakandi	23 38.5 N	89 33.5 E	771.9
37	R- 402	Bhagyakul	23 30.0 N	90 13.0 E	937.9
38	R- 403	Bhanga	23 24.0 N	89 59.0 E	1039.4
39	R- 404	Bhusna (Boalmari)	23 23.0 N	89 43.0 E	802.7
40	R- 406	Faridpur	23 37.5 N	89 51.0 E	1075.0
41	R- 407	Fatehpur	23 15.3 N	90 0.0 E	945.4
42	R- 409	Haridaspur	23 2.0 N	89 48.0 E	942.8
43	R- 410	Madaripur	23 10.5 N	90 11.5 E	1059.3
44	R- 411	Madhukhali	23 33.4 N	89 38.0 E	648.4
45	R- 413	Palong	23 13.0 N	90 20.0 E	1076.8
46	R- 414	Shibchar	23 21.5 N	90 8.5 E	987.8
47	R- 451	Abhoynagar	23 1.0 N	89 27.0 E	891.2
48	R- 452	Alamdanga	23 47.0 N	88 57.0 E	749.8
49	R- 453	Benapole	23 2.0 N	88 54.5 E	623.8
50	R- 454	Chaugacha	23 16.0 N	89 2.0 E	726.1
51	R- 455	Dattanagar	23 26.0 N	88 50.0 E	723.3
52	R- 456	Jessore	23 11.0 N	89 14.0 E	838.6
53	R- 457	Jhenaidah	23 33.0 N	89 11.0 E	943.9
54	R- 458	Kaliganj (Jessore)	23 24.0 N	89 10.0 E	845.9
55	R- 459	Keshabpur	22 54.5 N	89 15.0 E	811.0
56	R- 460	Magura	23 29.0 N	89 25.0 E	990.5
57	R- 461	Narail	23 11.0 N	89 31.0 E	790.2
58	R- 462	Salikha	23 19.0 N	89 23.0 E	671.5
59	R- 463	Sailkupa	23 43.0 N	89 16.0 E	865.6
60	R- 501	Bagerhat	22 40.0 N	89 46.0 E	1059.3

* Sum of 80% dependable monthly rainfall.

Data not used.

Contd....

Table 3.10

80% Dependable Annual Rainfall (mm)

Sl.No.	Station No.	Station Name	Latitude deg min N	Longitude deg min E	Annual *
61	R- 502	Benerpota	22 44.0 N	89 5.0 E	809.2
62	R- 503	Chalna	22 36.0 N	89 32.0 E	909.8
63	R- 504	Dumuria	22 47.0 N	89 24.0 E	795.4
64	R- 505	Islamkati	22 44.0 N	89 15.0 E	671.7
65	R- 506	Kaikhali	22 12.0 N	89 5.0 E	916.8
66	R- 507	Kalaroa	22 51.0 N	89 3.0 E	739.4
67	R- 508	Kaliganj (Khulna)	22 27.0 N	89 2.0 E	775.9
68	R- 509	Kapilmuni	22 41.5 N	89 19.5 E	804.3
69	R- 510	Khulna	22 49.0 N	89 34.0 E	952.7
70	R- 511	Mollahat	22 55.5 N	89 47.0 E	860.9
71	R- 512	Morrelganj	22 28.0 N	89 52.0 E	1008.5
72	R- 513	Nakipur	22 22.0 N	89 4.0 E	897.2
73	R- 514	Nalianala	22 28.0 N	89 26.0 E	1050.4
74	R- 515	Paikgacha	22 35.0 N	89 19.0 E	805.8 #
75	R- 516	Rampal	22 34.0 N	89 39.7 E	875.3
76	R- 517	Rupsa - East	22 49.0 N	89 32.0 E	744.0
77	R- 518	Satkhira	22 42.0 N	89 4.0 E	922.5

* Sum of 80% dependable monthly rainfall.

Data not used.

Contd....

Table 3.11

Mean Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
1	R- 019	Kushtia	6.3	20.3	26.9	89.3	185.7	248.9	305.2	268.4	207.4	132.8	16.7	8.9	1516.8	1523.0
2	R- 030	Rajbari	3.8	16.9	33.3	124.5	224.1	306.5	313.1	290.2	236.9	119.8	21.4	10.2	1700.7	1695.5
3	R- 038	Sujanagar	7.6	15.2	33.1	92.8	197.8	288.3	333.2	285.2	249.7	126.7	19.8	6.2	1655.6	1661.1
4	R- 041	Bheramara	8.7	16.9	25.6	85.9	179.9	254.9	273.1	260.7	234.6	115.5	15.6	8.1	1479.5	1474.6
5	R- 214	Amla	8.3	19.0	26.9	82.2	163.1	227.4	288.9	267.7	227.3	121.2	22.6	8.8	1463.4	1461.2
6	R- 217	Sikarpur (Pragpur)	4.8	10.6	22.8	69.4	151.8	214.1	324.3	232.3	265.1	102.0	11.6	7.9	1416.7	1407.9
7	R- 223	Hogalbaria	4.8	16.7	27.1	77.4	148.2	252.6	338.7	295.7	274.8	111.8	14.7	5.9	1568.4	1589.2
8	R- 224	Chuadanga	6.4	15.0	24.6	106.0	167.5	245.9	318.1	270.8	237.9	129.0	21.0	7.5	1549.7	1580.9
9	R- 225	Meherpur	7.8	21.3	26.1	62.5	144.7	227.9	301.4	281.0	242.5	110.4	18.7	9.4	1453.7	1476.5
10	R- 252	Bakerganj	8.1	16.7	29.1	101.8	186.0	436.9	487.1	398.0	292.3	175.6	36.0	10.4	2178.0	2183.6
11	R- 253	Bamna	10.2	17.9	35.3	78.5	157.1	453.4	555.8	448.3	328.9	200.4	51.3	12.5	2349.6	2346.1
12	R- 254	Banaripara	7.1	19.7	45.3	106.3	211.7	413.4	414.6	384.3	316.5	142.7	37.4	13.5	2112.5	2106.6
13	R- 255	Bauphal	6.7	13.3	34.7	99.0	233.2	556.7	549.0	490.6	366.2	195.2	55.7	11.1	2611.4	2651.3
14	R- 256	Barguna	8.9	14.0	30.5	86.4	193.9	494.5	535.7	513.8	352.4	238.4	43.0	16.6	2528.1	2521.6
15	R- 257	Barhanuddin	6.5	20.8	51.0	126.1	230.3	541.7	604.5	518.4	346.4	221.5	55.1	12.0	2734.3	2682.9
16	R- 258	Barisal	10.9	20.6	37.5	105.3	217.9	425.3	419.6	388.5	317.0	174.7	45.0	12.3	2174.6	2190.5
17	R- 259	Bhandaria	15.7	17.9	37.3	111.3	194.7	467.1	521.3	418.7	336.8	174.0	45.9	16.0	2356.7	2355.4
18	R- 260	Bhola	5.7	25.0	41.9	134.8	257.2	487.1	468.6	460.4	313.0	201.2	46.2	11.7	2452.8	2451.4
19	R- 261	Daulatkhan	4.6	30.0	43.5	125.8	256.7	539.5	593.9	556.4	366.1	242.1	47.8	17.7	2824.1	2879.0
20	R- 262	Golachipa	8.6	28.3	45.8	103.4	240.4	550.8	659.9	631.5	481.8	306.8	75.7	8.4	3141.4	3156.8
21	R- 263	Gournadi	9.6	19.1	54.7	113.4	234.3	406.3	436.7	384.2	287.7	162.1	48.6	17.1	2173.8	2157.9
22	R- 264	Jhalakati	8.1	14.8	33.1	95.3	198.8	409.4	395.6	356.2	277.4	160.0	47.9	14.7	2011.3	2067.1
23	R- 265	Mathbaria	6.6	15.9	31.1	66.2	222.0	472.3	584.7	530.1	353.2	153.4	37.3	5.5	2478.3	2390.7
24	R- 266	Patuakhali	11.1	16.5	40.5	94.9	228.6	534.1	532.0	462.5	373.9	202.2	60.5	13.5	2570.3	2467.9
25	R- 267	Pirojpur	7.0	19.4	42.0	91.6	189.0	426.8	408.2	382.5	312.6	160.9	35.9	13.5	2089.4	2094.1
26	R- 269	Khepupara	5.2	24.0	31.3	119.8	213.2	511.6	643.4	545.1	401.9	189.5	59.5	17.4	2761.9	2730.6
27	R- 270	Anjurhat (Mayerchar)	7.2	18.0	31.8	107.0	243.2	460.6	651.5	554.2	306.6	169.9	78.0	3.8	2631.8	2551.6
28	R- 271	Nazirpur	3.6	16.4	34.3	136.9	196.6	367.6	357.1	361.5	319.0	207.1	43.1	18.9	2062.1	2081.8
29	R- 272	Patharghata	8.9	19.8	26.4	81.8	187.0	395.8	618.1	580.6	364.9	207.7	52.3	12.6	2555.9	2514.1
30	R- 273	Rangabali	2.5	18.4	20.0	95.5	203.9	463.7	632.7	543.2	423.2	128.6	61.5	0.2	2593.4	2731.3

* Sum of monthly means.

\# Mean of annual rainfall values for complete years.

Contd...

Table 3.11

Mean Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
31	R- 354	Chandpur	6.9	18.7	62.2	141.8	249.8	382.8	384.8	325.7	235.7	153.1	31.4	10.9	2003.8	2052.5
32	R- 357	Daudkandi	10.9	33.8	117.1	261.5	383.3	501.7	530.8	395.4	312.5	190.8	49.6	15.6	2803.0	2885.1
33	R- 364	Lakshmipur	5.2	18.1	50.2	156.7	229.1	470.1	528.3	493.5	371.3	198.6	33.1	10.4	2564.6	2574.7
34	R- 365	Munshiganj	4.5	16.5	42.1	162.4	273.0	416.9	418.8	371.2	253.7	137.0	30.9	5.2	2132.2	2133.4
35	R- 372	Raipur (Noakhali)	6.0	15.5	44.3	146.2	204.1	402.6	425.7	377.7	286.4	164.8	29.1	9.4	2111.8	2142.0
36	R- 401	Baliakandi	5.8	10.7	27.9	103.2	196.7	259.5	300.0	251.9	210.7	128.1	28.2	4.2	1526.9	1558.4
37	R- 402	Bhagyakul	5.3	29.3	51.9	166.8	250.1	370.2	365.8	267.9	230.6	132.3	32.3	9.4	1911.9	1900.6
38	R- 403	Bhanga	7.3	15.9	43.2	154.9	214.1	348.1	371.0	285.9	210.1	135.2	35.1	10.0	1830.8	1847.5
39	R- 404	Bhusna (Boalmari)	6.5	18.4	39.9	123.0	211.6	290.8	323.2	271.8	259.9	144.0	36.5	6.9	1732.5	1761.3
40	R- 406	Faridpur	6.9	22.5	47.8	140.3	252.0	355.1	331.4	287.7	248.7	139.6	34.3	10.8	1877.1	1930.2
41	R- 407	Fatehpur	10.0	18.6	43.6	141.3	224.9	372.9	344.6	271.7	226.7	139.8	37.3	8.8	1840.2	1722.5
42	R- 409	Haridaspur	8.4	21.1	47.9	115.3	189.1	354.2	345.9	299.3	254.8	124.8	31.7	8.2	1800.7	1784.4
43	R- 410	Madaripur	9.6	21.8	54.6	141.4	252.0	361.0	377.6	317.6	245.0	150.4	40.0	10.9	1981.9	2017.0
44	R- 411	Madhukhali	1.9	17.6	65.8	142.9	258.4	314.1	330.9	227.5	270.9	140.7	39.3	2.9	1812.9	1844.4
45	R- 413	Palong	6.1	18.5	44.5	145.7	238.7	396.7	408.3	368.8	283.7	135.0	37.8	7.2	2091.0	2090.0
46	R- 414	Shibchar	11.5	18.3	44.2	198.7	236.6	409.6	414.4	319.3	280.0	135.4	35.7	7.5	2111.2	2202.5
47	R- 451	Abhoynagar	8.2	22.1	33.1	84.2	181.3	336.6	399.1	407.0	290.1	142.6	23.5	9.2	1937.0	1898.2
48	R- 452	Alamdanga	7.2	16.8	25.4	97.2	156.2	248.8	311.8	271.4	232.3	114.6	25.1	7.9	1514.7	1546.5
49	R- 453	Benapole	15.5	23.4	32.6	68.1	142.7	238.0	314.9	299.0	275.8	86.4	25.9	11.0	1533.3	1546.1
50	R- 454	Chaugacha	11.1	18.1	29.9	76.9	154.7	293.0	336.7	285.7	250.6	127.8	30.1	13.0	1627.6	1653.5
51	R- 455	Dattanagar	7.0	18.8	29.5	61.5	127.5	251.6	321.0	294.7	232.0	104.9	21.1	9.6	1479.2	1469.4
52	R- 456	Jessore	11.8	21.8	36.4	83.0	179.5	307.4	341.5	311.8	246.3	126.8	28.9	10.3	1705.5	1738.2
53	R- 457	Jhenaidah	5.8	19.9	46.7	82.9	189.6	272.5	329.0	258.6	232.5	124.2	28.3	12.1	1602.1	1619.4
54	R- 458	Kaliganj (Jessore)	7.0	16.7	43.4	84.0	187.6	292.9	345.6	296.5	241.6	126.5	27.5	11.8	1681.1	1695.7
55	R- 459	Keshabpur	8.7	28.3	43.2	76.3	172.1	311.7	360.8	312.3	287.7	125.4	30.8	10.1	1767.4	1758.4
56	R- 460	Magura	6.2	20.9	46.1	104.0	213.8	309.6	330.9	292.5	252.0	129.7	30.6	8.7	1745.0	1743.1
57	R- 461	Narail	7.7	20.3	43.4	82.4	180.9	308.1	339.3	336.8	241.6	130.2	27.6	9.1	1727.4	1718.3
58	R- 462	Salikha	10.1	15.4	42.8	98.5	189.6	333.4	341.5	332.4	258.3	115.5	45.3	8.7	1791.5	1779.6
59	R- 463	Sailkupa	3.1	17.8	34.2	109.0	194.0	273.6	347.4	286.4	242.5	131.2	29.9	11.3	1680.4	1717.9
60	R- 501	Bagerhat	10.8	22.7	37.5	88.9	192.4	428.7	475.1	442.4	266.4	155.0	26.5	8.5	2154.9	2146.5

Contd...

* Sum of monthly means.

\# Mean of annual rainfall values for complete years.

Table 3.11

Mean Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
61	R- 502	Benerpota	12.3	24.8	38.6	78.2	124.0	312.5	338.9	312.3	271.4	119.3	23.9	12.1	1668.3	1625.6
62	R- 503	Chalna	7.9	19.9	31.7	82.5	156.4	332.9	365.1	340.9	286.3	137.9	33.4	12.6	1807.5	1851.9
63	R- 504	Dumuria	16.5	23.7	29.8	84.2	148.8	352.4	384.8	338.1	292.6	139.2	31.9	12.5	1854.5	1865.5
64	R- 505	Islamkati	9.7	12.3	26.2	75.9	123.3	262.8	334.3	278.0	245.3	104.7	22.2	4.0	1498.7	1551.4
65	R- 506	Kaikhali	8.7	12.9	30.9	47.2	130.4	326.2	411.1	357.4	364.9	175.8	47.8	10.9	1924.2	1933.0
66	R- 507	Kalaroa	11.3	25.0	30.6	66.8	112.5	291.2	342.3	321.9	275.7	122.4	19.5	9.5	1628.7	1632.2
67	R- 508	Kaliganj (Khulna)	8.2	24.6	30.3	43.8	124.0	301.4	330.2	319.0	266.3	129.9	30.3	11.4	1619.4	1701.8
68	R- 509	Kapilmuni	11.2	26.7	37.3	80.6	141.1	316.8	356.2	308.1	237.9	130.9	26.4	12.0	1685.2	1717.7
69	R- 510	Khulna	12.7	28.4	35.4	88.6	190.3	347.7	345.6	342.5	244.0	141.7	33.9	11.6	1822.4	1794.1
70	R- 511	Mollahat	14.1	25.6	39.7	90.1	200.4	402.0	420.5	383.1	313.1	137.6	24.7	8.9	2059.8	2166.2
71	R- 512	Morrelganj	8.8	14.4	28.9	89.6	183.9	434.8	458.7	401.6	305.8	150.7	43.8	4.4	2125.4	2125.2
72	R- 513	Nakipur	10.0	14.9	29.2	73.9	145.2	308.6	382.1	362.2	316.8	206.0	23.5	12.7	1885.1	1888.7
73	R- 514	Nalianala	11.8	17.3	36.6	75.7	171.5	368.7	378.0	342.6	339.8	142.9	28.0	12.1	1925.0	1865.8
74	R- 515	Paikgacha	12.8	19.1	25.0	78.8	182.1	376.4	334.7	328.4	234.6	132.5	29.1	14.4	1767.9	1697.7
75	R- 516	Rampal	8.5	27.9	36.1	89.8	166.2	348.8	441.5	362.1	301.7	162.4	44.9	14.3	2004.2	1996.5
76	R- 517	Rupsa - East	10.5	26.0	34.7	86.1	170.1	341.5	379.3	328.4	248.9	133.1	16.4	9.1	1784.1	1781.4
77	R- 518	Satkhira	19.8	33.3	35.8	91.0	124.9	331.2	370.0	329.6	297.9	132.5	31.4	10.8	1808.2	1839.8

* Sum of monthly means.

Mean of annual rainfall values for complete years.

Table 3.12

Median Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
1	R- 019	Kushtia	0.8	14.5	18.0	71.4	184.7	215.4	291.4	245.0	173.3	108.2	2.3	0.0	1325.0	1489.3
2	R- 030	Rajbari	0.0	12.7	17.5	96.8	229.9	302.9	276.3	280.5	187.3	83.4	2.5	0.0	1489.8	1635.5
3	R- 038	Sujanagar	1.5	5.0	20.4	63.3	168.4	278.7	300.4	225.4	225.0	109.8	8.6	0.0	1406.5	1642.3
4	R- 041	Bheramara	0.5	9.9	17.7	64.2	144.0	214.0	255.8	241.5	204.1	104.1	0.6	0.0	1256.4	1485.6
5	R- 214	Amla	1.5	10.7	19.1	63.4	165.3	218.6	288.1	255.6	200.0	123.5	6.1	0.0	1351.9	1463.0
6	R- 217	Sikarpur (Pragpur)	0.0	0.0	11.5	43.3	152.9	214.8	303.6	191.1	201.2	76.7	0.0	0.0	1195.1	1274.1
7	R- 223	Hogalbaria	0.0	2.5	16.5	50.8	128.6	205.9	295.4	242.3	224.1	107.6	0.0	0.0	1273.7	1541.9
8	R- 224	Chuadanga	0.0	4.8	12.7	78.8	169.2	225.1	324.5	241.9	220.7	106.0	3.9	0.0	1387.6	1505.4
9	R- 225	Meherpur	1.1	7.9	10.2	36.9	128.3	203.6	278.5	271.9	205.0	111.7	6.6	0.0	1261.7	1437.5
10	R- 252	Bakerganj	0.0	5.1	5.6	86.1	184.8	366.6	431.4	414.3	234.0	142.5	18.8	0.0	1889.2	2204.1
11	R- 253	Bamna	0.0	5.1	8.9	53.4	132.5	426.1	493.3	424.2	278.1	138.7	28.8	0.0	1989.1	2373.4
12	R- 254	Banaripara	0.0	14.8	15.5	97.9	214.7	381.4	426.9	300.0	236.3	134.5	11.4	0.0	1833.4	2010.7
13	R- 255	Bauphal	0.0	0.5	11.4	76.2	208.9	517.2	532.5	494.7	342.8	176.8	16.3	0.0	2377.3	2524.7
14	R- 256	Barguna	0.0	0.6	6.3	60.6	149.4	461.2	530.3	506.2	334.6	195.8	14.2	0.0	2259.2	2524.0
15	R- 257	Barhanuddin	0.0	7.6	13.0	109.2	199.5	509.7	538.2	498.8	311.4	192.0	18.6	0.0	2398.0	2711.2
16	R- 258	Barisal	2.2	17.8	17.6	91.5	208.6	407.0	401.6	380.2	273.4	174.8	11.7	0.0	1986.4	2101.8
17	R- 259	Bhandaria	0.0	6.4	17.5	69.3	181.0	432.0	495.3	382.8	290.8	182.8	9.4	0.0	2067.3	2201.4
18	R- 260	Bhola	0.6	17.3	15.0	119.4	233.8	467.6	477.5	444.2	292.3	175.3	11.7	0.0	2254.7	2433.5
19	R- 261	Daulatkhan	0.0	6.4	1.9	97.7	222.3	523.4	499.4	515.8	344.8	173.7	0.0	0.0	2385.4	2770.1
20	R- 262	Golachipa	2.2	8.1	23.6	67.5	173.1	487.8	652.4	576.0	412.6	257.1	51.7	0.0	2712.1	3163.3
21	R- 263	Gournadi	1.9	13.2	35.6	101.7	185.8	356.4	447.1	394.6	287.6	145.6	16.3	0.0	1985.8	2146.0
22	R- 264	Jhalakati	0.0	7.6	10.4	74.8	193.0	370.0	373.6	382.6	216.5	120.7	8.9	0.0	1758.1	2057.7
23	R- 265	Mathbaria	0.0	1.3	11.3	33.5	197.3	416.0	558.9	478.2	324.2	131.3	14.5	0.0	2166.5	2374.1
24	R- 266	Patuakhali	0.0	3.8	13.7	71.4	204.5	475.0	537.0	473.0	323.1	193.0	19.7	0.0	2314.2	2501.4
25	R- 267	Pirojpur	0.0	7.6	17.1	78.0	182.9	383.6	361.4	363.8	271.4	159.1	7.3	0.0	1832.2	2102.1
26	R- 269	Khepupara	0.0	6.4	6.1	59.5	193.9	479.6	627.3	514.8	353.0	159.8	30.5	0.0	2430.9	2659.0
27	R- 270	Anjurhat (Mayerchar)	0.0	15.9	0.3	76.5	225.5	377.0	663.8	478.2	261.5	132.0	13.5	0.0	2244.2	2254.2
28	R- 271	Nazirpur	0.0	2.9	3.3	84.6	195.4	342.8	343.8	335.5	261.4	254.5	12.4	0.0	1836.6	2048.3
29	R- 272	Patharghata	0.0	8.4	5.1	44.9	194.0	328.9	593.0	560.2	320.5	189.6	31.6	0.0	2276.2	2476.6
30	R- 273	Rangabali	0.0	0.0	5.1	48.8	117.4	386.9	589.8	530.8	453.8	123.2	2.5	0.0	2258.3	2658.6

* Sum of monthly medians.

\# Median of annual rainfall values for complete years.

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Table 3.12

Median Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
31	R- 354	Chandpur	0.0	3.3	30.5	116.9	248.4	373.4	367.1	292.4	232.2	127.0	8.1	0.0	1799.3	2079.5
32	R- 357	Daudkandi	0.0	25.3	87.6	176.0	322.2	470.9	496.6	390.8	302.9	164.5	24.4	0.0	2461.2	2819.5
33	R- 364	Lakshmipur	0.0	12.7	11.7	96.7	196.2	471.8	495.0	416.0	314.1	113.8	8.4	0.0	2136.4	2412.9
34	R- 365	Munshiganj	0.0	2.0	7.7	150.4	255.6	408.9	368.6	280.4	247.6	99.4	4.1	0.0	1824.7	1961.3
35	R- 372	Raipur (Noakhali)	0.0	8.1	22.8	128.2	184.7	396.3	390.8	344.3	252.9	116.1	16.0	0.0	1860.2	2127.8
36	R- 401	Baliakandi	0.0	7.1	10.4	77.0	194.0	238.5	279.3	272.8	216.9	113.0	24.4	0.0	1433.4	1486.1
37	R- 402	Bhagyakul	0.0	12.0	33.3	139.3	237.0	345.4	315.3	252.4	208.4	81.1	7.4	0.0	1631.6	1933.8
38	R- 403	Bhanga	0.0	11.4	41.9	135.7	189.6	326.4	333.3	272.4	195.8	100.7	24.6	0.0	1631.8	1876.8
39	R- 404	Bhusna (Boalmari)	0.0	14.9	16.6	88.9	182.9	281.5	273.4	228.8	257.2	119.5	12.7	0.0	1476.4	1782.8
40	R- 406	Faridpur	1.5	12.6	31.5	127.4	240.4	342.3	312.2	264.2	232.4	127.1	16.9	0.0	1708.5	1994.6
41	R- 407	Fatehpur	3.5	7.9	38.0	122.7	218.9	316.7	347.7	238.1	215.0	131.7	23.4	0.0	1663.6	1717.2
42	R- 409	Haridaspur	0.0	10.9	20.3	100.0	203.7	329.1	283.0	269.2	212.1	103.6	14.4	0.0	1546.3	1720.9
43	R- 410	Madaripur	1.5	11.0	34.3	121.9	213.2	338.4	341.4	339.1	225.3	133.4	11.1	0.0	1770.6	2039.2
44	R- 411	Madhukhali	0.0	11.7	7.9	139.9	236.5	299.6	358.3	177.7	239.6	98.3	10.2	0.1	1579.8	1811.7
45	R- 413	Palong	0.0	10.2	23.3	131.6	216.2	414.1	391.1	401.4	266.0	102.0	21.7	0.0	1977.6	2096.6
46	R- 414	Shibchar	0.0	2.8	18.3	180.5	238.3	350.3	385.4	269.7	212.9	134.6	10.1	0.0	1802.9	2021.6
47	R- 451	Abhoynagar	0.0	3.2	13.5	74.3	140.0	324.0	373.0	310.3	240.6	107.9	10.5	0.0	1597.3	1813.0
48	R- 452	Alamdanga	0.0	7.6	12.6	97.3	131.5	239.0	300.2	248.0	202.6	106.6	15.0	0.0	1360.4	1478.7
49	R- 453	Benapole	1.9	6.1	18.3	64.7	102.6	236.3	303.1	232.4	259.6	72.8	11.1	0.0	1308.9	1487.3
50	R- 454	Chaugacha	0.0	5.1	13.4	57.6	125.8	258.0	319.7	243.7	238.0	108.4	7.6	0.0	1377.3	1583.7
51	R- 455	Dattanagar	0.3	9.8	17.9	31.4	123.0	214.1	309.0	272.7	181.3	104.2	5.1	0.0	1268.8	1427.8
52	R- 456	Jessore	4.2	5.5	18.8	76.1	164.4	300.4	316.7	283.9	204.6	105.5	12.1	0.0	1492.2	1809.8
53	R- 457	Jhenaidah	0.0	10.4	38.6	65.5	170.9	260.6	271.2	248.0	201.4	118.8	7.6	0.0	1393.0	1623.0
54	R- 458	Kaliganj (Jessore)	0.0	7.6	27.6	77.4	176.3	282.7	319.5	251.0	225.0	91.9	11.4	0.0	1470.4	1697.0
55	R- 459	Keshabpur	1.0	11.4	13.7	52.7	160.5	274.0	354.8	291.7	230.3	105.6	5.3	0.0	1501.0	1823.2
56	R- 460	Magura	0.6	12.9	40.3	105.5	195.8	267.4	316.3	271.9	225.1	129.1	14.5	0.0	1579.4	1752.4
57	R- 461	Narail	0.0	13.7	30.5	73.2	164.0	274.3	335.9	330.6	200.4	111.6	2.5	0.0	1536.7	1721.4
58	R- 462	Salikha	3.8	4.6	10.1	74.8	185.3	269.9	303.9	249.3	219.0	115.3	1.5	0.0	1437.5	1784.8
59	R- 463	Sailkupa	0.0	14.0	20.6	74.1	185.0	249.2	313.3	250.6	235.3	96.3	7.6	0.0	1446.0	1679.6
60	R- 501	Bagerhat	3.8	8.9	20.5	71.7	147.3	358.0	464.0	457.1	232.8	144.1	12.7	0.0	1920.9	2118.3

Contd...

* Sum of monthly medians.

Median of annual rainfall values for complete years.

Table 3.12

Median Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
61	R- 502	Benerpota	3.0	13.4	28.6	58.9	115.5	243.4	292.7	300.9	223.2	126.3	3.6	0.0	1409.5	1667.7
62	R- 503	Chalna	0.0	10.4	18.8	62.9	150.2	283.6	328.6	323.0	252.0	126.2	10.9	0.0	1566.6	1796.3
63	R- 504	Dumuria	0.4	6.3	13.9	45.0	146.6	290.3	366.0	323.6	252.8	102.8	16.2	0.0	1563.9	1878.6
64	R- 505	Islamkati	0.0	0.0	1.9	53.3	110.0	234.5	311.2	268.4	243.9	87.6	0.0	0.0	1310.8	1543.8
65	R- 506	Kaikhali	0.5	0.0	5.4	19.0	131.8	288.4	373.9	352.7	351.0	156.1	9.3	0.0	1688.1	1868.5
66	R- 507	Kalaroa	1.6	7.1	12.6	46.9	104.8	261.5	330.8	294.4	185.7	97.0	6.7	0.0	1349.1	1544.4
67	R- 508	Kaliganj (Khulna)	0.0	9.7	9.6	25.1	89.2	273.3	303.3	284.5	236.6	122.6	7.6	0.0	1361.5	1588.9
68	R- 509	Kapilmuni	0.0	8.4	22.0	52.8	134.6	278.9	309.8	284.4	171.4	75.0	3.8	0.0	1341.1	1721.6
69	R- 510	Khulna	2.0	9.4	18.6	73.6	141.7	372.1	316.7	330.3	211.6	128.6	14.9	0.0	1619.5	1902.7
70	R- 511	Mollahat	0.0	15.3	26.6	80.0	180.5	338.5	404.9	355.2	280.7	110.3	10.2	0.0	1802.2	2162.3
71	R- 512	Morrelganj	1.5	0.0	4.7	69.9	162.9	412.5	422.0	362.0	262.7	109.7	4.3	0.0	1812.2	2009.8
72	R- 513	Nakipur	0.2	6.8	18.8	66.0	137.1	304.3	396.8	352.5	261.3	218.3	1.4	0.0	1763.5	1890.5
73	R- 514	Nalianala	0.0	5.8	13.9	56.0	162.4	341.4	344.7	346.6	267.1	127.8	17.3	0.0	1683.0	1879.4
74	R- 515	Paikgacha	0.0	10.3	9.5	50.6	177.1	349.4	307.5	316.8	210.9	122.4	3.4	0.0	1557.9	1654.4
75	R- 516	Rampal	1.5	12.7	25.2	80.5	166.4	299.2	412.5	374.5	279.0	138.0	22.5	0.0	1812.0	2136.0
76	R- 517	Rupsa - East	0.8	6.8	16.8	70.2	152.0	362.5	317.7	315.7	185.2	121.8	13.9	0.0	1563.4	1818.0
77	R- 518	Satkhira	0.6	14.6	21.3	78.0	126.3	298.4	359.7	312.6	240.0	116.4	9.8	0.0	1577.7	1803.9

* Sum of monthly medians.

\# Median of annual rainfall values for complete years.

Table 3.13

80% Dependable Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
1	R- 019	Kushtia	0.0	0.0	0.0	29.3	78.7	144.0	195.5	154.7	100.3	51.8	0.0	0.0	754.3	1231.1
2	R- 030	Rajbari	0.0	0.0	0.0	54.5	123.4	185.5	183.7	199.5	139.6	31.0	0.0	0.0	917.2	1314.7
3	R- 038	Sujanagar	0.0	0.0	0.0	34.8	82.2	164.2	215.2	171.6	124.9	32.6	0.0	0.0	825.5	1280.6
4	R- 041	Bheramara	0.0	0.0	0.0	25.4	75.6	127.0	195.6	179.0	140.7	25.9	0.0	0.0	769.2	1249.2
5	R- 214	Amla	0.0	0.0	0.0	23.3	81.1	147.3	203.1	183.6	122.6	30.6	0.0	0.0	791.6	1167.4
6	R- 217	Sikarpur (Pragpur)	0.0	0.0	1.0	13.5	71.2	126.9	154.5	122.1	108.1	19.0	0.0	0.0	616.3	873.0
7	R- 223	Hogalbaria	0.0	0.0	0.0	0.0	42.2	140.0	191.7	156.4	142.8	29.1	0.0	0.0	702.2	1171.0
8	R- 224	Chuadanga	0.0	0.0	0.0	18.5	93.7	132.1	178.0	179.3	134.6	54.4	0.0	0.0	790.6	1180.6
9	R- 225	Meherpur	0.0	0.0	0.0	2.5	76.2	125.5	170.9	192.0	141.1	14.7	0.0	0.0	722.9	1133.1
10	R- 252	Bakerganj	0.0	0.0	0.0	27.1	83.5	280.5	327.7	282.8	173.2	49.5	0.0	0.0	1224.3	1816.7
11	R- 253	Bamna	0.0	0.0	0.0	15.2	28.4	283.5	396.9	288.3	144.4	60.9	0.0	0.0	1217.6	1915.3
12	R- 254	Banaripara	0.0	0.0	0.0	19.3	66.6	239.2	319.6	224.0	140.8	49.5	0.0	0.0	1059.0	1588.7
13	R- 255	Bauphal	0.0	0.0	0.0	12.7	81.7	347.0	381.0	320.8	207.0	65.8	0.0	0.0	1416.0	2218.3
14	R- 256	Barguna	0.0	0.0	0.0	2.0	58.9	308.8	369.0	347.7	200.8	99.1	0.0	0.0	1386.3	2152.7
15	R- 257	Barhanuddin	0.0	0.0	0.0	29.2	124.4	380.9	361.8	319.4	220.6	87.7	0.0	0.0	1524.0	2230.5
16	R- 258	Barisal	0.0	0.0	0.0	51.2	98.8	243.5	324.7	245.3	196.7	79.9	0.0	0.0	1240.1	1838.0
17	R- 259	Bhandaria	0.0	0.0	0.0	25.4	92.2	332.0	326.5	225.3	187.8	47.9	0.0	0.0	1237.1	1897.3
18	R- 260	Bhola	0.0	0.0	0.0	57.1	97.7	306.9	283.1	345.0	201.4	72.4	0.0	0.0	1363.6	2134.1
19	R- 261	Daulatkhan	0.0	0.0	0.0	20.3	119.4	313.9	350.5	390.5	221.4	44.5	0.0	0.0	1460.5	2072.7
20	R- 262	Golachipa	0.0	0.0	0.0	35.0	87.3	386.0	336.1	362.1	245.9	109.8	0.0	0.0	1562.2	2404.2
21	R- 263	Gournadi	0.0	0.0	0.0	32.2	109.9	243.0	288.1	197.4	167.9	19.8	0.0	0.0	1058.3	1746.4
22	R- 264	Jhalakati	0.0	0.0	0.0	19.6	92.7	230.6	272.1	181.8	159.0	40.7	0.0	0.0	996.5	1655.9
23	R- 265	Mathbaria	0.0	0.0	0.0	1.8	36.0	260.0	405.3	296.7	188.2	35.8	0.0	0.0	1223.8	1988.6
24	R- 266	Patuakhali	0.0	0.0	0.0	34.0	120.5	342.4	385.9	255.0	210.0	92.8	0.0	0.0	1440.6	2175.0
25	R- 267	Pirojpur	0.0	0.0	0.0	22.9	95.7	281.2	264.6	221.6	199.5	73.8	0.0	0.0	1159.3	1602.0
26	R- 269	Khepupara	0.0	0.0	0.0	15.2	54.8	258.9	488.0	331.2	208.1	63.5	0.0	0.0	1419.7	2376.4
27	R- 270	Anjurhat (Mayerchar)	0.0	0.0	0.0	20.1	18.6	165.3	519.9	291.3	181.1	25.7	0.0	0.0	1222.0	1426.2
28	R- 271	Nazirpur	0.0	0.0	0.0	20.3	54.9	172.6	106.3	166.5	86.2	56.4	0.0	0.0	663.2	1580.5
29	R- 272	Patharghata	0.0	0.0	0.0	1.8	34.7	211.0	357.4	380.5	246.4	63.6	0.0	0.0	1295.4	2067.3
30	R- 273	Rangabali	0.0	0.0	0.0	0.0	63.5	231.1	493.1	413.9	123.2	38.1	0.0	0.0	1362.9	1999.8

* Sum of 80% dependable monthly rainfall.

\# 80% dependable annual rainfall estimated from all annual rainfall values for complete years.

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Table 3.13

80% Dependable Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
31	R- 354	Chandpur	0.0	0.0	2.5	44.0	119.0	258.1	245.1	188.8	119.4	16.5	0.0	0.0	993.4	1757.5
32	R- 357	Daudkandi	0.0	0.0	1.3	80.0	180.3	265.0	362.0	155.9	164.8	66.0	0.0	0.0	1275.3	2208.5
33	R- 364	Lakshmipur	0.0	0.0	0.0	35.0	120.5	263.1	332.9	298.1	223.1	62.6	0.0	0.0	1335.3	2068.2
34	R- 365	Munshiganj	0.0	0.0	0.0	50.8	95.3	237.9	241.2	161.0	110.0	24.1	0.0	0.0	920.3	1529.0
35	R- 372	Raipur (Noakhali)	0.0	0.0	0.0	60.9	107.9	204.1	278.5	205.1	157.2	54.6	0.0	0.0	1068.3	1762.1
36	R- 401	Baliakandi	0.0	0.0	0.8	37.8	83.1	171.7	162.0	104.8	153.6	58.1	0.0	0.0	771.9	1224.3
37	R- 402	Bhagyakul	0.0	0.0	2.8	76.1	141.0	198.0	208.4	134.2	126.6	50.8	0.0	0.0	937.9	1546.6
38	R- 403	Bhanga	0.0	0.0	3.0	70.4	95.3	250.6	273.4	146.2	150.0	50.5	0.0	0.0	1039.4	1581.4
39	R- 404	Bhusna (Boalmari)	0.0	0.0	0.0	41.7	83.3	167.4	202.9	142.0	131.0	34.4	0.0	0.0	802.7	1421.3
40	R- 406	Faridpur	0.0	0.0	4.5	67.8	165.6	225.3	228.1	173.9	143.5	66.3	0.0	0.0	1075.0	1530.1
41	R- 407	Fatehpur	0.0	0.0	1.8	65.9	124.7	210.4	206.3	164.8	124.6	46.9	0.0	0.0	945.4	1445.1
42	R- 409	Haridaspur	0.0	0.0	0.0	40.1	88.9	221.0	205.6	191.7	148.5	47.0	0.0	0.0	942.8	1403.2
43	R- 410	Madaripur	0.0	0.0	0.0	42.7	144.8	251.8	220.8	170.7	156.7	71.8	0.0	0.0	1059.3	1658.2
44	R- 411	Madhukhali	0.0	0.0	0.0	13.5	78.1	214.5	120.8	83.8	129.8	7.9	0.0	0.0	648.4	1506.2
45	R- 413	Palong	0.0	0.0	7.6	59.0	145.9	227.2	227.0	207.2	159.8	43.1	0.0	0.0	1076.8	1619.3
46	R- 414	Shibchar	0.0	0.0	0.0	85.0	92.0	257.5	239.1	142.3	136.1	35.8	0.0	0.0	987.8	1604.7
47	R- 451	Abhoynagar	0.0	0.0	0.0	27.7	63.9	182.2	251.3	212.6	128.8	24.7	0.0	0.0	891.2	1436.4
48	R- 452	Alamdanga	0.0	0.0	0.0	16.5	80.8	157.1	182.0	147.7	139.5	26.2	0.0	0.0	749.8	1250.4
49	R- 453	Benapole	0.0	0.0	1.3	25.4	38.4	112.7	191.9	163.1	68.6	22.4	0.0	0.0	623.8	1282.5
50	R- 454	Chaugacha	0.0	0.0	0.0	27.9	72.4	137.1	178.9	154.9	125.7	29.2	0.0	0.0	726.1	1254.4
51	R- 455	Dattanagar	0.0	0.0	0.0	8.9	80.8	148.5	192.9	178.0	83.0	31.2	0.0	0.0	723.3	1011.3
52	R- 456	Jessore	0.0	0.0	0.0	10.7	103.4	145.5	212.1	177.8	128.0	61.1	0.0	0.0	838.6	1279.6
53	R- 457	Jhenaidah	0.0	0.0	0.0	29.2	102.1	190.6	235.5	172.7	160.4	53.4	0.0	0.0	943.9	1328.3
54	R- 458	Kaliganj (Jessore)	0.0	0.0	0.0	22.1	87.2	154.3	226.1	189.0	117.7	49.5	0.0	0.0	845.9	1245.4
55	R- 459	Keshabpur	0.0	0.0	0.0	14.3	91.3	152.2	231.6	179.3	101.7	40.6	0.0	0.0	811.0	1298.3
56	R- 460	Magura	0.0	0.0	0.0	38.6	133.3	223.1	202.4	195.8	171.2	26.1	0.0	0.0	990.5	1415.8
57	R- 461	Narail	0.0	0.0	0.0	17.8	82.5	183.8	204.3	147.5	121.0	33.3	0.0	0.0	790.2	1361.0
58	R- 462	Salikha	0.0	0.0	0.0	18.0	67.1	153.6	164.6	140.2	98.3	29.7	0.0	0.0	671.5	1369.1
59	R- 463	Sailkupa	0.0	0.0	0.0	32.2	91.9	188.9	219.5	180.0	114.0	39.1	0.0	0.0	865.6	1283.0
60	R- 501	Bagerhat	0.0	0.0	0.0	13.0	80.7	297.6	269.2	238.5	115.9	44.4	0.0	0.0	1059.3	1707.8

* Sum of 80% dependable monthly rainfall.

80% dependable annual rainfall estimated from all annual rainfall values for complete years.

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Table 3.13

80% Dependable Monthly Rainfall (mm)

Sl.No.	Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
61	R- 502	Benerpota	0.0	0.0	0.8	34.1	61.5	171.3	159.8	219.3	132.4	30.0	0.0	0.0	809.2	1316.4
62	R- 503	Chalna	0.0	0.0	0.0	23.5	62.8	181.0	240.0	208.8	150.2	43.5	0.0	0.0	909.8	1391.9
63	R- 504	Dumuria	0.0	0.0	0.0	18.3	58.1	162.4	197.0	193.0	136.8	29.8	0.0	0.0	795.4	1446.5
64	R- 505	Islamkati	0.0	0.0	0.0	0.0	52.3	128.0	198.1	142.2	143.5	7.6	0.0	0.0	671.7	1189.0
65	R- 506	Kaikhali	0.0	0.0	0.0	3.6	30.4	139.7	300.9	164.3	199.1	78.8	0.0	0.0	916.8	1548.2
66	R- 507	Kalaroa	0.0	0.0	0.0	11.4	49.1	124.5	174.5	216.3	114.0	49.6	0.0	0.0	739.4	1298.2
67	R- 508	Kaliganj (Khulna)	0.0	0.0	0.0	0.0	39.2	123.6	238.4	204.9	127.9	41.9	0.0	0.0	775.9	1351.0
68	R- 509	Kapilmuni	0.0	0.0	0.0	7.6	49.5	158.2	244.3	206.8	93.5	44.4	0.0	0.0	804.3	1392.0
69	R- 510	Khulna	0.0	0.0	0.0	34.5	78.6	212.3	194.5	242.3	133.6	56.9	0.0	0.0	952.7	1375.2
70	R- 511	Mollahat	0.0	0.0	0.0	27.9	55.9	182.7	224.8	224.2	110.6	34.8	0.0	0.0	860.9	1556.2
71	R- 512	Morrelganj	0.0	0.0	0.0	13.9	66.9	253.4	280.4	236.0	147.3	10.6	0.0	0.0	1008.5	1613.3
72	R- 513	Nakipur	0.0	0.0	0.0	7.7	42.1	138.8	241.4	222.3	173.8	71.1	0.0	0.0	897.2	1551.3
73	R- 514	Nalianala	0.0	0.0	0.0	7.9	77.7	186.3	279.7	227.1	177.8	93.9	0.0	0.0	1050.4	1442.6
74	R- 515	Paikgacha	0.0	0.0	0.0	11.3	81.2	184.5	203.3	155.0	136.5	34.0	0.0	0.0	805.8	1209.9
75	R- 516	Rampal	0.0	0.0	0.0	22.9	65.0	214.9	190.4	186.0	133.5	62.6	0.0	0.0	875.3	1358.6
76	R- 517	Rupsa - East	0.0	0.0	0.0	1.5	53.9	132.9	234.2	194.9	77.8	48.8	0.0	0.0	744.0	1608.7
77	R- 518	Satkhira	0.0	0.0	0.0	30.4	52.1	175.3	263.1	230.0	136.9	34.7	0.0	0.0	922.5	1456.7

* Sum of 80% dependable monthly rainfall.

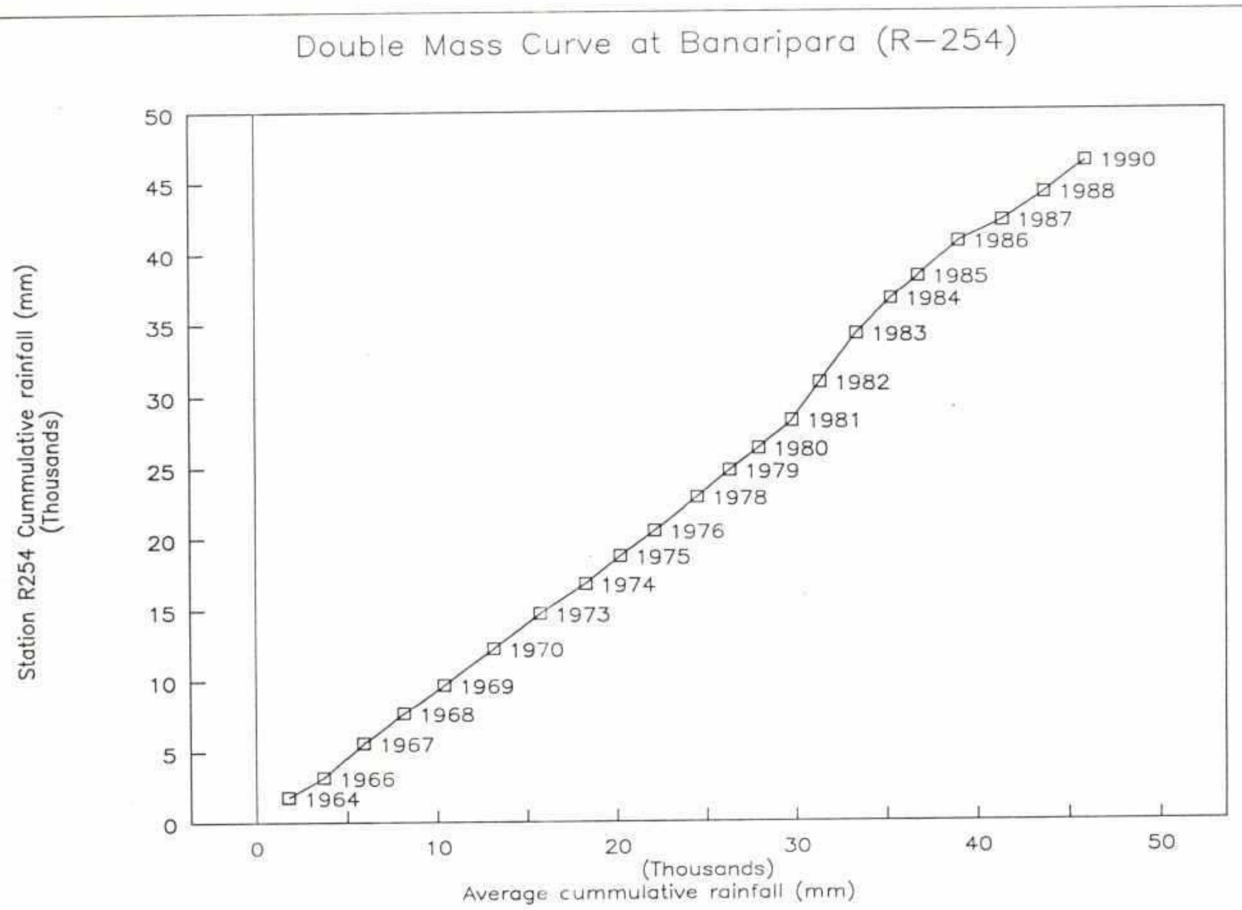
80% dependable annual rainfall estimated from all annual rainfall values for complete years.

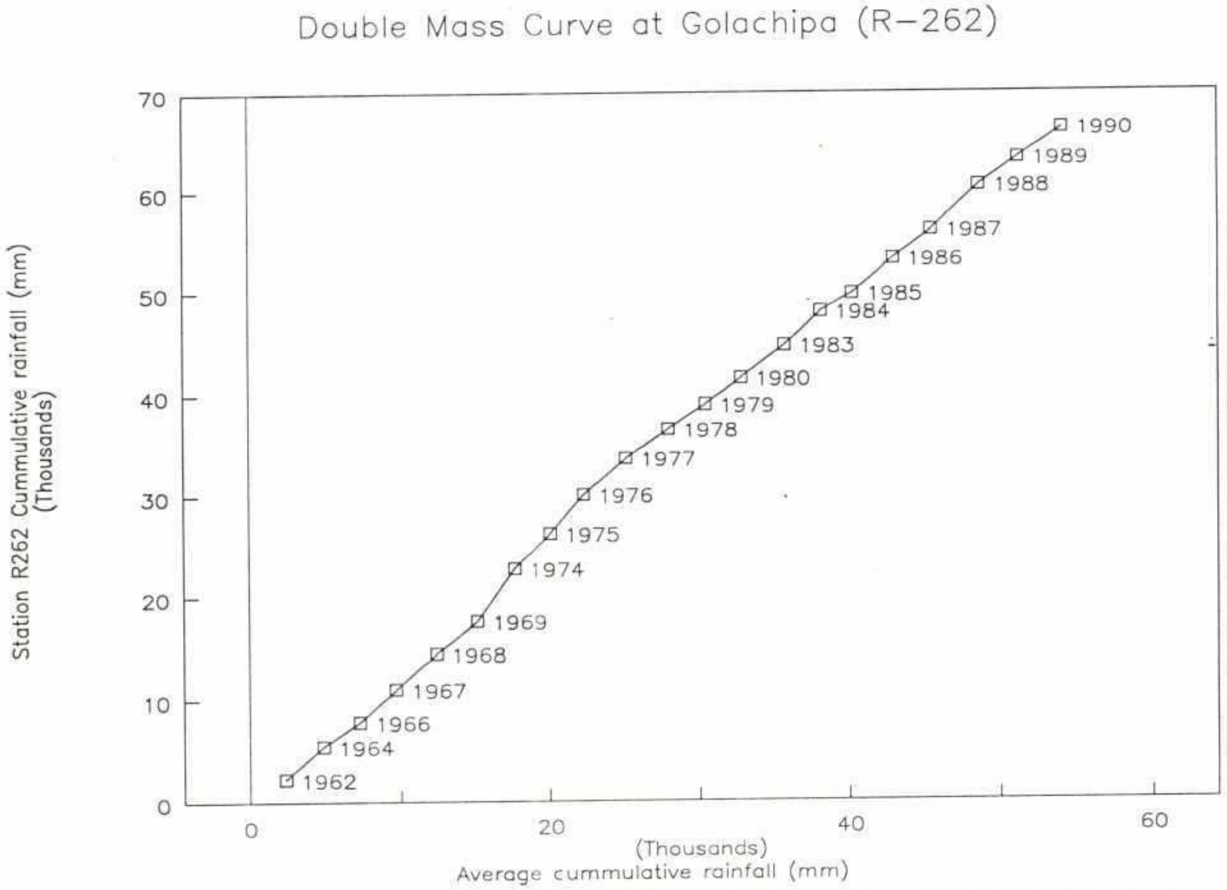
Table 3.14

Comparison of Long Term and Recent Annual Rainfall

Station Number Station Name	R-501 Bagerhat		R-258 Barisal		R-406 Faridpur		R-456 Jessore		R-510 Khulna		R-019 Kushtia		R-267 Pirojpur		R-518 Satkhira	
	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data	Long term data	Recent data
Years of Data	53	20	75	26	70	21	70	27	73	25	59	29	68	26	76	27
Mean	1894	2147	2176	2191	1870	1930	1674	1738	1730	1794	1617	1523	2133	2094	1760	1840
Std Dev	462	552	387	406	341	324	317	379	310	328	381	313	484	462	364	401
Skew	1.88	1.90	0.63	0.50	0.08	-0.10	0.15	-0.20	0.44	0.00	0.46	0.80	0.46	0.10	0.41	0.30
Kurtosis	6.87	4.50	-0.16	-0.60	-0.86	-1.00	-0.79	-1.20	-0.07	-1.20	-0.03	0.80	-0.17	-0.80	-0.55	-0.90
Minimum	1149	1490	1461	1613	1286	1339	1046	1046	1204	1299	846	1024	1223	1223	1188	1215
Maximum	4056	4056	3163	3163	2636	2561	2402	2402	2689	2426	2622	2470	3398	3060	2661	2661
Lower cutoff	731	1158	1110	1037	666	895	657	478	868	704	540	642	1055	975	736	981
Lower fourth	1588	1816	1890	1869	1539	1629	1401	1372	1499	1495	1310	1275	1853	1775	1459	1555
Median	1819	2118	2089	2102	1892	1995	1685	1810	1721	1903	1604	1489	2086	2102	1741	1804
Upper fourth	2160	2254	2410	2423	2121	2118	1897	1968	1920	2023	1824	1696	2386	2309	1941	1938
Upper cutoff	3017	2912	3190	3255	2994	2852	2641	2862	2552	2814	2595	2329	3184	3109	2664	2512
Outliers	4056	4056							2689		2622	2470	3316			2661
Outliers													3398			
% diff in mean		13.3		0.7		3.2		3.8		3.7		-5.8		-1.8		4.5
% diff in median		16.5		0.6		5.4		7.4		10.6		-7.2		0.8		3.6

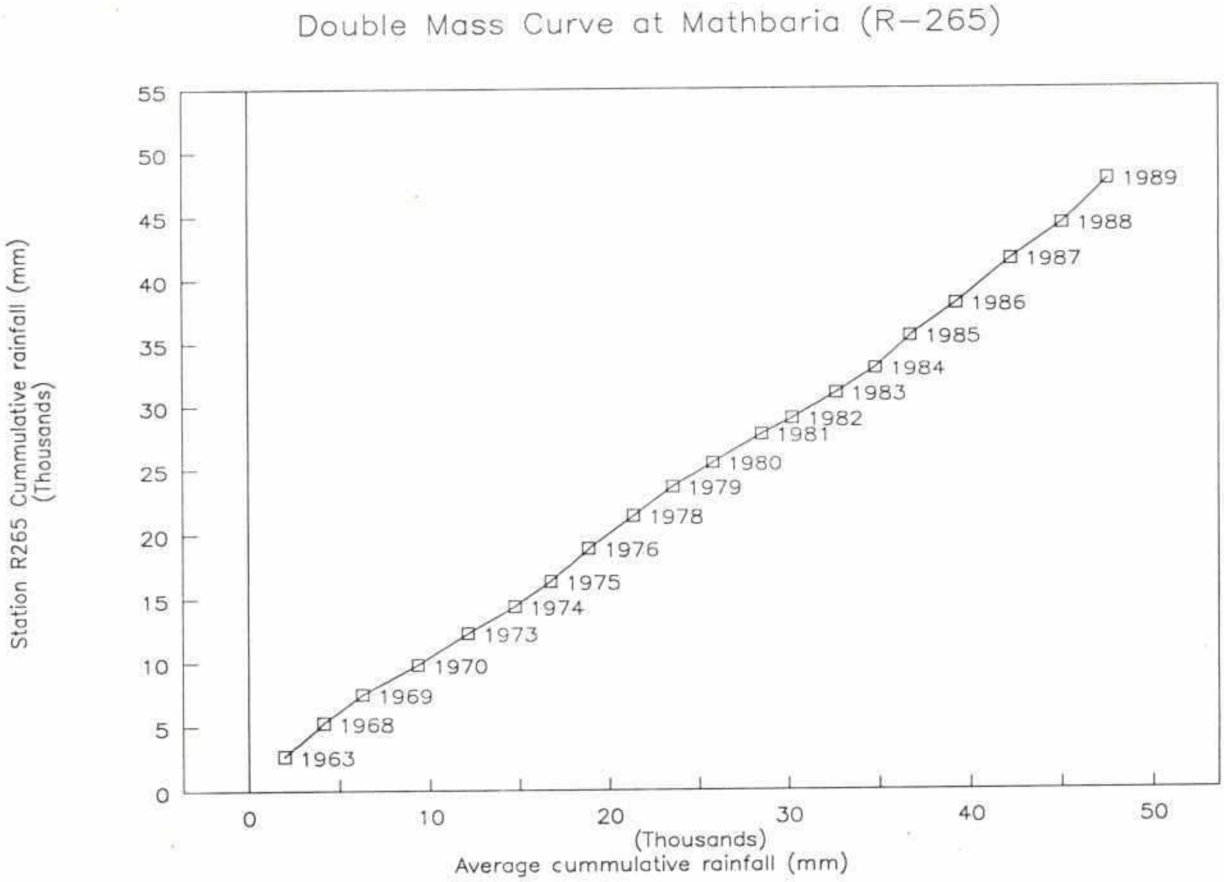
Figure 3.1

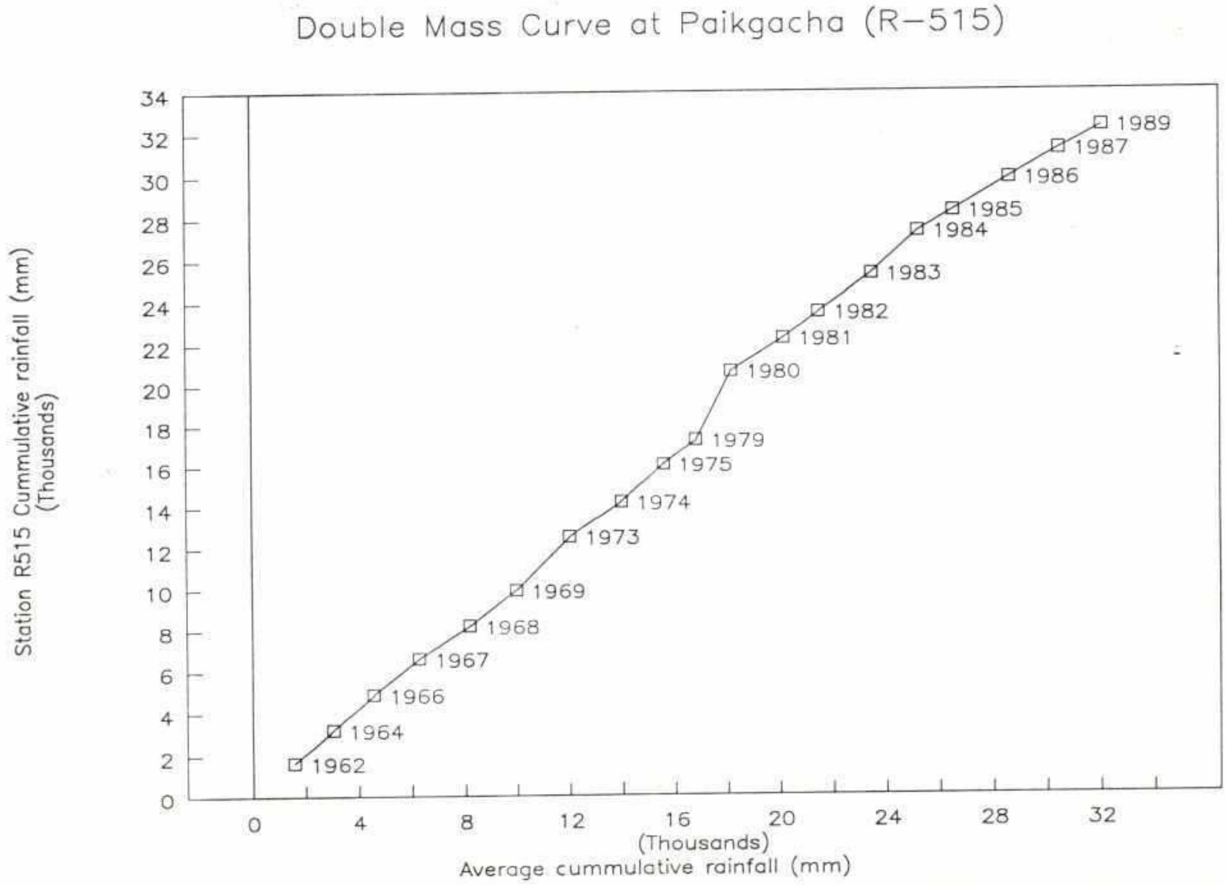




Double Mass Curve at Banaripara and Golachipa

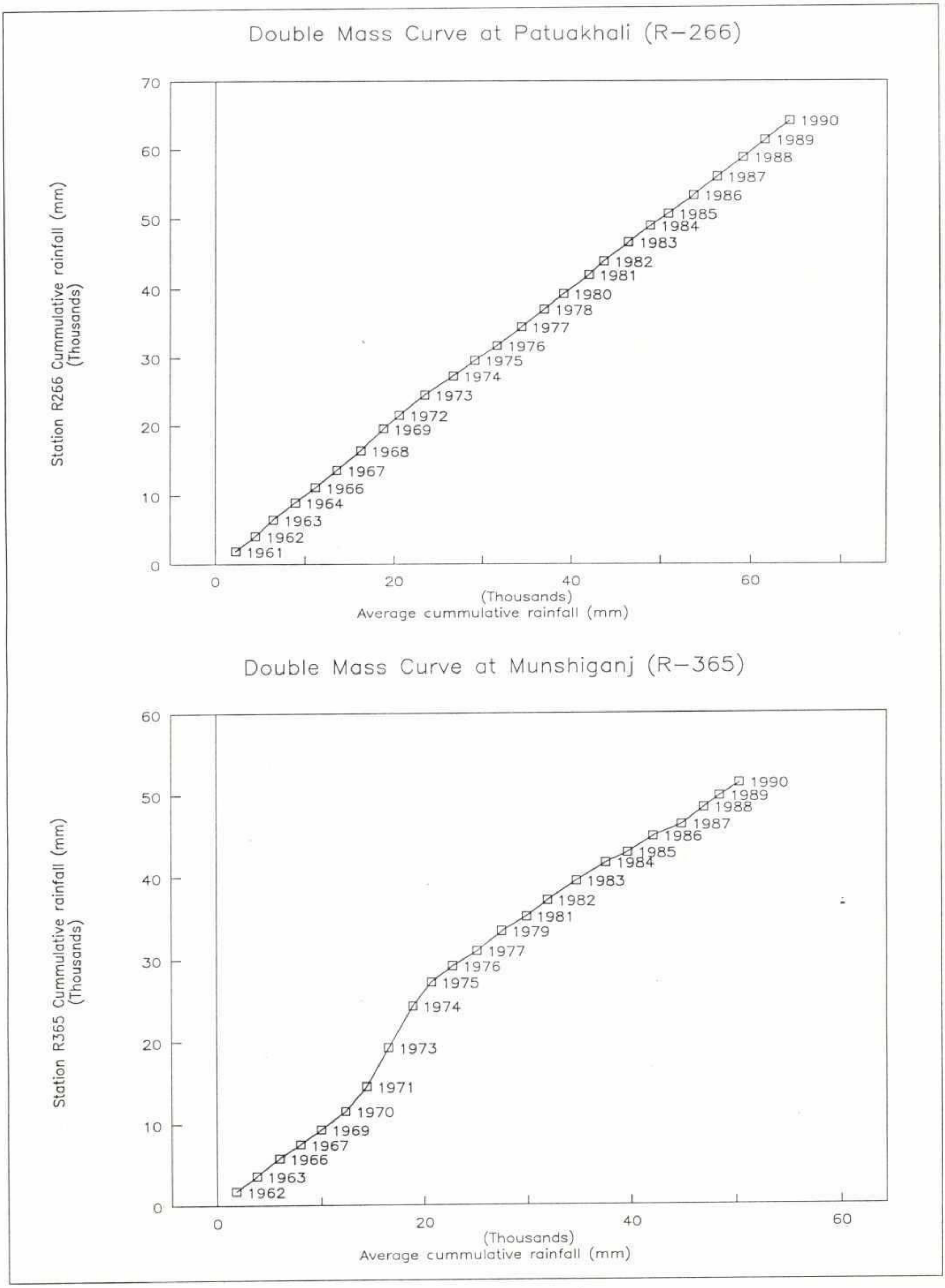
Figure 3.2





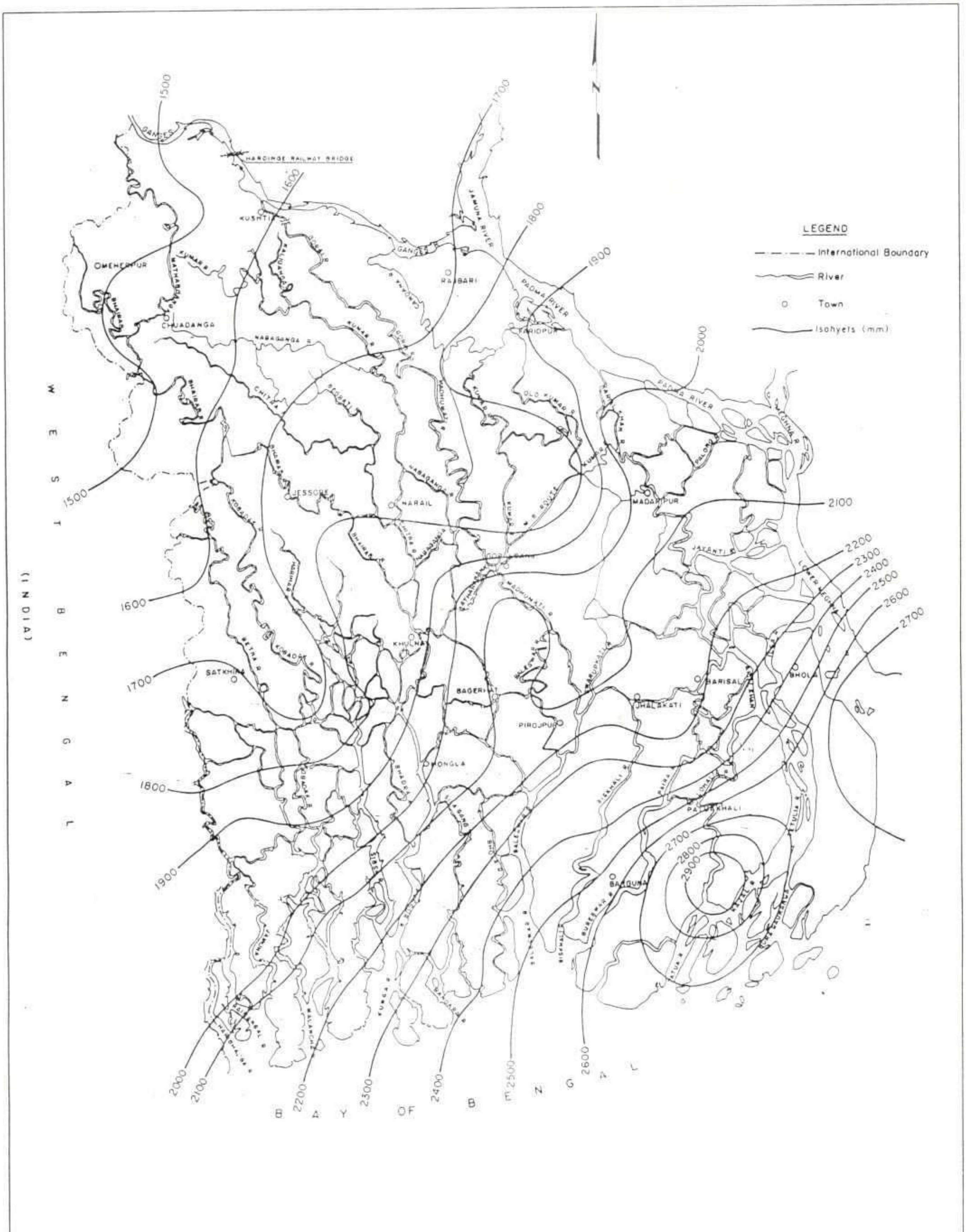
Double Mass Curve at Mathbaria and Paikgacha

Figure 3.3



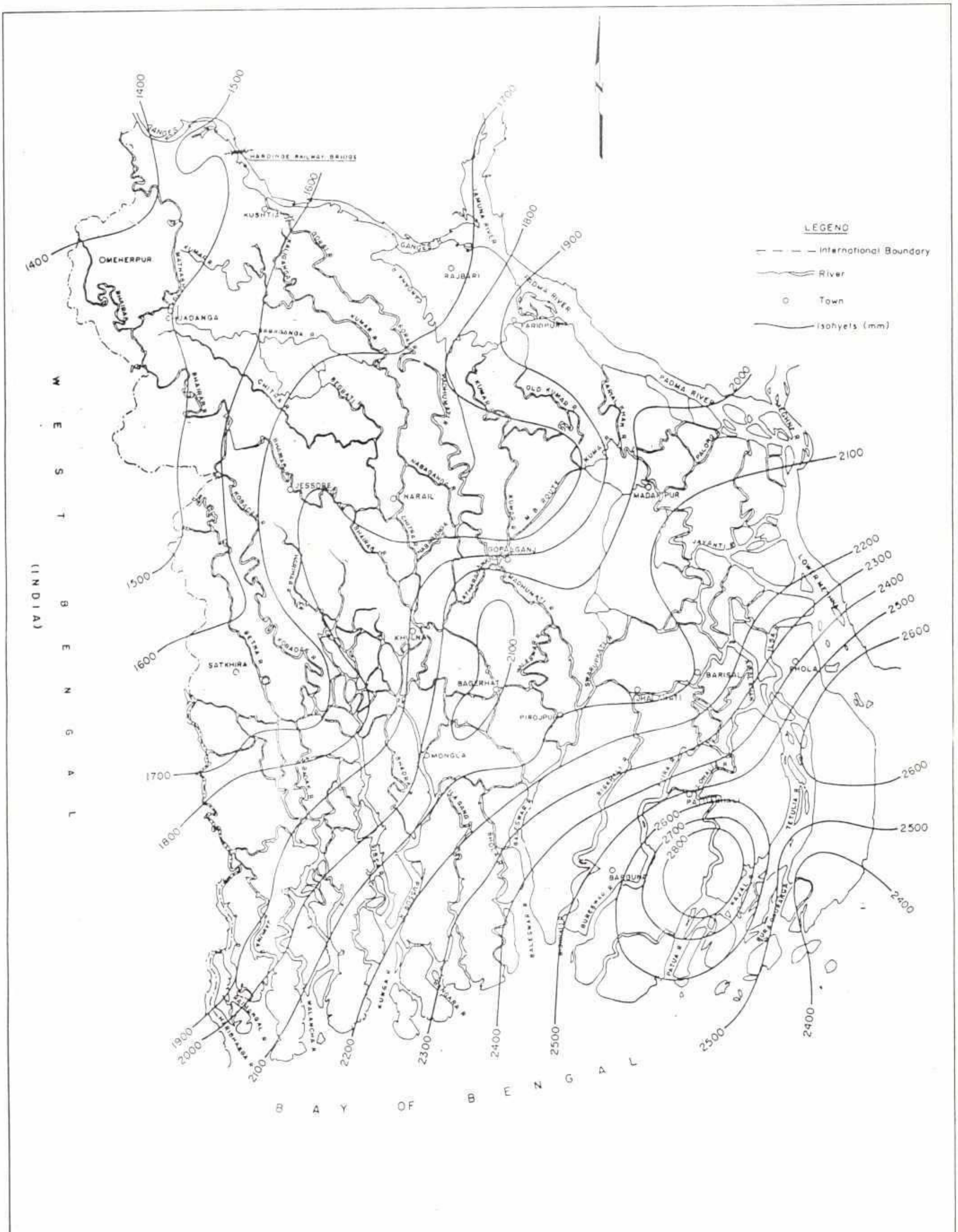
Double Mass Curve at Patuakhali and Munshiganj

Figure 3.4

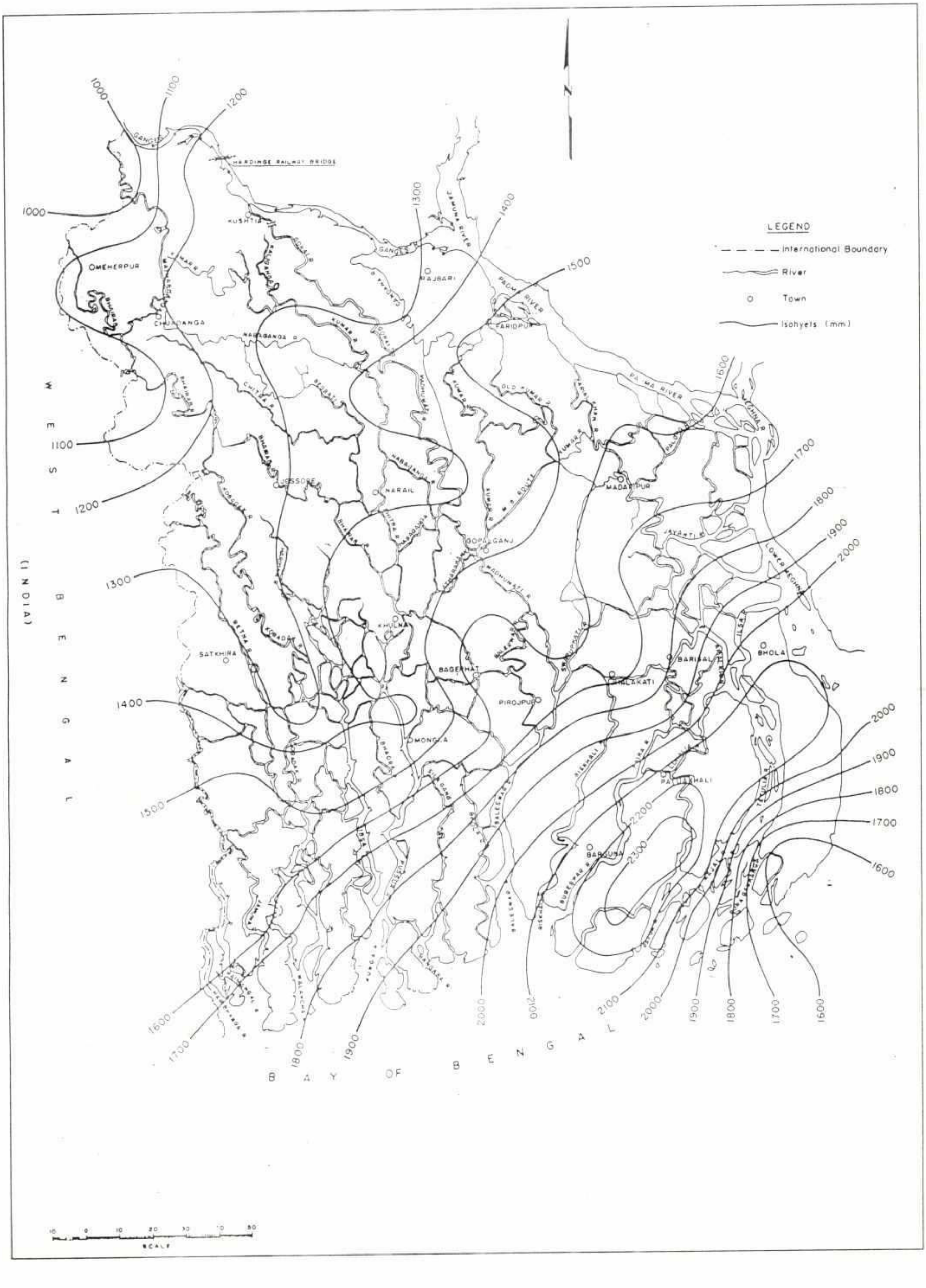


Mean Annual Rainfall

Figure 3.5

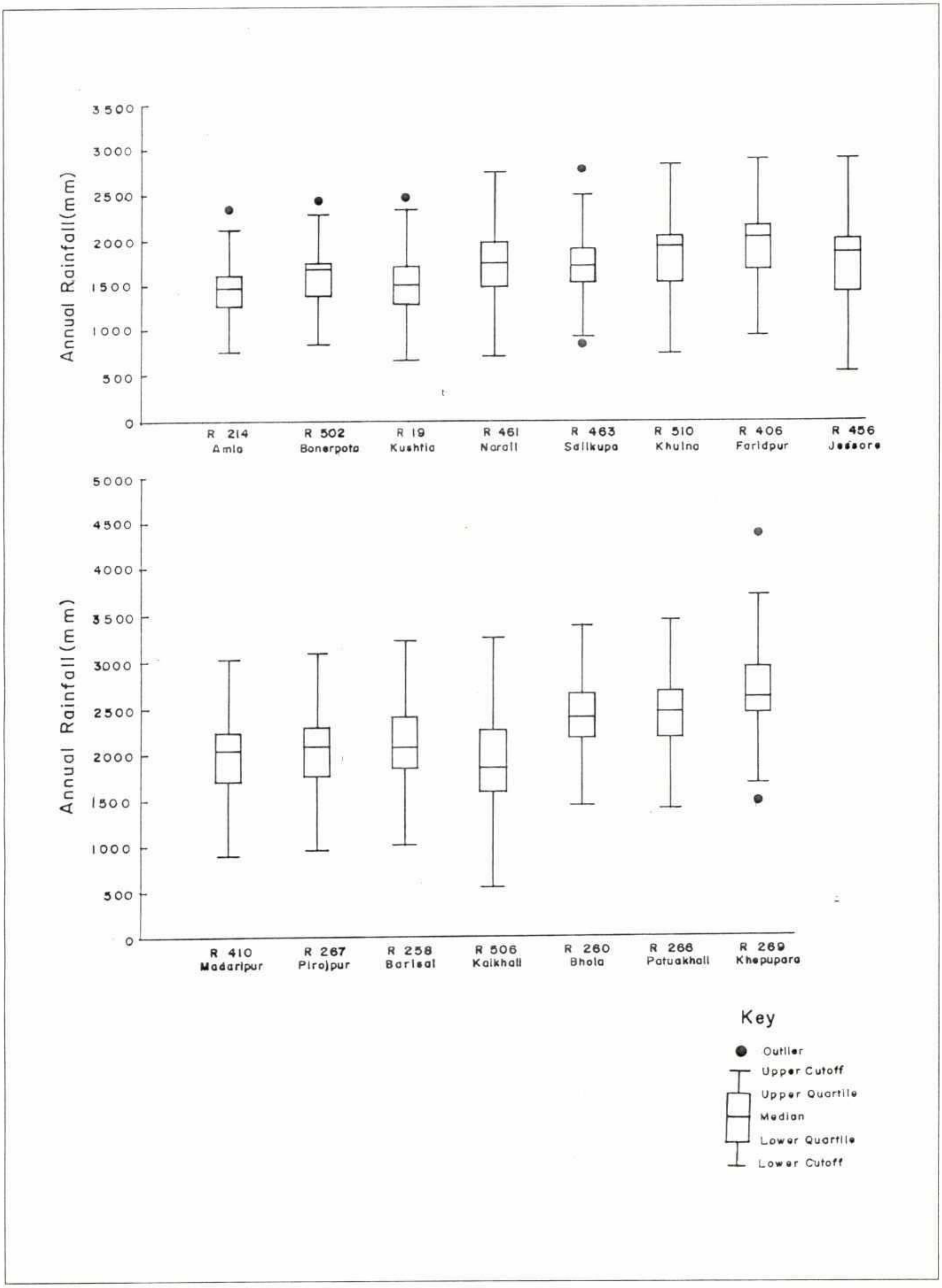


Median Annual Rainfall



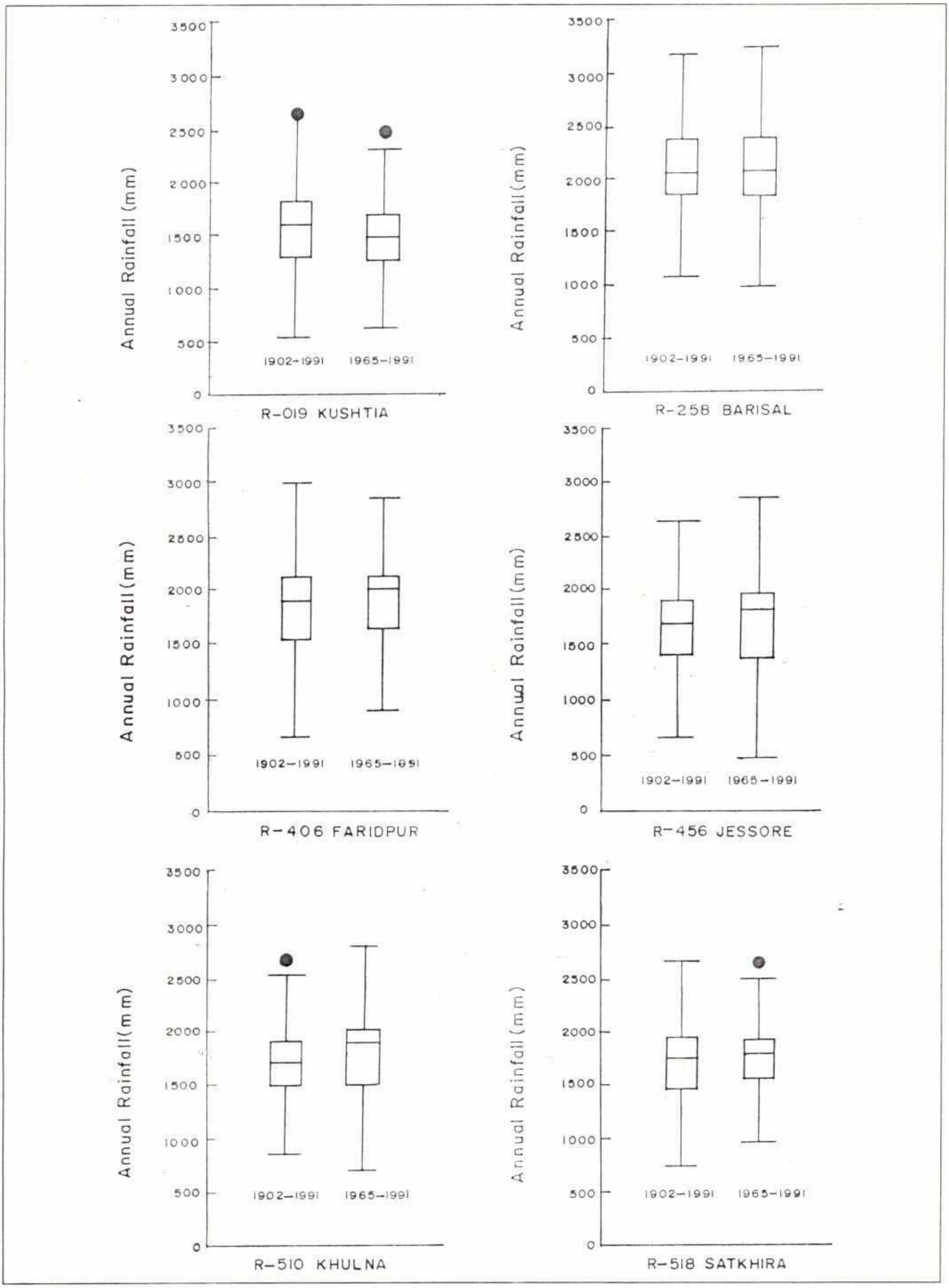
80% Probable Annual Rainfall

Figure 3.7



Box-Plots of Annual Rainfall

Figure 3.8



Comparison of Long Term and Recent Annual Rainfall

4 WATER LEVELS

4.1 Data Availability

Water levels are measured or have been measured at over 90 stations by the BWDB in the study area. A further 30 stations are located on the main rivers bordering the region. In addition to the BWDB, BIWTA also maintains water level gauges at about 25 stations in the area, some of which are equipped with automatic recorders. The SWMC have also either upgraded or installed some gauges for their use. The data at these stations however is for a short duration only. Water level gauges in the region are listed in Table 4.1 and their locations are shown in Figure 4.1.

Water level data is generally available for the period from 1965 to 1989. As explained in the Inception report and pointed out by the CAT mission in their report of December 1991, the region has been characterised by considerable changes over the years due to erosion/siltation and changing channel patterns. Whilst some insight may be gained by comparison of the historical levels with the results of long term simulation, they are of limited use as predictors for future development scenarios. Data has therefore been collected at selected stations only as shown in Tables 4.2 and 4.3.

4.2 Data Verification and Analysis

Water level data was checked for errors by plotting individual years and identifying inconsistencies and erroneous daily values. Basic statistical analysis was also done to identify outliers. Inconsistent data was rejected or where appropriate it was corrected using hydrological judgement. Annual peak water levels were observed to be a result of a gradual build up and are therefore less likely to be subject to erroneous daily readings. However as pointed out by FAP-25 in their Draft Main Report the single most important error is the shifting of gauges during the flood season without properly connecting the datum to the bench mark. This type of error is difficult to detect and correct and is beyond the scope of this study. Reported annual peaks have therefore not been corrected. Water level data on the main rivers and in the tidal areas was collected from FAP-25 who have carried out extensive checks.

Water levels in the tidal areas are reported as a pair of high and low water levels corresponding to high and low tide. Hourly readings were not available and in the absence of such data, the mean daily water level has been taken as the mean of the reported high and low water values.

Frequency analysis has been carried out for the annual peaks at non-tidal gauging stations. The Gumbel and Extreme Value Type III distributions were fitted to the data and the distribution which gave the best fit for events at higher return periods was chosen for that station. Other distributions were not assessed at this stage, but may be considered during the feasibility studies. Whilst recognizing the fact that peak water level data above bankful stage may belong to a different population as compared to peak levels within bank, it would not be judicious, given the limited data, to assume a mixed population and try and fit a mixed distribution to the data such as a two component extreme value distribution. The number of parameters to be estimated (4 parameters) would be disproportionately large compared to the sample sizes (approximately 20).

Frequency analysis plots at selected stations are shown in Figures 4.2 to 4.11. Location invariant plotting positions were used and the confidence limits were computed using the Bootstrap method, which is a non-parametric Monte Carlo technique for estimating standard errors and confidence intervals. The standard method of moving 1.96 standard errors away in either direction from the estimate relies on asymptotic normality which in extreme value theory is clearly not the case. The Bootstrap method has an added advantage of capturing the error inherent in selecting a model as an approximation rather than assuming as in classical analysis that the data are indeed a random sample from the fitted model, which is unlikely. The results of the frequency analysis are shown in Table 4.4.

The difference between a 2 year and a 100 year event on the main rivers ranges from 0.63 m on the Ganges at Hardinge Bridge to 1.35 m at Baruria. The differences increase on the smaller rivers and range from 1.45 m on the Gorai at Gorai Railway Bridge to more than 2 m on the Mathabanga. The increased differences are partly due to the evidence of trends in the water level records at gauges on the Mathabanga and the data should therefore be treated with caution.

The return periods at these stations for the 1988 flood which was the worst on record is shown in Table 4.5. This ranges from a 19 year event at Hardinge Bridge to a 82 year event at Mawa. Along the Gorai, the 1988 flood has a return period of 20 years at Gorai Railway Bridge and 23 years at Kamarkhali. On the Mathabanga, the 1988 flood had a return period of less than 10 years. A comparison with the FAP-25 results which fitted a Log-Normal distribution to the historical data except at Hardinge Bridge where a Gumbel distribution was fitted with left censoring is also shown in Table 4.5. The return periods for the 1988 flood computed by FAP-25 are of the order of 1 in 50 years along the major rivers except on the Ganges at Hardinge Bridge where it has a return period of 1 in 13 years. On the Gorai, the event had a return period of 17 years at Gorai Railway Bridge and 56 years at Kamarkhali. Figures 4.12 and 4.13 show the 1988 flood levels on the main rivers in comparison with a 1 in 2 year flood level.

A comparison with the FAP-25 results for peak water levels at various return periods is shown in Table 4.6. It can be seen that the difference in the levels predicted on the major rivers for the 1 in 100 year event using different distributions is of the order of -0.05 m. Along the Gorai however, the differences are upto +0.29 m at Kamarkhali for the 1 in 100 year event. The differences are smaller for levels predicted at lesser return periods which may be the criteria for embankment design along the secondary rivers.

The annual peak water level data at non-tidal stations was checked for trends using the Armsen test. The test showed no significant trends in the data on the main and secondary rivers. However, the test indicated an increasing trend in the records on Mathabanga at Kazipur, Hatboalia and Darsona. The results are given in Table 4.7. The number of observations in the data set ranged from 18 to 25.

Frequency analysis of peak annual mean water levels at tidal stations was also done and the results are shown in Table 4.8. The mean daily water level at tidal stations was taken as the mean of the reported pairs of high and low water levels at these stations.

The water level station at Choudharyhat on Arial Khan has been treated as a non-tidal station prior to 1984 by BWDB. It is understood from BWDB that the tidal effects were negligible at that time. Daily mean levels taken as the average of five 3-hourly daytime readings (0600 to 1800 hours) have been reported by BWDB. After 1984, the station was treated as a tidal station and a pair of daily readings corresponding to the high and low water levels has been reported. For the purpose of analysis, mean daily water level data for the period prior to 1984 has been combined with the average daily value of the high and low water readings after that period to form a time series at that station.

Trend analysis of maximum mean daily water levels at tidal-stations indicated a decreasing trend for the records at Choudharyhat on Arial Khan. The number of observations in the sample were 25 and the results of the trend analysis are shown in Table 4.9. Annual mean and maximum tidal ranges at tidal stations were also checked for trends and the results are shown in Tables 4.10 and 4.11. All stations except Madaripur and Daulat Khan indicated an increasing trend in the mean tidal range. Similar trend analysis of maximum tidal ranges indicated an increasing trend in the data at Dumuria, Rayenda, Chalna, Mongla and Chandpur. The results should however be interpreted with caution as the analysis was based on short records, generally of the order of 15 observations. The increasing trend in the maximum tidal range at Dumuria, Rayenda, Chalna, and Mongla would suggest narrowing of the channels due to siltation, but this is not conclusive.

Table 4.1

List of Hydrometric Stations

Sl.No.	Stn.No.	Station Name
1	1	Alipur Khal, Daratana-Ghasiakhali at Bagerhat
2	2	Alipur Khal, Daratana-Ghasiakhali at Kumarkhali
3	3	Anderson Khal at Brahmanbaria Railway Bridge
4	3 A	Anderson Khal at Brahmanbaria Railway Bridge
5	4	Arial Khan River at Kalikapur
6	4 A	Arial Khan River at Arial Khan
7	5	Arial Khan River at Madaripur
8	6	Bahia River at Surma Offtake
9	18	Barisal-Buriswar River at Barisal
10	18.1	Barisal-Buriswar River at Bakerganj
11	19	Barisal-Buriswar River at Mirzaganj
12	20	Barisal-Buriswar River at Astali
13	21	Begabati River at Arpara
14	22	Betna - Kholpetua River at Navaran
15	23	Betna - Kholpetua River at Kalaroa
16	24	Betna - Kholpetua River at Benerpota
17	25	Betna - Kholpetua River at Chapra
18	26	Betna - Kholpetua River at Pratabnagar
19	28	Bhadra River at Dumuria
20	29	Bhadra River at Suterkhali
21	30	Bhairab River (Lower) at Afraghat
22	31	Bhairab River (Lower) at Gilatala
23	37	Biskhali River at Jhalakati
24	38	Biskhali River at Basna
25	39	Biskhali River at Patharghata
26	50.6	Brahmaputra-Jamuna River at Teota
27	51	Chandana River/Arkandi Khal at Ramdia
28	51 A	Chandana River at Chandana Rwy. Bridge
29	52	Chandana River/Arkandi Khal at Ghoshpur
30	54	Chitra River at Kaliganj
31	55	Chitra River at Khatursagura
32	55 A	Chitra River at Ratnerdanga
33	56	Chitra River at Gobrahat
34	56.1	Chitra River at Narail (road crossing)
35	89.5	Ganges River at Golapnagar
36	89.9 L	Ganges River at Paksey Transit
37	90	Ganges River at Hardinge Bridge
38	91	Ganges River at Talbaria
39	91.1	Ganges River at Sengram
40	91.2	Ganges River at Mahandrapur
41	91.7 L	Ganges River at Teota
42	91.7 R	Ganges River at Urakanda
43	91.9 L	Ganges River at Baroria Transit
44	91.9 R	Ganges River at Goalundo Transit
45	92	Ganges River at Goalundo
46	92.3 L	Ganges River at Kadamtali

Contd....

Table 4.1

List of Hydrometric Stations

Sl.No.	Stn.No.	Station Name
47	92.3 R	Ganges River at Charshalda
48	93	Padma River at Kusum Hati
49	93.4 L	Padma River at Jashida
50	93.4 R	Padma River at Chrjanajat
51	93.5 L	Padma River at Bhagyakul
52	93.5 R	Padma River at Bateswar
53	93.6 L	Padma River at Wari
54	94	Padma River at Tarapsha
55	95	Ganges River at Sureswar
56	99	Gorai River at Gorai Rwy. Bridge
57	100	Gorai River at Janipur
58	101	Gorai River at Kamarkhali
59	101.5	Gorai River at Kamarkhali (Transit)
60	102	Gorai Madhumati River at Bhatiapara
61	103	Gorai Madhumati River at Bardia
62	104	Gorai Madhumati River at Manikdaha
63	105	Gorai Madhumati River at Atharabanki River
64	106	Gorai Madhumati River at Patghati
65	107	Gorai Madhumati River t Pirojpur
66	108	Gorai-Madhumati-Baleswar River at Charduani
67	160	Kobadak River at Andulbaria
68	161	Kobadak River at Tahirpur
69	162	Kobadak River at Jhikargacha
70	163	Kobadak River at Tala Magura
71	164	Kobadak River at Chandkhali
72	165	Kobadak River at Kobadak Forest Office
73	167	Kumar River at Ibrahimdi
74	168	Kumar River at Faridpur
75	169	Kumar River at Muzurdia
76	170	Kumar River at Bhanga
77	171	Kumar River at Geraganj
78	183	Lohalia River at Kaitpara
79	184	Lohalia River at Patuakhali
80	185	Lohalia River at Golachipa
81	187	Lower Kumar River at Takerhat
82	188	Lower Kumar River at Rajoir
83	189	Lower Kumar at Asgram
84	190	Lower Kumar at Mustafapur
85	191	Lower Kumar at Charmuguria
86	193	Madaripur Beel Route River at Kabirajpur
87	194	Madaripur Beel Route River at Fatehpur
88	195	Madaripur Beel Route at Jalipar
89	196	Madaripur Beel Route at Satpar
90	197	Madaripur Beel Route at Tentulia
91	198	Madaripur Beel Route at Haridaspur
92	205	Mathabhanga River at Kazipur

Contd....

Table 4.1

List of Hydrometric Stations

Sl.No.	Stn.No.	Station Name
93	205 A	Mathabhanga River at Insafnagar
94	206	Mathabhanga River at Hatboalia
95	207	Mathabhanga River at Chuadanga
96	208	Mathabhanga River at Darsana
97	215	Nabaganga River at Jhenaidah
98	216	Nabaganga River at Magura
99	216 A	Nabaganga River at Magura
100	217	Nabaganga River at Kalachandpur
101	217 A	Nabaganga River at Lohagora
102	218	Nabaganga River at Bardia
103	219	Nabaganga River at Gazirhat
104	219.2	Nangoora River at Bridge No. 27
105	220	Hilakhi River at Khepupara
106	241	Rupsa-Pussur River at Khulna
107	242	Rupsa-Pussur River at Jalma
108	243	Rupsa-Pussur River at Chalna
109	244	Rupsa-Pussur River at Mongla
110	253	Swarupkati River at Swarupkati
111	254	Satkhira Khal at Satkhira
112	255	Satkhira Khal at Shovonali
113	256	Satkhira Khal at Habraganj
114	258	Sibsa River at Paikgacha
115	259	Sibsa River at Nalianala
116	277	Meghna River at Chandpur
117	277.3	Meghna River at Nilkamal
118	277.5	Meghna River at Charkurulia
119	278	Meghna River at Daulatkhan
120	279	Meghna River at Jajauddin
121	288	Meghna River Offtake im Meghna
122	289	Tentulai River at Dhulia
123	290	Tentulia River at Dasina
124		Pussur River at Hiron Point
125		Pussur River at Sundari Kota
126		Pussur River at Mongla
127		Nilganj River at Khepupara
128		Meghna River at Char Ramdaspur
129		Barisal River at Barisal
130		Dakatia River at Chandpur
131		Lohalia River at Galachipa
132		Laukati River at Patuakhali
133		Jeffort Point (vs. Hiron Point)
134		Tiger Point (vs. Hiron Point)
135		Patua @ Rabnabad Channel (vs. Hiron Point)
136		Jaymon Reach (vs. Hiron Point)
137		Ghasiakhal (vs. Hiron Point)
138		Betibunia (vs. Hiron Point)
139		Chalna Reach (vs. Hiron Point)
140		Dasmonia (vs. Char Ramdaspur)

Table 4.2

Availability of Daily Water Level Data at Non-Tidal Stations

Sl.No.	Station Name	Station No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Bahadurabad	46.9 L	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
2	Baruria	91.9 L	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
3	Chandana Rly Bridge	51 A		C	C	C	C	C				C	C	C	C													
4	Darsona	208	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
5	Geraganj	171	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C			
6	Goalanda Transit	91.9 R	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C		C	C				C	C	
7	Gorai Rly Bridge	99	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C			C	C	C	C	
8	Hardinge Bridge	90	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
9	Hatboalia	206	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	
10	Jhikargacha	162	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C								
11	Kamarkhali	101	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
12	Kamarkhali	101.5	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C				C	C	C		
13	Kazipur	205	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
14	Magura	216	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
15	Mawa	93.5 L	C	C	C	C	C			C	C	C		C	C	C	C	C	C	C	C	C		C		C	C	

C Collected

Table 4.3

Availability of Water Level Data at Tidal Stations

Sl.No.	Station Name	Station No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Bagerhat	1				C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C		
2	Bardia	218				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C								
3	Barisal	18																			C	C	C	C	C			
4	Chalna	243				C	C	C		C	C	C	C	C	C			C	C		C							
5	Chandpur	277	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
6	Chowdhuryhat (Arial Khan)	4 A	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
7	Dasmonia	290	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	
8	Daulat Khan	278	C	C	C	C	C	C		C	C	C	C	C	C	C	C				C	C	C	C	C	C	C	
9	Dumuria	28				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C								
10	Golachipa	185	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	
11	Madaripur	5	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
12	Mongla	244	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
13	Paikgacha	258			C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
14	Patherghata	39	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
15	Patuakhali	184				C	C	C	C	C	C	C	C	C		C	C	C	C		C	C		C				
16	Rayenda	107.2			C	C	C	C		C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C		
17	Sarupkati	253				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C				

C Collected C Data in 'Non-Tidal' Form.

Table 4.4

Frequency Analysis of Historical Maximum Mean Daily Water Levels at Non–Tidal Stations (m) (1965 – 1989)

Station No.	Station Name	River	Return Period (years)							Fitted	Difference (m)
			2	5	10	20	50	100	200	Distribution	100yr – 2yr
46.9L	Bahadurabad	Brahmaputra	19.75	20.03	20.22	20.40	20.63	20.81	20.98	EV1	1.06
51A	Chandana	Chandana	10.56	11.15	11.54	11.91	12.40	12.76	13.12	EV1	2.20
90	Hardinge Bridge	Ganges	14.34	14.67	14.80	14.88	14.94	14.97	15.00	EV1	0.63
91.9L	Baruria	Ganges	8.17	8.54	8.78	9.01	9.30	9.52	9.74	GEV3	1.35
93.5L	Mawa	Padma	5.94	6.25	6.46	6.66	6.92	7.11	7.31	EV1	1.17
99	Gorai Rly Bridge	Gorai–Madhumati	12.76	13.15	13.41	13.66	13.97	14.21	14.45	EV1	1.45
101	Kamarkhali	Gorai–Madhumati	8.81	9.08	9.26	9.44	9.66	9.83	10.00	EV1	1.02
162	Jhikargacha	Kobadak	3.62	4.42	4.87	5.26	5.71	6.00	6.27	GEV3	2.38
171	Geraganj	Kumar	6.71	7.58	8.17	8.72	9.45	9.99	10.53	EV1	3.28
205	Kazipur	Mathabanga	15.00	15.96	16.41	16.75	17.08	17.27	17.42	GEV3	2.27
206	Hatboalia	Mathabanga	12.23	13.49	14.33	15.13	16.17	16.95	17.73	EV1	4.72
208	Darsona	Mathabanga	8.34	9.28	9.90	10.50	11.27	11.85	12.42	EV1	3.51

Table 4.5

Return Periods for the 1988 Flood Level

Station No.	Station Name	River	1988 Flood Level (m)	Return Period	Fitted Distribution	FAP 25 Return Period	Results Fitted Distribution
4A	Choudharyhat	Arial Khan	7.55	48	GEV3	50.64	LN3
46.9L	Bahadurabad	Brahmaputra	20.61	45	EV1	59.52	LN3
90	Hardinge Bridge	Ganges	14.87	19	GEV3	12.98	GEV3
91.9L	Baruria	Ganges	9.35	58	GEV3	54.40	LN3
93.5L	Mawa	Padma	7.06	82	EV1	58.01	LN3
99	Gorai Rly Bridge	Gorai-Madhumati	13.65	20	EV1	17.46	LN3
101.5	Kamarkhali Transit	Gorai-Madhumati	9.47	23	EV1	56.39	LN3
205	Kazipur	Mathabanga	16.24	7	GEV3		
208	Darsona	Mathabanga	9.82	9	EV1		

Table 4.6

Comparison of Water Level Frequency Results

River	Brahmaputra			Ganges			Ganges			Padma			Gorai-Madhumati			Gorai-Madhumati		
Station Name	Bahadurabad			Hardinge Bridge			Baruria			Mawa			Gorai Rly Bridge			Kamarkhali		
Station No.	46.9L			90			91.9L			93.5L			99			101		
Fitted Distribution	EV1	LN3	Diff	GEV3	EV1	Diff	GEV3	LN3	Diff	EV1	LN3	Diff	EV1	LN3	Diff	EV1	LN3	Diff
Return Period																		
2	19.75	19.78	-0.03	14.34	*	-	8.17	8.14	0.03	5.94	5.91	0.03	12.76	12.91	-0.15	8.81	8.86	-0.05
5	20.03	20.04	-0.01	14.67	*	-	8.54	8.51	0.03	6.25	6.22	0.03	13.15	13.30	-0.15	9.08	9.10	-0.02
10	20.22	20.21	0.01	14.80	*	-	8.78	8.76	0.02	6.46	6.44	0.02	13.41	13.51	-0.10	9.26	9.23	0.03
50	20.63	20.57	0.06	14.94	14.97	-0.03	9.30	9.32	-0.02	6.92	7.01	-0.09	13.97	13.88	0.09	9.66	9.46	0.20
100	20.81	20.73	0.08	14.97	15.02	-0.05	9.52	9.57	-0.05	7.11	7.27	-0.16	14.21	14.01	0.20	9.83	9.54	0.29

* FAP 25 analysis was done using left censoring and hence comparision of peak levels at lower return periods would be misleading.

EV1 Gumbel
GEV3 General Extreme Value Type III
LN3 3 Parameter Log Normal

Table 4.7

Trend Analysis of Annual Maximum Mean Water Levels at Non–Tidal Stations (1965 – 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
46.9L	Bahadurabad	Brahmaputra	0.3036	0.619	25
90	Hardinge Bridge	Ganges	1.1911	0.883	25
91.9L	Baruria	Ganges	0.4437	0.671	25
93.5L	Mawa	Padma	0.7331	0.768	22
99	Gorai Rly Bridge	Gorai–Madhumati	0.9587	0.831	22
101.5	Kamarkhali Transit	Gorai–Madhumati	1.3733	0.915	23
162	Jhikargacha	Kobadak	0.8333	0.798	18
171	Geraganj	Kumar	0.3169	0.624	23
205	Kazipur	Mathabanga	1.7816	0.963 *	21
206	Hatboalia	Mathabanga	1.9175	0.972 *	22
208	Darsona	Mathabanga	2.7070	0.997 *	22

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 4.8

Frequency Analysis of Historical Maximum Mean Daily Water Levels at Tidal Stations (m) (1965 – 1989)

Station No.	Station Name	River	Return Period (years)							Fitted	Difference (m)
			2	5	10	20	50	100	200	Distribution	100yr – 2yr
4A	Choudhuryhat	Arial Khan	6.42	6.92	7.17	7.36	7.56	7.68	7.77	GEV3	1.26
5	Madaripur	Arial Khan	4.29	4.75	5.06	5.35	5.73	6.01	6.29	EV1	1.72
39	Pathergatha	Bishkali	1.44	1.76	1.97	2.17	2.44	2.64	2.83	EV1	1.20
107.2	Rayenda	Gorai–Madhumati	2.28	2.61	2.82	3.03	3.30	3.50	3.70	EV1	1.22
185	Golachipa	Lohalia	2.00	2.35	2.58	2.80	3.08	3.30	3.51	EV1	1.30
218	Bardia	Nabaganga	3.90	4.21	4.41	4.60	4.86	5.04	5.23	EV1	1.14
243	Chalna	Rupsa–Pussur	1.71	1.99	2.18	2.35	2.58	2.76	2.93	EV1	1.05
244	Mongla	Rupsa–Pussur	1.49	2.01	2.36	2.69	3.12	3.44	3.76	EV1	1.95
258	Paikgacha	Sibsa	1.56	1.97	2.24	2.49	2.83	3.08	3.33	EV1	1.52
277	Chandpur	Surma–Meghna	4.43	4.69	4.86	5.02	5.23	5.39	5.55	EV1	0.96
278	Daulat Khan	Surma–Meghna	2.66	3.00	3.23	3.44	3.72	3.93	4.14	EV1	1.27
290	Dasmonia	Tentulia	2.24	2.43	2.53	2.62	2.72	2.78	2.83	GEV3	0.54

Table 4.9

Trend Analysis of Annual Maximum Mean Water Levels at Tidal Stations (1965 – 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
4A	Choudharyhat	Arial Khan	1.8450	0.967 *	25
5	Madaripur	Arial Khan	0.6306	0.736	25
39	Pathergatha	Bishkali	0.1240	0.549	24
107.2	Rayenda	Gorai–Madhumati	0.6945	0.756	21
185	Golachipa	Lohalia	1.3205	0.907	23
218	Bardia	Nabaganga	0.6928	0.756	15
243	Chalna	Rupsa–Pussur	0.7931	0.786	13
244	Mongla	Rupsa–Pussur	1.2091	0.887	27
258	Paikgacha	Sibsa	0.5737	0.717	21
277	Chandpur	Surma–Meghna	0.8397	0.799	19
290	Dasmonia	Tentulia	0.7923	0.786	23

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 4.10

Trend Analysis of Annual Mean Tidal Range (1965 - 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
5	Madaripur	Arial Khan	0.1399	0.556	19
39	Patherghata	Bishkhali	2.5981	0.995 *	8
107.2	Rayenda	Baleswar	2.5951	0.995 *	17
185	Golachipa	Lohalia	1.7518	0.960 *	14
243	Chalna	Rupsa-Pussur	3.8436	1.000 *	13
244	Mongla	Rupsa-Pussur	3.1966	0.999 *	16
277	Chandpur	Meghna	2.3480	0.991 *	17
278	Daulat Khan	Meghna	1.4013	0.919	11
290	Dasmonia	Tentulia	3.3555	1.000 *	13

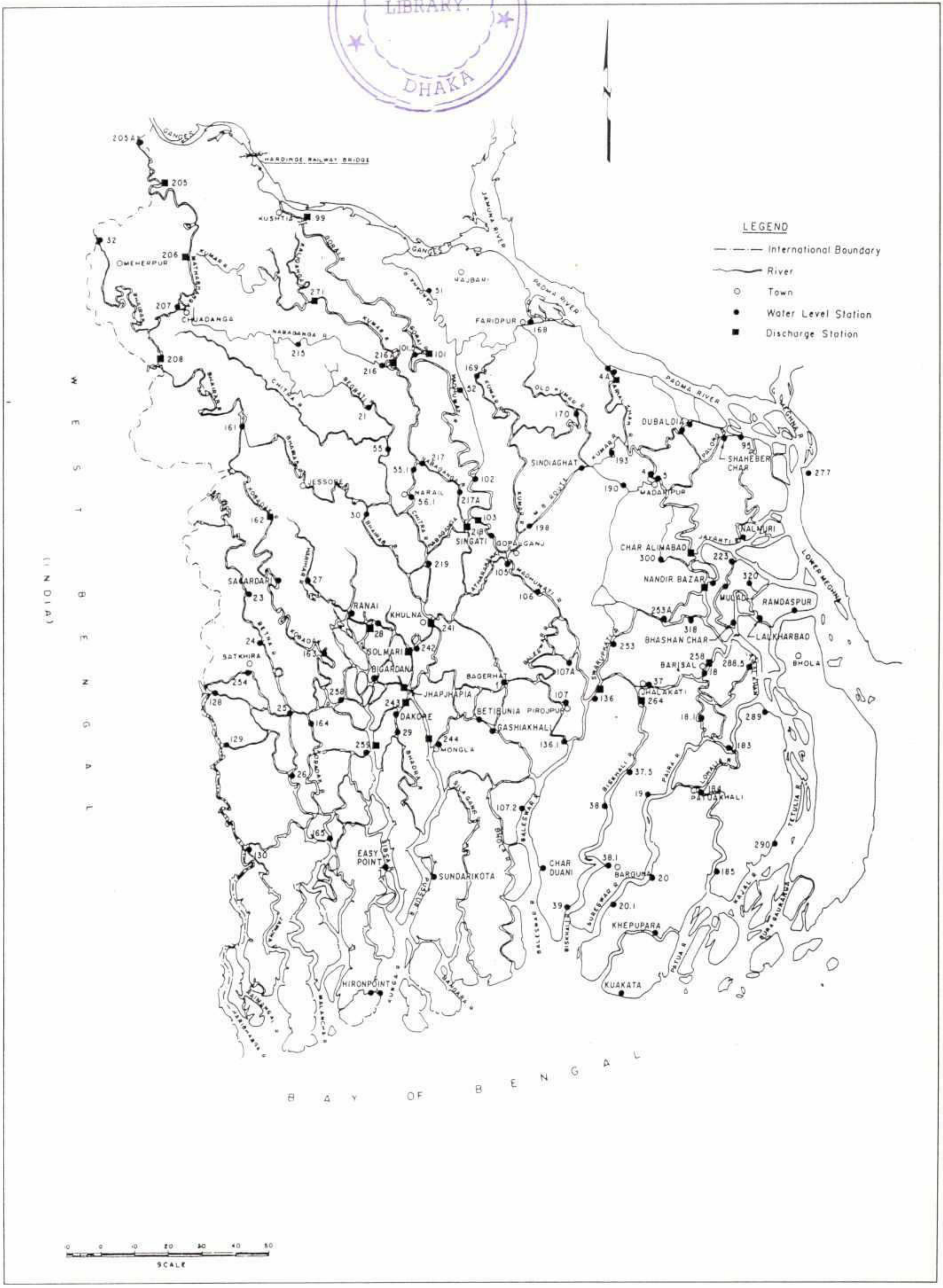
Table 4.11

Trend Analysis of Annual Maximum Tidal Range (1965 - 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
5	Madaripur	Arial Khan	1.4694	0.929	19
28	Dumuria	Bhadra	3.3651	1.000 *	15
39	Patherghata	Bishkhali	0.1237	0.549	8
107.2	Rayenda	Baleswar	3.0071	0.999 *	17
185	Golachipa	Lohalia	0.6569	0.744	14
218	Bardia	Nabaganga	1.9795	0.976 *	15
243	Chalna	Rupsa-Pussur	2.3793	0.991 *	13
244	Mongla	Rupsa-Pussur	2.7464	0.997 *	16
253	Swarupkhati	Swarupkhati	1.4234	0.923	14
258	Paikgacha	Sibsa	4.8013	1.000 *	21
277	Chandpur	Meghna	1.8537	0.968 *	17
278	Daulat Khan	Meghna	0.0000	0.500	11
290	Dasmonia	Tentulia	0.7931	0.786	13

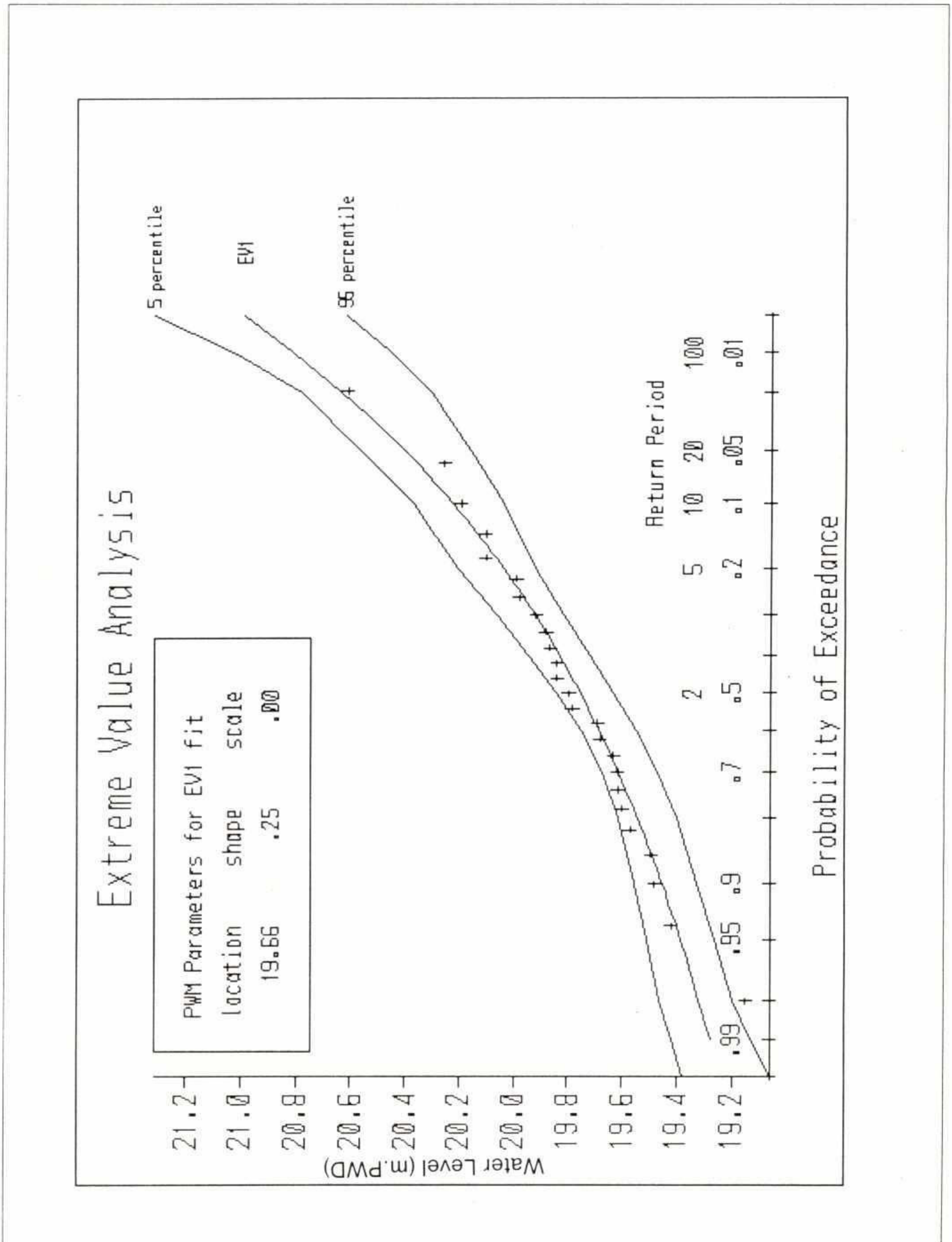
Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Figure 4.1



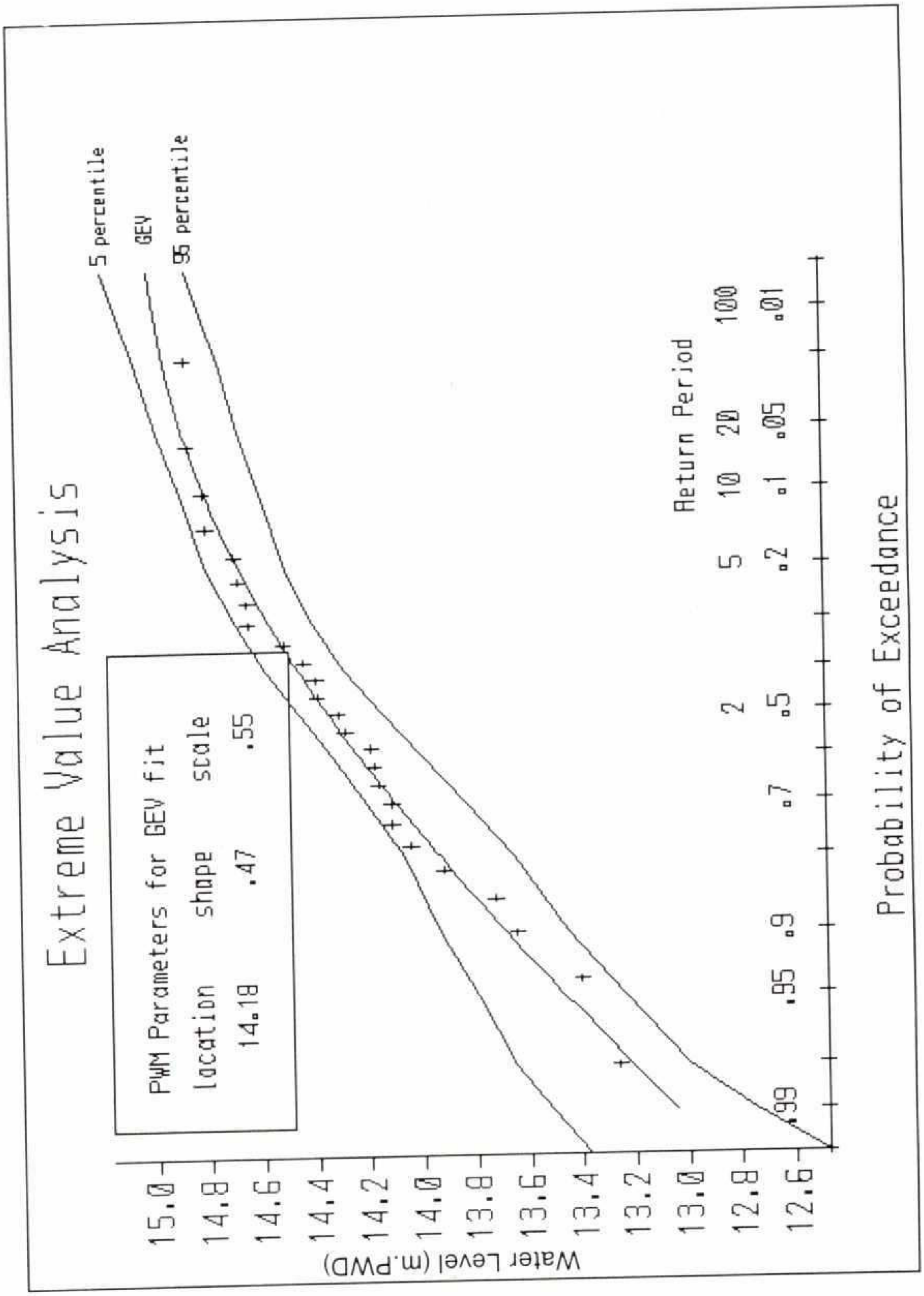
Location of Hydrometric Stations

Figure 4.2



Frequency of Peak Levels - River Brahmaputra at Bahadurabad

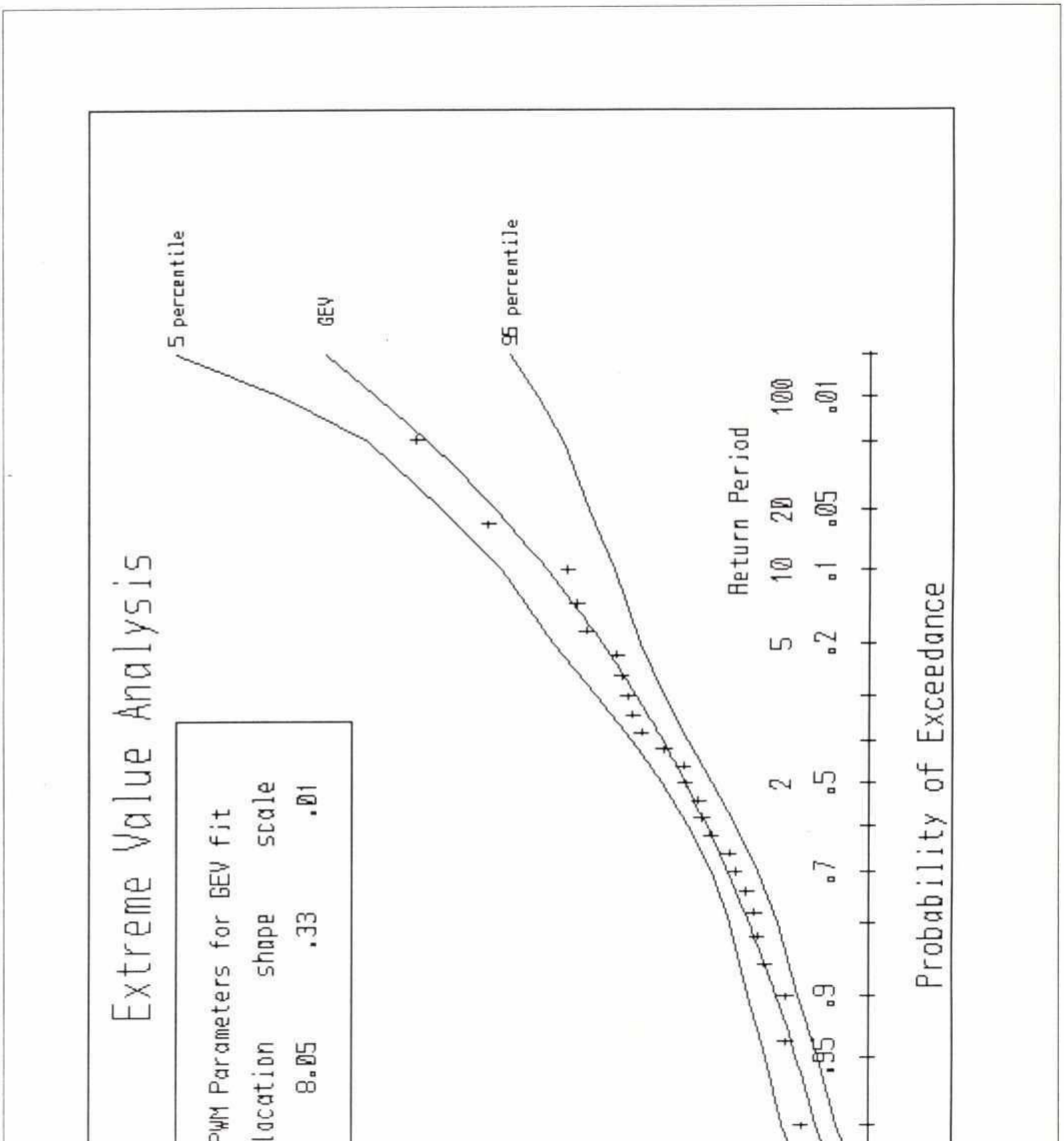
Figure 4.3



Frequency of Peak Levels - River Ganges at Hardinge Bridge

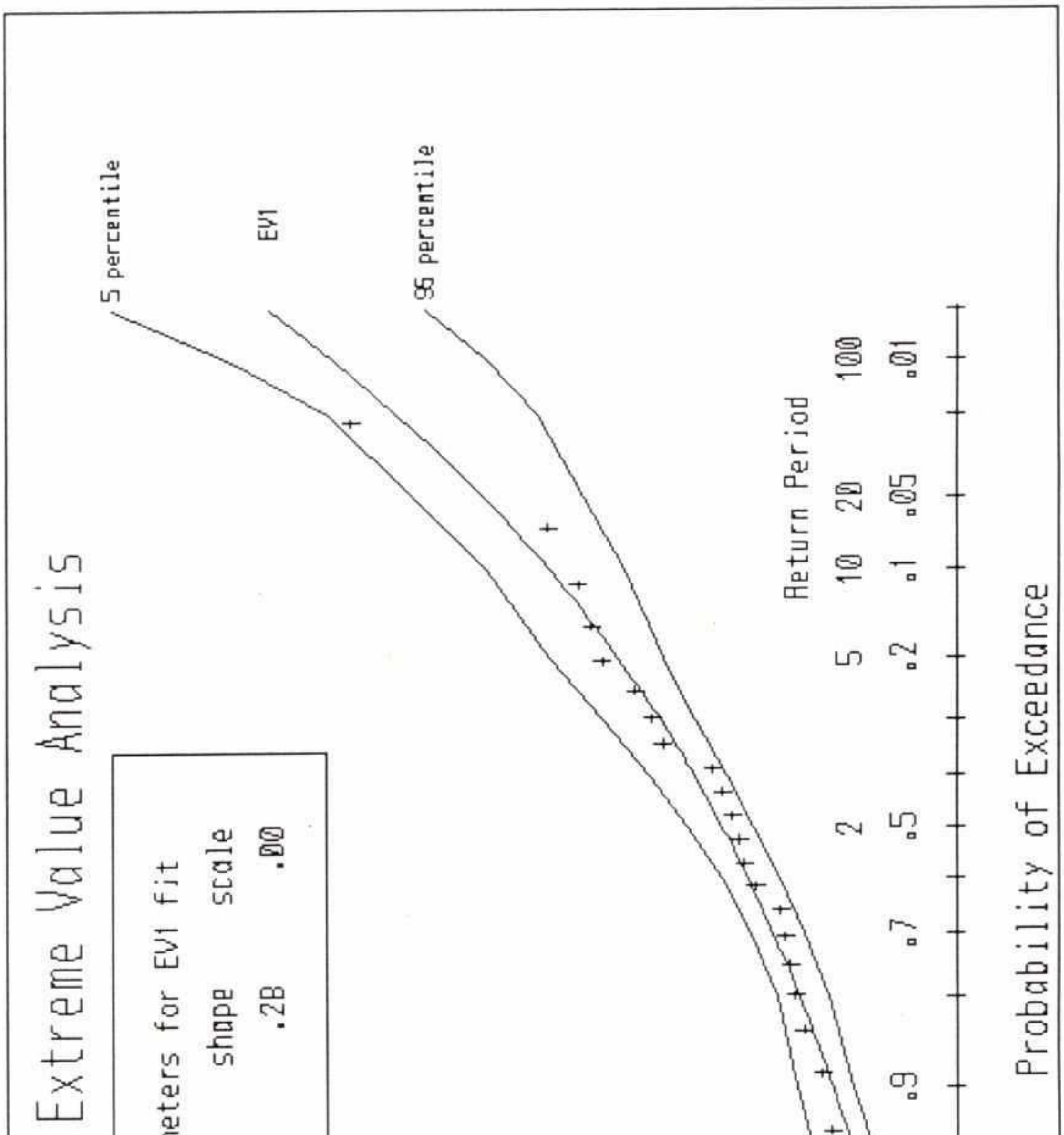
91

Figure 4.4



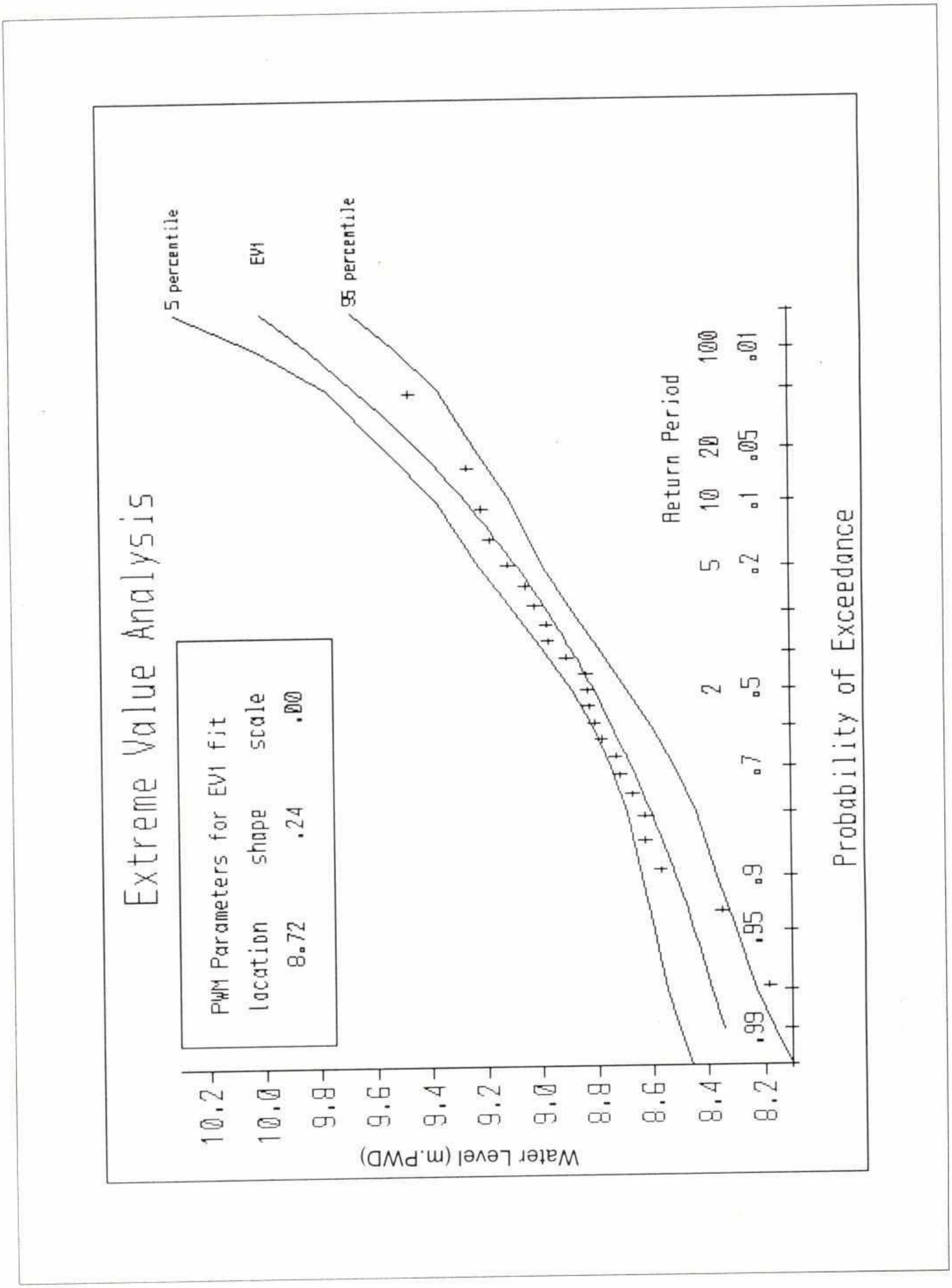
Frequency of Peak Levels - River Padma at Baruria

Figure 4.5



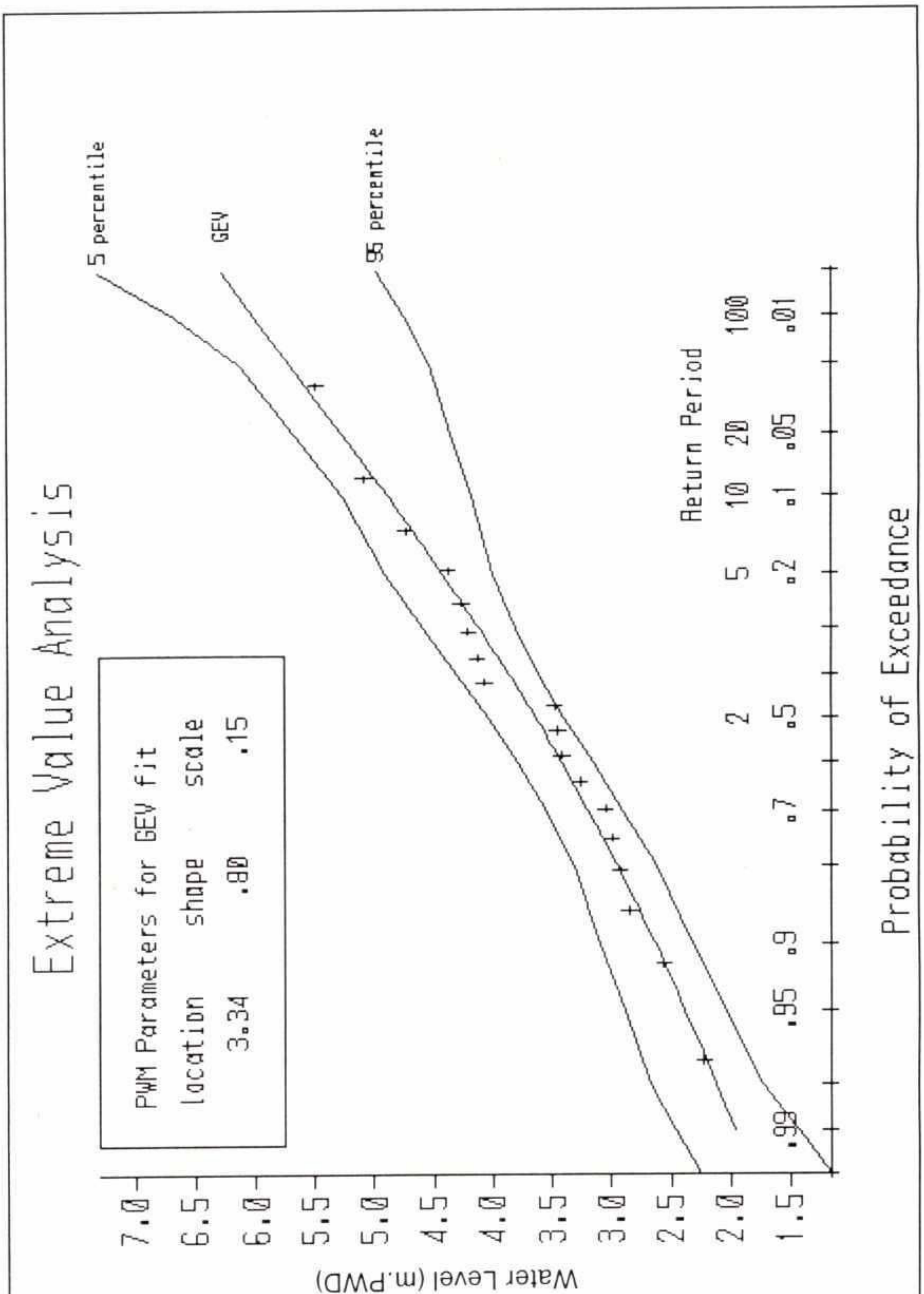
Frequency of Peak Levels - River Padma at Mawa

Figure 4.6



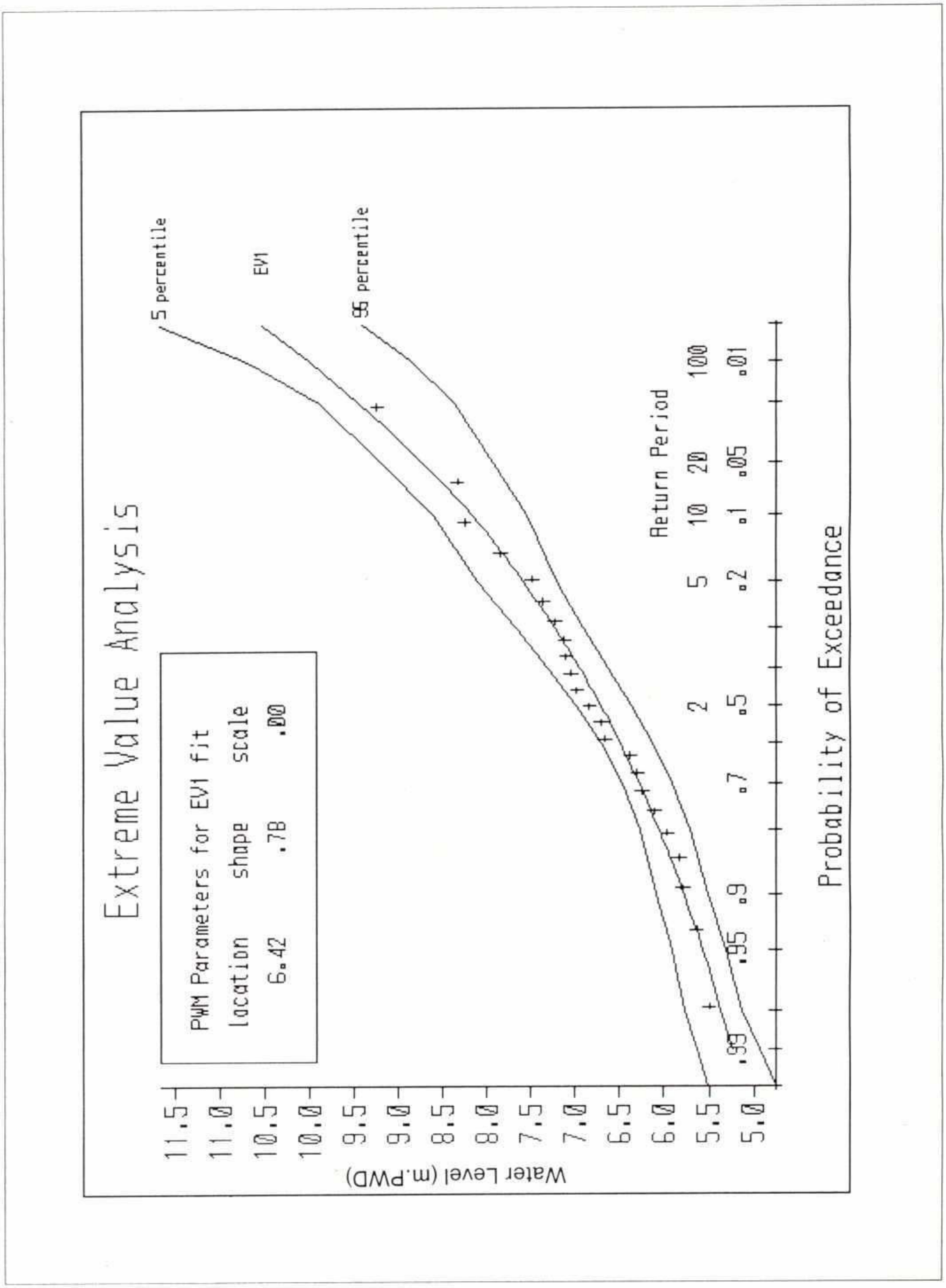
Frequency of Peak Levels - River Gorai at Kamarkhali

Figure 4.7



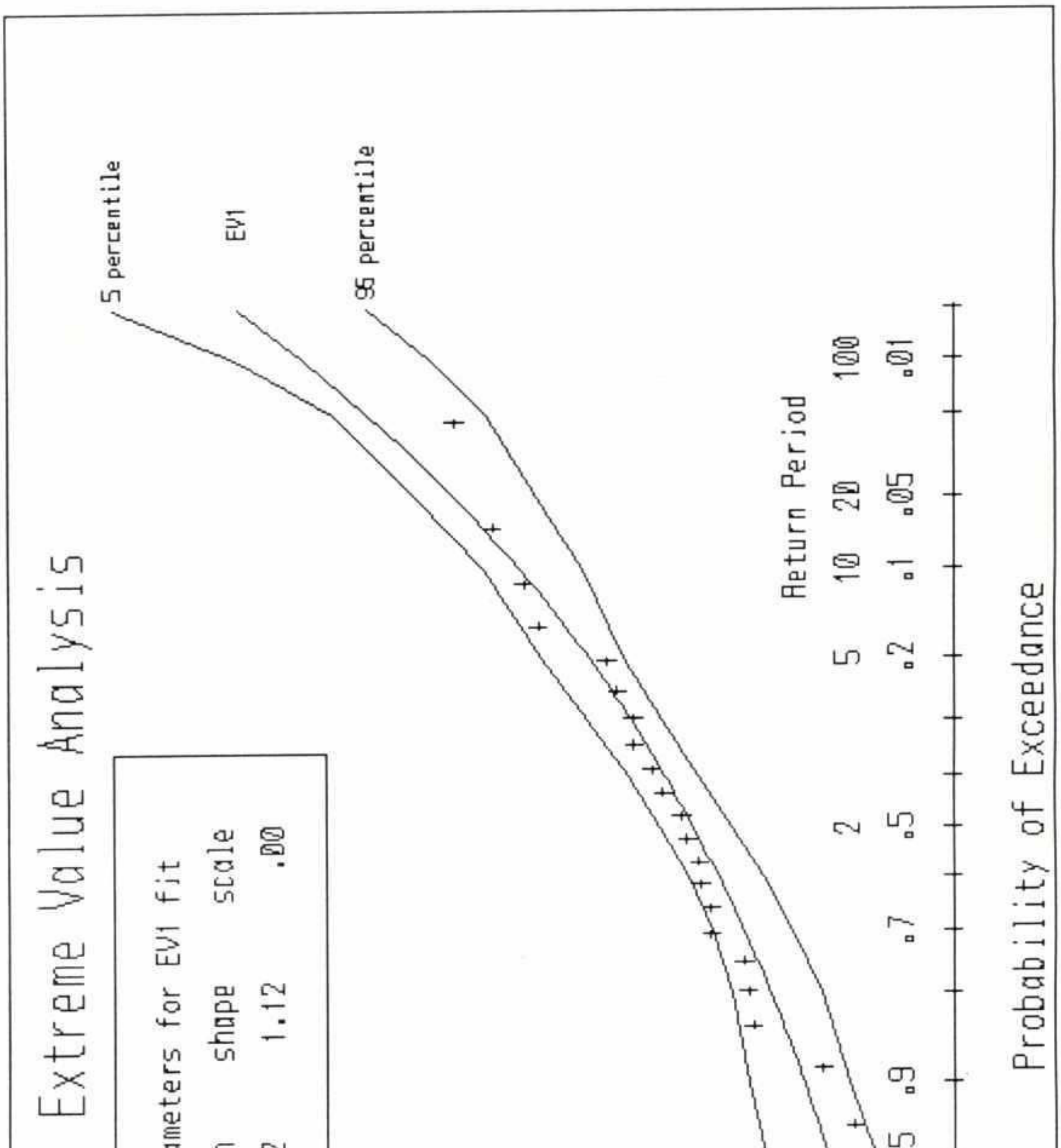
Frequency of Peak Levels - River Kobadak at Jhikarghacha

Figure 4.8



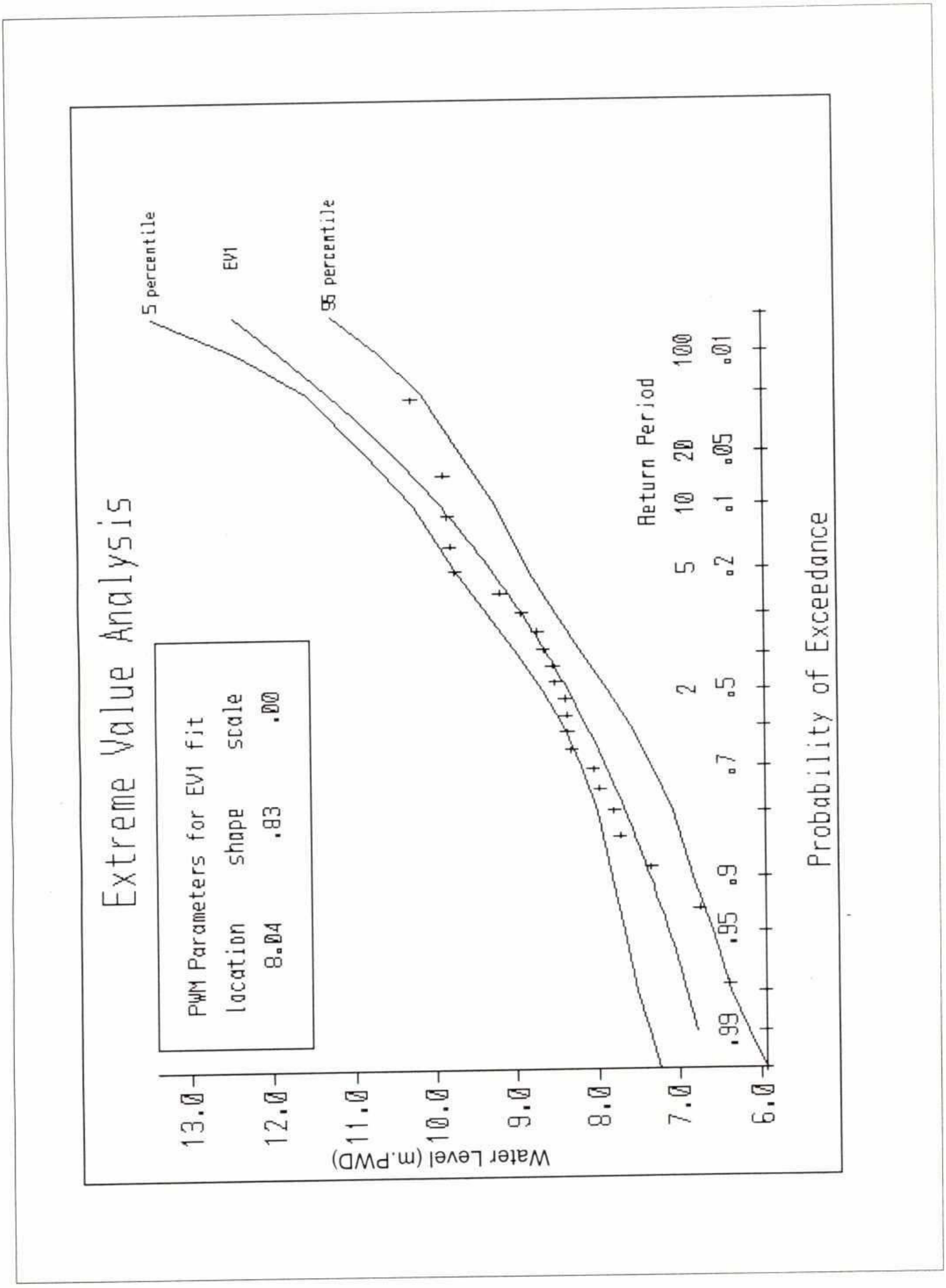
Frequency of Peak Levels - River Kumar at Geraganj

Figure 4.9



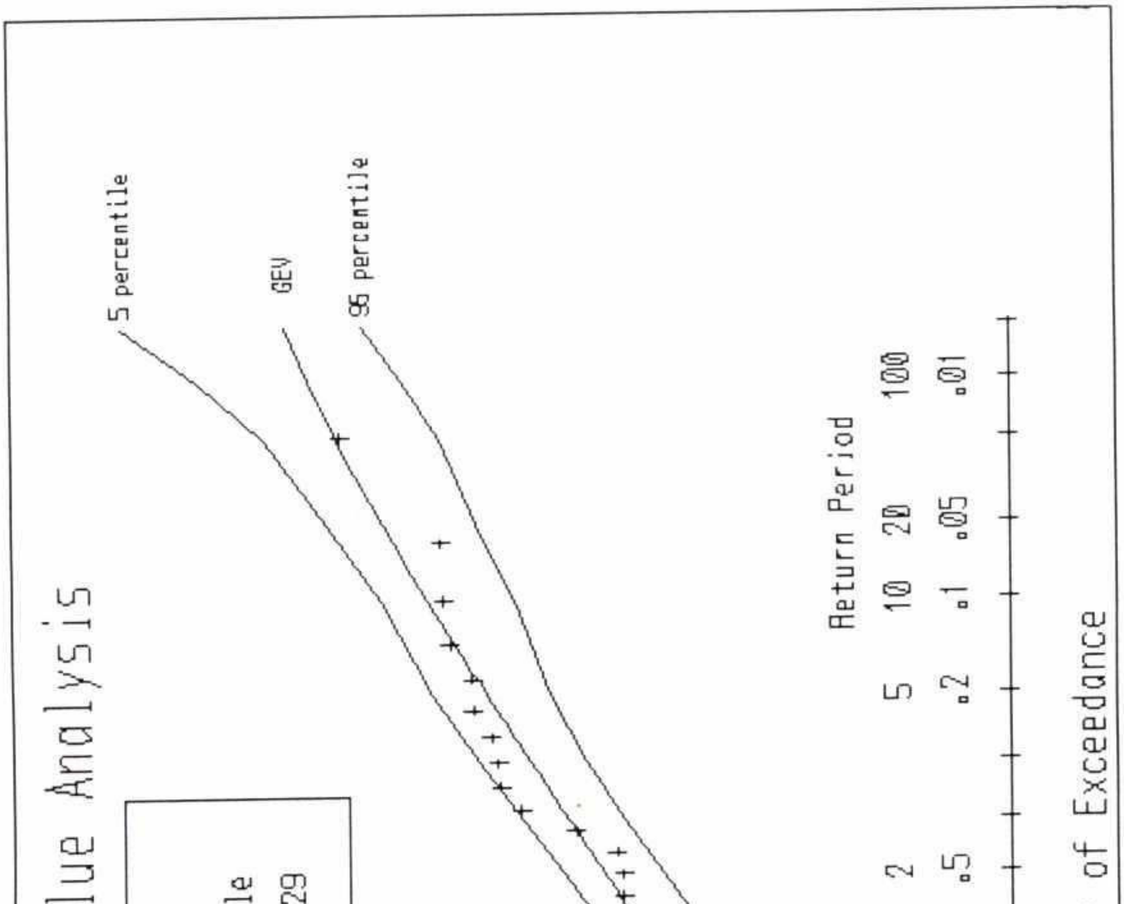
Frequency of Peak Levels - River Mathabhanga at Hatboalia

Figure 4.10



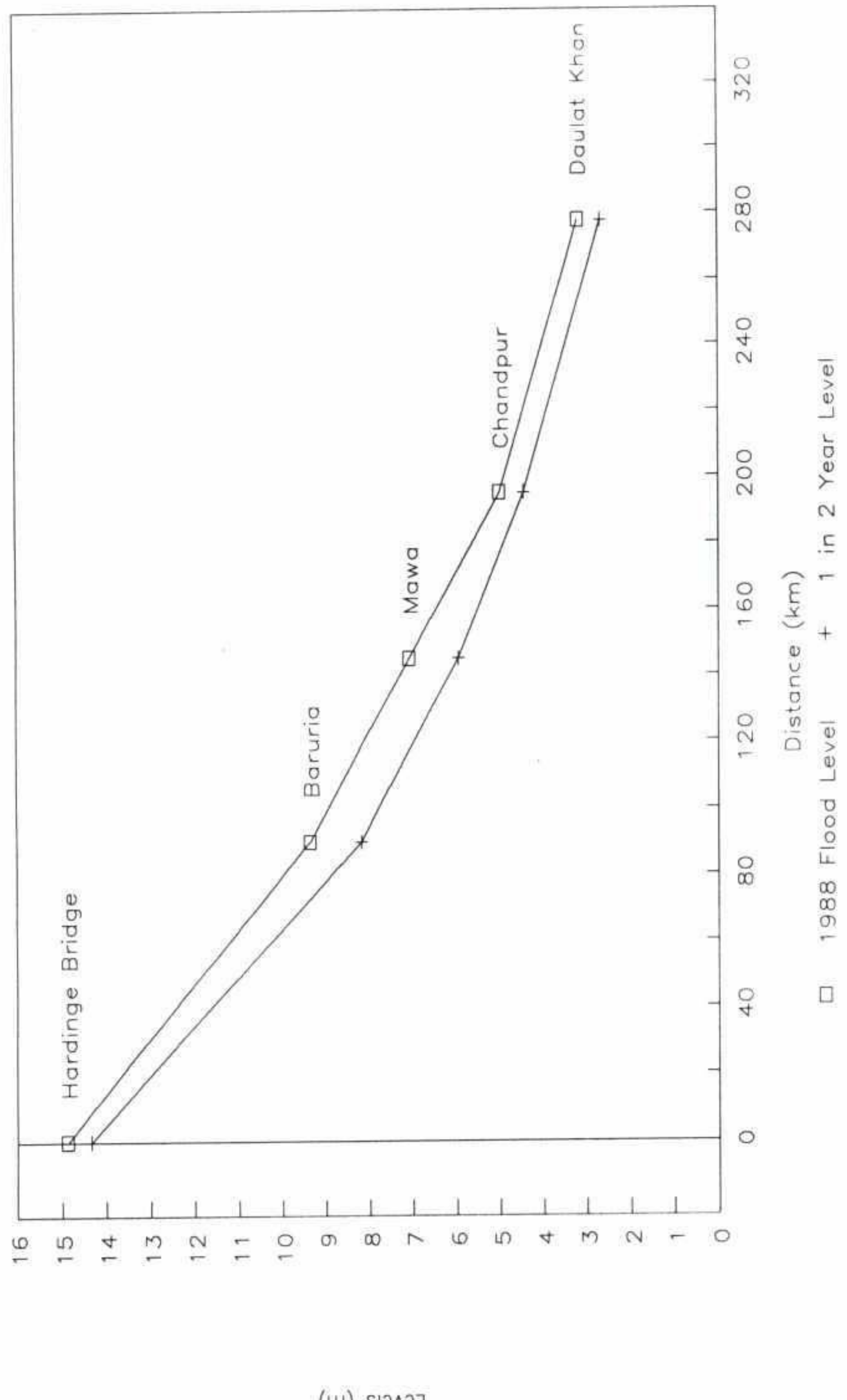
Frequency of Peak Levels - River Mathabhanga at Darsona

Figure 4.11



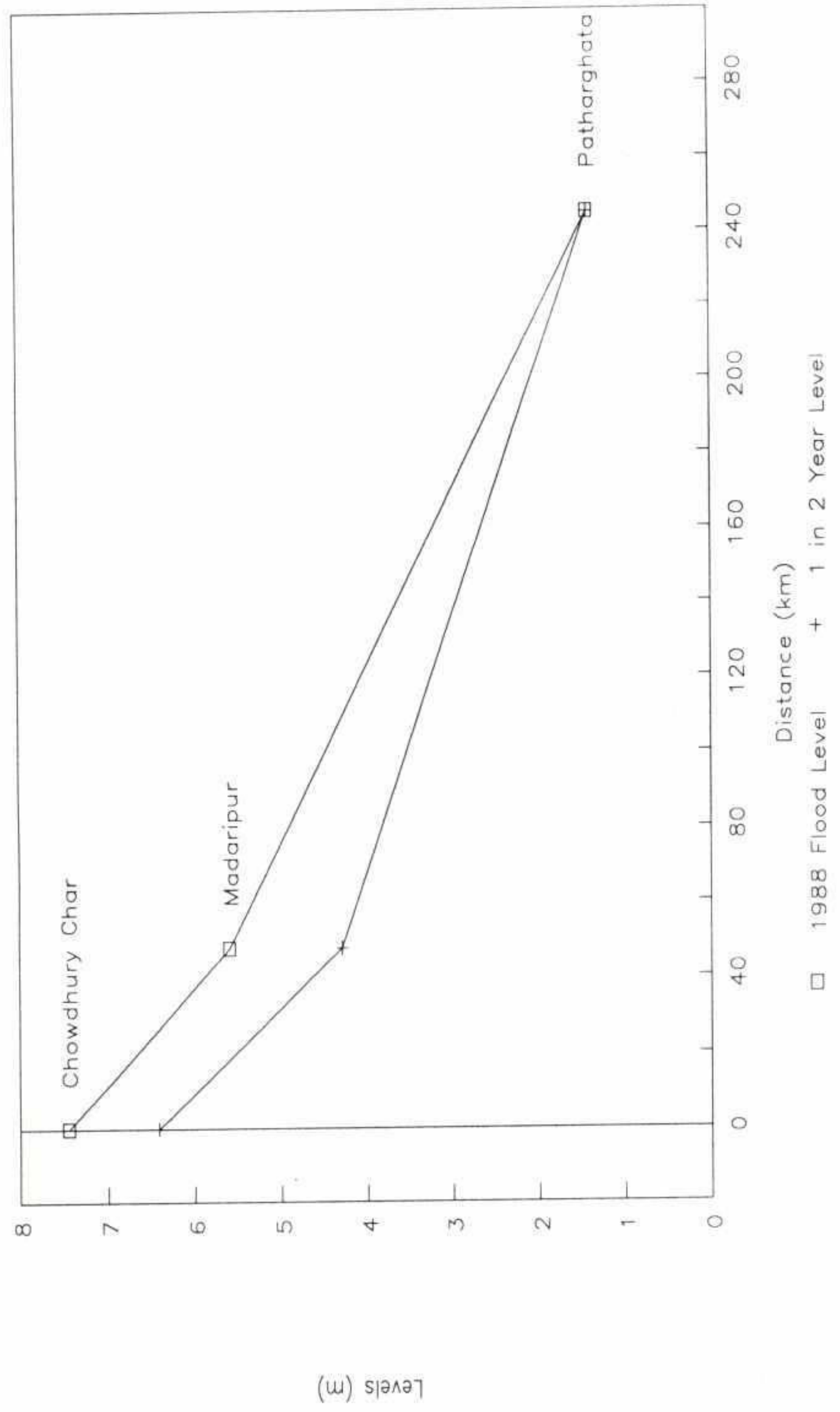
Frequency of Peak Levels - River Arial Khan at Chowdhuryhat

Figure 4.12



Comparison of the 1988 Flood Level and a 1 in 2 Year Flood Level on the Ganges-Padma-Meghna

Figure 4.13



Comparison of the 1988 Flood Level and a 1 in 2 Year Flood Level on the Gorai and Arial Khan

5 RIVER FLOWS

5.1 Data Availability

Discharge is measured or has been measured at 11 non-tidal stations in the study area. These are predominantly located in the north-west corner of the region as shown in Figure 4.1. Discharge data has also been collected at 5 stations along the major rivers. Data availability is shown in Table 5.1.

Tidal discharge measurements are made by BWDB at Bardia and Khulna during the dry season between November to June. Measurements are made once a month during the spring tide either during the new moon or the full moon. Although this information gives an indication of the maximum tidal flow at these stations, the data is too sparse for a detailed and meaningful analysis to be carried out. SWMC has also taken measurements during the last 2 years at a few locations in the area for their model calibrations. Tidal discharge data has therefore not been collected.

5.2 Data Verification and Analysis

Discharge data was checked for errors by plotting individual years and identifying inconsistencies and erroneous daily values. Random checks were made using rating curves to convert water level data into discharges. Basic statistical analysis was also done to identify outliers. Inconsistent data was rejected or where appropriate it was corrected using hydrological judgement. Annual peak discharges were observed to be a result of a gradual build up and are therefore less likely to be subject to erroneous daily readings. However since discharges are converted from water levels, any errors in the water level readings will be reflected in the discharge readings. Errors associated with shifting gauges where the datum has not been connected to a bench mark are an example of errors which are difficult to detect and correct. Reported annual peak discharges have not been corrected in this study.

The discharge in the Gorai River at Gorai Railway Bridge was compared with the discharge at Kamarkhali further downstream. It was observed that in most cases, the flow at Kamarkhali was less than the flow at Gorai Railway Bridge, inspite of Kamarkhali being further downstream. Sample hydrographs are shown in Figure 5.1. This may be due to overbank spilling in the intermediate region with the result that the part of the flood flows are bypassing the gauging station at Kamarkhali and therefore not being measured. The discharge data at Kamarkhali should be treated with caution and may not represent the available resource at that point in the catchment. It is understood that the SWMC and BWDB are jointly investigating the source of the discrepancy in the flood discharge records.

It is not clear how the discharge data for Choudharyhat on the Arial Khan (4A) has been computed by BWDB. The station is on the border of the tidal influence zone but even then does experience a mean annual tidal range of the order of 0.11 m. Seasonal variations are of the order of 0.14 m during the dry season and 0.10 m during the wet season. The mean annual maximum tidal range is of the order of 0.44 m. Rating curves have been provided for a number of years and mean daily water levels have been converted into discharge records by BWDB. This procedure is clearly flawed when the gauging station is subject to significant seasonal tidal influences, particularly in the wet season. Discharge data at this station should therefore be used with caution and primarily for the purpose of giving an indication of the relative amounts of water flowing in various months.

Trend analysis of the mean annual flows was done using the Armsen test and the results are shown in Table 5.2. The test identified the data at Baruria on the Padma and at Geraganj on the Kumar as having an increasing trend. The records at Gorai Railway Bridge on the Gorai were identified as having a decreasing trend. This observation should however be viewed in the light of the relatively small number of observations and should be treated as indicative but not conclusive evidence. A similar analysis of mean flows in March showed trends in the records at Bahadurabad, Hardinge Bridge, Gorai Railway Bridge, Geraganj, Hatboalia and Darsona. The results of the trend analysis are shown in Table 5.3.

Mean, median and 80% dependable monthly flows are reported in Tables 5.4 to 5.6. Histograms showing the mean and 80% probable monthly flows are presented in Figures 5.2 to 5.5.

Frequency analysis of discharge data was done by fitting the Gumbel and Extreme Value Type III distributions to the annual maximum discharges at each station. The results of the best fit distribution are shown in Table 5.7 and Figures 5.6 to 5.13. Growth factors for flood frequencies have been computed by taking the 2 year flood as the mean annual flood and these are shown in Table 5.8. The growth factors for the 1 in 100 year event are of the order of 1.65 for the major and secondary rivers.

Table 5.1

Availability of Daily Discharge Data

Sl.No.	Station Name	Station No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Bahadurabad	46.9 L	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
2	Baruria	91.9 L		C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	
3	Bhairab Bazaar	273	C	C	C	C	C	C	C	C	C	C	C	C					C	C	C	C	C	C	C	C	C	
4	Chandana Rly. Bdg.	51 A	C	C	C	C	C	C		C		C	C	C	C													
5	Chowdhuryhat (Arial Khan)	4 A	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	
6	Darsona	208		C	C	C	C	C		C	C	C	C	C	C	C	C	C	C		C	C	C	C	C			
7	Geraganj	171	C	C	C	C		C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
8	Gorai Rly. Bdg.	99	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
9	Hardinge Bridge	90	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
10	Hatboalia	206			C	C	C	C		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	
11	Ibrahimdi	167								C	C	C	C	C														
12	Jhikargacha	162	C	C	C	C		C		C	C	C	C	C	C	C	C	C	C	C	C	C						
13	Kamarkhali	101.5	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C				C				
14	Kazipur	205			C	C	C	C		C	C	C	C	C	C					C	C	C	C	C	C	C	C	
15	Magura	216 A						C						C	C	C	C	C	C									
16	Mawa	93.5 L	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	

C — Collected

Table 5.2

Trend Analysis of Mean Annual Flow (1965 - 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
4A	Choudharyhat	Arial Khan	0.9342	0.825	11
46.9L	Bahadurabad	Brahmaputra	1.1843	0.882	22
90	Hardinge Bridge	Ganges	0.3384	0.632	22
91.9L	Baruria	Ganges	1.6889	0.954 *	17
93.5L	Mawa	Padma	0.9151	0.820	13
99	Gorai Rly Bridge	Gorai-Madhumati	2.2713	0.988 *	23
101.5	Kamarkhali Transit	Gorai-Madhumati	0.2969	0.617	15
162	Jhikargacha	Kobadak	0.1789	0.571	10
171	Geraganj	Kumar	1.8787	0.970 *	6
205	Kazipur	Mathabanga	0.4671	0.680	11
206	Hatboalia	Mathabanga	0.7515	0.774	6
208	Darsona	Mathabanga	-0.3397	0.367	4
273	Bhairab Bazaar	Surma-Meghna	0.9011	0.816	7

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 5.3

Trend Analysis of Mean March Flow (1965 – 1991)

Station No.	Station Name	River	Standard Normal Deviate	Probability = P(z)	No of Observations
4A	Choudharyhat	Arial Khan	1.5909	0.944	18
46.9L	Bahadurabad	Brahmaputra	1.7115	0.957 *	24
90	Hardinge Bridge	Ganges	3.3805	1.000 *	23
91.9L	Baruria	Ganges	0.5737	0.717	21
93.5L	Mawa	Padma	0.8650	0.806	17
99	Gorai Rly Bridge	Gorai-Madhumati	3.4478	1.000 *	25
101.5	Kamarkhali Transit	Gorai-Madhumati	1.1363	0.872	18
162	Jhikargacha	Kobadak	1.6423	0.949	14
171	Geraganj	Kumar	1.8684	0.969 *	11
205	Kazipur	Mathabanga	0.0000	0.500	14
206	Hatboalia	Mathabanga	1.6889	0.954 *	17
208	Darsona	Mathabanga	1.8684	0.969 *	11

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data ie. the time series is not stationary.

Table 5.4

Mean Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Bahadurabad	46.9 L	4840	4130	4770	7910	15210	29910	47150	44330	39520	25000	11110	6780	20055	20190
2	Baruria	91.9 L	7190	6200	6240	9080	15980	31780	58230	71240	67200	38780	16670	9950	28212	28170
3	Bhairab Bazaar	273	410	293	374	1133	2775	6208	10345	11762	10727	8144	3458	990	4718	4859
4	Chowdhuryhat (Arial Khan)	4 A	86	60	70	118	255	632	1359	1864	1535	829	316	156	607	568
5	Darsona	208	15	14	15	12	12	19	49	163	217	134	45	21	60	61
6	Geraganj	171	3	3	3	5	14	25	33	42	44	37	16	5	19	17
7	Gorai Rly. Bdg. (1)	99	190	137	98	113	175	576	2715	4936	4645	2175	731	340	1403	1395
	Gorai Rly. Bdg. (2)	99	116	80	56	62	123	491	2670	4737	4598	2041	609	240	1319	1302
8	Hardinge Bridge (1)	90	2234	1738	1366	1391	1742	3990	18709	37679	36105	16099	5856	3344	10854	11108
	Hardinge Bridge (2)	90	1790	1325	1041	1042	1433	3689	20031	39280	38420	16595	5621	2885	11096	10962
9	Hatboalia	206	9	8	7	6	6	9	27	128	160	66	13	10	37	35
10	Jhikargacha	162	6	5	4	4	4	9	16	21	25	22	13	8	11	10
11	Kamarkhali (1)	101.5	303	175	124	136	192	554	2466	4421	3955	2023	913	526	1316	1359
	Kamarkhali (2)	101.5	343	164	107	117	181	525	2684	4415	3944	2007	1024	621	1344	1327
12	Kazipur	205	3	2	2	2	2	2	20	106	123	29	4	3	25	28
13	Mawa	93.5 L	7210	6220	6530	9780	15630	29040	55300	71580	66120	36050	15810	10060	27444	27470

* Average of monthly values

Average of mean annual flow for complete years

(1) Based on series 1964 to 1989 (includes pre-Farakka period)

(2) Based on series 1975 to 1989 (excludes pre-Farakka period)

Table 5.5

Median Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Bahadurabad	46.9 L	4790	3920	4740	7710	14170	31180	47380	42390	37560	24660	11000	6510	19668	19700
2	Baruria	91.9 L	7110	6180	6220	9170	16040	31880	56460	67510	65690	39430	16680	10010	27698	28920
3	Bhairab Bazaar	273	407	305	370	1141	2585	5519	10362	11557	10229	8040	3319	871	4559	5005
4	Chowdhuryhat (Arial Khan)	4 A	54	40	44	99	268	605	1240	1905	1401	690	212	106	555	543
5	Darsona	208	14	13	13	12	12	14	30	180	208	111	49	22	57	62
6	Geraganj	171	3	3	2	5	14	20	32	39	41	32	16	5	18	16
7	Gorai Rly. Bdg. (1)	99	174	112	71	57	122	584	2612	4828	4764	1965	698	356	1362	1355
	Gorai Rly. Bdg. (2)	99	104	48	18	28	81	395	2612	4762	4790	1931	596	244	1301	1339
8	Hardinge Bridge (1)	90	2243	1695	1304	1364	1618	3764	18369	38117	36048	15185	5748	3367	10735	11169
	Hardinge Bridge (2)	90	1653	1310	1011	981	1485	3235	21361	39269	40326	15329	5064	2770	11150	11169
9	Hatboalia	206	7	7	6	5	6	7	24	119	155	59	12	9	35	35
10	Jhikargacha	162	6	5	4	4	4	6	9	18	19	16	13	8	9	10
11	Kamarkhali (1)	101.5	212	151	127	129	183	505	2425	4548	4383	2129	767	400	1330	1303
	Kamarkhali (2)	101.5	163	102	81	132	208	499	2909	5182	4558	2183	667	321	1417	1302
12	Kazipur	205	2	2	2	2	1	2	13	112	111	24	4	3	23	26
13	Mawa	93.5 L	7250	6380	6380	9350	14780	30400	53660	69070	67240	38660	15280	9850	27358	27910

* Average of monthly values

\# Average of median annual flow for complete years

(1) Based on series 1964 to 1989 (includes pre-Farakka period)

(2) Based on series 1975 to 1989 (excludes pre-Farakka period)

Table 5.6

80% Dependable Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Bahadurabad	46.9 L	4330	3680	3880	6300	12500	24530	41210	34910	32210	18130	9240	5910	16403	17700
2	Baruria	91.9 L	6630	5600	5710	7780	11960	25460	50240	58990	55380	29190	13650	8920	23293	24470
3	Bhairab Bazaar	273	149	112	214	759	1601	4344	8272	10125	8497	6373	2336	637	3618	3686
4	Chowdhuryhat (Arial Khan)	4 A	23	15	15	39	123	437	1022	1222	998	557	164	52	389	434
5	Darsona	208	11	11	12	9	10	12	18	101	97	72	25	16	33	51
6	Geraganj	171	1	1	2	3	4	10	16	28	29	23	12	3	11	11
7	Gorai Rly. Bdg. (1)	99	55	29	11	14	67	284	2129	3904	3804	1445	417	158	1026	1151
	Gorai Rly. Bdg. (2)	99	4	3	2	1	38	259	2071	3857	3874	1301	400	39	987	1078
8	Hardinge Bridge (1)	90	1453	1060	806	741	1186	2394	12481	26650	25510	10556	4090	2186	7426	10224
	Hardinge Bridge (2)	90	1302	884	742	725	1070	2365	13552	29896	30533	10820	3846	2064	8150	8685
9	Hatboalia	206	4	4	3	3	3	3	6	93	81	17	7	4	19	26
10	Jhikargacha	162	4	4	3	2	3	5	6	9	12	11	6	5	6	7
11	Kamarkhali (1)	101.5	97	64	36	43	76	426	1781	3396	2587	1257	454	208	869	1151
	Kamarkhali (2)	101.5	60	33	15	4	38	239	1439	50	194	1128	409	187	316	977
12	Kazipur	205	2	2	1	1	1	1	2	50	41	8	2	1	9	21
13	Mawa	93.5 L	6010	4770	5460	7820	12120	21700	47360	60100	54030	27190	12700	8590	22321	23810

* Average of monthly values

Average of 80% dependable annual flow for complete years

(1) Based on series 1964 to 1989 (includes pre-Farakka period)

(2) Based on series 1975 to 1989 (excludes pre-Farakka period)

Table 5.7

Frequency Analysis of Historical Maximum Mean Daily Flows (cumecs) (1965 - 1989)

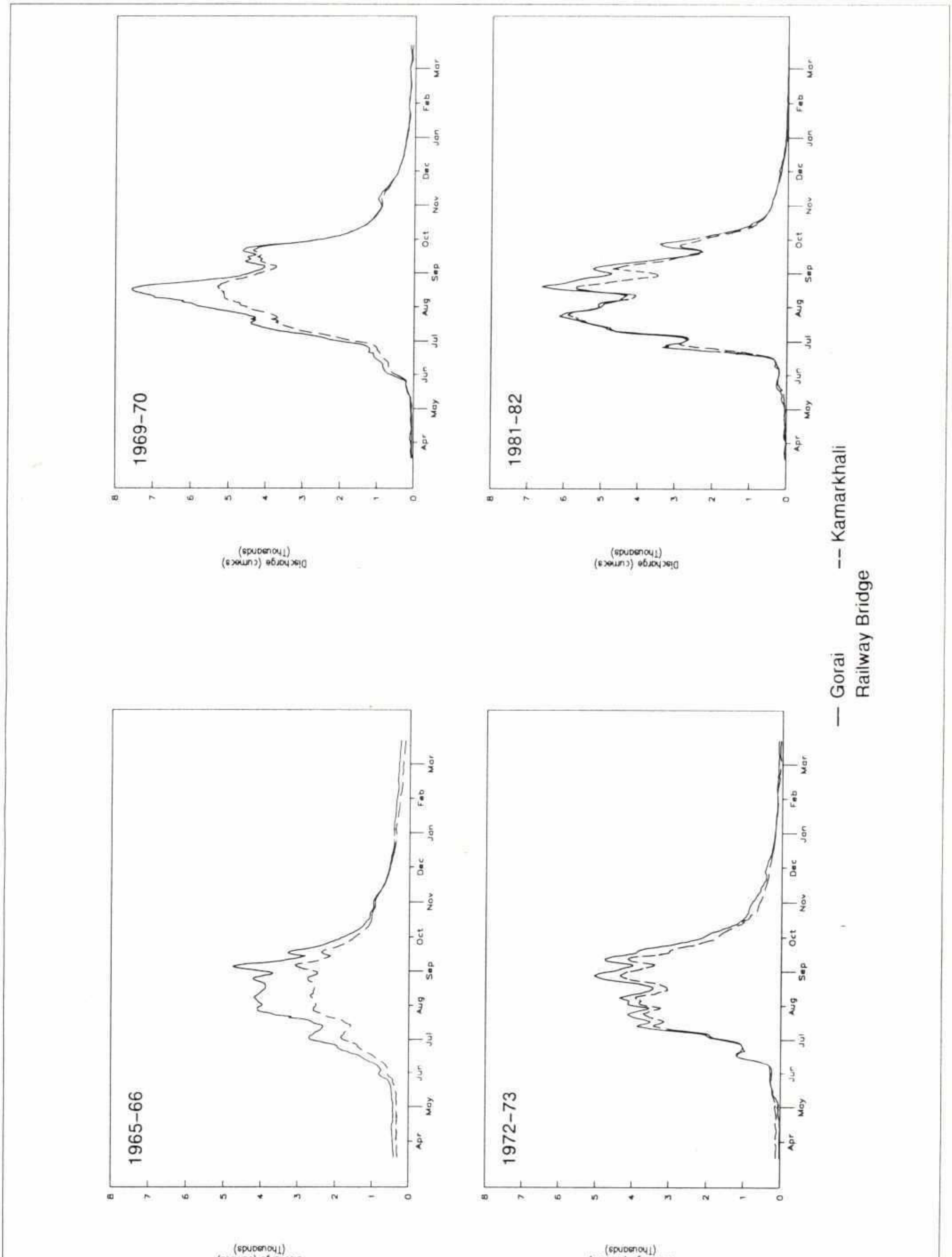
Station No.	Station Name	River	Return Period (years)							Fitted Distribution
			2	5	10	20	50	100	200	
4A	Choudharyhat	Arial Khan	2494	3161	3520	3814	4132	4331	4502	GEV3
46.9L	Bahadurabad	Brahmaputra	67130	77900	85040	91880	100740	107380	113990	EV1
51A	Chandana	Chandana	57	78	91	105	122	134	147	EV1
90	Hardinge Bridge	Ganges	48821	59055	65831	72330	80743	87048	93329	EV1
91.9L	Baruria	Ganges	87880	102310	111860	121020	132870	141760	150610	EV1
93.5L	Mawa	Padma	87740	100640	109180	117370	127980	135920	143840	EV1
99	Gorai Rly Bridge	Gorai-Madhumati	6127	7198	7907	8587	9467	10126	10784	EV1
101	Kamarkhali	Gorai-Madhumati	5433	6425	7081	7711	8526	9137	9746	EV1
162	Jhikargacha	Kobadak	47	80	102	123	151	171	191	EV1
171	Geraganj	Kumar	96	161	205	246	299	340	379	EV1
205	Kazipur	Mathabanga	219	317	382	445	526	586	647	EV1
206	Hatboalia	Mathabanga	227	322	384	445	523	581	639	EV1
208	Darsona	Mathabanga	275	356	410	462	529	579	629	EV1

Table 5.8

Growth Factors for Historical Maximum Mean Daily Flows (cumecs) (1965 - 1989)

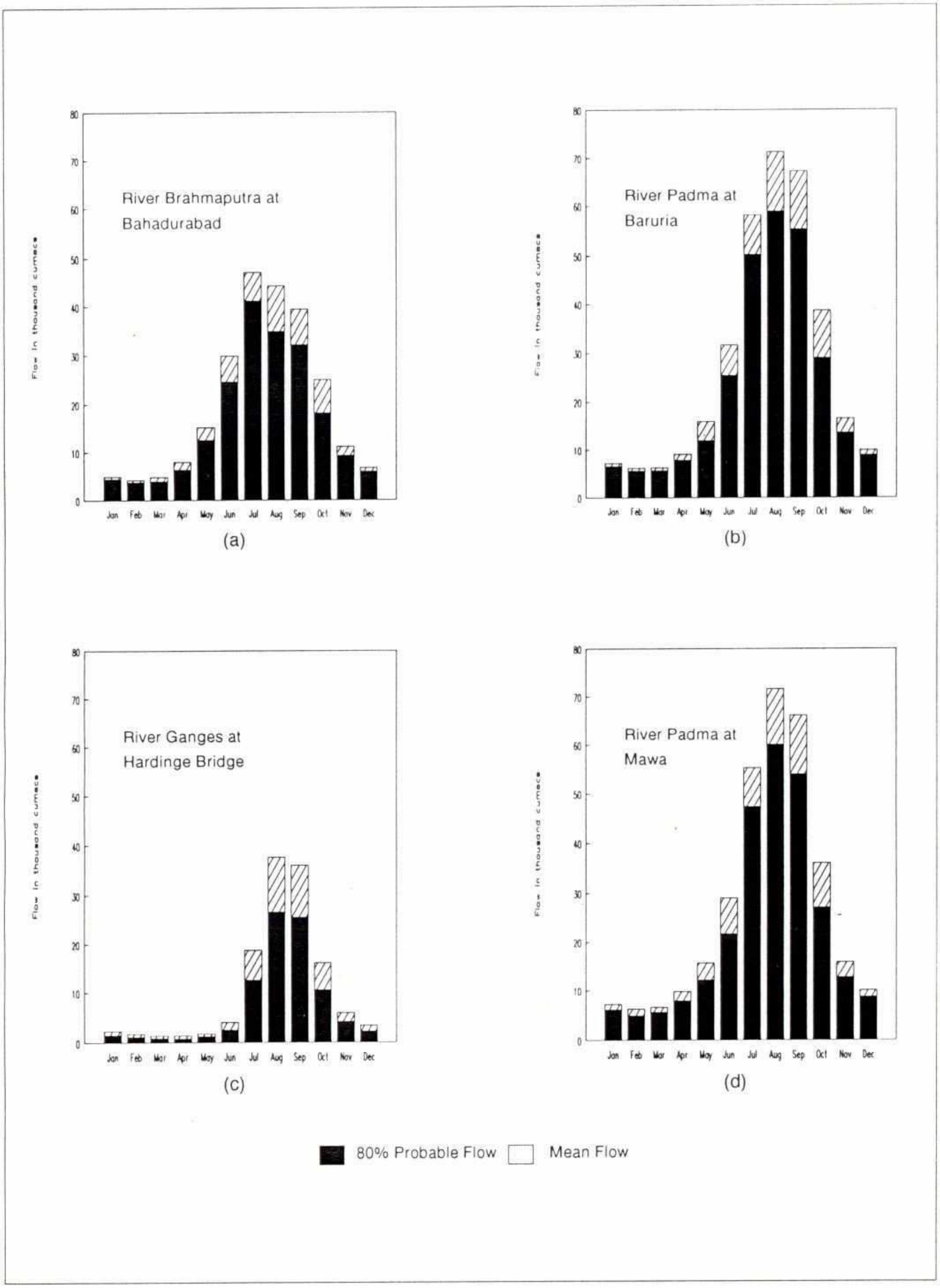
Station No.	Station Name	River	Return Period (years)							Fitted
			2	5	10	20	50	100	200	Distribution
4A	Choudharyhat	Arial Khan	1.00	1.27	1.41	1.53	1.66	1.74	1.81	GEV3
46.9L	Bahadurabad	Brahmaputra	1.00	1.16	1.27	1.37	1.50	1.60	1.70	EV1
51A	Chandana	Chandana	1.00	1.37	1.60	1.84	2.14	2.35	2.58	EV1
90	Hardinge Bridge	Ganges	1.00	1.21	1.35	1.48	1.65	1.78	1.91	EV1
91.9L	Baruria	Ganges	1.00	1.16	1.27	1.38	1.51	1.61	1.71	EV1
93.5L	Mawa	Padma	1.00	1.15	1.24	1.34	1.46	1.55	1.64	EV1
99	Gorai Rly Bridge	Gorai-Madhumati	1.00	1.17	1.29	1.40	1.55	1.65	1.76	EV1
101	Kamarkhali	Gorai-Madhumati	1.00	1.18	1.30	1.42	1.57	1.68	1.79	EV1
162	Jhikargacha	Kobadak	1.00	1.70	2.17	2.62	3.21	3.64	4.06	EV1
171	Geraganj	Kumar	1.00	1.68	2.14	2.56	3.11	3.54	3.95	EV1
205	Kazipur	Mathabanga	1.00	1.45	1.74	2.03	2.40	2.68	2.95	EV1
206	Hatboalia	Mathabanga	1.00	1.42	1.69	1.96	2.30	2.56	2.81	EV1
208	Darsona	Mathabanga	1.00	1.29	1.49	1.68	1.92	2.11	2.29	EV1

Figure 5.1



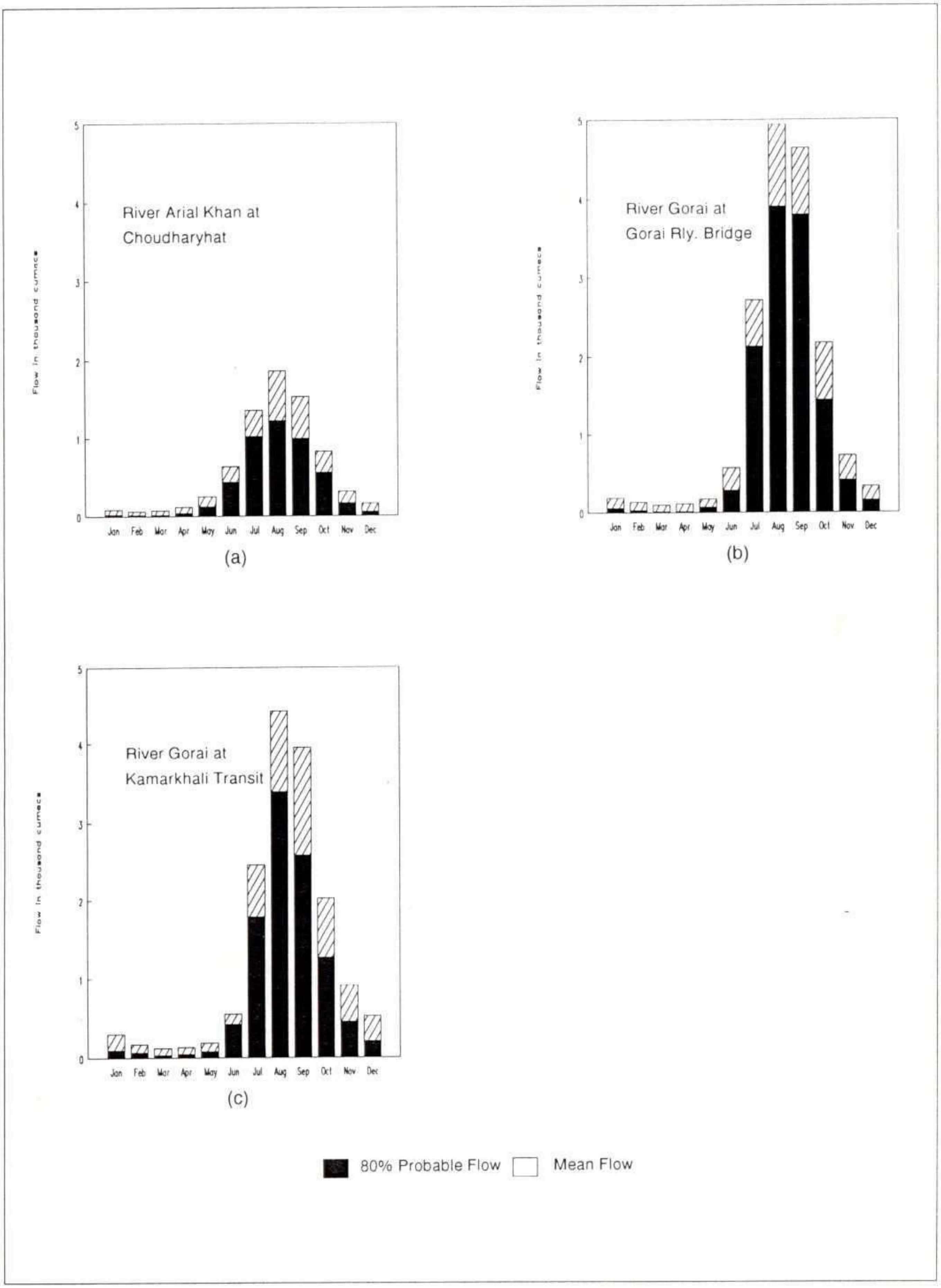
Comparison of Flows in River Gorai

Figure 5.2



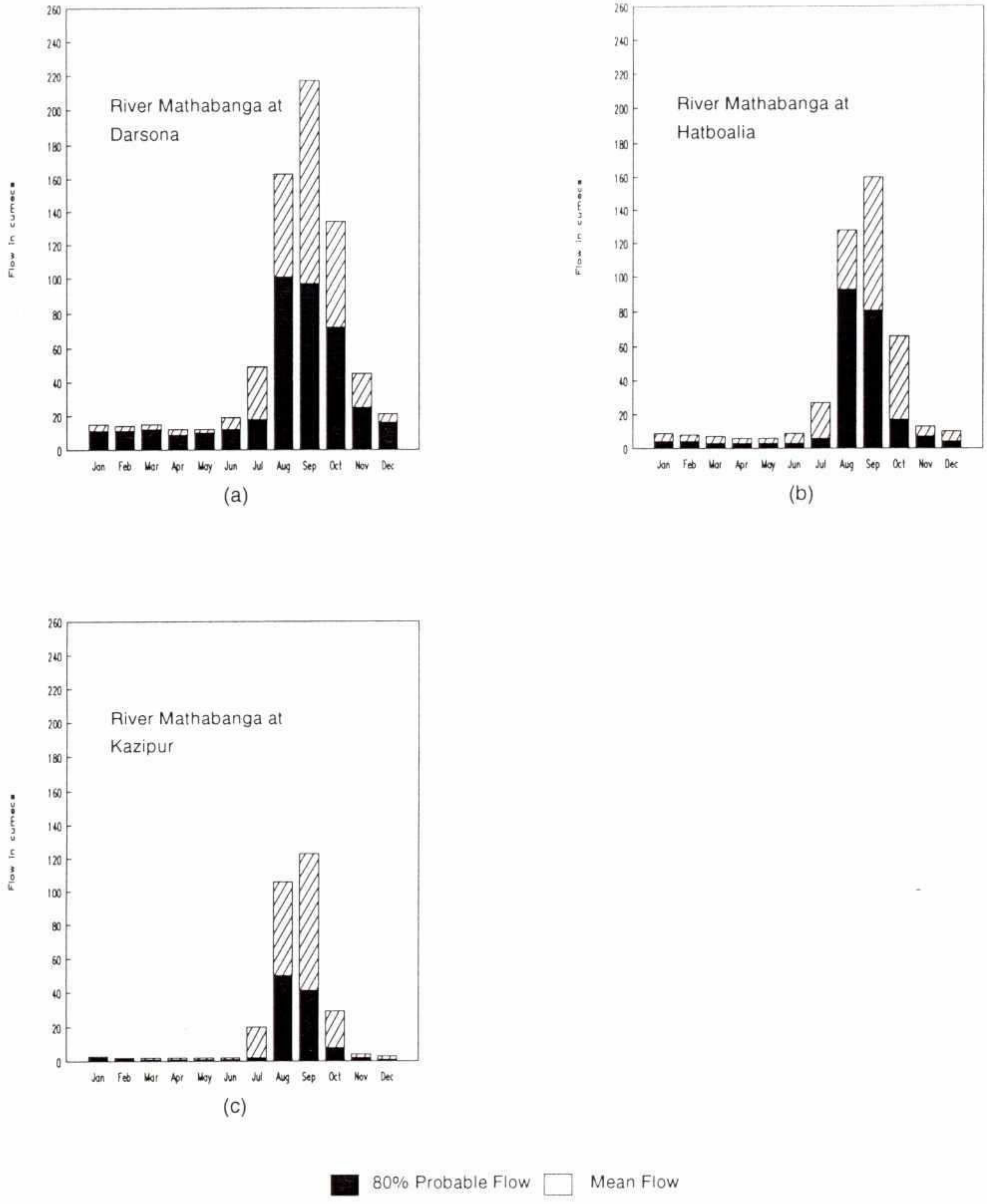
Monthly River Flows of Brahmaputra, Ganges and Padma

Figure 5.3



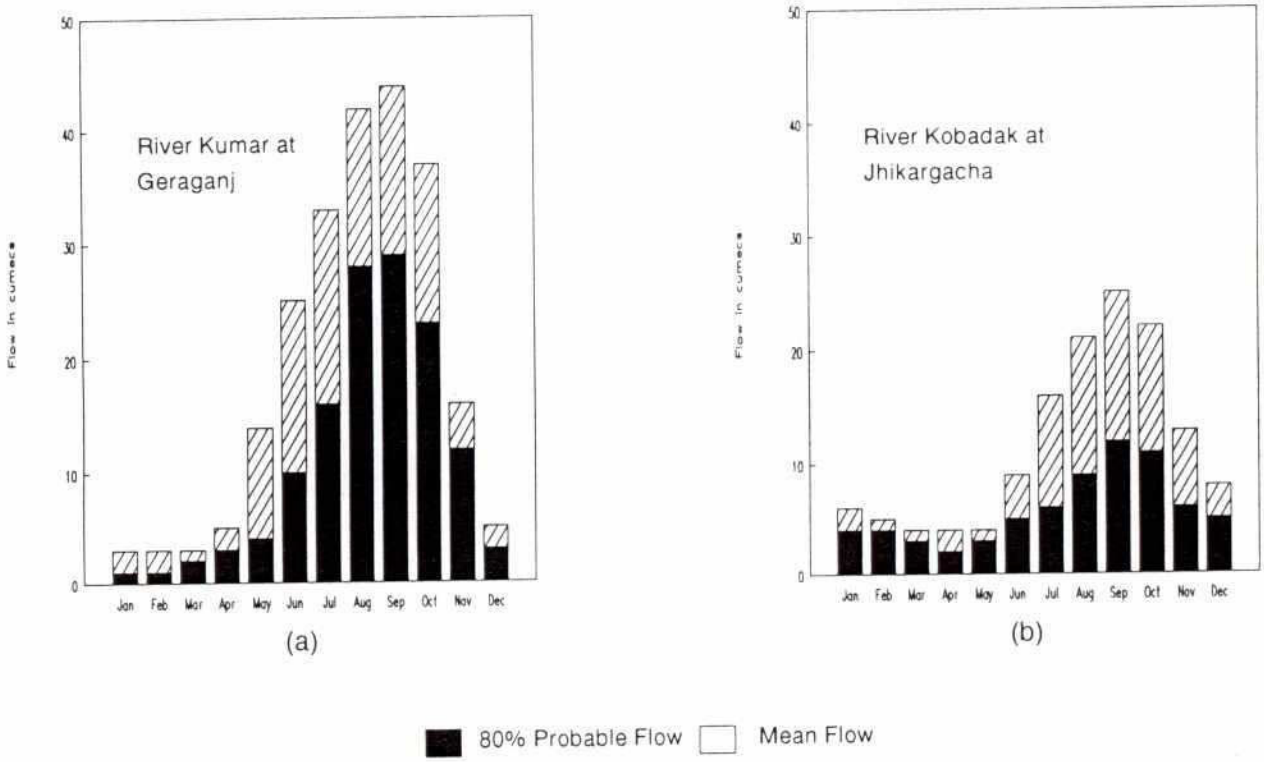
Monthly River Flows of Arial Khan and Gorai

Figure 5.4



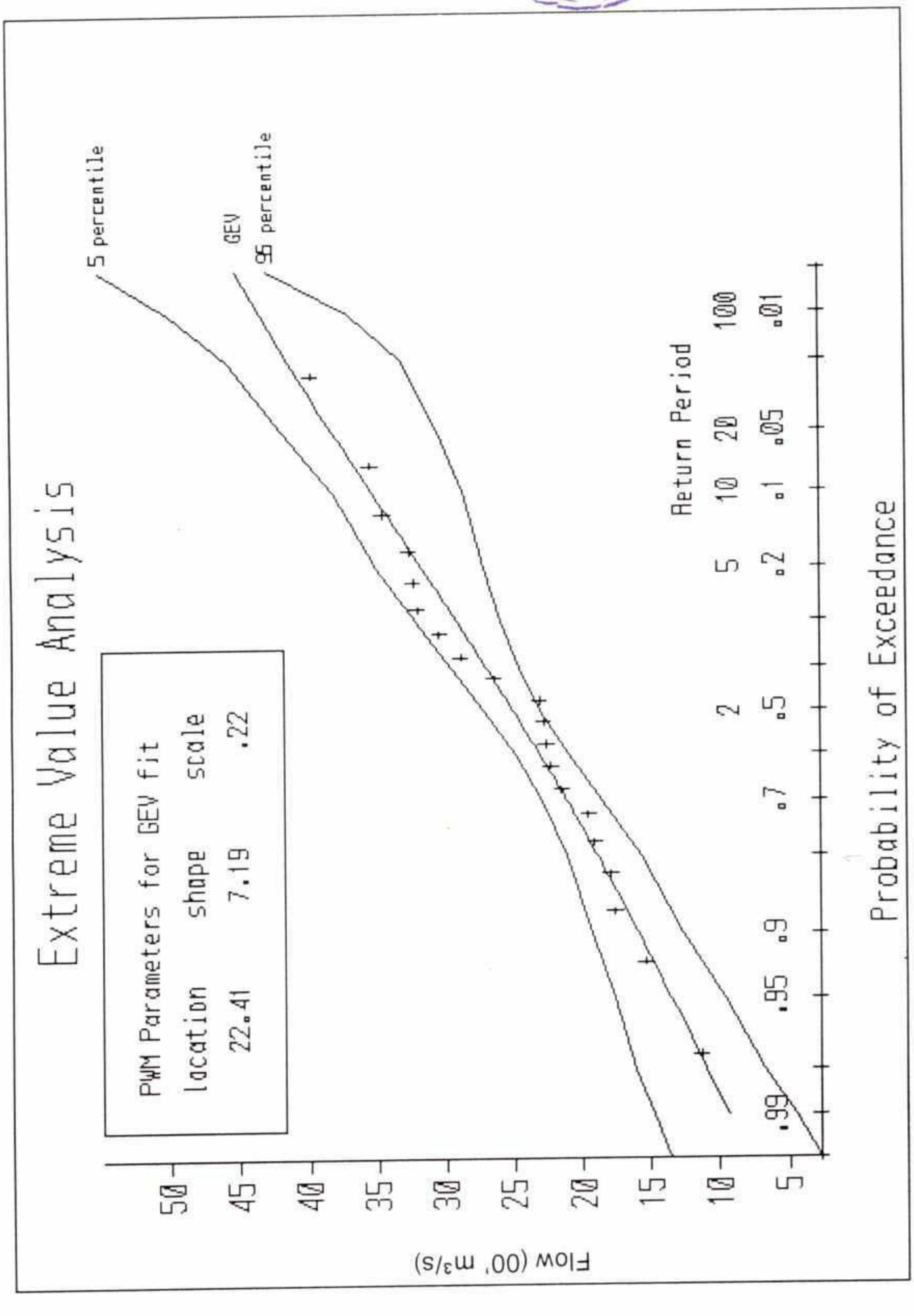
Monthly River Flow of Mathabhanga River

Figure 5.5



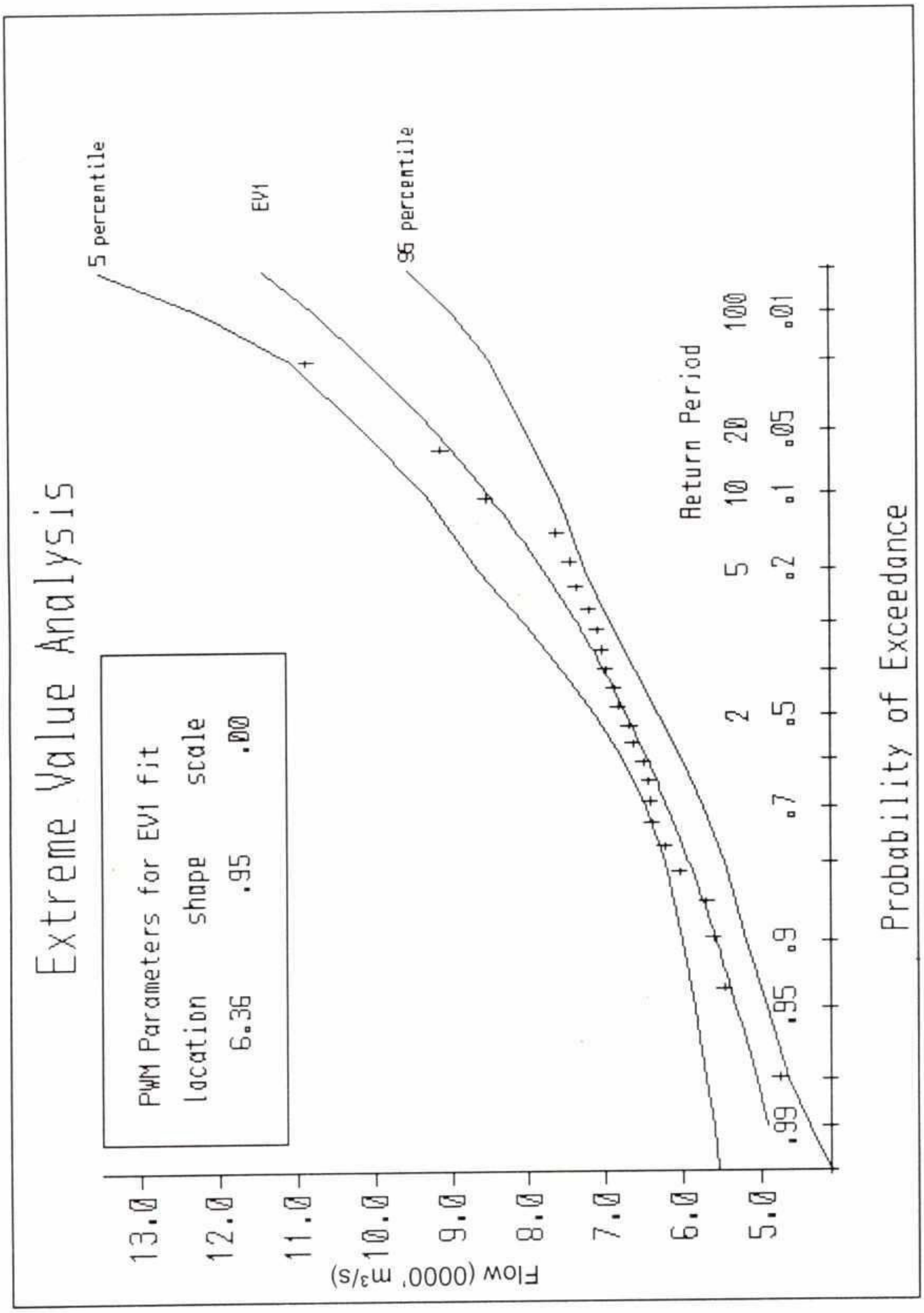
Monthly River Flows of Kumar and Kobadak

Figure 5.6



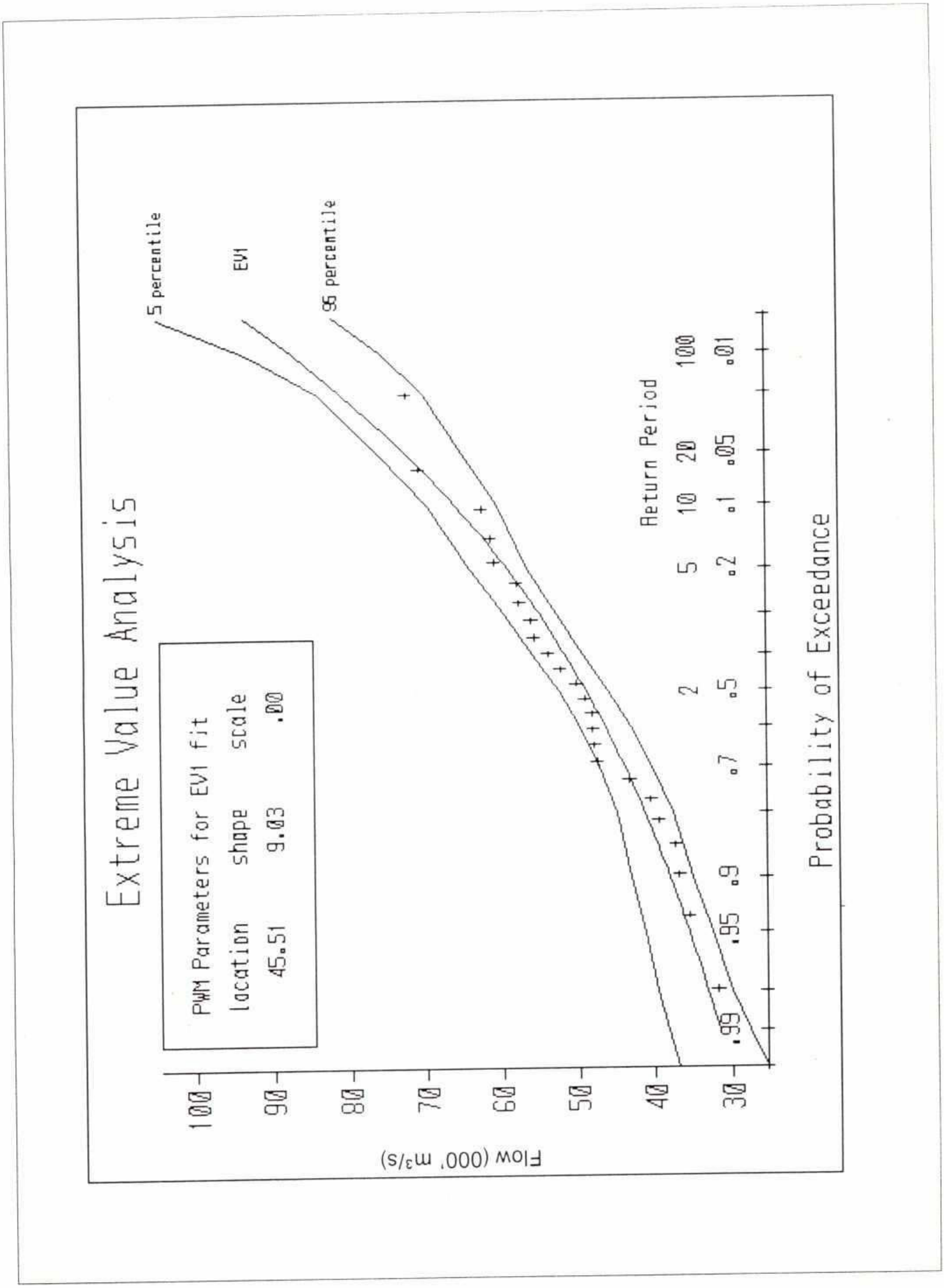
Frequency of Peak Flows - River Arial Khan at Chowdhuryhat

Figure 5.7



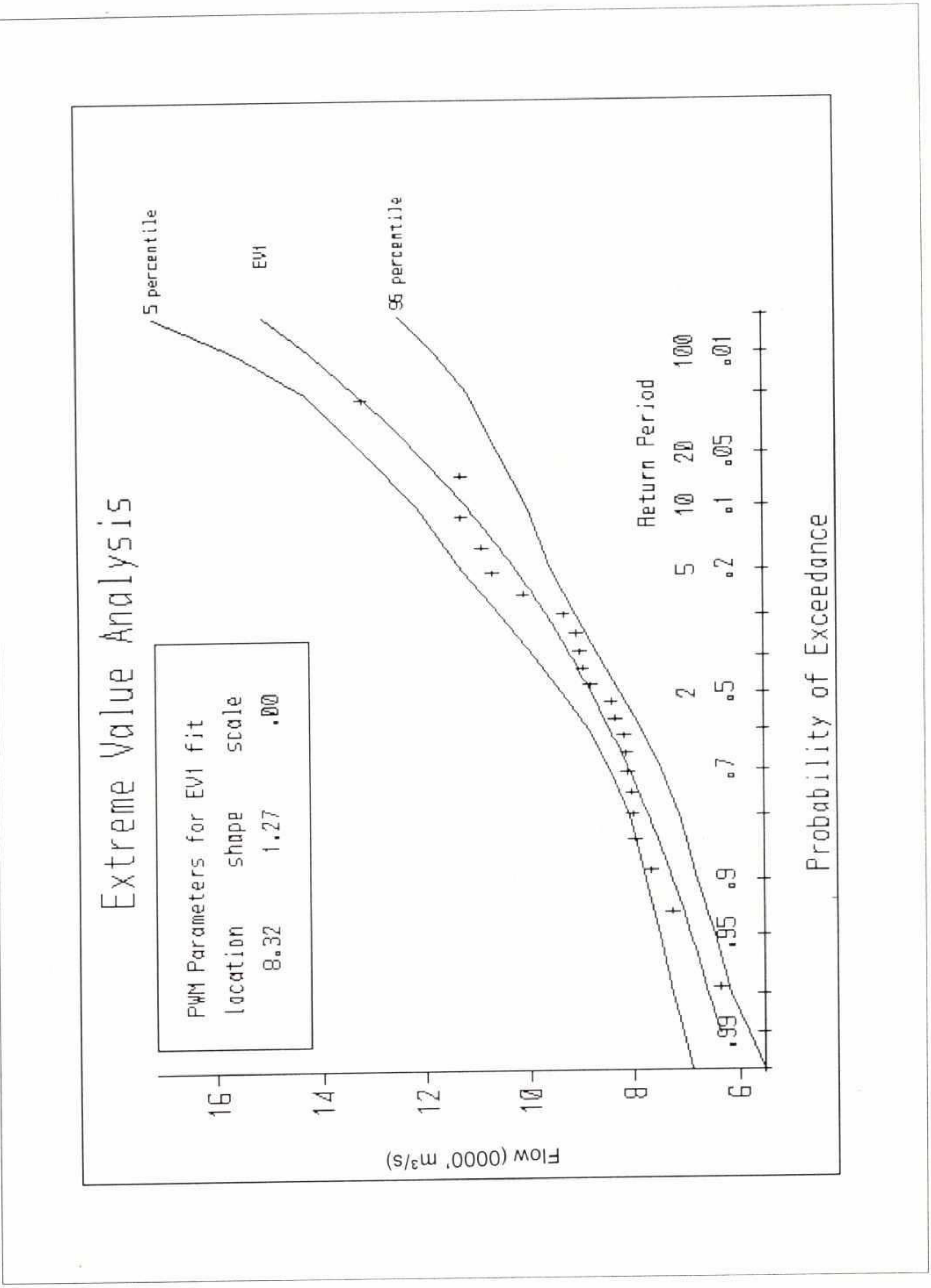
Frequency of Peak Flows - River Brahmaputra at Bahadurabad

Figure 5.8



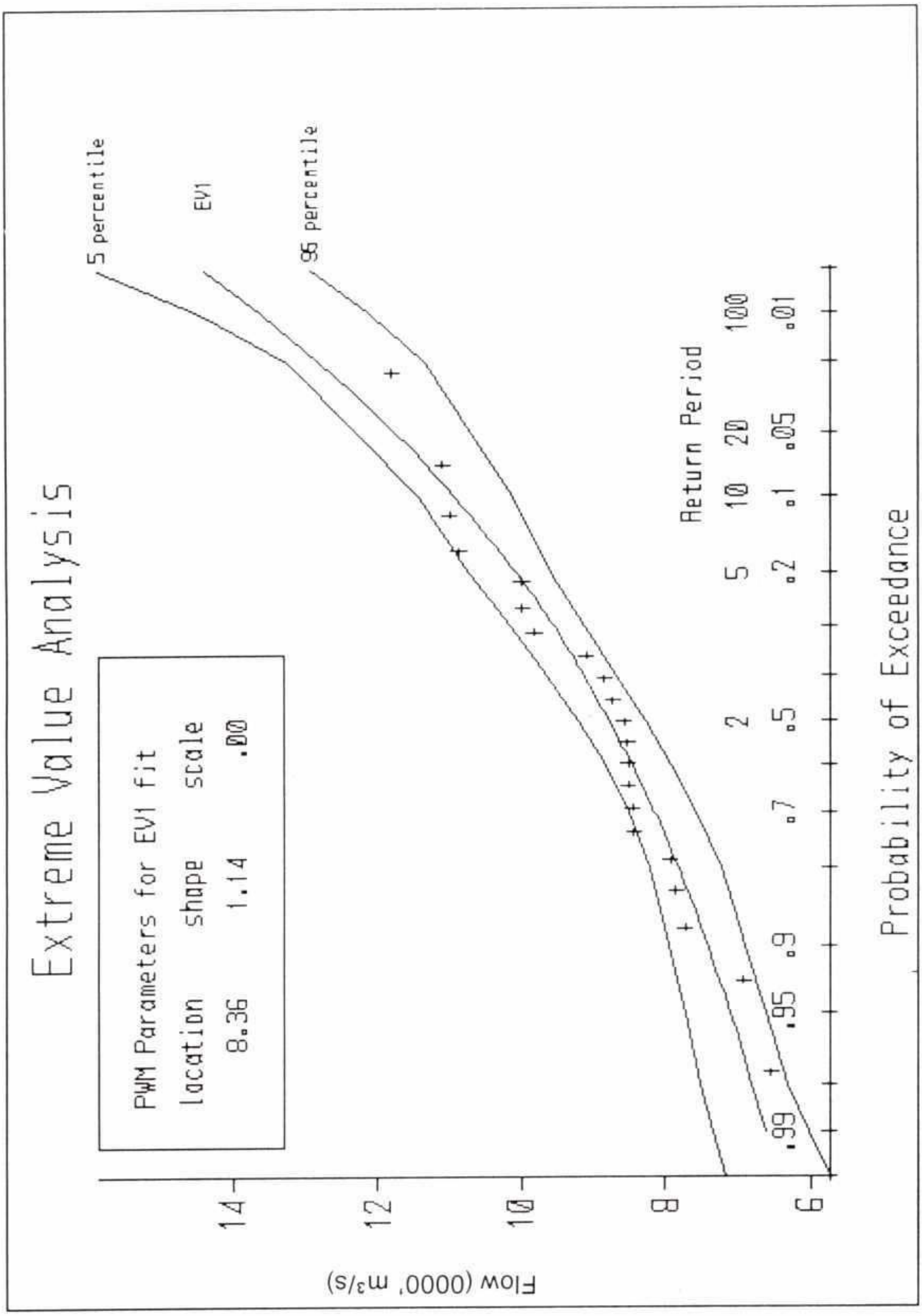
Frequency of Peak Flows - River Ganges at Hardinge Bridge

Figure 5.9



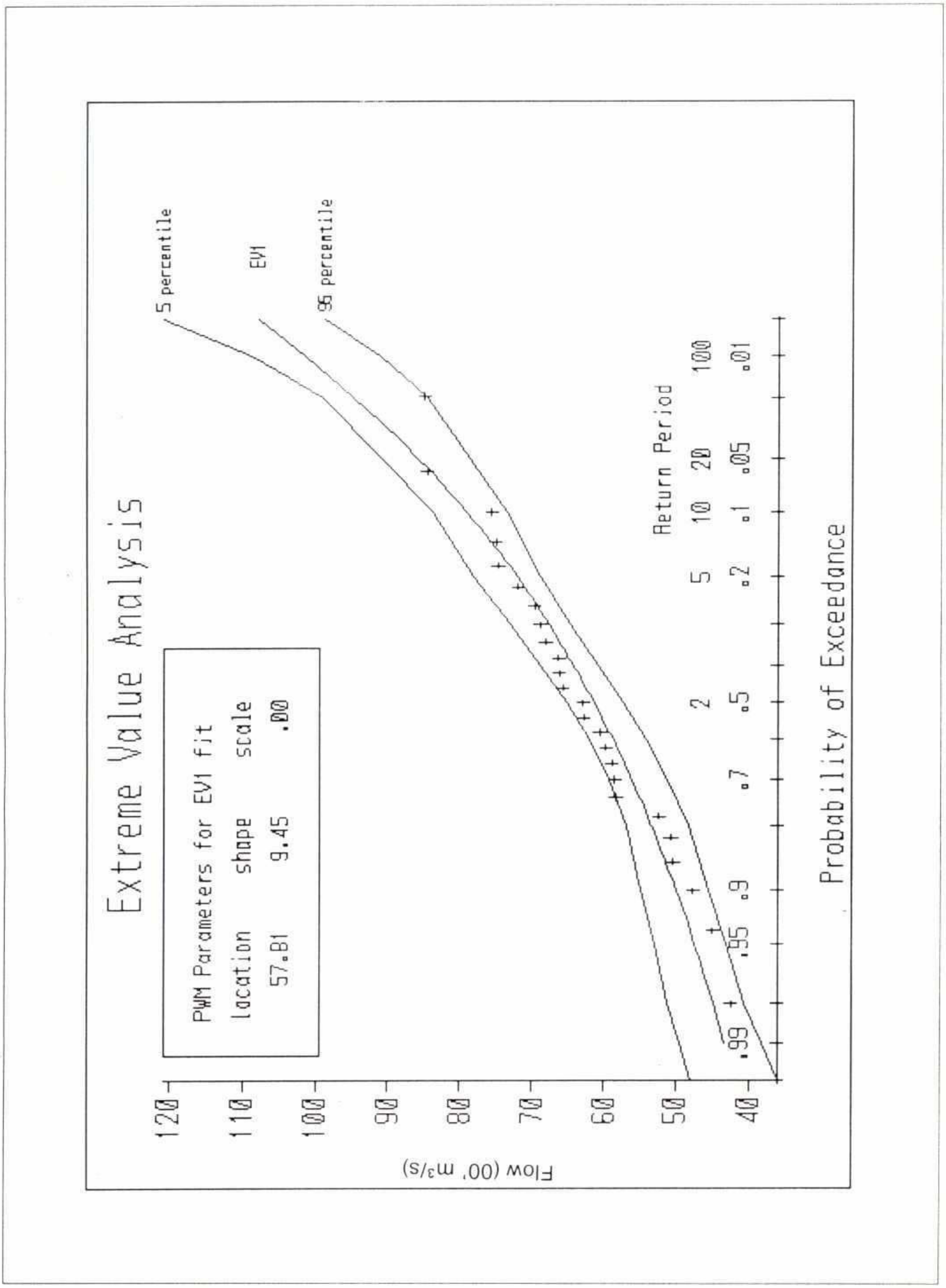
Frequency of Peak Flows - River Padma at Baruria

Figure 5.10



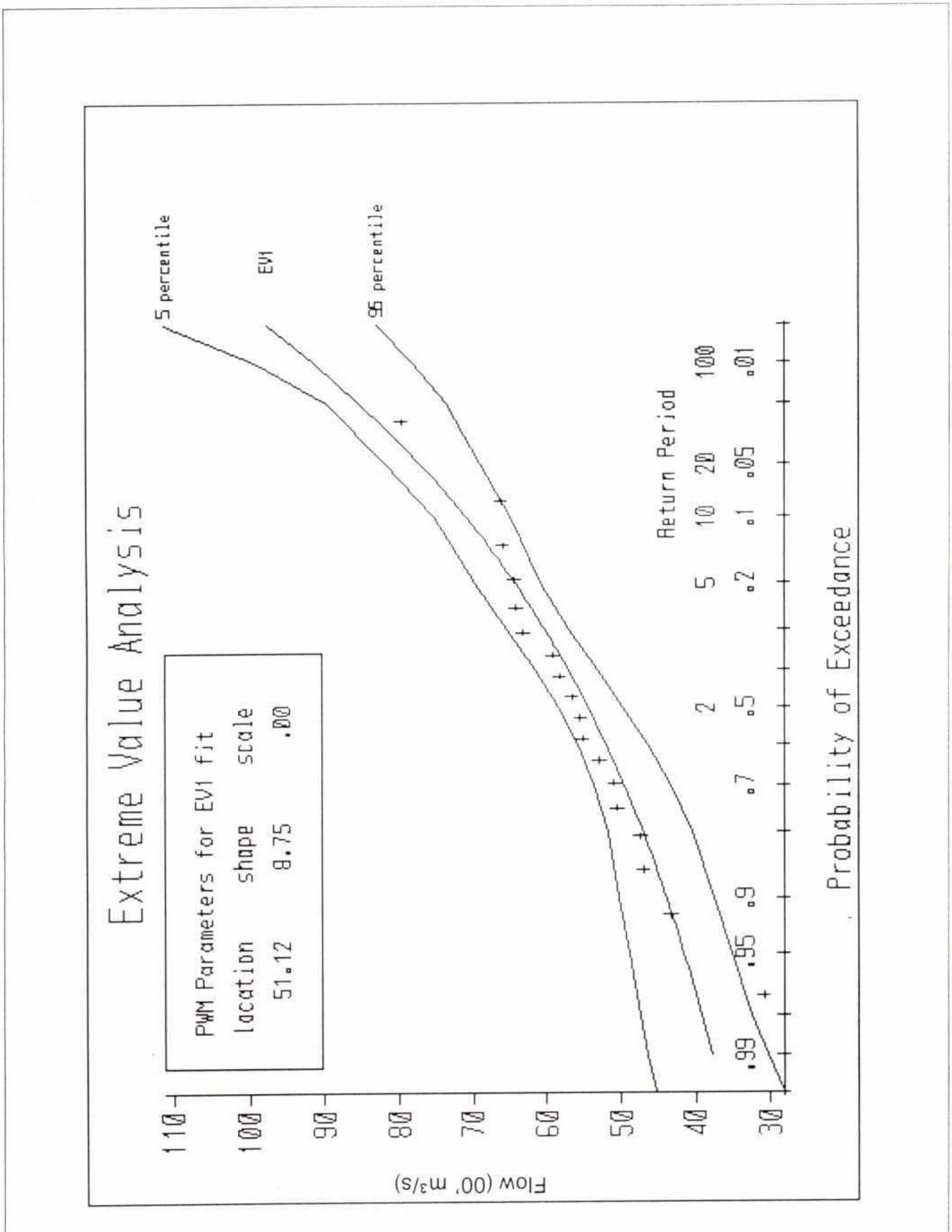
Frequency of Peak Flows - River Padma at Mawa

Figure 5.11



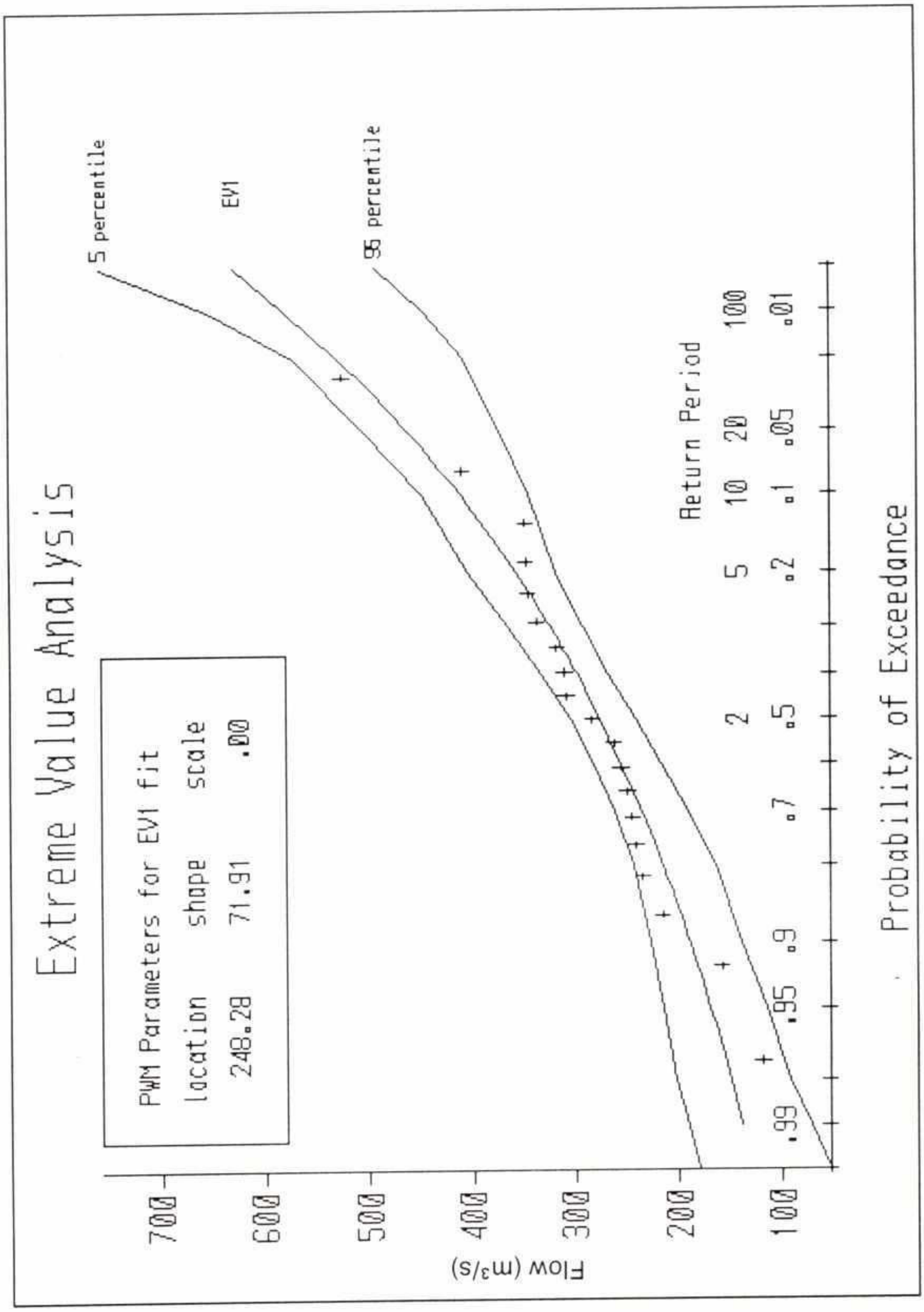
Frequency of Peak Flows - River Gorai at Gorai Railway Bridge

Figure 5.12



Frequency of Peak Flows - River Gorai at Kamarkhali

Figure 5.13



Frequency of Peak Flows - River Mathabhanga at Darsona

6 RATING CURVES

6.1 Data Availability

Rating curves for the non-tidal stations in the study area were constructed from observed discharge and water level measurements carried out by BWDB. The availability of data is shown in Table 6.1.

6.2 Observations

Measurements used in constructing rating curves have been plotted at five year intervals and are shown in Figures 6.1 to 6.5. Considerable scatter was observed at Chowdhuryhat (4A), Jhikargacha (162) and Geraganj (171). Examination of the rating curves suggests that

- at Choudharyhat on River Arial Khan (4A), the channel cross sectional area has increased with time resulting in a flatter rating curve.

- the section at Chandana Railway Bridge on River Chandana (51A) appears to be stable.

- the channel at Gorai Railway Bridge on the Gorai River (99) appears to be gradually silting up particularly in the low flow channel section although the trend is not conclusive by a visual inspection.

- the channel cross sectional area at Kamarkhali on River Gorai (101.5) appears to be increasing, probably due to scouring and/or erosion.

- the channel section at Jhikargacha on the Kobadak River (162) has undergone significant changes with time resulting in an increased cross sectional area. The scatter of measurements at the lower range of discharges is high enough to suggest that even at low lows, considerable morphological changes may have taken place.

- at Geraganj on River Kumar (171), the channel appears to have a significantly increased cross sectional area with time. The rating curve for 1984/85 is much flatter than the rating curve for 1974/75. During the calibration of the Rainfall- Runoff Model (NAM) new rating curves were developed for this station (see Volume 2, Section 4, Hydraulic Studies).

- the channel at Kazipur on River Mathabanga (205) appears to be stable.

- the channel at Hatboalia on the Mathabanga River (206) appears to be stable although there is some scatter at low flows.

- the channel at Darsona on River Mathabanga (208) appears to be stable.

Revision of rating curves and subsequent modification of discharge records has not been carried out as part of this study. Examination of records suggest that the changes due to rating curve revisions will be minor and will not change the statistics of the flow records significantly to affect the results at a regional planning level.

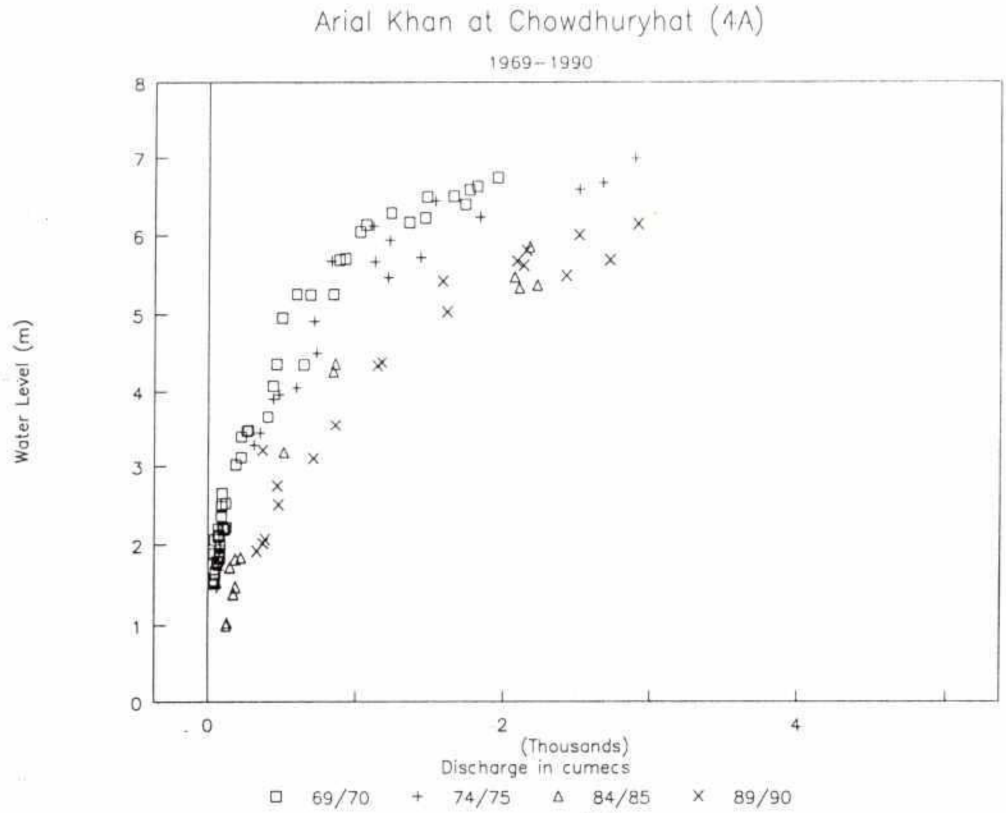
Table 6.1

Availability of Observed Water Level and Discharge Data for Construction of Rating Curves

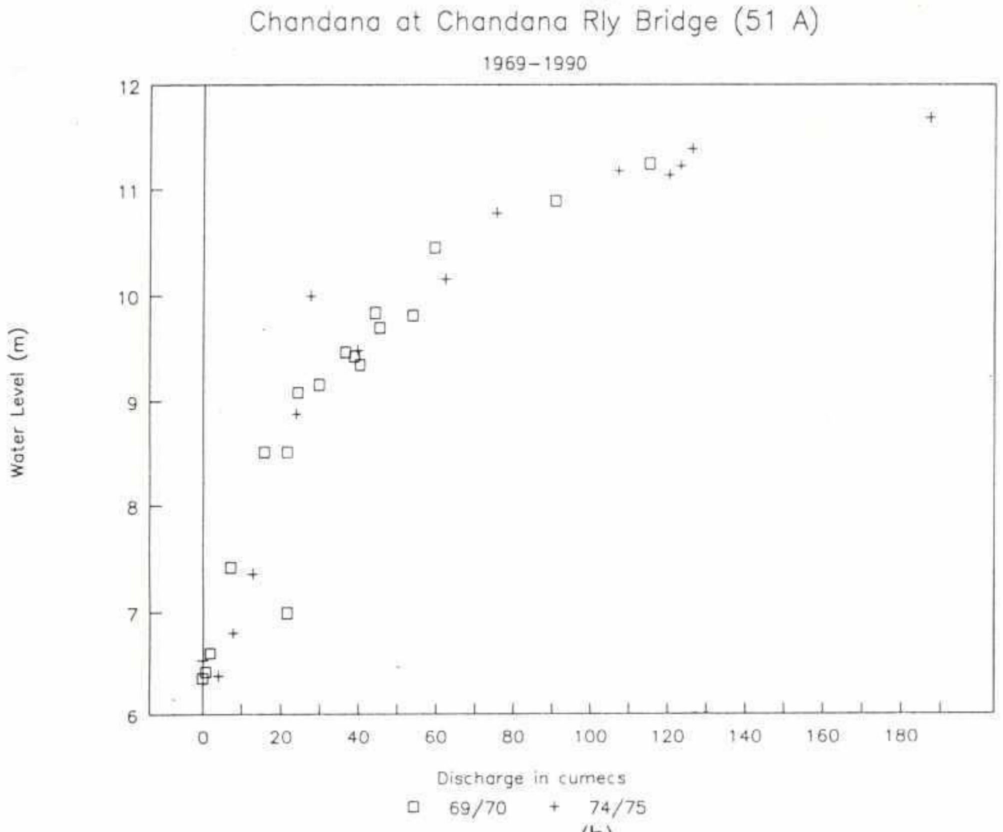
Sl.No.	Station Name	Station No.	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Chowdhuryhat (Arial Khan)	4 A		C		C	C	C		C	C	C	C	C							C	C	C	C	C	C	C	
2	Chandana Railway Bridge	51 A		C		C	C	C		C		C	C	C														
3	Gorai Rly Bridge	99		C		C	C	C		C	C	C		C							C	C	C	C	C	C	C	
4	Kamarkhali Transit	101.5		C		C	C	C		C	C	C	C	C														
5	Jhikargacha	162		C		C		C			C	C	C	C		C	C	C	C	C	C	C						
6	Ibrahimdi	167								C	C	C	C	C														
7	Geraganj	171		C		C		C		C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C		
8	Kazipur	205				C	C	C		C	C	C	C							C	C	C	C	C	C	C	C	
9	Hatboalia	206				C	C			C	C	C	C					C	C	C	C	C	C	C	C	C	C	
10	Darsona	208				C	C	C		C	C	C	C		C	C	C	C	C		C	C	C	C	C	C		
11	Magura	216 A						C						C														

C — Collected

Figure 6.1



(a)



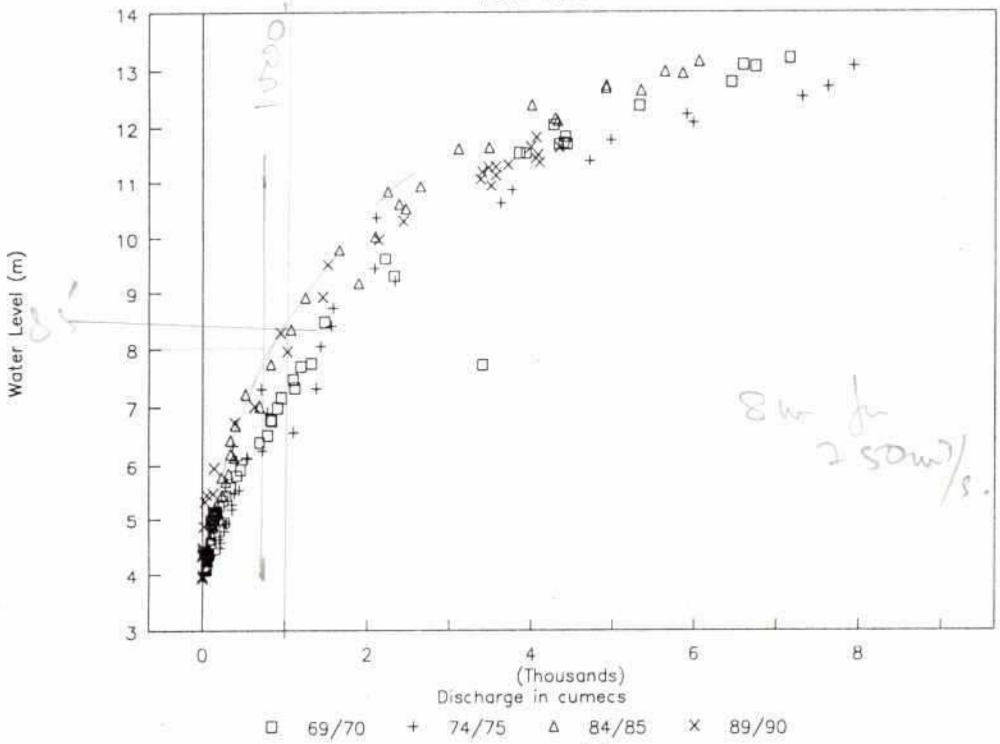
(b)

Rating Curves for Arial Khan and Chandana Rivers

Figure 6.2

Gorai at Gorai Railway Bridge (99)

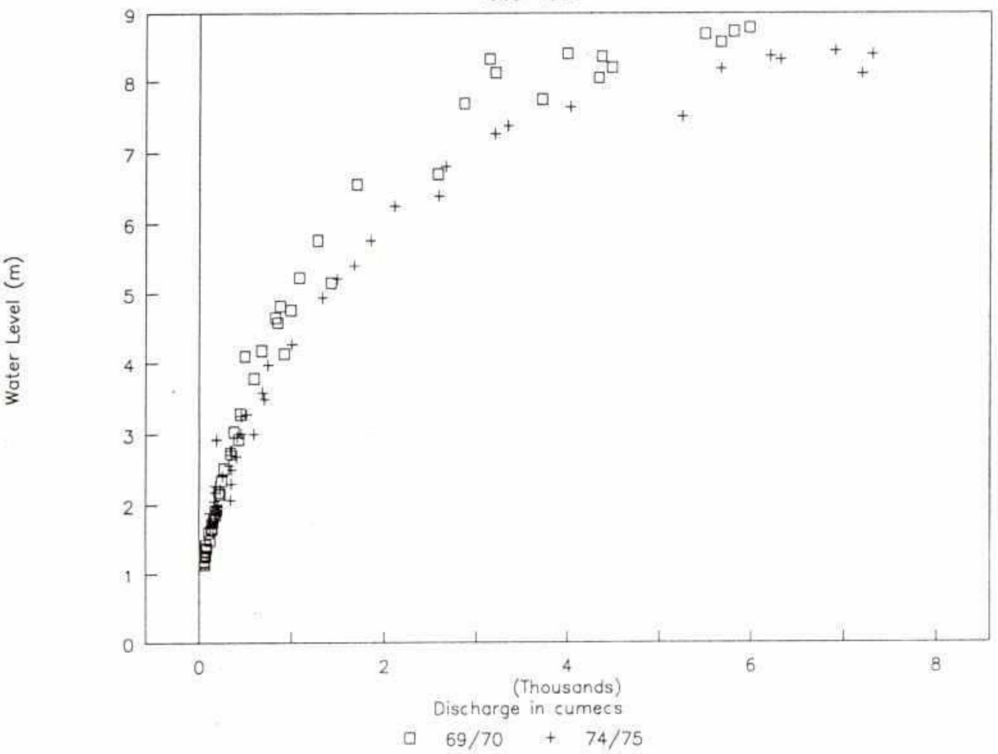
1969–1990



(a)

Gorai at Kamarkhali Transit (101.5)

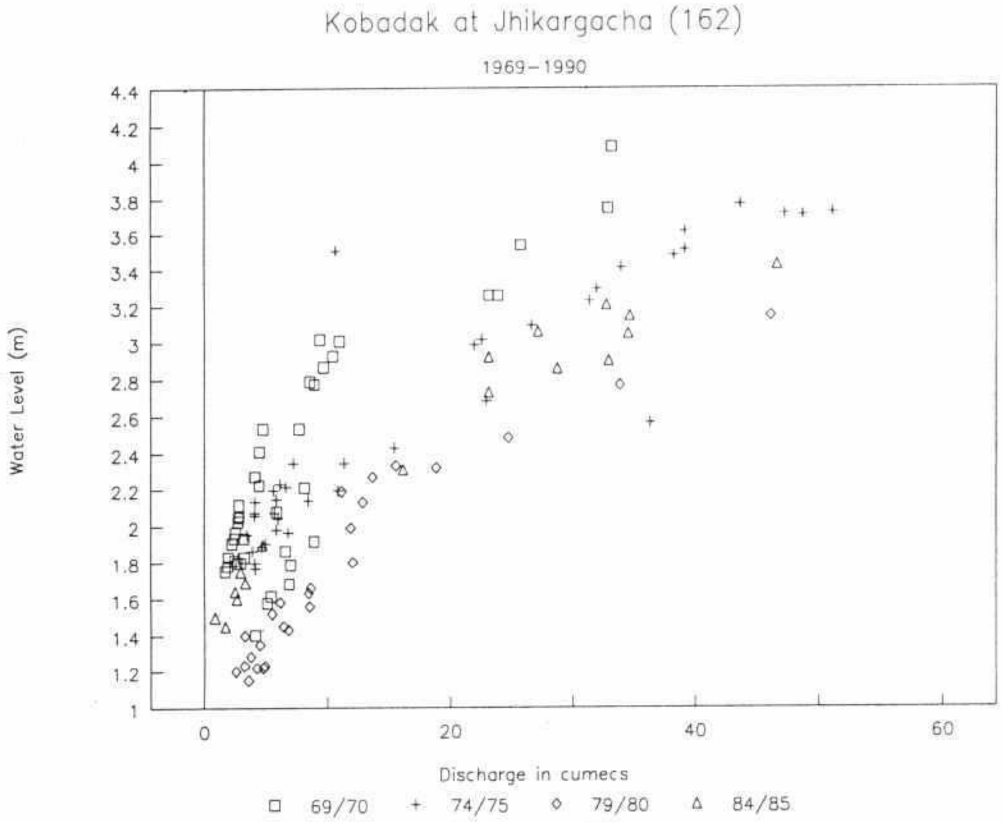
1969–1990



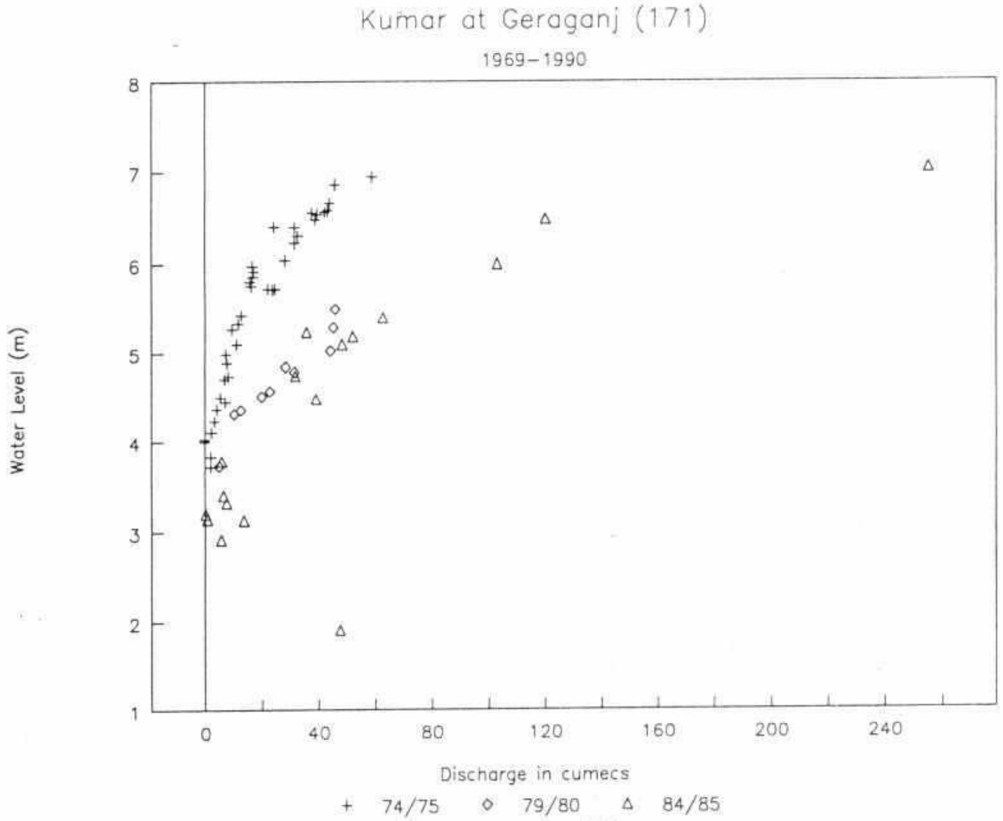
(b)

Rating Curves for River Gorai

Figure 6.3



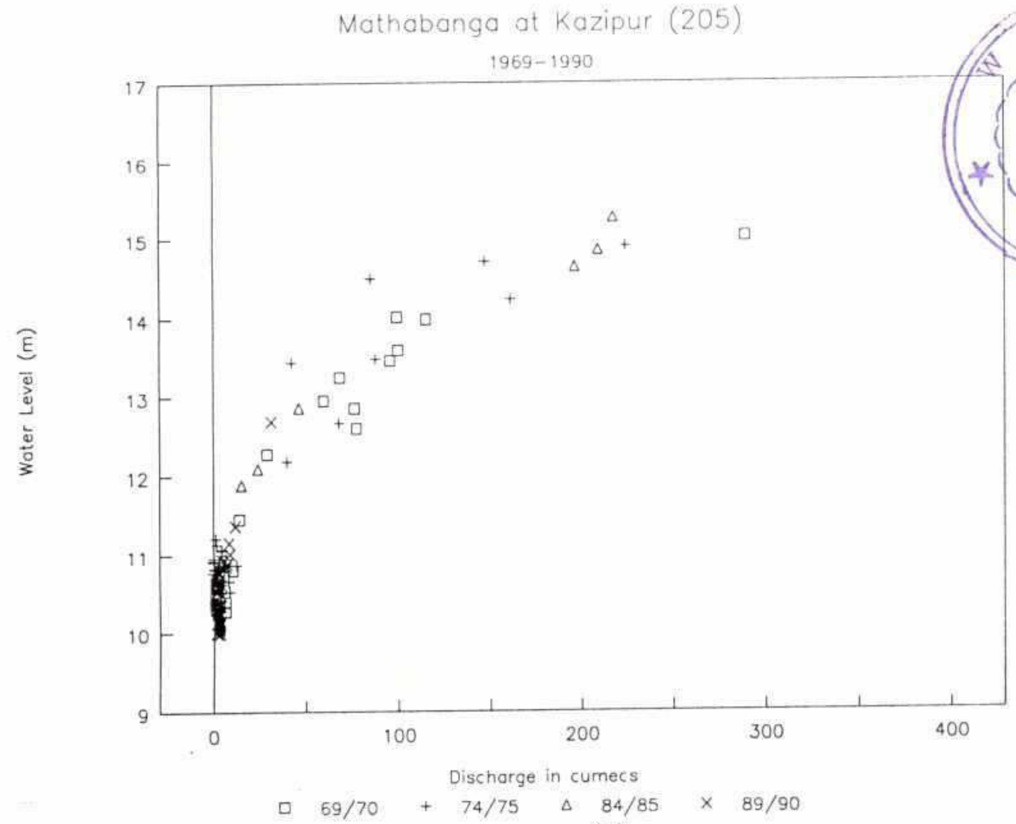
(a)



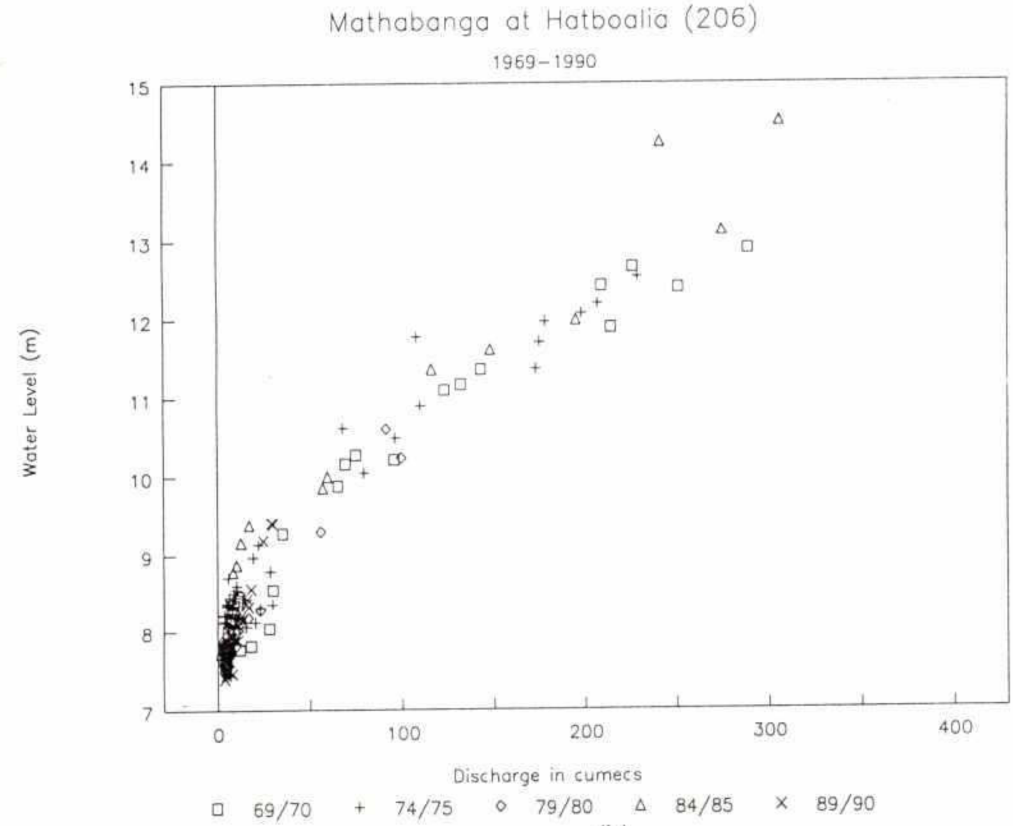
(b)

Rating Curves for Kobadak and Kumar

Figure 6.4



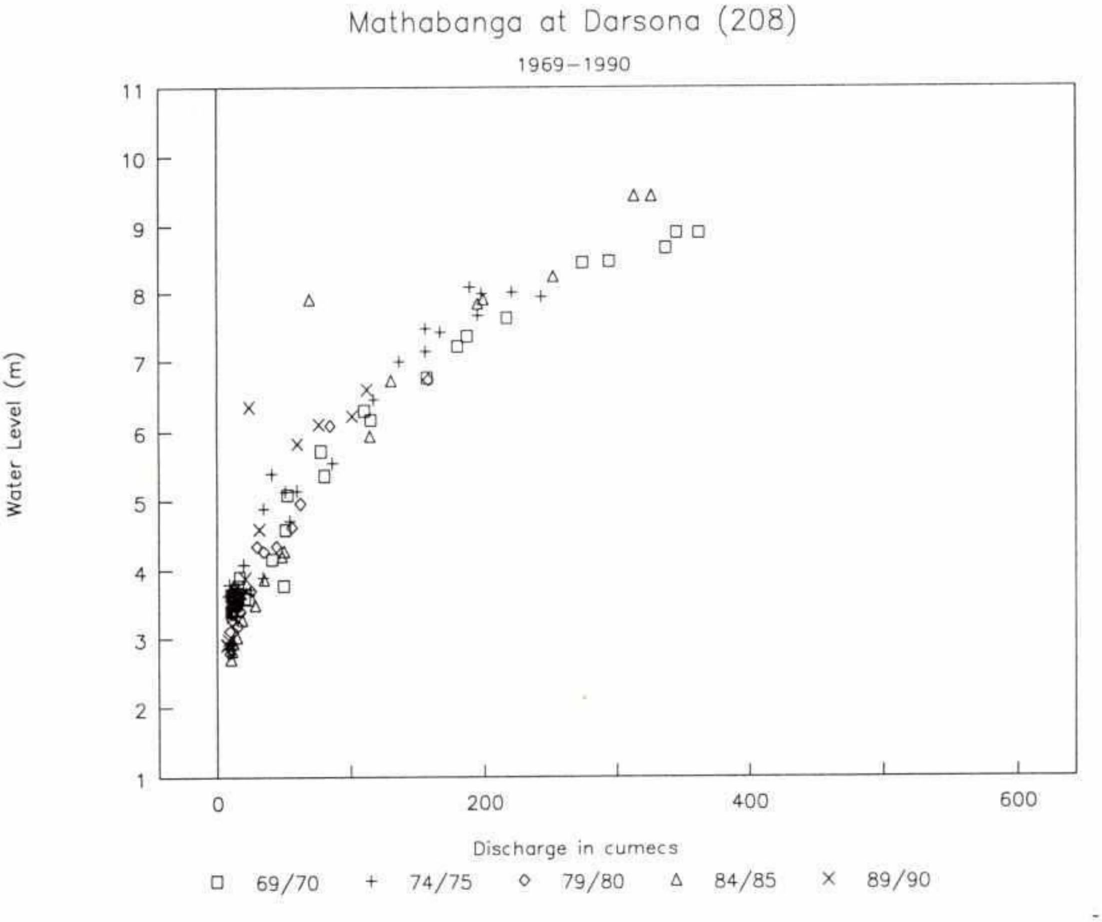
(a)



(b)

Rating Curves for River Mathabhanga

Figure 6.5



Rating Curves for River Mathabhanga

7 SALINITY

7.1 Data Availability

Long term surface salinity data was available from the Ganges Study from 1976 onwards at 76 stations in the region for which the locations of 64 stations are known. Data is sampled at high and low water slacks on a fortnightly basis. Monthly maximum salinity data has been compiled and was readily available. This data has been collected and the period of record is shown in Table 7.1. An alternative series of salinity has been collected from Khulna Newsprint Mills covering the period from 1972 to 1992. The location of the salinity sampling stations is shown in Figure 7.1.

The Delta Development Project has monitored the salinity levels at number of locations in the rivers around Polders 22 and 29. SWMC is conducting its own intensive salinity data collection programme in the region. However, this data is only be available for a limited duration and is primarily being used by SWMC to calibrate and verify the regional models.

Although the surface sampling network is extensive and covers the region adequately, there are very few automatic recorders equipped with current meters and conductivity transducers. Measurements of vertical salinity profiles are also limited and are largely confined to those collected by the Pussur Sibsa Study in 1990. Mean monthly maximum salinities in the study area are given in Table 7.2.

7.2 Long Term Trend in Salinity

The long term maximum monthly salinity series obtained from the Ganges Study show rather large variations from year to year and contain very high values in recent years, which are not consistent with the rest of the historical data. The data collected from the Khulna Newsprint Mills is believed to constitute the most reliable long term series for the area. The maximum salinity recorded in April at this location is shown in Figure 7.2. It can be seen that the year to year differences in the maximum salinity data are of similar magnitude as the range of the data. The first order differences have therefore been taken to examine the trend and a regression line has been drawn through them as shown in Figure 7.3.

As a first estimate of the trend, difference between the median of the first half of the data (1973-1982) and the second half of the data (1983-1992) is of the order of 3.72 kg/m^3. However, to characterize this change systematically over the entire period of record, the trend is best estimated in terms of the first differences and is of the order of 0.08 kg/m^3/yr as shown in Figure 7.3. Such an analysis of first order differences emphasizes that it is not the sequence of magnitude that is important but whether or not the difference from year to year is growing positively on the average in any significant way. It should be emphasised that about this average rate of increase, the year to year variability is huge and therefore the simple extrapolation of any trend would need to have added on to it the probability distribution of the salinity in any given year. Therefore, any forecast of a salinity in any given year over a future horizon is likely to have very wide confidence limits attached to it. However, the first order difference analysis has uncovered the expected rise within a hugely variable data set.

Due to the trend and the wide confidence limits attached to any estimates of maximum monthly salinity, the choice of a typical salinity year is governed by the confidence attached to the quality of the data at the boundary and monitoring points in the region. Estimates of the maximum monthly salinities from trend analysis were compared for goodness of fit with observed values and account was taken of the availibility of salinity data along the coastline which forms the boundary conditions to the models, to select a typical salinity year. 1991 was found to satisfy both criteria and the period March-April 1991 was therefore selected as a representative period for modelling the salinity intrusion in the Southwest Area.

Table 7.1

Availability of Monthly Maximum Salinity Data

Sl.No.	Station Name	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1	Abhoynagar						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2	Afrahat						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
3	Amaisor										C	C	C	C	C	C	C	C	C	C	C
4	Amtali						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
5	Arpara						C	C	C	C	C	C		C	C	C	C	C	C	C	C
6	Atharobanki						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7	Babuganj						C	C	C	C	C	C		C	C	C	C	C	C	C	C
8	Bagherhat					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
9	Bamna						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10	Bardia						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
11	Barguna						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
12	Barishal						C	C					C	C	C	C	C	C	C	C	C
13	Betagi						C	C	C	C	C	C		C	C	C	C	C	C	C	C
14	Bhatiapara						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
15	Chalna						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
16	Chandpur					C	C			C		C	C	C	C	C	C	C	C	C	C
17	Char Duani															C	C	C	C	C	C
18	Charfesion					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
19	Charpenua														C	C	C	C	C	C	C
20	Chital Khali															C	C	C	C	C	C
21	Darsona							C	C	C	C	C		C	C	C	C	C	C	C	C
22	Dasmonia					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
23	Daulat Khan					C					C	C	C	C	C	C	C	C	C	C	C
24	Dhulia				C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C
25	Dumuria							C	C	C	C	C	C	C	C	C	C	C	C	C	C
26	Gazirhat							C	C	C	C	C	C	C	C	C	C	C	C	C	C
27	Gobraghat						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
28	Golachipa					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
29	Golbonia															C	C	C	C	C	C
30	Gouranadi						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
31	Haridaspur						C		C			C	C	C	C	C	C	C	C	C	C
32	Hazimara							C		C	C	C	C	C	C	C	C	C	C	C	C
33	Hironpoint						C		C	C	C	C	C	C	C	C	C	C	C	C	C
34	Ilshaghat				C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C
35	Jhalakati														C	C	C	C	C	C	C
36	Jhikargacha						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
37	Jogikhali										C	C	C	C	C	C	C	C	C	C	C
38	Kalaroa						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
39	Kaliganj					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
40	Kamarkhali					C	C			C	C	C	C	C	C	C	C	C	C	C	C
41	Kawkhali						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
42	Keshabpur						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
43	Khulna					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
44	Lohalia												C	C	C	C	C	C	C	C	C
45	Magura						C	C	C						C	C	C	C	C	C	C

C = Collected

Contd..

Table 7.1

Availability of Monthly Maximum Salinity Data

Sl.No.	Station Name	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
46	Mirzaganj						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
47	Mollekerber														C	C	C	C	C	C	C
48	Mongla					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
49	Morelganj							C	C	C	C	C	C	C	C	C	C	C	C	C	C
50	Nalianala						C	C	C	C				C	C	C	C	C	C	C	C
51	Navaroon													C	C	C	C	C	C	C	C
52	Nilkamal							C		C	C	C	C	C	C	C	C	C	C	C	C
53	Paikgacha						C	C	C	C	C	C				C	C	C	C	C	C
54	Patgati						C	C	C		C	C	C	C	C	C	C	C	C	C	C
55	Patharghata						C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
56	Patuakhali					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
57	Pirojpur									C		C	C	C	C	C	C	C	C	C	C
58	Putkhali										C	C			C	C	C	C	C	C	C
59	Rayenda					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
60	Ramdaspur											C				C	C	C	C	C	C
61	Satkhira															C	C	C	C	C	C
62	Swarupkati								C	C	C	C	C	C	C	C	C	C	C	C	C
63	Tajumuddin					C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
64	Wazirpur						C	C	C	C	C	C		C	C	C	C	C	C	C	C
65	Jhenaidah										C	C	C	C	C						
66	Kalikapur										C	C		C	C						
67	Kathuli										C			C	C						
68	Khepupara										C	C	C	C	C						
69	Mazirhat																C	C	C	C	C
70	Mawa												C	C	C						
71	Narayanganj												C	C	C						
72	Arial Khan						C					C		C	C						
73	Satnal												C	C	C						
74	Takerhat										C	C		C	C						
75	Taherpur										C			C	C				C		
76	Tarpasha													C	C						

C Collected

Table 7.2

Mean Monthly Maximum Salinity (Micro-Mhos at 25 Degree Celsius)

Sl.No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Abhoynagar	602	673	1357	4720	2522	425					389	464
2	Afrahat	558	607	999	2274	2991	369					369	460
3	Amaisor	470	482	528	505	438	327					346	377
4	Amtali	332	947	1051	913	518	343					240	253
5	Arpara	518	552	586	541	480	399					365	470
6	Atharobanki	486	583	921	1376	1267	438					321	449
7	Babuganj	284	309	340	291	265	220					239	272
8	Bagherhat	2050	4648	9382	13014	11320	7605					767	1623
9	Bamna	518	969	1581	1120	638	700					307	382
10	Bardia	423	480	763	1640	2316	494					335	380
11	Barguna	320	672	1310	1252	712	341					267	334
12	Barishal	294	334	325	311	249	212					260	256
13	Betagi	336	337	329	357	289	255					283	336
14	Bhatiapara	403	408	440	441	432	338					321	387
15	Chalna	5890	10920	16313	21211	18739	11070					590	2215
16	Chandpur	249	270	271	230	225	187					223	262
17	Char Duani	888	1333	4975	4365	1487	673					544	652
18	Charfesion	7519	10561	15250	13466	7343	2412					2222	4125
19	Charpenua	261	323	362	291	265	233					249	248
20	Chital Khali	2467	6050	9008	7367	1195	549					405	598
21	Darsona	608	626	622	621	569	526					533	650
22	Dasmonia	293	419	995	1089	353	239					251	264
23	Daulat Khan	549	2681	2781	2563	574	387					323	455
24	Dhulia	295	325	1097	1064	286	218					251	273
25	Dumuria	3576	6688	13885	18006	19473	17790					925	1721
26	Gazirhat	495	577	1809	3993	3239	674					320	371
27	Gobraghat	598	616	617	637	634	374					419	532
28	Golachipa	325	413	1187	1518	1086	334					308	300
29	Golbonia	467	1079	2385	2508	1112	518					308	383
30	Gouranadi	320	348	352	337	282	240					283	292

Contd....

Table 7.2

Mean Monthly Maximum Salinity (Micro-Mhos at 25 Degree Celsius)

Sl.No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
31	Haridaspur	480	426	437	378	288	240					367	391
32	Hazimara	285	300	330	273	257	230					220	254
33	Hironpoint	30632	34762	39195	41109	39804	28558					16034	22969
34	Ilshaghat	344	648	1793	1724	389	237					234	261
35	Jhalakati	250	265	240	220	195	185					252	242
36	Jhikargacha	220	200	370	360	254	230					180	205
37	Jogikhali	500	540	468	490	580	350					360	450
38	Kalaroa	480	440	1000	500	670	200					200	220
39	Kaliganj	330	360	380	470	360	280					280	330
40	Kamarkhali	423	456	491	481	418	314					344	392
41	Kawkhali	238	250	280	220	150	130					195	220
42	Keshabpur	600	500	650	340	880	480					220	490
43	Khulna	380	440	1000	900	1300	190					280	280
44	Lohalia	245	250	250	200	200	185					200	220
45	Magura	420	400	520	420	440	250					280	440
46	Mirzaganj	215	240	310	240	200	180					205	205
47	Mollekerber	2800	3400	9840	2400	1600	1400					650	650
48	Mongla	2300	3700	6000	6000	7900	1900					320	425
49	Morelganj	700	1800	4000	4000	950	380					465	475
50	Nalianala	6000	9600	2000	15300	8000	3180					410	2000
51	Navaroon	260	260	320	380	280	260					200	190
52	Nilkamal	200	200	205	180	125	95					175	170
53	Paikgacha	5500	6800	8000	7500	8000	8000					675	1500
54	Patgati	260	300	360	260	230	195					240	280
55	Patharghata	525	1400	4500	3500	260	240					530	530
56	Patuakhali	225	250	300	300	200	180					200	220
57	Pirojpur	325	320	430	390	300	280					310	290
58	Putkhali	540	510	460	420	370	260					360	400
59	Rayenda	510	570	1100	1450	740	390					278	320
60	Ramdaspur	205	245	285	280	180	195					200	205

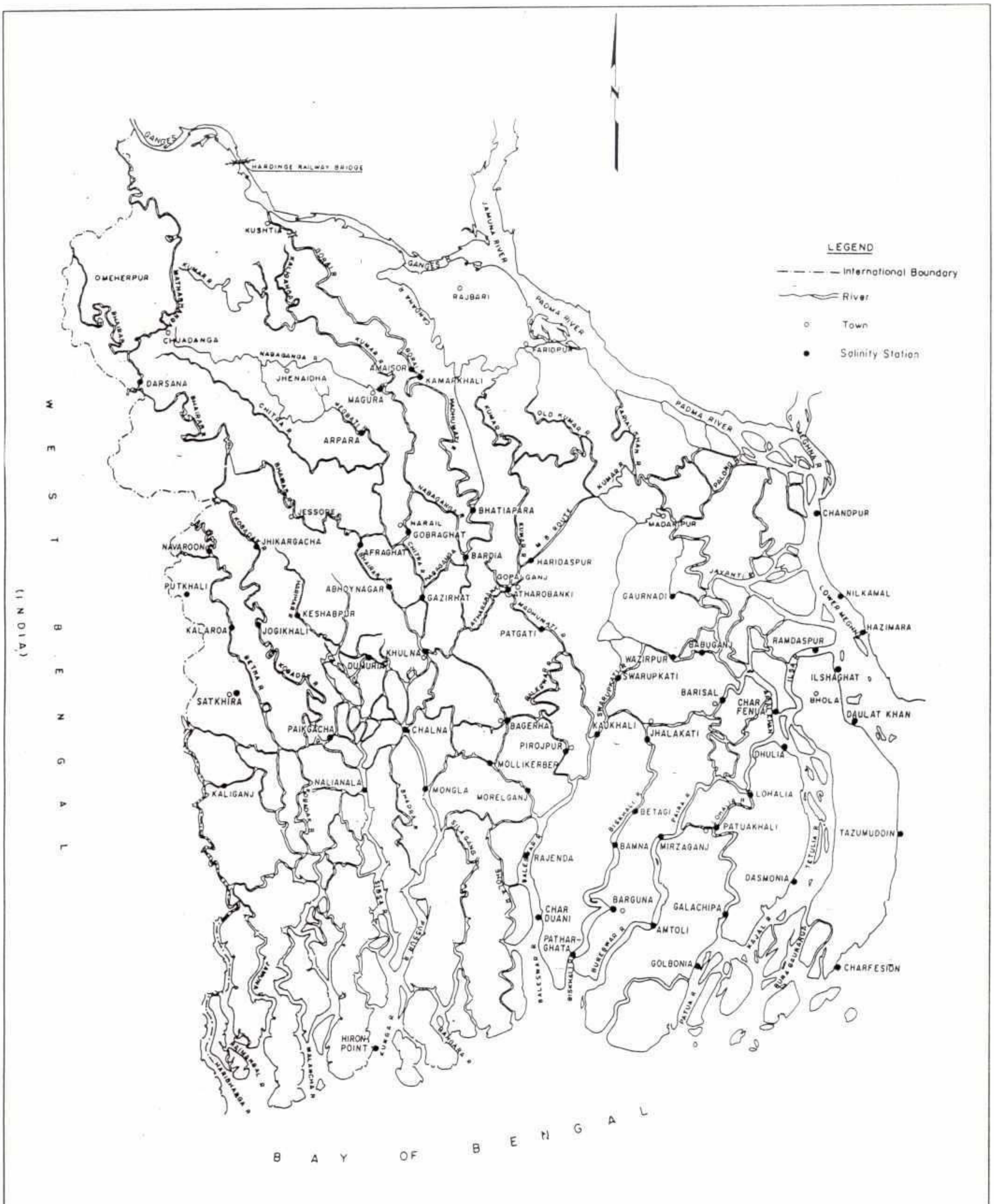
Contd....

Table 7.2

Mean Monthly Maximum Salinity (Micro-Mhos at 25 Degree Celsius)

Sl.No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
61	Satkhira	7500	8000	16500	21000	21000	2660					3000	3700
62	Swarupkati	270	260	260	230	165	150					185	205
63	Tajumuddin	380	2200	6570	5600	1200	390					280	430
64	Wazirpur	260	250	240	220	180	140					190	200
65	Jhenaidah	280	310	340	355	300	260					295	295
66	Kalikapur	340	340	240	290	210	180					280	300
67	Kathuli	460	400	395	430	300	340					370	480
68	Khepupara	8800	9000	9000	8000	6000	1300					6500	8000
69	Mazirhat	230	260	270	210	195	190					210	210
70	Mawa	320	380	360	430	600	580					380	300
71	Narayanganj	560	700	420	650	480	230					250	330
72	Arial Khan	420	490	440	250	240	210					500	320
73	Satnal	260	350	220	220	200	200					300	260
74	Takerhat	400	410	240	220	265	240					290	360
75	Taherpur	460	425	340	400	420	440					370	400
76	Tarpasha	310	380	420	390	380	380					390	300

Figure 7.1



Location of Salinity Monitoring Stations

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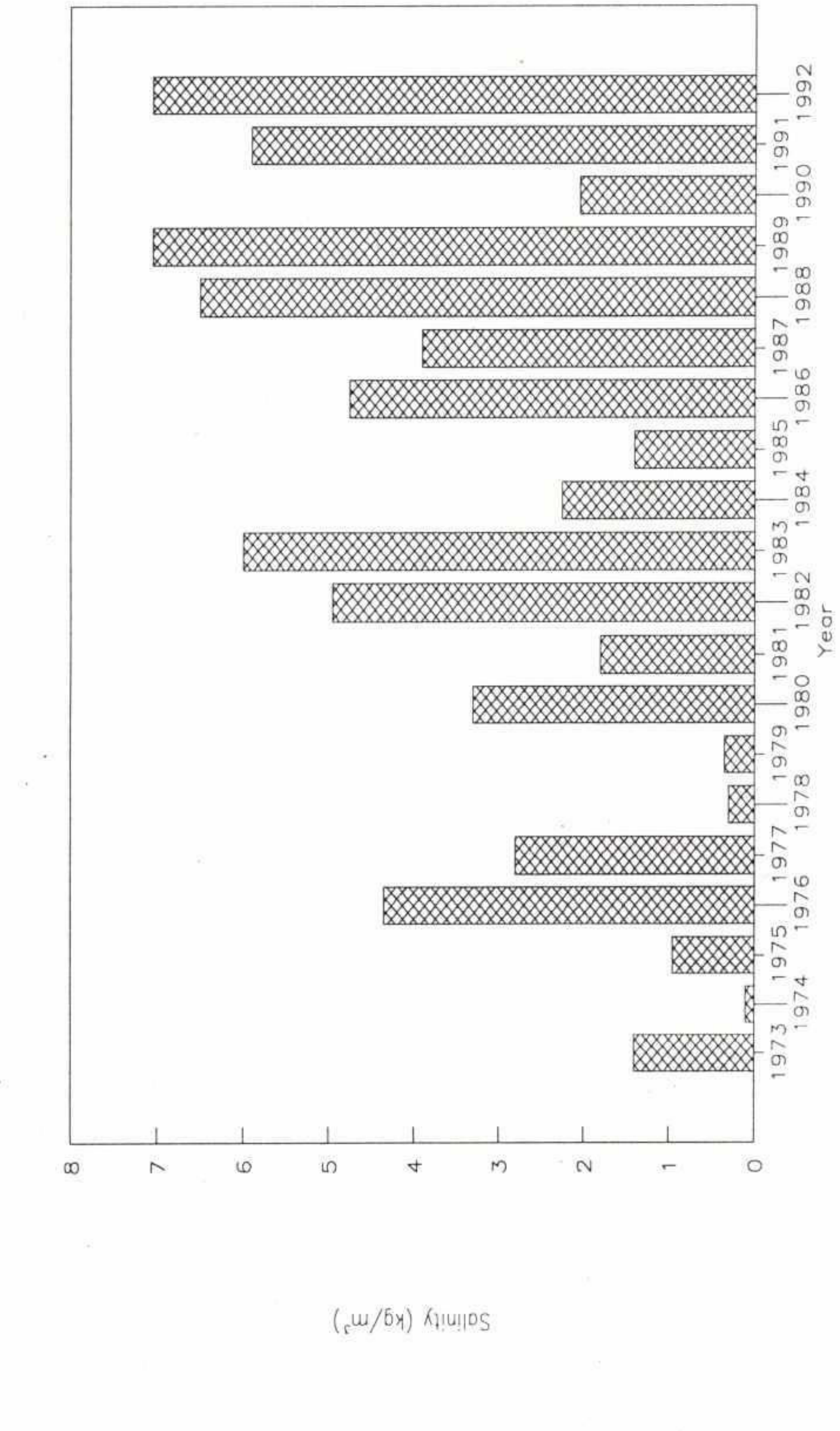
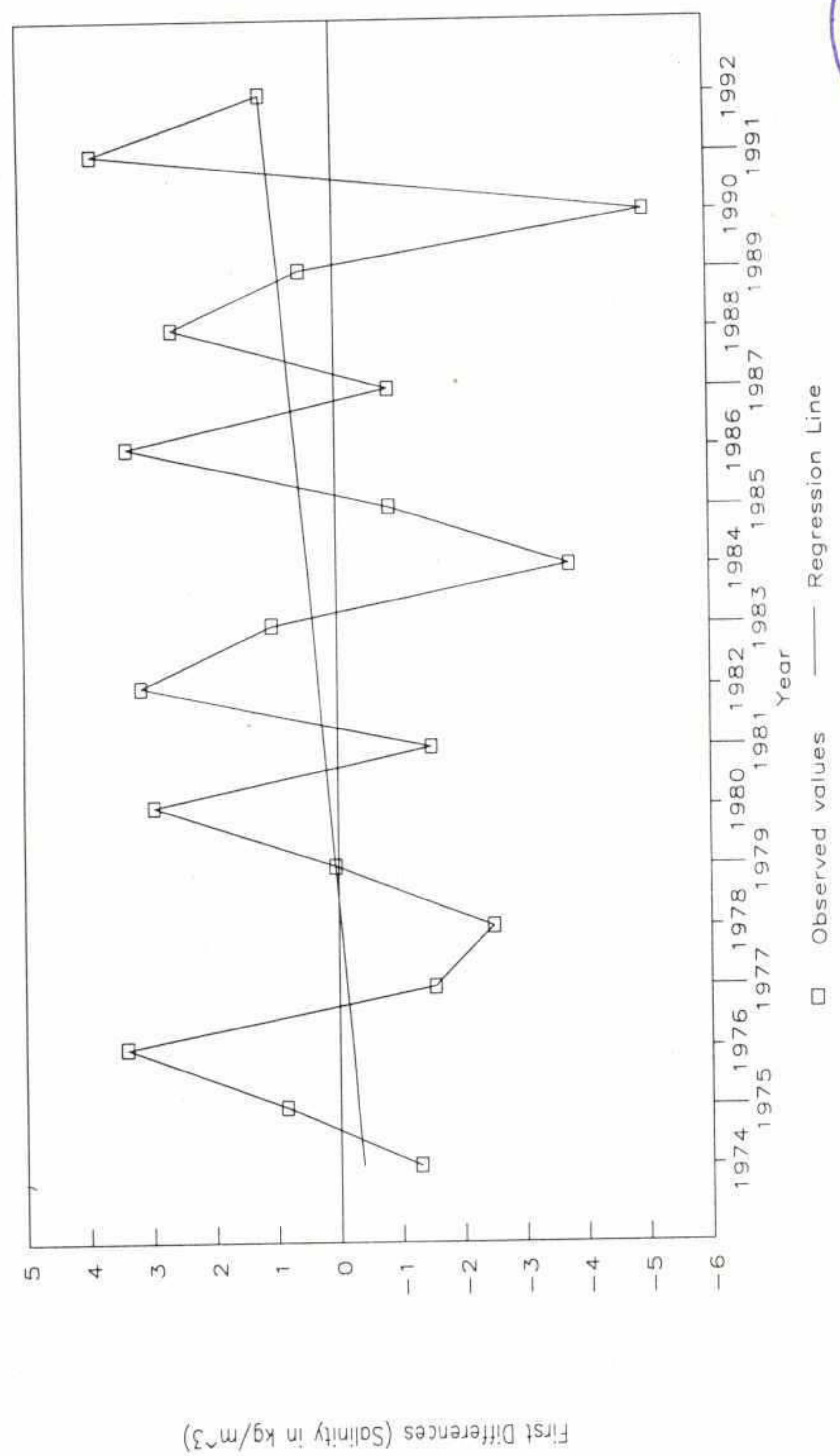
Figure 7.2



Maximum Salinity in April Measured at Khulna Newsprint Mills

Figure 7.3



First Order Difference of Maximum Salinity
in April at Khulna Newsprint Mills

8 WATER BALANCE

Long term (1965-1991) water balance in individual catchments of the study area have been computed based on the Rainfall-Runoff (NAM) simulation model. NAM is a conceptual type rainfall-runoff model with lumped parameters which computes runoff due to rainfall over a rural catchment. The NAM model operates by continuously accounting for moisture in four different storages representing the physical elements in the catchment. It takes account of irrigation and is suitable for simulating the hydrological behaviour of catchments with very flat topography and standing water condition which are found in irrigated rice areas.

Mean, median and 80% probability rainfall, runoff and groundwater recharge have been computed (see Volume 2, Section 4, Hydraulic Studies) for the existing condition scenario and are shown in Table 8.1.

Table 8.1
Long Term Rainfall–Runoff Simulation in NAM Catchments (1965–1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SW1	Rainfall (mm)	Mean	6	14	25	75	156	249	326	266	257	101	15	8	1498	
		Median	1	10	18	68	144	213	290	224	221	112	5	0	1307	
		80%	0	2	4	32	96	171	226	164	148	46	0	0	889	
	Runoff (mm)	Mean	0	0	0	0	3	23	76	153	214	189	41	3	701	46.8
		Median	0	0	0	0	1	11	54	141	196	152	26	1	582	44.6
		80%	0	0	0	0	0	5	10	44	142	117	17	0	335	37.7
	Recharge (mm)	Mean	0	0	0	4	31	78	119	124	105	60	5	1	527	35.2
		Median	0	0	0	0	25	76	124	134	108	50	0	0	516	39.5
		80%	0	0	0	0	5	55	87	102	73	13	0	0	335	37.6
SW2	Rainfall (mm)	Mean	6	19	30	89	182	250	317	281	235	120	25	9	1562	
		Median	2	16	23	78	167	228	317	247	217	110	16	0	1419	
		80%	0	2	4	37	112	185	229	196	140	66	0	0	970	
	Runoff (mm)	Mean	0	0	0	2	11	46	106	147	141	101	15	1	569	36.5
		Median	0	0	0	0	8	24	90	140	138	78	4	0	482	34.0
		80%	0	0	0	0	1	5	66	104	80	41	0	0	297	30.6
	Recharge (mm)	Mean	1	2	3	11	35	49	58	60	55	42	10	3	331	21.2
		Median	0	2	2	10	38	53	62	62	60	41	5	0	334	23.6
		80%	0	0	0	4	23	40	56	59	51	32	1	0	266	27.4
SW3	Rainfall (mm)	Mean	5	18	42	100	211	284	344	289	254	123	33	11	1714	
		Median	0	14	40	76	194	256	317	268	239	114	19	0	1536	
		80%	0	1	2	54	129	189	248	199	165	64	0	0	1052	
	Runoff (mm)	Mean	1	0	1	4	16	55	111	175	240	208	56	10	876	51.1
		Median	0	0	0	1	8	33	97	183	245	200	45	5	816	53.1
		80%	0	0	0	0	2	9	64	97	180	156	38	3	550	52.3
	Recharge (mm)	Mean	0	0	0	7	44	73	96	102	90	68	11	3	495	28.9
		Median	0	0	0	1	38	69	107	109	105	70	2	0	500	32.6
		80%	0	0	0	0	16	63	97	98	74	49	0	0	395	37.6
SW4	Rainfall (mm)	Mean	5	17	37	102	210	281	333	278	244	120	25	8	1659	
		Median	1	12	32	90	194	259	304	248	216	109	10	0	1475	
		80%	0	1	3	39	139	210	246	180	162	58	0	0	1037	
	Runoff (mm)	Mean	0	0	0	3	17	55	124	184	214	177	41	5	820	49.4
		Median	0	0	0	0	9	34	113	180	204	160	31	1	732	49.6
		80%	0	0	0	0	3	14	71	120	155	129	17	0	508	49.0
	Recharge (mm)	Mean	0	0	0	6	41	82	111	113	95	64	7	1	521	31.4
		Median	0	0	0	0	40	87	124	121	107	67	0	0	545	37.0
		80%	0	0	0	0	12	50	105	104	62	34	0	0	366	35.3
SW5	Rainfall (mm)	Mean	4	16	45	138	237	304	329	282	246	124	25	8	1756	
		Median	0	15	27	108	239	280	301	261	203	107	7	0	1549	
		80%	0	0	2	74	163	224	224	192	153	54	0	0	1087	
	Runoff (mm)	Mean	0	0	1	6	24	66	135	174	191	162	42	5	806	45.9
		Median	0	0	0	1	15	48	120	155	162	146	27	1	676	43.7
		80%	0	0	0	0	6	15	86	118	122	91	12	0	450	41.4
	Recharge (mm)	Mean	0	0	2	14	62	90	115	114	94	68	11	2	571	32.5
		Median	0	0	0	7	58	103	124	122	96	66	0	0	576	37.2
		80%	0	0	0	0	41	64	110	99	77	26	0	0	416	38.3
SW6	Rainfall (mm)	Mean	7	18	27	81	157	241	323	282	244	111	22	9	1522	
		Median	2	11	12	72	164	220	313	272	224	105	9	0	1405	
		80%	0	0	3	15	105	152	223	188	154	52	0	0	892	
	Runoff (mm)	Mean	0	0	0	3	4	24	54	97	228	228	54	6	698	- 45.9
		Median	0	0	0	0	3	14	39	71	229	212	46	4	618	44.0
		80%	0	0	0	0	1	2	13	43	145	163	30	2	399	44.7
	Recharge (mm)	Mean	0	0	0	4	25	66	112	125	100	55	5	0	492	32.3
		Median	0	0	0	0	16	54	113	137	99	52	0	0	471	33.5
		80%	0	0	0	0	0	22	74	94	76	7	0	0	273	30.6
SW7	Rainfall (mm)	Mean	6	18	35	88	184	257	327	285	240	117	29	10	1597	
		Median	1	11	26	85	174	244	328	259	214	102	15	0	1457	
		80%	0	0	2	31	120	173	211	208	159	40	0	0	945	
	Runoff (mm)	Mean	0	0	0	2	11	47	110	157	169	120	23	2	641	40.1
		Median	0	0	0	0	7	34	112	162	156	107	11	0	590	40.5
		80%	0	0	0	0	2	6	42	94	115	61	2	0	322	34.1
	Recharge (mm)	Mean	0	0	0	2	23	54	82	87	80	55	9	1	392	24.5
		Median	0	0	0	0	19	57	91	93	90	59	1	0	410	28.2
		80%	0	0	0	0	1	31	72	81	71	35	0	0	292	30.9
SW8	Rainfall (mm)	Mean	6	19	40	77	176	265	330	290	238	116	27	11	1595	
		Median	2	11	27	61	157	242	293	269	206	94	14	0	1375	
		80%	0	0	3	28	131	176	233	211	152	70	0	0	1005	
	Runoff (mm)	Mean	0	0	0	1	6	32	91	135	148	111	28	3	555	34.8
		Median	0	0	0	0	2	17	72	116	138	97	13	0	456	33.2
		80%	0	0	0	0	1	4	22	86	90	56	6	0	265	26.4
	Recharge (mm)	Mean	0	0	0	4	26	55	85	90	83	63	12	3	422	26.5
		Median	0	0	0	0	22	58	92	93	90	61	8	0	424	30.8
		80%	0	0	0	0	10	35	84	91	78	46	0	0	342	34.1

Contd....

Table 8.1
Long Term Rainfall–Runoff Simulation in NAM Catchments (1965–1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SW9	Rainfall (mm)	Mean	8	19	47	91	202	305	343	300	251	120	30	11	1727	
		Median	4	12	30	82	190	258	306	260	220	108	12	0	1482	
		80%	0	1	5	37	132	181	236	213	152	67	0	0	1024	
	Runoff (mm)	Mean	0	0	0	2	9	44	113	160	172	139	42	6	688	39.8
		Median	0	0	0	0	5	25	95	162	160	123	37	1	608	41.1
		80%	0	0	0	0	2	9	47	109	108	92	17	0	384	37.5
	Recharge (mm)	Mean	0	1	2	9	40	68	88	91	85	68	15	4	470	27.3
		Median	0	0	0	4	38	67	93	93	90	70	10	0	465	31.4
		80%	0	0	0	0	20	53	84	93	82	52	0	0	384	37.4
SW10	Rainfall (mm)	Mean	8	18	46	103	202	305	340	307	254	124	30	9	1746	
		Median	4	12	33	85	204	261	309	290	219	104	17	0	1538	
		80%	0	2	3	43	128	206	238	189	177	61	0	0	1047	
	Runoff (mm)	Mean	1	0	0	2	11	46	99	154	183	159	56	12	724	41.5
		Median	0	0	0	0	6	28	72	136	164	155	45	7	614	39.9
		80%	0	0	0	0	1	17	52	100	123	110	31	5	439	42.0
	Recharge (mm)	Mean	0	0	1	7	26	50	60	61	58	51	18	3	335	19.2
		Median	0	0	0	3	27	54	62	62	60	62	11	0	340	22.1
		80%	0	0	0	0	13	40	61	62	60	46	2	0	284	27.1
SW11	Rainfall (mm)	Mean	7	20	46	125	222	287	331	282	260	127	36	10	1752	
		Median	0	12	36	105	219	277	279	240	247	89	15	0	1520	
		80%	0	2	3	53	139	190	226	189	159	57	0	0	1017	
	Runoff (mm)	Mean	2	0	1	5	16	56	111	159	178	153	59	16	754	43.0
		Median	0	0	0	1	9	37	104	148	163	141	45	8	657	43.2
		80%	0	0	0	0	4	19	57	106	131	95	29	3	442	43.4
	Recharge (mm)	Mean	1	2	5	16	34	42	46	46	44	40	20	7	305	17.4
		Median	0	1	3	13	36	45	47	47	45	47	18	1	301	19.8
		80%	0	0	0	5	25	39	47	47	45	34	4	0	246	24.2
SW12	Rainfall (mm)	Mean	7	17	47	143	239	315	347	278	239	135	38	10	1817	
		Median	1	16	46	115	252	286	312	253	212	107	19	1	1620	
		80%	0	2	4	71	160	236	266	195	173	61	0	0	1166	
	Runoff (mm)	Mean	1	0	0	6	21	68	137	172	175	148	57	14	801	44.1
		Median	0	0	0	0	11	50	141	171	166	136	45	6	727	44.9
		80%	0	0	0	0	3	19	87	114	145	110	27	2	508	43.6
	Recharge (mm)	Mean	1	2	6	22	47	56	62	62	60	53	22	7	399	21.9
		Median	0	1	5	18	48	58	62	62	60	59	20	0	394	24.3
		80%	0	0	0	9	35	51	62	62	60	49	7	0	335	28.8
SW13	Rainfall (mm)	Mean	9	19	33	67	154	273	324	299	244	115	27	12	1576	
		Median	1	6	26	47	125	238	313	311	216	107	8	0	1396	
		80%	0	0	3	26	105	161	215	196	118	55	0	0	879	
	Runoff (mm)	Mean	0	0	0	1	3	27	87	131	159	125	36	4	572	36.3
		Median	0	0	0	0	1	10	90	140	133	116	23	0	513	36.7
		80%	0	0	0	0	0	2	11	62	90	51	4	0	220	25.0
	Recharge (mm)	Mean	2	4	6	14	45	75	107	109	101	73	16	6	557	35.4
		Median	0	1	3	8	39	82	120	119	103	83	7	0	565	40.5
		80%	0	0	0	2	29	48	93	96	91	30	0	0	390	44.3
SW14	Rainfall (mm)	Mean	10	21	41	87	190	317	359	334	258	129	29	11	1787	
		Median	5	14	29	74	171	275	339	308	207	123	19	0	1563	
		80%	0	1	2	36	119	203	267	214	157	75	1	0	1074	
	Runoff (mm)	Mean	0	0	0	1	7	41	127	174	166	124	35	3	678	37.9
		Median	0	0	0	0	3	21	121	160	134	115	18	0	572	36.6
		80%	0	0	0	0	0	6	54	128	110	53	2	0	354	32.9
	Recharge (mm)	Mean	2	2	5	13	50	91	117	120	108	81	20	6	614	34.3
		Median	1	0	1	13	43	94	124	124	112	92	10	0	614	39.3
		80%	0	0	0	1	29	69	115	117	98	43	0	0	472	44.0
SW15	Rainfall (mm)	Mean	14	28	46	98	215	384	418	384	296	135	34	11	2062	
		Median	6	13	32	77	200	313	396	366	259	123	18	0	1802	
		80%	0	0	1	37	140	213	275	253	150	61	0	0	1129	
	Runoff (mm)	Mean	1	0	0	2	15	77	181	238	226	167	62	8	979	47.4
		Median	0	0	0	0	10	77	187	232	201	145	26	1	880	48.8
		80%	0	0	0	0	1	18	106	156	160	78	11	0	530	47.0
	Recharge (mm)	Mean	4	6	9	20	53	77	92	93	88	74	35	6	558	27.1
		Median	2	2	5	15	53	87	93	93	90	90	32	0	562	31.2
		80%	0	0	0	6	38	62	93	93	90	53	3	0	438	38.8
SW16	Rainfall (mm)	Mean	8	17	44	118	202	378	394	364	299	160	38	13	2036	
		Median	2	10	21	95	203	333	388	316	249	178	14	0	1811	
		80%	0	0	0	52	143	241	259	243	200	68	1	0	1208	
	Runoff (mm)	Mean	1	0	0	6	15	67	165	221	213	166	68	12	934	45.9
		Median	0	0	0	1	8	41	167	216	191	164	61	1	849	46.9
		80%	0	0	0	0	3	24	110	156	149	80	9	0	529	43.8
	Recharge (mm)	Mean	2	2	5	18	50	79	91	93	90	76	36	9	550	27.0
		Median	0	1	0	13	50	85	93	93	90	93	32	0	550	30.4
		80%	0	0	0	3	31	69	93	93	90	53	5	0	437	36.2

Contd....

Table 8.1
Long Term Rainfall–Runoff Simulation in NAM Catchments (1965–1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SW17	Rainfall (mm)	Mean	8	19	49	128	213	334	354	289	242	127	35	10	1806	
		Median	2	12	37	114	213	334	327	250	231	92	22	0	1635	
		80%	0	1	2	80	135	242	250	206	152	50	0	0	1118	
	Runoff (mm)	Mean	1	0	1	4	19	67	138	173	174	142	53	12	784	43.4
		Median	0	0	0	2	14	65	133	166	166	123	48	5	722	44.2
		80%	0	0	0	0	4	34	105	123	124	82	18	2	493	44.1
	Recharge (mm)	Mean	1	1	2	10	25	35	40	40	39	36	19	5	252	14.0
		Median	0	0	0	8	26	37	40	40	39	40	20	0	251	15.4
		80%	0	0	0	2	18	34	40	40	39	35	8	0	216	19.3
SW18	Rainfall (mm)	Mean	15	27	33	69	141	275	335	328	283	110	26	11	1654	
		Median	6	10	22	63	128	238	329	294	237	92	13	0	1431	
		80%	0	1	2	35	79	159	240	240	141	39	0	0	935	
	Runoff (mm)	Mean	1	1	0	1	4	26	105	165	189	147	43	7	689	41.7
		Median	0	0	0	0	1	13	96	150	163	121	25	1	569	39.7
		80%	0	0	0	0	0	4	45	107	132	75	7	0	370	39.5
	Recharge (mm)	Mean	4	5	6	14	43	79	113	122	108	76	17	5	592	35.8
		Median	1	1	2	11	38	79	121	124	117	80	6	0	579	40.5
		80%	0	0	0	4	21	57	108	124	96	32	0	0	442	47.3
SW19	Rainfall (mm)	Mean	11	24	37	66	148	292	350	325	277	115	28	10	1682	
		Median	6	10	25	60	135	239	321	291	224	108	11	0	1430	
		80%	0	1	0	28	91	186	255	237	146	44	0	0	989	
	Runoff (mm)	Mean	0	0	0	1	4	30	107	171	181	139	42	6	682	40.5
		Median	0	0	0	0	2	18	95	169	168	108	17	0	577	40.3
		80%	0	0	0	0	0	5	44	119	128	65	3	0	365	36.9
	Recharge (mm)	Mean	3	4	6	12	38	67	90	93	85	64	21	6	487	29.0
		Median	1	1	3	10	38	66	93	93	90	64	6	0	465	32.5
		80%	0	0	0	3	20	56	93	93	87	40	0	0	391	39.5
SW20	Rainfall (mm)	Mean	11	25	43	72	184	311	370	329	276	119	31	10	1780	
		Median	3	16	24	62	167	247	350	293	214	110	8	0	1492	
		80%	0	0	2	35	118	195	292	196	142	55	0	0	1035	
	Runoff (mm)	Mean	2	1	1	4	6	31	108	184	219	185	67	16	823	46.2
		Median	0	0	0	0	2	20	100	198	219	146	55	10	751	50.3
		80%	0	0	0	0	1	5	42	132	162	126	29	3	500	48.3
	Recharge (mm)	Mean	2	4	7	14	49	80	102	105	96	71	23	5	558	31.3
		Median	0	1	2	10	45	85	109	109	105	58	7	0	531	35.6
		80%	0	0	0	3	27	69	104	109	93	39	0	0	443	42.8
SW21	Rainfall (mm)	Mean	9	21	35	82	195	335	400	388	290	138	24	9	1927	
		Median	1	5	14	65	189	279	366	301	220	101	12	0	1552	
		80%	0	0	1	29	115	192	267	229	156	41	0	0	1028	
	Runoff (mm)	Mean	0	0	1	1	12	58	146	209	211	169	63	11	882	45.8
		Median	0	0	0	0	6	36	130	201	167	157	49	4	751	48.4
		80%	0	0	0	0	2	19	71	122	126	51	7	0	398	38.8
	Recharge (mm)	Mean	1	1	2	5	21	36	45	46	45	40	22	6	269	13.9
		Median	0	0	0	3	21	39	46	47	45	47	23	1	270	17.4
		80%	0	0	0	0	10	26	45	47	45	32	5	0	209	20.4
SW22	Rainfall (mm)	Mean	12	26	33	61	134	307	378	349	312	138	37	13	1801	
		Median	2	10	14	41	115	242	347	346	266	139	18	0	1541	
		80%	0	0	1	20	50	183	302	272	149	62	0	0	1038	
	Runoff (mm)	Mean	1	0	0	1	3	32	142	204	199	146	45	8	780	43.3
		Median	0	0	0	0	1	15	113	195	197	115	24	0	660	42.8
		80%	0	0	0	0	0	4	82	150	135	53	1	0	425	40.9
	Recharge (mm)	Mean	4	6	7	14	46	99	147	150	133	94	25	9	734	40.7
		Median	1	2	2	9	37	96	155	155	150	106	10	0	721	46.8
		80%	0	0	0	2	12	66	147	148	116	43	0	0	535	51.5
SW23	Rainfall (mm)	Mean	12	22	35	75	165	322	386	336	285	135	32	14	1820	
		Median	1	16	18	55	163	283	361	335	251	108	10	0	1601	
		80%	0	0	0	24	105	199	288	261	156	56	0	0	1088	
	Runoff (mm)	Mean	10	5	4	7	24	68	154	194	182	148	72	28	895	49.2
		Median	6	4	3	3	18	71	145	191	180	129	57	18	824	51.5
		80%	4	1	1	0	9	39	90	153	150	82	24	13	568	52.2
	Recharge (mm)	Mean	2	3	4	11	37	61	76	77	73	65	29	9	446	24.5
		Median	0	1	1	7	37	65	78	78	75	78	20	0	438	27.3
		80%	0	0	0	1	22	49	78	78	75	41	2	0	345	31.7
SW24	Rainfall (mm)	Mean	10	24	40	90	185	377	450	385	309	150	43	13	2076	
		Median	3	17	23	83	191	323	489	378	266	120	19	0	1912	
		80%	0	0	0	31	95	272	322	259	187	82	0	0	1249	
	Runoff (mm)	Mean	5	4	5	15	45	128	249	279	242	168	66	18	1222	58.9
		Median	2	2	3	6	47	116	224	266	212	174	45	11	1108	58.0
		80%	1	1	1	1	15	84	174	198	179	82	22	5	762	61.0
	Recharge (mm)	Mean	2	4	7	21	62	115	150	153	137	93	27	5	777	37.4
		Median	0	1	2	17	62	122	155	155	143	112	11	0	781	40.9
		80%	0	0	0	3	34	92	155	155	132	43	1	0	615	49.3

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Table 8.1
Long Term Rainfall-Runoff Simulation in NAM Catchments (1965-1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SW25	Rainfall (mm)	Mean	11	23	49	101	212	417	463	409	310	147	38	11	2191	
		Median	6	13	28	79	225	386	444	401	252	145	17	0	1996	
		80%	0	1	1	31	114	281	348	272	180	71	2	0	1302	
	Runoff (mm)	Mean	1	0	0	6	19	98	234	282	254	183	68	11	1158	52.9
		Median	0	0	0	0	14	80	230	277	240	158	54	2	1055	52.9
		80%	0	0	0	0	1	34	171	211	198	122	13	0	750	57.6
	Recharge (mm)	Mean	1	1	3	11	49	97	124	124	119	100	31	5	663	30.3
		Median	0	0	0	2	50	109	124	124	120	121	14	0	664	33.3
		80%	0	0	0	0	18	80	124	124	120	71	2	0	539	41.4
SW26	Rainfall (mm)	Mean	13	26	37	79	177	339	385	347	280	133	34	13	1863	
		Median	1	10	21	52	164	300	370	335	258	105	20	0	1635	
		80%	0	0	0	33	116	199	261	235	148	58	0	0	1049	
	Runoff (mm)	Mean	2	1	0	3	12	68	182	220	198	146	53	9	894	48.0
		Median	0	0	0	0	6	53	177	217	177	150	41	1	822	50.3
		80%	0	0	0	0	1	30	119	148	150	52	4	0	504	48.0
	Recharge (mm)	Mean	4	6	7	18	56	93	120	122	112	86	27	7	657	35.3
		Median	0	2	2	10	52	93	124	124	120	107	9	0	643	39.3
		80%	0	0	0	5	33	79	124	124	109	32	0	0	505	48.1
SW27	Rainfall (mm)	Mean	11	17	28	66	162	359	461	443	351	175	48	12	2133	
		Median	2	11	11	34	167	296	434	465	321	166	28	0	1934	
		80%	0	0	0	19	52	235	326	350	244	95	1	0	1322	
	Runoff (mm)	Mean	8	3	3	7	27	85	207	273	263	201	94	31	1203	56.4
		Median	6	2	1	1	24	79	196	257	243	185	76	24	1095	56.7
		80%	3	1	1	0	7	47	136	187	215	158	44	15	814	61.6
	Recharge (mm)	Mean	2	2	4	10	39	73	92	93	90	88	40	9	541	25.3
		Median	0	0	1	4	43	83	93	93	90	93	31	0	531	27.5
		80%	0	0	0	1	9	60	93	93	90	88	11	0	444	33.6
SC1	Rainfall (mm)	Mean	11	21	52	194	255	377	387	313	252	132	41	9	2045	
		Median	3	11	41	184	234	348	361	297	209	134	17	0	1840	
		80%	0	0	9	91	150	275	272	178	166	60	0	0	1200	
	Runoff (mm)	Mean	5	1	0	9	21	50	93	136	176	158	71	22	742	36.3
		Median	3	0	0	1	13	34	87	131	152	143	64	18	647	35.2
		80%	1	0	0	0	4	17	48	101	127	109	38	10	454	37.9
	Recharge (mm)	Mean	0	0	1	21	59	81	91	91	85	72	30	5	538	26.3
		Median	0	0	0	13	62	88	93	93	90	86	23	0	547	29.8
		80%	0	0	0	2	35	75	93	93	87	52	1	0	437	36.4
SC2	Rainfall (mm)	Mean	11	21	55	177	261	383	391	333	254	138	41	10	2074	
		Median	5	10	45	174	255	367	372	341	243	122	16	0	1950	
		80%	0	0	7	85	163	282	300	196	172	70	1	0	1275	
	Runoff (mm)	Mean	7	1	1	12	24	60	110	177	237	213	96	30	968	46.6
		Median	5	0	0	3	15	43	95	181	222	209	93	27	893	45.8
		80%	2	0	0	1	4	18	50	129	192	145	50	15	607	47.6
	Recharge (mm)	Mean	0	0	3	21	65	93	107	106	98	81	33	5	611	29.5
		Median	0	0	0	14	67	103	109	109	105	102	25	0	632	32.4
		80%	0	0	0	1	36	84	108	109	94	39	0	0	472	37.0
SC3	Rainfall (mm)	Mean	6	19	49	154	246	377	409	356	270	135	38	7	2065	
		Median	1	12	32	130	234	362	380	376	257	97	16	0	1897	
		80%	0	0	8	70	146	243	231	222	158	55	3	0	1135	
	Runoff (mm)	Mean	1	0	1	6	26	70	134	187	211	170	66	14	887	42.9
		Median	0	0	0	1	13	51	123	180	195	157	57	10	787	41.5
		80%	0	0	0	0	6	27	73	132	146	111	26	3	525	46.2
	Recharge (mm)	Mean	0	0	2	14	48	77	91	92	84	70	28	3	511	24.7
		Median	0	0	0	7	43	87	93	93	90	93	20	0	526	27.7
		80%	0	0	0	0	32	67	93	93	90	46	1	0	421	37.1
SC4	Rainfall (mm)	Mean	7	21	48	121	226	397	418	372	285	157	48	14	2115	
		Median	1	14	33	97	216	353	419	378	252	159	24	0	1946	
		80%	0	0	1	65	133	273	343	218	208	102	1	0	1344	
	Runoff (mm)	Mean	1	0	1	8	32	132	287	332	281	198	61	12	1344	63.6
		Median	0	0	0	1	24	90	287	354	260	192	39	0	1247	64.1
		80%	0	0	0	0	4	53	202	275	183	114	6	0	836	62.2
	Recharge (mm)	Mean	0	0	1	13	49	98	124	123	112	88	25	6	639	30.2
		Median	0	0	0	0	56	114	124	124	120	110	7	0	654	33.6
		80%	0	0	0	0	10	69	124	124	102	60	0	0	489	36.4
SC5	Rainfall (mm)	Mean	9	20	57	137	247	385	411	363	268	143	46	13	2097	
		Median	2	16	48	130	234	324	385	367	258	121	26	0	1911	
		80%	0	0	2	53	143	272	315	202	141	76	2	0	1205	
	Runoff (mm)	Mean	1	0	1	9	31	88	159	197	193	145	46	9	879	41.9
		Median	0	0	0	1	21	69	162	209	189	132	34	1	819	42.9
		80%	0	0	0	0	6	45	96	151	136	87	12	0	533	44.2
	Recharge (mm)	Mean	0	0	0	5	26	51	62	62	58	51	22	4	341	16.3
		Median	0	0	0	0	25	59	62	62	60	62	16	0	347	18.1
		80%	0	0	0	0	9	40	62	62	60	41	0	0	274	22.7

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Table 8.1
Long Term Rainfall–Runoff Simulation in NAM Catchments (1965–1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SC6	Rainfall (mm)	Mean	7	19	56	145	244	380	406	346	258	139	38	9	2048	
		Median	1	10	27	126	252	363	333	336	253	135	15	0	1850	
		80%	0	0	8	65	138	280	299	210	147	59	4	0	1211	
	Runoff (mm)	Mean	0	0	1	5	21	61	127	164	165	127	48	9	729	35.6
		Median	0	0	0	0	14	47	127	170	151	118	39	3	669	36.2
		80%	0	0	0	0	4	32	83	126	117	80	13	0	454	37.5
	Recharge (mm)	Mean	0	0	3	14	51	80	93	93	85	71	29	4	522	25.5
		Median	0	0	0	5	50	89	93	93	90	87	23	0	530	28.6
		80%	0	0	0	0	30	73	93	93	90	45	1	0	425	35.1
SC7	Rainfall (mm)	Mean	9	16	38	107	209	418	439	388	307	160	51	15	2158	
		Median	1	9	17	82	203	375	449	362	248	152	14	1	1912	
		80%	0	1	0	48	142	307	342	245	182	72	3	0	1342	
	Runoff (mm)	Mean	2	0	1	11	40	153	284	302	257	179	67	16	1313	60.8
		Median	0	0	0	0	34	136	295	278	214	170	43	3	1172	61.3
		80%	0	0	0	0	7	84	220	240	187	82	19	0	839	62.5
	Recharge (mm)	Mean	1	1	5	22	68	124	153	153	135	99	30	7	800	37.1
		Median	0	0	0	13	81	130	155	155	150	112	8	0	803	42.0
		80%	0	0	0	1	38	109	155	155	120	73	1	0	652	48.6
SC8	Rainfall (mm)	Mean	8	18	39	105	220	422	424	391	302	160	51	15	2156	
		Median	2	14	16	95	220	393	422	404	256	152	13	0	1987	
		80%	0	1	0	56	109	284	343	256	195	86	1	0	1331	
	Runoff (mm)	Mean	1	0	0	6	25	106	197	212	185	131	53	12	930	43.1
		Median	0	0	0	1	20	86	205	218	166	122	34	4	856	43.1
		80%	0	0	0	0	4	41	132	166	123	70	20	0	555	41.7
	Recharge (mm)	Mean	1	1	4	16	47	78	93	93	88	77	31	7	535	24.8
		Median	0	0	0	9	51	83	93	93	90	87	21	0	528	26.6
		80%	0	0	0	4	25	64	93	93	90	71	2	0	442	33.2
SC9	Rainfall (mm)	Mean	7	20	47	128	241	435	451	414	306	166	48	14	2277	
		Median	3	18	21	106	244	412	438	387	326	150	22	0	2127	
		80%	0	0	1	77	109	329	361	267	212	87	3	0	1445	
	Runoff (mm)	Mean	1	0	0	6	22	101	221	268	257	194	76	14	1160	50.9
		Median	0	0	0	1	12	69	214	280	258	191	65	4	1094	51.4
		80%	0	0	0	0	1	41	167	222	183	138	36	0	789	54.6
	Recharge (mm)	Mean	1	2	6	25	69	108	124	124	118	104	42	8	731	32.1
		Median	0	0	1	16	66	118	124	124	120	124	35	0	728	34.2
		80%	0	0	0	9	35	89	124	124	120	96	7	0	604	41.8
SC10	Rainfall (mm)	Mean	8	17	35	105	213	443	472	405	302	159	44	11	2214	
		Median	3	12	11	92	215	379	459	415	259	151	16	0	2012	
		80%	0	1	0	50	106	324	344	289	191	66	3	0	1373	
	Runoff (mm)	Mean	0	0	0	3	12	68	154	167	141	93	30	4	670	30.3
		Median	0	0	0	0	7	60	154	171	141	88	14	0	636	31.6
		80%	0	0	0	0	1	20	105	120	97	53	5	0	403	29.4
	Recharge (mm)	Mean	2	3	7	26	68	107	122	124	117	94	30	6	707	31.9
		Median	1	2	1	20	76	114	124	124	120	99	14	0	694	34.5
		80%	0	0	0	8	34	92	124	124	120	74	4	0	581	42.3
SC11	Rainfall (mm)	Mean	11	17	36	83	200	456	568	483	354	172	51	12	2443	
		Median	1	6	19	64	195	387	567	459	285	162	23	0	2169	
		80%	0	0	0	22	93	344	443	370	253	75	0	0	1600	
	Runoff (mm)	Mean	4	1	3	9	51	200	442	512	447	315	126	28	2137	87.5
		Median	0	0	0	0	37	182	435	494	418	302	105	10	1983	91.4
		80%	0	0	0	0	8	101	337	430	379	203	55	3	1516	94.7
	Recharge (mm)	Mean	3	3	7	17	57	95	109	109	105	101	43	9	656	26.8
		Median	0	0	2	13	66	102	109	109	105	109	32	0	646	29.8
		80%	0	0	0	2	30	85	109	109	105	100	11	0	549	34.3
SC12	Rainfall (mm)	Mean	8	16	41	90	211	501	559	490	364	195	60	14	2548	
		Median	3	4	19	75	202	415	563	485	336	189	29	0	2320	
		80%	0	0	0	26	136	332	422	395	224	102	3	0	1640	
	Runoff (mm)	Mean	3	0	2	10	45	182	373	421	377	267	116	28	1826	71.7
		Median	0	0	0	0	34	180	358	422	358	275	107	13	1748	75.3
		80%	0	0	0	0	20	117	280	350	313	184	49	4	1315	80.2
	Recharge (mm)	Mean	2	3	8	19	62	97	109	109	105	103	49	11	676	26.5
		Median	0	0	2	14	67	100	109	109	105	109	46	0	660	28.4
		80%	0	0	0	3	44	95	109	109	105	107	17	0	587	35.8
SC13	Rainfall (mm)	Mean	8	21	44	100	244	552	612	543	411	218	68	12	2833	
		Median	3	5	19	72	229	487	630	540	415	206	38	0	2643	
		80%	0	0	1	36	126	382	477	416	228	123	0	0	1788	
	Runoff (mm)	Mean	1	0	4	18	71	258	458	488	423	277	100	18	2116	74.7
		Median	0	0	0	1	58	230	438	494	392	277	66	6	1962	74.2
		80%	0	0	0	0	25	179	328	396	322	141	45	1	1436	80.3
	Recharge (mm)	Mean	2	4	10	26	86	139	155	155	150	126	47	8	907	32.0
		Median	0	0	2	15	93	144	155	155	150	144	33	0	891	33.7
		80%	0	0	0	5	58	130	155	155	150	89	15	0	757	42.3

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Table 8.1

Long Term Rainfall–Runoff Simulation in NAM Catchments (1965–1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SC14	Rainfall (mm)	Mean	10	16	31	81	202	453	587	551	356	218	48	16	2568	
		Median	0	6	13	67	204	382	558	523	332	187	28	0	2299	
		80%	0	0	0	9	99	269	426	404	231	89	3	0	1530	
	Runoff (mm)	Mean	13	4	2	4	23	78	185	236	232	183	107	44	1111	43.2
		Median	11	3	1	1	21	66	178	222	227	182	103	38	1051	45.7
		80%	7	2	1	0	3	48	135	195	194	161	78	25	850	55.5
	Recharge (mm)	Mean	1	0	1	7	36	73	90	93	90	93	78	24	586	22.8
		Median	0	0	0	0	37	81	93	93	90	93	90	10	586	25.5
		80%	0	0	0	0	7	64	92	93	90	93	65	0	504	33.0
SC15	Rainfall (mm)	Mean	7	20	35	104	213	510	627	568	398	215	56	16	2771	
		Median	1	8	12	63	210	467	615	552	374	195	30	0	2526	
		80%	0	0	0	26	121	319	493	404	242	128	5	0	1737	
	Runoff (mm)	Mean	15	2	2	10	48	148	316	389	384	303	172	67	1855	67.0
		Median	9	1	0	1	28	131	309	374	358	309	172	49	1740	68.9
		80%	2	0	0	0	13	99	253	322	328	221	110	26	1374	79.1
	Recharge (mm)	Mean	3	4	8	23	80	134	154	155	150	155	123	41	1032	37.3
		Median	0	1	1	12	92	144	155	155	150	155	149	13	1026	40.6
		80%	0	0	0	7	40	120	155	155	150	155	92	0	874	50.3
SC16	Rainfall (mm)	Mean	8	20	35	77	209	424	553	513	349	166	45	9	2407	
		Median	0	10	14	52	228	394	595	487	327	149	14	0	2270	
		80%	0	0	0	18	91	293	429	362	237	91	2	0	1523	
	Runoff (mm)	Mean	4	3	6	15	60	155	327	382	338	230	90	22	1633	67.8
		Median	3	2	1	4	43	147	348	370	309	210	75	13	1525	67.2
		80%	1	0	0	1	16	95	264	316	279	173	42	9	1198	78.7
	Recharge (mm)	Mean	1	3	8	19	72	121	152	155	150	131	36	5	853	35.5
		Median	0	0	0	9	86	132	155	155	150	147	18	0	853	37.6
		80%	0	0	0	1	26	98	155	155	150	109	4	0	697	45.8
SC17	Rainfall (mm)	Mean	8	21	48	115	226	409	434	388	294	152	51	15	2160	
		Median	2	14	29	90	219	376	452	363	266	143	28	0	1981	
		80%	0	0	0	66	126	289	357	226	195	95	1	0	1355	
	Runoff (mm)	Mean	2	0	1	5	21	78	165	211	223	181	75	20	983	45.5
		Median	0	0	0	1	16	54	158	216	226	168	70	10	918	46.4
		80%	0	0	0	0	3	36	106	160	166	133	40	1	644	47.6
	Recharge (mm)	Mean	1	0	1	8	27	50	62	62	60	58	34	8	370	17.1
		Median	0	0	0	1	29	56	62	62	60	62	40	0	371	18.7
		80%	0	0	0	0	10	39	61	62	60	62	11	0	305	22.5

9 REPRESENTATIVE YEARS FOR SIMULATION

In the absence of long term simulation, it has been considered a resonable approach to evaluate planning options, at least at pre-feasibility levels, on the basis of "representative" years. The representative years have been selected based on simple ranking of simulated flow and water level series as extracted from the General Model runs 1965 - 1989 at key locations in the region. The selected locations are shown on Figure 9.1 and detailes given in the following table.

Location for Extraction of Representative Time Series

No.	Location	River	Chainage(km)	
			for Flow	for Water Level
1	Gorai Railway Bridge	Gorai	3.50	7.00
2	Kamarkhali	Gorai	80.50	78.00
3	Madaripur	Arial Khan	37.70	36.00
4	Bardia	Rupsa	3.25	0.00
5	Khulna	Rupsa	36.50	40.00
6	Mongla	Rupsa	60.00	65.00
7	Bamna	Bishkhali	57.00	60.00

For each location the annual, wet season (June - October), and dry season (November - March) flows as well as annual maximum water levels have been ranked and the exceedance probability determined.

April has been left out of the analysis, as this month for some years was found to be affected by non representative initial conditions in the simulation.

Due to the size and complexity of the study area a given physical event will not necessarily have the probability of exceedance all over the area and hence the representative years, such as a typical "average", "wet" or "dry", have been selected on the basis of an 'average excedance probability' assigned to each event (year) by averaging the probabilites calculated for this event at all seven locations in the area.

The representative years have been utilized for selection of relevant simulation periods for the different hydrodynamic modelling scenarios.

Table 9.1 shows the annual simulated flow statistics (1965-1989) of all the seven stations ranked in decending order. Average representative return periods for the region have been computed from the aggregated ranking and are shown in Table 9.2. As can be seen from these tables, the average "wet" and "dry" years are different for the stations. However, from the aggregated ranking, the "typical" wet, average and dry years for the region as a whole can be represented by 1985, 1981 and 1979, respectively. Similar statistics are obtained for the wet season, and dry season flows as well as for the peak water level (see Tables 9.3. to 9.8). The results of the ranking analysis are summarised in the following Table. Based on the analysis of peak water levels, the extreme high flood level year is found to be 1988, 1982 an average year and year 1984 with an approximate return period of 4 years (see Table 9.8).

Representative Years

Basis	Typical Classifications		
	Wet Year	Average Year	Dry Year
1. Annual Flow	1985	1981	1979
2. Wet Season Flow (June - Oct.)	1978	1986	1979
3. Dry Season Flow (Nov. - April)	1985	1972	1981

Table 9.1

Ranking of Annual Flows (m^3/s) at the Selected Stations

RANK	STATIONS													
	GORAI RLY. BRDG		KAMARKHALI		MADARIPUR		BARDIA		KHULNA		MONGLA		BAMNA	
	Year	Flow	Year	Flow	Year	Flow	Year	Flow	Flow	Year	Year	Flow	Year	Flow
1	1973	1662	1973	1685	1988	1749	1985	1639	1985	1803	1970	2017	1988	1907
2	1978	1600	1978	1616	1987	1632	1973	1598	1975	1766	1975	1985	1980	1882
3	1985	1542	1985	1555	1974	1561	1975	1561	1970	1750	1985	1942	1987	1813
4	1975	1529	1975	1552	1980	1545	1980	1494	1973	1734	1973	1901	1974	1759
5	1980	1409	1969	1432	1984	1344	1970	1486	1980	1636	1986	1770	1985	1604
6	1969	1409	1974	1427	1989	1300	1978	1453	1978	1581	1978	1758	1970	1579
7	1974	1403	1980	1425	1977	1297	1974	1358	1986	1533	1980	1754	1984	1534
8	1977	1355	1977	1368	1973	1184	1969	1332	1974	1498	1987	1683	1975	1502
9	1987	1340	1987	1366	1981	1153	1986	1323	1969	1479	1974	1672	1989	1435
10	1984	1332	1986	1362	1985	1150	1981	1295	1987	1471	1969	1661	1977	1431
11	1986	1330	1984	1354	1970	1141	1987	1292	1988	1435	1988	1621	1973	1383
12	1970	1313	1970	1341	1975	1115	1988	1281	1981	1429	1984	1597	1978	1266
13	1988	1288	1988	1312	1978	1112	1972	1262	1984	1416	1981	1586	1981	1253
14	1983	1265	1983	1297	1983	1021	1977	1261	1972	1411	1983	1559	1983	1163
15	1981	1254	1981	1273	1966	1009	1984	1254	1977	1384	1977	1546	1969	1149
16	1968	1235	1968	1254	1969	978	1983	1232	1983	1382	1972	1535	1966	1137
17	1982	1209	1967	1229	1968	917	1989	1195	1968	1347	1968	1530	1965	1098
18	1967	1209	1982	1221	1982	915	1968	1185	1965	1318	1965	1495	1986	1077
19	1976	1193	1976	1213	1986	903	1976	1172	1989	1300	1976	1468	1968	1072
20	1989	1139	1989	1154	1976	900	1967	1167	1976	1293	1967	1427	1972	1053
21	1972	1102	1972	1114	1967	879	1965	1135	1967	1287	1989	1422	1967	1027
22	1966	956	1966	970	1979	865	1982	1120	1982	1187	1982	1279	1982	1011
23	1965	939	1965	956	1965	723	1966	974	1966	1077	1966	1204	1979	1005
24	1979	814	1979	829	1972	679	1979	872	1979	975	1979	1126	1976	1001

Table 9.2

Average Return Period of Annual Flow Over the Region as a Whole

Year	Avg. Return Period	Representative Year
1985	6.7	WET YEAR
1973	5.7	
1980	5.2	
1975	5.0	
1974	4.0	
1978	3.7	
1970	3.5	
1987	3.4	
1988	2.8	
1969	2.5	
1984	2.4	
1977	2.3	
1986	2.2	
1981	2.0	AVERAGE YEAR
1983	1.7	
1989	1.6	
1968	1.5	
1972	1.4	
1967	1.3	
1976	1.3	
1982	1.2	
1965	1.2	
1966	1.2	
1979	1.1	DRY YEAR

Table 9.3

Ranking of Dry Season (Nov–Apr) Flows (m^3/s) at the Selected Stations

RANK	STATIONS													
	GORAI RLY. BRDG		KAMARKHALI		MADARIPUR		BARDIA		KHULNA		MONGLA		BAMNA	
	Year	Flow	Year	Flow	Year	Flow	Year	Flow	Flow	Year	Year	Flow	Year	Flow
1	1973	519	1973	537	1989	247	1973	736	1973	831	1973	909	1989	352
2	1985	481	1985	499	1985	243	1985	670	1985	750	1985	788	1985	349
3	1969	337	1969	348	1988	230	1970	479	1970	565	1970	610	1986	329
4	1974	317	1974	331	1987	223	1983	467	1986	535	1986	602	1988	319
5	1970	289	1970	303	1986	217	1969	459	1983	530	1975	567	1973	316
6	1972	288	1972	297	1973	180	1974	458	1974	525	1974	557	1987	300
7	1978	270	1978	283	1970	170	1975	442	1975	524	1983	555	1970	251
8	1983	266	1983	282	1965	146	1986	437	1969	520	1969	550	1975	226
9	1975	261	1975	277	1975	142	1978	412	1978	477	1978	507	1983	222
10	1967	242	1967	251	1969	140	1972	392	1980	452	1980	485	1977	186
11	1977	237	1977	249	1966	138	1980	388	1977	450	1977	484	1974	185
12	1965	232	1986	248	1967	137	1977	382	1972	440	1988	473	1980	176
13	1986	230	1965	241	1983	136	1987	364	1989	429	1989	465	1967	175
14	1968	228	1968	239	1980	136	1989	356	1968	424	1972	461	1979	172
15	1987	195	1987	210	1972	132	1968	356	1987	423	1968	459	1966	168
16	1966	176	1980	186	1977	132	1967	355	1967	413	1987	451	1965	166
17	1980	173	1966	184	1974	130	1965	335	1988	408	1967	441	1969	158
18	1982	153	1982	163	1979	123	1988	326	1965	390	1965	418	1978	156
19	1976	136	1976	146	1976	120	1982	316	1982	366	1966	405	1984	154
20	1984	122	1984	132	1984	120	1966	292	1966	358	1982	393	1968	152
21	1989	106	1989	119	1978	118	1976	285	1976	341	1981	372	1976	144
22	1981	101	1981	111	1982	114	1981	275	1981	337	1976	371	1972	144
23	1988	95	1988	109	1968	110	1984	243	1984	289	1979	317	1981	125
24	1979	67	1979	75	1981	107	1979	227	1979	281	1984	310	1982	124

Table 9.4

Average Return Period of Dry Season Flow Over the Region as a Whole

Year	Avg. Ret. Period (exceedence)	Avg. Ret. Period (non-exceedence)	Representative Dry Year
1981	1.1	9.3	DRIEST
1979	1.2	7.3	
1984	1.2	6.9	
1976	1.2	5.3	
1982	1.3	5.0	
1966	1.5	3.1	
1968	1.5	2.9	
1965	1.7	2.4	
1988	1.8	2.3	
1967	1.9	2.2	
1980	1.9	2.1	
1972	2.1	2.0	AVERAGE
1987	2.1	1.9	
1989	2.1	1.9	
1977	2.1	1.9	
1978	2.2	1.8	
1969	3.2	1.4	
1974	3.2	1.4	
1975	3.2	1.4	
1983	3.2	1.4	
1986	3.6	1.4	
1970	5.3	1.2	
1973	10.9	1.1	
1985	12.5	1.1	

Table 9.5

Ranking of Wet Season (Jun–Oct) Flows (m^3/s) at the Selected Stations

RANK	STATIONS													
	GORAI RLY. BRDG		KAMARKHALI		MADARIPUR		BARDIA		KHULNA		MONGLA		BAMNA	
	Year	Flow	Year	Flow	Year	Flow	Year	Flow	Flow	Year	Year	Flow	Year	Flow
1	1978	3520	1978	3545	1988	3819	1978	3007	1978	3262	1978	3661	1988	4111
2	1973	3399	1973	3437	1987	3586	1973	3002	1973	3243	1973	3542	1987	3951
3	1975	3354	1975	3391	1974	3467	1975	2838	1975	3102	1987	3542	1974	3860
4	1985	3208	1985	3215	1980	3466	1980	2735	1986	3074	1986	3536	1980	3643
5	1980	3165	1980	3187	1984	2995	1985	2714	1987	3062	1970	3517	1984	3405
6	1984	3035	1984	3080	1977	2841	1981	2712	1984	3035	1975	3499	1977	3059
7	1987	3006	1987	3054	1989	2729	1988	2709	1988	3022	1984	3442	1989	2963
8	1969	2979	1969	3024	1981	2571	1984	2691	1970	2989	1988	3403	1973	2891
9	1977	2970	1988	3011	1973	2565	1987	2681	1969	2956	1969	3365	1970	2814
10	1988	2967	1974	3006	1978	2464	1974	2669	1981	2953	1974	3337	1978	2786
11	1974	2961	1977	2992	1975	2463	1986	2667	1974	2952	1981	3231	1981	2757
12	1986	2929	1986	2990	1970	2448	1969	2658	1980	2872	1968	3154	1975	2712
13	1981	2870	1981	2905	1985	2425	1970	2582	1985	2829	1977	3140	1985	2597
14	1970	2773	1970	2825	1983	2208	1977	2563	1977	2800	1976	3086	1969	2508
15	1983	2751	1983	2805	1966	2208	1976	2476	1968	2745	1980	3057	1966	2489
16	1982	2718	1976	2748	1969	2114	1989	2469	1976	2709	1983	3041	1983	2432
17	1976	2711	1982	2736	1968	2014	1968	2414	1983	2675	1985	3016	1968	2339
18	1968	2683	1968	2717	1982	1993	1967	2392	1989	2666	1967	2940	1982	2213
19	1967	2626	1967	2664	1976	1962	1983	2388	1967	2630	1989	2924	1967	2196
20	1989	2599	1989	2624	1967	1895	1982	2311	1982	2430	1982	2629	1976	2185
21	1972	2280	1972	2297	1979	1881	1972	2092	1972	2230	1965	2485	1979	2169
22	1966	2088	1966	2113	1986	1836	1966	2001	1966	2192	1966	2459	1986	2140
23	1965	1958	1965	1989	1965	1527	1965	1922	1965	2160	1972	2413	1965	1811
24	1979	1858	1979	1887	1972	1424	1979	1818	1979	2018	1979	2345	1972	1603

Table 9.6

Average Return Period of Wet Season Flow Over the Region as a Whole

Year	Avg. Return Period	Representative Year
1978	7.0	WETTEST
1973	6.5	
1987	5.0	
1975	4.3	
1988	4.1	
1984	4.1	
1980	3.6	
1974	3.0	
1985	2.5	
1981	2.4	
1977	2.4	
1970	2.3	
1969	2.3	
1986	2.0	AVERAGE
1989	1.6	
1983	1.6	
1968	1.5	
1976	1.5	
1982	1.4	
1967	1.3	
1966	1.3	
1972	1.1	
1965	1.1	
1979	1.1	

Table 9.7

Ranks of Peak Water Level (m)

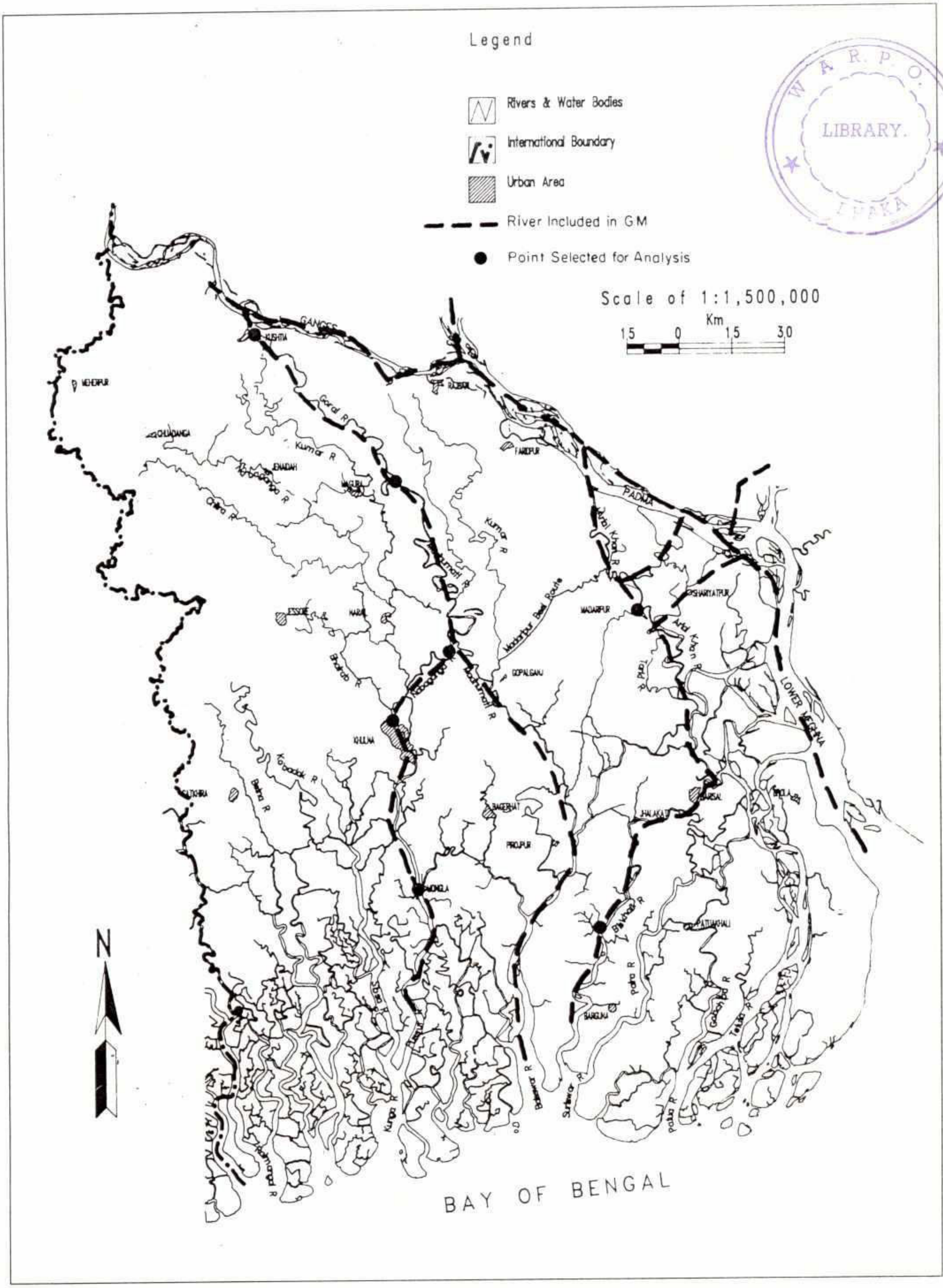
RANK	STATIONS													
	GORAI RLY. BRDG		KAMARKHALI		MADARIPUR		BARDIA		KHULNA		MONGLA		BAMNA	
	Year	WL	Year	WL	Year	WL	Year	WL	Year	WL	Year	WL	Year	WL
1	1988	13.71	1988	9.66	1988	5.92	1986	2.67	1986	2.42	1989	1.87	1988	1.93
2	1987	13.64	1987	9.55	1980	5.5	1987	2.66	1987	2.4	1986	1.65	1984	1.83
3	1978	13.36	1978	9.21	1987	5.39	1988	2.63	1970	2.37	1985	1.62	1974	1.71
4	1982	13.33	1982	9.17	1974	5.38	1970	2.61	1969	2.23	1988	1.59	1970	1.7
5	1976	13.31	1976	9.15	1984	5.12	1969	2.46	1988	2.12	1970	1.54	1985	1.65
6	1980	13.18	1983	9.09	1983	4.99	1978	2.44	1979	2.02	1974	1.48	1987	1.57
7	1983	13.18	1980	9.08	1966	4.97	1984	2.43	1975	2.02	1984	1.4	1980	1.54
8	1969	13.1	1984	9.05	1977	4.89	1982	2.4	1984	2	1981	1.38	1979	1.53
9	1984	13.09	1969	9.04	1973	4.85	1983	2.4	1974	1.99	1987	1.34	1986	1.5
10	1974	12.98	1974	8.89	1970	4.81	1974	2.4	1978	1.98	1976	1.26	1981	1.47
11	1986	12.93	1986	8.83	1975	4.79	1976	2.39	1989	1.94	1977	1.19	1969	1.43
12	1975	12.84	1975	8.7	1978	4.78	1980	2.39	1976	1.93	1983	1.18	1972	1.41
13	1967	12.8	1967	8.7	1981	4.76	1981	2.36	1983	1.92	1978	1.15	1978	1.38
14	1973	12.76	1973	8.62	1969	4.74	1973	2.35	1980	1.92	1973	1.11	1977	1.32
15	1977	12.76	1977	8.61	1968	4.7	1967	2.32	1982	1.92	1980	1.11	1989	1.32
16	1981	12.74	1985	8.55	1985	4.67	1985	2.3	1968	1.91	1972	1.11	1982	1.3
17	1985	12.73	1981	8.55	1976	4.65	1975	2.3	1977	1.91	1969	1.05	1975	1.29
18	1968	12.56	1968	8.37	1982	4.64	1979	2.27	1981	1.89	1965	0.98	1966	1.27
19	1966	12.43	1966	8.28	1979	4.57	1977	2.26	1985	1.89	1966	0.98	1973	1.23
20	1970	12.37	1970	8.23	1989	4.53	1966	2.23	1973	1.87	1967	0.98	1967	1.2
21	1979	12.26	1979	8.13	1986	4.52	1989	2.22	1967	1.85	1968	0.98	1965	1.17
22	1965	12.19	1965	8.09	1967	4.44	1968	2.21	1966	1.8	1979	0.96	1968	1.16
23	1972	12.15	1972	8.07	1965	4.41	1972	2.12	1972	1.73	1982	0.91	1976	1.09
24	1989	11.89	1989	7.91	1972	4.41	1965	2.11	1965	1.73	1975	0.88	1983	1.08

Table 9.8

Average Return Period of Peak Water Level

Year	Avg. Return Period	Representative Year
1988	10.9	EXTREME
1987	6.7	
1984	3.8	
1974	3.4	
1986	3.1	
1978	2.9	
1980	2.8	
1970	2.6	
1969	2.6	
1983	2.3	
1976	2.2	
1985	2.1	
1982	2.0	
1981	1.9	
1977	1.8	
1973	1.7	
1975	1.7	
1979	1.7	
1989	1.6	
1967	1.4	
1966	1.4	
1968	1.3	
1972	1.3	
1965	1.3	

Figure 9.1



Points Selected for Evaluation of Representative Years

Hydrogeology

SOUTHWEST AREA WATER RESOURCES MANAGEMENT PROJECT

FINAL REPORT

HYDROGEOLOGY

CONTENTS

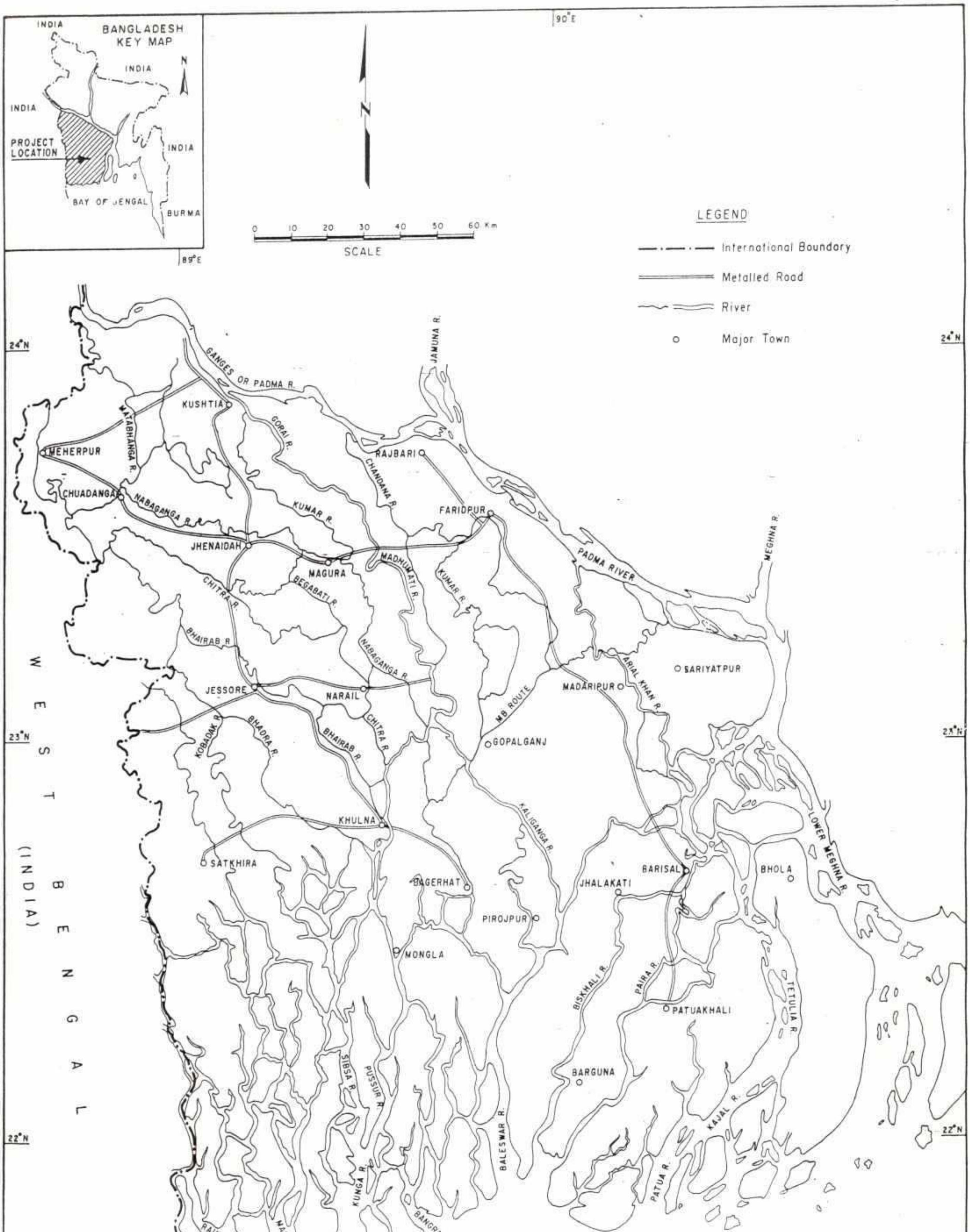
LIST OF TABLES

LIST OF FIGURES

GLOSSARY

BADC	Bangladesh Agricultural Development Corporation
BWDB	Bangladesh Water Development Board
DSSTW	Deep-Set Shallow Tubewells
DTW	Deep Tubewells
FAP	Flood Action Plan
HTW	Hand Tubewells
MOSTI	Manually Operated Shallow Tubewells for Irrigation
MPO	Master Plan Organisation
O & M	Operation and Maintenance
AST	Agricultural Sector Team
CIDA	Canadian Internatioal Development Agencies
NMIDP	National Minor Irrigation Development Project

Figure I-1



LOCATION MAP

1 INTRODUCTION

1.1 Background

The Southwest Area Water Resources Management Project, FAP 4, includes a requirement to provide a management plan for land and water resources. A key element in this plan is groundwater, which is a source of potable water and winter irrigation water within the project area, as it is in many other regions of Bangladesh. In recognition of the potential for additional groundwater development, hydrogeological studies have been incorporated into the study to provide an assessment of the groundwater resources in relation to the various tubewell technologies currently available. In addition, it is necessary to consider the possible changes to the aquifer system as a result of implementing schemes such as flood protection and drainage, which have a bearing on the prevailing recharge -discharge conditions.

The Project area is shown in Figure 1.1

1.2 Objectives

The objective of this report is to provide a review of groundwater resources availability under existing and possible future conditions.

Specific topics to be addressed include:

- a review of the project area hydrogeology and delineation of the aquifer system;
- recharge processes and quantities;
- groundwater quality, particularly salinity;
- current groundwater abstraction and trends in tubewell numbers
- the potential for additional groundwater development and a strategy for its implementation, taking into account the new climate of deregulation, under NMIDP,
- the capital and operating costs of tubewells
- the potential impact of flood control and drainage on groundwater recharge

This report summarises the findings of the studies with respect to the hydrogeology of the project area. In addition to production of this report, information on groundwater resources has been provided on an ad-hoc basis for input data to the NAM and RAOM resource optimisation models.

1.3 Method of Approach

The work has relied heavily upon data provided through various MPO studies, including the most recent National Water Plan - Phase II Project (MPO, 1991). Because groundwater resources continue to be developed in the project area the MPO figures have been amended where appropriate on the basis of new statistics. In terms of methodology however, MPO techniques of assessment have generally been followed.

A full reference list of sources consulted is included at the end of this report.

2 HYDROGEOLOGICAL CONDITIONS

2.1 Physical Setting

2.1.1 Topography

The project area (Figure 1.1) has an area of 40,450 square km. bounded to the west by the border with India, to the north and east by the Ganges-Padma and Meghna rivers, and to the south by its coastline on the Bay of Bengal. It is low-lying land of gentle relief on the edge of the river delta; more than half of it less than 5m above sea level. About 10% of the area is coastal mangrove forest (Sundarbans)and about 17% consists of permanent open water, including rivers and beels. About 62% is cultivated.

Within the generally flat topography however there is significant land diversity. For example, the concept of a 'homestead level' exists which is locally the highest land and therefore least vulnerable to flooding. The homestead level may be several meters higher than the surrounding agricultural land.

This local variation is important hydrogeologically because it is related to the depth and duration of flooding during the wet season, and hence has a bearing on recharge. MPO (1987) produced a land classification for the whole of Bangladesh based on depth of flooding. The classification system is shown in Table 2.1 and the distribution of the various land types within the project area is given in Table 2.2. Similar data are available for each upazila within the project area.

TABLE 2.1

MPO Land Types Based on Flood Depth

LAND TYPE	DESCRIPTION	FLOOD DEPTH (CM)	NATURE OF FLOODING
F0	Highland	0-30	Intermittent
F1	Medium - High	30-90	Seasonal
F2	Medium - Low	90-180	Seasonal
F3	Lowland	over 180	Seasonal
F4	Low-Very Low	over 180	Seasonal/ Perennial

(MPO 1987)

TABLE 2.2

Approximate Distribution of Land Types in the Project Area

LAND TYPE	APPROXIMATE AREA	
	%	Km^2
F0	17	6800
F1	35	14200
F2	11	4400
F3 + F4	4	1550
Sundarbans	10	4050
Open Water	17	7000
Other	6	2450
Total	100	40450

(MPO 1991, Project Data)

2.1.2 Drainage

The major river systems drain south and south eastwards towards the Bay of Bengal. In addition, because the project area is on the edge of the delta, it contains a complicated network of distributaries which carry water spilled over from the main river channels. The amount of water leaving the whole system in Bangladesh is enormous, varying from over 100,000 m^3/s in August to 7000 m^3/s in February (1983 data).

Many of the project area rivers are tidal and the waters are sometimes saline, both for considerable distances inland. The Padma, for example, is tidal as far upstream as Faridpur. Salinity distributions vary in accordance with the volume of freshwater flowing southwards in the rivers, though in general the drainage between the Gorai and Lower Meghna rivers produces a tongue of low salinity in surface waters. The significance of salinity in relation to groundwater is discussed in Section 2.4.1 of this report.

2.2 Geology

2.2.1 Regional Setting

The project area is located on the south western part of an extensive alluvial plain of Quaternary sediments laid down by the Ganges - Brahmaputra - Meghna river system, known as the Bengal Basin. It is probable that as much as 15,000 - 18,000 m of mainly unconsolidated sediments of Tertiary - Recent age exist beneath the central parts of the project area. The Basin is bordered to the north by the Shillong Massif and the Himalayas, to the west by the Indian shield, and to the east by the Arkan Chin Massif.

The geology of the Basin is widely described in the literature. Data obtained from oil and gas exploration has been collected for regional hydrogeological studies (UNDP 1982, MPO 1984, 1987) and the references cited contain a comprehensive bibliography.

In terms of this project only those units of Pleistocene - Holocene (Recent) age are important hydrogeologically and the following geological description is restricted accordingly. For the present, older units are too deep (ie below 200-300m) to warrant serious consideration given the groundwater resources available in the younger sediments, though deeper aquifers are exploited for water elsewhere in Bangladesh. In particular the southwest area has the potential for salinity problems due to its coastal location and uncontrolled deep drilling increases the risk of bringing in saline groundwater.

2.2.2 Geology of the Project Area

(a) Stratigraphy

The study area is covered entirely by Holocene river alluvium comprising deltaic, terrace, meander, interstream and swamp deposits. These sediments continue to accumulate from detritus deposited by the main rivers, particularly on the floodplain of the Meghna.

Although the sediments become progressively older with depth there is no specific evidence of wells in the project area encountering Pleistocene sediments because of their general similarity in lithology to Holocene sediments and lack of fossil evidence. Elsewhere in Bangladesh, Pleistocene to early Holocene sediments, which were laid down by an ancestral river system, have been uplifted and are exposed at the surface. These older sediments are slightly compacted and oxidized as compared with the Holocene sediments. However, again, there is no record of such deposits occurring within the project area.

(b) Lithology

The lithology of the various sediments referred to above varies from clay, through silt, to fine, medium and occasionally coarse sand. The geometry of individual sedimentary units is inevitably complex and there is a general lack of horizontal continuity on a local scale. Also, there is an upward fining of the sequence, while the degree of sorting decreases with depth.

A fairly broad correlation between lithology and depth has been established for the youngest sediments in Bangladesh and its principal characteristics are thought to apply to the project area. The three uppermost units, each of which is important hydrogeologically, are as follows:

(i) an upper, surface layer, of mainly clay and silt, which in parts of Barisal, Khulna and Faridpur contains peat layers

(ii) an intermediate layer of mainly fine sand and clay referred to as the Composite Aquifer;

(iii) a deeper layer, containing mainly fine to coarse sand and known as the Deep Aquifer, which is separated from the Composite Aquifer sequence by a clay layer

In general in the south west and south central area the upper clay layer is comparatively thick, and this is particularly true in southern Barisal District when it may be up to 150m thick. In such areas the composite and deep aquifer sequences are probably found in the 150-300m depth range.

The hydrogeological significance of these lithological units is described in Section 2.3 of this Annex.

(c) Structure

Major regional structural features of the Bengal Basin have been investigated as part of oil/gas and minerals exploration, and various troughs, saddles and faults can be identified within it. However there are no apparent major structures within the Pleistocene to Holocene sediments of project area, such as faults and folds, which would be hydrogeologically significant.

2.3 Hydrogeology

2.3.1 The Aquifer System

The aquifer system can be described in accordance with the lithological units referred to above. The main hydrogeological characteristics of each unit are as follows:

(a) Upper Clay and Silt

This unit is characterised by high porosity but low permeability. Due to its extensive thickness in parts of the study area it effectively precludes major groundwater development because it is unable to support tubewells itself and makes the lower aquifers too deep to be economically exploited on a large scale for irrigation. In most parts of the study area its main importance is the extent to which it controls downward percolation to the deeper units below.

(b) Composite Aquifer

This unit is characterised by high porosity and moderate permeability. Where it is shallow enough to be exploited it is capable of providing water to HTW and MOSTI.

(c) Main Aquifer

The main aquifer is characterised by high porosity and moderate to high permeability. Where it is accessible it is an important aquifer which provides large quantities of water to DTW and STW/DSSTW.

The distribution of these units is such that the most favourable hydrogeological conditions exist in the north part of the project area, in the Southwest (North) and Southwest (North east) development blocks. This distribution is reflected in the map of groundwater development zones (Figure 4.1).

It is perhaps worth noting that in some parts of Bangladesh, notably in Dhaka, deeper aquifers are used for public domestic water supplies. Whilst there is the potential for such abstraction in the southwest region, it would need to be preceded by very detailed studies because of the risk of saline water intrusion. Wells at Khulna are approaching 300m in depth and saline intrusion is already occurring there (see Section 2.4.1).

2.3.2 Groundwater Distribution

These units are generally in hydraulic continuity and function as a locally confined or semi-confined storage system. Hydraulic continuity exists with surface water, though there is a relatively small volumetric transfer of water between the two, due to low hydraulic gradients, and a generally low permeability in the surface layers. Most natural groundwater movement is vertical, either downwards in response to infiltration of rainfall or floodwater, or upward, in response to capillary rise. Regional groundwater flow is important in the extent to which it is a control on saline water ingress (Section 2.4.1).

Groundwater observation wells monitored by BWDB and other organisations concerned with groundwater development show a pattern which is characteristic of other alluvial areas in Bangladesh. Hydrographs of 4 typical project area observation wells are shown in Figures 2.1 - 2.4 and the well locations are shown in Figure 2.5. Figure 2.5 also shows the elevation of the water table at the end of the irrigation season in April 1991, water level contours, and flow directions.

The characteristic hydrograph pattern is:

(i) A variation in groundwater levels corresponding to the wet and dry seasons;

(ii) Lowest water levels at the end of the dry season in April/May;

(iii) A rapid rise following the onset of the rain, to field capacity (aquifer-full conditions) in the wet season;

(iv) A dry season recession, to complete the cycle.

In many cases the lowest recorded water level is during April 1989, when the onset of the rain was unusually late. Hydrographs over a longer period often show a general trend of increasing maximum depths to groundwater, as a result of increased pumping for irrigation (see Figure 3.3). However, aquifer-full conditions are always established during the wet season so it is also a process of storage manipulation to increase recharge and is therefore a beneficial effect.

Figures 2.1 - 2.4 show an interesting variation in trends. Figure 2.1 (wells JE-35 and JE-44) show a trend of decreasing water levels as increased abstraction approaches potential recharge. Conversely Figure 2.2 (well KT-51) indicates that groundwater abstraction is decreasing locally. Figures 2.3 and 2.4 indicate fairly constant abstraction, in which Figure 2.4 is interesting for the particularly low 1989 level.

2.3.3 Aquifer Parameters

Aquifer parameter data for the study area are relatively sparse. The main aquifer transmissivity is thought to be about 1500 - 3000 m^2/d in the northern part of the study area, reducing to perhaps 900 m^2/d in the south (BWDB data). These figures are presumed not to refer to the full thickness of the main aquifer into which wells are often partially penetrating, so actual transmissivity may be higher. Given the storage conditions described above, storativity values in the range 10^{-3} - 10^{-4} would be expected in the south, higher in the north. Aquifer parameter values for the study area are generally lower than average for Bangladesh; compared with other regions, hydrogeological conditions in the SW/SC regions are generally less favourable for groundwater development.

2.4 Water Quality Aspects

2.4.1 Salinity and Saline Intrusion

The relationship between fresh and saline groundwaters in the coastal regions of Bangladesh is understood at a conceptional level only and not in detail. The principal components and relationships in the southwest study area are probably as follows:

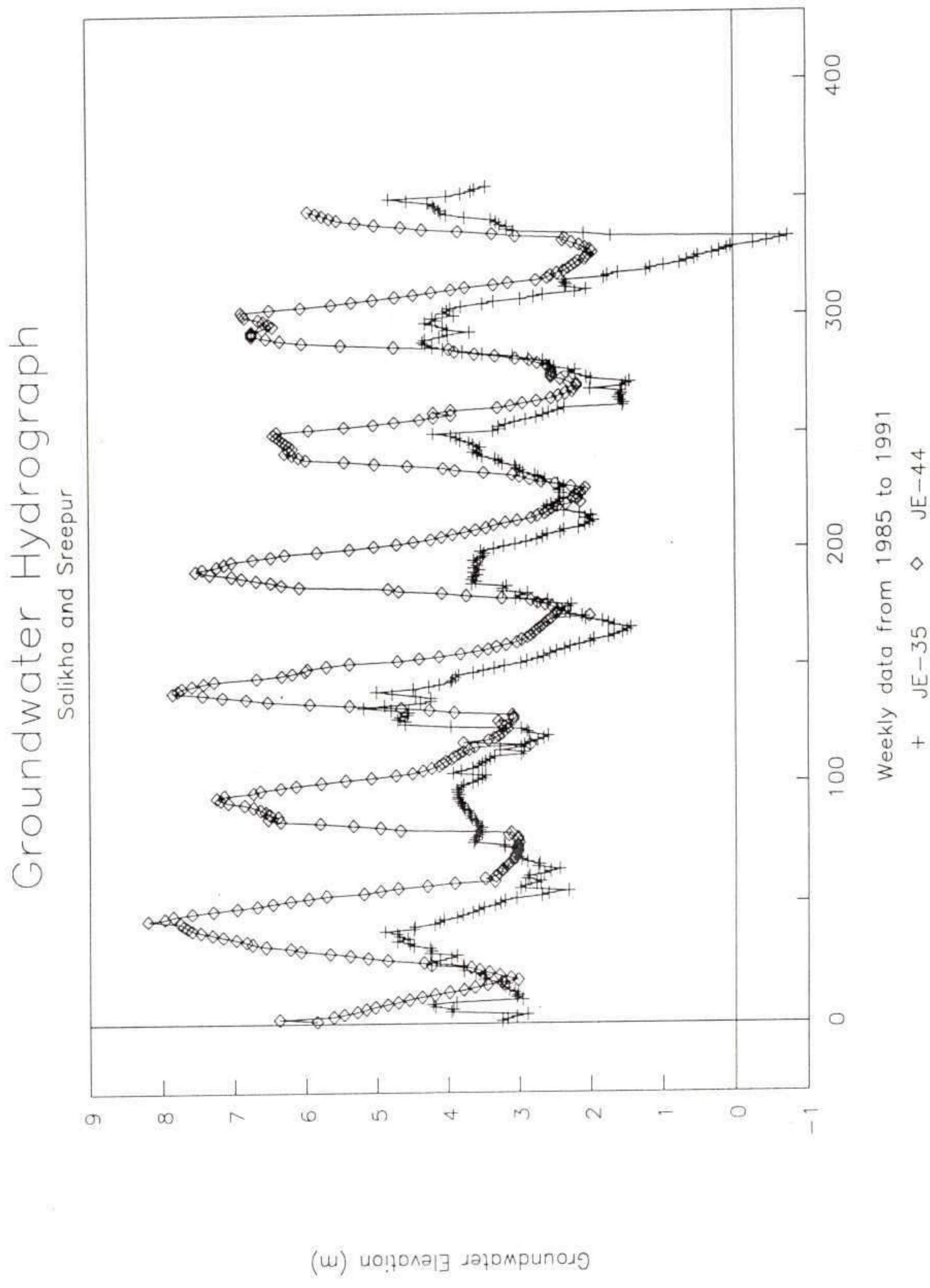
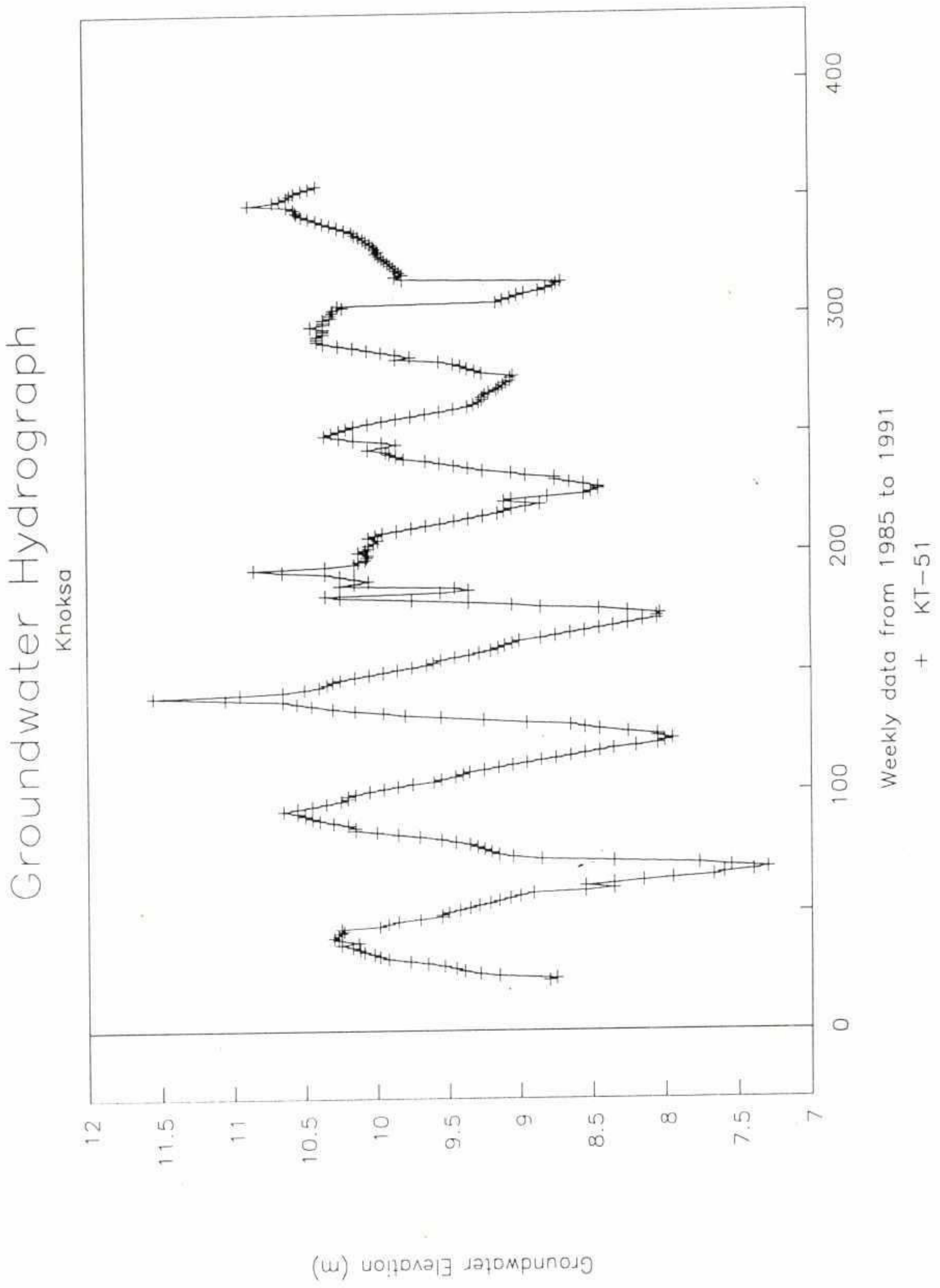

Groundwater Hydrograph
Salikha and Sreepur
Groundwater Elevation (m)
9
8
7
6
5
4
3
2
1
0
−1
0
100
200
300
400
Weekly data from 1985 to 1991
+ JE−35 ◇ JE−44

Figure 2.2


Groundwater Hydrograph
Khoksa
Weekly data from 1985 to 1991
+ KT-51
Groundwater Elevation (m)
0
100
200
300
400
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7

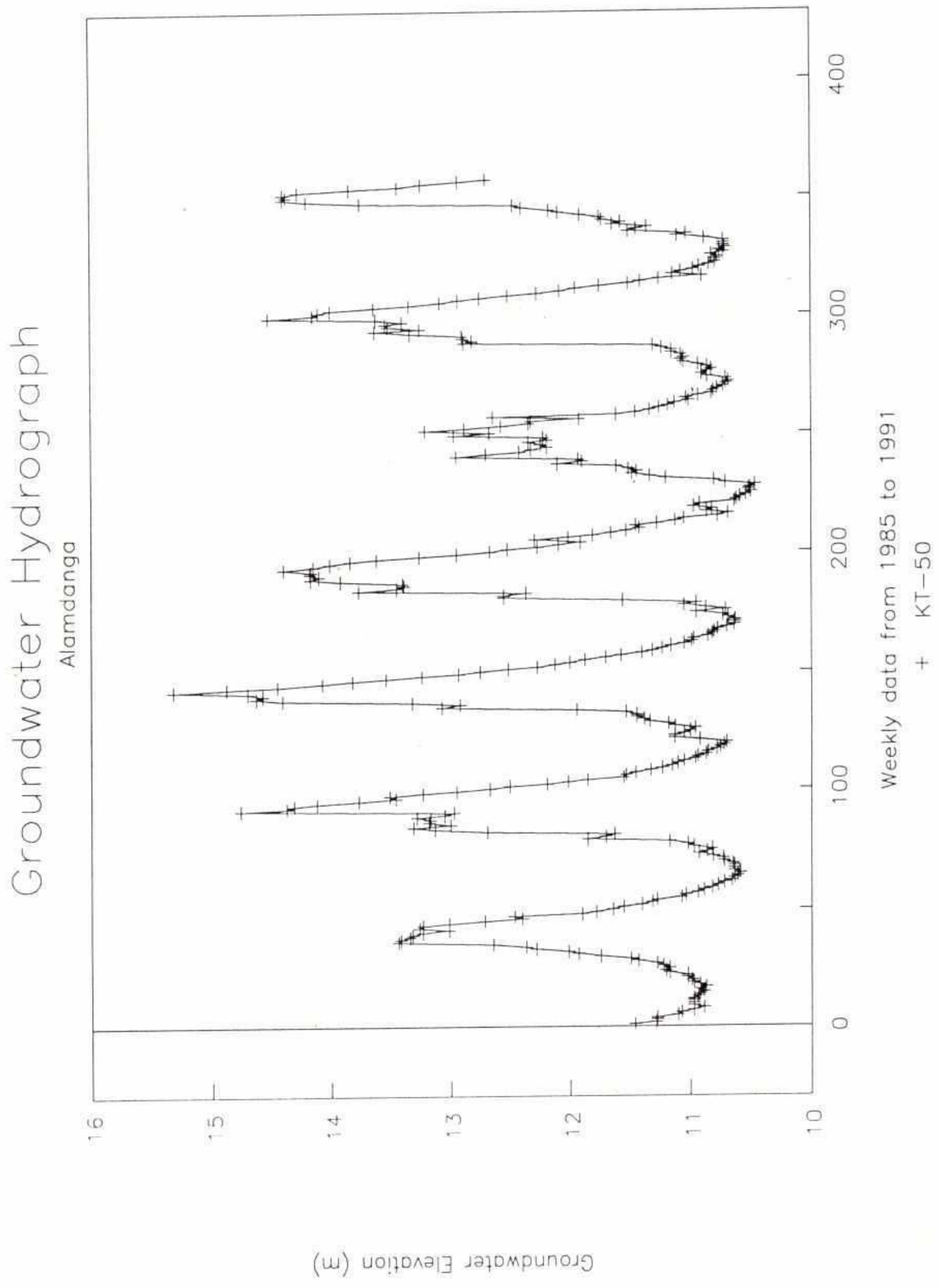
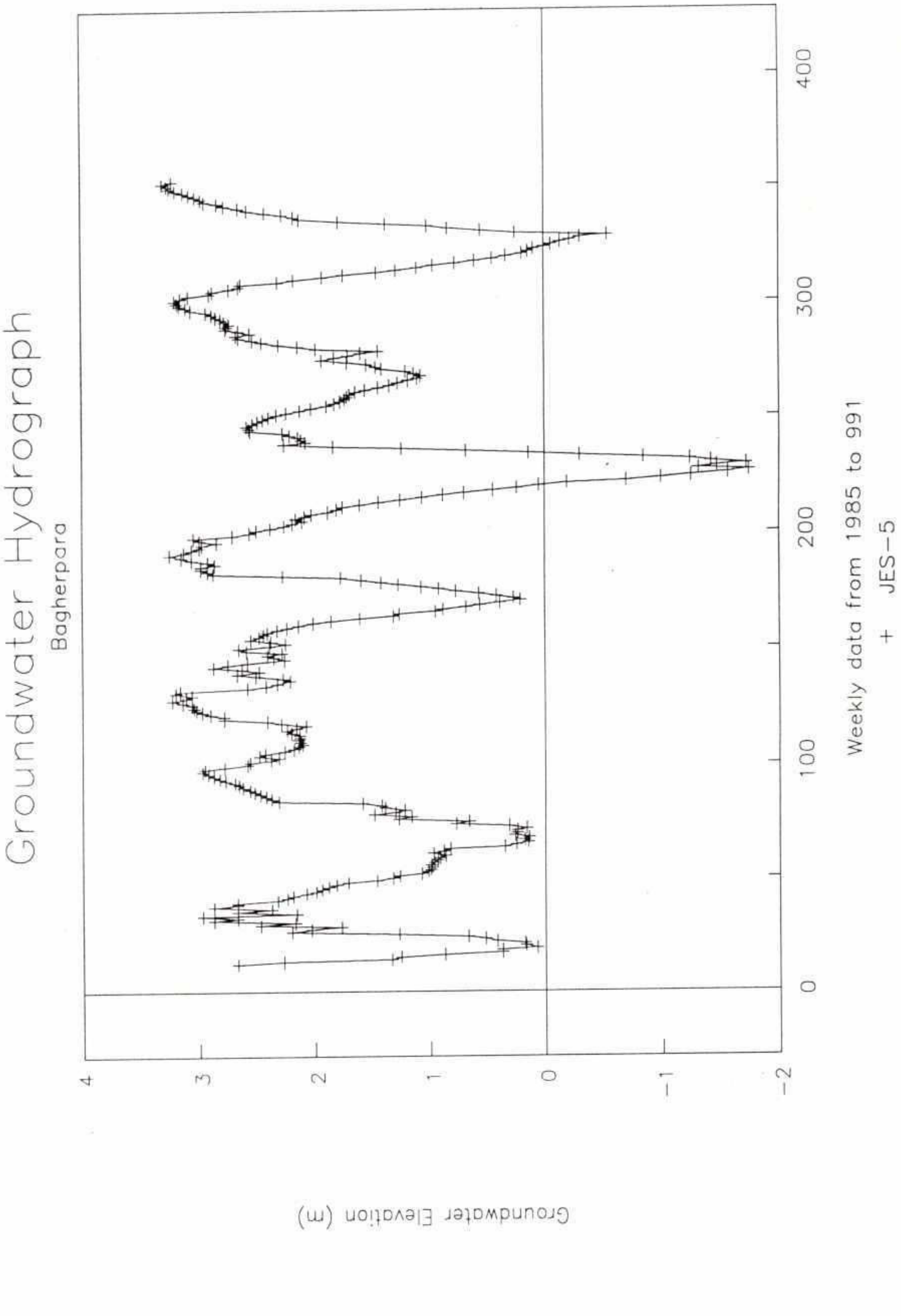

Groundwater Hydrograph
Alamdanga
Weekly data from 1985 to 1991
+ KT-50
Groundwater Elevation (m)
0
100
200
300
400
10
11
12
13
14
15
16

Figure 2.4



Groundwater Hydrograph
Bagherpara
Groundwater Elevation (m)
4
3
2
1
0
-1
-2
0
100
200
300
400
Weekly data from 1985 to 991
+ JES-5

(a) The presence of a saline front and lenses of freshwater in the upper aquifer;

(b) The presence of a the saline wedge in deeper aquifers;

(c) The existence of hydraulic continuity between groundwater and saline river waters.

The most important cases are (a) and (b), which are shown diagrammatically on Figure 2.6. The general salinity distribution in the deep aquifer, as indicated by TDS, is shown in Figure 2.7.

In the upper aquifer (case (a)) the position of the saline front is controlled by regional flow of groundwater towards the sea, and the prevailing recharge conditions. In addition freshwater lenses may occur, overlying the saline water. Under natural conditions only minor seasonal changes take place in these relationships between fresh and saline waters.

However groundwater abstraction has the potential to cause adverse change. Over-abstraction of groundwater for irrigation upstream, for example, in the unconfined aquifer parts of the Kushtia/Jessore area, will tend to cause movement of the saline front inland, resulting in more southerly wells beginning to pumping brackish and saline groundwater. Similarly, over abstraction or badly planned abstraction of water from the freshwater lenses - usually for potable water supply purposes - will cause up-coning of saline water, again with the effect of making wells go saline. These problems have already occurred in Khulna; no piped town supply is understood to be available from the lens, which has in parts become saline, and saline intrusion is also occurring in the deeper aquifers.

The freshwater lenses are a useful water resource in otherwise saline groundwater areas, which can be exploited if, properly managed. The appropriate technique is to 'skin off' freshwater by using numerous small- capacity wells, thereby avoiding excessive drawdown which will cause up-coming. In any event, the depth and extent of the lens needs to be thoroughly understood prior to its exploitation.

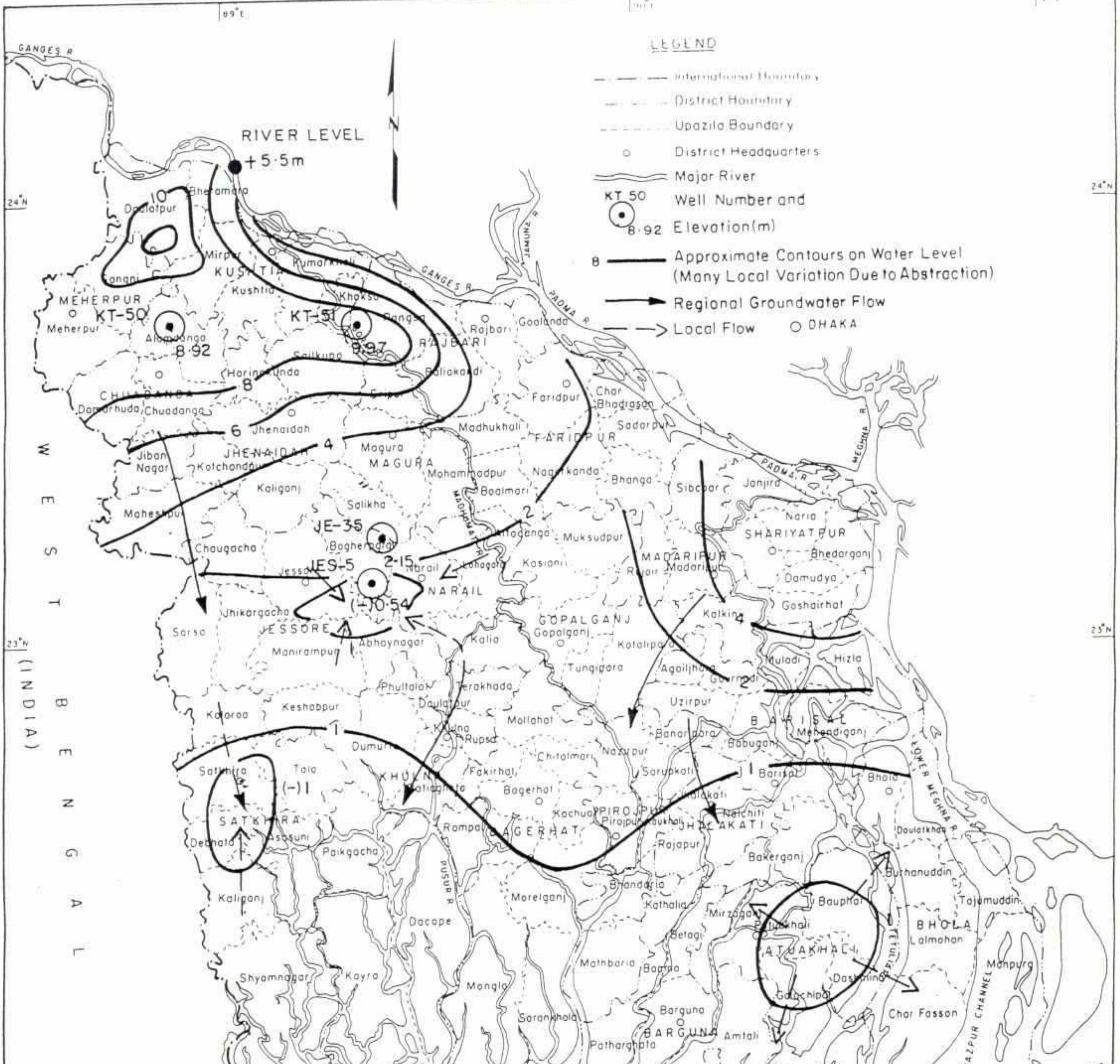
The position of the saline wedge in the deeper aquifers is even less well defined. Its position is again controlled by southwards groundwater flow from northern parts of the project area, and over abstraction within the region will tend to cause the wedge to move inland, thus putting the existing irrigation wells at risk.

The general risk to groundwater as a result of saline intrusion is a real one, and it is a problem which needs to be taken seriously. There are numerous examples world-wide of similar hydrogeological conditions where unplanned development has led to the catastrophic loss of fresh groundwater resources; the Chao Phrya basin of southern Thailand is a good example. There, badly managed groundwater abstraction has led to saline water ingress over a wide area, and severe subsidence problems.

Because it is unlikely that hydrogeological investigations of sufficient detail to fully understand the three dimensional relationship between fresh and saline groundwater will be instigated, the MPO proposal to allow for creation of a buffer zone, in which irrigation development is limited, is sensible. The buffer zone consists of districts between the known areas of saline water in the south and areas of high groundwater abstraction in the north.

An example of a district in the buffer zone is Khulna. Inevitably however, because groundwater in many upazilas in Khulna District is conveniently available and fresh, there is significant development already. In order that no further abstraction can be planned, in Tables 4.2 and 4.3 in Section 4 of this Annex that in Khulna District available recharge is set at zero because it is regarded as being 100% constrained against salinity.

Figure 2.5



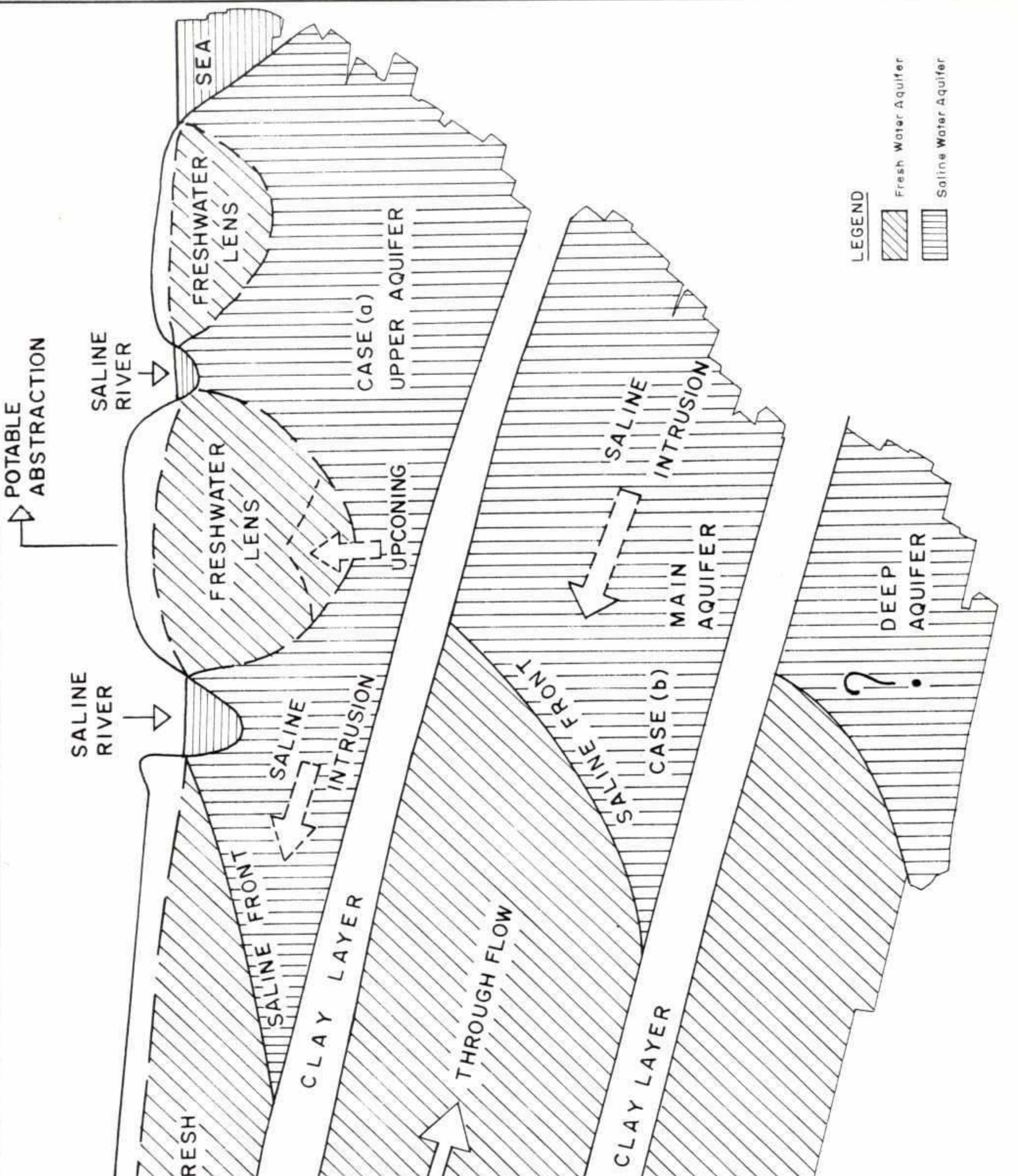
NOTE

Some Levels Negative
South of Khulna, Satkhira

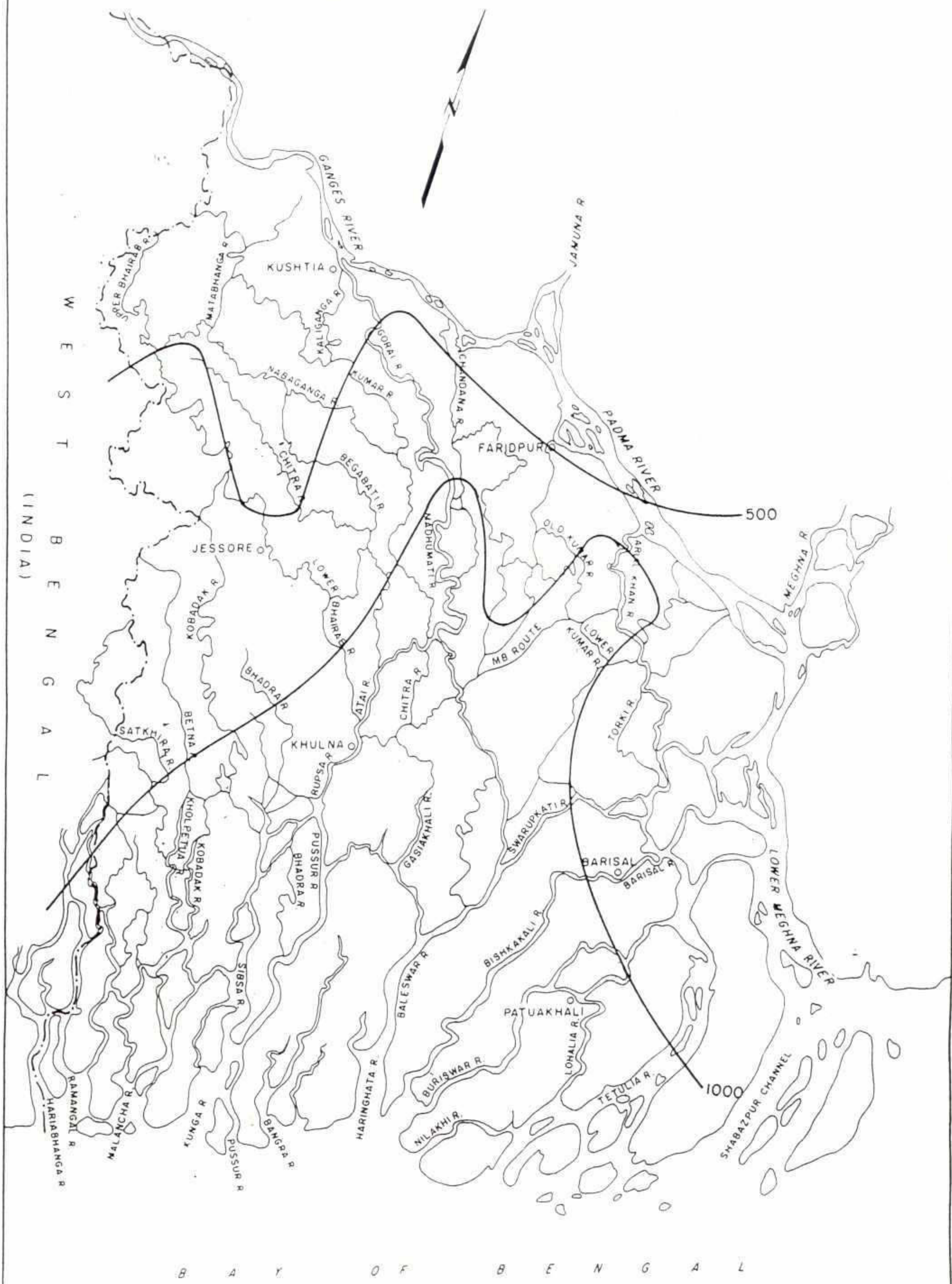
SOURCE: BWDB GROUDWATER MONITORING DATA

WELL HYDROGRAPH LOCATIONS AND WATER LEVEL CONTOURS ON 29-4-1991

Figure 2.6



SALINITY DISTRIBUTIONS AND PROCESSES



SOURCE: (MPO/HARZA, 1987)

TDS OF MAIN AQUIFER (MG/L)

The analysis of available groundwater presented later in this Annex takes into account the requirement to protect the existing resources against salinity.

The relationship between groundwater and saline river water (case C) is a much less significant problem, if it is a problem at all. In general, the interchange of waters between rivers and the aquifer is low because:

(a) the hydraulic gradient between the two is low;

(b) upper aquifer permeabilities are also comparatively low.

Thus while dry season groundwater abstraction takes place at a time when river water salinity is at its highest in upstream waters, there is no guarantee that it will be drawn into nearby wells. Also, because there is a baseflow recession between October and January, any incoming saline water is likely to be flushed back out again.

2.4.2 Other Water Quality Issues

Groundwater analyses for project areas wells are given in Table 2.3. The data were obtained by the BWDB groundwater circle and cover all major ions and some minor ions. The sample locations are shown in Figure 2.8.

Fresh groundwaters are of the Na - Ca - HCO_3 type, typical of many areas of Bangladesh, with TDS values generally less than 500 mg/l. More southerly wells show evidence of salinity with high Na - C1 values. There are anomalies and inconsistencies in the data which are probably attributable to sampling protocol, mixed waters and analytical error.

In terms of minor ions, iron is often high, up to 10 mg/l even in fresh water wells. Boron values are occasionally anomolously high, which is a feature of many groundwaters in Bangladesh, for which no satisfactory explanation has been provided.

Apart from Na - Cl salinity there is no significant groundwater quality problem in the study area.

2.4.3 Groundwater Quality Protection

In addition to controlling abstraction rates so as to avoid saline intrusion, the matter of groundwater pollution caused by over-use of fertilisers and pesticides should also be considered as part of implementing irrigation projects.

Application of fertiliser creates the possibility of raising nitrate levels in groundwater which are regarded as a health-hazard when consumed regularly at levels of over 50 mg/l (as NO3). Possible effects are 'blue-baby syndrome' which is a respiratory problem in nursing infants and there is a possible link to stomach cancers. Similarly, pesticides and their residues are in some cases known to be carcinogenic and are rigidly controlled in international drinking water quality standards.

While the consequences of nitrate and pesticide loading are unknown for Bangladesh conditions, it would be sensible to instigate monitoring, and some thought could be given to drawing up simple codes of good agricultural practice for their use.

TABLE 2.3
Groundwater Quality, Southwest Area

Station No.	Location Upazila/ District	Period	pH	Calcium Ca mg/l	Magnesium Mg mg/l	Sodium Na mg/l	Iron Fe mg/l	Manganese Mn mg/l	Carbonate Co3 mg/l	Bi-Carbonate HCo3 mg/l	Chloride Cl mg/l	Sulphate So4 mg/l	Free Co2 mg/l	Sio2 mg/l	Boron B mg/l	TDS mg/l
S-56	Bheramara	8-4-86	9.00	138.77	61.05	119.11	0.58	NT	NT	484.21	298.20	24.51	37.55	11.80	0.04	902
	Kushtia	14-5-90	-	51.00	48.00	55.23	0.11	NT	NT	449.75	32.40	29.40	23.94	40.00	0.09	499
S-55	Daulatpur	27-4-86	10.00	30.98	26.73	44.23	5.25	NT	17.70	149.49	38.26	49.02	6.00	20.60	NT	312
	Kushtia	14-5-90	-	60.60	32.04	50.07	5.56	NT	NT	400.46	43.73	39.20	19.51	35.50	NT	487
S-57	Kushtia	28-4-86	10.00	18.97	30.37	33.25	9.75	NT	11.75	137.52	44.77	24.51	7.80	18.40	NT	265
	Kushtia	13-5-90	-	41.00	15.90	64.37	4.80	NT	9.70	296.34	19.18	21.04	8.38	45.00	0.08	384
S-59	Darsana	17-4-86	10.00	23.08	28.25	19.30	0.09	NT	11.80	167.38	13.40	9.83	11.98	23.20	NT	218
	Kushtia	14-5-90	-	55.30	58.02	95.41	0.61	0.01	NT	471.93	102.38	50.96	29.90	25.00	0.03	643
-	Khoksha	1990	-	43.00	37.98	207.72	1.73	0.02	NT	474.40	28.42	60.27	17.11	42.50	NT	667
	Kushtia															
S-58	Meherpur	16-4-86	10.00	21.09	34.32	33.22	0.16	NT	17.68	209.23	14.41	24.53	4.90	15.30	NT	270
	Meherpur	14-5-90	-	56.30	48.42	57.12	0.34	NT	NT	484.25	33.10	19.60	29.92	27.75	NT	503
S-62	Jessore	8-4-86	8.00	77.15	38.88	152.91	1.65	NT	NT	541.00	129.22	34.25	19.02	22.00	0.18	730
	Jessore	16-5-90	-	18.32	26.82	131.75	1.31	NT	26.16	295.73	94.43	22.54	1.92	42.75	0.22	526
S-64	Jhikargacha	24-4-86	9.50	21.49	29.42	28.00	5.90	NT	11.81	161.45	35.71	24.49	8.00	16.40	NT	260
	Jessore	29-5-90	-	43.30	21.78	23.10	7.16	NT	20.00	218.10	18.19	9.78	NT	35.00	NT	308
S-60	Jhenaidah	29-4-86	8.00	19.07	32.20	59.58	4.90	NT	23.57	209.23	11.41	49.03	NT	24.80	NT	335
	Jhenaidah	13-5-90	-	27.66	16.02	22.22	0.09	NT	20.10	129.38	20.17	14.70	2.75	36.00	0.04	240
S-61	Magura	18-4-86	9.00	12.98	38.38	53.20	6.00	0.02	23.48	233.14	15.39	24.51	5.90	24.00	NT	320
	Magura	26-5-90	-	24.00	18.18	55.90	0.08	0.03	13.10	213.17	21.86	29.34	3.95	40.00	NT	321
BADC STW	Mohammadpur Magura	24-4-86	10.00	21.01	34.62	26.29	7.50	NT	11.80	179.31	25.31	19.64	7.00	22.80	NT	265
Shallow Well no-86	Sailkupa Jhenaidah	1986	-	15.50	23.31	51.70	0.11	0.02	11.80	128.52	39.26	29.41	10.00	27.80	0.12	270
S-63	Narail	25-5-90	-	13.60	42.24	230.77	4.00	NT	21.80	306.82	288.26	14.68	NT	31.00	NT	818
	Narail		-													
S-65	Khulna	21-4-86	9.00	82.17	195.91	2734.03	28.75	0.02	11.80	257.05	4771.20	9.71	4.91	30.80	0.23	8000
	Khulna	22-5-90	-	24.00	27.78	209.35	0.64	NT	27.88	282.17	226.63	30.87	NT	30.05	0.18	741
S-54	Khalishpur	26-4-86	10.00	29.50	58.02	316.59	2.42	NT	11.69	143.36	506.00	117.60	5.80	24.80	NT	1145
	Khulna	24-5-90	-	23.28	22.62	199.10	0.07	NT	38.20	320.37	170.96	16.17	NT	30.00	0.05	683

Source : Ground Water Circle, BWDB.

[samad\swr\tab2-3]

TABLE 2.3 (Continued)
Groundwater Quality, Southwest Area

Station No.	Location Upazila/ District	Period	pH	Calcium Ca mg/l	Magnesium Mg mg/l	Sodium Na mg/l	Iron Fe mg/l	Manganese Mn mg/l	Carbonate Co3 mg/l	Bi-Carbonate HCo3 mg/l	Chloride Cl mg/l	Sulphate So4 mg/l	Free Co2 mg/l	Sio2 mg/l	Boron B mg/l	TDS mg/l
D-28	Paikgacha	1986	-	25.57	39.76	57.73	12.25	NT	11.76	328.79	17.99	4.91	24.80	26.40	0.60	370
	Khulna															
S-66	Satkhira	23-4-86	9.50	15.57	44.65	42.47	1.65	NT	17.59	227.16	47.70	9.78	3.48	20.00	NT	317
	Satkhira	29-5-90	-	35.60	15.60	48.73	3.60	NT	13.94	146.02	40.75	56.33	2.75	71.00	NT	381
D-29	Kaliganj	1986	-	20.57	71.38	66.11	1.34	NT	35.38	322.83	81.54	19.56	3.89	25.60	NT	489
	Satkhira															
S-68	Bagerhat	24-4-86	9.50	25.51	31.59	61.42	12.65	NT	11.82	149.48	121.26	19.57	3.04	12.80	NT	380
	Bagerhat	28-5-90	-	68.00	46.98	533.86	11.60	NT	145.44	755.34	450.28	26.46	NT	37.50	NT	1713
S-67	Chalna	24-4-86	8.50	11.08	41.31	346.83	1.41	NT	35.30	292.92	447.30	4.88	NT	15.70	0.08	1055
	Khulna	28-5-90	-	139.3	212.22	39.60	6.90	NT	21.84	222.41	765.38	8.80	6.70	48.50	0.13	1365
W-71	Faridpur	1985	-	34.00	36.45	59.44	0.63	0.04	29.42	263.08	30.81	24.54	2.89	24.00	NT	376
	Faridpur															
W-70	Rajbari	1985	-	14.00	39.49	66.01	0.11	NT	29.35	203.27	17.19	19.64	5.00	24.00	0.04	318
	Rajbari															
W-73	Gopalganj	1985	-	23.02	30.07	38.62	18.75	NT	17.68	185.31	28.31	19.62	5.00	18.40	0.04	294
		1990	8.72	31.00	18.00	87.71	0.16	0.02	50.30	267.39	20.39	9.80	NT	22.50	0.02	387
S-64	Gopalganj	1985	-	61.62	68.04	71.93	1.60	NT	40.20	603.77	9.04	49.06	NT	25.80	0.03	595
W-72	Gopalganj	1985	-	30.99	39.79	17.97	15.50	NT	29.48	209.23	17.09	24.39	3.02	23.70	0.18	291
W-74	Madaripur	1985	-	37.05	27.33	61.78	1.52	NT	11.59	191.29	93.93	4.95	6.80	20.00	0.50	360
W-75	Barisal	1985	-	16.99	8.81	163.01	0.40	NT	35.25	269.01	94.43	4.88	2.05	12.80	0.21	477
		1990	8.71	71.00	3.00	111.61	0.17	NT	33.94	322.84	76.14	3.43	NT	17.50	0.10	491
27	Tushkhali	1985	-	29.00	32.50	2625.00	1.97	NT	88.20	669.53	3677.80	4.87	NT	22.20	0.10	6822
	Barisal															
W-76	Bhola	1985	-	28.03	23.69	169.44	0.70	NT	35.21	298.92	149.10	4.97	3.01	13.70	0.58	580
		1990	8.50	19.30	20.22	60.23	0.16	NT	9.70	101.01	60.63	3.43	2.39	30.00	0.45	313
S-24	Lalmohon	1985	-	164.83	64.70	716.31	0.47	NT	NT	35.86	1540.70	9.89	51.00	17.10	0.39	2539
	Bhola	1990	6.75	165.00	88.98	448.56	0.80	NT	NT	36.97	1219.14	3.43	9.10	0.42	0.30	1957
S-23	Lalmohon	1985	-	34.98	9.72	1957.15	0.90	NT	5.90	89.67	1081.70	19.58	13.00	8.00	0.36	5113
	Bhola	1990	8.58	31.00	18.36	170.64	0.08	NT	33.94	325.30	139.76	3.43	NT	24.50	0.35	601

Source : Ground Water Circle, BWDB.

[samad\swr\tab2-3]

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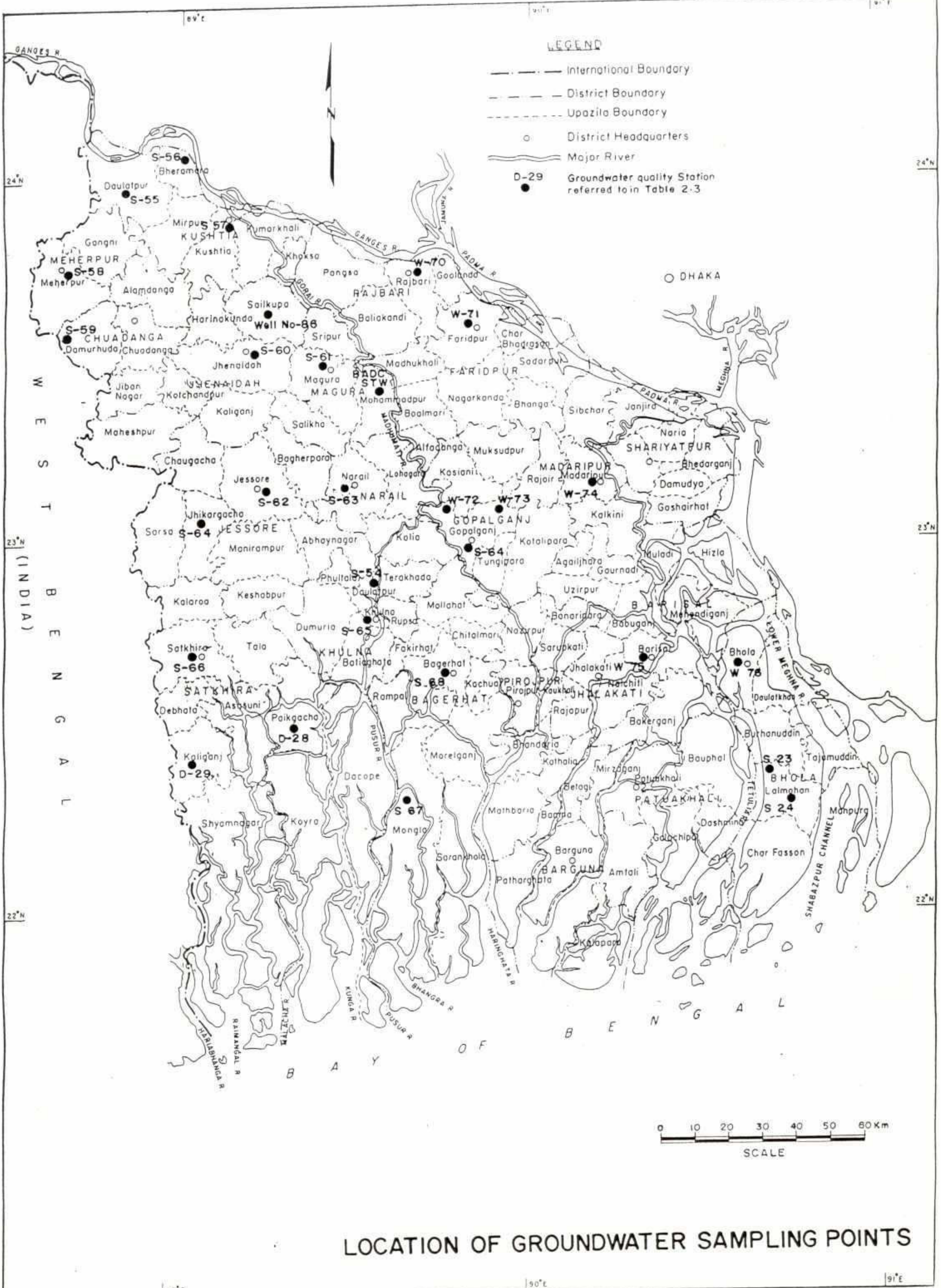
Figure 2.8



LOCATION OF GROUNDWATER SAMPLING POINTS

3 GROUNDWATER RESOURCES EVALUATION

3.1 Recharge

The usual method of evaluation of available groundwater resources which is adopted in Bangladesh is based on a calculation of recharge. Recharge is the process by which water infiltrates during the wet season and restores the groundwater levels to field capacity. It is usually expressed as a depth of water per unit area, or as a seasonally available volume.

In the context of this report and the area under study, the primary sources of natural recharge are taken to be direct rainfall and flood waters; other potential sources such as groundwater inflows, are considered to be negligible (UNDP, 1982: MPO/Harza, 1986).

Recharge which occurs under natural conditions is referred to as Actual Recharge. However, if groundwater levels are artificially lowered by abstraction, the opportunity is created for increasing recharge to some maximum value. This value is a function of the soil conditions (which determine infiltration rate) and availability of water at the surface; the maximum value is referred to as Potential Recharge.

Determination of recharge has been an important component of numerous hydrogeological studies carried out in Bangladesh in recent years. (UNDP/UNDTCD, 1981, 1982; Karim, 1984; Sir M. MacDonald and Partners, 1984; MPO/Harza, 1986). In particular MPO/Harza (1986) calculated recharge based on distributed parameter models which have simulated the recharge process in individual catchments. This work probably represents the most reliable estimate currently available and has been used as the basis for assessment in this Annex.

The concepts of actual and potential recharge are shown in Figure 3.1, and the process involved in depleting storage in order to create higher recharge is shown in Figure 3.2. Figure 3.3 shows hydrograph data from Comilla Kotwali in southeast Bangladesh and is a field example of recharge being increased by abstraction.

3.2 The Depth-Storage Concept

Another important concept in understanding the recharge mechanism is depth-storage, and its relationship with recharge. An underlying principle is depth-related specific yield. The main points are illustrated in Figure 3.4.

Using a lithological log obtained from drilling samples, an estimated value of specific yield (Sy) can be estimated for each layer (Figure 3.4 (a)). Values of Sy ascribed to individual layers can be integrated to provide a depth-related cumulative value of Sy, (Figure 3.4 (b)), which, when multiplied by the depth, gives a depth-storage curve (Figure 3.4 (c)). This curve can be used to indicate:

(a) The amount of water in storage for any specified depth and hence the available abstraction for a specified water level.

(b) The water-level equivalent of some specified value of recharge, and hence a depth to which groundwater level must reduce in order to accept that value of recharge during the monsoon.

The importance of using depth-related Sy data in producing the storage curve, rather than an assumed constant value, is also illustrated in Figure 3.4. For a water level depth of, say,

Figure 3.1

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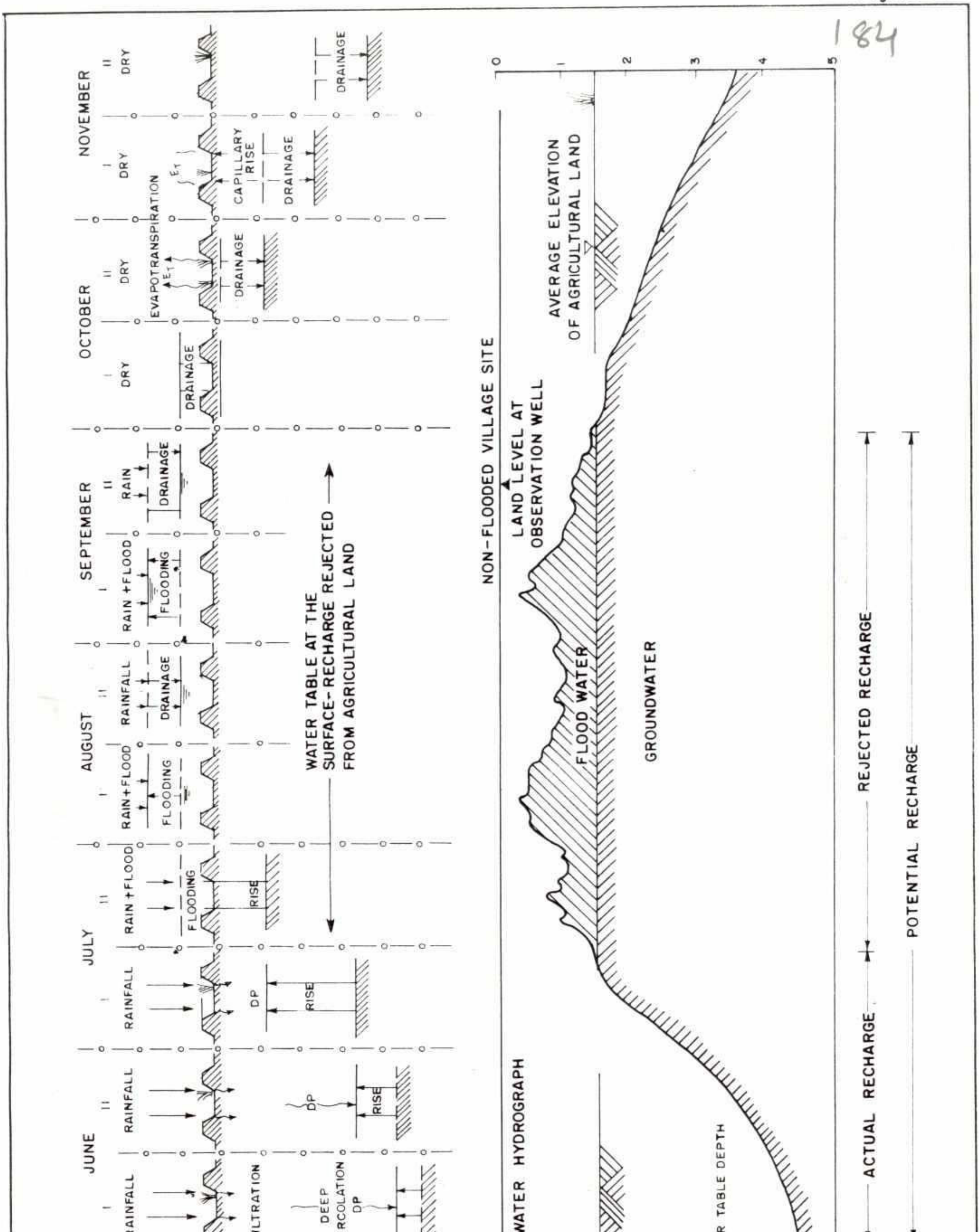
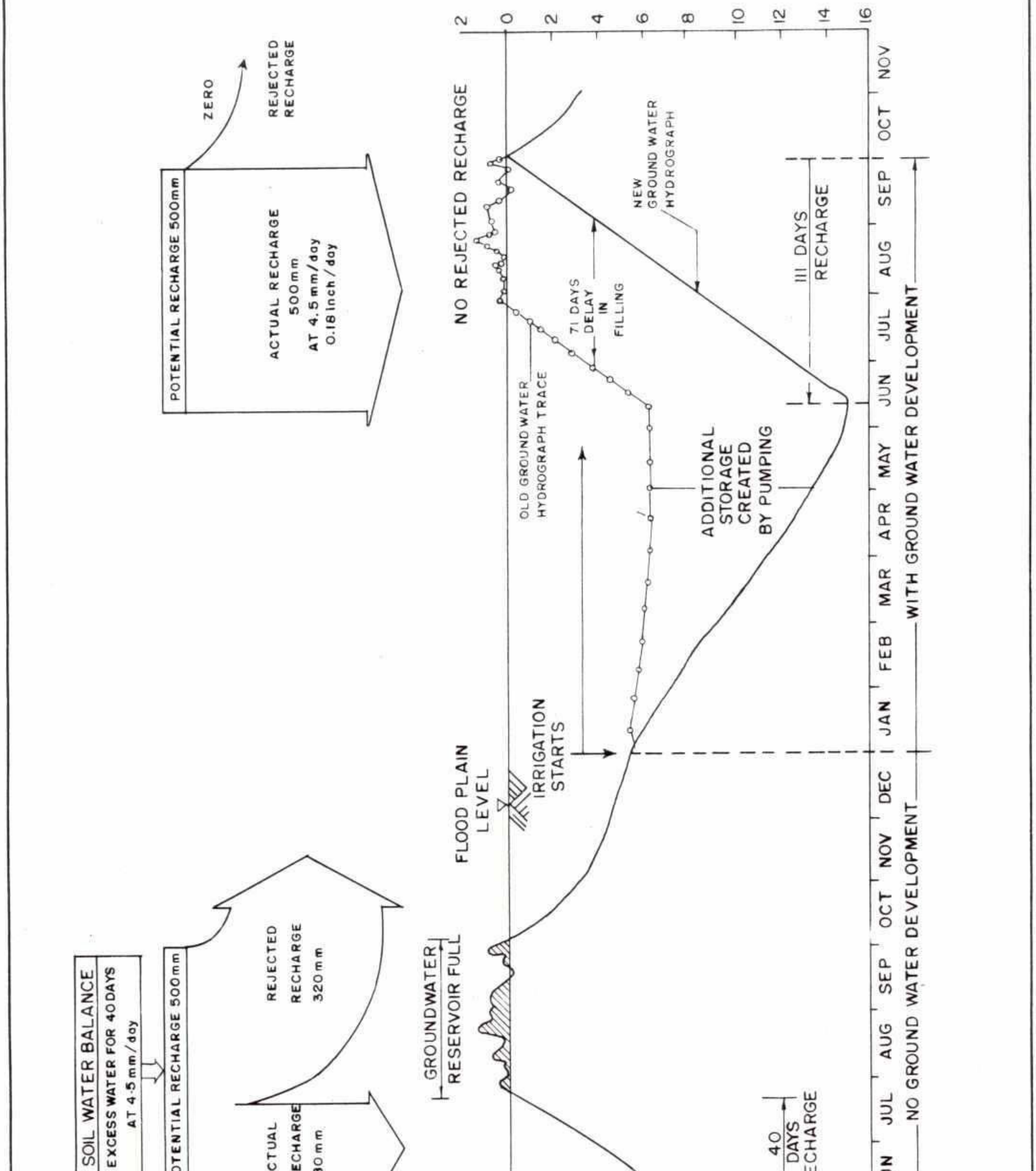


SOURCE M.P.O/HARZA 1986

RECHARGE CONCEPTS: LAND, WATER AND GROUNDWATER ENVIRONMENT DURING THE MONSOON PERIOD



SOURCE: MPO/HARZA, 1986

STORAGE MANIPULATION: GROUNDWATER STORAGE CREATION TO CAPTURE POTENTIAL RECHARGE

10m, the storage would be significantly overestimated by using an assumed constant 15% specific yield. Conversely, for a specified recharge value or storage available for abstraction, the depth to which regional water levels would fall would be under-estimated on the basis of the constant 15% assumption.

It is also important to recognise the necessity for accurate recording and interpretation of drilling samples to define lithologies, in order that the depth-specific yield relationship can be accurately determined.

The relationship is of particular value in assessment of the viability of the STW/DTW pumping options, given that the suction limit on STW's can be related to a value of storage, thus indicating the approximate quantity of water which can be abstracted using STW. Under the NWP-II Study (MPO, 1991) resource potential has been calculated for each different tubewell technology for each upazila in Bangladesh.

3.3 Recharge Calculations

The MPO/Harza modelling studies (MPO/Harza, 1985) to determine groundwater recharge were based on simulation of the surface water- groundwater system during the period 1964-1982 for individual river catchments at 10-day time steps. Finite difference models of representative catchments were developed and calibrated, and the same parameters were then used in the large scale models. The input data included soil and aquifer parameters, hydrometeorological data and agricultural factors.

In addition to providing estimates of potential and actual recharge as defined in Section 3.1, the Master Plan studies included determination of usable and available recharge. Usable recharge is taken as 75% of the mean annual potential recharge to allow for uncertainties/errors in calculation/estimation, reduction in recharge due to FCDI schemes etc. Available recharge is the usable recharge less;

(a) Losses which occur between the end of the monsoon period and the commencement of irrigation (mainly base-flow and evapo -transpiration).

(b) Stored groundwater which is unavailable due to a series of identifiable constraints, of which additional baseflow reduction is probably the most significant constraint in the project area.

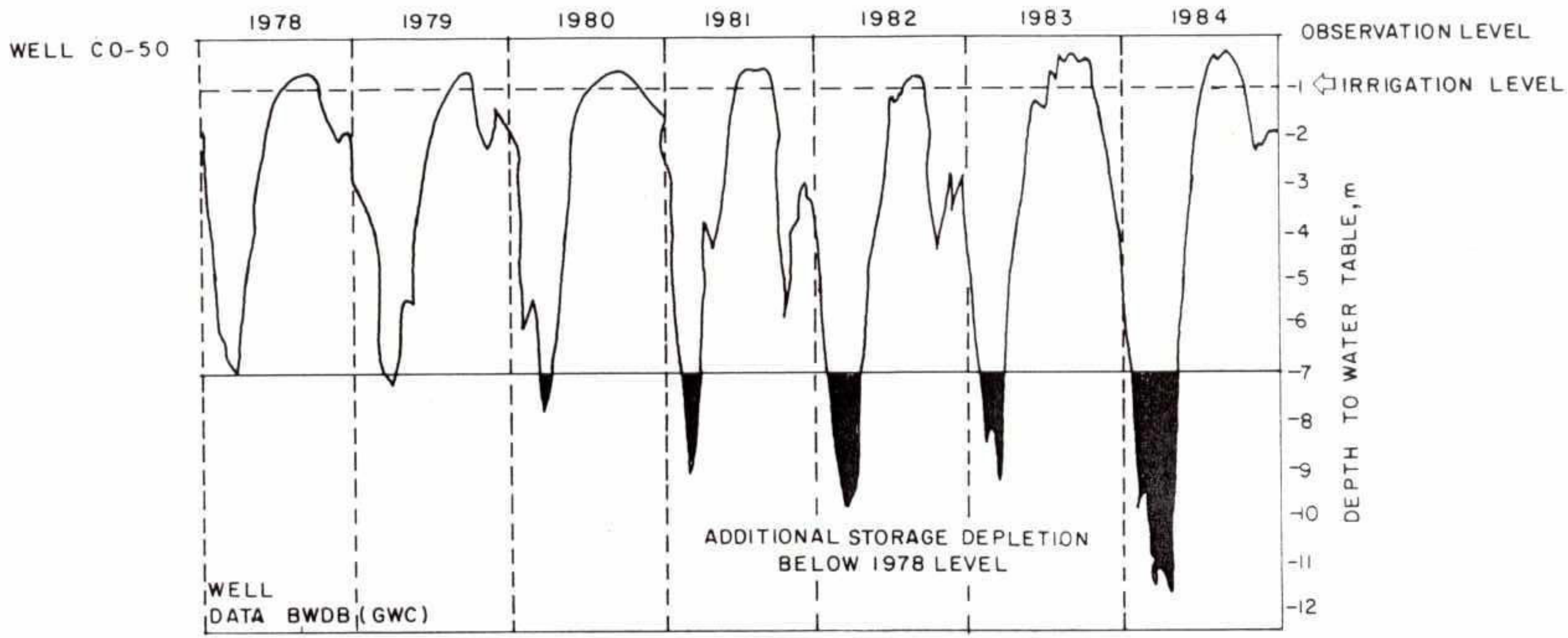
(c) Allowance for other constraints such as salinity

Values of potential, usable and available recharge for the project area are given in Table 3.1. For the purposes of this Annex, values in the medium category have been used to represent an 'average' condition; here, the word 'medium' refers to soil permeability conditions. More detailed monitoring at upazila level might result in use of the high or low category.

3.4 The Effects of Flood Protection on Recharge

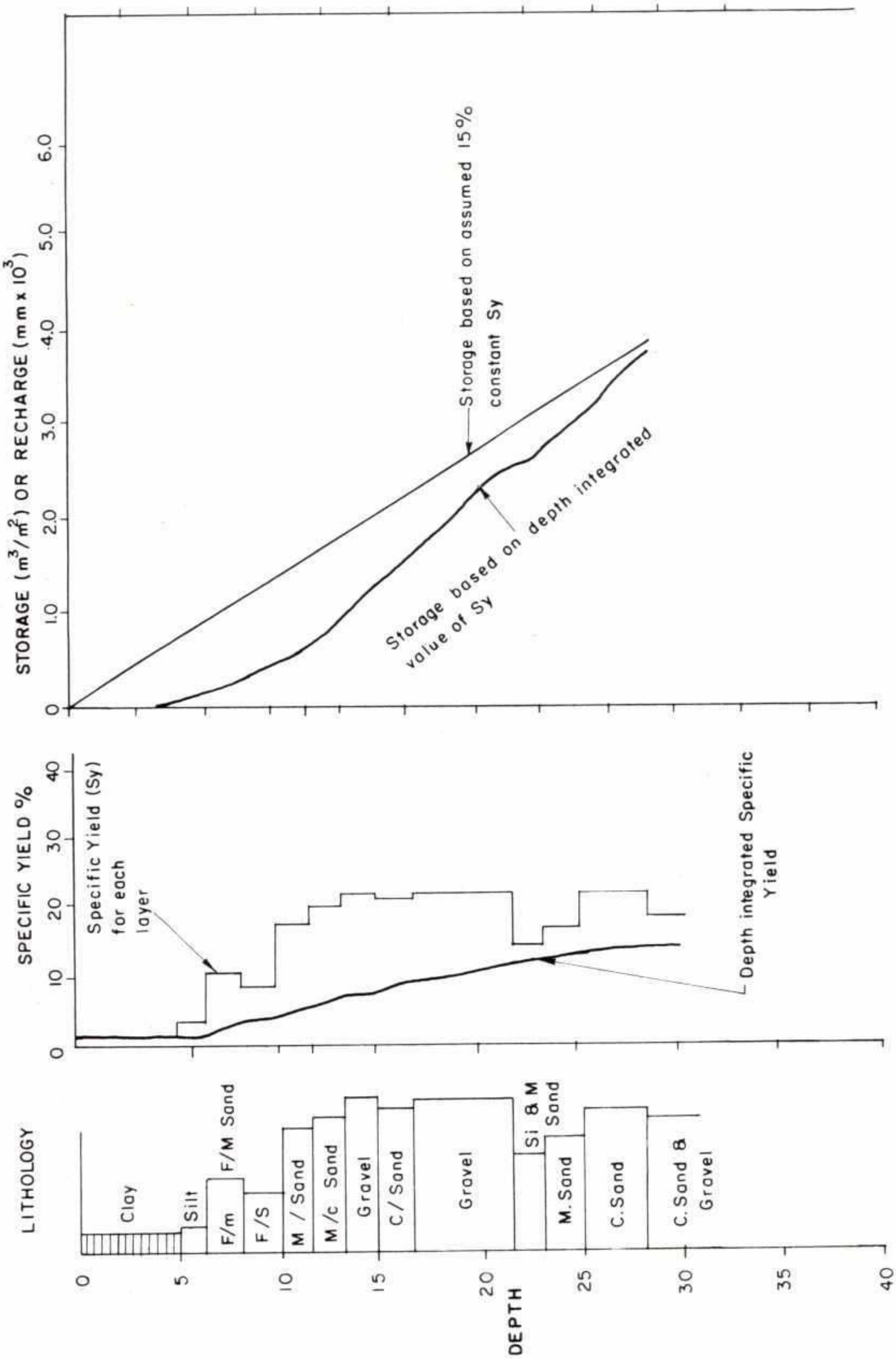
Flooding of land is an important factor in the recharge process and flood protection has the effect of reducing potential recharge. In the extreme case, full flood protection (FFP) could eliminate flooding while controlled flood protection (CFP) would tend to shorten the period of inundation. In both cases, significant reduction in potential recharge can be anticipated in areas subject to prolonged flooding.

ANNUAL RECHARGE BALANCE							
RECHARGE POTENTIAL mm	500	500	500	500	500	500	500
WATER TABLE DEPTH, m	6·9	7·3	7·9	9·2	9·9	9·6	11·4
ACTUAL RECHARGE mm	157	168	183	227	254	242	337
REJECTED POTENTIAL RECHARGE mm	343	332	317	273	246	258	163



SOURCE MPO/HARZA 1986

STORAGE MANUPULATION IN COMILLA (KOTWALI)



SOURCE: MPO/HARZA, 1986

DEPTH–STORAGE RELATIONSHIP

TABLE 3.1

PROJECT AREA RECHARGE ESTIMATES

District / Thana	Gross Area	Mean Annual Rainfall	RECHARGE: POTENTIAL HIGH		POTENTIAL MED		POTENTIAL LOW		USABLE HIGH		USABLE MED		USABLE LOW		AVAILABLE (Percentage reduction for constraint) % CONST. TYPE	%	HIGH	MED
	Km²	mm	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	TYPE	%	Mm3	Mm3
KUSHTIA																		
Bheramara	152	1479	270	41.04	225	34.20	180	27.36	203	30.86	169	25.69	135	20.52	*1	72.30	22.31	18.57
Daulatpur	466		300	139.80	250	116.50	200	93.20	225	104.85	188	87.61	150	69.90	*1	72.30	75.81	63.34
Kumarkhali	328		300	98.40	250	82.00	200	65.60	225	73.80	188	61.66	150	49.20	*1	72.30	53.36	44.58
Khoksa	98		420	41.16	350	34.30	280	27.44	315	30.87	263	25.77	210	20.58	*1	72.30	22.32	18.63
Kushtia	315	1517	300	94.50	250	78.75	200	63.00	225	70.88	180	56.70	150	47.25	*1	72.30	51.24	40.99
Mirpur	326		270	88.02	225	73.35	180	58.68	203	66.18	169	55.09	135	44.01	*1	72.30	47.85	39.83
CHUADANGA																		
Alamdanga	349	1515	223	77.83	185	64.57	148	51.65	167	58.28	139	48.51	111	38.74	*1	77.25	45.02	37.47
Damurhuda	308		300	92.40	250	77.00	200	61.60	225	69.30	188	57.90	150	46.20	*1	77.25	53.53	44.73
Chudanga	287	1550	240	68.88	200	57.40	160	45.92	180	51.66	150	43.05	120	34.44	*1	77.25	39.91	33.26
Jiban Nagar	202		300	60.60	250	50.50	200	40.40	225	45.45	188	37.98	150	30.30	*1	77.25	35.11	29.34
MEHERPUR																		
Gangni	344		240	82.56	200	68.80	160	55.04	180	61.92	150	51.60	120	41.28	*1	73.00	45.20	37.67
Meherpur	372	1454	336	124.99	280	104.16	224	83.33	252	93.74	210	78.12	168	62.50	*1	73.00	68.43	57.03
JESSORE																		
Abhynagar	246	1937	360	88.56	300	73.80	240	59.04	270	66.42	225	55.35	180	44.28	*1	77.25	51.31	42.76
Bagherpara	272		360	97.92	300	81.60	240	65.28	270	73.44	225	61.20	180	48.96	*1	77.25	56.73	47.28
Chougachha	269	1628	360	96.84	300	80.70	240	64.56	270	72.63	225	60.53	180	48.42	*1	77.25	56.11	46.76
Jhikergacha	308		420	129.36	350	107.80	280	86.24	315	97.02	263	81.00	210	64.68	*1	77.25	74.95	62.58
Jessore	435	1705	360	156.60	300	130.50	240	104.40	270	117.45	225	97.88	180	78.30	*1	77.25	90.73	75.61
Kesabpur	259	1767	360	93.24	300	77.70	240	62.16	270	69.93	225	58.28	180	46.62	*1	77.25	54.02	45.02
Manirampur	445		360	160.20	300	133.50	240	106.80	270	120.15	225	100.13	180	80.10	*1	77.25	92.82	77.35
Sarsha	341		360	122.76	300	102.30	240	81.84	270	92.07	225	76.73	180	61.38	*1	77.25	71.12	59.27
JHENAIDAH																		
Harinakunda	228		300	68.40	250	57.00	200	45.60	225	51.30	188	42.86	150	34.20	*1	78.70	40.37	33.73
Jhenaidah	471	1602	330	155.43	275	129.53	220	103.62	248	116.81	206	97.03	165	77.72	*1	78.70	91.93	76.36
Kaliganj	315	1681	420	132.30	350	110.25	280	88.20	315	99.23	263	82.85	210	66.15	*1	78.70	78.09	65.20
Kotchandpur	171		420	71.82	350	59.85	280	47.88	315	53.87	263	44.97	210	35.91	*1	78.70	42.39	35.39
Mahespur	422		420	177.24	350	147.70	280	118.16	315	132.93	263	110.99	210	88.62	*1	78.70	104.62	87.35
Sailkupa	372	1680	330	122.76	275	102.30	220	81.84	248	92.26	206	76.63	165	61.38	*1	78.70	72.61	60.31
MAGURA																		
Mohammadpur	233		480	111.84	400	93.20	320	74.56	360	83.88	300	69.90	240	55.92	*1	75.33	63.19	52.66
Magura	401	1745	330	132.33	275	110.28	220	88.22	248	99.45	206	82.61	165	66.17	*1	75.33	74.91	62.23
Sripur	183		420	76.86	350	64.05	280	51.24	315	57.65	263	48.13	210	38.43	*1	75.33	43.42	36.26
Salikha	227	1791	360	81.72	300	68.10	240	54.48	270	61.29	225	51.08	180	40.86	*1	75.33	46.17	38.47
Narail																		
Kalia	305		480	146.40	400	122.00	320	97.60	360	109.80	300	91.50	240	73.20	*1	75.75	83.17	69.31
Lohagara	300		360	108.00	300	90.00	240	72.00	270	81.00	225	67.50	180	54.00	*1	75.75	61.36	51.13
Narail	385	1727	420	161.70	350	134.75	280	107.80	315	121.28	263	101.26	210	80.85	*1	75.75	91.87	76.70
KHULNA																		
Terakhada	189		480	90.72	400	75.60	320	60.48	360	68.04	300	56.70	240	45.36	*2	0.00	0.00	0.00
Phultala	75		480	36.00	400	30.00	320	24.00	360	27.00	300	22.50	240	18.00	*2	0.00	0.00	0.00
Daulatpur	113		450	50.85	375	42.38	300	33.90	338	38.19	281	31.75	225	25.43	*2	0.00	0.00	0.00
Dumuria	455	1854	480	218.40	400	182.00	320	145.60	360	163.80	300	136.50	240	109.20	*2	0.00	0.00	0.00
Rupsa	82	1784	480	39.36	400	32.80	320	26.24	360	29.52	300	24.60	240	19.68	*2	0.00	0.00	0.00
Baitaghata	246		540	132.84	450	110.70	360	88.56	405	99.63	338	83.15	270	66.42	*2	0.00	0.00	0.00
Paikgachha	283	1768	660	186.78	550	155.65	440	124.52	495	140.09	413	116.88	330	93.39	*2	0.00	0.00	0.00
Dacope	209		480	100.32	400	83.60	320	66.88	360	75.24	300	62.70	240	50.16	*2	0.00	0.00	0.00
Koyra	263	No Data Available																
Khulna	19	No Data Available																
SATKHIRA																		
Kalaroa	233	1629	360	83.88	300	69.90	240	55.92	270	62.91	225	52.43	180	41.94	*2	0.00	0.00	0.00
Tala	336		360	120.96	300	100.80	240	80.64	270	90.72	225	75.60	180	60.48	*2	0.00	0.00	0.00
Asasuni	411		540	221.94	450	184.95	360	147.96	405	166.46	338	138.92	270	110.97	*2	0.00	0.00	0.00
Syamnagar	1901		720	1368.72	600	1140.60	480	912.48	540	1026.54	450	855.45	360	684.36	*2	0.00	0.00	0.00
Kaliganj	331	1619	360	119.16	300	99.30	240	79.44	270	89.37	225	74.48	180	59.58	*2	0.00	0.00	0.00
Debhata	170		420	71.40	350	59.50	280	47.60	315	53.55	263	44.71	210	35.70	*2	0.00	0.00	0.00
Satkhira	365	1808	360	131.40	300	109.50	240	87.60	270	98.55	225	82.13	180	65.70	*2	0.00	0.00	0.00

Note :

*1 Base Flow Losses
*2 Salinity : 100 Percent Salinity Constraints
*3 Fcdi And Fcd (Small Reductions Only, For Reduced Period Of Inundation)
*4 Poor Aquifer (Thick Clay Surface Layer)

TABLE 3.1 (Continued)
PROJECT AREA RECHARGE ESTIMATES

District / Thana	Gross Area	Mean Annual Rainfall	RECHARGE: POTENTIAL HIGH		POTENTIAL MED		POTENTIAL LOW		USABLE HIGH		USABLE MED		USABLE LOW		AVAILABLE (Percentage reduction for constraint): % CONST		HIGH	MED
	Km²	mm	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	mm	Mm3	TYPE	%	Mm3	Mm3
BAGERHAT																		
Mollahat	217	2060	540	117.18	450	97.65	360	78.12	405	87.89	338	73.35	270	58.59	*2,3,4	0.00	0.00	0.00
Fakirhat	160		540	86.40	450	72.00	360	57.60	405	64.80	338	54.08	270	43.20	*2	0.00	0.00	0.00
Chitalmari	137		1200	164.40	1000	137.00	800	109.60	900	123.30	750	102.75	600	82.20	*2	0.00	0.00	0.00
Bagerhat	269	2155	540	145.26	450	121.05	360	96.84	405	108.95	338	90.92	270	72.63	*2	0.00	0.00	0.00
BARISAL																		
Agailjhara	160		1200	192.00	1000	160.00	800	128.00	900	59.03	750	45.34	600	29.82	*1,4	0.00	0.00	0.00
Gaurnadi	139	2174	600	83.40	500	69.50	400	55.60	450	62.55	375	52.13	300	37.34	*1,4	0.00	0.00	0.00
Wazirpur	246		720	177.12	600	147.60	480	118.08	540	73.27	450	55.34	360	36.02	*2,4	0.00	0.00	0.00
Babuganj	147		600	88.20	500	73.50	400	58.80	450	37.41	375	30.00	300	20.80	*3,4	0.00	0.00	0.00
Bakerganj	388	2178	720	279.36	600	232.80	480	186.24	540	88.79	450	69.86	360	47.99	*3,4	0.00	0.00	0.00
Mehendiganj	349		1080	376.92	900	314.10	720	251.28	810	44.75	675	39.62	540	31.83	*1,4,5	0.00	0.00	0.00
Hizla	458		1200	549.60	1000	458.00	800	366.40	900	40.64	750	35.76	600	28.50	*1,4,5	0.00	0.00	0.00
Muladi	261		1020	266.22	850	221.85	680	177.48	765	67.01	638	54.18	510	38.12	*1,4,5	0.00	0.00	0.00
Barisal	292	2175	780	227.76	650	189.80	520	151.84	585	65.00	488	53.00	390	37.54	*2,4	0.00	0.00	0.00
JHALAKATI																		
Nalchiti	233		660	153.78	550	128.15	440	102.52	495	41.28	413	33.41	330	23.95	*2	0.00	0.00	0.00
Rajapur	163		600	97.80	500	81.50	400	65.20	450	29.88	375	23.86	300	16.89	*2	0.00	0.00	0.00
Jhalakati	194	2011	840	162.96	700	135.80	560	108.64	630	19.78	525	17.43	420	13.97	*2	0.00	0.00	0.00
PIROJPUR																		
Nazirpur	225	2062	600	135.00	500	112.50	400	90.00	450	44.71	375	35.29	300	24.52	*1,4,5	0.00	0.00	0.00
Banaripara	129	2112	600	77.40	500	64.50	400	51.60	450	58.05	375	48.37	300	41.63	*2	0.00	0.00	0.00
Swarupkati	183		660	120.78	550	100.65	440	80.52	495	49.83	413	40.04	330	27.61	*2	0.00	0.00	0.00
Kaukhali	80		660	52.80	550	44.00	440	35.20	495	17.53	413	14.12	330	9.92	*2	0.00	0.00	0.00
FARIDPUR																		
Modhukhali	217	1813	480	104.16	400	86.80	320	69.44	360	78.12	300	65.10	240	52.08	*1	72.67	56.77	47.31
Boalmari	331	1732	420	139.02	350	115.85	280	92.68	315	104.27	263	87.05	210	69.51	*1	72.67	75.77	63.26
Alfadanga	93		480	44.64	400	37.20	320	29.76	360	33.48	300	27.90	240	22.32	*1	72.67	24.33	20.27
Nagarkanda	383		480	183.84	400	153.20	320	122.56	260	99.58	300	114.90	240	91.92	*1	72.67	72.36	83.50
Bhanga	217	1831	540	117.18	450	97.65	360	78.12	405	87.89	338	73.35	270	58.59	*1	72.67	63.87	53.30
Sadarpur	271		720	195.12	600	162.60	480	130.08	540	146.34	450	121.95	360	97.56	*1	72.67	106.35	88.62
Char Bhadrason	165		720	118.80	600	99.00	480	79.20	540	89.10	450	74.25	360	59.40	*1	72.67	64.75	53.96
Faridpur	386	1877	540	208.44	450	173.70	360	138.96	405	156.33	338	130.47	270	104.22	*1	72.67	113.61	94.81
GOPALGANJ																		
Tungipara	176		960	168.96	800	140.80	640	112.64	720	126.72	600	105.60	480	84.48	*1	75.20	95.29	79.41
Kotwalipara	367		960	352.32	800	293.60	640	234.88	720	264.24	600	220.20	480	176.16	*1	75.20	198.71	165.59
Kasiani	282		540	152.28	450	126.90	360	101.52	405	114.21	338	95.32	270	76.14	*1	75.20	85.89	71.68
Muqsudpur	331		330	109.23	275	91.03	200	66.20	248	82.09	206	68.19	165	54.62	*1	75.20	61.73	51.28
Gopalganj	370		660	244.20	550	203.50	440	162.80	495	183.15	413	152.81	330	122.10	*1	75.20	137.73	114.91
MADARIPUR																		
Kalkini	284		720	204.48	600	170.40	480	136.32	540	153.36	450	127.80	360	102.24	*1	77.75	119.24	99.36
Rajair	230		600	138.00	500	115.00	400	92.00	450	103.50	375	86.25	300	69.00	*1	77.75	80.47	67.06
Sibchar	334	2111	600	200.40	500	167.00	400	133.60	450	150.30	375	125.25	300	100.20	*1	77.75	116.86	97.38
Madaripur	284	1982	600	170.40	500	142.00	400	113.60	450	127.80	375	106.50	300	85.20	*1	77.75	99.36	82.80
RAJBARI																		
Pangsa	453		360	163.08	300	135.90	240	108.72	270	122.31	225	101.93	180	81.54	*1	71.50	87.45	72.88
Baliakandi	227	1527	360	81.72	300	68.10	240	54.48	270	61.29	225	51.08	180	40.86	*1	71.50	43.82	36.52
Goalanda	150		600	90.00	500	75.00	400	60.00	450	67.50	375	56.25	300	45.00	*1	71.50	48.26	40.22
Rajbari	277	1701	540	149.58	450	124.65	360	99.72	405	112.19	338	93.63	270	74.79	*1	71.50	80.21	66.94
SARIAPTUR																		
Janjira	253		960	242.88	800	202.40	640	161.92	720	182.16	600	151.80	480	121.44	*1	78.50	143.00	119.16
Naria	233		960	223.68	800	186.40	640	149.12	720	167.76	600	139.80	480	111.84	*1	78.50	131.69	109.74
Bhederganj	300		840	252.00	700	210.00	560	168.00	630	189.00	525	157.50	420	126.00	*1	78.50	148.37	123.64
Gosairhat	145		1200	174.00	1000	145.00	800	116.00	900	130.50	750	108.75	600	87.00	*1	78.50	102.44	85.37
Damadya	90		960	86.40	800	72.00	640	57.60	720	64.80	600	54.00	480	43.20	*1	78.50	50.87	42.39
Sariatpur	173	2091	720	124.56	600	103.80	480	83.04	540	93.42	450	77.85	360	62.28	*1	78.50	73.33	61.11

[samad\swr\tab3-1]

The relationship between depth and duration of flooding with recharge is simulated by the MPO recharge model. In order to determine the effects of FFP and CFP it would be necessary to run the model while changing the input parameters for flooding. On the North Central Regional Study, where hydrogeological conditions are amongst the most favourable in Bangladesh, the effects of CFP and FFP have been simulated, and reductions in potential recharge of 10 - 15% (CFP) to over 50% (FFP) have been estimated. In the absence of model testing the following figures have been assumed to be applicable to the southwest study area:

Case	Land Type	% Reduction in Potential Recharge
CFP	F0, F1	5%
	F2, F3	10-15%
FFP	F0, F1	10-15%
	F2, F3	50%

However these figures should be used with caution as this does not take into account the different rainfall pattern of the NC Region and SW Region.

If flood protection is going to be installed over extensive areas of high ground water utilisation the implications for recharge would need to be examined using the MPO model. However, the amount of F3 and F4 land in the Southwest study area is comparatively small.

3.5 Trends in Growth of Tubewell Numbers

Other than where indicated, all data in this section were obtained from statistics held by BADC or BWDB.

(a) Shallow Tubewells (STW)

The national growth rate in shallow tubewells is shown in Table 3.2. Since 1985, the equipment market has been progressively deregulated and a significant growth in STW numbers has been observed.

TABLE 3.2

National Growth in Shallow Tubewell Numbers

Year	National Total	Increase	% Growth
1986	145000		
1987	159000	14000	10
1988	183000	24000	15
1989	223000	40000	22

(MMP, 1991)

Study area data are shown by District in Table 3.3 and summarised in Table 3.4. Although the years for which data are available are not strictly comparable, the figures indicate a generally similar trend of high growth rate during the late 1980's, possibly slowing down since then.

TABLE 3.3

Growth in Shallow Tubewell Numbers by District in Project Area

DISTRICT	NUMBER OF SHALLOW TUBEWELLS IN YEAR SHOWN		
	1985	1989	1991
Kushtia	503	1713	1717
Chuadanga	2420	3612	4369
Meherpur	1134	2704	2871
Jessore	4838	11897	16680
Jhenaidah	2709	6525	8617
Magura	361	2094	3038
Narail	364	1424	1828
Faridpur	2257	5331	5911
Gopalganj	448	912	970
Madaripur	921	2178	2178
Rajbari	661	2526	2730
Sariatpur	234	418	426
Khulna	75	256	440
Satkhira	2329	5458	8413

TABLE 3.4

Total Growth in Shallow Tubewell Numbers in Project Area

YEAR	TOTAL NUMBER OF TUBEWELLS	INCREASE	% GROWTH
1985	19254		
1989	47048	27794	144.4
1991	55819	8871	19.6

(b) Deep Tubewells (DTW)

The growth in DTW is a more involved issue. Nationally they have tended to be installed under specific projects (such as the IDA DTW projects 1 and 2) by BADC and with 75% subsidies on capital costs. Elimination of subsidies, deregulation and no further public sector installation of DTW are new policies which will be investigated under NMIDP so the future growth in DTW is predictable.

The growth in DTW numbers in the south west study area is shown in Table 3.5. As can be seen, the growth rates are variable and there are reductions in some upazilas. This may be due to equipment or tubewell failure. The generally high incidence of DTW in some upazilas compared with others probably relates to changing aquifer conditions in that in some places only DTW can fully access the available recharge. It could also reflect BADC activities enforcing government policy to restrict DTW growth in vulnerable zones.

TABLE 3.5

GROWTH OF DEEP TUBEWELL IN SWA

District / Thana	Operating number of Deep Tubewell						
	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
KUSHTIA							
Bheramara	15	16	19	18	18	15	9
Daulatpur	149	152	161	140	143	136	97
Kumarkhali	16	16	16	11	11	11	15
Khoksa	6	7	8	13	16	39	44
Kushtia	3	3	3	5	5	5	8
Mirpur	3	3	3	1	6	9	9
CHUADANGA							
Alamdanga	43	45	51	51	46	45	23
Damurhuda	85	86	88	113	146	175	177
Chuadanga	90	92	94	105	100	103	75
Jiban Nagar	39	42	46	46	49	48	35
MEHERPUR							
Gangni	118	110	112	136	124	122	132
Meherpur	150	160	168	171	164	137	106
JESSORE							
Abhaynagar	2	1	1	1	2	2	2
Bagherpara	34	40	42	47	48	50	23
Chougachha	44	57	60	62	78	88	114
Jhikergacha	135	145	152	159	166	155	197
Jessore	103	120	131	151	168	165	201
Kesabpur	2	1	1	1	2	2	7
Manirampur	87	95	101	105	118	120	163
Sarsha	220	222	226	247	257	261	286
JHENAIDAH							
Harinakunda	5	4	3	2	5	5	3
Jhenaidah	35	34	33	57	70	83	85
Kaliganj	55	60	80	92	89	100	85
Kotchandpur	36	40	43	49	51	49	38
Mahespur	81	78	66	72	73	65	43
Sailkupa	-	-	-	-	1	1	1
MAGURA							
Mohammadpur	7	6	4	2	1	2	2
Magura	27	25	24	19	23	21	22
Sripur	-	-	-	-	-	2	6
Salikha	8	7	5	5	8	11	12
NARAIL							
Kalia	-	-	-	-	-	-	-
Lohagara	-	-	-	-	-	-	-
Narail	-	-	-	1	-	-	-

TABLE 3.5 (Continued)

GROWTH OF DEEP TUBEWELL IN SWA

District / Thana	Operating number of Deep Tubewell						
	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
FARIDPUR							
Faridpur	96	94	95	100	102	91	73
Modhukhali	22	19	17	18	24	24	14
Boalmari	28	41	43	47	46	44	31
Alfadanga	-	-	-	-	1	2	1
Nagarkanda	36	30	17	29	36	35	14
Bhanga	36	30	33	34	37	34	20
Sadarpur	13	12	14	17	20	19	12
Charbhadrason	4	4	4	5	6	7	4
GOPALGONJ							
Gopalgonj	-	-	-	-	-	-	-
Tungipara	-	-	-	-	-	-	-
Kasiani	-	-	1	1	3	4	5
Muqsudpur	6	8	11	13	13	15	13
Kotwalipara	-	-	-	-	-	-	-
MADARIPUR							
Madaripur	-	-	-	-	-	2	2
Kalkini	-	-	-	-	-	-	-
Rajair	-	-	-	-	3	9	9
Sibchar	2	5	11	10	9	9	9
RAJBARI							
Rajbari	55	60	57	58	65	54	55
Pangsa	46	60	64	74	76	57	80
Baliakandi	17	16	21	25	26	23	95
Goalanda	2	1	1	1	2	2	8
SARIATPUR							
Sariatpur	-	-	-	-	-	-	-
Janjira	-	-	-	-	-	-	-
Naria	-	-	-	-	-	-	-
Bhedargonj	-	-	-	-	-	-	-
Gosairhat	-	-	-	-	-	-	-
Damadya	-	-	-	-	-	-	-

Source : Bangladesh Agriculture Development Corporation [samad\swr\tab3-5]

3.6 Summary

In the context of the alluvial aquifers of Bangladesh, groundwater availability in assessed from estimates of recharge, the main source of which is direct infiltration of rainfall and floodwater during the monsoon. This water infiltrates and fills the unsaturated zone created by the dry season groundwater level recession.

Actual recharge occurring under natural conditions can be enhanced by lowering the water table; this leads to the concept of potential recharge, which is the maximum recharge which could take place for given soil and hydrometeorological conditions. Usable recharge is generally taken to be 75% of the potential recharge to allow for errors in estimation of physical processes and parameters. The available recharge is some percentage of usable recharge, to allow for base flow losses and planning constraints.

Lithological data can be used to estimate the depth-related specific yield for the area, and hence a derivation of depth-storage relationship. Thus water level changes in an area can be related to a volume of stored groundwater or its equivalent in terms of depth per unit area.

4 DEVELOPMENT STRATEGY

4.1 Methodology

This section provides a development strategy for groundwater in the study area. The general approach adopted has been to calculate the additional area available for irrigation in each upazila, and the amount of water needed to irrigate it. This water requirement is then compared with estimates of available recharge. After taking into account existing groundwater use for irrigation, together with an allowance for potable use, a development strategy is calculated which shows how much groundwater can be taken by different tubewell technologies.

This methodology is described in detail in Section 4.3. A discussion of tubewell technologies is given below.

4.2 Tubewell Technologies

Groundwater is abstracted for irrigation in Bangladesh using a series of different pumping methods (or "Tubewell Technologies") as described below:

(a) Shallow Tubewells (STW)

These are tubewells fitted with suction-mode pumps capable of abstracting 14 l/s (0.5 cusec) from pumping water levels up to 7.5 m below ground level.

(b) Deep Set Shallow Tubewells (DSSTW)

These are similar to STW but the pump is set in a 1.2 m deep pit, thus extending the suction limit to 8.5 to 9.5 m.

(c) Deep Tubewells (DTW)

These are tubewells fitted with force-mode pumps (usually shaft driven turbines) capable of producing 28-56 l/s (1-2) cusec) from pumping water levels of up to 20-25 m below ground level.

(d) Manually Operated Shallow Tubewells for irrigation (MOSTI).

These wells produce small quantities of irrigation water by use of a manually operated pump.

It is useful to note that the concepts of DTW and STW differ in terms of depth to water and hence pumping mode but not necessarily the depth of the tubewell. Also, it is generally accepted that when all cost factors are taken into account, STW, or, when necessary, DSSTW, are the favoured pumping option. DTW are a viable option only where hydrogeological conditions are such that the available groundwater resources cannot be abstracted by STW or DSSTW alone.

Generally, more favourable hydrogeological conditions such as high aquifer transmissivity lead to higher specific capacity wells, less drawdown during pumping, and more opportunity for using STW.

4.3 Calculation of Development Potential

4.3.1 Existing Groundwater Consumption for Irrigation

Existing consumption of groundwater for irrigation is shown on Table 4.1, which summarises the present (1991) situation.

The number of minor irrigation units is taken from a recent and very thorough census by AST/CIDA (1991), from which the average area (ha) of land irrigated by each unit can be calculated. The water duty estimates for each upazila depend upon soil characteristics etc, and are taken from MPO (1985). The total abstraction by each unit type in each upazila can be calculated as shown in Table 4.1 and summed to give the total groundwater used for irrigation in each upazila.

4.3.2 Additional Water Requirements for Irrigation

The additional area is calculated as the total irrigable area less the area currently under irrigation. When the additional area is multiplied by the water duty the water requirement to irrigate the additional area is calculated. Relevant data are given, by upazila, in Table 4.2.

4.3.3 Groundwater Development Potential

Table 4.3 shows the extent to which the project area irrigation water requirement can be met by groundwater.

Existing groundwater use for minor irrigation (from Table 4.1) is added to the potential additional water requirement for irrigation (from Table 4.2) together with an allowance for potable use, to provide a total potential demand for water (Table 4.3, column 4). The 10 M m^3/a allowance for potable use is conservative and is unlikely to be exceeded; it is equivalent to a population of over 0.25 million in each upazila, consuming 100 l/h/d.

The medium category of available recharge (from Table 3.1) is then shown in comparison with the total water requirement, as a basis for providing a strategy for meeting the total potential demand for water, that is, by groundwater and/or by surface water. The results are shown in columns 6a and 6b of Table 4.3. Points to note are:

(a) In most cases, available recharge is less than the total demand so that the development target for irrigation by groundwater is available recharge less the allowance for potable use.

(b) In some cases, groundwater abstraction is already in excess of the MPO available recharge estimate, in which case the development target for groundwater is a negative value (see Section 4.5)

(c) Occasionally, available recharge is in excess of the total water requirement in which case there is potentially no need for development by surface water

(d) Where groundwater is 100% constrained, no development targets are shown. It should be noted that this includes the buffer zone against salinity as recommended by MPO. In this buffer zone the groundwater may be fresh but it was to be left undeveloped to provide a protection zone against possible saline water ingress. As seen in Table 4.1 however, some groundwater development has taken place in the buffer zone in Khulna and Satkhira districts.

TABLE 4.1
EXISTING MINOR IRRIGATION

District / Thana	1 Gross area of Thana Km²	2 MPO Water duty estimate for Thana ha/Mm³	3 Number of units in Thana (1991 census by CIDA) STW	DSSTW	DTW	LLP	4 Total area irrigated by each mode (Km²) STW	DSSTW	DTW	LLP	Total GW	Total ALL	5 Total abstraction by each mode (Mm³) STW	DSSTW	DTW	LLP	6 Total minor irrigation abstraction (Mm³) GW	ALL
KUSHTIA																		
Bheramara	152	153	280	0	10	16	10	0	2	1	12	13	6.41	0	1.31	0.89	7.71	8.60
Daulatpur	466	150	162	0	40	7	6	0	8	1	14	14	3.78	0	5.33	0.40	9.11	9.51
Kumarkhali	328	150	251	18	6	18	9	1	1	2	11	12	5.86	0	0.80	1.02	6.85	7.87
Khoksa	98	148	109	7	42	3	4	0	8	0	12	13	2.58	0	5.68	0.17	8.35	8.52
Kushtia	315	159	311	0	2	32	11	0	0	3	11	14	6.85	0	0.25	1.71	7.10	8.81
Mirpur	326	159	604	0	9	61	21	0	2	5	23	28	13.30	0	1.13	3.26	14.43	17.69
CHUADANGA																		
Alamdanga	349	148	782	0	45	35	27	0	9	3	36	39	18.49	0	6.08	2.01	24.57	26.58
Damurhuda	308	146	1692	0	179	36	59	0	36	3	95	98	40.56	0	24.52	2.10	65.08	67.18
Chudanga	287	148	910	0	112	34	32	0	22	3	54	57	21.52	0	15.14	1.95	36.66	38.61
Jiban Nagar	202	146	985	0	39	12	34	0	8	1	42	43	23.61	0	5.34	0.70	28.96	29.65
MEHERPUR																		
Gangni	344	148	1034	0	121	11	36	0	24	1	60	61	24.45	0	16.35	0.63	40.80	41.44
Meherpur	372	148	1837	0	139	33	64	0	28	3	92	95	43.44	0	18.78	1.90	62.23	64.12
JESSORE																		
Abhynagar	246	141	575	3	3	42	20	0	1	4	21	24	14.27	0	0.43	2.53	14.77	17.30
Bagherpara	272	151	1203	0	78	43	42	0	16	4	58	61	27.88	0	10.33	2.42	38.22	40.64
Chougachha	269	139	1608	0	112	44	56	0	22	4	79	82	40.49	0	16.12	2.69	56.60	59.29
Jhikergacha	308	145	1638	1	192	68	57	0	38	6	96	102	39.54	0	26.48	3.99	66.04	70.03
Jessore	435	143	1842	7	206	34	64	0	41	3	106	109	45.08	0	28.81	2.02	74.07	76.09
Kesabpur	259	148	4333	4	8	76	152	0	2	6	153	160	102.47	0	1.08	4.36	103.65	108.01
Manirampur	445	148	1949	0	126	75	68	0	25	6	93	100	46.09	0	17.03	4.31	63.12	67.43
Sarsha	341	148	3532	0	261	114	124	0	52	10	176	186	83.53	0	35.27	6.55	118.80	125.34
JHENAIDAH																		
Harinakunda	228	153	480	0	3	2	17	0	1	0	17	18	10.98	0	0.39	0.11	11.37	11.48
Jhenaidah	471	139	1768	0	85	18	62	0	17	2	79	80	44.52	0	12.23	1.10	56.75	57.85
Kaliganj	315	153	1408	0	91	4	49	0	18	0	67	68	32.21	0	11.90	0.22	44.10	44.33
Kotchandpur	171	153	854	0	40	6	30	0	8	1	38	38	19.54	0	5.23	0.33	24.76	25.10
Mahespur	422	139	3415	0	49	21	120	0	10	2	129	131	85.99	0	7.05	1.28	93.04	94.32
Sailkupa	372	153	692	2	1	7	24	0	0	1	24	25	15.83	0	0.13	0.39	15.98	16.37
MAGURA																		
Mohammadpur	233	153	504	0	2	28	18	0	0	2	18	20	11.53	0	0.26	1.56	11.79	13.35
Magura	401	153	1200	0	20	52	42	0	4	4	46	50	27.45	0	2.61	2.89	30.07	32.95
Sripur	183	159	223	1	1	4	8	0	0	0	8	8	4.91	0	0.13	0.21	5.04	5.26
Salikha	227	159	1111	0	12	40	39	0	2	3	41	45	24.46	0	1.51	2.14	25.97	28.10
NARAIL																		
Kalia	305	139	235	1	0	115	8	0	0	10	8	18	5.92	0	0.00	7.03	5.94	12.97
Lohagara	300	150	834	0	0	67	29	0	0	6	29	35	19.46	0	0.00	3.80	19.46	23.26
Narail	385	140	759	0	1	196	27	0	0	17	27	43	18.98	0	0.14	11.90	19.12	31.02
KHULNA																		
Terakhada	189	139	9	0	0	38	0	0	0	3	0	4	0.23	0	0.00	2.32	0.23	2.55
Phultala	75	142	47	0	0	65	2	0	0	6	2	7	1.16	0	0.00	3.89	1.16	5.05
Daulatpur	113	No data available					0	0	0	0	0	0						
Dumuria	455	150	287	0	0	128	10	0	0	11	10	21	6.70	0	0.00	7.25	6.70	13.95
Rupsa	82	142	8	0	0	8	0	0	0	1	0	1	0.20	0	0.00	0.48	0.20	0.68
Baitaghata	246	151	3	0	0	3	0	0	0	0	0	0	0.07	0	0.00	0.17	0.07	0.24
Paikgachha	283	142	86	0	0	4	3	0	0	0	3	3	2.12	0	0.00	0.24	2.12	2.36
Dacope	209	No data available					0	0	0	0	0	0						
Koyra	263	142	0	0	0	10	0	0	0	1	0	1	0.00	0	0.00	0.60	0.00	0.60
Khulna	19	No data available																
SATKHIRA																		
Kalaroa	233	147	645	0	264	73	23	0	53	6	75	82	15.36	0	35.92	4.22	51.28	55.50
Tala	336	151	1215	8	12	39	43	0	2	3	45	49	28.16	0	1.59	2.20	29.94	32.13
Asasuni	411	142	503	6	0	17	18	0	0	1	18	19	12.40	0	0.00	1.02	12.55	13.56
Syamnagar	1901	142	19	0	0	362	1	0	0	31	1	31	0.47	0	0.00	21.67	0.47	22.14
Kaliganj	331	142	1078	20	0	225	38	1	0	19	38	58	26.57	0	0.00	13.47	27.06	40.53
Debhata	170	142	662	18	6	6	23	1	1	1	25	26	16.32	0	0.85	0.36	17.61	17.96
Satkhira	365	150	4295	54	172	18	150	2	34	2	187	188	100.22	1	22.93	1.02	124.41	125.43
BAGERHAT																		
Mollahat	217	143	9	0	0	41	0	0	0	3	0	4	0.22	0	0.00	2.44	0.22	2.66
Fakirhat	160	147	14	0	0	12	0	0	0	1	0	2	0.33	0	0.00	0.69	0.33	1.03
Chitalmari	137	137	0	0	0	96	0	0	0	8	0	8	0.00	0	0.00	5.96	0.00	5.96
Kachua	123	137	0	0	0	3	0	0	0	0	0	0	0.00	0	0.00	0.19	0.00	0.19
Morelganj	439	139	0	0	0	8	0	0	0	1	0	1	0.00	0	0.00	0.49	0.00	0.49
Sarankhola	151	139	0	0	0	26	0	0	0	2	0	2	0.00	0	0.00	1.59	0.00	1.59
Monglaport	211	No data available					0	0	0	0	0	0						
Rampal	320	No data available					0	0	0	0	0	0						
Bagerhat	269	139	3	0	0	6	0	0	0	1	0	1	0.00	0	0.00	0.37	0.00	0.37
BARISAL																		
Agailjhora	160	140	0	0	0	432	0	0	0	37	0	37	0.00	0	0.00	26.23	0.00	26.23
Gaurnadi	139	141	0	0	0	454	0	0	0	39	0	39	0.00	0	0.00	27.37	0.00	27.37
Wazirpur	246	142	0	0	0	413	0	0	0	35	0	35	0.00	0	0.00	24.72	0.00	24.72
Babuganj	147	163	0	0	0	92	0	0	0	8	0	8	0.00	0	0.00	4.80	0.00	4.80
Bakerganj	388	181	1	0	0	124	0	0	0	11	0	11	0.02	0	0.00	5.82	0.02	5.84
Mehendiganj	349	137	0	0	0	348	0	0	0	30	0	30	0.00	0	0.00	21.59	0.00	21.59
Hizla	458	137	1	0	0	186	0	0	0	16	0	16	0.03	0	0.00	11.54	0.03	11.57
Muladi	261	138	0	0	0	202	0	0	0	17	0	17	0.00	0	0.00	12.44	0.00	12.44
Barisal	292	164	0	0	0	222	0	0	0	19	0	19	0.00	0	0.00	11.51	0.00	11.51

[samad\swr\tab4-1]

TABLE 4.1 (Continued)
EXISTING MINOR IRRIGATION

District/Thana	1 Gross area of Thana	2 MPO Water duty estimate for Thana	3 Number of units in Thana (1991 census by CIDA)				4 Total area irrigated by each mode (Km²)						5 Total abstraction by each mode (Mm³)				6 Total minor irrigation abstraction (Mm³)	
	Km²	ha/Mm³	STW	DSSTW	DTW	LLP	STW	DSSTW	DTW	LLP	Total GW	Total ALL	STW	DSSTW	DTW	LLP	GW	ALL
JHALAKATI																		
Naichiti	233	167	0	0	0	132	0	0	0	11	0	11	0.00	0	0.00	6.72	0.00	6.72
Rajapur	163	165	0	0	0	312	0	0	0	27	0	27	0.00	0	0.00	16.07	0.00	16.07
Kathalia	152	165	0	0	0	25	0	0	0	2	0	2	0.00	0	0.00	1.29	0.00	1.29
Jhalakati	194	167	0	0	0	149	0	0	0	13	0	13	0.00	0	0.00	7.58	0.00	7.58
PIROJPUR																		
Nazirpur	225	136	0	0	0	88	0	0	0	7	0	7	0.00	0	0.00	5.50	0.00	5.50
Banaripara	129	149	0	0	0	90	0	0	0	8	0	8	0.00	0	0.00	5.13	0.00	5.13
Swarupkati	183	152	0	0	0	24	0	0	0	2	0	2	0.00	0	0.00	1.34	0.00	1.34
Kaukhali	80	159	0	0	0	23	0	0	0	2	0	2	0.00	0	0.00	1.23	0.00	1.23
Bhandaria	154	165	0	0	0	21	0	0	0	2	0	2	0.00	0	0.00	1.08	0.00	1.08
Matbaria	322	165	0	0	0	244	0	0	0	21	0	21	0.00	0	0.00	12.57	0.00	12.57
Pirojpur	141	159	0	0	0	29	0	0	0	2	0	2	0.00	0	0.00	1.55	0.00	1.55
BARGUNA																		
Betagi	167	*1 165	0	0	0	21	0	0	0	2	0	2	0.00	0	0.00	1.08	0.00	1.08
Bamna	92	*1 165	0	0	0	39	0	0	0	3	0	3	0.00	0	0.00	2.01	0.00	2.01
Patharghata	234	*1 165	0	0	0	43	0	0	0	4	0	4	0.00	0	0.00	2.22	0.00	2.22
Amtali Bandar	627	*1 165	0	0	0	163	0	0	0	14	0	14	0.00	0	0.00	8.40	0.00	8.40
Barguna	327	*1 165	6	0	0	75	0	0	0	6	0	6	0.00	0	0.00	3.86	0.00	3.86
PATUAKHALI																		
Mirzaganj	164	*1 165	0	0	0	30	0	0	0	3	0	3	0.00	0	0.00	1.55	0.00	1.55
Bauphal	421	*1 165	0	0	0	71	0	0	0	6	0	6	0.00	0	0.00	3.66	0.00	3.66
Dasmina	221	*1 165	0	0	0	51	0	0	0	4	0	4	0.00	0	0.00	2.63	0.00	2.63
Galachipa	744	*1 165	2	0	0	96	0	0	0	8	0	8	0.04	0	0.00	4.95	0.04	4.99
Kalapara	412	*1 165	0	0	0	13	0	0	0	1	0	1	0.00	0	0.00	0.67	0.00	0.67
Patuakhali	373	*1 165	0	0	0	68	0	0	0	6	0	6	0.00	0	0.00	3.50	0.00	3.50
FARIDPUR																		
Modhukhali	217	154	742	0	26	23	26	0	5	2	31	33	16.86	0	3.38	1.27	20.24	21.51
Boalmari	331	148	791	0	2	54	28	0	0	5	28	33	18.71	0	0.27	3.10	18.98	22.08
Alfadanga	93	148	422	0	22	10	15	0	4	1	19	20	9.98	0	2.97	0.57	12.95	13.53
Nagarkanda	383	148	1056	0	85	102	37	0	17	9	54	63	24.97	0	11.49	5.86	36.46	42.32
Bhanga	217	154	1177	0	0	98	41	0	0	8	41	50	26.75	0	0.00	5.41	26.75	32.16
Sadarpur	271	153	411	0	35	10	14	0	7	1	21	22	9.40	0	4.58	0.56	13.98	14.53
Char Bhadrason	165	154	99	0	18	0	3	0	4	0	7	7	2.25	0	2.34	0.00	4.59	4.59
Faridpur	386	154	1213	1	6	60	42	0	1	5	44	49	27.57	0	0.78	3.31	28.37	31.68
GOPALGANJ																		
Tungipara	176	123	1	0	0	112	0	0	0	10	0	10	0.03	0	0.00	7.74	0.03	7.77
Kotwalipara	367	124	1	0	0	317	0	0	0	27	0	27	0.03	0	0.00	21.73	0.03	21.76
Kasiani	282	140	368	0	0	253	13	0	0	22	13	34	9.20	0	0.00	15.36	9.20	24.56
Muqsudpur	331	118	422	0	4	382	15	0	1	32	16	48	12.52	0	0.68	27.52	13.19	40.71
Gopalganj	370	128	178	0	0	410	6	0	0	35	6	41	4.87	0	0.00	27.23	4.87	32.09
MADARIPUR																		
Kalkini	284	140	94	0	1	787	3	0	0	67	3	70	2.35	0	0.14	47.78	2.49	50.28
Rajair	230	131	590	0	13	107	21	0	3	9	23	32	15.76	0	1.98	6.94	17.75	24.69
Sibchar	334	153	615	0	0	73	22	0	0	6	22	28	14.07	0	0.00	4.06	14.07	18.12
Madaripur	284	149	879	0	37	414	31	0	7	35	38	73	20.65	0	4.97	23.62	25.61	49.23
RAJBARI																		
Pangsa	453	153	1116	2	26	5	39	0	5	0	44	45	25.53	0	3.40	0.28	28.97	29.25
Baliakandi	227	149	491	2	23	3	17	0	5	0	22	22	11.53	0	3.09	0.17	14.67	14.84
Goalanda	150	131	238	0	77	2	8	0	15	0	24	24	6.36	0	11.76	0.13	18.11	18.24
Rajbari	277	140	885	1	78	14	31	0	16	1	47	48	22.13	0	11.14	0.85	33.29	34.14
SARIATPUR																		
Janjira	253	153	114	0	5	99	4	0	1	8	5	13	2.61	0	0.65	5.50	3.26	8.76
Naria	233	148	179	17	0	287	6	1	0	24	7	31	4.23	0	0.00	16.48	4.64	21.12
Bhederganj	300	137	53	1	0	235	2	0	0	20	2	22	1.35	0	0.00	14.58	1.38	15.96
Gosairhat	145	136	0	0	0	224	0	0	0	19	0	19	0.00	0	0.00	14.00	0.00	14.00
Damadya	90	136	13	0	0	263	0	0	0	22	0	23	0.33	0	0.00	16.44	0.33	16.77
Sariatpur	173	150	67	0	0	373	2	0	0	32	2	34	1.56	0	0.00	21.14	1.56	22.70

[samad\swr\tab4.1]

Note : *1 No assessement has been made by MPO. The water duty for Barguna and Patuakhali has been assumed considering the water duty of surrounding planning areas.

** Area under different modes calculated based on MPO estimate of irrigated area per unit :
STW = 3.5 ha; DSSTW = 3.5 ha; DTW = 20 ha; LLP = 8.5 ha.

Source : MPO and CIDA Data

TABLE 4.2
POTENTIAL ADDITIONAL WATER REQUIREMENT FOR IRRIGATION

	1	2		3	4	5	6	7	8
District / Thana	Gross area	Irrigable Area		Area (1991) Irrigated by gravity (Project data)	Area (1991) Irrigated by Minor irrig. (Table 4.1)	Total Area Irrigated (1991) (3)+(4)	Balance for for future Development (2)-(5)	MPO Water Duty (Table 4.1)	Potential Addl. Water Requirement for Irrigation (6÷7)
	Km²	%	Km²	Km²	Km²	Km²	Km²	ha/Mm3	Mm3
KUSHTIA									
Bheramara	152	75	114	27	13	40	74	153	48.56
Daulatpur	466	75	350	9	14	24	326	150	217.30
Kumarkhali	328	75	246	76	12	89	157	150	104.98
Khoksa	98	75	74	7	13	20	54	148	36.19
Kushtia	315	75	236	171	14	185	52	159	32.53
Mirpur	326	75	245	182	28	210	34	159	21.56
CHUADANGA									
Alamdanga	349	75	262	130	39	170	92	148	62.19
Damurhuda	308	75	231	6	98	104	127	146	86.88
Chudanga	287	75	215	61	57	118	97	148	65.65
Jiban Nagar	202	75	152	1	43	44	107	146	73.47
MEHERPUR									
Gangni	344	75	258	8	61	69	189	148	127.59
Meherpur	372	75	279	7	95	102	177	148	119.51
JESSORE									
Abhynagar	246	75	185	5	24	30	155	141	109.87
Bagherpara	271	75	203	3	61	64	139	151	92.17
Chougachha	269	75	202	3	82	85	117	139	83.91
Jhikergacha	308	75	231	1	102	103	128	145	88.49
Jessore	435	75	326	1	109	110	216	143	151.15
Kesabpur	259	75	194	3	160	163	31	148	20.95
Manirampur	445	75	334	6	100	106	228	148	153.99
Sarsha	341	75	256	1	186	186	70	148	47.10
JHENAIDAH									
Harinakunda	228	75	171	162	18	180	0	153	
Jhenaidah	471	75	353	74	80	154	199	139	143.08
Kaliganj	315	75	236	3	68	71	165	153	108.02
Kotchandpur	171	75	128	2	38	40	88	153	57.61
Mahespur	422	75	317	4	131	135	181	139	130.34
Sailkupa	372	75	279	225	25	250	29	153	18.67
MAGURA									
Mohammadpur	233	75	175	3	20	24	151	153	98.69
Magura	401	75	301	89	50	140	161	153	105.13
Sripur	183	75	137	111	8	119	18	159	11.17
Salikha	227	75	170	23	45	67	103	159	64.64
NARAIL									
Kalia	305	75	229	8	8	16	213	139	153.13
Lohagara	300	75	225	5	29	34	191	150	127.31
Narail	385	75	289	7	27	34	255	140	182.07
KHULNA									-
Terakhada	189	75	142	5	4	8	133	139	Salinity
Phultala	75	75	56	2	7	9	47	142	Constraints
Daulatpur	113	75	85	0	0	0	0		
Dumuria	455	75	341	6	21	27	315	150	
Rupsa	82	75	62	2	1	3	59	142	
Baitaghata	246	75	185	3	0	3	181	151	
Paikgachha	283	75	212	4	3	8	205	142	
Dacope	209	75	157	0	0	0	0		
Koyra	263	75	197	3	1	4	193	142	
Khulna	19		0	0	0	0	0		
SATKHIRA									
Kalaroa	233	75	175	2	82	84	0	147	
Tala	336	75	252	4	49	52	0	151	
Asasuni	411	75	308	5	19	24	0	142	
Syamnagar	1901	75	1426	5	31	37	0	142	
Kaliganj	331	75	248	5	58	62	0	142	
Debhata	170	75	128	2	26	27	0	142	
Satkhira	365	75	274	4	188	192	0	150	
BAGERHAT									
Mollahat	217	75	163						
Fakirhat	160	75	120						
Chitalmari	137	75	103						
Kachua	123	75	92						
Morelganj	439	75	329						
Sarankhola	151	75	113						
Bagerhat	269	75	202						

Due to presence of poor aquifer and salinity constraints there is no groundwater development in these areas

[samad\swr\tab4-2]

TABLE 4.2 (Continued)

POTENTIAL ADDITIONAL WATER REQUIREMENT FOR IRRIGATION

District / Thana	1 Gross area	2 Irrigable Area		3 Area (1991) Irrigated by gravity (Project data)	4 Area (1991) Irrigated by Minor Irrig. (Table 4.1)	5 Total Area Irrigated (1991) (3)+(4)	6 Balance for for future Development (2)-(5)	7 MPO Water Duty (Table 4.1)	8 Potential Addl. Water Requirement for irrigation (6÷7)
	Km²	%	Km²	Km²	Km²	Km²	Km²	ha/Mm3	Mm3
BARISAL									
Agailjhora	160	75	120		Due to presence of poor aquifer and salinity constraints				
Gaurnadi	139	75	104		there is no groundwater development in these areas				
Wazirpur	246	75	185						
Babuganj	147	75	110						
Bakerganj	388	75	291		Do				
Mehendiganj	349	75	262						
Hizla	458	75	344						
Muladi	261	75	196						
Barisal	292	75	219						
JHALAKATI									
Nalchiti	233	75	175						
Rajapur	163	75	122						
Kathalia	152	75	114		Do				
Jhalakati	194	75	146						
PIROJPUR									
Nazirpur	225	75	169						
Banaripara	129	75	97						
Swarupkati	183	75	137						
Kaukhali	80	75	60		Do				
Bhandaria	154	75	116						
Matbaria	322	75	242						
Pirojpur	141	75	106						
BARGUNA									
Betagi	167	75	125						
Bamna	92	75	69						
Patharghata	234	75	176		Do				
Amtali Bandar	627	75	470						
Barguna	327	75	245						
PATUAKHALI									
Mirzaganj	164	75	123						
Bauphal	421	75	316						
Dasmina	221	75	166						
Galachipa	744	75	558		Do				
Kalapara	412	75	309						
Patuakhali	373	75	280						
FARIDPUR									
Modhukhali	217	75	163	3	33	36	127	154	82.15
Boalmari	331	75	248	4	33	37	212	148	142.93
Alfadanga	93	75	70	1	20	21	48	148	32.72
Nagarkanda	383	75	287	2	83	84	203	148	137.04
Bhanga	217	75	163	1	50	50	112	154	73.01
Sadarpur	271	65	176	1	22	23	153	153	100.10
Char Bhadrason	165	55	91	0	7	7	83	154	- 54.13
Faridpur	386	75	290	2	49	51	239	154	155.18
GOPALGANJ									
Tungipara	176	60	106	3	10	12	94	123	76.05
Kotwalipara	367	55	202	5	27	32	170	124	137.26
Kasiani	282	75	212	3	34	37	174	140	124.33
Muqsudpur	331	75	248	3	48	51	197	118	166.93
Gopalganj	370	75	278	4	41	45	233	128	181.70
MADARIPUR									
Kalkini	284	75	213	5	70	75	138	140	98.30
Rajair	230	70	161	2	32	34	127	131	96.79
Sibchar	334	75	251	1	28	29	222	153	144.84
Madaripur	284	75	213	2	73	76	137	149	
RAJBARI									
Pangsa	453	75	340	5	45	50	290	153	189.58
Baliakandi	227	75	170	1	22	23	147	149	98.89
Goalanda	150	55	83	1	24	25	58	131	44.17
Rajbari	277	75	208	3	48	51	156	140	111.76
SARIATPUR									
Janjira	253	60	152	1	13	14	138	153	89.87
Naria	233	60	140	2	31	33	107	148	72.24
Bhederganj	300	55	165	3	22	25	140	137	102.07
Gosairhat	145	60	87	2	19	21	66	136	48.80
Damadya	90	75	68	1	23	24	44	136	32.13
Sariatpur	173	75	130	1	34	35	95	150	63.19

[samad\swr\tab4-2]

TABLE 4.3

TOTAL WATER REQUIREMENT AND RECHARGE (DEVELOPMENT POTENTIAL)

District / Thana	1 Existing Ground Water use for Minor Irrigation (Table 4.1)	2 Potential Additional water requir. for irrigation (Table 4.2)	3 Allowance for Potable or other use (estimated)	4 Total Water Requi. (1)+(2)+(3)	5 Rcharge (Table 3.1. med. category)		6 Development Target for Irrigation by	
					(5a) Usable	(5b) Available	(6a) Groundwater 5b-(1+3)	(6b) Surface water 2-6a
	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)
KUSHTIA								
Bheramara	7.71	48.56	10.00	66.27	25.65	18.54	0.83	47.72
Daulatpur	9.11	217.30	10.00	236.41	87.40	63.19	44.08	173.22
Kumarkhali	6.85	104.98	10.00	121.83	61.66	44.58	27.73	77.25
Khoksa	8.35	36.19	10.00	54.54	25.77	18.63	0.28	35.91
Kushtia	7.10	32.53	10.00	49.63	59.06	42.70	25.60	6.93
Mirpur	14.43	21.56	10.00	45.99	55.01	39.77	15.34	6.22
CHUADANGA								
Alamdanga	24.57	62.19	10.00	96.76	48.50	37.47	2.89	59.30
Damurhuda	65.08	86.88	10.00	161.97	57.90	44.73	Over abstraction	86.88
Chudanga	36.66	65.65	10.00	112.30	43.10	33.29	do	65.65
Jiban Nagar	28.96	73.47	10.00	112.43	38.00	29.36	do	73.47
MEHERPUR								
Gangni	40.80	127.59	10.00	178.40	51.60	37.67	Over abstraction	127.59
Meherpur	62.23	119.51	10.00	191.73	78.30	57.16	do	119.51
JESSORE								
Abhynagar	14.77	109.87	10.00	134.64	55.35	42.76	17.98	91.88
Bagherpara	38.22	92.17	10.00	140.38	61.20	47.28	Over abstraction	92.17
Chougachha	56.60	83.91	10.00	150.52	60.52	46.75	do	83.91
Jhikergacha	66.04	88.49	10.00	164.53	81.00	62.57	do	88.49
Jessore	74.07	151.15	10.00	235.22	97.90	75.63	do	151.15
Kesabpur	103.65	20.95	10.00	134.60	58.30	45.04	do	20.95
Manirampur	63.12	153.99	10.00	227.11	100.13	77.35	4.23	149.76
Sarsha	118.80	47.10	10.00	175.90	76.72	59.27	do	47.10
JHENAIDAH								
Harinakunda	11.37		10.00	21.37	43.00	33.84	Fully Irrigated	
Jhenaidah	56.75	143.08	10.00	209.83	97.00	76.34	9.59	133.49
Kaliganj	44.10	108.02	10.00	162.12	83.00	65.32	11.22	96.80
Kotchandpur	24.76	57.12	10.00	91.88	45.00	35.42	0.65	56.47
Mahespur	93.04	130.34	10.00	233.38	111.00	87.36	Over abstraction	130.34
Sailkupa	15.98	18.67	10.00	44.65	77.00	60.60	34.62	
MAGURA								
Mohammadpur	11.79	98.69	10.00	120.48	70.00	52.73	30.94	67.75
Magura	30.07	105.13	10.00	145.20	83.00	62.52	22.46	82.67
Sripur	5.04	11.17	10.00	26.21	48.00	36.16	21.12	
Salikha	25.97	64.64	10.00	100.60	51.00	38.42	2.45	62.18
NARAIL								
Kalia	5.94	146.09	10.00	162.03	91.50	69.31	53.37	92.72
Lohagara	19.46	123.51	10.00	152.97	67.50	51.13	21.67	101.84
Narail	19.12	170.17	10.00	199.29	101.00	76.51	47.39	122.78
KHULNA								
Terakhada	0.23		Due to salinity constraints (Buffer Zone) the area is not recommended for development by groundwater					
Phultala	1.16							
Daulatpur								
Dumuria	6.70							-
Rupsa	0.20							
Baitaghata	0.07							
Paikgachha	2.12							
Dacope	0.00							
Koyra	0.00							
Khulna	0.00							
SATKHIRA								
Kalaroa	51.28		Due to salinity constraints the district is not recommended for development of groundwater for irrigation					
Tala	29.94							
Asasuni	12.55							
Syamnagar	0.47							
Kaliganj	27.06							
Debhata	17.61							
Satkhira	124.41							
BAGERHAT								
Mollahat	0.22		Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.					
Fakirhat	0.33							
Chitalmari	0.00							
Kachua	0.00							
Morelganj	0.00							
Sarankhola	0.00							
Monglaport	0.00							
Rampal	0.00							
Bagerhat	0.00							

[samad\swr\tab4-3]

TABLE 4.3 (Continued)

TOTAL WATER REQUIREMENT AND RECHARGE (DEVELOPMENT POTENTIAL)

District / Thana	1 Existing Ground Water use for Minor Irrigation (Table 4.1)	2 Potential Additional water requir. for irrigation (Table 4.2)	3 Allowance for Potable or other use (estimated)	4 Total Water Requi. (1)+(2)+(3)	5 Rcharge (Table 3.1. med. category) (5a) Usable	 (5b) Available	6 Development Target for Irrigation by (6a) Groundwater 5b-(1+3)	 (6b) Surface water 2-6a
	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)	(Mm³)
BARISAL								
Agailjhora	0.00	Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.						
Gaurnadi	0.00							
Wazirpur	0.00							
Babuganj	0.00							
Bakerganj	0.02							
Mehendiganj	0.00							
Hizla	0.03							
Muladi	0.00							
Barisal	0.00							
JHALAKATI								
Nalchiti	0.00	Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.						
Rajapur	0.00							
Kathalia	0.00							
Jhalakati	0.00							
PIROJPUR								
Nazirpur	0.00	Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.						
Banaripara	0.00							
Swarupkati	0.00							
Kaukhali	0.00							
Bhandaria	0.00							
Matbaria	0.00							
Pirojpur	0.00							
BARGUNA								
Betagi	0.00	Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.						
Bamna	0.00							
Patharghata	0.00							
Amtali Bandar	0.00							
Barguna	0.00							
PATUAKHALI								
Mirzaganj	0.00	Due to presence of poor aquifer conditions and salinity constraints there is no major groundwater development for irrigation in this district.						
Bauphal	0.00							
Dasmina	0.00							
Galachipa	0.04							
Kalapara	0.00							
Patuakhali	0.00							
FARIDPUR								
Modhukhali	20.24	82.15	10.00	112.39	65.10	47.31	17.07	65.08
Boalmari	18.98	142.93	10.00	171.91	86.89	63.14	34.17	108.77
Alfadanga	12.95	32.72	10.00	55.67	27.90	20.27	0.00	32.72
Nagarkanda	36.46	137.04	10.00	183.50	114.90	83.50	37.04	100.00
Bhanga	26.75	73.01	10.00	109.76	73.24	53.22	16.47	56.53
Sadarpur	13.98	100.10	10.00	124.08	121.95	88.62	64.64	35.46
Char Bhadrason	4.59	54.13	10.00	68.72	74.25	53.96	39.37	14.76
Faridpur	28.37	154.69	10.00	193.06	130.28	94.67	56.30	98.38
GOPALGANJ								
Tungipara	0.03	76.05	10.00	86.08	35.65	26.81	16.78	59.27
Kotwalipara	0.03	137.26	10.00	147.29	54.28	40.82	30.79	106.47
Kasiani	9.20	124.33	10.00	143.53	55.93	42.06	22.86	101.47
Muqsudpur	13.19	166.93	10.00	190.13	68.27	51.34	28.14	138.79
Gopalganj	4.87	181.70	10.00	196.57	76.95	57.87	43.00	138.70
MADARIPUR								
Kalkini	2.49	98.30	10.00	110.79	116.46	90.55	78.05	20.25
Rajair	17.75	96.79	10.00	124.54	86.25	67.06	39.31	57.48
Sibchar	14.07	144.84	10.00	168.91	125.25	97.38	73.31	71.52
Madaripur	25.61	92.13	10.00	127.74	106.50	82.80	47.19	44.94
RAJBARI								
Pangsa	28.97	189.58	10.00	228.55	101.92	72.87	33.90	155.68
Baliakandi	14.67	98.89	10.00	123.55	51.08	36.52	11.85	87.03
Goalanda	18.11	44.17	10.00	72.28	56.25	40.22	12.10	32.06
Rajbari	33.29	111.76	10.00	155.05	93.49	66.85	23.55	88.21
SARIATPUR								
Janjira	3.26	89.87	10.00	103.13	148.64	87.60	74.34	
Naria	4.64	72.24	10.00	86.88	90.80	61.17	46.53	25.71
Bhederganj	1.38	102.07	10.00	113.45	157.50	123.64	112.26	
Gosairhat	0.00	48.80	10.00	58.80	98.82	65.48	55.48	
Damadya	0.33	32.13	10.00	42.46	50.39	32.83	22.50	9.63
Sariatpur	1.56	63.19	10.00	74.75	77.85	61.11	49.55	13.64

[samad\swr\tab4-3]

4.3.4 Development Potential by Tubewell Technology

The development potential by tubewell technology is shown in Table 4.4, to provide a recommended development strategy in each upazila for which there is capacity for additional groundwater development.

The basis of the table is a comparison of MPO NWP-II recommendations (as to how the available recharge should be exploited by the various tubewell technologies) with existing tubewell development. An assumption of the MPO work is that the order of preference is STW, DSSTW and DTW.

The MPO recommendations are shown in Table 4.4, column 3. Column 2 shows the existing distribution of STW, DTW etc. For the purposes of this work the potable reserve is grouped in with existing STW abstraction.

The difference between the data shown in columns 2 and 3 is the recommended strategy for future development and is shown in column 4 of Table 4.4.

The amount of land that could be irrigated by the currently unused groundwater, is shown in Table 4.5.

4.4 Summary of Results

The results of the Section 4 calculations are summarised in the form of a map, shown here in Figure 4.1. The map shows the various categories of upazila as follows:

(a) Upazilas where there is scope for additional groundwater development, which mainly in the northern part of the project area;

(b) Upazilas where MPO estimates of recharge are currently being exceeded;

(c) Upazilas in the buffer zone where fresh groundwater exists but which should remain unexploited for large-scale irrigation and conserved as a protection against salinity;

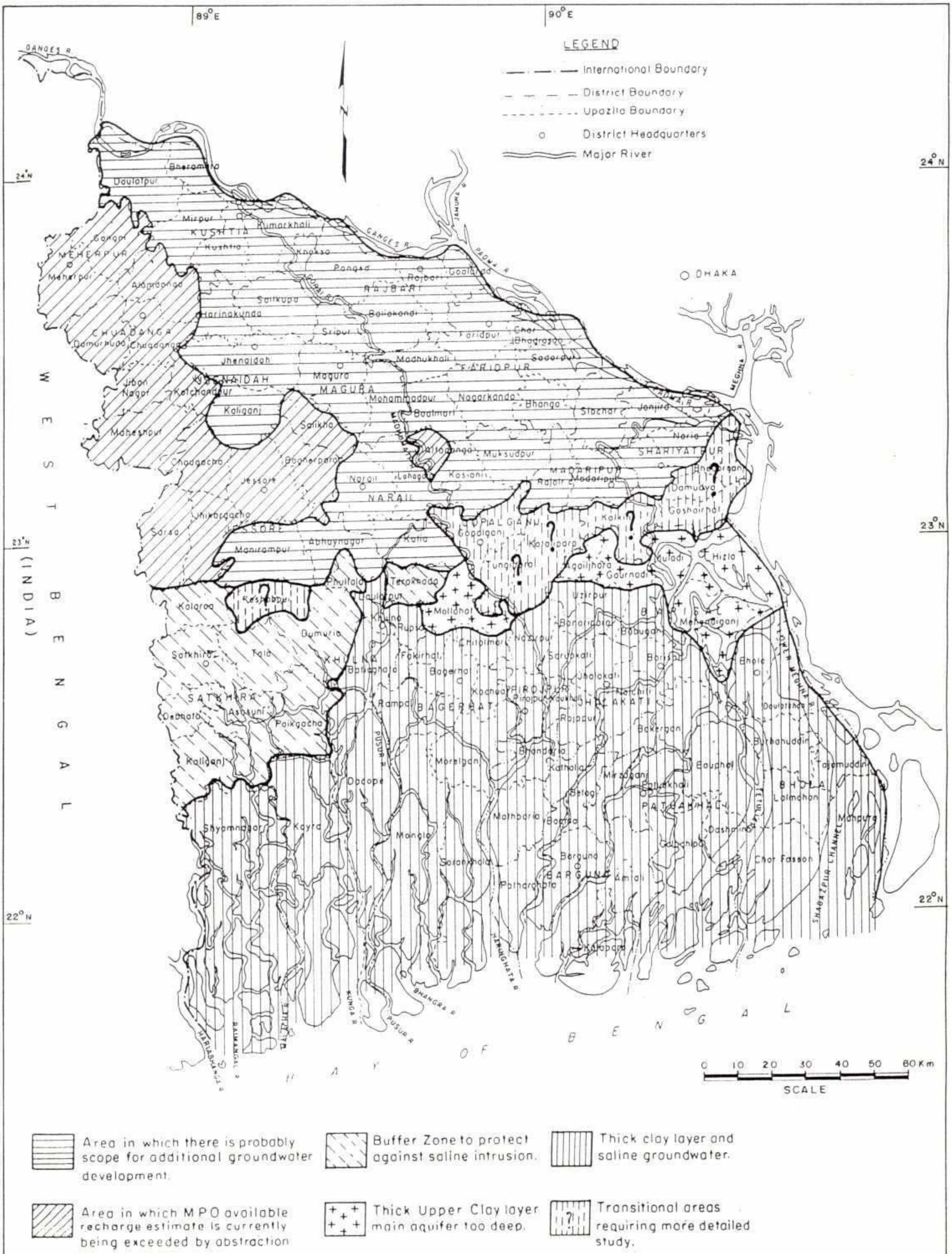
(d) Upazilas where the main groundwater body is already saline;

(e) Upazilas where groundwater potential is very low due to the thickness of the upper clay layer.

It is worth noting that some upazilas are transitional between the various categories. For example, upazilas in the south of Gopalganj, Madaripur, and Sharyatpur districts (Tungipara, Kotalipara, Kalkini, Damudya, Goshairhat) have a low existing groundwater utilisation, probably due to a deep, low permeability upper clay layer. As seen on Figure 4.1, they are probably transitional to the upazilas further south in which the upper clay is particularly thick. However, unlike the southern upazilas no 'poor aquifer' constraint has been applied. The recommended development potential in these upazilas should be treated with caution.

In areas where current groundwater abstraction exceeds MPO recharge estimates, often significantly, there are no reported problems. This suggests that the MPO estimates are over-conservative and should be re-examined based on monitoring data obtained in recent years. For example, a study of the relationship between recorded abstraction and observed groundwater depletion may provide a revised depth storage relationship and a revised specific yield estimate. Then, in conjunction with known well specific capacities, a revised development potential for each tubewell technology could be calculated. Such activities are part of groundwater management, the issue of which is discussed below.

Figure 4.1



GROUNDWATER DEVELOPMENT ZONES

TABLE 4.4

Development Potential for Tubewell Technologies

District / Thana	1	2					3				4			
	Development Target for Irrigation by Groundwater	Volume Currently Abstracted by Technologies (From Table 4.1)					Development Potential for Technologies (Using Medium Category from MPO)				Balance for Future Development (Development Strategy)			
	Mm^3	Mm^3					Mm^3				Mm^3			
		STW	Potable	DSSTW	DTW	Total	STW	DSSTW	DTW	Total	STW	DSSTW	DTW	Total
KUSHTIA														
Bheramara	0.83	6.40	10.00	0.00	1.31	17.71	2.79	15.75	0.00	18.54	0.00	0.83	0.00	0.83
Daulatpur	44.08	3.78	10.00	0.00	5.33	19.11	0.00	41.71	21.48	63.19	0.00	27.93	16.15	44.08
Kumarkhali	27.73	5.85	10.00	0.00	1.00	16.85	0.00	13.79	30.67	44.58	0.00	0.00	27.73	27.73
Khoksa	0.28	2.58	10.00	0.00	5.77	18.35	0.00	4.09	14.54	18.63	0.00	0.00	0.28	0.28
Kushtia	25.60	6.85	10.00	0.00	0.25	17.10	0.00	27.76	14.94	42.70	0.00	10.91	14.69	25.60
Mirpur	15.34	13.30	10.00	0.00	1.13	24.43	0.00	39.77	0.00	39.77	0.00	15.34	0.00	15.34
CHUADANGA														
Alamdanga	2.89	18.49	10.00	0.00	6.08	34.57	19.49	17.98	0.00	37.47	0.00	2.90	0.00	2.90
Damurhuda	Grounwater	40.56	10.00	0.00	24.52	75.08	25.94	18.79	0.00	44.73	0.00	0.00	0.00	0.00
Chudanga	fully	21.52	10.00	0.00	15.14	46.66	15.98	17.31	0.00	33.29	0.00	0.00	0.00	0.00
Jiban Nagar	developed	23.61	10.00	0.00	5.34	38.95	15.85	0.00	13.51	29.36	0.00	0.00	0.00	0.00
MEHERPUR														
Gangni	Grounwater	24.45	10.00	0.00	16.35	50.80	22.23	15.44	0.00	37.67	0.00	0.00	0.00	0.00
Meherpur	fully developed	43.44	10.00	0.00	18.78	72.22	9.15	48.01	0.00	57.16	0.00	0.00	0.00	0.00
JESSORE														
Abhynagar	17.98	14.27	10.00	0.00	0.50	24.77	0.00	28.22	14.53	42.75	0.00	3.95	14.03	17.98
Bagherpara	Grounwater	27.88	10.00	0.00	10.33	48.21	0.00	8.51	38.77	47.28	0.00	0.00	0.00	0.00
Chougachha	fully	40.49	10.00	0.00	16.12	66.61	0.00	46.75	0.00	46.75	0.00	0.00	0.00	0.00
Jhikergacha	developed	39.54	10.00	0.00	26.48	76.02	0.00	27.53	35.04	62.57	0.00	0.00	0.00	0.00
Jessore		45.08	10.00	0.00	28.81	83.89	0.00	36.30	39.33	75.63	0.00	0.00	0.00	0.00
Kesabpur	do	102.47	10.00	0.00	1.08	113.55	1.80	43.24	0.00	45.04	0.00	0.00	0.00	0.00
Manirampur	4.23	46.09	10.00	0.00	17.03	73.12	0.00	41.00	36.35	77.35	0.00	0.00	4.23	4.23
Sarsha	do	83.53	10.00	0.00	35.27	128.80	3.56	55.71	0.00	59.27	0.00	0.00	0.00	0.00

[samad\swr\tab4-4]

TABLE 4.4 (Continued)

Development Potential for Tubewell Technologies

District / Thana	Development Target for Irrigation	2 Volume Currently Abstracted by Technologies (From Table 4.1)					3 Development Potential for Technologies (Using Medium Category from MPO)				4 Balance for Future Development (Development Strategy)			
	Mm³	Mm³					Mm³				Mm³			
		STW	Potable	DSSTW	DTW	Total	STW	DSSTW	DTW	Total	STW	DSSTW	DTW	Total
JHENAIDAH														
Harinakunda	12.47	10.98	10.00	0.00	0.39	21.37	1.69	17.60	14.55	33.84	0.00	0.00	12.47	12.47
Jhenaidah	9.59	44.52	10.00	0.00	12.23	66.75	3.82	36.64	35.88	76.34	0.00	0.00	9.59	9.59
Kaliganj	11.22	32.21	10.00	0.00	11.90	54.11	0.00	1.96	63.36	65.32	0.00	0.00	11.21	11.21
Kotchandpur	0.65	19.54	10.00	0.00	5.23	34.77	0.00	15.94	19.48	35.42	0.00	0.00	0.65	0.65
Mahespur	G. water fully Dev.	85.99	10.00	0.00	7.05	103.04	0.00	42.81	44.55	87.36	0.00	0.00	0.00	0.00
Sailkupa	34.62	15.83	10.00	0.00	0.13	25.96	0.00	10.30	50.30	60.60	0.00	0.00	34.64	34.64
MAGURA														
Mohammadpur	30.94	11.53	10.00	0.00	0.26	21.79	0.00	26.37	26.36	52.73	0.00	4.84	26.10	30.94
Magura	22.46	27.46	10.00	0.00	2.61	40.07	2.50	9.38	50.64	62.52	0.00	0.00	22.46	22.46
Sripur	21.12	4.91	10.00	0.00	0.13	15.04	1.09	6.51	28.56	36.16	0.00	0.00	21.12	21.12
Salikha	2.45	24.46	10.00	0.00	1.15	35.61	0.00	8.46	29.96	38.42	0.00	0.00	2.45	2.45
NARAIL														
Kalia	53.37	5.92	10.00	0.00	0.00	15.92	0.00	0.00	69.31	69.31	0.00	0.00	53.39	53.39
Lohagara	21.67	19.46	10.00	0.00	0.00	29.46	0.00	25.56	25.57	51.13	0.00	0.00	21.67	21.67
Narail	47.39	18.98	10.00	0.00	0.14	29.12	0.00	8.42	68.09	76.51	0.00	0.00	47.39	47.39
FARIDPUR														
Modhukhali	17.07	16.86	10.00	0.00	3.38	30.24	0.00	0.00	47.31	47.31	0.00	0.00	17.07	17.07
Boalmari	34.17	18.71	10.00	0.00	0.27	28.98	0.00	17.05	46.09	63.14	0.00	0.00	34.16	34.16
Alfadanga	G. Water fully Dev.	9.98	10.00	0.00	2.97	22.95	6.28	13.99	0.00	20.27	0.00	0.00	0.00	0.00
Nagarkanda	37.04	24.97	10.00	0.00	11.49	46.46	0.00	47.60	35.90	83.50	0.00	12.63	24.41	37.04
Bhanga	16.47	26.75	10.00	0.00	0.00	36.75	0.00	27.14	26.08	53.22	0.00	0.00	16.47	16.47
Sadarpur	64.64	9.40	10.00	0.00	4.58	23.98	0.00	0.00	88.62	88.62	0.00	0.00	64.64	64.64
Char Bhadrason	39.37	2.25	10.00	0.00	2.34	14.59	0.00	0.00	53.96	53.96	0.00	0.00	39.37	39.37
Faridpur	56.30	27.57	10.00	0.00	0.80	38.37	0.00	22.73	71.94	94.67	0.00	0.00	56.30	56.30

[samad\swr\tab4-4]

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TABLE 4.4 (Continued)

Development Potential for Tubewell Technologies

District / Thana	1	2					3				4			
	Development Target for Irrigation by Groundwater	Volume Currently Abstracted by Technologies (From Table 4.1)					Development Potential for Technologies Using Medium Category from MPO				Balance for Future Development (Development Strategy)			
	Mm³	Mm³					Mm³				Mm³			
		STW	Potable	DSSTW	DTW	Total	STW	DSSTW	DTW	Total	STW	DSSTW	DTW	Total
GOPALGANJ														
Tungipara	16.78	0.03	10.00	0.00	0.00	10.03	0.00	0.00	26.81	26.81	0.00	0.00	16.78	16.78
Kotwalipara	30.79	0.03	10.00	0.00	0.00	10.03	0.00	0.00	40.82	40.82	0.00	0.00	30.79	30.79
Kasiani	22.86	9.20	10.00	0.00	0.00	19.20	0.00	0.00	42.06	42.06	0.00	0.00	22.86	22.86
Muqsudpur	28.14	12.52	10.00	0.00	0.68	23.20	0.00	42.62	8.72	51.34	0.00	20.10	8.04	28.14
Gopalganj	43.00	4.87	10.00	0.00	0.00	14.87	0.00	0.00	57.87	57.87	0.00	0.00	43.00	43.00
MADARIPUR														
Kalkini	78.05	2.35	10.00	0.00	0.14	12.49	0.00	0.00	90.55	90.55	0.00	0.00	78.06	78.06
Rajair	39.31	15.76	10.00	0.00	1.98	27.74	0.00	0.00	67.03	67.03	0.00	0.00	39.32	39.32
Sibchar	73.31	14.07	10.00	0.00	0.00	24.07	0.00	0.00	97.38	97.38	0.00	0.00	73.31	73.31
Madaripur	47.19	20.65	10.00	0.00	4.96	35.61	0.00	0.00	82.80	82.80	0.00	0.00	47.19	47.19
RAJBARI														
Pangsa	33.90	25.53	10.00	0.00	3.44	38.97	0.00	0.00	72.87	72.87	0.00	0.00	33.90	33.90
Baliakandi	11.85	11.53	10.00	0.00	3.14	24.67	0.00	12.42	24.10	36.52	0.00	0.00	11.85	11.85
Goalanda	12.10	6.36	10.00	0.00	11.76	28.12	0.00	0.00	40.22	40.22	0.00	0.00	12.10	12.10
Rajbari	23.55	22.13	10.00	0.00	11.17	43.30	0.00	50.81	16.04	66.85	0.00	18.68	4.87	23.55
SARIATPUR														
Janjira	74.34	2.61	10.00	0.00	0.65	13.26	0.00	0.00	87.60	87.60	0.00	0.00	74.34	74.34
Naria	46.94	4.23	10.00	0.00	0.00	14.23	0.00	0.00	61.17	61.17	0.00	0.00	46.94	46.94
Bhederganj	112.26	1.38	10.00	0.00	0.00	11.38	0.00	0.00	123.64	123.64	0.00	0.00	112.26	112.26
Gosairhat	55.48	0.00	10.00	0.00	0.00	10.00	0.00	0.00	65.48	65.48	0.00	0.00	55.48	55.48
Damadya	22.50	0.33	10.00	0.00	0.00	10.33	0.00	0.00	32.83	32.83	0.00	0.00	22.50	22.50
Sariatpur	49.55	1.56	10.00	0.00	0.00	11.56	0.00	0.00	61.11	61.11	0.00	0.00	49.55	49.55

[samad\swr\tab4-4]

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TABLE 4.5
Maximum Additional Land that could be Irrigated by Groundwater

District / Thana	Additional available Groundwater Medium Category	MPO Water duty Estimate	Additional Irrigable Area by Groundwater
	Mm3	ha/Mm3	ha
KUSHTIA			
Bheramara	0.83	153	127
Daulatpur	44.08	150	6612
Kumarkhali	27.73	150	4160
Khoksa	0.28	148	41
Kushtia	25.60	159	4070
Mirpur	15.34	159	2439
CHUADANGA			
Alamdanga	2.90	148	429
Damurhuda	0.00	146	0
Chudanga	0.00	148	0
Jiban Nagar	0.00	146	0
MEHERPUR			
Gangni	0.00	148	0
Meherpur	0.00	148	0
JESSORE			
Abhynagar	17.98	141	2535
Bagherpara	0.00	151	0
Chougachha	0.00	139	0
Jhikergacha	0.00	145	0
Jessore	0.00	143	0
Kesabpur	0.00	148	0
Manirampur	4.23	148	626
Sarsha	0.00	148	0
JHENAIDAH			
Harinakunda	Fully Irrigated		
Jhenaidah	9.59	139	1333
Kaliganj	11.21	153	1715
Kotchandpur	0.65	153	99
Mahespur	0.00	139	0
Sailkupa	34.64	153	5300
MAGURA			
Mohammadpur	30.94	153	4734
Magura	22.46	153	3436
Sripur	21.12	159	3358
Salikha	2.45	159	390
NARAIL			
Kalia	53.39	139	7421
Lohagara	21.67	150	3251
Narail	47.39	140	6635
FARIDPUR			
Modhukhali	17.07	154	2629
Boalmari	34.16	148	5056
Alfadanga	0.00	148	0
Nagarkanda	37.04	148	5482
Bhanga	6.76	154	1041
Sadarpur	64.64	153	9890
Char Bhadrason	39.37	154	6063
Faridpur	56.30	154	8670
GOPALGANJ			
Tungipara	16.78	123	2064
Kotwalipara	30.79	124	3818
Kasiani	22.86	140	3200
Muqsudpur	28.14	118	3321
Gopalganj	43.00	128	5504
MADARIPUR			
Kalkini	78.06	140	10928
Rajair	39.32	131	5151
Sibchar	73.31	153	11216
Madaripur	47.19	149	7031
RAJBARI			
Pangsa	33.90	153	5187
Baliakandi	11.85	149	1766
Goalanda	12.10	131	1585
Rajbari	23.55	140	3297
SARIATPUR			
Janjira	74.34	153	11374
Naria	46.94	148	6947
Bhederganj	112.26	137	15380
Gosairhat	55.48	136	7545
Damadya	22.50	136	3060
Sariatpur	49.55	150	7433

[samad\swr\tab4-5]

4.5 Other Issues

4.5.1 Groundwater Management

The recommendations of the FAP-4 project will include promotion of schemes which have a component covering groundwater development. For example, in the Second Interim Report, schemes Padma-Kumar and Arial Khan-Bisarkandi included use of groundwater and were ranked 1 and 4 respectively in an order of preference. As shown in this annex, DTW will be the recommended main source of groundwater, the method which is most likely to have a detrimental effect on other users. Some consideration therefore needs to be given to the matter of groundwater management, to avoid problems.

In the past, BADC have had a major role in controlling groundwater abstraction by DTW, particularly under the IDA Deep Tubewells-II project, which ran from 1983 to 1992. However views and policies on the regulation of DTW installation changed substantially during the life of this project. Under the 1985 Groundwater Management Ordinance, restrictions were placed on well siting. The Ordinance was enforced by Upazila Irrigation Committees which included a BADC Senior Sub-Assistant Engineer. Because it had financial control over the subsidy towards DTW, BADC controlled the number of wells which could be drilled in each Thana and so was able to exercise tight control over this method of groundwater development.

In 1989 the Ordinance was suspended and there is a continuing move towards the de-regulation of groundwater. Under the NMID project which is now expected to commence in May 1993, private sector involvement in DTW installation will be encouraged and subsidies towards the cost of DTW will cease, as will BADC's control. In a deregulated environment, tubewell development for irrigation will be self-financing and self regulating. It is argued in the documentation covering NMIDP, that encroachment (too-close spacing of wells) will not be a major problem because water supplied by an unsubsidised DTW will not be price competative with existing wells. Thus abstraction will be controlled by market forces and it is probable that there is now enough experience in local farmer communities for money not to be wasted on groups of wells being drilled too close together to the detriment of all.

It is probable, as explained below, that BADC will have an important advisory role to play under NMIDP whilst in the past they have been seen mainly as a drain on the public purse, which is one reason for deregulation. However it is probable also that by enforcing regulation based on current over-conservative estimates of recharge, irrigation development has been seen to have been unjustifiably restricted. In a deregulated environment it is argued that this would not be the case.

Under the deregulated system, BADC will have to compete with private contractors for tubewell installation but it is intended that its main role will be in promotion and marketing of new technologies. However, BADC are holders of important groundwater monitoring data, particularly groundwater level data, and this should continue under the NMIDP. Such data are crucial in improving and refining estimates of groundwater availability, such as the MPO models, and, as such, BADC as a provider of sound advice is in a unique position to influence groundwater development for the better. It should be noted however that BADC's role under NMIDP has yet to be confirmed and the project will not be funding monitoring schemes outside of its own project area.

In the case of the SWA, the issue of saline intrusion is a special complication. Saline intrusion is not an issue in areas such as those covered by the Deep Tubewells-11 project and so salinity problems did not feature in the criteria for DTW planning controls exercised by BADC. While market-forces may control groundwater abstraction to avoid problems such as encroachment, saline intrusion is a regional problem which can only be dealt with at policy level.

Ideally, legislation similar to the 1985 Ordinance is required to exclude drilling and operation of tubewells in the buffer zone; with the political will and sufficient foresight, this ought to be achievable. However a particular argument in favour of deregulation is that the rules against uncontrolled development are not possible to apply in practice. If the latter is accepted as being the case, which is in accordance with the spirit of NMIDP, in order to establish the buffer-zone of no groundwater development as recommended herein, a non-regulatory method is required. Probably the most sensible way is to provide a cheap and convenient surface water alternative, though it is appreciated that this is not necessarily straightforward in engineering terms.

However, expansion of minor irrigation is inexorable, and in a deregulated market DTW might begin to appear in the buffer zone. Whilst accepting the conservative nature of the MPO approach, widespread saline intrusion would have disastrous and irreversible consequences and caution is justifiable. The domestic water supply situation at Khulna is a good example of how quickly problems can arise. Monitoring of the situation within the proposed buffer zone is therefore of utmost importance.

4.5.2 Effects on Rural Water Supplies

The major source of domestic water supply in the project area is groundwater pumped from hand tubewells (HTW). The operation of HTW is put under threat by groundwater pumping for irrigation because it may cause groundwater levels to fall to an extent below which HTW will not operate. The failure of HTW, particularly at the end of the irrigation season when groundwater levels are at their lowest, is commonly reported.

HTW come in two types, suction-mode and force-mode. In practice, suction mode pumps have a maximum lift of about 6m; many such wells were installed by UNICEF/DPHE in the 1970's. More recently, force mode 'Tara' pumps have become available, which have a pumping lift of 15m. Both are under threat from irrigation wells but, clearly, suction mode pumps are at most risk. The main types of irrigation wells, STW, DSSTW and DTW, have practical maximum pumping lifts of 7.0m, 9.0m and 20.0m respectively, so the greatest threat to HTW is from operation of DTW.

The reverse situation is also true because in theory if groundwater levels are maintained so that HTW will always operate, DTW operation must be restricted, so in that sense HTW are a constraint to full irrigation development by DTW. In practice, hydrogeological conditions will vary and because local (well) pumping levels are below regional levels, DTW and HTW can coexist.

From a technical point of view the relationship between HTW and other tubewell operation is sometimes more complex in practice than is simulated by the MPO development potential model. For example one reason why HTW can continue to operate in areas where pumping water levels in DTW are apparently too deep is because the HTW take water from a shallower upper aquifer which is separated from the deeper aquifer by a semi confining layer. Also, if sensible well spacing criteria are observed, as mentioned above, groundwater levels between irrigation wells should be high enough for HTW to continue to operate, even with full development of available recharge.

Wells such as observation wells, DTW and HTW are usually sited on higher ground than STW and often when depths-to-water are quoted, these elevation differences are not taken into account. This is another source of confusion when the operational effects of one well type on another are being considered.

In project terms, an allowance has been made for potable use in both the groundwater resources evaluation and in the RAOM model. Also, as has been demonstrated extensively throughout Bangladesh, the MPO estimates of available recharge are very conservative and it is likely, in practice, that more groundwater is available for irrigation than has been assumed. In combination, these factors tend towards the conservation of rural water supplies obtained from HTW when the recommendations of the project to develop groundwater are taken up.

Nevertheless, because rural water supplies are of such vital importance and given that:

- there is a trend towards deregulation in the provision of irrigation wells so there will be less control of tubewell design and siting;
- most additional groundwater in the project area is expected to come from DTW, which are the greatest threat to HTW;
- regardless of safety factors, problems with HTW do occur as a result of irrigation wells;

it is considered that some action is required to protect HTW supplies. This would best be achieved by instigating programmes to install force-mode Tara HTW in those areas where irrigation by DTW is to be extended. Such areas can be identified from the output of this project. It might be argued that provision of Tara pumps should be preceded by monitoring to see if there is an adverse effect. However because HTW supplies are so precious provision should be made for installation of Tara pumps wherever DTW installation is set to significantly increase. It is appreciated that Tara pump HTW would be installed by DPHE under separate funding assistance distinct from minor irrigation sector work but only basic liaison would be required for the programmes to run in parallel.

It is understood from DPHE that almost all of HTW in the project area are suction mode wells. The total number of HTW in thanas where groundwater development by DTW is possible is about 95,000. Each new Tara HTW costs Tk 11,000 so the total mitigation cost is in the order of Tk 1.05×10^9 (USD 27 million).

These mitigation costs are based on the current situation of one HTW serving 133 people on average. However the target is to have one HTW serving 100 people so, because the cost of a suction mode HTW is only Tk 5000 the actual cost of meeting the target will be greater by Tk 0.19×10^9 taking into account the price difference between force mode HTW and suction mode tubewells.

4.5.3 Khulna Water Supplies

This section is a review of issues relevant to the problem of water supply to the town of Khulna, in the south western part of the project area. Khulna is a large centre of population, in which water is needed for domestic and industrial purposes. The current source of this water is mainly groundwater, with some industrial abstraction from the Bhairab River.

Khulna's problem is maintenance of groundwater quality, which is at risk from saline intrusion. The hydrogeological situation in which Khulna is located is illustrated in Figure 2.6.

A visit to Khulna city by project staff in September 1992 indicated that the city's water supply is obtained from a series of HTW and DTW, both public and privately operated.

The main town supply comes from deep wells installed from the mid 1970's onwards, mainly under Dutch aid programmes in collaboration with DPHE. The wells are now operated by the Khulna city corporation water works department.

Project records show that there are 45 deep wells, approximately 230-290m deep, located as a series of separate wells and in well fields. 36 wells are currently in operation. Some of the wells were tested to over 60 l/s but the design output is 19 l/s; in practice the design yield is frequently exceeded. At the depths shown, the wells are probably drawing water from the main aquifer, the deep aquifer or both. There are also 1460 HTW, some of which exploit the lens and others exploit deeper aquifers.

The limited data available clearly indicate that the effects of saline intrusion are being experienced in these wells. A 1987 report (AQUA, 1987) on construction of 7 new deep wells indicated chloride concentrations 35-318 mg/l when the wells were tested:

WELLFIELD NAME	WELL NO	Cl (mg/l)
Muzgunni	1	128
"	2	117
"	3	318
Tootpara	2	81
"	3	40
Nirala	1	37
"	2	42
"	3	35

This range of chloride values is quite wide and could indicate vertical or spatial variation or both. It is certainly indicative of a salinity hazard and the need for great caution in abstraction and wellfield management.

Currently, chloride values are up to 941 mg/l which indicates a significant deterioration in quality since the 1987 data were obtained. The population in Khulna are said to be tolerant to the current salinity levels but it would appear that it is only a matter of time before the wells become unusable.

A town the size of Khulna needs a robust and reliable fresh water supply, and it seems unlikely to survive for much longer under the existing regime of groundwater pumping. Also, the Bhairab River on which the town is located,is saline to a point further upstream than Khulna itself. Possible future options are reviewed below:

(a) Continued groundwater utilisation under a different regime of abstraction

If the relationship between abstraction and salinity distributions was fully understood, it might be that a modified regime of pumping would maintain or marginally improve the quality of the supply. Actions would include redistribution of pumping and possibly drilling of additional wells in low salinity areas (probably to the north). The programme would necessitate thorough study of available reports on the area together with some exploratory drilling and testing. However this strategy is a holding position only and not a long term solution to the problem of finding a reliable water supply for Khulna.

(b) Groundwater abstraction outside of Khulna and transmission of water by pipeline

This is another possibility but the current indications are not encouraging. In the Khulna district thanas north of Khulna town there is only limited use of groundwater for irrigation and no deep tubewells. Whether this is due to a known salinity problem in deeper aquifers or maintenance of the MPO recommended buffer zone by BADC is not clear. However it would seem that it would be necessary to go a considerable distance away from Khulna to safely locate a wellfield, which may in any case detrimentally affect other local groundwater users. Having looked at this strategy we do not think that it is an option which warrants further detailed consideration.

(c) Surface Water Augmentation

A possible scheme would be to release enough water into upstream river systems to keep the Bhairab River fresh all the year round. However, it is understood that such a scheme would be expensive. It should be noted that improving surface water quality will not significantly affect groundwater quality in the lens because the lateral transfer of water is small.

Short of additional studies it is concluded that whichever option is considered, solving the water supply problem at Khulna will be a difficult and expensive business. In general however we consider that surface water is a more likely long term solution for the water supply at Khulna than groundwater. The surface water options are discussed in detail elsewhere in this report.

5 TUBEWELL COSTS

Tables 5.1 - 5.7 provide data on the construction, operation and maintenance costs of DTW and DSSTW/STW, including diesel powered and electrically powered alternatives. The figures are based on BADC 1989 data (Halcrow/BCB, 1989) with an inflation on costs of 5% plus other minor cost amendments. The cost totals accord with current BADC figures.

Other assumptions are:

(a) All wells exploit the main aquifer to about 100m which is a reasonable assumption for the more favourable groundwater areas in the northern part of the study area. Only the main aquifer is capable of sustaining such wells.

(b) For diesel powered wells, O & M costs are based on a 3 year cycle which excludes an engine overhaul, the normal cost of which is Tk 20 - 25,000.

(c) The anticipated life expectancy for a tubewell is 25 years, during which time some tubewell maintenance might be required. However, the costs spread out over this period would be negligible.

A summary of costs is given below:

	Item	Cost (Tk)
(a)	DTW, electrical, installation	618,200.00
(b)	DTW, diesel, installation	761,200.00
(c)	DTW, electrical, cost/hr O & M	22.50/hr
(d)	DTW, diesel, cost/hr O & M	84.00/hr
(e)	STW/DSSTW, electrical, installation	40,286.00
(f)	STW/DSSTW, diesel, installation	34,600.00
(g)	STW/DSSTW, electrical, cost/hr O & M	4.60/hr
(h)	STW/DSSTW, diesel, cost/hr O & M	21.00/hr

TABLE 5.1

COST ESTIMATE OF 100M DEEP TUBEWELL (57 l/s CAPACITY)
(Electric Motor Driven)

Sl No	Item	Unit/ Qnty	Cost in Taka			
			F.E. Compon-ents C&F	Duties & Taxes	Local Currency	Total
1	Transportation and Mobilisation of drilling equipments, preparation of drilling etc.	L.S.			28000	28000
2	Sinking (100 M)				52000	52000
3	Gravel Packing	600 cft			21000	21000
4	Verticality test	L.S.			500	500
5	Straightness test	L.S.			500	500
6	Sieve analysis 15 Nos samples @ Tk.100/- /sample	L.S.			1500	1500
7	Development test	L.S.			6000	6000
8	Step test	L.S.			4500	4500
9	Electric conductivity test	L.S.			250	250
10	pH test	L.S.			250	250
11	Sand content test	L.S.			500	500
12	Motor (35 H.P)	1			37000	37000
13	Pump (57 l/s turbine with 21.34m column pipe)	1			170000	170000
14	152.43 (6" nominal) mm dia G.I. Pipe @ Tk.1380/m	42 m			58000	58000
15	152.43 (6" nominal) mm dia stainless steel strainer @ Tk.3450/m	31 m			107000	107000
16	355.69 (14" nominal)mm dia Housing pipe @Tk.2100/m	27 m			56700	56700
17	Accessories (bail plug, centralizer, reducing socket well cap etc)	L.S.			5000	5000
18	Pump House including discharge box	L.S.			51000	51000
19	Well commissioning	L.S.			12500	12500
	Sub-Total cost Taka				612200	612200
	5% above on sinking cost				6000	6000
					6182000	6182000

SOURCE : BADC

TABLE 5.2

COST ESTIMATE OF 100M DEEP TUBEWELL (57 l/s CAPACITY)
(Diesel Operated)

Sl No	Item	Unit/ Qnty	Cost in Taka			
			F.E. Compon-ents C&F	Duties & Taxes	Local Currency	Total
1	Transportation and Mobilisation of drilling equipments, preparation of drilling etc.	L.S.			28000	28000
2	Sinking (100 M)	600 cft			52000	52000
3	Gravel Packing	L.S.			21000	21000
4	Verticality test	L.S.			500	500
5	Straightness test	L.S.			500	500
6	Sieve analysis 15 Nos samples @ Tk.100/- /samples	15 Nos			1500	1500
7	Development test	L.S.			6000	6000
8	Step test	L.S.			4500	4500
9	Electric conductivity test	L.S.			250	250
10	pH test	L.S.			250	250
11	Sand content test	L.S.			500	500
12	Engine	1	96000	64000	160000	160000
13	Gear head with spicer shaft	L.S.			20000	20000
14	Pump (57 l/s turbine with 21.34m column pipe)	1			170000	170000
15	152.43 (6" nominal) mm dia G.I. Pipe @ Tk.1380/m	42 m			58000	58000
16	152.43 (6" nominal) mm dia stainless steel strainer @ Tk.3450/m	31 m			107000	107000
17	355.69 (14" nominal)mm dia Housing pipe @Tk.2100/m	27m			56700	56700
18	Accessories (bail plug, centralizer, reducing socket well cap etc)	L.S.			5000	5000
19	Pump House including discharge box	L.S.			51000	51000
20	Well commissioning	L.S.			12500	12500
	Total cost Taka				755200	755200
	5% above on sinking cost				6000	6000
					761200	761200

SOURCE : BADC

TABLE 5.3

OPERATION AND MAINTENANCE COST OF (57 l/s) DEEP TUBEWELL
(Diesel Operated)

Time	Operating Hours	Details of items with rate		Total Cost
1st Year	1000 Hrs	H.S. Diesel @ Tk.14.00 litre (4.5460 lit/hr)		63644.00
		Mobil @ Tk.26.40/litre (0.181 lt/hr)		4778.40
		Gear Oil	L.S.	2000.00
		Salary of Operator @ Tk.1500.00 Per Month		6000.00
		Maintenance cost (L.S.)		6000.00
2nd Year	1000 Hrs	H.S. Diesel (as in 1st year)		63644.00
		Mobil @ Tk.26.40 litre (0.222 lit/hr)		5860.80
		Gear Oil	L.S.	2000.00
		Salary of Operator (as in 1st year)		6000.00
		Maintenance cost	L.S.	7000.00
3rd Year	1000 Hrs	H.S. Diesel (as in 1st year)		63644.00
		Mobil (as in 2nd year)		5860.80
		Gear Oil (as in 2nd year)		2000.00
		Salary of Operator (as in 2nd year)		6000.00
		Maintenance cost	L.S.	8000.00
3 Years	3000 Hrs	Therefore, operation and maintenance cost per hour = Tk. 84.00	Total Tk	252432.00

SOURCE: BADC

TABLE 5.4

COST ESTIMATE OF 46M SHALLOW TUBEWELL (15 l/s CAPACITY)
(Diesel Operated)

Sl No	Item	Unit	Cost in Taka			
			F.E. Components C&F	Duties & Taxes	Local Currency	Total
1	Drilling @ Tk.50.00/meter (depth 46m)	1			2300	2300
2	Sinking material					
	i) Screen @ Tk.430.50/m	12m			5166	5166
	ii) Casing @ Tk.234/m	34m			7956	7956
	iii) Transport	L.S.			1000	1000
3	Engine (diesel) 6 H.P.	1	14000	2100		16100
4	Pump					
	i) Centrifugal pump	1			4410	4410
	ii) Accessories (Bailplug, Nipple, Bend, Tee, Socket etc.)	L.S.			1400	1400
5	Miscellaneous 10% of totally procured items 2(i) + 2(ii) + 4(i) + 4(ii)				1954	1954
			14000	2100	24186	40286

SOURCE: BADC

TABLE 5.5

COST ESTIMATE OF 46M SHALLOW TUBEWELL (15 l/s CAPACITY)
(Electric Motor Driven)

Sl No	Item	Unit	Cost in Taka			
			F.E. Components C&F	Duties & Taxes	Local Currency	Total
1	Drilling @ Tk.50.00/meter (depth 46m)	1			2300	2300
2	Sinking material					
	i) Screen @ Tk.430.50/m	12m			5160	5160
	ii) Casing @ Tk.234/m	34m			7956	7956
	iii) Transport	L.S.			1000	1000
3	Motor (5 H.P.) with starter	1			10500	10500
4	Pump					
	i) Centrifugal pump	1			4410	4410
	ii) Accessories (Bailplug, Nipple, Bend, Tee, Socket etc.)	L.S.			1350	1350
5	Miscellaneous 10% of totally procured items 2(i) + 2(ii) + 4(i) + 4(ii)				1888	1888
	TOTAL				34564	34564
					SAY	34,600

SOURCE: BADC

TABLE 5.6

OPERATION AND MAINTENANCE COST OF 15 l/s SHALLOW TUBEWELL

(Diesel Operated)

Time	Operating Hours	Details of items with rate		Total cost
	1100 Hrs	H.S. Diesel @ Tk.14.00/litre (1.15 lit/hr)		17725.40
		Mobil @ Tk.26.40/litre (0.045 lit/hr)		1306.80
		Gear Oil	L.S.	500.00
		Maintenance	L.S.	3000.00
3 Years	1100 Hrs			22532.20
Therefore, operation and maintenance cost per hour = Tk.20.48 say Tk.21.00				

SOURCE: BADC

TABLE 5.7

ANNUAL OPERATION AND MAINTENANCE OF ELECTRICALLY OPERATED TUBEWELLS, 1991

A. DEEP TUBEWELL				
Sl No	Item	Local Cost Taka	Foreign Cost Taka	Total Taka
1	Manager's salary	6000	-	6000
2	Operators salary	1500	-	1500
3	Repairs/spares	500	500	1000
4	Miscellaneous costs	800	200	1000
5	Pumping costs	13000	-	13000
	Total	21800	700	22500
(Total cost/Hr = Tk.22.50 assuming 1000 hrs running each year)				
B. SHALLOW TUBEWELL				
1	Operators/Manager salary	3000	-	3000
2	Repairs and spares	300	200	500
3	Miscellaneous costs	225	75	300
4	Pumping costs	1250	-	1250
	Total	4775	275	5050
Total cost/Hr = Tk.4.60 assuming 1100 hrs. running each year)				

SURCE: BADC

Note: 1. Pumping costs based on 1992 electricity charges
2. Maintenance costs assumed to be 4% cost of engine plus 1% cost of pump.
3. Maintenance costs 2% of all other costs

6. CONCLUSIONS

(a) A hydrogeological system is recognisable in the Southwest and South Central Regions of Bangladesh which is similar to many other areas of Bangladesh. However, due to a general southwards fining of the deltaic sediments and particularly thick upper clay layer in some areas, hydrogeological conditions are generally less favourable for groundwater development than elsewhere in most of Bangladesh.

(b) In particular, there is the potential problem of saline intrusion. Saline fronts are present in the deep and shallow aquifers, which will move inland if abstraction is badly managed. Some freshwater lenses used for potable water supply are already saline. The interchange between groundwater and seasonally saline river water is not thought to be a significant problem.

(c) There is no other known natural groundwater problem though the situation on groundwater contamination by fertiliser and pesticides is unknown.

(d) The MPO recharge model is applicable to the project area and provides values of potential and usable recharge. These values can be constrained to provide data on available recharge. Small constraints are applicable for baseflow losses but 100% constraints apply to saline water areas, a buffer zone to protect against salinity, and poor aquifer conditions.

(e) Implementation of flood protection schemes has the effect of reducing potential recharge. However, the most significant effects are experienced on areas of deep, prolonged flooding, i.e. F3/F4 land types, which occupy a small percentage of the project area.

(f) A growth in tubewell numbers between 1985 and 1991 has been experienced as it has elsewhere in Bangladesh. The incidence of DTW in the project area probably reflects the generally poorer aquifer conditions as well as the fact that DTW have been heavily subsidised.

(g) In most upazilas, available recharge is less than the potential water demand for irrigation and potable water supplies. In those upazilas where current groundwater abstraction (including potable use) is less than available recharge, a development strategy for the balance can be devised. The development strategy consists of a plan to extract the water by a mix of STW, DSSTW and DTW, in addition to those already installed. The area for additional development is shown on Figure 4.1 and the land area in each upazila which can be irrigated by the available groundwater is given in Table 4.5.

(h) In some areas groundwater abstraction currently exceeds MPO estimates of available recharge, though apparently without adverse effects at present. It is probable in such cases that the MPO estimates are under-estimated. Abstraction problems in STW/HTW due to low water levels have been reported but this is more likely to be due to inadequate spacing between wells than widespread abstraction in excess of recharge.

(i) The quality of the water supply at Khulna is deteriorating due to saline intrusion. It is unlikely that the long term water supply requirements for Khulna can be met by groundwater.

7 RECOMMENDATIONS

7.1 Maintenance of a Buffer Zone

The regulatory issues concerning the buffer zone to prevent saline intrusion have been discussed separately. However, as explained in this report, further study is needed to establish the necessary limits of the buffer zone, with respect to the transitional areas. These areas are transitional between thanas where aquifer conditions are favourable but groundwater development needs to be controlled, and those to the south where groundwater development is inhibited by poor aquifer conditions due to a very thick surface clay layer.

The additional work would be restricted to desk study collection of drilling records in the relevant area (see Figure 4.1) together with monitoring data. This would allow identification of those thanas where groundwater development is possible but where it should be discouraged and alternative irrigation water sources made available (see section on groundwater management). This should be an action on BADC under its new role within NMIDP, although at present it does not have a formal remit to deal with such matters.

7.2 The Effects of Flood Protection

As explained in this Report, flood protection works have the potential to cause reductions in recharge because they can lead to reduced periods of inundation. If additional groundwater development is planned in areas where FCD is also to be implemented it would be worth examining the significance of the expected reduction in flood duration. This would mean accessing the MPO recharge model and revising the input parameters to obtain revised estimates of recharge. However it is really only necessary where FCD would involve complete cessation of inundation. Otherwise the effect is expected to be so slight in consideration of the conservative nature of MPO recharge estimates, additional modelling studies would be unjustified.

Any necessary work would need to be carried out with the cooperation of WARPO or its successor organisation and would involve approximately 2 m/m of effort, one expatriate (a hydrogeologist with modelling experience) and one local (a hydrogeologist familiar with the MPO model).

7.3 Revision of MPO Recharge Estimates

The groundwater resources evaluation in this Volume uses output from MPO models to assess the amount of water available for future development. In some cases, the MPO limits are already being exceeded though there are no reports of significant problems in tubewell operation. This situation is seen in many other areas in Bangladesh where MPO figures have been shown to be under-estimated.

This is not a criticism of the models, however; the input data to them has been sensibly cautious. What has been missing, however, is feedback to the model of monitoring data on groundwater levels and abstraction, taken in the last 5-8 years. This would have enabled revised estimates of recharge and resource potential to be made and, probably, a relaxation of some of the controls on groundwater development exercised by BADC.

In the event, with the advent of NMIDP, BADC will cease to have a regulatory role and groundwater development will be controlled by market forces. However, under implementation of NMIDP, BADC should retain a monitoring role in which hydrogeological data can be obtained and used to refine estimates of groundwater availability. If problems do occur or are anticipated, BADC would have the necessary data to provide appropriate advice.

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How BADC can be reorganised to fulfill this need requires careful consideration and its role under NMIDP has yet to be defined. Such issues will be addressed under NMIDP, which should include details of the studies required to revise the currently available estimates of recharge made by MPO.

7.4 Groundwater Pollution Monitoring

This Report points out the need for monitoring of nitrates and pesticide residues in groundwater. However, NMIDP has an environmental component which covers all such work. This would sensibly become part of the remit for BADC in its groundwater monitoring role which should extend to all areas where irrigation and groundwater extraction are taking place, not just those groundwater irrigation areas identified under NMIDP. However NMIDP has no provision for funding outside its own project area.

7.5 Management

As discussed in Section 4.5.1, even within a deregulated market it will be necessary to monitor behaviour of the hydrogeological system in response to groundwater abstraction in order to identify adverse effects and what might be causing them. It is the project's view that this monitoring role should be with BADC and developed under the technical assistance element in NMIDP. It is appreciated that at present NMIDP is not in a position to fund monitoring activities outside of its project area, but its in a strong position to influence policy and BADC's role should be a matter of immediate consideration.

7.6 Rural Water Supply

Where projects in SWA will involve significant increases in DTW installations, a parallel programme of installation of force-mode Tara pumps should be instigated. Although hydrogeological analysis suggests this is not always necessary, problems do occur and domestic water supplies should not be put at risk.

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Resource Allocation and Optimisation Model
(RAOM)

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SOUTHWEST AREA WATER RESOURCES MANAGEMENT PROJECT (FAP-4)

RESOURCE ALLOCATION AND OPTIMISATION MODEL

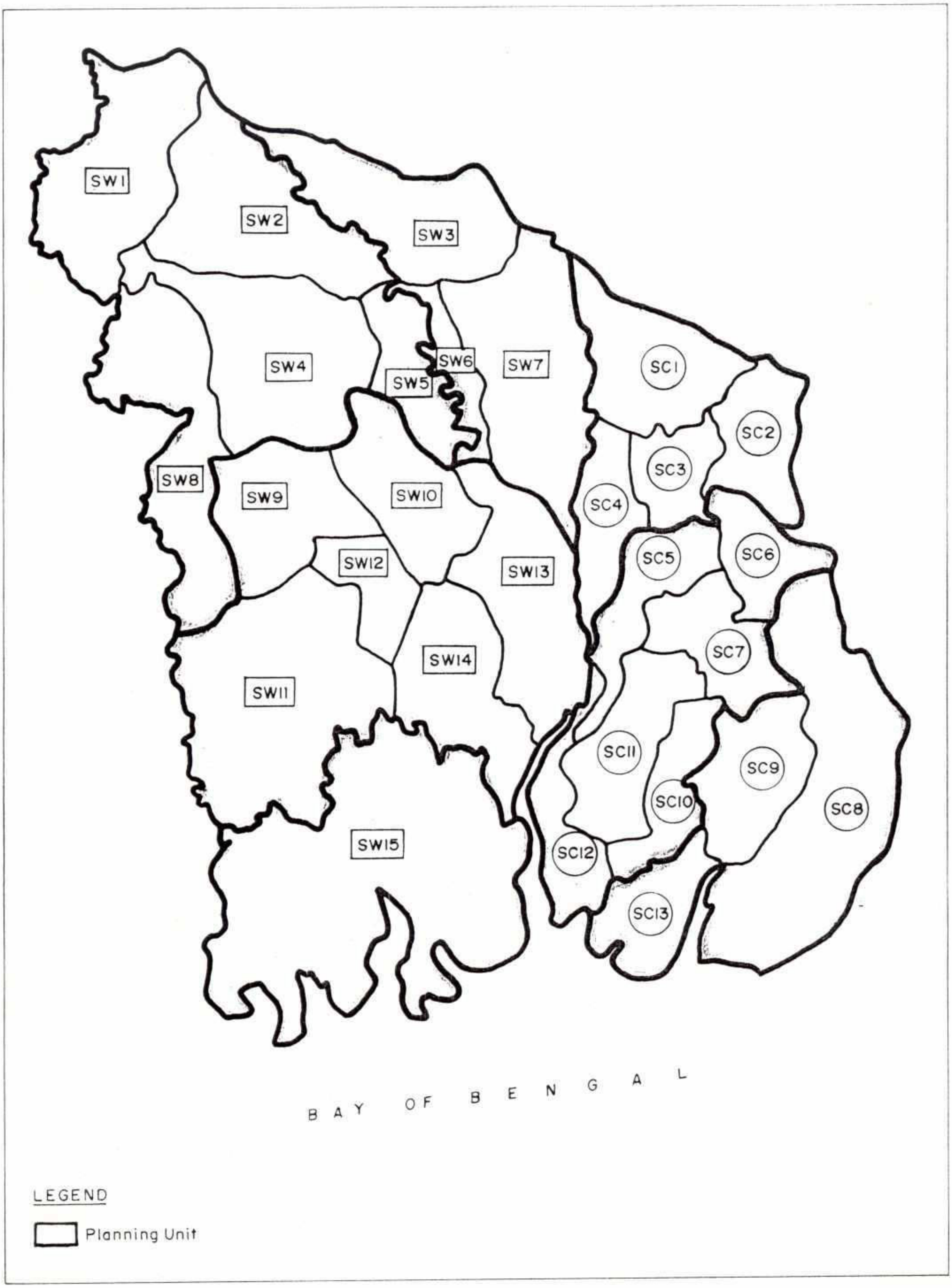
CONTENTS

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AEZ	Agro-Ecological Zone
BIWTA	Bangladesh Inland Water Transport Authority
BWDB	Bangladesh Water Development Board
CIDA	Canadian International Development Agency
DSSTW	Deep Set Shallow Tubewell
DTW	Deep Tubewell
FCD	Flood Control and Drainage
GIS	Geographic Information System
MPO	Master Plan Organisation
NAM	Rainfall Runoff Model
NCA	Net Cultivable Area
NPV	Net Present Value
PU	Planning Unit
RAOM	Resource Allocation and Optimisation Model
SODAPS	Soil Survey Data Processing System
STW	Shallow Tubewell
SWA	Southwest Area

Figure 1.1



Planning Units

1 INTRODUCTION

The Resource Allocation and Optimisation Model (RAOM) is a mixed integer linear programming model purpose built to assist with the analysis of strategic development options within the Southwest Area. Originally developed as two models, one covering the Southwest Region and one the South Central Region, the later availability of more powerful software enabled their combination into a single model embracing the whole Area and enabling better representation of the overall long term development choices.

The combined RAOM represents the key development resources in the study areas: water, land, people. The model attempts to match these resources in a sustainable manner to the principal development demands of the area in an optimal manner, ensuring that this is achieved with minimum economic cost or maximum economic benefit whilst meeting specified development targets.

Water resources are split up, conceptually, into surface and ground water, with a provision which was not ultimately used for them to be used conjunctively. The surface water system is represented in each model as a network which conveys water from the border rivers, and runoff originating within the study areas, through the South West Area to the sea.

Land resources are classified and specified in terms of their general suitability for agriculture, aquaculture, forestry and other specific uses. Agricultural land is classified by 'land type' using the data and definitions produced by MPO in Phase 1 of the National Water Plan.

The third key resource of the South West Area is population. It is this population which provides the manpower for the activities within the region and it is the same population which generates the demands for land, water, food (carbohydrate and protein, especially fish and shrimps), fuel (agricultural by-product and timber), and fodder. These need to be met on a sustainable basis to ensure that the area is able to support its population.

The representations are simplified because software constraints do not permit the detailed modelling of the network; this reduction in detail is acceptable for the purposes of regional planning where other data as well as planning decisions apply to planning units as a whole. Nevertheless, once the most attractive development options for each unit were identified, more detailed investigations of specific options have been carried out using conventional methods, and the results of these have been fed back into the model as further refinement.

The main aim of the RAOM has been to assist with the development of a long term regional management plan with an approach that is not significantly different to a non-optimal one. The model incorporates features which account for the use of groundwater alone, conjunctive use of groundwater and surface water, and surface water alone. The model is also capable of looking into the effect of saline intrusion and could consider environmental issues related to flow levels and siltation of channels.

The model divides the whole area into two parts, the South West and the South Central. Each of these is divided into 15 and 13 Planning Units (PU) respectively (see Figure 1.1). The resources and production requirements available to each unit or required by each unit are inventoried. The GIS and Upazila statistics are used to assist this process. The designer can choose the incremental area to transfer from the existing situation to any combination of flood protection, groundwater and surface water low lift/diversion irrigation. It is also possible to choose how much incremental culture fishery, social forestry and, in selected units with saline water, shrimp fishery to have. The effects of flood control on existing capture fishery and available groundwater are modelled. The model will choose the appropriate incremental pumping and water diversion capacities that are required and will compute key input and output resource requirements, ensuring that they are met.

The incremental costs and benefits per unit area for each transition are estimated as net present values at an assumed discount rate and a simple economic evaluation is made. Costs can be minimized or net benefits maximized. Policy options on food and energy security, labour, jobs, cash income can be explored in terms of 'shadow prices and costs. Certain environmental issues can be modelled by noting the effects on flow requirements and saline intrusion. The sundarbans are preserved by ensuring that the freshwater flows to them remain the same at present or some factor of this.

2 FORMULATION OF THE WATER RESOURCES NETWORK

The water resources system comprises the following key sub-systems:

- the surface water (river) network, its boundaries (i.e. inflows and tidal levels) and the internal demands made on it in terms of abstractions as well as flow distribution, drainage, navigation etc

- the aquifer system and its boundaries (ie recharge and deep percolation) and abstraction from it

The essential linkages between and within the above systems are represented in the RAOM. In some cases these linkages cannot be fully described in this class of model (eg flow distribution, saline intrusion, tidal and fluvial sediment transport and associated channel changes), but these processes are represented by the various hydraulic and geomorphological models being used on the study. The output from these process models has been used however to formulate boundary conditions and internal requirements and/or constraints within each development area.

The formulation of each of the above sub-systems in the RAOM is described below.

2.1 The Surface Water Network

In the RAOM the parameters describing the capacity of the river channels, and their connections and interconnections, are assumed to be independent variables for the purposes of the optimisation analysis at each snapshot. In practice these parameters are highly dependent on the interactions within and between all the processes within it as demonstrated by the process models.

The surface water network has been schematised (see Figure 2.1) with reference to the following sources of mapped data:

(i) The GIS map of the river network which is derived from the 1990 SPOT images (at a scale of 1:50 000) in order to identify the major channels and channel groups within the system

(ii) The network schematics showing the channels represented in the 1-D hydrodynamic (MIKE 11) models.

(iii) The BIWTA map of navigation routes which indicates which channels are designated navigation routes

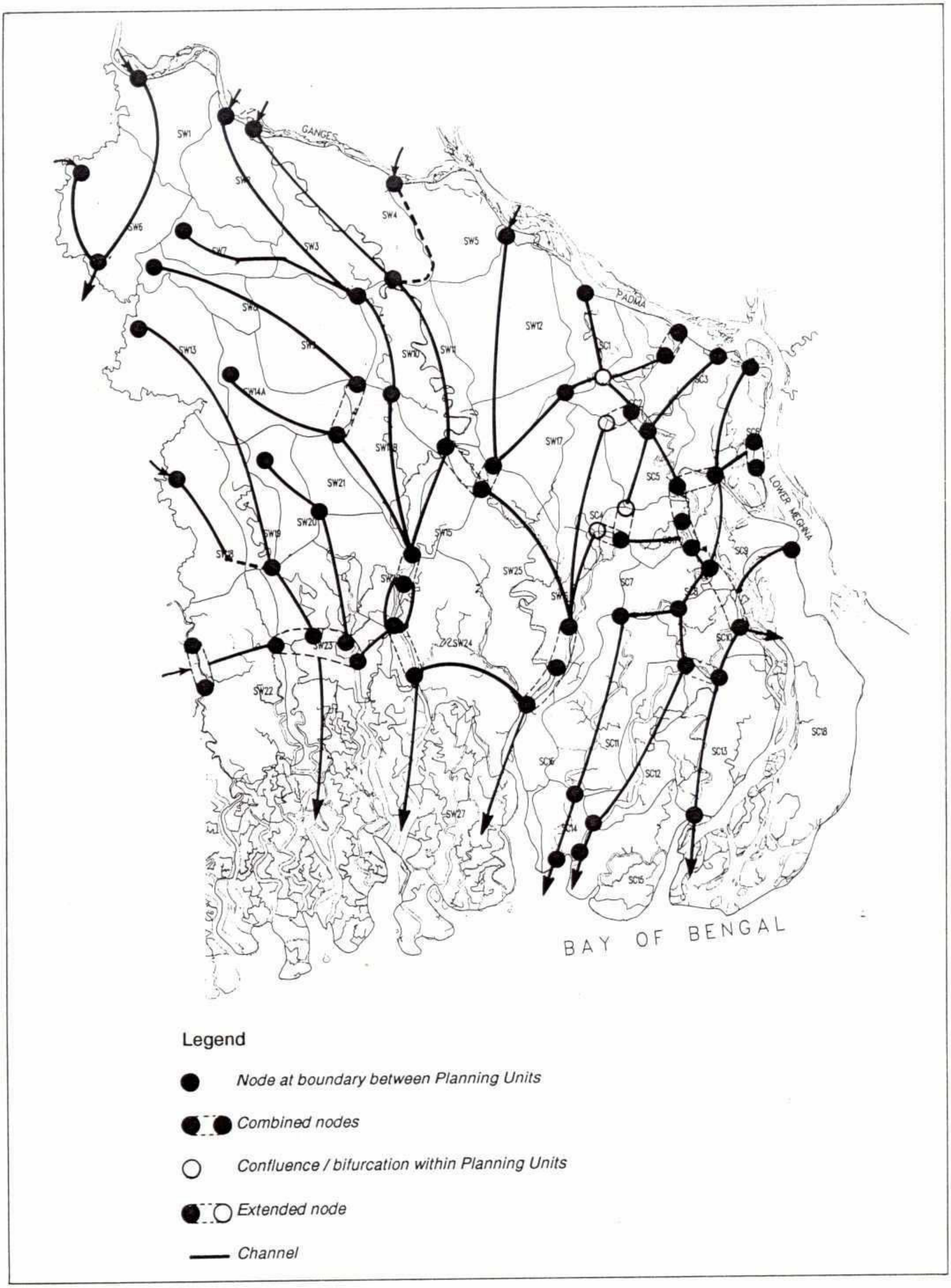
For the purposes of regional resource allocation it is not necessary to represent the surface water network in the same degree of detail as it is represented in the 1-D hydrodynamic model. Nevertheless the aggregation of channels and local channel networks into a coarse network within the RAOM has been devised so as to represent, either explicitly or implicitly, those channels which:

- carry significant flows during the dry season

- are currently under consideration for enlargement as part of a proposals to change the distribution of dry season surface water flow within the study area

- have been identified as possible water transfer routes into the study areas from the border rivers or from an adjacent study area.

Figure 2.1



Schematisation of Surface Water Network

The distribution of flows between different parts of the network will in practice depend on the respective conveyances (a function of channel size and hydraulic gradient) of the channels emanating from junctions or bifurcations. Channel conveyances will usually be determined by the natural evolution of the channel network. At certain locations it may be feasible to intervene by dredging, cuts or building control structures, and there will be costs associated with this.

Those splits that will inevitably be dominated by nature and those which can be secured by means of and intervention can be specified (by making them fixed values rather than decision variables) in the RAOM. Implicit in this is the recognition that whilst this split of flows will not necessarily provide the optimal water distribution if technical feasibility were ignored, it is nevertheless a realistic description of the situation.

The surface water network and the development blocks can be conceptualized as set of interlinked nodes between which water is transferred. This is illustrated in Figure 2.1. At those nodes which represent planning units the continuity equation can in principle include all the following terms:

- surface water inflows to the planning unit
- surface runoff resulting from rainfall on that unit
- surface water abstracted from within the unit to satisfy major and minor surface irrigation, either as the sole source or in conjunction with groundwater
- groundwater abstracted for use in conjunction with surface water
- surface water outflows from each unit.

The continuity equation for each planning unit is written for each month and takes the following general form:

$$\sum I_{i,t}+\sum Idb_{j,t}+RO_t=GWc_t+SW_t+\sum Odb_{k,t}+\sum O_{i,t} \qquad (1)$$

where	$I_{i,t}$	is the inflow from nodes i in month t
	$Idb_{j,t}$	is the inflow from planning unit in month t
	RO_t	is the monthly runoff from within the unit
	GWc_t	is the monthly groundwater abstraction within the unit used conjunction with surface water
	SW_t	is the monthly surface water abstraction within the unit
	$Odb_{k,t}$	is the outflow from the unit to planning unit k in month t
	$O_{i,t}$	is the outflow to nodes i in month t

At the channel network nodes (bifurcations, confluences and areas of dense channel interconnections) the continuity equations do not contain surface-water or ground-water abstraction terms and only represent the surface flow mass balance. They thus take the following simplified form:

$$\sum I_{i,t}+\sum Idb_{j,t}=\sum Odb_{k,t}+\sum O_{l,t} \quad (2)$$

The following assumptions are implicit in the continuity equations as they are written in the current versions of the model:

(i) All the surface runoff originating within the planning unit is assumed to be usable for irrigation within the block - this assumption is not strictly true since the runoff is by definition surplus to effective rainfall (as a consequence of assumptions made in the NAM modelling) and is thus only partly available for irrigation elsewhere within the unit because of time lags in the real system.

(ii) The declared proportional split of flows between two channels at a bifurcation is constant throughout the year.

(iii) Channel losses through evaporation and seepage are negligible in comparison to the volume of flow.

2.2 Groundwater

The groundwater sub-system is represented only as a constraint to prevent over abstraction. The changes in aquifer storage through abstraction and recharge is not modelled in the RAOM.

The ground-water abstraction constraint is written over a whole year and takes the following general form.

$$\sum GW_t+\sum GWc_t\leq PA_{abs} \quad (3)$$

where Gwc_t is the monthly groundwater abstraction within the unit used conjuctively with surface water

GW_t is the monthly groundwater abstraction within the unit other than that used conjunctively with surface water

PA_{abs} is the safe annual abstraction of groundwater

There is an additional constraint to prevent wasting of groundwater. This is also written on an annual basis and takes the following form:

$$\sum GW_t + \sum GWc_t \geq \sum (CWR - e.SW)_t + D_{urban} + D_{rural} + D_{aqua} \qquad (4)$$

where Gwc_t is the monthly groundwater abstraction within the unit used conjunctively with surface water

GW_t is the monthly groundwater abstraction within the unit other than that used conjunctively with surface water

D_{urban} is the annual urban and industrial water demand

D_{rural} is the annual rural water demand

D_{aqua} is the annual water demand for aquaculture

Since abstracting groundwater incurs a cost, the above inequality will be treated as an equality when the objective function includes cost minimisation. Thus, wasteful over abstraction is prevented.

In some areas abstraction from groundwater already exceeds what is recognised to be a prudent level of available recharge. To avoid infeasibility as a result of this current situation the formulae above have been modified to include an additional variable which is a measure of the annual volume of over-abstraction. Once determined for the current situation, this additional variable is then fixed.

3 REPRESENTATION OF LAND RESOURCES AND INTERVENTIONS

In general terms the overall development objective in SWA can be described as identifying and devising water management projects that will contribute to maximising the sustainable production of the Area through making the best use of the available land, water, economic and management resources whilst at the same time meeting various development and production targets. One of these targets, arguably the most fundamental, is that the Southwest Area should be capable of supporting its population in terms of its basic needs on a basis which is sustainable in time. Basic needs are taken to include food (both food-grains and protein - vegetable and animal, including fish and shrimps), fuel (principally for cooking), fodder for livestock which provides draught power, and wood for the construction of houses.

3.1 Land Resources

A set of definitions is therefore required to describe the production potential of different land resource units within the study area in terms of outputs that are able to meet the above basic needs. In selecting a suitable set of land resources definitions, land resource classifications currently used in Bangladesh have been considered. These included:

- the Soil Survey Data Processing System (SODAPS) classification which is based on the depth and duration (seasonal or permanent) of inundation or flooding as inferred from the cropping pattern being practiced by the farmers in that area

- the Agro-Ecological Zone (AEZ) classification which is a modification of the SODAPS classification

- the Master Planning Organisation (MPO) classification (as used in Phase 1 of the National Water Plan) and based on simplified SODAPS definitions

The SODAPS and the MPO classifications, and less so the AEZ classification, are most suited to planning rice dominated agricultural activities. Their suitability to describing the potential of tidally flooded areas and areas with aquaculture (shrimps, flood plain fishery and culture fishery) has had to be considered. Modifications have been made to these definitions, by adapting or combining definitions where necessary, to adequately describe the potential of the land resources in the project area with respect to the following potential productive activities, each of which is represented in the RAOM.

(i) Cultivation, both rainfed and irrigated, and under various degrees of flood protection and drainage - here land suitability is determined by factors including the following:

  - climate and soil quality

  - the topography of the area, topography being a key factor in determining the suitability of the land to different crops, its vulnerability to flooding, and the requirements for drainage

  - the origin, timing, duration, and depth of flooding, in that this promotes or prevents the growth of different crops; bearing in mind that flooding can result from one or more of the following processes: rainfall runoff, high river levels and high tidal levels

  - the quality and availability of water, from both surface and ground water sources, for supplementary wet-season and/or dry-season irrigation

(ii) Aquaculture, including flood plain capture fisheries, culture fisheries, brackish-water and sweet-water shrimp in this case the productive potential depends on areas and depths of water bodies and their seasonal fluctuations; the proximity of water bodies to rivers and their elevation with respect to river channels; and water quality throughout the life-cycle of the fish and shrimps

(iii) Forestry, both social and estate - land suitability and the vulnerability of tree species to flooding need to be taken into account here

(iv) Land for rural homesteads; urban areas; industrial buildings; and communications infrastructure (roads and railways) - here land suitability depends on its relative elevation with respect to sources of flood water and the degree of flood protection or flood proofing available (either as a natural feature of the land or through intervention by man)

For regional planning purposes, the land resources have been categorised in a manner to best represent the major differences in land use and productivity between areas. A summary of these categorisations as used in the RAOM is given in Figure 3.1.

The land resources are represented by four principal overlays, viz:

- Whether an area is within agricultural land or not and, if so, whether it is within an FCD scheme or not
- What soil association the area is within or overlaps and within each soil association the proportions of depth of inundation, high permeability and of saline, peat or acid sulphate soils
- Whether an area is within or outside the fresh surface water zone as determined by peak dry season isohalines
- Which planning unit the area falls within

The classifications used above are as follows:

- Inundation classes are:

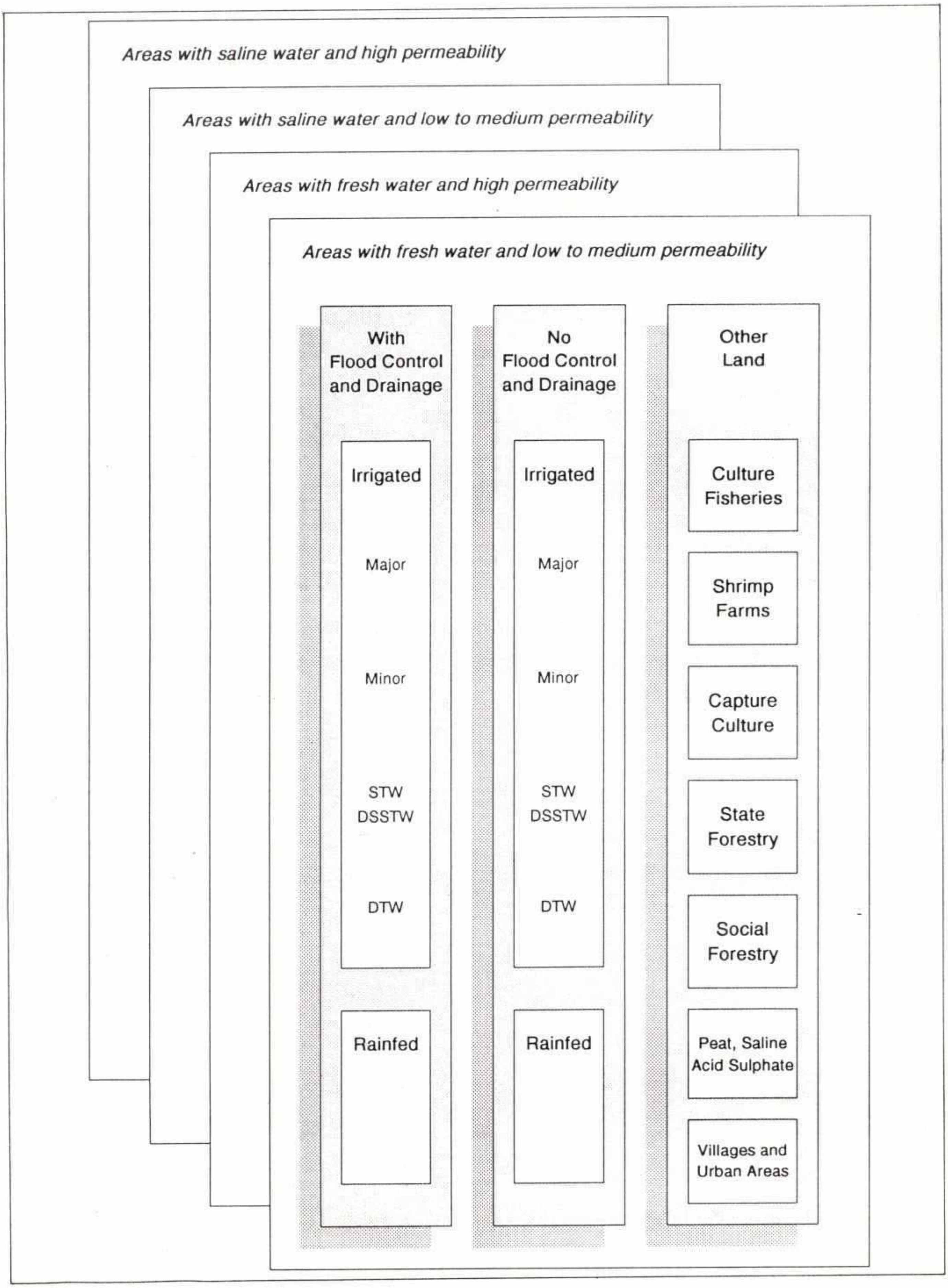
  F0 - Less than 30 cm inundation
  F1 - Between 30 and 90 cm
  F2 - Between 90 and 180 cm
  F3 - Greater than 180 cm

- High permeability is categorised as being greater than 305 cm/day
- The fresh water zone is taken as being up to 2000 micromhos - cm conductivity

These main categorisations are then subdivided as follows by reference to land use:

Agricultural areas	-	Under major irrigation
		Under minor irrigation
		Under DSSTW/STW irrigation
		Under DTW irrigation
		Rainfed

Figure 3.1



Categorisation of Land Resources

Other Areas - State Forests
Social Forests (around homesteads)
Village and Urban areas
Shrimp farms
Other culture fisheries (ponds and beels)
Capture fisheries (estuaries rivers and baors)
Unused or unproductive land

All agricultural land is measured as gross cultivable areas inclusive of embankment and irrigation distribution facilities so that direct trade-offs between land uses are possible.

Unit area input/output functions and costs are adjusted from values associated with net cultivable areas to allow for these additional areas used in the model over and above the NCA. Data for minor and tubewell irrigation and population information (used to derive village and social forestry areas) are drawn from upazila statistics and are assumed uniformly spread across the upazila. State forest areas are from Forestry Department records, fisheries data is from the Department of Fisheries with projections made to create current areas and all other information is from SODAPS or BWDB maps. In order to clearly demarcate land the following additional rules have been used in assembling planning unit data:

- land within major irrigation areas apparently under minor or tubewell irrigation is pre-allocated to the latter categories

- all land areas of whatever category are net of village, urban and social forestry area

- in saline peat or acid sulphate soils where irrigation or culture fishery projects are known or are estimated to occur the land is pre-allocated to irrigation rather than the former categories (this device ensures that water resource requirements are met whilst at the same time recognising that no further development of irrigation or FCD should be considered, given the soil restrictions).

The consequences of these manipulations are importantly that no land is double counted and that the sum of each category of land (especially major irrigation, state forestry and saline, peat and acid sulphate soils) is not necessarily the familiar gross area figures frequently quoted. Capture fisheries, covering rivers, baors and estuaries, is a somewhat arbitrary area defined by the extent to which estuaries are included within planning unit boundaries.

3.2 Development Interventions

In order to select the best mix of schemes to satisfy the overall development objectives for the SWA, it is necessary to:

- evaluate the productive potential of each planning unit

- describe its input requirements in terms of key resources

- identify, and evaluate (in terms of costs and benefits), the effects of development interventions (which form the possible components of development schemes) on the productive potential of the land

The RAOM therefore contains a description of the effects of each of the possible development interventions, in terms of the changes in input requirements and in the output potential of the land, attributable to their implementation.

Transitions in land resource potential can be conceptualized as a set of superimposed activities, where each activity modifies a particular attribute of the land resource category. Projects then comprise a collection of land development interventions which include the following:

(i) Schemes for flood control and drainage (FCD) which are designed to alter the susceptibility of land to flooding from rivers, or the sea, and to improve the drainage of rainfall runoff, thus allowing higher cropping intensities - these are represented explicitly in the RAOM

(ii) Irrigation to enable further changes to the cropping patterns and thereby increase cropping intensities - this is represented explicitly in the RAOM

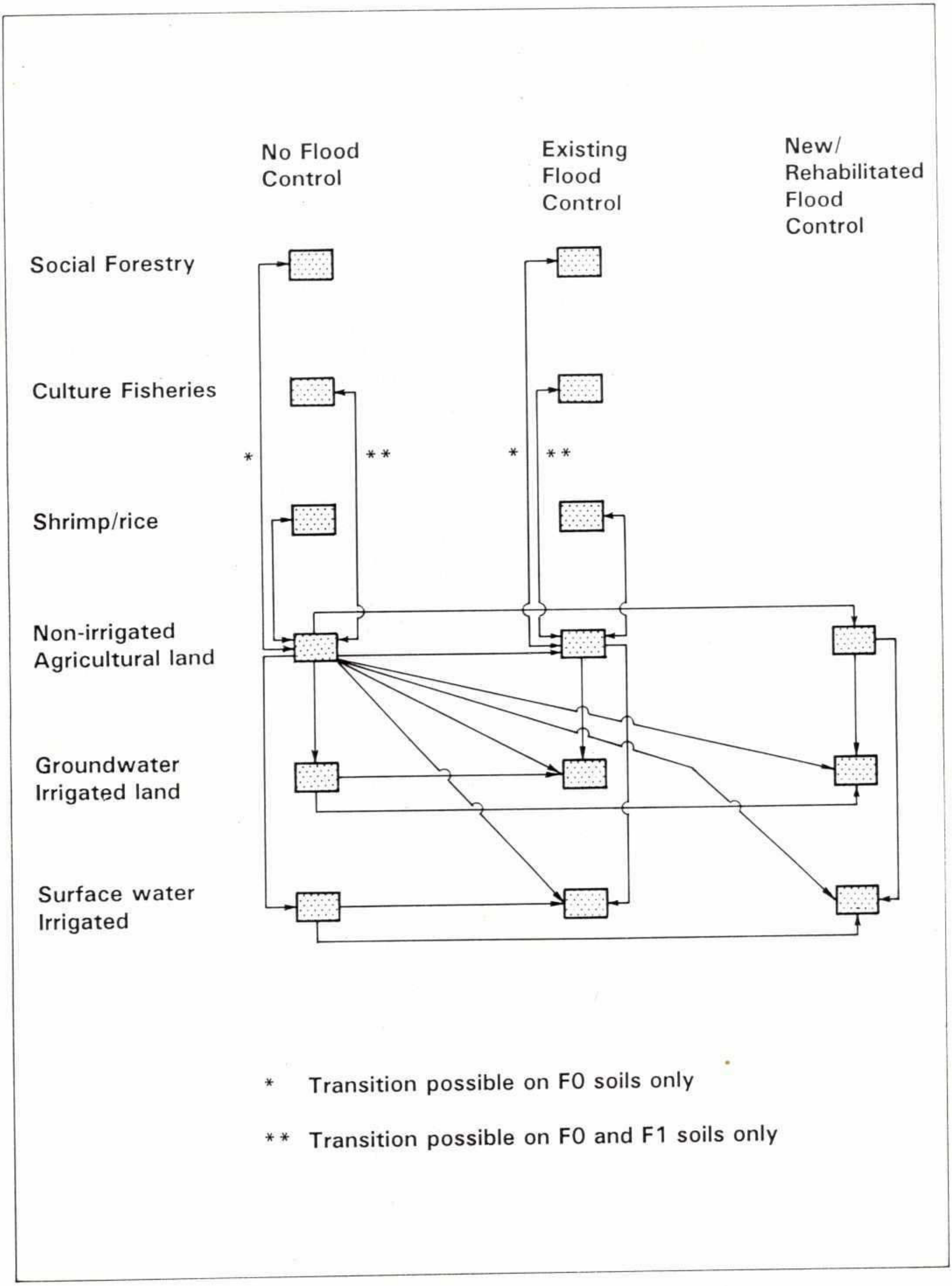
(iii) Changes of land use from agriculture to shrimp or fish farming or to forestry or vice-versa, again this ie explicity modelled

(iv) Improvements in soil management and agricultural practices that would raise productivity - this is not represented in RAOM

(v) Transfer of surface water from one river basin to another to augment supplies - this is modelled in specific instances only.

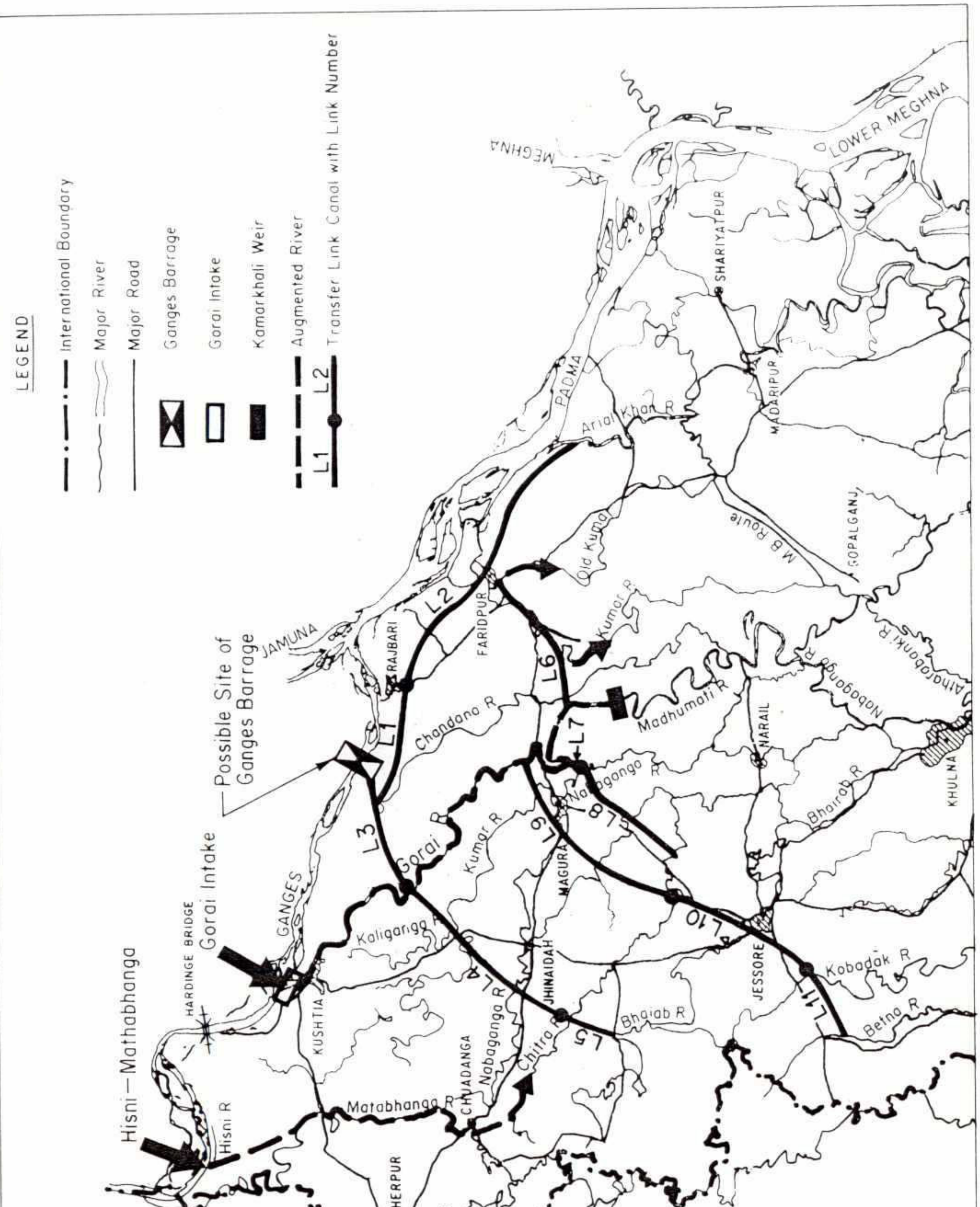
The main transitions in land resource potential are illustrated in Figure 3.2 and the surface water augmentation choices are shown in Figure 3.3.

Figure 3.2



Land Resource Potential and Transitions

Figure 3.3



Main Augmentation and Transfer Choices

4 MODEL STRUCTURE

The RAOM is constructed in a spreadsheet environment using Lotus 2.2 with the linear optimisation add-in "What's Best."

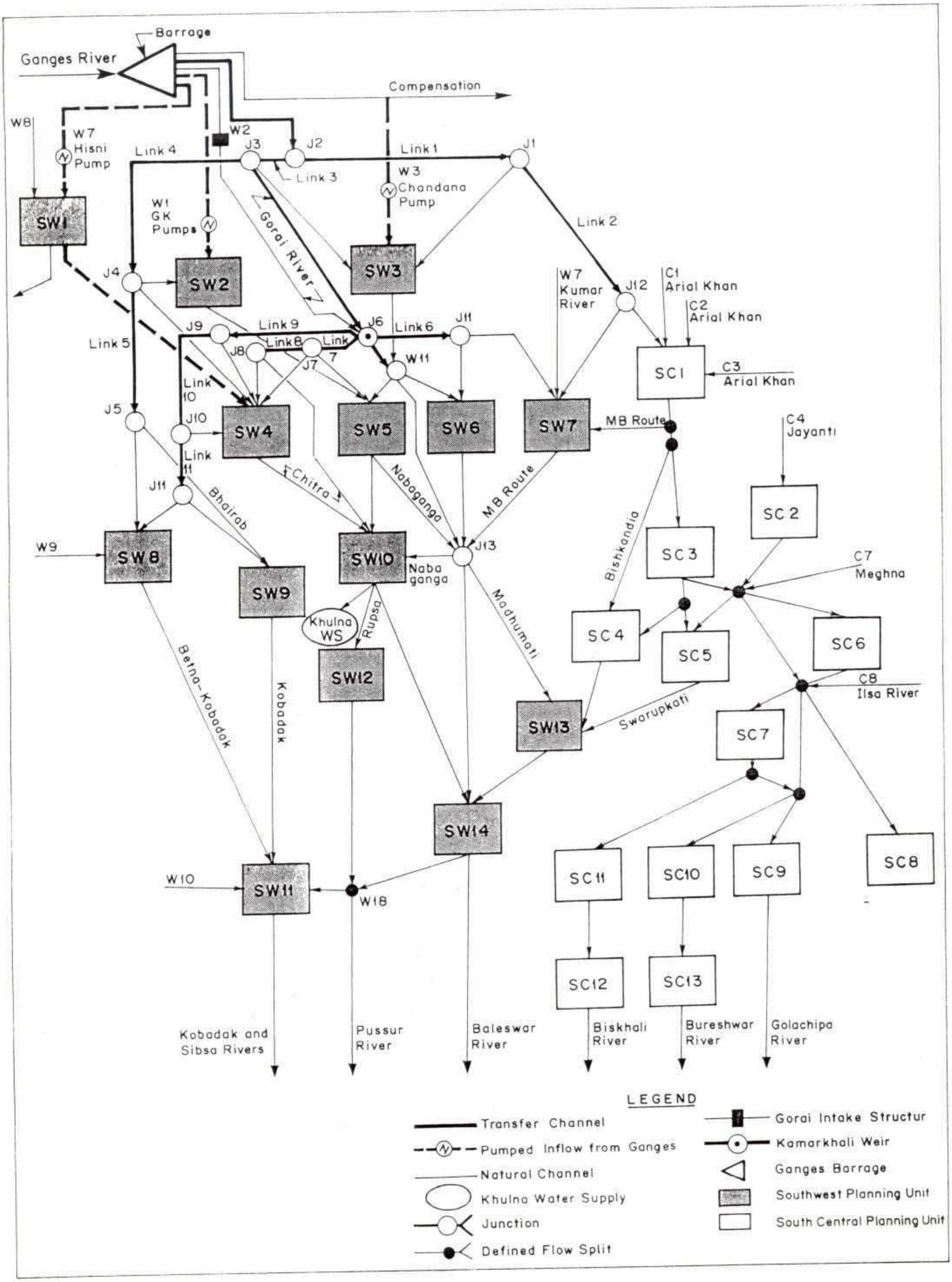
The model is structured into seven key areas:

- Basic Data, defining the land and water resources available, the population and its current and future needs, the cost and impacts of the various interventions
- System State Variables, which describe the flows throughout the system on a monthly basis
- Decision Variables, which determine the size of the interventions proposed
- Constraints, which ensure that the system operates within feasible bounds
- Strategic Constraints, which cause solutions to be within pre-determined limits
- Production Functions, which determine the magnitude of inputs, outputs, costs and benefits
- Objective Functions, which define the goals which the optimisation seeks to achieve.

A full print-out of the model is given in Appendix A and an overall schematic is presented in Figure 4,1.

The model functions by virtue of an optimisation add-in which is capable of adjusting the variable cells to give solutions which are both firstly, feasible and, secondly, optimal with respect to, the set objective. In the process, feasible solutions are determined by those which do not force any constraint to turn negative. Constraints are cells in the spreadsheet in which essentially the size of a variable or a set of variables has to be greater or less than another number, determined by an equation in that cell representing the difference between the two. Optimal solutions are achieved by maximising or minimising a function related to the variables, eg maximising total benefits or minimising costs.

Figure 4.1



Schematic Layout of RAOM

5 DATA REQUIREMENTS

The conclusion drawn from RAOM are a product of the data entered. Much effort was given to establishing a reliable data set and cross-checking this with values used in other parts of the study to ensure consistency. In the following paragraphs a brief summary is given of the data used.

5.1 Land Resources (Rows 141 - 161)

The land areas used are based on an extensive review of the extent of cultivated land and other uses such as for fisheries and forestry. The agricultural areas are drawn from BBS data, the extent of irrigation from MPO, BWDB and the CIDA surveys. The values are combined using the GIS based on the best spatial definition possible assuming uniform distribution within each individual boundary. Boundaries used include MPO planning units, thana boundaries, BWDB scheme maps, soil association maps and district boundaries. Planning Unit boundaries were then overlayed and the totals of each land category were abstracted. Full details are given in Volume 11 of this Report.

5.2 Existing Inundation Classes (Rows 164 - 171)

The MPO categorisation of inundations depths was used and the extent of each category in each MPO Planning Area was transformed into proportions of categories in each Planning Unit using the GIS. Further details are in Volume 11 also.

5.3 Soil and Water Parameters (Rows 174 - 179)

Soil associations were categorised into heavy and light soil and the relative proportions of these in each Planning Unit were abstracted using the GIS. The data given in the model is shown as a matter of record only. The only use that is made of it is in the pre-processing of irrigation water requirement data and in determining irrigation efficiencies.

5.4 Surface Water Resources (Rows 201 - 276)

Inflows into and outflows from the study area across the boundaries have been estimated from values determined from the Mike 11 modelling results. Similarly runoff within each Planning Unit is based on the NAM catchment runoff results aggregated using the GIS. Two sets are available representing mean values and 80% dependable values. For regional planning purposes mean values were used on the basis that this would best represent the tendency of maximising the use of surface water resources when developed through localised systems. Tests were carried out in the analyses to investigate the sensitivity of application of 80% dependable flows. The overall inflow/outflow relationships of the RAOM and Mike 11 were compared to check the calibration of the RAOM values in the reference situation.

Within the Regions certain flow splits are prescribed according to channel geometry. The values adopted are determined from relative discharges observed in the Mike 11 model.

5.5 Groundwater Availability (Rows 281 - 316)

The available groundwater in each Planning Unit is based on the MPO estimates for each upazilla and transformed into Planning Unit data using the GIS. The basis to these estimates is given in the Hydrogeology Annex of this Report (see Volume 5). To these values were added supplementary amounts determined using RAOM to be the minimum amounts necessary to satisfy the existing extent of groundwater development for irrigation and potable supply requirements. These extra amounts reflect the fact that in some areas current abstractions exceed the MPO safe estimates already. Once calculated for the reference situation no further exceedance was permitted. The groundwater availability is treated as an annual amount and it was decided not to constrain abstractions within individual months.

Depths to groundwater were taken also from MPO data and given an approximate distribution throughout the year. These depths are used only for the purposes of determining monthly pumping heads and energy requirements.

5.6 Pump Capacities (Rows 321 - 326)

Data on existing pump capacities is taken from the CIDA survey of tubewells and low lift pumps and transformed to Planning Units using the GIS (see data in Hydrogeology Annex and also in Volume 11).

5.7 Irrigation Efficiencies (Rows 328 - 340)

Irrigation efficiencies are based on FAO Paper 24 and take account of soil permeability. The basic efficiencies of surface and groundwater systems reflect both of these. Assumptions are made of the amounts of return flow from both systems to either the surface water system or the groundwater and from these are determined two sets of factors : the first set relates to the sizing of the delivery system and the second to the net impact on resource depletion. The contribution of surface irrigation to groundwater recharge was in the end ignored for two reasons : firstly it may be assumed to be a sufficiently local effect that, given a surface water system and groundwater system would not be situated on the same land, the nearest groundwater schemes would not benefit significantly, and secondly that it lead to illogical solutions where surface schemes were being implemented simply to enable further groundwater development.

5.8 Crop Water Requirements (Rows 342 - 417)

These are determined separately for each inundation class in each Planning Unit for two classes of permeability and pre-combined to give a weighted value based on the proportion of each permeability class in each Planning Unit. The cropping patterns used in the calculation are based on those determined by MPO for each of their Planning Areas according to inundation class. Account is also taken of the differing climatic conditions in each Planning Unit also. Further details are provided in Appendix B.

5.9 Environmental Flows (Rows 421 - 436)

In addition to forcing regional outflows to match those determined by Mike 11, minimum outflows can be set for each Planning Unit.

5.10 Labour Requirements (Rows 441 - 456)

Labour requirements are determined from estimates made for the average cropping patterns on irrigated and rainfed land on each inundation class. No regional variation is represented as in practice labour requirements do not represent a significant constraint on development options. Further details are given in Volumes 6 and 10.

5.11 Outputs/Yields etc (Rows 461 - 519)

Estimates are provided for each cropping pattern of outputs in terms of food energy, protein, fuel energy, income, jobs and yields of principal items. Similarly outputs are estimated for fishery and forestry activities. The bases to these estimates are given in the relevant Annexes to this Report.

5.12 Annual Requirements (Rows 521 - 593)

Basic rural and urban population data for each Planning Unit split approximately into the relevant categories of male/female and working. Also included are estimated overall growth rates from which projections are made for the pre-set "Target Year". Linked to these are estimates of per capita and total demands for food, fuel, fodder, protein and potable water supplies.

The requirements for domestic and industrial water including for Khulna, have been assessed on a per head of population basis with the projected increase in population for the year 2020. These are given by planning units and are given in Rows 584 and 585.

5.13 Inundation Classes under Full Flood Protection and Drainage (Rows 868 - 863)

The proportionate distribution of inundation classes under full flood protection was estimated using a simple rainfall - runoff model. The model incorporates a linearised area - elevation graph for each Planning Unit, rainfall determined from the NAM runoff model, an outfall level from the Mike 11 results and assumes that compartmentalisation will be undertaken. The model computes the maximum storage within the Planning Unit and hence the distribution of inundation classes. This somewhat crude representation was necessitated by the otherwise enormous amount of data and analysis that would have been required. A sensitivity test was carried out which demonstrates that even with major changes in assumptions of the conversion in land classes only small changes in incremental benefit occurred however. Thus although this is only a simple representation, in terms of affecting strategic choices, it appears an adequate basis for regional level planning. Further details are given in Volume 8.

5.14 Cost and Benefit Data (Rows 1221 - 1338)

Development costs of new and rehabilitated FCD expressed on a unit area basis are derived from sample costings across the area. The financial values are converted to economic terms by pre-application of economic conversion factors (see Economic Annex) and application of an NPV factor which assumes unit area construction takes 3 years and a discount rate of 12% is applicable.

Irrigation development costs include area development and pump installation costs for both surface and groundwater schemes and a further distribution cost for surface schemes. These are each transformed into economic costs in a manner similar to the FCD schemes. Groundwater pump costs reflect the mix, determined by MPO, of future STW, DSTW and DTW technologies. The cost of augmentation works, barrages and links are based again on estimates of individual works expressed in economic terms. Unit costs for transfer channels and for all pumps are expressed in terms of a fixed amount plus an amount proportionate to installed capacity.

Energy costs relate to a function of the volume pumped and lift required in each pump times an assumed mix of electricity and diesel unit costs. An NPV factor is applied to all annual costs. O & M annual costs are estimated as a percentage of capital costs.

Agricultural benefits are based on the unit net value of the cropping pattern on each inundation class under rainfed or irrigated conditions, again using the patterns derived from MPO data and applied appropriately to each Planning Unit. Full details are given in the Economics Annex. Similarly unit area benefits are ascribed to all forms of fisheries and forestry and are converted into NPV terms.

6 MODEL OPERATION AND RUNS

6.1 Introduction

The RAOM can be operated in a number of different ways according to preference. These are briefly described below. These notes are not intended as a comprehensive user guide given that to prepare such a guide in a fool-proof manner would require many weeks of additional work.

The system state and decision variables each can be allowed to vary or can be fixed at a preset number, which can be zero. In this way particular solutions can be tested against optimal ones and the results compared.

By applying constraints in an appropriate manner solutions can be obtained which fit within upper and lower bounds. For instance it is possible to find solutions for which the area developed is constrained to a maximum amount or to be within a tolerable range of a proposed solution. Similar constraints can be applied in a wide variety of ways. Further illustrations are given in later sections.

The third main operating choice is the selection of objective function. The principal choices in the RAOM as it is set up are:

- Total costs
- Total benefits
- Benefits minus costs
- Total Food Imports
- Total Imports
- Surface Irrigated Areas

The most usual objective function is to maximise benefits less costs to yield the solution with the best incremental net benefits. This is not the same as the highest benefit/cost ratio since the model would choose all developments which intrinsically have a positive NPV with a discount rate of 12%. As may be seen from the results the resulting benefit/cost ratios calculated from a range of solutions show a typically downward trend with increasing size of project as developments with lower NPV's (but still positive) are allowed.

Other possible uses of the objective functions are to maximise surface irrigated areas (to see how large an area could be developed under any one set-up of the model), maximise benefits irrespective of costs or to minimise imports. By combining objectives, multi-purpose solutions can be found. For example maximising surface irrigated areas plus benefits minus costs ensures that the maximum area is developed at least cost and if not all the area is irrigable then the better parts are selected.

6.2 Typical Set-up Choices

In order to maintain consistency of approach given the large number of variables which require constraining to investigate the alternative development strategies, a "user - friendly" set-up procedure has been constructed in the top pages of the model.

Screen 1 : Model notes and reminders

Screen 2 : A series of ceiling proportions including land in each planning unit not within the saline front, the maximum which could be converted to shrimp, the maximum which could be commanded by the surface system and the maximum which is suited to irrigation according to soil considerations. The land available outside the saline area is automatically adjusted if flows are allocated to salinity control. In practice the maximum shrimp area and soil suitability criteria were not used as they are effectively controlled by other constraints. These constraints could be used to set even lower constraints if required.

Screen 3 : Target year sets the population figures and related demands as well as controlling proportional development if those constraints are used. Interest rate is set at 12.0% and should not be varied as some of the unit area costs are pre-calculated assuming this rate.

Groundwater can be constrained to not exceeding a proportion of the ultimate development as defined by an earlier run (504e), full development being assumed to occur by 2005.

Similarly the total costs and areas of surface cost of FCD and surface irrigation development can be set as being proportional to an ultimate solution based on the target year and selected start and completion years.

Social forestry and culture fisheries can be constrained to not change or to be allowed to change to agricultural land or to increase by loss of agricultural land up to a ceiling amount per household. Target areas for new and rehabilitated FCD and surface irrigated areas may be set and the solution forced to be within $\pm$ 500 ha of these values in each planning unit. As finally set up, the final planned development areas appropriate to a target year can be automatically imported using a macro.

Independent ceilings on the total area developed or the total surface irrigation area can also be applied in each Region.

Screen 4 : In this screen the size of the Ganges Barrage reservoir can be varied as well as Gorai river capacities and demands for Khulna water supply. Also the maximum transfer from the SW Region to the SC Region can be set as well as minimum outflows from SW10, representing salinity control flows.

Other numbers that can be set are the maximum number of transfer links developed in a particular solution as well as the means of forcing a solution which must contain the Ganges Barrage with either a high or low offtake.

Screen 5 : This screen contains the integer variables (1/0) of the main components of the transfer systems. A value of 1 means the component is included and of 0 means that it is excluded. If the integer variable is fixed (by protecting the cell) the solution cannot be different from the selected choice and the base cost of that component will be included at a minimum. If the variable is unprotected (shows green on a colour monitor), then the solution can be either 1 or 0 for that component, ie the model will choose whether it is necessary and/or beneficial to build it.

Action Page: Found by pressing ALT-7, the action page contains the objective functions as well space to write brief notes to summarise the purpose of a model run. When a run is completed ALT-S saves a summary of the results to a separate file and ALT-Q details of the areas developed.

6.3 Sequence of Runs for Strategic Analyses

During development of the model and initial trials, a large number of runs were undertaken to investigate the workings of the model and to draw initial conclusions from the results as to likely favourable strategies. These early runs lead to progressive refinement of the model in order to better represent the behaviour of the land and water resources system. The refinements were mainly effected by constructing additional constraints intended to bound solutions to within practical limits. In some instances, the model had to be restructured to allow better definition of proposed developments. At all stages of model development close interaction was maintained between the modelling team and the subject matter specialists to ensure that the best possible representations were made and that the lessons learnt from the model results could be fed back into the development planning process. This close cooperation is an essential feature of the RAOM technique and brings with it the added advantage of promoting a consistent approach to the planning process.

The final sets of runs are given in Appendix B which lists the runs undertaken and provides a summary of the results of each. The main categories of run undertaken were:

(i) Calibration Run : Run 950

In this run no development was allowed at all with the target year set at 1991. Values of recurrent costs and benefits for existing developments were thus determined from which in all future runs incremental costs and benefits could be determined.

(ii) Reference Situation : Runs 504a - 504e

In these runs no development is allowed other than groundwater irrigation. A pre-run was undertaken to assess the maximum area that could be profitably developed. This was then set as an objective attainable in 2005. The reference situation was then defined against different target years up to 2020 with groundwater developed proportionately to 2005 and remaining constant against increasing demands thereafter.

(iii) Development without surface water augmentation : Runs 950 - 954

In this sequence of runs the ultimate situation (Run 954) is defined first and then intermediate solutions are tested for different development target years. No transfer channels or augmentation works were permitted.

(iv) Gorai Augmentation Scheme : Runs 951 - 958

The same procedure as above was adopted except that the Gorai Intake, Kamarkhali Weir and Links 6 - 8 were allowed. Links 9 - 11 are not allowed as they require a high command level at Kamarkhali weir possible only with a Ganges Barrage. In the preliminary analyses comparisons were made of development options with and without each of the links. In the final runs the sequence was confirmed by allowing a choice between either Link 6 or 7 first, the latter being chosen preferentially.

(v) Ganges Barrage Development : Runs 951 - 962

A similar set of runs was undertaken with choices open for the Ganges Barrage. In the preliminary analyses it was determined that Links 9 - 11 offered no comparative advantage over the other choices for western transfers and these were discarded along with the related options of a low level offtake (via the Gorai intake) from the Ganges Barrage and a higher Kamarkhali weir. The preliminary analyses also indicated that Link 3 should be constructed before Link 1 and the final runs confirmed that Link 4 and 5 should be constructed before Links 1 and 2. Similarly, early tests indicated investment should be concentrated in the Ganges Barrage transfer canals before embarking on the Hisni Scheme. Although it was recognised that transfers to the South Central Region had an apparent benefit, it was decided that this option should not form part of the base case for the Ganges Barrage development. Similarly, whilst positive returns could be gained from allocating flows to salinity control, it was reasoned that this also should not be considered as part of the base case as essentially the base case analyses were to do with the choices of where first to irrigate rather than the trade-off between irrigation and salinity control, a scenario which was subsequently investigated.

(vi) Final Ganges Barrage Development : Runs 1051 - 1062

In this final series, development areas were preset based on actual areas determined on the basis of the previous runs and on the aggregates of actual developments identified by reference to practical scheme boundaries and content. These were defined by the engineering team using the earlier results as guidance to the nature of development in each Planning Unit and then locating known or possible schemes to best match the optimal development pattern. As may have been expected, similar but slightly less beneficial results were obtained.

(vii) Additional Model Analyses : Runs 963 - 978

In these additional runs a number of different development options were tested to give credence to the strategies that emerged from the earlier runs. Scenarios that were tested included:

- Transfers to the South Central Region
- Comparison of this with Salinity Control
- Various levels of salinity control
- Maximum irrigated areas with differing assumptions on Ganges flows
- Impact of increased efficiencies
- Impact of allowing social forestry and culture fisheries to vary
- Impact of policies to reduce shortages.

6.4 Results of Different Analyses

As indicated a full set of results from all of the above analyses are presented in Appendix C. The conclusions drawn from these are presented in Section 5.3 of the Main Report and are not repeated here. It is important to recognise, these results should be treated as indicative rather than necessarily absolute. The RAOM is not without its limitations in terms of representation of system behaviour and spatial aggregation.

Nevertheless experience with similar models in the past suggests that the solutions obtained are robust in terms of the underlying trends and general conclusions drawn as to the nature and sequence of development. The process of model construction and refinement leads inevitably to a much clearer understanding of the relative merits of alternative developments to the extent that, frequently in the end, the answers usually seem obvious, even if at the outset this was not necessarily the case.

6.5 Post-Processing

For the purposes of defining the actual financial and economic cash flows, data was abstracted from the results files of the final series (1051 - 1068) and set sequentially against the results obtained from the reference situation (Runs 504a - 504e). Incremental values were determined for each 5 year interval. Investments were spread equally throughout each period with recurrent costs built up in proportion to cumulative investment and set one year later. Benefits were treated similarly except that a build-up of seven years (base case) was associated with each years incremental agricultural benefits. Benefits arising from flood damage reduction and losses relating to capture fisheries were assumed to have a one year build up. Where groundwater irrigation was replaced by surface water schemes the capital costs of the "negative" development was set at zero but the reduction in recurrent costs was taken into consideration.

The financial investment flow was calculated on a similar basis with conversion factors applied to the economic NPV costs to determine 1991 level financial values.

It is interesting to note that this post-processing lead to a recalculation of the benefit/cost ratios of the entire Ganges Barrage Development base case with values of 1.28 for the Southwest Region and 1.74 for the two Regions together compared with the RAOM output of 1.14 and 1.41 respectively. The comparison indicates that the assumptions made with respect to calculation of NPV's within the RAOM are reasonable and that no major distortions would have occurred that might significantly alter the choices made in the model.

6.6 Risk Assessment

A feature of RAOM is its facility to enable planners to indulge in "what if" assessments. A number of these have already been carried out and are discussed in the Main Report. The essence of these assessments is that any decision to be made are in the end a function of the quality of data and of the assumptions made. By varying these data and assumptions and re-running the model, the impact of changed circumstances can be rapidly evaluated. Furthermore, RAOM automatically calculates the incremental net benefits of any particular solution and therefore by comparison of results a "cost" can be associated with any change in assumptions or of policy. The "cost" is the loss of benefits from the so-called optimal choices.

A major issue surrounding the Southwest Area development is the question of augmentation from the Ganges and the risks associated with such a policy given the presence of Farakka Barrage under the control of India upstream. In the analyses presented in the Main Report, the impact of varied assumptions of flows in the Ganges are discussed. These highlight the impact on total irrigated area and on economic performance of the scheme of lower and greater flows.

It is recommended in the Main Report that further detailed studies of surface water augmentation schemes are undertaken and that these should include a more detailed assessment of risk. The key issue is that, under the circumstances, it is not possible to attribute any probabilities to future flows downstream of Farakka other than to the very small amounts contributed by inflows derived from the catchment below Farakka. Consequently planners must try a series of "what-if" assessments to assist the decision makers in evaluating the consequences of their choices.

For the Gorai Augmentation Project, the key area of risk is the impact of reduced flows in the Ganges on flows diverted into the Gorai and thereafter on areas irrigated. Mitigation of this risk is possible by being prepared to intervene in the Ganges with either temporary or permanent works to facilitate diversion. Permanent works amount to the Ganges Barrage. Temporary works could be either additional dredging or sand-bagging or some other works to enable low flows to enter the Gorai. By considering the cost of such temporary works, the options for Gorai intake design and the impacts of downstream flows it would be possible to modify RAOM (or construct a new mini-model) to investigate these choices and evaluate under varied assumptions of inflows what is the most robust strategy to adopt.

For the Ganges Barrage Project, again the key question is the impact of different release patterns from Farakka. The principal means of risk mitigation is construction of a transfer from the Brahmaputra within Bangladesh to give Bangladesh assured control over inflows to the Ganges Barrage. With modifications to include this option and global representation of other uses of Brahmaputra flows, the RAOM would be an ideal means to undertake preliminary assessment of the viability of these mega-projects against varied assumptions on the plausibility of water sharing agreements with India.